

Advancing Materials and Manufacturing: CAMS2016 Abstracts

C.C. Berndt, A.S.M. Ang and D.P. Hodgson (Editors)

Introduction

The Combined Materials Societies Conference (CAMS) was held at Swinburne University of Technology from December 6th to 8th, 2016. The 220 following abstracts are based on the submissions of the authors.

The editing process incorporated formatting and standardization of the provided author input. For example, the affiliations of the authors are grouped rather than associating every author with their specific organization. As well, several abstracts included figures. These figures have not been included in this document.

The 3 Plenary presentations are listed first. Then the order of the presentations is in accord with the 13 symposia within CAMS2016. Table 1 lists these symposia with the corresponding Symposia Chairs. A 14th session incorporated the posters.

Several of the posters were also delivered as oral presentations. Keynote and Invited presentations are indicated.

Table 1. CAMS2016 Symposia and Symposia Chairs.

| | | |
|---|---|--|
| A | Future manufacturing, processes and products | Yvonne Durandet (Swinburne University of Technology) |
| B | Biomaterials and ceramics | Andrew Ruys (University of Sydney) |
| C | Translational research in polymers and composites | Bronwyn Fox, Nishar Hameed (Swinburne University of Technology) |
| D | Durable materials for demanding environments | Matthew Barnett (Deakin University) |
| E | Materials for energy generation, conversion & storage | Lan Fu (Australia National University), Judy Hart (University of New South Wales), Rachel Caruso (University of Melbourne) |
| F | Advances in materials characterisation | Julie Cairney, Vijay Bhatia (University of Sydney) |
| G | Advances in steel technology | Elena Pereloma (University of Wollongong) |
| H | Corrosion, degradation & wear of materials | Scott Wade (Swinburne University of Technology), Nick Birbilis (Monash University) |
| I | Light metals design | Nicole Stanford (Monash University) |
| J | Thermal-mechanical and processing | Matthew Dargusch (University of Queensland), Mark Easton (RMIT University) |
| K | Nanostructured and nanoscaled materials | Jan Seidel (University of New South Wales) |
| L | Geopolymers & use of waste materials | Rachel San Nicolas (University of Melbourne) |
| M | Nuclear waste & fuel | Daniel Gregg, Lou Vance (Australian Nuclear Science and Technology Organization) |
| P | Poster session | A.S.M. Ang (Swinburne University of Technology) |

Two short courses were held the day before the conference. These courses are described below.

Short Courses

Use of Metallography in Failure Analysis

Instructor: George F. Vander Voort

Vander Voort Consulting L.L.C. and Consultant – Struers Inc.

This course is designed to teach fundamental principles for analysis of metal failures with a strong emphasis on the use of microscopy techniques. The following main topics will be covered:

- “How to Conduct the Failure Analysis” will discuss the following topics: why do we do failure analysis, causes of failures, examination steps for failures, tool of the analyst, examination sequence, examination of fractures, macroscopic and microscopic methods for failure analysis, analytical tools, typical questions to answer in the analysis program, and writing the report, making recommendations and follow up.
- “Fractography” will cover the examination of fractures and will discuss and illustrate the following topics: fracture modes and mechanisms, macroscopic and microscopic characteristics of ductile fractures, brittle fractures (cleavage or intergranular), fatigue fractures, and corrosion-assisted fractures. Each topic will be illustrated using macroscopic images, light optical microscope images of fracture paths and fracture surfaces and SEM images and TEM replicas of fractures.
- “Failures Due to Materials or Manufacturing Problems” will cover and illustrate failures due to material problems, such as: initiation sites at shrinkage cavities in castings, hydrogen blisters and hydrogen flake failures, failures due to poor formability, failures due to internal liquid metal embrittlement, failures due to nonmetallic inclusions, grain boundary carbide films and seams and laps. Failures due to manufacturing problems included: heat treatment problems, such as, decarburization, over- or under-austenitization, decarburization, excessive carburization, failure to temper, temper embrittlement, quench cracks, over-heating or incipient melting, and flame impingement; plus, grinding abuse, improper electrical-discharge machining (EDM), and welding failures.
- “Failures Due to Service Problems” will cover and illustrate failures due to corrosion problems (SCC, intergranular corrosion, sensitization and exfoliation), creep, embrittlement phenomenon (sensitization, sigma precipitation, 700 °F embrittlement of ferrite in stainless steels, embrittlement from excessive nitride precipitation and liquid metal embrittlement), fatigue, thermal fatigue and wear.
- “Failure Examples” provides detailed studies of specific failure case histories: A Loran C tower in Greenland that collapsed when one guy wire broke; the derailment of an Auto- Train system in Florence, SC, when a drive axle failed due to an over-heated friction bearing; and, ASTM A490 high-strength steel bolts that failed after being installed in structural beams in the Collins Power Plant in Morris, Illinois.

Thermal Spray Technology

Instructor: Professor Christopher C. Berndt

Professor of Surface Science and Interface Engineering – Swinburne University of Technology, VIC

Thermal spray technology and coatings solve critical problems in demanding environments. They provide “solutions” to engineering needs involving wear, high temperature and aqueous corrosion, and thermal regulation and degradation. Thermal spray is being increasingly used to manufacture net-shapes, advanced sensors and materials for the biomedical and energy/environmental marketing sectors. These and a vast array of emerging applications take advantage of the rapid and cost-effective capabilities of thermal spray technology in the OEM and repair industries. Topics covered in this course include:

- Surface Science: Wear, corrosion, hardening, carburizing, nitriding, electroplating, electroless plating, phosphating, vapor deposition, hard facing, relative attributes and deficiencies of these processes.
- Equipment & Theory: History, methodology, flame spray, HVOF, D-gun®, twin wire-arc spray, plasma spray, emerging technologies (e.g., cold spray, vacuum wire processes, etc.) material feed systems, cooling needs, gas supply systems, controls, sensors and automation, spray booth design, health and safety.
- Processing & Design: Bonding, cleaning, processing, masking techniques, substrate surface preparation, temperature control, spray pattern, process variation, automation, fusing, densification, finishing, stripping, deposition efficiencies, good design practices for substrates.
- Materials: Feedstock production methods and how this is reflected in the feedstock morphology; blended and composite materials; quality indicators for feedstocks; feedstock flow and its critical importance to achieving an economic process; particle classification methods; quality control; material specifications and standards.
- Applications: Aerospace (thermal barrier coatings, abradables, wear resistant coatings etc.), automotive, biomedical, ceramic & glass, marine, anti-skid, electronics, printing, processing industries, textiles, infrastructure. 6. Testing & Characterization: Sectioning, mounting, grinding, polishing, etching, hardness testing tensile adhesion/cohesion, powder size/chemistry/ phase, porosity determinations.

Acknowledgements

Finally, and with gratitude, CAMS2016 had many key financial supporters. These include:

- Conference Partners: Australian Nuclear Science and Technology Organisation (ANSTO) and Thermo Fisher Scientific.
- Conference Sponsors: Struers Inc., ATA Scientific, Carl Zeiss, Coherent Scientific, American Elements.
- Exhibitors: Scientex, Newspec, Olympus, Australian Microscopy and Microanalysis Research Facility (AMMRF), Solartron Analytical, Lastek, AXT, and Springer.

Swinburne University of Technology and Deakin University also contributed significant resources that supported this conference. The CAMS2016 co-Chairs thank the leadership of these universities for their support and encouragement.

Plenary Presentations

Plenary Day 1: Prof. Michael Khor, Nanyang Technological University, Singapore

Advanced materials processing trends: towards a more integrated and data-intensive approach for sustainable manufacturing

In the past 30 years, advanced materials processing has seen unprecedented progress into new frontiers resulting in increased changes to the manufacturing sector. Traditional manufacturing as we know it has been gradually replaced by irrefutable developments such as an ever increasing reliance on modeling and simulation; materials innovation; information technology and orientation towards sustainable manufacturing. This talk will focus on the development on advanced materials using various analytical tools to better elucidate the forces that provided the drive to the demand as well as the competition among materials which determine the future directions of advanced materials research. Examples can be seen in various aspects of advanced materials including aerospace; biomaterials and automobile industries. An example is the large investments in graphene and carbon nanotubes for nanoscale applications which have the potential to fundamentally change electronics and renewable-energy applications. Past trends will be presented so that its development can be better understood from the present-day perspectives; these examples include metal matrix composites and other “hot” topics such as biomaterials; additive manufacturing and advanced surface engineering.

Plenary Day 2: Prof. David St John, University of Queensland, Australia

A personal perspective on the intersection between materials science and the research priorities of manufacturing and government

A scientific journey of over forty years supported and inspired by creative interactions with the manufacturing industry and government priorities is explored. This exploration focuses on examples of the presenter’s research from peritectic solidification to extractive metallurgy, tough ceramics, light metal alloy design, corrosion, casting and back to the study of solidification characteristics such as hot tearing and grain refinement. The varied pathways of this research were built on a foundation of a strong desire to carry out fundamental research that was influenced by industry and government research priorities. Another important factor that facilitated applied and scientific discovery is the joy of collaboration. In parallel to details of the science, the talk will reflect on these considerations in terms of what research was selected, how it was undertaken and the impact the outcomes had on manufacturing and the field of materials science.

Plenary Day 3: Prof. B.S. Murty, Indian Institute of Technology – Madras, India

Challenges in high entropy alloy research

High entropy alloys (HEAs) are a new class of multi-component equiatomic (or near equiatomic) alloys, which form simple solid solutions due to their high configurational entropy. The formation of nanocrystalline HEAs has made them more interesting due to their fundamental and technological importance. It is important to note that all multi-component equiatomic alloys do not lead to the formation of single phase solid solution or for that matter mixture of solid solutions. In a number of cases, these so called HEAs, have shown the formation of intermetallic phases and in some cases phase separation of certain elements with high positive enthalpy of mixing with other elements. Prediction of the phase formation in high entropy alloys is a major challenge in this field. Understanding the stability the phases is also a major challenge due to the sluggish diffusivity in these alloys. Processing of the alloys for useful applications is also an important area that is attracting the attention of researchers in this field. The present paper addresses a number of these issues based on the ongoing work in the research group of the speaker.

Symposium A: Future manufacturing, processes and products

Keynote A1 J. Norrish: University of Wollongong

From rapid prototyping to repair and additive manufacture using robotic arc welding

The paper will discuss the development of robotic arc welding for the manufacture of metallic prototype components, repair of damaged and defective parts and the production of low volume fabrications. The viability of the approach for a range of materials from nickel super alloys and titanium alloys to in situ alloyed and functionally graded structures will be demonstrated. The concept of integrated deposition and finish machining of large near net components will be discussed and the latest developments in robot program generation for low volume additive manufacture will be described.

Invited A1 C. Thong, S. Petinakis: CSIRO

Designing commercial products using advanced materials and manufacturing: Increasing the impact of material science

In recent years, there has been discussion by various bodies and organisations about the impact of science, its benefit for society and effective methods for commercialisation. Collaboration between design and science has been identified as a method for increasing this. This presentation will explore how interdisciplinary collaboration, that is, integrating design and business with scientific enquiry, can provide effective research and development outcomes and strategies to increase the impact of science. Three project examples will be used to do this; A) new materials development for Microwave Modified Timber, B) new applications for biopolymer composite materials, C) sustainable applications for additive manufacturing. They demonstrate design and business inclusion influenced outcomes positively, and in ways that would not otherwise have been considered in traditional material science approaches. Such impacts include early integration lowering risk and timeframes, the ability to align science with societal need and commercial constraints and shaping the development of material characteristics that are useful in product application.

A1 M. Easton, Y.F. Yang, S. Zhu, T. Abbott, M. Brandt: RMIT University

Opportunities and challenges for using selective laser melting to prototype aluminium die castings

Additive manufacturing (AM) provides an alternate approach for prototyping aluminium high-pressure die-cast components to the more resource-intensive sand or investment casting. Direct manufacturing of components will eliminate the need for the production of moulds and possibly heat treatment to obtain comparable properties. One of the important considerations is how the properties of AM components compare with their high-pressure die-cast counterparts. This paper shows that the selectively laser melted (SLM) AlSi12Mg alloy has similar properties to the alloy produced by high-pressure die casting. To a large extent this is because both techniques have fast cooling rates of the order of 1000°C/s, which lead to well refined microstructures. However, the SLM alloy tends to show some anisotropy in mechanical properties including strength and ductility, which is dependent on the build geometry. The anisotropy in strength appears to be related to the build layer boundaries and the orientation of the columnar grains that cross the layer boundaries. The amount and distribution of porosity appear to be more important to the anisotropy in ductility. This paper will outline a framework for understanding the properties of SLM aluminium alloys and identify ways to optimize the properties of such alloys.

A1 X. Zhang, M. Leary, M. Qian: RMIT University, Northeastern Uni. (China)

Effect of geometric parameters on Ti-6Al-4V orthopaedic implant strut morphology manufactured by selective electron beam melting (SEBM)

Selective electron beam melting (SEBM) is a promising technique for the manufacture of intricate lattice geometries for cellular implants. However, it has been observed that manufacturability and strut “morphology” are highly dependent on geometric and process parameters. SEBM is subject to specific process limits such as minimum manufacturable feature size and inclination angle for a given build material. At default layer thickness, the structural continuity between the layers becomes a problem as the strut angle relative to the build plate decreases for small cross-sections. It should be recognised that there is often a disparity between the intended structural design and that achieved in practice. For example, volumetric defects are often present and strut thickness and geometries are not always faithfully reproduced due to manufacturing constraint, unmelting titanium powder particles and the stair-case effect, strut morphology, especially surface roughness is of critical importance to enable osteogenesis in orthopaedic implants. It is shown that the interaction between the cellular structure and the surrounding cells and tissues is strongly dependent on the surface properties. Due to the heat flux is more likely to go through the melted part rather than the sintered powder, the roughness depends on the build orientation.

This work provides an experimental investigation of the manufacturability of SEBM Ti-6Al-4V lattice struts of different diameters and inclination angles. The influence of strut diameter and inclination angle on strut morphology and surface roughness is reported.

Invited A1 I. Timokhina, H. Beladi, P.D. Hodgson: Deakin University

Nanostructural engineering of advanced high strength steels

The development of modern steels is based on the tailoring of the microstructure to achieve the required properties. While historically this was performed at the micrometer scale length there is now the scope to undertake this at the nano-scale or atom scale. This presentation reviews recent work related to the development of ultrafine and nano-scale microstructures in advanced high strength steels (AHSS) using advanced characterization techniques such as Atom Probe Tomography (APT) and Transmission Electron Microscopy (TEM). This includes the development of ultrafine ferrite through phase transformation, the nano-scale and ultrafine bainite formation, precipitation and cluster strengthening of ferritic matrix, nano-twins formation in the high Mn steel and bake hardening of steels.

Keynote A2 H. Li, Z. Pan, D. Ding, S. Van Duin, J. Norrish: University of Wollongong

Recent development in wire arc additive manufacturing (WAAM) at University of Wollongong

The Welding Engineering Research Group was originally established as a result of the significant involvement of UOW in the CRC for Welded Structures. It continues to conduct both industrially focused applied research and more fundamental studies in joining technology. The group is internationally recognized for its work on welding process technology and materials weldability. More recently a strong robotic automation activity has been developed in collaboration with the Applied Automation Group in the Engineering Manufacturing Strength. The group has access to excellent state of the art welding and automation equipment and is backed by substantial metallurgical facilities.

The group also maintains strong contacts with other national and international partners. It is a key partner in the Australian National Defence Materials Technology Centre (DMTC) and Energy Pipeline CRC (EPCRC).

UOW research team has made significant progress on wire based additive manufacturing technology recently. Additive manufacturing offers a further alternative to conventional manufacturing techniques. Research at UOW has focused on out of vacuum GTAW/GMAW deposition of Ti alloys, steels, Al alloys and Cu alloys using robotic welding and machining for large 3D structures. In situ alloying of intermetallics based on the Ti-Al, Fe-Al system is also under investigation with air platform applications in mind.

A2 K. Jarvis, S. McArthur: ANFF-Vic Biointerface Engineering Hub, Swinburne University of Technology

Investigating the effect of reactor geometry on plasma polymerised acrylic acid films

Plasma polymerization modifies surfaces via the deposition of a thin film containing specific functional groups. The organic monomer is introduced into the chamber as a vapour, fragmented via radio frequency and deposited onto all surfaces in contact with the plasma. Acrylic acid is a commonly used monomer for plasma polymerisation and produces a negatively charged carboxylic acid terminated surface. Plasma polymerization was carried out in a custom-built stainless steel T-shaped reactor. The aluminium disk electrode was located in three different positions (end, front and top), to investigate its effect on film uniformity. The surface chemistry was analysed with X-ray photoelectron spectroscopy while the film thickness was determined using spectroscopic ellipsometry. With the electrode at the front, the film thicknesses decreased while the carboxylic acid group concentrations increased as the distance from the electrode increased due to decreased fragmentation further from the electrode. For the electrode at the front, thicker films with lower carboxylic acid concentrations were once again deposited for films closest to the electrode. For the electrode at the top, the film thicknesses and surface chemistry were more uniform than for either of the other configurations as all samples were the same distance from the electrode. These results have shown that reactor geometry is important for producing uniform plasma polymerised acrylic acid films.

A2 M. Okazaki, Y. Yonaguni, S. Yamagishi: Nagaoka University of Technology (Japan)

Effect of loading frequency on thermo-mechanical fatigue failure modes of a thermal barrier coatings

Landed based gas turbine systems have high capability to accommodate frequent and rapid load changes in power generation systems, where thermal barrier coatings (TBCs) on Ni-base superalloy components play an key role. In this study the thermo-mechanical fatigue (TMF) behavior of a TBCed superalloy specimen was experimentally explored when the specimen was exposed to non-steady state thermo-mechanical fatigue (NSS-TMF) loadings in which the temperature gradient was in non-steady state. The failure behavior was compared with that of isothermal low cycle fatigue (LCF) and the steady state TMF (SS-TMF) in which the temperature gradient was in steady state. The experimental works clearly demonstrated that the NSS-TMF cycles promoted the delamination of ceramic top coat, and significantly reduced the fatigue life. The failure modes was also different between the NSS- and SS-TMF failures.

A2 M. Weiss, B. Abeyrathna, B. Rolfe, L. Pan, R. Ge: Wuhan Iron and Steel Company, Deakin University

Flexible roll forming of components with variable depth

Roll forming is increasingly used in the automotive industry to form Ultra High Strength Steels to structural and crash components. However the traditional roll forming process is limited to straight longitudinal sections which restricts its application in the automotive industry. The current Flexible

Roll Forming (FRF) process enables the roll forming of profiles that are variable in width over the length of the component but to significantly increase its industrial uptake sections that vary in width as well as depth need to be producible.

In this work, the FRF of an automotive bumper section showing a variation in width is numerically analyzed and optimized applying the commercial software package COPRA® FEA RF. A prototyping tool is manufactured and, applying a new flexible roll forming approach, components manufactured. The new concept contains a die set to clamp the sheet which moves through a set of rolls which are movable and incrementally bend the material into shape. Forming strains and final part shape are analyzed experimentally and applied to verify the numerical model. The numerical model is then applied to further analyze the process to understand material behavior as well as shape defects and to develop forming approaches for part quality improvement.

A2 A.S.M. Ang, V. Luzin, C.C. Berndt, A. Anupam, S. Praveen, R.S. Kottada, B.S. Murty: ANSTO, Swinburne University, IIT Madras

Residual stress and mechanical characterisation plasma sprayed high entropy alloys

High Entropy Alloys (HEAs) are a new class of alloys with multi-principle elements in equi-atomic ratio that present novel phase structures. HEAs are known to for their high temperature microstructural stability, enhanced oxidation and wear resistance properties. To date, our research has been on HEA powders of AlCoCrFeNi and MnCoCrFeNi prepared via mechanical alloying, and subsequently, deposited by the atmospheric plasma spray (APS) technique. In this work, the objective is to characterise the residual stress profile of these coating systems that consist of both candidate HEA bond coat material and a conventional plasma spray NiCrAlY bond coat. These coating systems are used in critical applications, such as thermal barrier coatings (TBCs) for jet engine turbine blades that experience large temperature and mechanical loads. Thus, knowledge of stresses and their link with other properties and production parameters is essential for quality control of the coatings. We present findings on the co-relationships between the (1) processing conditions, (2) resultant microstructure, (3) residual stresses and (4) final mechanical properties of coatings. It will enable the evaluation and design of the potential of using HEA materials as a new generation TBC bond coat material.

Keynote A3 C.Y. Chan: Lee Kee Holdings Limited

Inheritance & innovation in the traditional metal industry

Metal industry is often regarded as a traditional industry. This in part is due to the emergence of new and advanced materials which can provide extraordinary advantages in their properties, weight and strength. Nonetheless, traditional metals retain their position in many engineering industries with their robust material properties, reliability and competitive costs in mining and manufacturing. By taking the audience through the journey of the transformation of a traditional Hong Kong metal shop to a listed company in the Asia Pacific region, this talk aims to explore the market challenges and opportunities which could drive metal related businesses to a new paradigm of success. The talk also covers how SMEs in Greater China region make changes in business when facing global economic challenges.

A3 D. Jiang, E. Brodie, J. Krechman, M. Jurg, M. Brameld, N. Stanford, N. Birbilis, C. Hutchinson: Woodside Energy, Monash University

3D printing of duplex stainless steels

Stainless steels are used extensively by the food, chemical and oil and gas industries. They are available in a range of grades with the choice depending on the mechanical, chemical and thermal

loadings. Austenitic grades such as 316 are probably the most common, but ferritic, duplex (ferrite + austenite), martensitic and precipitate hardened are all used. Stainless steels are also one of the more popular metals used for 3D printing. The Austenitic 316 grade has been studied most widely and can generally be 3D printed to create components of sound mechanical integrity, minimal porosity and acceptable corrosion resistance. However, austenitic stainless steels are limited in the strengths they can achieve and are susceptible to stress corrosion cracking (SCC). In more demanding applications, where SCC is possible and/or higher strengths are required, Duplex stainless steels (such as 22Cr Duplex or 25Cr super Duplex) are used. From the point of view of 3D printing, duplex grades represent an interesting material because the very fast cooling rates ensure that the duplex structure is not created in the as-printed state and post printing heat treatments are unavoidable. In this work we report our activities on 3D printing duplex stainless steels and the post printing thermal treatments required to obtain a suitably duplex structure. The microstructural evolution, mechanical and electrochemical responses of the material is discussed, as a function of the printing conditions and subsequent thermal treatments.

A3 N. Gurung, Y. Durandet: Swinburne University of Technology

Study of the piercing stage of self piercing rivets

Self-piercing rivets has become one of the leading technologies in the design and assembly of light vehicles. With the significant implementation by the leading automotive manufacturers in Europe and America, it has become an alternative to traditional joining techniques like resistance spot welding. However when it comes to materials with increased hardness, strength or thickness, the ability of the SPR to deform and fill the die is limited. The ability to pierce and flare in a ductile manner becomes restricted degrading the joint quality and narrowing the performance window. The objective of the paper is to study the piercing stage of the SPR using hard materials. An experimental programme is conducted where three different materials (G300, SS304 and MS) with variable thickness is used to create joints using various rivet from HENROB with variable length and hardness. The effect of the orientation is also studied in the paper. Similarly a test rig is developed to avoid the C-Frame deflection in the SPR rig and to study the piercing of the materials without creating any joints. The same test is simulated in LS-DYNA and the force-displacement curves obtained from all three tests are compared to each other.

A3 M. Ramajayam, N. Stanford: Monash University, Deakin University

Microstructure development and solute behaviour in Fe-C and Fe-C-V alloys during strip casting

Strip casting is a manufacturing process for producing thin steel sheets directly from liquid steel. This process induces rapid cooling, and therefore the microstructure development during strip casting is significantly different from conventional casting techniques. Very limited studies exist on the effect of solutes such as carbon and vanadium on the microstructure development during strip casting. The microstructure evolution and solute behaviour of Fe-C binary and Fe-C-V ternary alloys were studied under strip casting conditions. The ferrite morphology was found to be a complex mixture of various austenite decomposition products and therefore required a multi scale characterization approach. Microstructural characterization was carried out using optical microscopy, scanning and transmission electron microscopy, and electron back scatter diffraction techniques. Atom probe tomography and energy dispersive spectroscopy techniques were used to characterize the material chemistry. The Fe-C binary alloys containing up to 0.5wt% carbon were studied. With increasing carbon concentration, it was found that the volume fraction of ferrite decreased and was replaced by pearlite. Ternary Fe-C-V alloys, from 0.02 to 0.5 wt% carbon and 0

to 1wt% vanadium were examined. In micro alloy compositions, the as-cast microstructure was Widmanstätten ferrite.

In alloys containing 1wt% vanadium, increasing the carbon concentration above 0.02wt% transforms the massive ferrite microstructure to a fully bainite microstructure.

It is proposed that solute segregation of carbon and vanadium to prior austenite grain boundaries result in a change from Widmanstätten ferrite to bainite under strip casting conditions, but only above a minimum solute concentration.

A3 Y. Durandet: Swinburne University of Technology

Thermal-mechanical joining of magnesium

Structural adhesive bonding and Self-Pierce Riveting (SPR) are complementary and compatible joining technologies that may be used to assemble a wide range of material combinations including aluminium and steel, with a range of surface conditions such as coated, pre-lubricated, pre-painted, and with inter-layered adhesive or sealant. Both are relatively quiet and clean processes that require a fraction of the power needed for welding, and involve no fusion. Thus, both are increasingly used in aluminium intensive lightweight vehicles. However, as SPR is a joining-by-forming process that involves significant localised plastic deformation, joining of materials with high strength or low ductility at room temperature is challenging and can lead to cracking in the ply or rivet materials. This presentation presents a thermal-mechanical approach to joining with examples given where SPR of magnesium with and without adhesive was enabled using laser preheating and with minimal changes to existing SPR tooling.

A3 L. Djumas, A. Molotnikov, G. Simon, Y. Estrin: Monash Uni., NUST (Russia)

Topological interlocking - towards new hybrid materials

Composites play an important role as structural materials in a broad range of fields due to their potential to combine beneficial properties of their constituents. Nature provides inspiration in developing novel materials, as natural composites display fascinating architectures at multiple length scales, each of which can influence the properties of the material. One principle of interest is the combination of hard building blocks, which constitute a majority phase, and a soft matrix phase, thus mimicking the microstructure of nacre or bone, with its exceptional fracture toughness.

This work presents a geometrical concept known as topological interlocking which can be employed to vary the geometry of the hard building blocks and potentially produce structures with improved properties compared to a traditional brick-and-mortar design. The concept of topological interlocking is based on periodic assemblies of identical, discrete elements with specifically designed geometries, where each block is kinematically held in place by its neighbours. Utilising this concept we have created hybrid materials by adding a soft phase at the interfaces of hard topologically interlocked blocks, and thus achieving superior mechanical properties.

In this talk we present the results of a study detailing the various experimental and computational modelling work done to develop and fabricate a range of multi-material topologically interlocked structures utilising additive manufacturing techniques. These polymer hybrids combine multiple concepts, including topological interlocking, hierarchical architecture and nacre-like design. The results confirm that the ability to fabricate hierarchically interlocking structures with multiple length scale features opens up an exciting avenue for this technology.

Keynote A4 M. Qian: RMIT University

Additive manufacturing of Ti-6Al-4V: Microstructure, defects, tensile properties, and fatigue strength

The capabilities of metal additive manufacturing (AM) are evolving rapidly thanks to both the increasing industry demand and improved scientific understanding of the process. Ti-6Al-4V is the single most extensively studied metallic material for AM, and AM Ti-6Al-4V parts have found important applications in a variety of industry sectors. This paper discusses several recent developments made in the AM of Ti-6Al-4V by both SLM and SEBM. These include (i) microstructural development through massive and martensitic transformations and in-situ precipitation, (ii) the positional dependence of pore size, morphology and orientation and other microstructural features and their influence on tensile properties; (iii) the influence of as-built surface conditions on mechanical properties, (iv) the influence of sample orientation and size on the microstructural development of Ti-6Al-4V and its mechanical properties, and (v) the tensile and fatigue properties that can be achieved in the as-built state with or without post processing. The presentation is based on several recent publications (Acta Mater, 2016:104;303-311; 2015:85;74-84; Metall Mater Trans A 2015:46;3824-3834; JOM 2016:68;791-798; 2016:68;799-805; 2015:67;668-673; 2015:67;555-563).

Invited A4 J. Sankar: NC A&T State University (USA)

Revolutionizing metallic biomaterials for biodegradable implants – A global status

The purpose of the National Science Foundation (NSF) - Engineering Research Center (ERC) is to transform current medical and surgical treatments by creating "smart" implants for craniofacial, dental, orthopedic, cardiovascular, thoracic and neural interventions. The ERC is developing biodegradable metals with the premise that new kinds of implants can adapt to the human body and eventually dissolve when no longer needed, eliminating multiple surgeries and reduce health care costs. Magnesium based biodegradable systems offer significant therapeutic advantages over implants used today. Breakthrough activities include development, processing and testing of novel degradable alloy systems, new improved versions of existing clinical-use plates, screws and stents, innovative nanocoating technologies to yield special surface functionalities and methods to control implant corrosion, biocompatibility and improved bone growth. These innovations would particularly benefit pediatric patients suffering from cleft palate, angular deformities of long bones, limb length discrepancies, or trauma including fractures that require pins and screws for repair, then later remove, refit and re-implant the current generation of devices. Biodegradable stents could reduce or eliminate the need for additional invasive procedures. Sensors and other neural applications developed by the ERC will provide new information on the biological response of the body to implanted devices.

The talk will specifically provide a status update on the various innovations, translation and trailblazing pathways for developing the biodegradable implants and the impact of Mg knowledge in other multiple future applications through holistic University- Industry partnerships for economic ecosystem and commercialization.

Invited A4 W. Xu, E. Lui, M. Qian, M. Brandt: RMIT University

Regulate microstructure in situ in Ti-6Al-4V additively manufactured by selective laser melting for superior mechanical properties

α' martensite is usually dominant in Ti-6Al-4V additively manufactured by SLM and it is not easily achievable to transform it in situ into more desired ($\alpha+\beta$) microstructures in the current SLM practice. Such a metastable microstructure is problematic as it leads to inadequate mechanical

performances at room temperature while affecting the structural stability under loading or impacting conditions in service. Consequently, post-SLM heat treatment is often necessary. This study is motivated to optimize the SLM processing windows to achieve preferred ($\alpha + \beta$) microstructures in situ for superior mechanical properties. We show that, through a proper selection of the SLM processing parameters, it is practical to realise significant in-situ α' martensite decomposition for precise microstructural control to produce lamellar ($\alpha + \beta$) microstructures with a tuneable lath width in the range of 0.18-0.75 μm . A microstructure “signature” for SLM Ti-6Al-4V has thus been proposed for its future additive manufacturing with desired mechanical properties.

A4 M. Jurg, W. Yan, A. Molotnikov: Monash University

Surface improvement for complex selective laser melting Ti-6Al-4V in fatigue applications

Selective laser melting (SLM) while able to produce extremely complex geometries often suffers from a poor surface finish with a high roughness, making it unsuited to fouling environments or cyclic loading without additional surface finishing. Post-machining of complex geometries can be cost prohibitive, or where the surface is not readily accessible contact methods such as machining become infeasible. To address this shortcoming a non-contact chemical finishing technique has been developed for SLM Ti-6Al-4V using a hydrofluoric/nitric acid solution, achieving a surface roughness comparable to that of machining. The method has shown a consistent linear material removal rate, which can be compensated for in design, and a doubling of the effective endurance limit over the as-built condition.

Keynote A5 B. Fox: Swinburne University of Technology

The ‘Factory of the Future’ and high volume automated materials

Swinburne’s Factory of the Future aims to play a leading role in the global drive to integrate the design, automation and control of manufacturing systems.

In the past two decades, cure cycle times for carbon fibre composites have been dramatically reduced from hours to minutes. At the same time, the global market for carbon fibre composites is confidently expected to grow exponentially to \$36 billion by 2020 with key applications in aerospace, automotive, defence, wind energy and civil engineering. Now composite cure cycle times are no longer the rate limiting step in the production process, the remaining challenge is to increase production rates by replacement of manually intensive steps with automated production.

An example of the state of the art for automated composite production is the BMW i3 battery electric vehicle manufacturing plant in Leipzig, Germany. The i3’s carbon fibre composite “life module” is built using several of the latest technologies for industrial automation. However, it is noted that whilst this process represents a paradigm shift in advanced composite manufacture, there are still significant manufacturing challenges which further innovative research can help overcome. The cure cycle time for the carbon fibre composite components is 8 minutes (automotive targets are under 1 minute to compete with sheet metal forming) and this process requires some manual intervention.

This presentation will describe the current capabilities of the Factory of the Future and will highlight the future directions for the development of a new High Volume Automated Composite Centre.

A5 N. Perevoshchikova, J. Rigaud, B. Finnin, S. Sha, X. Wu: Monash University, ENSIACET (France)

Optimisation of selective laser melting parameters for the Ni-based superalloy IN-738 LC using Doehlert's design

The Ni-based superalloy IN-738 LC is known to be susceptible to porosity and different types of cracking during the build-up process and challenging to manufacture using Selective Laser Melting (SLM). Determining a feasible set of operating parameters for SLM of nickel based super alloys usually involves several cycles of estimation and evaluation. Factorial experiments or fractional factorial experiments are undertaken where one parameter is usually fixed while another is varied and then a series of evaluation methods are applied to determine the relative density and level of cracking as an assessment of the integrity of a component. This work evaluates a new approach to experimental design based on the Doehlert method that assists in determining an optimal (feasible) set of operating parameters. It takes advantage of background knowledge to inform the set of experiments and the assessment of outputs, hence limiting the number of experiments and the time taken to arrive at an optimal solution set. The mechanical properties of the newly SLM IN738 followed by standard heat treatment are compared to those of conventionally manufactured cast-material demonstrating promising performance results. The experimental method was able to provide a (successful) set of optimised parameters after only 14 experiments, a marked improvement over earlier methods, which have typically required several times more experiments, sample assessments and a much longer development time to produce a similar outcome.

A5 C. Hutchinson, M. Jurg, W. Sun, S. Thomas, M. Brameld, N. Birbilis: Monash University, Woodside Energy

On demand 3D printing of stainless steel parts

3D metal printing offers some advantages over conventional metal processing. Most commonly referred to are the extra degrees of freedom afforded to component design, the decrease in the number of joints in a component (e.g. welds) and the decrease in the quantity of material that is machined away in the case of expensive metals used in aerospace such as Ti or Ni. An additional advantage that is rarely spoken of, but is particularly pertinent to Australia, is that an ability to print metallic components on site, and on-demand, provides a security of supply to companies using some metallic components. In the case of stainless steels, which are used throughout the food, chemical, and oil and gas industries, there are no production facilities in Australia. As a result, parts must either be sent from overseas when required, or replacement parts must be stored in Australia. Both options have a significant cost and represent a supply chain security issue.

In this presentation we discuss our developments in 3D printing of stainless steels in collaboration with our industry partner Woodside Energy. The objective is to develop the capability for on site, on demand 3D printing of stainless steel parts for use in Woodside's production facilities to resist corrosive fluids and seawater. In the form of a case study, we discuss the development path from the conception of the idea, 3D printing, mechanical and electrochemical testing, component design, all the way through to field trials of a real 3D printed stainless steel component.

A5 P. Chandran, A. Zafari, K. Xia, University of Melbourne

Phase evolution during mechanical alloying of Al and Nb

Al and Nb can form trialuminide Al_3Nb possessing high strength and stiffness. However, Al-Nb alloys cannot be processed by conventional methods since Nb has zero equilibrium solubility in Al at room temperature and negligibly small solubility even at elevated temperatures. High energy mechanical milling, a non-equilibrium method, is often employed to force alloying in such an

immiscible system. In the present study, alloying of Al with 2.5, 5 and 10 at.% Nb, respectively, was carried out by ball milling of elemental Al and Nb particles. The evolution of phases and particle morphologies during milling was studied using X-ray diffraction (XRD), scanning electron microscopy (SEM) and differential scanning calorimetry (DSC). Al supersaturated solid solutions were formed with 2.5 and 5 at.% Nb after prolonged milling whereas Al_3Nb in the form of nanoscale particles was mostly produced with 10 at.% Nb. Nano Al_3Nb precipitates were also obtained during subsequent ageing of the two leaner alloys, potentially providing significant precipitation strengthening.

A6 A.S.M. Ang, R. Piola, W. Neil, C.C. Berndt, M. Leigh, H. Howse, S.A. Wade: Swinburne Uni., Defence Science and Technology Group, United Surface Technologies, MacTaggart Scott Australia

Novel carbide-based coatings for marine hydraulic applications: mechanical, biofouling and corrosion performance

Hydraulic components are used in a wide range of marine applications in which they are exposed to environments that can seriously degrade longevity and operational performance. In many instances, suitable coatings can be applied as a protective layer on the component to militate against corrosion and biofouling. Our previous work has reported that high velocity oxygen fuel coating (HVOF) technology has the potential to achieve carbide-based nickel rich coatings with dense, low porosity microstructure that exhibit high bond strengths, low oxide content. In this work, we report on these HVOF coatings' mechanical properties and evaluate the coatings' endurance for hydraulic applications by performing pressurised cyclic testing. We also expose these coatings in various Australian marine sites and present preliminary results of biofouling rates, corrosion rates of these HVOF coatings, as well as reporting any changes to the surface metrology.

A6 T. Majumdar, J. Wang, E. Massahud, N. Birbilis: Centro Federal de Educação Tecnológica de Minas Gerais (Brazil), Monash University

A novel methodology for examining the re-passivation characteristics of highly noble alloys

Ti-based alloys are widely regarded as the best material for stress-bearing implants, due to important properties such as low cytotoxicity. However, the behaviour of Ti-based alloys in physiological conditions is not yet fully understood, particularly their corrosion resistance. Any surface damage to implants can lead to corrosion, however, Ti-based alloys have the capacity to 'heal' scratches through re-passivation processes.

To date little work has examined the re-passivation rates of Ti-based alloys. Current experimental designs do not allow for the accurate measurements of Ti-based alloy breakdown potentials in physiological solutions (MEM, FBS etc.), due to the presence of dense, protective surface films which require a high potential to be broken down ($>1VSCE$, the limit of conventional set-ups).

This study presents a novel testing technique to accurately determine re-passivation characteristics for several Ti-based alloys, namely Selective Laser Melted (SLM) Ti-6Al-4V, cast Ti-6Al-4V, Commercially Pure (C.P.) Ti, Ti-29Ni-13Ta-4.5Zr (referred to as TNTZ), Direct Laser Deposition (DLD) fabricated 50Ti-35Nb-15Zr (referred to as DLD TNZ-A), 67Ti-25Nb-8Zr (referred to as DLD TNZ-B) and pure Ti (referred to as DLD TNZ-C), through manual film damage. The time taken to re-establish the baseline (pre-damage) current density was found to be different for all alloys tested, indicating different re-passivation rates. The key results indicate that both fabrication method and alloy composition play an important role in re-passivation rates. This methodology can be utilised for the further study of other similarly noble alloys and alloy compositions.

A6 P. Sutar, S. Khot, S. Mishra, S. Telrandhe, R.K.P.Singh: Indian Institute of Technology, Bharat Forge Limited (India)

Machinability improvement of Ti-6Al-4V by laser surface treatment

This work presents the study on effect of continues laser (Fiber Laser) on Ti- 6Al-4V titanium alloys machinability. Laser with 200-300W power was used. After laser surface treatment, Modified surface characterized for microstructure change, new phase formation with EBSD analysis and XRD. Then samples were used for turning operation. Machining was performed on modified layer in dry machining condition. A significance changes in the microhardness was observed for all laser treated samples. Significant reduction in cutting forces for all laser treated samples. Significant reduction in variation was observed for maximum power and minimum scanning speed.

A6 Y. Tian, D. Tomus, P. Rometsch, X. Wu: Monash University

On influence of processing parameters on surface roughness of Hastelloy X produced by selective laser melting (SLM)

Selective laser melting (SLM) technology is a layer-wise powder-based additive manufacturing method capable of building 3D components from their CAD models. This approach offers enormous benefits for generating objects with geometrical complexity. However, due to the layer-wise nature of the process, surface roughness is formed between layers, thus influenced by layer thickness and other processing parameters. In this study, systematic research has been carried out to study the influence of processing parameters on surface roughness in Hastelloy X alloy and samples used were manufactured using EOSINT M 280 machine. Laser power, scan speed, layer thickness and sloping angle of a surface were systematically varied to understand their effects on surface roughness. The arithmetic average roughness, Ra, was measured by surface roughness tester and an optimum condition for achieving the lowest roughness for upper surface (slope angle $>90^\circ$) and down surface (slope angle $<90^\circ$) has been obtained, respectively. The formation mechanism for the roughness on these two types of surfaces has been studied. Computer simulation was also used to understand thermal profiles at those two surfaces and their resultant influence on surface roughness. The simulated result has been found to be consistent with the measured. Scan strategies of contour scan and skywriting were found helpful for reducing surface roughness.

Symposium B: Biomaterials and ceramics

Keynote B1 M. Lord, J. Rnjak-Kovacina, X. Lin, K. Chandrasekar, J. Whitelock: UNSW

Extracellular matrix-based biomaterials for cardiovascular devices

Glycosaminoglycans, such as heparin, have been widely incorporated into biomaterials for regenerative medicine applications, yet the parent proteoglycans from which these glycosaminoglycans have been derived have gained much less attention. Proteoglycans are ubiquitous extracellular matrix molecules that drive cell function including organ development and repair.

We have demonstrated that coatings of the vascular proteoglycan, perlecan, promote endothelialisation whilst inhibiting smooth muscle cell proliferation, platelet adhesion and activation. This coating improved endothelialisation of vascular grafts by 36% and reduced thrombosis by 65% over the current materials in an ovine carotid model over 6 weeks. These studies are promising; however the yield of naturally derived proteoglycans limits the clinical translation of this work. Thus the aims of this research are to bioengineer proteoglycan containing biomaterials for cardiovascular applications.

The C-terminal region (domain V) of perlecan was recombinantly expressed in mammalian cells as a proteoglycan at a 6 fold increase in yield compared to perlecan from primary human endothelial

cells. Domain V was effective in promoting endothelial, but not smooth muscle cell or platelet adhesion. In the absence of glycosaminoglycans domain V supported the adhesion of endothelial cells and platelets via integrin $\alpha 2\beta 1$ but not smooth muscle cells. This suggests that domain V may have roles in encouraging endothelialization of materials while inhibiting unwanted activities associated with platelet and smooth muscle cell adhesion that lead to thrombosis and restenosis in current cardiovascular devices. These activities have been determined in vitro when coated onto biomaterials and will be assessed in vivo in the near future for vascular grafts, stents and the storage of platelets prior to transfusion.

B1 R. Mehmood, P. Koshy, C.C. Sorrell, M. Lord: UNSW

Predicting the unpredictable: Nanoceria as nanomedicine for cancer prevention

Cerium oxide nanoparticles have shown promising signs for use in nanomedicine applications to combat diseases such as cancer, neurodegenerative disorders, and cardiovascular problems and this is owing to their anti-oxidant and enzyme-mimetic properties. Nanoceria thus has the potential to serve as a therapeutic and radioprotective agent in cancer treatment. In radiation therapy, nanoceria can be used to sensitise cancer cells while protecting normal cells from radiation. The anti-oxidation behaviour of nanoceria helps to scavenge ROS, which are the major species responsible for triggering abnormalities in healthy cells and tissues. Numerous methods have been used to synthesise and functionalise nanoceria of varying physicochemical properties for biomedical applications. For cancer prevent, there is a direct and indirect effect; directly it can oxidise tumour microenvironments by producing ROS which help to kill cancer cells, while indirectly is adopts a bifunctional role to mediate the stroma-tumour interaction and in the inhibition of angiogenesis in cancer cells. The bifunctional role enables its use as a novel material for cancer therapy. In the present work cerium oxide nanoparticles of varying shapes and morphologies were fabricated and functionalised prior to their incorporation of nanomedical applications.

B1 A. La Fontaine, A. Zavgorodniy, H. Liu, R. Zheng, M. Swain, J. Cairney: The University of Sydney

Atomic scale compositional mapping reveals Mg-rich amorphous calcium phosphate in human dental enamel

Human dental enamel, the hardest tissue in the body, plays a vital role in protecting teeth from wear as a result of daily grinding and chewing as well as from chemical attack. It is well established that its mechanical strength and fatigue resistance is derived from its hierarchical structure, which consists of periodically-arranged bundles of hydroxyapatite (HAP) nanowires. However, we do not yet have a full understanding of the in vivo HAP crystallization process that leads to this structure. Mg²⁺ ions, present in many biological systems, regulate HAP crystallization by stabilizing its precursor, amorphous calcium phosphate (ACP), but their atomic scale distribution within HAP is unknown. Here we use atom probe tomography (APT) to provide the first direct observations of an intergranular Mg-rich ACP phase between the HAP nanowires in mature human dental enamel. We also observe Mg-rich elongated precipitates and pockets of organic material among the HAP nanowires. These observations support the post-classical theory of amelogenesis (i.e. enamel formation), and suggest that decay occurs via dissolution of the intergranular phase. This information is also useful for the development of more accurate models to describe the mechanical behaviour of teeth.

B1 X-B. Chen: Monash University

Osteoanabolic implant materials for orthopedic treatment

Osteoporosis is becoming more prevalent due to the aging demographics of our population. Osteoporotic bone is more prone to fracture than normal bone, and current orthopaedic implant materials are not ideal for the osteoporotic case due to modulus mismatch. We developed a strontium phosphate (SrPO₄) coating on a titanium-29niobium-13tantalum-4.6zirconium (TNTZ, wt.%) implant material with comparative Young's modulus value to that of natural bone. We aimed to thereby modulate the activity of osteoblast and osteoclast cells in order to promote bone formation. TNTZ, a material with excellent biocompatibility and extreme bio-inertness was pretreated in a concentrated alkaline solution under hydrothermal conditions, followed by a coating growth process to achieve a full surface coverage with SrPO₄. With the resulting release of Sr ions from the SrPO₄ coating, osteoblast cells demonstrated increased proliferation and differentiation, whilst the cellular responses of osteoclasts were suppressed, compared with the control case, i.e. bare TNTZ. This TNTZ implant with a near physiologic Young's modulus and with SrPO₄ coating provides a new direction in the design and manufacture of implantable devices used in the management of orthopaedic conditions in the osteoporotic individual.

B1 C. Joseph, C. McCarthy, A. Francis, A. Tyo, H. Fisher, J. Altscheffel, B. Spalding, R. Rajachar: Michigan Technological University (USA)

Development of a novel nitric oxide releasing fibrin microgel composite hydrogel for tendon repair

Tendon injuries can be acute or chronic, and in both cases can lead to fiber degeneration and pain in injured tissues. Invasive surgical techniques are often used in their repair. A minimally invasive approach to the stabilization and healing of tendon injuries may be achieved through an injectable poly (ethylene) glycol (PEG)-fibrinogen hydrogel incorporating nitric oxide (NO) releasing fibrin microparticles with beneficial wound healing and cell adhesive properties. The aim of this work is to fabricate NO releasing microparticles and incorporate them into a PEG-fibrinogen hydrogel for use in an injectable tendon repair system.

NO releasing fibrin microparticles were generated using a simple emulsion polymerization process through which particle size distribution can be controlled using fluid shear stresses generated via stirring. S-Nitroso-N-acetyl-D-penicillamine (SNAP) was synthesized and used as the NO donor for this work. A fibrinogen-SNAP blend was used to create the microparticles at three different mixing speeds, and the mean particle diameters ranged from 78–193 μm. NO release studies show consistent, controlled release for the individual particles as well as for the composite hydrogels. Mechanical characterization shows that in compression, both control hydrogels and microgels demonstrated evidence for strain stiffening behavior while a significant increase in the ultimate failure was seen between control hydrogels and microgels. Microgels were found to be significantly lower than control gels in swelling ratio and water content, while degradation times were very similar. Cells cultured on these novel materials spread and maintained viability.

B1 N. Gui, M. Qian, R. Shukla, W. Xu, J. Tian: Macquarie University, RMIT University

The role of microgrooved titanium surface topography on human fetal osteoblasts

In order to promote fast and long-lasting osseointegration and minimize the adverse responses, a variety of surface modification methods have been utilized for orthopaedic implant surface designs in the past years. Surface topography is reported to exert more influence than other surface characteristics (including surface chemistry etc.) on implant integration. In order to quantify the individual features on cell responses, microgrooves with various dimensions were fabricated on

titanium surface. Human fetal osteoblasts (hFOB 1.19) were cultured on microgrooved surface. Cell shape, morphology, viability, proliferation and osteoblastic capacity (alkaline phosphatase activity) were investigated using SEM and confocal microscopy. Surface characteristics of these microgrooved patterns were quantitatively and qualitatively studied by employing SEM, 3D optical profiler and sessile contact angle measurements. These results revealed that osteoblast responses are notably influenced by microgrooved patterns.

B1 L. Yin, B. Cliffe, H.D. Marsh: James Cook University

Mapping of microstructure and mechanical properties of a dugong (Dugong Dugon) tusk

The dugong (Dugong dugon), or sea cow, is the only extant herbivorous mammal that is strictly marine. The dugong is classified as vulnerable in the red list of endangered species of the International Union for Conservation. The second upper incisor teeth form tusks, which erupt in mature males and some old females. Dugong tusks are used in intra-specific interactions and many animals bear tusk scars. Little is known about the microstructure and mechanical properties of dugong tusks. In this study, we mapped the microstructure of a naturally dried dugong tusk and measured its mechanical properties using indentation techniques. The dugong tusk had a very thin enamel layer of less than 300 nm, which is easily abraded, and dentine. The incremental growth layer groups in the dentine are used for age determination. The mean and standard deviation of the hardness for the enamel ranged from 2.74 ± 0.36 GPa to 3.49 ± 0.22 GPa. The mean and standard deviation of the fracture toughness for the enamel was in the range of 0.52 ± 0.14 MPa.m^{1/2} to 0.76 ± 0.15 MPa.m^{1/2}. The mean and standard deviation of the hardness for the dentin ranged from 0.21 ± 0.01 GPa to 0.42 ± 0.02 GPa. The variation of the mechanical properties of the dugong tusk reveals their heterogeneous, microstructure-dependent nature.

B2 E. Onal, B. Chen, X. Wu, A. Molotnikov: Monash University

Additive manufacturing of lattice structures for orthopaedic implants

Metal additive manufacturing (AM) is gaining popularity as a new manufacturing technique to produce bespoke biomedical implants. In particular, periodic lattice structures produced by Selective Laser Melting (SLM) are promising candidates to obtain biomedical implants with tailored mechanical properties and porosity. The present work will summarise our systematic study of mechanical properties and biological response of porous Ti-6Al-4V lattice structures fabricated by SLM.

Three distinct cell geometries, namely FCC, Octet (combination of FCC and Challis' cell), BFCCz (Combined BCC and FCC with xy plane removed with Z struts) were analysed using cubes of 10 mm³ which were produced by the EOS M280 machine. The overall porosity of the samples was modified by changing the strut diameter sizes from 0.4 to 0.8 mm. Compression tests were conducted on an Instron 5982 mechanical testing machine at a rate of 4mm/minute and video recordings are utilised to capture the failure mode of each of the cell geometries.

In addition to mechanical tests, in vitro cell testings were performed with human osteoblasts on the same lattices and the interplay between biological response and mechanical properties of various pore size and geometry will be discussed.

B2 C.C. Sorrell, W-F. Chen, P. Koshy: UNSW

Photocatalytic activation of biomaterials

Photocatalytic materials generally must be activated by ultraviolet (UV) radiation owing to their large band gaps. However, these materials recently have gained considerable interest because they can be activated by both X-rays and ultrasound. Consequently, they may have applications as self-

sterilising devices in the form of coatings and as therapeutic agents in the form of nanoparticles. A summary of some of the work in these areas that has been undertaken at UNSW Australia during the past decade will be given.

B2 G.V. Franks: University of Melbourne

Forming dense complex shaped ZrB₂ ceramics by freeze casting

The most common use of freeze casting is in the preparation of porous ceramic materials where the porosity is created by voids formed when growing ice crystals reject the particles so that the ice crystal becomes a pore former. Instead, we aim to produce dense ceramic monoliths with complex shape by freeze casting under conditions that minimize the segregation of particles ahead of the solidification front. The use of cyclohexane rather than water as a vehicle for the suspension is important since the water crystals are much larger than those formed in cyclohexane. The influence of the freezing rate and solids concentration is investigated. Heat transfer modelling is used to better understand the freezing front velocity at different locations in a solidifying component. Pore sizes in the component depend on the freezing front velocity, with larger pores formed for slower freezing. When the freezing front velocity varies from location to location within a component, the pore size will also vary with location. Smaller pores are easier to be removed during sintering than large pores. As such, different parts of the object can densify differently (rate and extent of densification) and result in differential shrinkage. Excessive differential shrinkage results in stress and cracking of components. Understanding the influence of suspension formulation, and freezing rate can help one to avoid such problems.

B2 M.L. Sesso, G.V. Franks: The University of Melbourne

Fracture toughness of wet particulate materials: Influence of saturation

The formation of many advanced ceramics into functional complex shaped components requires starting materials in powder form to be processed in a wet state. Further understanding of the mechanisms involved in the fracture of wet particulate networks will aid in the processing of new materials. Specifically, knowledge of the fracture toughness of saturated, partially saturated and desaturated particulate bodies will aid in understanding drying cracks. In this study, the mode I fracture toughness of ceramic particle bodies ranging from dry to nearly fully saturated at various particle concentrations were measured. The effect of initial flaw size on the fracture toughness was also investigated. For the dry green bodies, increasing the solids content from approximately 35 to 50 vol. % more than doubled the fracture toughness, whereby the same solids content increase in the wet bodies displayed a less pronounced effect. In addition, the variation in fracture toughness between the wet and dry bodies was greater for larger initial flaw sizes. These differences in fracture toughness values were related to the critical strain energy release rate required to propagate an unstable crack through the dry and wet particulate networks. The dry bodies were shown to exhibit primarily brittle fracture, whereas the wet bodies displayed signs of plastic flow that increased that critical strain energy required to form the new surface.

B2 N. Scales, J. Chen, G.R. Lumpkin, I. Karatchevtseva, A. Stopic, V. Luca: ANSTO, CNEA (Argentina), University of Wollongong

Carbon-zirconium carbide sphere materials as irradiation hosts for radionuclide production

This presentation reports on new porous composite sphere materials with intended application as reusable irradiation hosts for the production of commercially important radionuclides, whilst generating lower waste volumes. The materials were produced from organic polymeric substrates

incorporating Zr, which were then subjected to carbothermal reduction. The resulting products were characterised with respect to composition, chemical structure and porosity. The inorganic phases typically comprised ZrC and zirconia polymorphs, although one material in particular, was shown to consist of substantially phase pure ZrC. Adsorption studies demonstrated promising selectivity for oxospecies-forming elements, providing a facile means of introducing the target nuclides into the host matrix.

B2 W-F. Chen, P. Koshy, C.C. Sorrell: UNSW

Photocatalytic activity of vanadium-doped TiO₂ thin films under long-term and repeated cyclic testing in different dye solutions

Photocatalytic TiO₂ is considered an effective option for water and air purification. Vanadium-doped TiO₂ thin films were fabricated by sol-gel method (using titanium isopropoxide and isopropanol), followed by deposition on soda-lime silica glass substrates by spin coating and annealing at 450°C for 2 h. The dopant concentration was in the range of 0.00-1.00 mol%. The undoped and doped TiO₂ thin films were characterised using glancing-angle X-ray diffraction (GAXRD), laser Raman microspectroscopy (Raman), atomic force microscopy (AFM), and ultraviolet-visible spectrophotometry (UV-Vis). GAXRD and Raman data showed that the films were composed of crystalline anatase, with the crystallinity varying with the dopant concentration. UV-Vis data showed that all of the films were highly transparent. The photocatalytic activity of these films was evaluated in terms of degradation of different dye solutions (methylene blue, methyl orange, reactive black) which represent different organic dyes typically present in water, under varying UV irradiation times. Furthermore, the films were cleaned to remove the dye solution and then retested for photocatalytic activity for varying number of cycles to determine if the doping concentration and dye composition would impact on the photocatalytic efficiency.

B3 M. Nanko, H.V. Pham: Nagaoka University of Technology (Japan)

Ni/Al₂O₃ Nanocomposites as Multi-functional Structural Ceramics

Alumina-based nanocomposites dispersed with nano-Ni particles are well-known metal/ceramic nanocomposites with superior mechanical properties, high fracture strength, high hardness and high fracture toughness, as well as ferromagnetism. As well, Ni/Al₂O₃ nanocomposites has thermal oxidation-reduced self-healing capability on surface cracks. Thermal oxidation treatment leads to the formation of oxidation product, NiAl₂O₄, on the surface of not only bulk of Ni/ Al₂O₃ nanocomposites, but also surface crack inside. Filling surface cracks with the oxidation product decreases stress intension at the tip of surface crack, resulting in recovery of the mechanical strength which is decreased by the surface crack. Outward diffusion of cations is important for thermal oxidation-induced self-healing performance on this nanocomposite system. The recovery of mechanical strength is effective at elevated temperatures such as 1000°C, as well as room temperature.

B3 E. Obbard, P. Burr, D. Gregg, K-D. Liss, K. Johnson, S. Middleburgh: Westinghouse (USA), UNSW, ANSTO, KTH

In-situ diffraction of uranium nitride/silicide composite as accident tolerant nuclear fuel

Uranium nitride/silicide composite nuclear fuel combines the excellent thermal properties (60 W/mK at 600 °C, T_m 2850°C) of UN with the oxidation resistance of U₃Si₂ by encapsulating UN particles in a silicide intergranular matrix. Conventional sintering of UN-10wt.% U₃Si₂ composite results in the formation of a three-phase microstructure – UN, U₃Si₂ and a recently reported ternary phase. It is unclear to what extent the ternary phase degrades the accident tolerant properties of the

composite. However, spark-plasma sintering, with suitable sintering parameters, yields a microstructure without the ternary phase. To investigate if the composite's microstructure is retained during an accident scenario, we performed in-situ neutron powder diffraction for quantitative phase analysis while heating the sample to ~1600 °C, which simulates the thermal profile of a station black-out scenario. The data is presented for various UN/U₃Si₂ compositions.

Symposium C: Translational research in polymers and composites

Keynote C1 M. Gee: Boeing

Industry-university partnerships: Arranged marriage or perfect match?

Driving collaboration is a mantra commonly seen in business mission statements. The strategy underlying this ethos is that collaboration with universities and research institutes provides access to world class technologies. Alignment of these technologies with the needs of industry gives a business the competitive edge. In spite of this, industry-university partnerships are not common and often fail to deliver.

The release of the Australian Government's National Innovation and Science Agenda last year is a clear push for universities to work more closely with industry to foster an innovation-based economy. But isn't this just an arranged partnership and a recipe for failure? Don't we all want to find our perfect match?

In 2015, after a long career as a research and teaching academic, I was recruited from academia to join Boeing. As a tech head, I was drawn by what might be on the other side...the dark side, as is the view of many of my university colleagues. In my role at Boeing, I help grow partnerships with universities and arrange perfect R&D matches. In what has been a steep learning curve and a thrilling ride, I have been able to marry my two worlds. In my talk, I want to share with you some of the lessons I've learned along the way, seeing what research means from both sides, so that you might find your perfect R&D match in this age of innovation.

Invited C1 D.A. Lewis: Flinders University

A case study of turning science into a new product: How it was actually done

It has been well documented that Australia has one of the worst technology conversion rates from University to Industry in the OECD. This had led to increasing pressure on researchers to think about commercialisation of their technology through the governments increased focus on innovation and translational research. Despite the governments' hope that this will happen and researchers willingness, not surprisingly, there are many challenges that have to be overcome. Ultimately, a broad team with commercial, manufacturing and scientific expertise to be successful. Factors such as the type of customer (whether it be a business or consumer) and the maturity of the market that is being targeted are critical because they provide the product attributes and target costing.

In this presentation, I will discuss the successful product development of a photochromic sunglass lens developed by Zeiss. I will show some of the science behind the product, describe the roles of the players who made it possible and the process that underpinned the whole project.

Invited C1 B. Dunstan: Asia Pacific Engineering Director of Multimatic

Carbon Fibre Composites: At a cross roads in the automotive industry?

Carbon fibre composites are at a cross roads in the automotive industry today. Cycle times are decreasing towards the target of a part per minute, but costs are still too high. This due in part to high fibre costs and waste is still too high. In this talk Multimatic's Asia Pacific Engineering Director, Brad Dunstan, will cover the engineering and manufacturing processes that Multimatic

have developed to allow them to design and manufacture some of the world's leading super cars such as the Aston Martin 177 and the Ford GT.

Keynote C1 A.P. Mouritz: RMIT University

Improving the explosive blast resistance of fibre-polymer composites

An overview of experimental research into improvements to the explosive blast resistance of fibre reinforced polymer composite materials used in military and civil structures is presented. Fibreglass and carbon fibre composite targets were impulsively loaded by shock waves of increasing intensity generated by plastic explosive charges. The dynamic deformation behaviour, internal damage, and post-blast mechanical properties of the composites were determined. Damage within composite materials initiates with matrix cracking and fibre-matrix interfacial debonding, and then develops into delamination cracks and broken fibres with increasing shock wave impulse until eventually the entire target ruptures. With the initiation and spread of delamination cracking and broken fibres there is a corresponding reduction to the post-blast mechanical properties of composites. Experimental testing reveals that the explosive blast damage resistant of composite materials is dependent on a multitude of factors, including the type of fibre reinforcement, fibre architecture, type of polymer matrix, and the interfacial bond strength between the fibre reinforcement and matrix. This information can be used in materials selection to create composites with enhanced explosive blast damage resistance and improved post-blast properties.

Keynote C2 A.K-T. Lau: Swinburne University of Technology

Natural fibre composites - Their properties and applications

Natural fibers such as palm, bamboo, sisal, hemp, coir and even pineapple leaves have been well recognized as good reinforcements as well as commonly called "supplements" for plastic products. In the past few years, the increase of petroleum price and newly announced environmental regulations around the world have brought up a difficulty toward the plastic product industry due to the increases of raw materials costs (for both non-biodegradable and biodegradable plastics) and disposal charges for non-degradable and non-disposable products. Redesigning plastic products that can fulfil green regulations (4Rs) would increase initial set-up costs for recruiting high-caliber designers and engineers, redeveloping production lines, and investing items related to research and development (R&D). By reducing the amount of plastics use for new products with achieving the same mechanical and thermal strengths, or even better, can greatly save the whole product costs in the long run. For animal-based fibers, due to their biodegradable and bioresorbable properties, they are ideal to be mixed with bio-polymers to form complete biocomposites for bone repairs or other similar functions. However, the understandings of the properties of fibers, their bonding characteristics with other materials, manufacturing processes and resultant properties of their composites are essential before fully adopting them for real-life applications. In this session, a brief summary on the recent development of plant-based and animal-based fibre polymer materials/products will be given. Several key issues such as their strength (raw materials and their composites), manufacturing processes (pre-treatment and post-treatment) and potential applications will be discussed in detail.

Invited C2 N. Bai, M. Abdullah, K Saito, G.P. Simon: Monash University

Stimulated healing of polymer coatings

Coatings are often crosslinked polymers in order to have the hardness and abrasion resistance required to successfully perform the protective function. In addition, if they are protecting an optical element (such as an ophthalmic lens) or a visual component (coating on a car), they need to be

transparent. Scratches on the coating can thus cause functional problems, as well as reducing aesthetics. Since the coatings are network polymers, they cannot be induced to flow to repair the cracks. In this talk I will detail two related strategies that my colleagues and I have developed to repair scratches on epoxy and acrylic coatings. Both are autonomous, in that they involve the scissioning, molecular flow and reformation of the crosslinker element of a thermoset coating. Flow occurs since, if possible, the drive towards lower surface area causes the polymer molecules to fill the scratches. It is important to then be able to reform the crosslinked system after flow has occurred. In one case we will use heat as the stimulus to cause scission and a different temperature to cause healing. In the other instance we will use UV light) of different wavelengths to cleave and heal the network. The advantages of the systems we propose is that the additive can be used with conventional and widely used epoxy resins and acrylic monomer. Some examples of how this technology can be used in a practical sense, will also be shown.

Invited C2 B. Laycock: University of Queensland

Wood biopolymer composites

Wood plastic composites (WPCs) have been burgeoning internationally over recent decades. The WPC market is projected to be worth up to \$4.6 billion US dollars globally by 2019, with a compound annual growth rate of 12.2% between 2014 and 2019. These composites find use in many applications, from automotive parts to building structure components, such as decking and railings. WPCs are typically produced by compounding lignocellulosic fillers with molten polymers, and can be processed to a desired shape using standard extrusion technologies. Polyolefins such as polyethylene (PE) and polypropylene (PP) remain the primary resins used in commercial WPCs, being both cost effective and durable, with relatively low moisture permeability.

In recent years, however, there has been a growing interest in the utilisation of biodegradable polymers to replace polyolefin as the polymer matrix for composite applications. With such complete biodegradability, the applications of WPCs can be extended to relatively short-term uses such as food packaging, pallets and interior furnishing. Biodegradable plastics can be based on natural resources (thermoplastic starch and polyhydroxyalkanoates (PHAs)) or be synthetically produced (polylactic acid (PLA) and poly(caprolactone) (PCL)). However, the use of biodegradable plastics in composite applications has been limited by their higher cost, poor moisture and gas barrier properties, slow crystallisation rate, poor stability and narrow processing windows. In addition, thorough life cycle analysis has to be performed to assess the environmental impact of this new generation of material. This presentation will discuss recent results in the production of PHA-wood composites, and in particular will review the effect of processing conditions, additives and biopolymer composition on composite properties.

Invited C3 M. Heitzmann: The University of Queensland

A productised approach to translational research and industry engagement

Industry engagement and rapid translation of research results to industrial applications are at the forefront of the national science agenda. This increased focus on translational research presents an opportunity for research groups to develop and test new engagement strategies, ultimately allowing them to better position themselves in a very competitive research market.

A productised approach to industry engagement and translational research is one such strategy which has been successfully used by the UQ Composites group to build a very strong portfolio of new and exciting industry-near projects over a very short period of time. Productisation is not an entirely new concept and has been promoted as a strategy to streamline the product innovation process by

reducing ambiguity since the early 2000s. However, in the context of translational research productisation might not be a concept which is overly familiar to most academics.

This talk introduces productisation as an alternative strategy to the more traditional strategies which are mainly capability and facility focused. The concept of productisation is first introduced and it is discussed how it can be applied to industry engagement and translational research. The presentation will use a number of recent projects of the UQ Composites group as an example to illustrate the usefulness, but also the dangers of such an approach to translational research. The presentation will conclude with a discussion of how a productised approach can potentially be used to foster new engagement pathways, outside of the traditional industry/research partnerships.

Keynote C3 D.J. Martin: The University of Queensland

Cellulose nanofibres from spinifex arid grasses: 'Greener, Longer and Tougher', thanks to 20 million years of resilient adaptation

We recently discovered [1,3,4] that a unique, very high grade of cellulose nanofibre can be readily and cost-effectively produced from endemic Australian spinifex grasses from the *Triodia* genus. These fascinating extremophile grasses, with over 20 million years of evolution, have presented us with a most unique source for nanocellulose. Our fibrillation process involves a mild pulping procedure followed by either a low mechanical energy treatment or a mild sulfuric acid hydrolysis. We have demonstrated that a high content of residual hemicellulose and lignin in bleached and unbleached pulp results in superior cell wall deconstruction, and consequently, the production of longer and more flexible nanofibres. When benchmarked against the other leading academic and commercially available materials, spinifex nanofibres have the highest aspect ratio compared against nanofibres obtained through the mechanical or chemical treatments of the other sources of cellulose. This novelty means that our method of fibrillation, and more importantly, this source of cellulose (*Triodia* includes 69 species) have the potential to directly address the current technological bottlenecks that have so far limited the widespread translation of nanocellulose technology into more applications. This presentation will give an overview of our team's research and technology development activities related to spinifex nanofibre production, with potential applications including ultrathin condoms and gloves [2], polymer composites, ultra-tough paper products and low cost, renewable carbon fibres. It will also introduce a landmark umbrella agreement and commercial partnership between The University of Queensland (UQ) and The Indjalandji-Dhidhanu traditional owner group, which has provided a framework accommodating shared future commercial benefits and Indigenous economic development from the generated project IP.

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Invited C3 G.K. Such: University of Melbourne

Engineering 'Smart' nanoparticles for improved nanomedicine

The development of nanoparticle carriers that enhance drug delivery while reducing harmful side effects is an area of active research. The physical and chemical properties of materials are often exploited to form nanoparticles with features including controlled drug release, improved

bioavailability, high drug loading and targeted delivery. However, there are many technological challenges that must be overcome to fully realize the potential of nanoparticles in therapeutic delivery, and one major challenge is engineering effective endosomal escape. The internalization of nanoparticles often results in the entrapment of the particles inside endosomal compartments, where enzymes that can degrade the cargo reside. Therefore, to achieve effective therapeutic delivery, materials used as drug carriers need to be designed to ensure the effective release of the therapeutic from the endosomes. However, while there are many carriers that can achieve endosomal escape, there is still limited knowledge on the characteristics that are required. In this study, we have developed pH responsive nanoparticles that we can use as a “smart” model to understand this important cellular phenomena. These particles are designed using a simple nanoprecipitation of a dual component poly[2-(diethylamino)ethyl methacrylate] (PDEAEMA) and poly(ethylene glycol)-b-poly[2-(diethylamino)ethyl methacrylate] (PEG-b-PDEAEMA) mixture. These particles are of interest as they can be tailored to degrade over a wide pH range, can load a range of cargo and importantly have tunable endosomal capabilities. This modular nanoparticle offers important insights into the design of effective nanocarriers.

Invited C3 E. Hilder: University of SA

Polymeric monolithic materials for analytical applications

Polymer based monoliths were introduced over 20 years ago. The relatively simple preparation, robustness, high permeability to flow, mass transfer via convection and flexible chemistry has since seen these materials used in a range of applications such as chromatography and as supports for synthesis, catalysis and immobilized enzymes. These same properties make monolithic polymers an excellent choice as materials for sampling and sample preparation, particularly for miniaturized technologies with the potential to produce cleaner extracts and facilitate rapid sample preparation for mass spectrometry (MS).

This presentation will introduce monolithic micro-sampling devices developed for sampling and sample preparation of biological samples, including whole blood. Monolithic micro-sampling devices prepared within disposable pipette tips have been developed for in-tip separation of blood cells from plasma and as immobilized enzyme reactors (IMER) for protein digestion. Subsequent micro-solid phase extraction (μ -SPE) was achieved using high surface area polymer monoliths. The μ -SPE device was then directly hyphenated with both ESI-MS and nanospray-MS. Microextraction by packed sorbent (MEPS) in which the SPE phase is placed within an exchangeable needle hub integrated into an analytical syringe is also demonstrated for μ -SPE. A workflow was developed using the monolith filtration and enzyme reactor technology in combination with an at-line micro SPE-ESI-MS approach enabling both sample preparation and analysis to be completed in < 20 min, facilitating high-throughput sample analysis in a standard bioanalysis workflow. New, high surface area polymeric monolithic sorbents tailored for SPE of small and medium sized molecules will also be introduced and are shown to provide significant advantages over particle-based sorbents, providing greater reproducibility in the sorbent bed. In a further embodiment the selective extraction of small molecules from complex matrices such as plasma will be demonstrated, using new restricted access poly(DVB)-g-PEGMA monoliths.

The majority of this work was undertaken as part of an integrated research program between academic and industry based researchers. This presentation will also demonstrate how using this approach that fundamental research can lead to early translation to new commercial products.

Invited C4 R. Al-Mahaidi: Swinburne University of Technology

Seismic performance assessment of CFRP-repaired RC structures using hybrid simulation

This paper investigates the seismic performance of a previously-damaged column that was re-paired using carbon-fiber reinforced polymer (CFRP). For this purpose, a limited-ductile RC column was damaged under simulated ground motions, repaired in plastic regions and then retested under the same loading conditions. Hybrid simulation, as a novel experimental technique, was used to capture the response of the specimen from linear-elastic range to collapse. This method combines computer simulations and physical testing allowing to experimentally test specific parts of a complete system in realistic scenarios. A state-of-the-art hybrid testing facility, referred to as the Multi-Axis Substructure Testing (MAST) system was used, which is capable of simulating complex time-varying six-degrees-of-freedom boundary effects on large-scale structural components using mixed load/deformation modes. The results reinforce the notion that CFRP is capable of re-instating column strength and ductility, reducing the likelihood of column replacement.

Invited C4 J. Ma: University of South Australia

Processing polymers with graphene sheets

Of all engineering materials, polymers have witnessed rapid increase in applications over the past decades due to their low manufacturing cost and decent specific strength. However, polymers are limited by low absolute stiffness and strength and lack of functional properties such as electrical and thermal conductivity. Processing polymers with graphene sheets holds great potential to address these limitations.

Invited C4 J. Mardel: CSIRO

Failure analysis of composite materials

The failure analysis of composite materials can be a complex investigation requiring the use of chemical, optical and mechanical techniques. It is often not obvious what the causes are or the most appropriate technique required to successfully determine what has happened to the sample or structure you are presented with. This talk will present a number of case studies describing composite materials failures analysis and detail the cause(s) involved in the premature failure of the materials or components; including contamination during the manufacturing process, problems with manufacturing and design. The second section of the talk will focus on designing composite systems so that failure is controlled, using the example of a ballistic protection system. The final section of the presentation will focus on the design of accelerated ageing trials of aerospace composites and whether it is possible to design regimes that accurately reproduce in-service degradation mechanisms to allow for service life prediction and/or determining residual service life.

Keynote C4 G. Prusty: University of New South Wales

Automated manufacture of advanced composites: Processing and online monitoring

The increasing use of composite materials in many advanced structures brings with it a need to establish inspection and monitoring regimes to ensure structural integrity and safe operation throughout the service life. This results in the fast-growing composite industry searching for a technologically and economically feasible structural health-monitoring (SHM) method to identify and assess processing defects in advanced composite structures manufactured using automated fibre placement technology, at the very early stage of manufacturing. Optical fibre based photonic sensing technologies are getting increasingly common for SHM of composite structures.

One major component of this presentation will be the online monitoring of processing defects during automated fibre placement. Laminated composites are commonly being used in aerospace, marine, automotive and renewable energy industries for various applications due to their excellent mechanical characteristics, like higher stiffness and strength, over traditional metals. However, their specific mechanical properties might be significantly affected due to the presence of any flaw or damage during operational life within the structure. Such damages may occur during the manufacturing, due to improper processing parameters, or after that in the operational service, as a result of structural damage due to fatigue or impact by foreign object. Automated tape/fibre placement (ATP/AFP) are the modern technologies that have revolutionized the production of composite structures for the aerospace industry in the last decade. Our recent work at UNSW Australia on the use of fibre optic sensing methods for in-situ processing defect identification demonstrates the feasibility of adapting such technology at a larger scale that can ensure high level of quality assurance for the composite components fabricated using automated fabrication methods.

Symposium D: Durable materials for demanding environments

Keynote D1 M.R. Ripoll: AC2T Research GmbH (Austria)

Enhanced wear protection by microstructural design of high speed steel laser hardfacings

The use of components in highly demanding applications requires the design of new materials that are able to fulfil the increasing demands in terms of high strength, toughness and wear resistance while simultaneously providing an adequate corrosion protection. However, in many demanding applications such as mining, dredging, tunnelling or in agricultural equipment, the size of the used components limits the use of these novel materials due to economic constraints and their application is often restricted to the form of thick coatings, commonly named claddings or hardfacings. Hardfacings provide a cost-effective solution to increase wear and corrosion resistance of components operating under aggressive environments. However, the toughness of hardfacings is sometimes not adequate due to the high cooling rates undergone during the deposition process, which results in a high cracking susceptibility and an excess of brittleness in operation. In order to enhance toughness of laser hardfacings, two main parameters can be modified: heat treatment of the hardfacing during or after deposition or chemical composition of the alloy. A modification of the chemical composition is often preferred for economic reasons, since hardfacings are mostly used in an as-deposited condition. The present work addresses the role of niobium as doping element for microstructural design of high speed steel laser hardfacings in order to increase their toughness and ductility while simultaneously maintaining hardness thus enhancing their wear and corrosion resistance.

Invited D1 J.D. Gates: University of Queensland

The ball mill edge-chipping test (BMECT) for high-productivity evaluation of relative fracture resistance of hard alloys

Abrasion-resistant alloys utilise high hardness in order to resist indentation by abrasive particles, but increasing hardness is generally associated with reducing fracture toughness. The balance between a desired level of wear resistance and the necessary fracture resistance forms the core of materials-selection strategies. However, preparation of specimens and measurement of fracture toughness (K_{Ic}) is time-consuming and expensive, hence rarely done for mining industry consumables, and the measurements that are performed are usually statistically poor. Charpy impact toughness also requires significant specimen machining to obtain each individual data point, and statistical scatter is often problematic.

To permit the routine assessment of resistance to cracking in hard alloys, a new laboratory test known as the ball-mill edge chipping test (BMECT) has been developed. Specimens with sharp edges are tumbled in a laboratory ball mill along with a make-up charge of conventional steel grinding balls. Almost unlimited numbers of specimens can be tested simultaneously. The specimens can either be blocks that are surface-ground on all faces to leave sharp edges and corners; or commercial grinding balls into which slots have been cut with a water-cooled abrasive saw. When tumbled in the mill without any abrasive medium, the exposed edges repeatedly chip, leading to weight loss. The test can be interrupted and specimens weighed, then the test resumed, as often as deemed necessary to obtain good statistics. Somewhat surprisingly, the rate of weight loss is only weakly sensitive to the initial sharpness of the edges, and the edge chipping continues at an almost constant rate of weight loss for as much as 2 hours. The reproducibility of results has been found to be remarkably good - apparently because the weight loss accrues from many hundreds of small chipping events distributed over the exposed length of specimen edges.

Investigations to date indicate that the BMECT provides good differentiation between alloys. For example, a white cast iron tailored to give a low-carbon martensite matrix gave very much lower chipping weight loss, hence higher fracture resistance, than an alloy with high-C martensite. The reproducibility of the difference between the two alloys was excellent. The paper presents preliminary data on the correlation between BMECT performance and conventional measures of fracture resistance such as Charpy impact toughness.

Invited D1 B. Hebbar: Keech Australia

Wear-resistant materials for mining applications

The cost of downtime and replacing wear parts in mining presents a continuous challenge to material technologists. With the advent of large scale mining operations and the introduction of mega size excavators, primary and secondary crushers, and ball mills there is significant demand for better wear (abrasion) resistant materials with higher toughness.

Normally a material that is highly resistant to abrasion is hard and brittle and lacks toughness. The development of better wear resistant materials invariably aims at improving the toughness in addition to enhancing the abrasion resistance. For several decades austenitic manganese steels, some low alloy steels and white irons were in use for applications involving severe abrasive wear. In recent years many low alloy steels and high chromium irons have been developed along with non-conventional materials like rubber, ceramics and composites.

The selection of appropriate materials for a given application is dependent on the degree of impact and the type of abrasive wear mechanisms involved. The wear resistance of a material is also connected with the type of abrasive material being excavated or crushed. Hence a good complete solution to a wear problem can be obtained by choosing the right material for the given application. The hardness of the abrasive material and the size and shape of the abrasive particle has a very strong influence on wear rate. In addition to this the wear rate is also dependent on the corrosive and thermal environments in the actual field application. These variables poses further challenge for the researchers to measure and assess the relative wear properties of wear resistant materials. Some practical experience and advice on selection of wear materials for a given application in mining is discussed in this presentation.

Invited D1 K. Dolman: Weir Minerals Australia

New developments in chromium carbide hardfaced welding consumables

The cost of abrasive and erosive wear to Australian mining, mineral processing, gravel and cement works is estimated at 1% of Gross National Product. Total wear costs to Australian Industries = \$15 Billion per annum.

Throughout Australia, about 200,000 square meters of CrC wear plate is replaced annually with material costs = \$300 Million plus maintenance labour and plant downtime costs estimated at \$1 – 2 Billion pa.

There has been very little change in hardfaced (HF) wear plate products over the past 35 years since the standard AS/NZS 2576 was first published. AS/NZS 2576 contains three general grades of chromium carbide (CrC) weld deposits:

- Type 2355 – austenitic CrC
- Type 2460 – complex CrC containing NbC, TiC, WC and Mo₂C.
- Type 2565 – martensitic CrC containing boron.

This presentation illustrates a number of deficiencies in the current CrC wear plate products, originating from the quality of the welding consumables, and describes several ways to improve the performance and service life of these HF weld deposits.

Invited D2 M.P. Pereira, A. Mostaani, B.F. Rolfe: Deakin University

Modelling the scratch test to better understand abrasive wear

Abrasive wear of machinery and tools is a significant issue in mining and minerals processing industries. For many years, scratch test experiments have been used to understand the abrasive wear of metals, providing information about friction, scratch hardness and two body abrasive wear behaviour during a single idealised asperity interaction. Based on the analysis of experimental scratch tests, theoretical models of abrasive wear modes and wear maps have been developed. This work uses finite element models to investigate the material behaviour during the scratch test, with the aim to further develop our understanding of abrasive wear mechanisms for steels. In particular, the model focusses on predicting the transition from pure ploughing, which is essentially a zero wear mode, to pure cutting, where all material displaced by the hard asperity is removed. Critical to this is the failure and fracture behaviour of the material. Therefore, three different ductile fracture models were incorporated into the finite element model of the scratch test, for a number of geometry and material conditions. The patterns of damage initiation and propagation were compared with experimental results from the literature. This work shows that the choice of fracture model produces significant variation in the failure region and resulting wear mechanism predicted to occur during the scratch test. This work highlights the role of the damage model in accurately capturing wear modes and material removal during two body sliding interactions.

D2 V. Bhatia, G. Proust, J. Cairney: Sydney University

Improved wear resistance of Hadfield steel through the addition of carbides

High manganese steel, more commonly referred to as Hadfield steel or Mangalloy, is an austenitic manganese steel that exhibits high toughness, strain hardening and wear resistance after work hardening. Due to these unique properties it is used extensively in the mining industry for hammer tips and rock crushers. However, in extremely high wear applications, the wear rate can be so high in comparison to the rate of work hardening that the alloy never reaches peak hardness. One proposed method to increase the wear life and take full advantage of the work hardening is to utilise carbides within the matrix of the steel. The potential benefit of this is two fold: Firstly, hard carbides

would typically increase the wear resistance of the alloy. Secondly, the Hadfield steel matrix would be provided enough time to work harden.

However, the negative influence of carbides on toughness is a concern as Hadfield steels are normally used in high impact applications. A balance is therefore required between increasing the wear resistance and maintaining an adequate toughness for the required application.

This research focuses on Fe–12.1 wt.% Mn–1.2 wt.% C alloys with Nb containing carbides formed in-situ. Alloys are cast with a nominal 5,10 and 15 vol% carbides. The mechanical properties including toughness and wear resistance are compared to standard Hadfield steel. Microstructural characterisation is also performed before and after failure to assess the failure mechanisms.

D2 H. Li, A. Al-Juboori, H. Zhu, D. Wexler, C. Lu, A. McCusker, L. Cheng: University of Wollongong

Thermomechanical simulation of white etching layer formation on the rail steel

Understanding that cracks in rails can and do lead to disasters and must remain a constant area of concern in safety delivery and duty of care is not a concept that is likely to be disputed by many. On the other hand postulating that containing, controlling and mitigating the effects of cracks in rails is the dominant factor in cost management for the provision of rail services may be a highly debatable point. It has been considered that the white etching layer formed at rail surface plays an important role on crack initiation.

The experimental study was performed to examine the formation of white etching layer on the rail steel using thermo-mechanical simulation test. The purpose of this study is to explore whether the martensite structure can be formed on the rail steel at the temperature below a critical transformation point when the pressure is combined with a heating process. The test has been conducted with different temperature and constant pressure that rail surface experiences during operation. The findings have shown that a significant effect of pressure on the transformation temperature in the rail steel when it is combined with heating. In addition, it has noticed that the depth of martensite layer under contact area has increased with rising temperature. Furthermore, the phase transformation temperatures have been calculated theoretically using the empirical formula and considerable difference was found between these results and those obtained from the test due to pressure applied.

Invited D2 G. Proust, W.H. Kan, V. Bhatia, K. Dolman, T. Lucey, X. Tang, C. Li, J. Cairney: The University of Sydney, Weir Minerals Australia

The development of NbC reinforced martensitic stainless steel composites for high wear applications

In order to develop a viable replacement for the high chromium white cast irons that are typically used in mining and mineral processing industries, AISI 440B martensitic stainless steel composites reinforced with NbC particles have been developed using a vacuum induction furnace. Following hardening heat treatment, the microstructure of these composites were analysed using scanning electron microscopy, electron backscatter diffraction and energy dispersive X-ray spectroscopy. These composites were capable of being heat treated to produce a fully martensitic matrix without any retained austenite, which was not possible with conventional high chromium white cast irons. The wear performance of these composites was then compared to that of an appropriate high chromium white cast iron benchmark using pin on disc tests. SiC, Si₃N₄, WC and ZrO₂ balls were used as pin materials to compare different types of wear mechanisms. The results of all test types revealed that the composites offered better wear performance than the white cast iron benchmark even for low total carbide volume fractions.

Invited D3 M. Barnett: Deakin University

A material property map for wear resistant steels

It is common to compare automotive sheet steels on a 'banana' plot of tensile ductility against strength. Such a plot guides steel selection and design. The current talk presents an analogue for wear resistant steels. The basis for the analysis is a series of instrumented gouge tests on differing steels and steel microstructures. It is shown that, with appropriate normalizations, an intrinsic 'scratch ductility' can be obtained from a series of gouging tests. Plotting this against hardness normalized by the operating load provides a strength against ductility plot up on which contours of constant wear rates can be overlaid. It is shown that such a plot provides useful insight into the selection of wear resistant steels for ground engaging applications as well as pointing to promising directions for steel design.

D3 G. Saha, D. Fabijanic, B. Hebbar, M.R. Barnett: Deakin University, Keech Casting

Characterization of a worn excavator digger tooth

Excavator digger teeth experience significant stress, strain and temperature effects which lead to severe wear loss within a very short service period. The present study aims to investigate the wear mechanisms of a worn excavator digger tooth.

This research work outlines; a detailed 'forensic' examination of a worn digger tooth used in an iron ore mine. The worn tooth profile is superimposed with a new tooth profile to study the change in geometrical shape. It provides an idea about the severe and mild wear zones. Based on surface profilometric measurements of wear grooves, a material property wear map is constructed by plotting cutting/plasticity ratio as a function of depth of penetration. The dominant wear mechanism is found to be cutting. The cross-sectional microstructure shows a white layer at the surface followed by a workhardened subsurface. The thickness of white layer corresponds to groove depth. Embedded ore particles and adiabatic shear zones (ASB) are also characteristics of the deformed microstructure. EBSD analysis of the white layer reveals a fine equiaxed grain structure.

D3 A. Ghaderi, D. Fabijanic, M. Barnett: Deakin University

Influence of the abrasive size indenter on the scratch resistance of a high strength martensitic steel

The present work studies the size effect of indenter on the abrasive wear resistance of a high strength martensitic steel. Scratch testing was used with different spherical indenter tips ranging from 0.18 to 1.9 mm at different loads. For each indenter size, the loads of the scratches were chosen in such a way to induce a range of different scratch depths. The scratch profiles were measured using profilometry method in order to estimate the wear volume and to obtain the ratio of the wear volume to the groove volume, f . It is found that at a given load, the wear rate of the material strongly depends on the size of the indenter. Also, the f parameter varies from zero (ploughing mode) to one (cutting mode) once it is plotted as a function of the scratch depth. The scratch depths normalised by the indenter tip radius show that there is a critical normalised value for all scratches in which the transition from ploughing to cutting occurs. This parameter is expressed as 'scratch ductility' and it is proposed to be considered as a material property. An abrasive wear map based on the scratch ductility and the hardness of the material is used to demonstrate how the wear modes and wear rates change as a function of the abrasive indenter size.

D3 B.T. Narayanaswamy, P.D. Hodgson, P. Cizek, A. Ghaderi, Q. Chao, H. Beladi: Deakin University

Investigation on the abrasive wear behaviour of ferrous microstructures with similar bulk hardness levels using a scratch-tester method

The abrasive behaviour of four different ferrous microstructures with similar hardness levels subjected to high strain scratch tests were studied. During the scratch test, a robust indenter traverses a groove on the microstructure surface, thereby simulating a two-body abrasive wear. The scratch tests allowed more control over the abrasive environment (i.e. constant indenter tip geometry and sliding speed), which greatly enabled to study the process of material removal in the microstructures. In the current study, the microstructures revealed a distinct abrasive behaviour with respect to groove characteristics and sub-surface deformation layers. In general, multiphase microstructures (i.e. bainite and pearlite) displayed better abrasive resistance than the single-phase microstructures (i.e. martensite and tempered martensite). The groove characteristics were greatly determined by the properties of the metallurgical structures and the normal load subjected during scratch testing. For instance, a transition in the material removal mechanism, i.e. ploughing to cutting mechanism was observed in all microstructures in the load range of 200 N to 2000 N. Thereby, this led to superior abrasive performance of the microstructures at relatively low loads (i.e. 200 N to 500 N). Furthermore, the occurrence of work-hardening phenomenon (i.e. hardness increment) in the sub-surface layer appeared to have a positive impact during abrasion.

D3 A. Kostryzhev, C. Killmore, E. Pereloma: BlueScope Steel Ltd, University of Wollongong

Wear resistance of quenched and tempered steels microalloyed with titanium

Quenched and tempered (Q&T) medium carbon steels are widely used to manufacture ground engaging tools and earth moving equipment. The most cost-effective approach to increase wear resistance of Q&T steels is the microstructure reinforcement with hard carbide particles. In this work the effect of TiC particles, having five times higher hardness than that of the metallic matrix, was investigated. Five steels containing 0.02, 0.12, 0.25, 0.44 and 0.68 wt.% Ti were melted, hot rolled and heat treated in the laboratory. The hot rolled samples were additionally processed in a Gleeble thermomechanical processing simulator. The microstructure was characterised using optical, scanning and transmission electron microscopy, and microhardness testing. The wear tests were conducted using a CETR pin-on-disk apparatus. For the hot rolled samples, with an increase in Ti content, both hardness and wear resistance decreased, which can be related to the increased area fraction and number density of large (>100 nm) TiC particles, decreased area fraction and number density of small (<50 nm) Fe₃C particles, and an excessive matrix depletion with C and Ti. In contrast, the hardness and wear resistance in the Gleeble processed samples were higher than those in the hot rolled samples, and the wear resistance showed a maximum with an increase in Ti content. This can be related to a lower number density and area fraction of large TiC particles and stronger matrix in the Gleeble processed samples. Effects of processing on TiC particle size distribution and, related to it, hardness and wear resistance are discussed.

D3 J. Erkkilä: SSAB Special Steels

Wear scenarios and selection of wear resistant materials

Material flows in different material handling processes such as in mines and quarries subject the machinery to multiple wear scenarios. The most typical of these scenarios being sliding wear, impact wear and squeezing wear. The selection of the wear resistant materials influence the lifetime of the components and the production output of the machines significantly. Finding a wear material

suitable for all wear situations is challenging because usually increasing sliding wear resistance decreases impact wear resistance and vice versa. Standardized methods of measuring wear resistance give limited information on the performance of the material in reality because of the nature of wear tests. To better evaluate the wear with loose abrasives drum wear test method is introduced. Every wear situation requires a combination of wear materials to meet the type of abrasive that is being processed. The wear resistant materials in material handling machinery have been traditionally selected from castings, hardfacings, common steels, tool steels, engineering steels and wear resistant steels. In the present paper wear mechanisms are introduced in more detail and an alternative drum wear testing method is introduced. Material selection for wear resistant materials is introduced with practical examples.

Symposium E: Materials for energy generation, conversion & storage

Keynote E1 K. Lu: Virginia Polytechnic Institute and State University (USA)

Material needs and developments in energy conversion, harvesting, and storage

Energy and materials have a continual and mutually enriching relationship. In the complex web of energy resource, production, storage, use, and efficiency, materials play a critical role as diverse and far-reaching as energy itself. In this talk, material needs for energy production, conversion, harvesting, and storage will be examined. For example, generating electricity from the most abundant fossil fuel, coal, efficiently and with no environmental damage, presents notable challenges to developing higher performance materials in harsh environments. New materials that increase the efficiency of the energy conversion and lower its cost would provide valuable flexibility in energy conversion. New nuclear fuels and cladding materials would realize a new generation of safer, more efficient nuclear reactors. Materials can also store and deliver energy in the forms of batteries, supercapacitors, and biofuels. High performance materials for energy storage would enable more energy efficient vehicles and off-grid operation. It is these fascinating material behaviors and properties that give us the high hope of tackling the challenging energy problems. As specific examples to address these issues, our decade long efforts in nanoscale material patterning and templating will be presented. Our continuous efforts on solid oxide fuel cell material development and nuclear material advancement will be explained.

Invited E1 V.K. Peterson: ANSTO

Progressing energy technologies through understanding atomic-scale materials function using neutron/X-ray scattering and computational methods

Functional materials form the central part of many important energy technologies. A material's atomic-scale structure and dynamics underpin performance, and their characterization is central to technology advancement. Key to understanding here is the characterization of the material as it functions and responds to external stimuli. Neutron/X-ray scattering in combination with computational chemistry approaches have made important contributions to this understanding. Modern high-speed instrumentation allows the rapid collection of data, enabling real-time information concerning the material to be gained while it functions, and the combination of first-principles computations with neutron scattering is particularly powerful in understanding the structure/dynamic function. Using these characterization approaches, deep insights into the functionality of materials such as rechargeable battery electrodes and sorbent materials used for the separation and storage of energy-relevant gases can be gained.

Invited E1 Y.H. Ng., University of New South Wales

Photoelectrochemical water splitting using bismuth-based ternary oxide semiconductors

Bismuth based ternary oxide powders (such as BiVO_4 , Bi_2WO_6 and Bi_2MoO_6) have been reported to be active for oxidation of organic substances and water under visible light. In general, these materials have sufficient absorption within the solar spectrum and stability against photocorrosion. The preparation of bismuth based ternary oxide is inexpensive, environmentally benign and can be made using a number of different facile methods. In this presentation, we investigate the performance of these bismuth based ternary oxides in photoelectrochemical water splitting. A few aspects will be highlighted to substantiate the differences when they were employed in photocatalytic water splitting or through photoelectrochemical means. It is generally acknowledged that surface area and crystallinity of photocatalysts are critical factors regulating performances in powder-type suspension reactions. When they were made into thin film, quality of the contact between bismuth based ternary oxides and the charge collecting substrate becomes another crucial factor. In this work, we also discuss a few strategies formulated to directly synthesise these ternary oxide thin films without having the powder oxide as the intermediate.

BiVO_4 , Bi_2WO_6 and Bi_2MoO_6 thin films are synthesised in this work. BiVO_4 with controlled exposed facet is engineered to study the dynamic of charge interactions between their respective facets. It is revealed that a balance of charge transfer and charge trapping are occurring to govern the overall performance of BiVO_4 . From that point of view, specific interface is engineered to boost the higher charge transfer efficiency, for example, by using graphene as electron mediator. Bi_2WO_6 and Bi_2MoO_6 thin films are synthesised by a direct conversion of anodised WO_3 and MoO_3 films. The adhesion of the resultant Bi_2WO_6 and Bi_2MoO_6 on the substrate is highly stable. With the control of synthesis parameter, a concentration gradient can be introduced to form the composite of Bi_2WO_6 - WO_3 and Bi_2MoO_6 - MoO_3 with desired composition. With the favourable band alignment in this composite material, an improved activity in photoelectrochemical water oxidation is observed.

E1 L. Fu, Z. Li, Q. Gao, Z. Li, K. Peng, L. Li, S. Mokkaapati, K. Vora, H.H. Tan, C. Jagadish, Z. Zhong, J. Wu, G. Zhang, Z. Wang: University of Electronic Science and Technology of China, The Australian National University

Axial junction InP single nanowire solar cells

III-V compound semiconductor nanowires (NWs) have shown great promises for electronic, optoelectronic and photovoltaic device applications. Nanowires can be fabricated by a variety of crystal growth techniques, among which the selective area epitaxy (SAE) growth has the advantages of accurate control of the position, geometry, uniformity and doping of NWs to achieve excellent and reproducible device performances. In this work we demonstrate single axial p-i-n junction InP nanowire (NW) solar cells grown by selective-area metal organic vapor phase epitaxy (SA-MOVPE) technique. A power conversion efficiency of up to 6.47% was realized in the single NW solar cell (horizontally lying on substrate) without any surface passivation. Electron beam induced current (EBIC), photocurrent mapping, and numerical simulation were performed to investigate the electrical properties of the NW solar cells and their influence on device performance, which are essential for an in-depth understanding of the design requirements for NW solar cells. By further deposition of a conformal SiN_x layer on the single NW solar cell devices by plasma-enhanced chemical vapor deposition (PECVD), overall efficiency improvement has been achieved with a remarkable up to 62% increase to a peak efficiency of 10.48%, which to our knowledge is the highest efficiency reported for horizontal single NW solar cells. This has been attributed to an enhanced optical antenna effect and effective surface passivation due to SiN_x coating, as respectively confirmed by numerical simulation and time-resolved photoluminescence (TRPL) measurements.

E1 S. Wang, H. Wang: South China University of Technology

Flexible SnO₂ CNFs film anode for high performance lithium-ion batteries

Flexible lithium-ion batteries have great potential as an alternative energy storage system for soft portable electronics. Here, we proposed a large scale preparation of large size, flexible, free-standing SnO₂/porous carbon nanofibers (SnO₂@N-CNF) film by electrospinning technology and post annealing. In the resulting SnO₂@N-CNF film, 5-10 nm SnO₂ nanoparticles were well dispersed and surrounded by intertwined nitrogen-doped porous carbon nanofibers. This unique nanostructure can provide a large contact area with electrolyte and effectively accommodate the huge volume change of the SnO₂ particles during lithium ion insertion and extraction. The SnO₂@N-CNF film could be directly used as electrode for lithium-ion batteries, and exhibited a stable reversible capacity of 754 mAh g⁻¹ during 300 cycles under a current density of 1 A g⁻¹ and superior rate capability (245.9 mAh g⁻¹ at 5000 mA g⁻¹). The design outperforms most of state-of-the-art electrode materials and displayed strong potential for flexible energy storage devices.

Keynote E2 A. Cuevas: The Australian National University

Selective materials for simple solar cells

As Solar Photovoltaic Energy becomes a mainstream source of electricity, it is timely to revisit the device that has made it possible, the silicon solar cell, and the on-going efforts to improve its performance and simplify its fabrication. To achieve those goals, it is essential to create regions in the semiconductor, or to deposit materials onto it, that transport either electrons or holes in a highly selective manner. This talk will focus on the implementation of electron-selective and hole-selective contacts based on materials having either a very low or very high work function. The latter include transparent metal oxides, like molybdenum oxide, and alkali metal salts, like lithium fluoride, whose application to silicon solar cells is relatively new. Recent research on deposited-junction silicon solar cells made with such materials will be overviewed.

Invited E2 K. Lu, A. Tricoli: The Australian National University

Nanoarchitectonics of chemical sensors and optoelectronic devices for personalized and preventive medicine

Nanostructured materials have the potential to significantly enhance the performance of several devices as recently demonstrated for solar cells, sensors and energy storage technologies. This has resulted in a rush toward novel applications ranging from flexible electronics to wearable nanogenerators. However, integration of nanomaterials in devices is challenging and their assembly in suboptimal morphologies may drastically limit the final performance. Here, we will present the nanoarchitectonics of zero-dimensional nanostructures for the fabrication of highly performing optoelectronic devices. We will showcase the use of scalable and low cost flame-synthesis approaches for the wafer-level nanofabrication of tailored and well-reproducible ultraporous nanoparticle networks. The fundamental mechanisms controlling the gas-phase self-assembly of these nanostructures will be discussed with respect to current limitations and future opportunities. In particular, the rapid high-temperature gas-phase fabrication of highly performing photodetectors for quantitative monitoring of UV radiation will be presented. We will demonstrate a rapid approach for the synthesis of tunable band-selective UV photodetector capable of detecting very low light intensities with record-high signal to noise ratios and very low power-consumptions. These results provide a robust set of guiding principles for the design of wearable electronic devices for personalized and preventive medicine.

Invited E2 Z. Yu: University of Wisconsin – Madison(USA)

Low-index photonic materials for photon management

Conventional photon management primarily relies on high refractive index materials to enhance the light-matter interactions because of their high optical density of states. We show that ultra-low index materials with optical density of states less than that of vacuum provide a completely different mechanism for effective photon management. They can drastically enhance the absorption cross section of nanoscale materials. For thin films, it can improve the performance of light trapping, exceeding the conventional light-trapping limit. Moreover, the ultra-low index materials suppress the radiative recombination, resulting in enhanced open circuit voltage in direct bandgap solar cells. They allow single-junction cells to operate at efficiency above the Shockley-Queisser limit under one sun.

Invited E3 F. Scholes: CSIRO

Powering the future with printed solar films

Solar energy is set to make an increasing contribution to global energy needs into the future. While traditional solar cells based on silicon are now ubiquitous on residential rooftops, they remain relatively expensive to manufacture (in terms of both energy and infrastructure) and are essentially one-size-fits-all in form factor. To address these issues, CSIRO has been working with university and industry partners to develop thin-film solar cells printed onto polymer films. This technology offers distinctive advantages such as low cost (i.e. they are compatible with inexpensive, roll-to-roll manufacturing processes) and a greater variety in form factor (i.e. they are flexible, lightweight and semi-transparent, making it possible to utilise them beyond the residential rooftop). Here, we will discuss our journey along the technology readiness scale, from the inception of the Victorian Organic Solar Cell (VICOSC) consortium in 2007 through our current efforts working with industry partners to develop products.

E3 J. Hart, F. Kurnia, N. Valanoor, Y.H. Ng, N. Allan: University of Bristol (UK), UNSW

Semiconductor solid solutions and heterostructures for visible-light photocatalysis: From design to application

Many potential semiconductors for photocatalysis of water splitting, including TiO_2 , have band gaps that are too large for absorption of visible light and hence have low efficiencies under sunlight. By combining two semiconductors together in a solid solution or heterostructure, it can be possible to tune the band gap and hence increase the photoactivity under visible light.

We have used density functional theory (DFT) calculations to investigate the properties of ZnS-GaP solid solutions. They are found to have small formation energies and tunable band gaps that depend on both composition and atomic ordering. Materials with direct band gaps in the energy range of visible light and close to the optimum for photocatalysis of water splitting under sunlight should be readily achievable.

From the DFT results, it can be seen that one of the keys to achieving these band gaps is the presence of direct interatomic bonds between the two compounds (e.g. Zn-P and Ga-S bonds). Thus, heterostructures consisting of alternating layers of the two compounds should also give similar band gaps in the energy range of visible light. Such heterostructures have been fabricated by pulsed laser deposition. Results of photoelectrochemical testing show high activity under visible light, in agreement with the computational predictions. The effect of the number of layers and thickness of each layer on the photoelectrochemical behaviour is investigated.

E3 G. Kaur, A. Kulkarni, S. Giddey, S.P.S. Badwal: CSIRO Energy

Developments in electrochemical reduction of CO₂ to value added chemicals

Globally over 32 billion tons of CO₂ is generated per annum with less than 1% utilised for the production of commodity chemicals. Recently significant effort is being devoted towards conversion of CO₂ into value added chemicals and fuels using both chemical and electrochemical processes. Electrochemical processes offer the advantage in that they can be directly coupled with renewable energy sources (solar, wind, tidal) thus allowing renewable energy to be stored and possibly transported in the chemical form for use later on. Current electrochemical processes for CO₂ conversion are at an early stage of development and electrolyte systems being considered are ionic liquids, aqueous and polymer membranes for low temperature (<100°C) operation and proton and oxygen ion conducting ceramic membranes for high temperature (>500°C) operation. The high temperature electrochemical systems, in addition to electrical energy, can also utilise thermal energy as an input from solar thermal concentrator or waste heat from industrial processes to reduce electrical energy input and boost efficiency. In this presentation a brief overview of electrochemical CO₂ conversion technologies would be provided, discussing state of the art and technical issues including materials challenges. The results from work at CSIRO Energy in this area would be presented.

E3 R.A. Caruso, W. Wu, D. Chen, F. Huang, Y-B Cheng: The University of Melbourne, Wuhan University of Technology (China), Monash University

Perovskite solar cells: Manipulating the morphology of individual layers to enhance efficiency

Research into perovskite based solar cells has recently attracted considerable attention due to the extremely fast pace in which the efficiencies of such cells has increased. These cells are substantially thinner than the dye-sensitized solar cell, and hence careful manipulation of the individual layers is required to allow effective function and prevent shorting. In our research, we have focussed on controlling the morphology of both the titania electron-transporting layer and the perovskite layer. Solvothermal approaches that can be varied in solvent composition and concentration, or temperature and duration have been used to influence the titania structure. The perovskite layer is improved using a gas-assisted spin coating approach followed by a vapour annealing step. These approaches decrease the pin-holes in the perovskite layer and give a smoother surface for the deposition of the hole-conducting layer. In this presentation a brief introduction to perovskite solar cells and our work in this area will be given.

E3 H-K. Ju, S. Giddey, S. Badwal: CSIRO

Electrochemical conversion of carbon and hydrocarbon in low temperature electrolysis cells for cost-effective hydrogen generation

Hydrogen is one of the best clean energy storage media as it has several attractive properties for utilization in fuel cells for stationary, distributed residential, transportation and portable power applications, offering high efficiency, zero carbon dioxide and low pollutant gases at the point of use. Recently, there is a renewed interest in hydrogen fueling stations for next generation fuel cell vehicles with many companies (Hyundai, Toyota, Honda, Daimler, Mercedes-Benz, etc.) going into mass production. However, hydrogen is supplied mainly by non-renewable fossil processes (natural gas and coal gasification) leading to large pollutant/greenhouse gas emissions. Hydrogen produced by water electrolysis coupled to a renewable energy sources is a clean fuel which can be generated at distributed sites, however, the process is energy intensive requiring 4.2–5.5 kWh/Nm³ of hydrogen produced. In this presentation, a new electrolysis process which utilizes renewable fuels

(carbon from biomass, methanol and ethanol) to reduce direct renewable energy input will be described. This co-water electrolysis process using methanol, ethanol, and carbon –blended with water can effectively reduce the electric energy requirement by more than 60% (to < 2 kWh/Nm³) at temperatures below 100°C, with balance provided by the chemical energy of carbon / hydrocarbons. This presentation will describe our R&D in this field with specific emphasis on materials and reaction mechanism related issues.

E3 J.S. Dargad: Dayanand Science College (India)

Cd_{1-x}Mn_xSe thin films preparation by CBD: Aspect on optical and electrical properties

CdMnSe dilute semiconductor or semimagnetic semiconductors have become the focus of intense research due to their interesting combination of magnetic and semiconducting properties, and are employed in a variety of devices including solar cells, gas sensors etc. A series of thin films of this material, Cd_{1-x}Mn_xSe ($0 \leq x \leq 0.5$), were therefore synthesized onto precleaned amorphous glass substrates using a solution growth technique. The sources of cadmium (Cd²⁺) and manganese (Mn²⁺) were aqueous solutions of cadmium sulphate and manganese sulphate, and selenium (Se²⁻) was extracted from a reflux of sodium selenosulphite. The different deposition parameters such as temperature, time of deposition, speed of mechanical churning, pH of the reaction mixture etc. were optimized to yield good quality deposits. The as-grown samples were thin, relatively uniform, smooth and tightly adherent to the substrate support. The colour of the deposits changed from deep red-orange to yellowish-orange as the composition parameter, x, was varied from 0 to 0.5. The terminal layer thickness decreased with increasing value of, x. The optical energy gap decreased from 1.84 eV to 1.34 eV for the change of x from 0 to 0.5. The coefficient of optical absorption is of the order of 10^{-4} - 10^{-5} cm⁻¹ and the type of transition ($m = 0.5$) is of the band-to-band direct type. The dc electrical conductivities were measured at room temperature and in the temperature range 300 K - 500 K. It was observed that the room temperature electrical conductivity increased with the composition parameter x up to 0.1, gradually decreasing thereafter. The thermo power measurements showed n-type conduction in these films.

Symposium F: Advances in materials characterisation

Invited F1 A. Ceguerra, A. Breen, L. Stephenson, S. Ringer: The University of Sydney

Data mining for atom probe spatial reconstructions

Atom probe microscopy is an advanced characterisation technique with atomic-scale chemical sensitivity in 3D, routinely capturing tens to hundreds of millions of atoms per experiment. Due to the large amount of data captured per experiment, analysis of each dataset for the purposes of materials engineering can become a challenge. For example, the spatial resolution of the 3D reconstruction is limited by how successfully it is calibrated using three key parameters: detector efficiency, image compression factor, and geometric field factor. These three parameters together need to be calibrated correctly in order to obtain the best spatial resolution for an atom probe microscopy dataset.

To this end, we have developed a suite of tools to mine the detector data. These tools allow us to determine the location of poles, index them, and reconstruct using a dynamic methodology. As a result, we are able to calibrate the reconstruction using proven techniques, thus improving the spatial resolution.

F1 P. Koshy, S.A. Koszo, C.C. Sorrell: UNSW, Vecor Australia Pty Ltd

High-performance ceramics from waste materials

Work at UNSW Australia has developed a patented materials and processing technology for the fabrication of an interconnected and percolated mullite fibre network using waste materials. The in situ fibre-reinforced composite displays outstanding long-term stability at high temperatures (up to 1600°C). Recent work has shown that this material also can serve as the feedstock for the fabrication for other high-performance ceramics, such as alumina-zirconia-silica refractories and alumina-mullite, mullite-zirconia, and alumina-titania composites. The characteristics of these ceramics can be tailored through the modification of the chemical composition and processing conditions.

F1 M. Parvizi, S.P. Ringer, M. Eizadjou: The University of Sydney

Transverse rolling and sequence heat treatment of ultra-fine grain duplex steel

Our work is focussed on the development of novel thermo-mechanical processing schedules for the production of third generation advanced high-strength steels (G3 AHSS). This particular study explores the effect of the sequence of cold rolling (CR) and intercritical annealing (IA) on the microstructure and mechanical properties of a new G3 AHSS with an ultrafine duplex (austenite + ferrite/austenite) microstructure. It has been shown that IA on a novel fully martensitic low-carbon medium manganese steel produces ultrafine duplex microstructure with high strength and high ductility. Subsequent CR of this duplex microstructure triggered a transformation-induced plasticity (TRIP) process and transformed more than 95% of the austenite to a'-martensite. This deformed microstructure (deformed ultrafine ferrite and a'-martensite) was the base material for this study.

Various IA heat treatments were applied to explore the microstructure and mechanical properties of this steel alloy. The effect of IA on microstructure (grains size, phase fractions and chemical composition of different phases) was investigated by means of SEM-transmission Kikuchi diffraction (TKD), atom probe microscopy (APM) and X-ray diffraction (XRD). The microstructure-property relationships of these steels is discussed in terms of a pathway for enhanced strengthening.

F1 F. Theska, S. Primig: UNSW

High-resolution characterization of advanced high-temperature materials

The design and development of future high-temperature resistant materials require a deeper understanding of their structure-property relationships. Highly durable materials in demanding applications, such as superalloys in aircraft engines or tool steels for high-performance functions, need as critical properties superior mechanical strength, corrosion resistance and low creep rates at elevated operation temperatures. Therefore, modern nickel-based superalloys are strengthened by the precipitation of nanometre-sized and ordered secondary phase clusters or particles. Certain novel carbon-free tool steels follow a similar approach of precipitation hardening by the formation of long-range ordered domains. The chemical and structural similarities of such microstructural features to their surrounding matrix material require advanced analytical methods down to the atomic scale.

Therefore, high-resolution characterization techniques are essential such as transmission Kikuchi diffraction, transmission electron microscopy and 3D atom probe tomography. The combination of these powerful tools with more conventional methods, for example mechanical testing, light optical microscopy and scanning electron microscopy, allows a correlative microscopy approach via several length scales. Consequently, this reveals phenomena such as precipitation, ordering and atomic clustering. Thus, correlative microscopy enables the design of novel processing routes for improved material properties and represents the base for future materials developments.

F1 H. Tsukamoto: Hosei University (Japan)

Mechanical properties of hot-rolled Al/ Fe clad structures

This study aims to investigate mechanical properties, including shear bonding strength, internal friction, dynamic elastic modulus, nanoindentation hardness and elastic modulus at the interfaces, of Al/ Fe clad structures bonded by hot rolling. Microstructures and chemical compositions are investigated using electric microscopes. Hot rolling temperature ranges from 200 to 400°C. The experimental results include the followings. At any temperatures of hot rolling, the bonding is soundly achieved, and some different microstructures and bonding strength are obtained at each hot rolling temperature. At Al/ Fe interfaces, some Al/ Fe intermetallics (FeAl, Fe₃Al, Fe₂Al₅) exist from the electric microscope examinations, and some part of interfaces include plastic flow layers, which can roll up some oxides of Al and Fe. These interface structures highly affect the bonding strength. In the hot rolling temperature range from 200 to 400°C, the maximum bonding strength is obtained in the samples hot-rolled at 350°C. From the fracture surface examinations, samples hot-rolled at 200, 250 and 400°C are fractured at Al/ Fe intermetallic interfaces, while samples hot-rolled at 300 and 350°C are fractured in Al layers, which means that the interface indicates strong bonding in samples hot-rolled at 300 and 350°C. For the internal frictions and dynamic elastic modulus, the samples hot-rolled at 300°C show the maximum internal friction and relatively low dynamic elastic modulus.

F1 R. Dippenaar: University of Wollongong

High-temperature Microscopy

High-temperature laser-scanning confocal microscopy has been developed as a technique to study solidification and high-temperature solid-state phase transformations. Because meniscus formation is a problem in the study of solidification, a new technique known as concentric solidification has been developed for use in high temperature microscopy. Because crystallographic information cannot be obtained by these techniques, solid-state phase transformation studies have been complemented by synchrotron and neutron diffraction analyses. Examples of solidification studies, solid-state phase transformation studies and the coupling of these studies with diffraction analyses will be presented.

F1 D. Bhattacharyya, A. Xu: ANSTO

In situ micro-mechanical testing – A novel method for testing irradiated materials

The ever-increasing need for more reliable, safe and ecologically friendly technologies for energy production is driving the search for safer and more efficient nuclear reactors worldwide. Such reactors would have extremely harsh environments with high radiation doses and temperatures, requiring specially designed and manufactured materials capable of withstanding such conditions. Ideally, candidate materials would have to be immersed in a reactor environment for many decades to achieve such high doses, consequently rendering them highly radioactive. To obviate the combined problems of extremely long holding duration and radioactivity in the samples, ion beam irradiation is generally used in many institutions worldwide for testing materials properties at high doses. This method imposes its own restriction – it produces only a shallow irradiated layer (< 20 microns, generally, in metallic materials). Micro-mechanical testing, employing pure tension, compression, fatigue, etc. as deformation modes, provides a much more robust method of testing such thin irradiated layers than other methods, such as nanoindentation. It provides results which are easier to interpret than nanoindentation, because of its uniaxial nature. We have successfully applied in situ micromechanical testing to ion irradiated materials and have obtained easily quantifiable results which show the effectiveness of this method in assessing the properties of such

materials. We present here the results of numerous tests on He²⁺ ion-irradiated and un-irradiated Ni single crystal thin films using an in situ micro-mechanical testing device and discuss their scientific implications.

F2 J-Y. Cho, W. Xu, M. Qian: RMIT University

Microstructural homogeneity of Ti-6Al-4V alloy manufactured by selective laser melting technique

As one of the additive manufacturing technologies to make metallic components, selective laser melting (SLM) is the techniques which have been used a lot in research and industry area. However although the fact that each layer has experienced repetitive heating and cooling leading to different and complex heat history, can make it hard to get homogenous microstructure, the homogeneity of microstructure of SLM built Ti-6Al-4V components has not been reported. Therefore, herein the microstructural homogeneity has been studied.

The 20 mm long and 12 mm wide Ti-6Al-4V cylinder sample manufactured by SLM technique with 60µm of layer thickness and 50.62 J/mm³ of energy density, was investigated. With image analysis, it was found that the lower part of the sample consists of α / β phase while upper region of the sample is composed of α' martensite phase. Furthermore, volume fraction of beta phase and alpha plate thickness gradually decrease as approaching top of the sample. Moreover, the region between top and below 3.5mm from top which corresponds to α' martensite region shows much lower elastic modulus than lower part but the hardness is not significantly changed in different position. In addition, by analysis the diffraction pattern acquired from micro XRD instrument, it was confirmed that there is no significant variation in lattice parameters of α' or α phase in different position of the sample and that of β phase formed in the α / β region is relatively constant. From these results, the conclusion that even though lattice parameter of each phase is not significantly changed, the microstructure and micro-mechanical property of Ti-6Al-4V parts fabricated by SLM is varied with different position, especially top side of the part because the upper region has less influence of the heat generated by deposition of new layer, can be drawn.

F2 S.H. Islam, M. Qian, D. Parker, R. Chen: RMIT University

Characterisation of the intermetallic layer of 55Al-Zn-Si-Mg hot dip coated steel strips using Focussed Ion Beam (FIB) and Transmission Electron Microscopy (TEM)

Coated steel strips have a very wide range of applications and are an integral part of our daily life. The coating process is realized by hot dipping the steel strips into a coating bath of an Al-Zn based alloy. An alloy or intermetallic layer up to 1 mm thick forms during the hot dip coil coating process between the steel substrate and the final coating overlay. The alloy layer not only provides essential metallurgical bonding between the two but also acts as the last barrier against corrosion. Despite being an established coating process, the phases present in this thin intermetallic layer have not been fully characterised as yet. Relevant information in the literature is largely based on data produced using scanning electron microscopy. . In this research, TEM samples are prepared using the FIB technique from the intermetallic layers observed in both industrially coated steel strips and those coated on a laboratory scale steel strips. The intermetallic layers are characterised using the FIB and TEM assisted with selected area electron diffraction (SAED) and Energy-dispersive X-ray spectroscopy (EDS). The various phases present in the intermetallic layers are identified.

Keynote F2 R. Marceau, A. Ceguerra, A. Breen, D. Raabe, N. Birbilis, S. Ringer: Uni. of Sydney, Monash University, Max-Planck-Institut für Eisenforschung (Germany)

Short-range order analysis of atom probe tomography data

We present quantitative analyses of short-range-order (SRO) alloy using atom probe tomography (APT) data from both Fe-Al intermetallic and Al-Ti-V-Cr high entropy alloys as case studies. This has been achieved by employing nearest-neighbour shell-based analysis of the three-dimensional atomic positions to determine chemically sensitive SRO information by calculating the generalised multicomponent (GM-)SRO parameters [1]. This formalism is an extension of the pairwise multicomponent SRO parameter developed by de Fontaine [2], which itself has roots in the pairwise Warren–Cowley SRO parameter for binary systems [3].

An Fe-18Al (at.%) alloy has been used in an attempt to understand the nature of the so-called ‘komplex’ phase state (or “K-state”), which is common to other alloy systems having compositions at the boundaries of known order-disorder transitions. The accuracy of this method with respect to limited detector efficiency and spatial resolution is tested against modelled D03 ordered data. It is demonstrated that lattice rectification of the experimental APT data prior to GM-SRO analysis provides improved information sensitivity. GM-SRO analysis is also applied to a novel, lightweight AlTiVCr high entropy alloy system to elucidate the site occupancies of its B2 structure.

[1] A.V. Ceguerra et al., Physical Review B, 82 (2010) 132201.

[2] D.J. de Fontaine, Journal of Applied Crystallography 4, (1971) 15.

[3] J.M. Cowley. Physical Review, 77 (1950) 669.

F3 E. Adabifiroozjahi, J. Hart, P. Koshy, C.C. Sorrell: UNSW

The interfacial characteristics of mullite-glass: molecular dynamic simulation

Mullite ceramics are very popular engineering materials due to their low price, good thermal shock resistance and high refractoriness. In mullite ceramics, there are usually two types of interface: mullite-glass and mullite-mullite. The former is necessary for growth of the mullite grains, while having the latter improves the thermomechanical behaviour. Understanding mechanical and chemical behaviour of these interfaces at the atomic scale is essential for understanding the bulk behaviour of mullite bodies. In this work, Molecular Dynamic simulations have been used to study the chemical and structural characteristics of mullite-mullite and mullite-glass interfaces. The glass structure was made by starting with a simulation cell containing 8072 O, 2600 Si and 1920 Al atoms and was heated to 15000K and subsequently cooled to 1800K (cooling rate: 2.55K/ns), followed by relaxation at the same temperature for 1 ns. Mullite (~8000 atoms in the simulation cell) was made by modifying the sillimanite structure and then relaxing at 1800K for 1 ns. Relaxed blocks of the mullite structure were then placed next to blocks of either glass or mullite, to generate the interfaces of interest. Three different crystallographic planes of mullite were used as the interfacial plane: (001), (010) and (100). The interfacial energies of (001)-(010), (010)-(100), (001)-(100), (001)-glass, (010)-glass, and (100)-glass were calculated based on NPT simulations at 1800K for 2ns. The result showed that glass-mullite interfacial energies ((001)-glass: 1.30 J/m², (010)-glass: 1.69 J/m², (100)-glass: 1.30 J/m²) are generally lower than mullite-mullite energies ((001)-(010): 2.47 J/m², (010)-(100): 1.22 J/m², (001)-(100): 2.32 J/m²).

F3 S. Khot, P. Sutar, S. Mishra, S. Telrandhe, R.K.P. Singh: Bharat Forge Limited (India), IIT-Bombay

Influence of laser parameter on surface microstructure modification of Ti-6Al-4V

Titanium and its alloys are widely used in the aerospace, chemical industries, biomedical application due to excellent properties such as light in weight, high strength, wear resistance, hardness and

thermal stability at higher temperature. Laser beams, apart from their directionality and high friction coefficient, they are widely used in surface modification in many metals. The present study shows effect of laser processing parameter on the subsurface microstructure changes, modified case depth, phase transformation and microhardness. A continuous 2 kW Fiber laser system with shrouding gas (argon) is used. A modified laser treated depth (including heat affected zone and transition zone) varies between 750 to 1150 μm . Modified surface characterized for microstructure change, new phase formation with EBSD analysis. Microstructural studies shows that needle like martensite structure formed in laser treated zone. A significance changes in the microhardness was observed for all laser treated samples.

F3 T. Ahmad, M.T.Z. Butt, M. Kamran, M. U. Manzoor: University of the Punjab (Pakistan)

Studying the effect of carbon fiber-silica sand nanoparticles on copper based hybrid composites

The aerospace and electronic industries have open new horizon for copper carbon fibers based composites. This research is to develop carbon fibers and silica sand nanoparticles reinforced copper matrix hybrid composite. Compcasting was selected to prepare these hybrid composites with wt.% ratio of carbon fibers and silica sand nanoparticles from 0.5, 1, 1.5 and 2 wt. %. The effect of varying carbon fiber and silica sand nanoparticles contents on the mechanical properties and microstructure of hybrid composite was studied. The yield strength decreases with increasing fibre and silica sand nanoparticles contents however an increase in ultimate tensile strength was found. A decreasing trend of electrical conductivity with increasing trend of reinforcements was observed. The microstructures of the hybrid composites were analyzed using optical and SEM microscopes.

F3 W.H. Kan, C. Albino, D. Dias-da-Costa, K. Dolman, T. Lucey, X. Tang, J. Cairney, G. Proust: Uni. of Sydney, Weir Minerals Australia, Uni. of Coimbra (Portugal)

Fracture toughness testing using digital image correlation and photogrammetry

Traditional fracture toughness testing of brittle specimens using three-point bending is challenging due to i) difficulties tracking crack propagation and obtaining full field displacement data, ii) the complicated experimental set up necessary for the measurements, iii) a lack in validity assurance prior to a test. Here we present a new technique based on digital image correlation and photogrammetry that has been developed and validated for tracking crack mouth opening displacement for brittle metallic specimens during fracture toughness testing. This technique was previously developed to evaluate cracking in large concrete beams but was further modified and down-scaled in order to work with our significantly smaller specimens. This approach offers several advantages over traditional methods based on strain gauges and/or extensometers. The measurement test is easier to set-up; it provides full field strain measurements; post-bending analyses can be carried out; and during the test, it is possible to track crack propagation. The accuracy of this new technique was evaluated using a notched dummy ductile steel specimen that was subjected to three-point bending to induce plastic deformation such that the resulting change in the notch gap could be verified using both the proposed technique and a scanning electron microscope. This technique was then applied to evaluate the fracture toughness of a hypoeutectic high chromium white cast iron reinforced with 27 vol% NbC. The results showed that this composite had comparable fracture toughness to conventional high chromium white cast irons of similar carbide volume fractions, indicating that the proposed technique was viable.

F3 A. Al-Zuheri: Ministry of Science and Technology (Iraq)

Exploring the chemical structure of the Iraqi oil shale and its hydrocarbon forms

The global impact of shale oil has revolutionised the world's energy markets, resulting in significantly lower oil prices, higher global gross domestic product, changed geopolitics and shifted business models for oil and gas companies. Further and developed research initiative is needed to fill critical gaps in knowledge at the interface of shale oil development along with environmental protection so the nation can better prepare for its energy future. This paper explores the characterisation of Iraqi originated oil shale using various analytical techniques, such as mass spectrometry (MS), infrared spectroscopy (IR), and Gas Chromatography Mass Spectrography (GC/MS). From analytical results it is found that the majority of chemical structure is in aliphatic hydrocarbon forms.

Invited F4 T. Song, M. Yan, N. Webster, M. Styles, J. Kimpton, M. Qian: Australian Synchrotron, RMIT Uni., South University of Science and Technology of China, CSIRO

Does crystal structure transition matter in the creation of nanoporous structure via dealloying approach?

Dealloying of intermetallic-type precursor alloys, like Al-Cu alloys consisting of tetragonal Al₂Cu and/or monoclinic AlCu, is becoming commonly practiced, offering a flexible approach to fabricating functionally desirable nanoporous structures. Dealloying inevitably deals with phase & crystal structure transitions. So far the understanding regarding this, however, has been mostly confined to the study of dealloying pathways of solid solution alloys completely overlooking the role of phase & crystal structure transitions. This hinders the comprehensive understanding of the dealloying mechanism as well as fabrication of advanced nanoporous structures. Because of these, we designed a combined in-situ and ex-situ dealloying study of as-cast Al-Cu alloys via high-resolution synchrotron X-ray diffraction, aiming to clarify the role of crystal structure transition on the dealloying. We have observed that the dealloying procedure from tetragonal Al₂Cu and monoclinic AlCu to cubic copper (Cu) had occurred in a clear sequence which collectively results in a hierarchical nanoporous Cu. Based on the solid experimental data obtained we have demonstrated the significance of crystal structure transitions during dealloying, which in turn implies that by manipulating crystal transitions, the creation of hybrid or hierarchical structures from the dealloying approach can become more designable. In the study, we have also discussed the kinetics for the formation of Cu phase during dealloying of intermetallic phase using the nucleation-growth model.

Invited F4 R. Acres, D. Cookson, K. Hayes: Australian Synchrotron

The Australian synchrotron and advanced materials: Challenge/Opportunity/Solutions

One of Australia's world class research facilities, the Australian Synchrotron, provides cutting edge tools to academic and industry researchers, empowering them to problem solve and innovate in a wide range of sectors, including materials science, advanced manufacturing and nanomaterials.

As well as servicing the traditional academic user base, the Australian Synchrotron has an Industry Engagement team focused on supporting commercial customers to utilise the synchrotron's capabilities. However, going beyond the academic user base presents some challenges as well as opportunities.

This presentation will:

- Discuss how to raise awareness and understanding of technical capabilities to potential commercial clients

- Share ways to inspire businesses to explore applications and capitalise on the opportunities arising from our world class infrastructure
- Showcase existing case studies, demonstrating successful connections between science and industry

Examples of case studies from the Australian Synchrotron will be presented that highlight the capabilities and advantages of the facility to commercial and academic users. Lessons learned will be shared as well as a practical approach to achieving “buy in” from key decision makers to achieve a mutually beneficial outcome.

F4 A. Xu, D. Bhattacharyya: ANSTO

Strain rate sensitivity tests at the micron scale – a novel in situ approach

Micro-scale mechanical testing is a novel method of testing materials which would otherwise be difficult to test (due to financial or technical limitations) via traditional macro-scale tests. Obvious examples include thin films, surface modified and single crystal materials to name a few. In the current report we present a fundamental study of effect of strain rate and crystal orientation on pure Ni single crystal thin films $\sim 12 \mu\text{m}$ thick. The samples are fabricated as dog-bone specimens using a Zeiss Auriga FIB-SEM of cross-section $\sim 12 \times 12 \mu\text{m}$ and gauge length $30 \mu\text{m}$. The dog-bone tensile samples are tested in situ on a micro-tensile testing device in a Zeiss UltraPlus SEM with images recorded at regular intervals. The resulting stress-strain plots are analysed in conjunction with its SEM images to evaluate the deformation of the materials along $\langle 100 \rangle$ and $\langle 110 \rangle$ orientations and at strain rates 0.0002 and 0.02 s^{-1} . Further microstructural analysis of the dislocation structure is carried out in a Joel® 2200 FS™ TEM. The results obtained are compared against expected literature trends in order to assess the similarities and differences between the bulk and micromechanical testing methods. It was also clear that we are able to reliably reproduce the yield stress, ultimate tensile stress and elongation across the difference samples tested through this micro-mechanical testing procedure. The success of this fundamental study of Ni single crystals demonstrates the economy, reliability and accuracy of micro-scale mechanical testing for future materials.

F4 T. Finlayson, C. Davidson, J. Griffiths, M. Fitzpatrick, E. Oliver, Q. Wang: Uni. of Melbourne, CSIRO, Coventry Uni. (UK), Rutherford Appleton Lab. (UK), General Motors (USA)

Stresses developed in the Si particles of an Al-Si composite under cyclic loading: their measurement and interpretation

The stresses in the particles of a two-phase composite (in our case the eutectic Si particles in an Al-7Si-0.4Mg casting alloy), arise from three sources. Firstly, the thermal expansion coefficient of the Al-based matrix is greater than that of the Si particles so that as the casting cools from its processing temperature, a thermal misfit compressive stress, σ_{th} , develops in the particles, balanced by tensile stresses in the matrix, that are often large enough to yield the matrix near the particle. Secondly, the Young's modulus of Si is greater than that of Al so that when a sample from the casting is loaded, an elastic misfit stress in the particles, σ_{el} , is developed, which is greater than that in the matrix. Thirdly, a plastic misfit stress, σ_{pl} , is generated when the matrix yields and flows around the (still-elastic) Si particles.

In a neutron diffraction experiment one measures the resultant strain in the Si particles (and hence, determines the particle stress) as a consequence of the combination of these three contributions to the stress, but their separation experimentally is difficult. One simplification is to reduce σ_{th} to zero by conducting an in-situ mechanical test at a sufficiently high temperature. For our Al-Si-Mg alloy, such a temperature is 130°C .

In-situ cyclic loading experiments and associated neutron diffraction, carried out on the ENGIN-X instrument at the ISIS pulsed neutron facility, will be presented and the results discussed in the light of current theoretical understanding of the mechanical behaviour of two-phase composites.

Symposium G: Advances in steel technology

Keynote G1 T. Furuhashi: Tohoku University (Japan)

Important roles of phase transformations on advanced design of modern high strength steels

In development of modern high strength steels, importance of strength and ductility/toughness balance is increasing and more advanced and sophisticated controls of microstructure formed during phase transformations are utilized. In the presentation, two major topics in high-strength low-alloy steels are discussed, with emphasis of thermodynamics, kinetics and crystallography; 1) nano-sized precipitation of alloy carbide accompanied during ferrite transformation for strengthening ferritic steels, and 2) substructure and transformation kinetics of bainite, which is important for toughness of high strength low alloy steels. In particular, important roles of migrating interphase boundaries during transformations will be discussed.

Keynote G1 S-J Kim: PosTech (S. Korea)

Development of ultrafine-grained 3rd generation medium Mn AHSS having interlath morphology

Researches on the development of medium Mn automotive steel sheets are booming recently in worldwide steel industry and academics because of the excellent balance of high strength and ductility of those steels. The medium Mn steels with low carbon less than 0.2% usually have (ferrite+metastable austenite) duplex phases, and the TRIP(transformation induced plasticity) and/or TWIP(twin induced plasticity) are the main mechanisms for achieving the excellent mechanical properties. Tensile strengths over 1,000 MPa and elongation over 30% are easily obtained by optimum alloy design and heat treatment. In this presentation, R&D activities on medium Mn steels for 3rd generation AHSS in Korea is briefly summarized, and the recent development of high strength Fe-10Mn- Al-C steel having ultrafine-grained interlath structure of martensite and austenite will be introduced. The interlath morphology was obtained by intercritical annealing followed by quenching and partitioning. The new technique is expected to open a new way for the industrial production of various grades of ultrafine-grained steels.

G1 M. Eizadjou, H-W Yen, S.P. Ringer: The University of Sydney, National Taiwan University (Taiwan)

Modulating of austenite stability in an Al-modified low C-medium Mn Duplex Steel

This work demonstrates our recent findings in the development of third generation advanced high-strength steels, where our focus is on tuning the degree of plasticity of the austenite in duplex austenite-(ferrite+martensite) steels. Our interest in microstructural engineering of austenite stems from the possibility of transformation-induced plasticity (TRIP) of this phase, which is well known to enhance ductility in these types of steels.

The current study aims to unveil the critical factors influencing the onset of austenite to martensite transformation during plastic deformation. Different annealing conditions were applied to a cold-rolled novel low carbon-medium manganese steel to tailor the chemical composition and grain size of austenite. The microstructure-properties relationships were studied by scanning electron microscopy-transmission Kikuchi diffraction, transmission electron microscopy and atom probe microscopy. It was found that both early and delayed onset of the TRIP effect will lead to worse

ductility. Hence, to achieve ultrahigh strength and excellent ductility in the steels, austenite stability shall be controlled to precisely trigger out TRIP and well match for the deformation of neighboring ferrite. The results show that short time annealing of our duplex steel eventuates in a large volume fraction of ultra-fine austenite (>40%) and superb combination of strength ($\sigma_y \cong 1.3 \text{ GPa}$) and ductility ($\epsilon_t \geq 25\%$). This work evidence that modulating of austenite to a marginal stability enables us to design strong and ductile steels.

G1 W. Sun, R. Marceau, D. Barbier, M. Styles; C. Hutchinson: Monash University, Deakin University, CSIRO, ArcelorMittal

New nano-precipitation hardened 2 GPa strength steel

The automotive industry is under increasing pressure from legislation on greenhouse emissions because cars are seen as a significant contributor to the atmospheric gases that accelerate global warming. Reducing the weight of automobiles is one way to help increase the fuel economy and hence reduce quantities of harmful gases released into the atmosphere. Weight reduction in the body panels is one area that has received attention because it accounts for ~25% of the total car mass. Using higher strength materials allows less material to be used while compensating for the loss of strength to support the same forces. Steels have the merit of being economical, strong and exhibit excellent formability and recyclability, thus being the dominant material employed in vehicle construction.

The objective of this project is to develop a new, weldable (ie. carbon content less than ~0.03wt.%) sheet steel with a yield strength of 2 GPa. The approach chosen is based on precipitation hardening of G-phase (a Ti silicide) in a cold rolled ferritic matrix. The cold rolled matrix contains large amount of defects which can provides nucleation sites for coherent G-phase within a short ageing time. As a result, a new class of steel exploiting the G-phase was developed with yield strengths close to 2.1 GPa and several percent tensile uniform elongation. The tensile behaviour will be demonstrated and the microstructural evolution during aging has been characterized by in-situ small angle x-ray scattering (SAXS) and Atom Probe Tomography (APT).

G1 S. Dhara, K. Wood, T. Dorin, R.K.W. Marceau, P.D. Hodgson: Deakin University, ANSTO

Towards a better understanding of carbide precipitation in a Ti-Mo microalloyed steel using SANS and APT

Interphase precipitation of complex carbides represents one of the main strengthening mechanisms in Ti-Mo microalloyed steels. It is assumed that the presence of Mo in the carbide lattice enhances the thermal stability of the nanoscale precipitates (<10 nm) over a wide range of thermomechanical processing conditions. To investigate this claim, we have used the complementary techniques of small angle neutron scattering (SANS) and atom probe tomography (APT). The evolution of precipitate size and volume fraction was monitored with SANS and APT was used to evaluate the precipitate composition evolution, and more specifically, the evolution of Ti/Mo ratio during the precipitation process. We confirm that the precipitates are thermally stable for a wide range of thermomechanical processing conditions. APT analysis also reveals a significant fraction of matrix Fe atoms inside the spherical precipitates containing Ti, Mo and C.

G1 S. Yang, C. Hutchinson: Monash University

Improving the fatigue response of steels through architected surfaces

Many applications of high strength materials in 'moving structures' applications are limited by fatigue. This form of loading occurs in all forms of engineering, and it has been estimated that 90%

of all metal failure is due to fatigue failure. Steels are one of the dominant engineering materials employed in ‘moving structures’ due to their advantages in cost, mechanical properties and recyclability, and thus new methods and ideas in fatigue design to increase the lifetime of ‘moving structures’ are desirable.

In this project, an attempt is made to improve the fatigue performance of martensitic steels by ‘architecturing’ the surfaces using cycles of carburization and decarburization to create a layered surface structure. The rationale is to simultaneously limit crack nucleation and crack growth and the inspiration is drawn from the success of the multilayer structures we see in teeth that perform so effectively in fatigue loading applications. An architecturally designed steel with a suitably conceived hierarchical surface structure, built upon an understanding of the service environment, will help to achieve a promising combination of properties.

The present study demonstrates the method to produce the architected steel with designed structure for fatigue applications, and elucidates the correlations between the different architected structures and the fatigue crack nucleation and fatigue growth crack characteristics.

Invited G2 M. Zhang, J. Li, M. Li, G. Wang, Q. Zheng: The University of Queensland, Baoshan Steel Company (China)

A novel approach to grain refinement of steel castings

The theories and models of grain refinement for cast metals developed in light alloys have been successfully applied to steel castings. However, due to the complexity of solidification process during steel casting, the grain refinement techniques for steels were developed for the ferrite and austenite, respectively. Calculations of the growth restriction factors identified a number of solutes that enabled grain size reduction through micro-alloying. The edge-to-edge matching model was used to seek effective nucleants that promote the heterogeneous nucleation of ferrite or/and austenite and therefore lead to significant grain refinement and increase in fraction of equiaxed grains in the steel ingots. At laboratory scale, the new grain refinement techniques resulted in the reduction in the as-cast grain sizes of a austenitic TWIP steel and a ferritic stainless steel from 3.00 mm down to 300 micrometer.

Invited G2 Simon P. Ringer: The University of Sydney

Thermo-mechanical processing advanced high-strength steels: Atom probe microscopy guided materials design

Motivated by the increasing environmental demand for stronger steels that achieve dramatic weight savings in engineered structures, this paper will summarize recent research on the design of advanced high strength steels (AHSS), Fig. 1 [1]. The critical enabler has been atom probe microscopy [2], where subnano- to nanoscale resolution of the chemistry and crystallography has guided selections of steel composition and thermo-mechanical treatment. Our focus is on steels exhibiting a reverse austenite transformation to obtain an austenite-ferrite duplex microstructure. We are seeking to extend the performance and practicality of third-generation (G3) AHSS utilizing an ultrafine grain size. Recent results using high pressure torsion on a TWIP steel to achieve nanostructured grain sizes will also be discussed [3]. [Editor’s note: Figure 1, supplied by the author, is not available in this abstract file.]

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2. B. Gault, M.P. Moody, J.M. Cairney, and S.P. Ringer, *Atom Probe Microscopy* (Springer, 2012).
3. X.H. An, Q.Y. Lin, G. Sha, M.X. Huang, S.P. Ringer, Y.T. Zhu and X.Z. Liao, *Microstructural evolution and phase transformation in twinning- induced plasticity steel induced by high-pressure torsion*, *Acta Materialia*, Vol. 109, pp. 300-313 (2016).

G2 L. Wang, L. Brassart, A. Arlazarov, C. Hutchinson: Monash University ArcelorMittal
The strength of tempered martensite

Martensite is a key constituent of almost all high strength steels. The traditional view of the strength of martensite (e.g 0.2% proof strength) is that it is largely due to solid solution strengthening by carbon and this is corroborated by experimentally observed correlations between hardness and the square root of carbon concentration. However, new experiments over the past decade have shown that this simple picture is not able to explain well the extended elastic-plastic transition and the high strain hardening rates.

Recently, a new interpretation of the yielding of martensite was proposed – the continuous composite approach (CCA) (Allain et al. ISIJ, 2012). This approach views martensite as a natural composite composed of a distribution of microstructural elements with different strengths that successively yield during deformation. The CCA approach has shown some success in describing both the strength and strain hardening behaviour of as-quenched martensite.

However, commercial martensitic steels are used in the tempered (or heavily auto-tempered) state. The concurrent occurrences of carbide formation, defect recovery and solute segregation during tempering and their effects on any potential composite strengthening effect of martensite remain to be characterised and understood. In this research, the mechanical response of tempered martensite is monitored using tensile and Bauschinger experiments. The ability of a CCA to describe the effects of tempering on the strength and strain hardening of martensite is discussed as well as the relationship between the ‘strength spectrum’ central to the CCA approach and the microstructural changes occurring in the microstructure of tempered martensitic steels.

G2 S. Pramanik, A.A. Saleh, A.A. Gazder, E.V. Pereloma: University of Wollongong
Microstructure evolution during the cold rolling of transformation and twinning -induced plasticity steel

Transformation and twinning-induced plasticity (TRIP-TWIP) steel is a class of advanced high strength steels containing 15-20%Mn with small additions of Al and Si. On straining this steel deforms via a combination of: slip, deformation twinning and transformation of the metastable face-centered-cubic austenite (γ) phase to hexagonal-closed-packed (hcp) ϵ and body-centered-cubic α' martensite.

A hot rolled Fe-17Mn-3Al-2Si-1Ni-0.06C (wt.%) TRIP-TWIP steel was cold rolled to 42%, 66% and 88% thickness reduction. The microstructural evolution with increasing cold reduction was studied with electron back-scattering diffraction (EBSD) and transmission electron microscopy (TEM). The hot rolled microstructure consists of coarse γ grains with annealing twins and ϵ and α' martensite platelets that formed on quenching. The transformation of γ to ϵ and α' martensite was observed during cold rolling. Once transformed, the α' martensite grains accommodated the additional strain imposed by further cold rolling reduction by a combination of pancaking and shear banding. After cold rolling, the microstructure was dominated by α' martensite, a small fraction of blocky ϵ -martensite and a trace amount of retained γ .

This work is supported by the Australian Research Council Discovery Grant (DP130101882).

Keynote G3 Y. Wu, W. Sun, M. Styles, A. Arlazarov, C. Hutchinson: Monash, CSIRO, ArcelorMittal
Batch annealing of 3 rd generation advanced high strength steels (AHSS)

The automotive industry is a major user of sheet steels for the fabrication of car chassis and panels. The materials used in these applications must meet strict safety regulations regarding energy

absorption during a crash but simultaneously they represent a non-negligible fraction of the total vehicle weight and hence we also want them to be light, to increase fuel efficiency. The next generation of sheet steels to fulfill this role are the 3rd Generation Advanced High Strength Steels (AHSS). These new steels typically contain 2-5 wt.% of Mn.

A key processing step of 3rd generation AHSS is a 'batch annealing' at temperatures ranging from 400 to 600°C, to precipitate cementite from a martensite/bainite matrix. This step is necessary to soften the materials before subsequent cold rolling. During batch annealing, Mn partitions to the growing cementite and this influences austenite reversion during the subsequent intercritical annealing. To optimize the batch annealing process, a detailed understanding of the kinetics of cementite precipitation, including the Mn content inherited by the cementite must be developed.

In this work, various powder diffraction techniques (including synchrotron and neutron powder diffraction), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and atom probe tomography (APT) have been used, to quantify the cementite transformation kinetics and the evolution of the chemistry of the cementite phase as a function of precipitation. The focus of this work is on the development of a predictive model for cementite precipitation in low carbon alloys with additions of Mn, Si, Al Cr and Mo, in the temperature range from 400 to 600°C.

Keynote G3 S. Takaki: Kyushu University (Japan)

Yielding mechanism of polycrystalline iron

Yield stress of polycrystalline metals increases with decreasing grain size, so called Hall-Petch relation. Our previous study proved that small amount of carbon below 60 ppm affects the Hall-Petch coefficient of polycrystalline iron and this results in the change of yield stress even in the same ferrite grain size. It seems that the yielding of polycrystalline iron is affected by carbon segregation at ferrite grain boundary. It was found that the yielding based on the grain refinement strengthening is always followed by the yield point elongation so that the yielding is characterized by the step in nominal stress-strain curves (Step yielding).

On the other hand, it is sure that yield stress is heightened by the aging at low temperature, so called the quench age-hardening. So far, it is believed that the quench age-hardening is generated due to the pinning of mobile dislocations which exist in the ferrite matrix. It was also found that the yielding related to the quench age-hardening is characterized by sharp yield drop (Spike yielding). In my presentation, the yielding behavior of polycrystalline iron will be introduced in terms of the mechanisms of grain refinement strengthening and particle dispersion strengthening.

G3 L. Brassart, K. Ismail, A.-P. Pierman, T. Pardoën, P.J. Jacques, Q. Lai, Y. Bréchet, A. Perlade: Monash Uni., Uni. Catholique de Louvain (Belgium), Uni. de Grenoble Alpes (France), ArcelorMittal (France)

Influence of microstructure and composition on the plastic and damage response of dual-phase steels: Experiments and micromechanical modeling

The engineering of Dual-Phase (DP) steels with optimized properties is very challenging due to the complexity of the microstructure and the large number of influencing parameters. In particular, the martensite volume fraction, hardness and morphology all significantly affect the effective response. This presentation will give an overview of our recent experimental and modeling efforts in the systematic investigation of the relative influence of each one of these parameters on the effective plastic and damage response of DP steels. The experimental study relies on model microstructures combining several volume fractions of martensite, martensitic carbon contents, and phase arrangements, which were generated by suitable control of the heat treatments. Experimental trends are rationalized by developing micromechanical approaches coupling plasticity and ductile fracture.

Our results highlight the key role of the martensite flow properties on the overall plastic and damage response of DP steels.

G3 N. Haghdadi, P. Cizek, P.D. Hodgson, G.S. Rohrer, V. Tari and H. Beladi: Deakin University, Carnegie Mellon University (USA)

Effect of transformation path on the austenite-ferrite interface characteristics in the duplex stainless steel

A thorough characterization of austenite-ferrite interfaces was carried out in a duplex stainless steel for two distinct microstructures (i.e. equiaxed vs. Widmanstätten) produced through different phase transformation mechanisms (i.e. diffusional vs. semi-displacive). Misorientation angle/axis analysis showed that a considerable amount of interphase boundaries obey Kurdjumov–Sachs (K-S) orientation relationship (OR) followed by Nishiyama-Wasserman (N-W) independent of the transformation path. The fraction of both K-S and N-W interfaces was, however, higher in the case of the Widmanstätten microstructure. The plane distribution analysis showed a relatively high anisotropy for the both microstructures with K-S and N-W interfaces tending to terminate on (111)FCC and (110)BCC planes. This is in line with both crystallographic constraints and the tendency to adopt low-energy interface configurations. Other austenite-ferrite interfaces which corresponded to neither K-S nor N-W ORs, however, tended to terminate on (111)FCC and (111)BCC planes. This is believed to be due to the nucleation of austenite with irrational ORs on (111)//(111) initial ferrite-ferrite boundaries, or due to a gradual deviation of ferrite planes from (110) towards (111) plane while austenite irrationally grows.

G3 E.V. Pereloma, A.A. Saleh, H.Th. Spanke, C.R. Killmore, A. Kostryzhev, A.A. Gazder: University of Wollongong

Application of advanced characterisation techniques to assist microstructure analysis of industrial steel grades

Recent advances in materials characterisation techniques for obtaining chemical, crystallographic and morphological information coupled with the development of in-house data acquisition and post-processing methodologies open pathways for in-depth characterisation of steel microstructures. This assists a better understanding of microstructure evolution during steels production and its control for achievement of the required properties. Examples of application of atom probe tomography, Electron Back-Scattering Diffraction coupled with Energy Dispersive X-ray spectroscopy and Transmission Kikuchi Diffraction to evaluate the effects of processing parameters on microstructure will be presented. These research projects were supported by the BlueScope Steel Metallurgy Centre, ARC HUB for Australian Steel Manufacturing and ARC Linkage grant (LP110100231).

G3 H. Bai, Y. Zhou, Q. Chao, H. Beladi: Deakin University, WISCO (China)

Study on recrystallization behavior of hot-dip galvanized coating

Fine and twinning-free zinc grains were typically preferred in hot-dip galvanized coatings because fine grains inhibited crack formation during sheet metal forming. In this study, the recrystallization behavior of zinc coating in a hot-dip galvanized IF steel sheet produced by WISCO was studied with the aid of polarized light microscopy, scanning electron microscopy (SEM) and electron backscattered diffraction (EBSD). The as-received material subjected to skin-pass rolling revealed the presence of significant mechanical twinning in the zinc coating. The annealing treatment of the as-received sheet in the range of 200–400°C resulted in recrystallization of the deforming coating, displaying the equiaxed, twin free grains. The extent of recrystallization strongly depended on the annealing temperature and almost fully recrystallized microstructure was observed at an annealing

temperature of 300°C and above. Furthermore, the average grain size of the recrystallized grains increased as the recrystallization temperature increased. The inhibitor layer of Fe₂Al₅, which is critical to the overall performance in a sheet metal forming operation, was stable during the reheat treatment. The recrystallized zinc coating exhibited a strong basal texture, which improved the crack resistance during the plastic deformation.

Keynote G4 K. Tsuzaki: Kyushu University (Japan)

High strength austenitic steels with martensitic transformation and deformation twinning: Hydrogen effects on tensile and fatigue properties

Hydrogen deteriorates tensile strength and enhances fatigue crack growth rate in steels irrespective of their matrix phases; ferrite and austenite, depending on ductility and strength. Hydrogen embrittlement has been intensively reported in high strength ferritic steels where hydrogen solubility is low and hydrogen diffusivity is high. However, the metallurgical defect formation and trapping mechanisms are still not completely clarified, although some major models have been proposed; Hydrogen Enhanced Localized Plasticity (HELP), Hydrogen Enhanced DEcohesion (HEDE), and Hydrogen Enhanced Strain-Induced Vacancies (HESIV).

Much attention has been recently paid into austenitic steels as structural materials of hydrogen infrastructure, because their hydrogen embrittlement susceptibility is low when the austenite phase is stable. However, hydrogen embrittlement becomes significant when the austenite is unstable and BCC martensite forms during deformation or service. This deterioration is explained by two factors; supersaturation and high diffusivity of hydrogen in BCC. Even if the austenite is unstable, HCP martensite forms instead of BCC when the stacking fault energy of steels is low. In this case, we can expect low hydrogen embrittlement susceptibility because of large solubility and low diffusivity of hydrogen in HCP like FCC. Moreover, fatigue crack growth rate may not be enhanced by HELP when crack growth is controlled by martensitic transformation with a fixed shear strain at a crack tip.

In this presentation, we introduce our recent studies on hydrogen effects on tensile and fatigue properties in several kinds of austenitic steels with different austenite stability. Some interesting findings are as follows. 1) When deformation twinning was enhanced by hydrogen in Fe-30Mn- 6Al stable austenite, tensile uniform elongation was increased. 2) Fatigue crack growth rate was however increased in hydrogen circumstance in the Fe-30Mn- 6Al. 3) Fatigue crack growth rate was not affected by hydrogen when the austenite phase transformed into HCP at the crack tip in Fe-30Mn-4Si- 2Al, although tensile uniform elongation was somewhat decreased by hydrogen.

Invited G4 M. Ferry, W. Xu: The University of New South Wales

Twin roll casting of sheet steel products: Alloy design, processing strategies and product quality

Crack formation and minimization are top priority work for Baosteel. We found the main reasons responsible for their formation are: (1) strip edge is cooled and solidified faster, therefore thicker than the rest of strip when it passes twin roll nip, causing the rest strip can't be fully solidified and thinner, (2) the strip edge region stops the thermal stress and strain in the rest region from relaxation along transverse direction, and (3) grooves on twin roll surface make the two cases even worse. We discussed the results with Baosteel colleagues, and designed some of possible technical measures for them to consider to minimize and overcome this defect.

We started to design two new types of alloys: silicon and duplex stainless steels. They are high value added, and may be more suitable for twin roll casting process, as strip casting low carbon steel is too difficult to compete with traditional brands in the Chinese market. Si steel coupons of 0.8 to

6.5% Si, representing low to high grades of steels, is to be processed on recently installed Gleeble 3500, to investigate their hot formability and evolution of microstructure and texture.

G4 S. Primig, S. Sackl, H. Leitner, M. Zuber, H. Clemens: UNSW, Boehler Edelstahl GmbH & Co KG, Stahl Judenburg GmbH, Montanuniversitaet Leoben (Austria)

Continuous versus conventional heat treatment of hardenable steels

Short-time continuous heat treatments are an interesting and economic alternative to conventional ones with comparably long isothermal holding times. Ultra-fast heating rates can, for example, easily be achieved by using inductive heating. Due to rapid heating to comparably higher target temperatures, isothermal holding times during e.g. hardening and tempering of steels can be significantly reduced which leads to a great potential for cost reduction. Furthermore, continuously heat-treated steels are known to exhibit less deviation in mechanical properties and less decarburization. Whereas the microstructural evolution during isothermal hardening and tempering of steels is well known, the differences in homogenisation and phase transformation kinetics during short-time continuous heat treatments still have to be established in order to process parts with similar or even better mechanical properties.

The current study will showcase the microstructural evolution during continuous versus conventional hardening and tempering of a 42CrMo4 steel and an HS6-5-2 tool steel. Each step of the heat treatment cycle has been studied comprehensively using state-of-the-art microstructural characterisation techniques such as scanning and transmission electron microscopy, electron back-scatter diffraction, micro probe, and atom probe tomography. The corresponding microstructure-property relationships of the final parts achieved by both heat treatment approaches will be discussed.

G4 S. Araki, D. Akama, T. Tsuchiyama, S. Takaki: Kyushu University (Japan)

Difference in age hardening behavior between carbon and nitrogen in ferritic steel

The yielding of polycrystalline metals is governed by the mechanism of grain refinement strengthening. In the case of ferritic steel, the yielding is characterized by a step-type yielding followed by a yield point elongation (step-yielding). The stress for step-yielding is known to follow the Hall-Petch relationship. On the other hand, a sharp yield-drop (spike-yielding) is sometime found in aged steels. It is recognized that the age hardening is caused by interstitial elements of C and N. The hardening effect of them are often regarded to be similar, and the amount of age hardening is usually explained as a function of (C+N). However, the authors reported that there is a significant difference in the stress for step-yielding between C- and N-added steels. In this study, the age hardening behaviors in ferritic steels containing about 60 ppm C or N (C60, N60) was investigated from the viewpoint of yield stress, and then the difference in hardening effect between C and N was discussed. The specimens were cold-rolled and then annealed at 973K, followed by water cooling. The aging treatment was performed at 443K. Tensile tests were carried out at an initial strain rate of 10^{-3}s^{-1} for plate test pieces standardized by JIS13B. The upper yield stress at which spike-yielding takes place increased with increasing aging time, and then saturated at a certain value. The saturated upper yield stress was much higher in C60 than in N60. This might be due to the difference in precipitation behavior between C and N.

G4 T. Dorin, K. Wood, N. Stanford, P. Hodgson: Deakin University, ANSTO, Monash University

Investigating precipitate composition, size and volume fraction evolution in strip cast steels with high sulphur and copper contents

The novel direct strip casting technology involves extremely rapid cooling which creates out of equilibrium microstructures. The obtained microstructures are typically super-saturated in the as-cast condition. Precipitation occurs during a subsequent heat treatment and thus the temperature and duration of this treatment strongly affects the final microstructure and mechanical properties of these metals making it necessary to understand and control it. With the rapid solidification, the alloying elements can be added above their maximum solid solubility at room temperature, thus giving opportunity to cast compositions that cannot be processed conventionally.

A series of three steel alloys with increasing Cu and S concentrations have been prepared by simulated direct strip casting. It was found that the rapid solidification that occurs during direct strip casting results in the formation of a high number density of fine MnS precipitates, thus cancelling the usual detrimental effect of S. Cu was found to be retained in solid solution above equilibrium concentration. Transmission electron microscopy (TEM), atom probe tomography (APT) and small angle neutron scattering (SANS) were used to quantify the precipitate formation during ageing at 600°C. Upon ageing, the MnS particles were found to increase in volume fraction, indicating that some S was retained in solid solution and this was confirmed with APT of an as-cast specimen. Ageing also resulted in the precipitation of Cu-rich precipitates. A new method to determine precipitate composition from SANS will be presented. The composition of the Cu-rich precipitates is found to depend on the alloy's bulk Cu content.

G4 J. Gao, R. Zhong: WISCO (China)

Simulation of temperature field during laser-welding of phosphoric steels

Automobile steel is widely used in the world, which is safer but heavier than other materials. Nowadays more and more companies want to use phosphoric steels to replace the traditional automobile steels because of their high strength/weight ratio and the low cost. So the phosphoric steel's welding condition plays an important role in its applications. Finite element simulation is a useful method to predict the welding progress, which can be conducted under many physical parameters, such as latent heat of fusion, convection, radiation, can be collected from other tests. Abaqus is a software to solve this issue and the results showed that the morphology of the weld by the simulation was the same as the actual weld. The isotherm appeared like an oval, before the heat there were more isotherm and the temperature gradient became much steeper, but after the heat the account of isotherm became less and the gradient relieved.

Invited G5 F. Barbaro: University of Wollongong

Developments in control of weld HAZ properties in modern high strength steels

Steel remains the foundation material for modern society. Revolutions in steelmaking and rolling technology have contributed to the widespread use of microalloying. Today, it is estimated that seventeen percent of all steel produced rely on microalloying additions to enhance both strength and toughness through grain size control. This makes common sense from an economic, weight saving viewpoint and is now appropriately acknowledged as environmentally responsible.

Optimum mechanical properties are dependent upon the fundamental alloy design along with judicious microalloying and controlled thermomechanical controlled processing (TMCP). Segregation and impurity levels are now mitigated as part of the overall alloy design. Weldability however remains the determinant in performance of the final fabricated structure.

A microalloying with titanium has been a common choice to minimise austenite grain coarsening in the weld HAZ through the grain boundary pinning action of TiN precipitation. The thermal stability of the TiN precipitates provided exceptional control of boundary migration compared to other microalloy additions. However, the required levels of titanium and nitrogen to ensure optimum precipitate size distribution and therefore HAZ properties can be difficult to control and has been the subject of considerable debate.

The present paper details the microstructure - property relationships following the welding of high strength API 5L grade pipe steels. Conventional microalloyed steels are compared with the latest high temperature processed (HTP) steels where carbon, nitrogen and niobium contents combine to optimize fracture toughness in both the coarse grained heat affected zone (CGHAZ) and the inter-critically reheated CGHAZ.

Keynote G5 Y. Adachi: Kagoshima University (Japan)

Artificial intelligence materials science (AI-MS)

This study highlights fusion of advanced artificial intelligence (AI) with materials science. As an approach, attention is placed on “data science” in combination with modelling. In order to understand the relationship between “cause (microstructure)” and “result (property)”, conventional machine learning such as Bayesian inference, neural network or support vector machine etc. is applied to material science. Furthermore, deep learning based on convolutional neural network is incorporated into microstructural image recognition. I will also briefly mention about development of a fully automated serial section 3D microscope to extract materials genomes from the 3D image.

G5 N. Haghdadi, P. Cizek, P.D. Hodgson, H. Beladi: Deakin University

Microstructure evolution of duplex stainless steel during hot uniaxial compression at different strain rates

The evolution of microstructure has been studied for a duplex stainless steel (50-50 austenite/ferrite) subjected to uniaxial compression at 1000°C under strain rates of 0.1 and 10 s⁻¹. It has been found that strain rate fundamentally changed the restoration mechanism in ferrite. At the lower strain rate, ferrite underwent continuous dynamic recrystallization characterized by a gradual increase in misorientation angles between adjacent subgrains. By contrast, at the higher strain rate ferrite dynamically softened through the discontinuous dynamic recrystallization (DDRX) mechanism associated with nucleation and growth of new grains. The nucleation of DDRX grains preferentially occurred along the ferrite/austenite interfaces. Despite the significant difference in ferrite microstructure evolution, austenite displayed rather similar microstructure characteristics for both the strain rates. In both cases, the bulk of austenite dynamically softened through dynamic recovery accompanied at high strains by a small fraction of new DDRX grains. The main feature of the austenite phase was the frequent formation of deformation bands separated by transition regions and largely filled with microbands (MBs). A detailed analysis revealed that, independent of the orientation of austenite grains, MB boundaries were typically aligned with high Schmid factor {111} slip planes.

G5 C. Ledermüller, S. Primig: The University of New South Wales

Microstructural engineering of modern high strength low alloy steels

High strength low alloy steels are widely used because of their excellent cost-performance ratio achieved by a clever alloying concept and thermo-mechanical processing. Compared to mild steels, these steels have a similar weldability but improved mechanical properties such as an increased yield strength due to grain refinement and precipitation hardening. This is achieved through the addition

of micro-alloying elements such as Ti, Nb and V. These steels find their application in various technologically important fields such as construction and automotive industries, e.g. in high rise buildings, pipe lines and heavy duty vehicles.

Nowadays the steadily growing population requires modern steel grades with superior strength and toughness for example in lightweight design of cars to reduce CO₂ emissions. Current approaches in the field of high strength low alloy steels are in the development of advanced processing routes and novel alloying concepts. Advanced thermo-mechanical processing allows to produce steels with grain sizes in the submicron regime enabling superior strength and toughness simultaneously. Modern high strength low alloy steel grades include additional alloying elements such as Cr, Mo and Cu to increase strength and impede precipitate coarsening.

The aim of this research is to enable microstructural engineering of modern high strength low alloy steels. Ultrafine grain sizes will be achieved by warm deformation of a martensitic starting microstructure in the ferrite region. These ultrafine grains will be decorated by fine scale precipitates, atomic clustering and grain boundary segregation during a subsequent direct aging step.

Invited G6 R. Dippenaar, S-C. Moon: University of Wollongong

High Speed Continuous Casting

Interesting new developments in steel processing technology centres on a move towards continuous rolling. Arvedi introduced the Arvedi Endless Strip Production process (ESP), while POSCO developed the CEM-process, in which a thin-slab caster is directly linked to a series of hot-rolling stands in order to achieve endless rolling without cutting the slab. By capitalizing on the thermo-mechanical advantages and metallurgical features of this process, ultra-thin gauge strip of High Strength Steel (HSS) and Advanced High Strength Steel (AHSS) can be easily rolled, thereby creating new markets.

In order to obtain the required mechanical properties in these steel grades it is necessary to design the composition close to the peritectic composition range. Steel of this composition is notoriously difficult to cast and are subject to surface quality problems. These problems are associated with the stress generation when the delta-ferrite phase transform to the gamma-austenite phase during cooling causing uneven solidification through shell bucking when the solidifying shell is extremely thin. These quality problems are exacerbated at high casting speeds because an significant increase in the heat flux.

In the present project, an attempt was made to obtain fundamental understanding of the rate and mechanism of the delta-ferrite to gamma-austenite phase transformation in commercially important advanced steel grades. In addition, techniques were developed to predict uneven solidification and to assess crack susceptibility by utilizing low-cost laboratory experiments.

G6 D. Akama, T. Tsuchiyama, S. Takaki: Kyushu University (Japan)

The effect of dislocation characteristics on yielding behavior in ultra-low carbon Fe-Ni martensite

It is generally known that the as-quenched martensite has low elastic limit despite of its high tensile strength and the contribution of mobile dislocations, which have introduced during martensitic transformation, is believed to be one of reasons for the low elastic limit. In order to clarify the contribution of mobile dislocations, it is important to understand the characteristics of the dislocations which have been introduced by martensitic transformation and the change of dislocation characteristics should be examined for deformed martensite quantitatively. Recently, Ungár proposed modified Williamson-Hall and Warren-Averbach (MWH/WA) method, which can evaluate not only dislocation density but also distribution of dislocations. In this study, we

investigated the characteristics of dislocation and its effect on the yielding behavior in ultra-low carbon martensitic steel. Fe-18%Ni-0.002%C alloy was solution-treated, followed by water quenching. And then the specimen was cold-rolled up to 40% thickness reduction. The value of dislocation density in as-quenched martensite was approximately $2 \times 10^{15} \text{ m}^{-2}$, and not changed by cold rolling. It should be noted that the dislocation distribution in as-quenched state was random, and changed to cell structure by 5% cold rolling. Focus on the yielding behavior, the elastic limit in as-quenched martensite was lower than that in 5% cold-rolled martensite. As a result, it is indicated that the dislocations in as-quenched martensite are easily moved at a low stress, that is, the mobile dislocations are randomly distributed dislocations introduced by martensitic transformation. Besides, tangling such dislocations by deformation causes increase in elastic limit.

**G6 I. Bikmukhametov, J. Wang, H. Beladi, P. Hodgson; I. Timokhina: Deakin University
Effect of strain on the precipitation kinetics in the Ti-Mo-steel advanced high strength steels**

A laboratory steel with composition of Fe-0.07C-1.34Mn-0.22Si-0.26Mo-0.08Ti (wt.%) was subjected to the thermomechanical processing with different strain level of 0, 0.3, 0.6 and 1 at the temperature of 890C followed by isothermal hold at 650C for 3600 s. The microstructure was studied by optical microscopy (OM), transmission electron microscopy (TEM) and atom probe tomography (APT). It has been found that an increase in the strain level leads to the formation of strain-induced precipitates along the sub-grain boundary in austenite. Moreover, an increase in strain led to the formation of two types of the precipitates in ferrite: (i) interphase precipitates formed along austenite/ferrite interface lines and (ii) randomly redistributed precipitates. It has been observed that the size of the particles and distance between the precipitates do not change with increasing the strain, while the distance between the precipitate rows and number density vary.

**G6 J. Wang, I. Timokhina, I. Bikmukhametov, P.D Hodgson: Deakin University
Precipitation on grain boundaries of Ti-Mo alloyed advanced high strength steels**

Nanoclusters and precipitates can effectively increase the strength and ductility of advanced high-strength steels (AHSSs). Charactering these clusters and precipitates become critical for understanding their precipitation and strengthening mechanisms. Transmission electron microscopy (TEM) can provide detailed structural information at atomic scale, but it is not effective for quantitative analysis of local chemical composition for nanoclusters and precipitates that are embedded in matrix. Atom probe tomography (APT) provides the capacity to map individual atoms of all elements in a three-dimensional structure with high spatial resolution. However, APT reconstruction may be affected by artefacts, such as local magnification effects. For a comprehensive study, correlative TEM and APT analysis is necessary for investigating nanoclusters and precipitates in AHSS steels. In this work, APT tips were prepared by site-specific lift-out method using focused ion beam (FIB) in a dual beam scanning electron microscopy. APT and TEM techniques were employed to characterize nanoclusters and precipitates in both grain interior and grain boundary in Ti-Mo alloyed steels produced by thermal-mechanical processing. The results show that nanoclusters of 1-2 nm in diameter coexist with precipitates of 5-10 nm in diameter. Large precipitates form on grain boundaries, while small nanoclusters disperse over the grain interior. The relationship between particle size and chemical composition were also investigated.

Symposium H: Corrosion, degradation & wear of materials

Keynote H1 I.S. Cole, F. Chen, C. Chu, M. Breedon, W. Ganther, E. Sapper: CSIRO, Boeing (USA)

Predicting material life: From Corrosion mapping to Computational Design

The paper will outline the computer based prediction of the life of corrodible materials at CSIRO. From 1991 till 2006 the group developed the multi-scale model (MSM) of corrosion using process models scaling from of 10⁻⁵m to 10⁶ m. MSM included, models of pollutant production, pollutant transport across the Australian continent, pollutant deposition, surfaces temperature, wetness and corrosion rate. The models were validated with long transept studies of corrosion across the continent. These models were extended to timber degradation and then to the degradation of coated aluminium on the exterior of aircraft.

From 2010 to 2016 the team has been extending this model by incorporating this model by incorporating electrochemical models under moisture films and models of oxide structure and molecular models defining the properties of inhibitors and linking these models together and with the previous MSM to predict the life of a structure as a function of the molecular characteristics of either inhibitors or oxide films. The new model structure scales from 10⁻¹⁰ m to 10⁶ m and can be used to design protective systems as well as predict there life . It is currently being used to predict the life and select viable inhibitors to protect structural aluminium on aircraft as a function of flight routes.

Invited H1 S. Lynch: Monash University

Overview of mechanisms and kinetics of environmentally assisted cracking

Failures due to SCC, HAC, and LME can be catastrophic and, hence, there have been a huge number of studies have been undertaken over the last 100 years or so in an attempt to understand the mechanisms and kinetics involved – with the aim of preventing failures and developing more-resistant materials. However, there are still many unresolved issues and controversies, which is somewhat surprising given the vast array of experimental and theoretical tools that are now available for studying the phenomena. One of the reasons for the lack of consensus is that, for SCC, there are so many possible material-environment interactions at crack tips, e.g. film rupture/re-passivation, localised dissolution, hydrogen generation, adsorption, and diffusion, vacancy generation and diffusion, and hydrogen/vacancy/dislocation interactions. Other reasons are that (i) there are no techniques for resolving atomic-scale crack-tip processes in bulk material, (ii) atomistic modelling techniques are not yet sufficiently developed to cope with all the complexities, (iii) complex commercial materials are often studied (owing to funding constraints) whereas more studies of single-phase single crystals and bi-crystals in environments of increasing complexity, to establish fundamental principles, should be carried out first, and (iv) some researchers either overlook or ignore evidence that doesn't agree with their views (and get away with it owing to inadequate refereeing of papers).

This presentation will review (often overlooked) critical observations (in simple systems in the first instance and then in more complex systems) and discuss the mechanisms of LME, HAC, and SCC that are likely to predominate for particular systems and fracture modes. The evidence suggests that an adsorption-induced dislocation-emission (AIDE)/nanovoid-coalescence mechanism accounts for embrittlement in many systems. Embrittling adsorbed species (which weaken substrate interatomic bonds at crack tips) include some metal atoms, hydrogen (on the crack-tip surface and at very-near-surface interstitial sites), and complex ions produced by de-alloying. Other viable mechanisms include (i) localised dissolution of anodic grain-boundary regions, and (ii) decohesion at grain boundaries owing to adsorbed or segregated hydrogen in conjunction with segregated impurities.

The often-cited hydrogen enhanced localised plasticity (HELP) mechanism, based on solute hydrogen facilitating dislocation activity in the plastic zone ahead of cracks, may make a small contribution in some cases but is relatively unimportant for most fracture modes.

H1 Y. Qiu, M. Gibson, H. Frasier, N. Birbilis: Monash University

Corrosion resistant light-weight High Entropy Alloy

High entropy alloys (HEAs) are a new class of alloy that was developed in the last decade. HEAs are defined as solid solution alloys that are composed of five or more principle elements in equimolar or near-equimolar ratios with concentration of each element in the range of 5 at.% to 35 at.%. The unique aspect of HEAs that has aroused interest in such systems, is that, instead of forming intermetallic phases, they seem to have the tendency to form solid solutions. Due to the simple microstructure of some HEAs, that is only FCC or BCC without the formation of intermetallics, HEAs can potentially exhibit excellent corrosion resistance. In addition, there is continuing high interest in developing light-weight alloys with high specific strength for energy saving such as transportation and energy. Therefore, designing simple solid solution light-weight HEAs (HEAs) with high specific strength is one of the main research aims. A novel light-weight (4.92 g cm^{-3}) AlTiVCr HEA system consisting of only four elements is presented. This alloy has a single-phase microstructure (B2 phase), exhibits extremely high hardness (498 HV), and excellent corrosion resistance in 0.6M NaCl electrolyte at 25°C, especially the excellent pitting corrosion resistance. The Al_xTi_yVCr system is also studied, these alloys also demonstrates a single-phase microstructure and excellent corrosion resistance in 0.6M NaCl electrolyte at 25°C.

H1 R. Liu, N. Birbilis: Monash University

On the development of corrosion resistant Mg alloys via cathodic poisoning

In recent decades, magnesium (Mg) alloys are increasingly being sought for use as structural materials to meet increasing light-weighting demands, because of their properties including high specific strength and ease of cast-ability. However poor corrosion resistance has greatly restricted the wider application of Mg alloys. Unlike other engineering alloys, such as aluminium (Al) alloys and many steels, Mg alloys do not passivate by the formation of protective surface films/oxides, and undergo high rates of corrosion in aqueous environments. As such, solving the corrosion issues is a high priority to ensure widespread applications of Mg alloys.

The kinetics of corrosion propagation and the corrosion morphology of Mg have been shown to be influenced by so-called cathodic activation. Cathodic activation implies that the rate of the cathodic partial reaction is enhanced as a result of anodic dissolution. This phenomenon was recently demonstrated to be moderated by the use of alloyed arsenic (As) as a cathodic poison, which retarded both the cathodic kinetic and its activation, leading to significantly improved corrosion resistance. The pursuit of alternatives to toxic As is important as a means to imparting a technologically safe and effective corrosion control method for Mg (and its alloys). This study was designed to develop more corrosion resistant Mg alloys by micro-alloying (alternate to As) with select elements with the prospect of serving as cathodic poisons and hence, providing an effective and safe corrosion prevention method of Mg. In the present work, Mg binary alloys with micro alloying additions of antimony (Sb), bismuth (Bi), germanium (Ge), tin (Sn) and lead (Pb) were investigated. Based on electrochemical and corrosion analysis presented herein, it has been observed that the selected elements can effectively suppress the cathodic activation and improve corrosion resistance of Mg alloys significantly. Cathodic activation of Mg following cyclic polarisation was also hindered by alloying with selected elements, which provides beneficial implications for future Mg alloys.

H1 M. Moriarty, T. Murray, C. Hutchinson: Monash University

The effect of phase fraction, size and connectivity on the dezincification resistance of duplex brasses

Duplex Brass (Cu-Zn) alloys are used extensively in the large-scale production of plumbing fittings, valves, and water control products. The ease with which these alloys are processed and their in-service characteristics, namely good mechanical strength and excellent corrosion resistance, are major advantages compared with other alloy families like Steel and Aluminium. One of the greatest issues encountered in service, however, is the gradual de-alloying process known as dezincification, which continues to be one of the greatest contributors to failures in the field. During this process Zinc is selectively leached out of the Brass leaving behind a weak porous copper layer, and Duplex Brasses are particularly susceptible to this attack because the β' phase contained within the alloy is preferentially attacked. The specific mechanisms by which this process proceeds is still not well defined and with the continuing evolution of Lead-free legislation around the world (United States 2014, Germany 4MS 2015), a vast array of new Duplex Brass alloys are becoming available to the market. This has directly resulted in dezincification resistance becoming an increasingly important topic of discussion. This research seeks to advance the knowledge around the preferential attack of the β' phase in Duplex Brasses due to dezincification, and specifically addresses the size, volume %, and morphology of this phase due to various heat treatments and thermomechanical processing, as well as the inhibiting effect of several alloying additions found in common industrial alloys used for plumbing applications.

H1 D.S. Ward, Adelaide Polymer Consultancy

Investigation of premature cracking failure in amorphous thermoplastic components

This paper discusses two cases where the author has investigated premature failure and cracking of thermoplastic components. In each case, the presence of low molecular weight species in intimate contact with an amorphous thermoplastic (ABS) has initiated cracking and failure at lower stress levels than would otherwise be expected. The techniques used in these investigations include microscopy, thermal analysis (Thermo Gravimetric Analysis and Differential Scanning Calorimetry), FTIR (Fourier Transform Infra Red Spectroscopy) and accelerated testing techniques. This failure mechanism, often abbreviated to ESC or Environmental Stress Cracking, is not widely understood or considered when selecting materials and the chemicals in contact with them. A greater awareness and understanding could help to avoid interactions leading to premature component failure.

Invited H2 D. O. Northwood, A.S. Toloei, V. Stoilov: University of Windsor (Canada)

Relationships between surface roughness and corrosion resistance

The relationship between surface roughness and corrosion resistance in 0.5M H₂SO₄ has been investigated for nickel, an active-passive metal, and mild steel, which undergoes active corrosion. Unidirectional surface roughness was created by grinding on SiC papers with grit sizes from G60 to G1200. Four roughness parameters were measured, namely: Ra, the average surface roughness; Rq, the root-mean-squared roughness; Rz, the average of the ten greatest peak-to-valley separations; Rt, the peak-to-valley difference calculated over the entire array. Higher roughness values were obtained for mild steel than for nickel. This is attributed to hardness differences. An increase in roughness led to an increase in corrosion rate for nickel but a decrease in corrosion rate for mild steel. A model is put forward to explain the different behaviours.

H2 A. Osman, M.A. Javed, L.L. Blackall, J.S. Leontini, S.A. Wade: Swinburne University of Technology

Effect of copper ions on the bacterial attachment and subsequent corrosion of copper by sulphate reducing bacteria

Copper has a long history of use in antimicrobial applications, both as a substrate material as well as an addition to paints or electrochemical systems that release copper ions into the local environment such as a piping system. Despite its antimicrobial properties, copper piping systems are still regularly reported to suffer from microbiologically influenced corrosion (MIC). In the present study, the effect of copper ions on the initial attachment of sulphate reducing bacteria (SRB) and subsequent corrosion of copper was investigated. Substrates of pure (99.9%) copper were exposed to the SRB *Desulfovibrio desulfuricans* growing in Modified Baar's medium. A range of techniques including scanning electron microscopy, 3D optical profilometry, weight loss, and light microscopy were employed to examine the bacterial attachment, biofilm development and subsequent corrosion of the tested substrates. Test results including a comparison between initial attachment of SRB on copper substrates with and without the presence of copper ions in the test medium will be presented.

H2 H.C. Phan, S.A. Wade, L.L. Blackall: Swinburne University of Technology

Is marine sediment the source of microbes associated with accelerated low water corrosion?

Corrosion in marine environments can come in many forms, an example of which is microbiologically influenced corrosion (MIC). Metal surfaces in marine waters come into contact with specific microorganisms activating aspects of their metabolic properties. For example, microbial communities have been shown to be present on metals suffering from a special case of MIC called accelerated low water corrosion (ALWC) and these microbes have been deemed responsible for the corrosion. The source of the microbes implicated in ALWC and the sequence of events from pristine metal surface in marine waters through to corrosion needs to be addressed in order to propose mitigation strategies. Simulation of real-world ALWC can be challenging and corrosion rates observed in laboratory tests are often substantially lower than those reported in the field. As a first experimental approach into the sequence of events leading to MIC, a study of the source of ALWC microorganisms was conducted. Although marine waters are potential origins, more likely are sediment surfaces since ALWC initiating microbes must have the ability and propensity to attach to solid substrata. Marine sediments adjacent to a sheet metal wall with evidence of ALWC were collected and evaluated for sulfate reducing bacteria, acid producing bacteria and iron-related bacteria using commercial kits. Additionally, microbes were isolated to pure culture using low nutrient marine-based agar media and incubated in either aerobic or anaerobic atmospheres. The results from the evaluations will be presented and comparisons between the kit based methods and pure cultures reported.

H2 S. Cao, S. Lim, X. Wu: Monash University

Stress-corrosion cracking in Ti-8Al-1Mo-1V

Effects of microtexture and $Ti_3Al(\alpha_2)$ precipitates on stress-corrosion cracking (SCC) properties of Ti-8Al-1Mo-1V have been investigated using a constant displacement SCC test in 0.1 M aqueous NaCl solution. SEM, TEM SAD pattern, HRTEM, and EBSD were employed to characterize microstructure and microtexture. Results reveal that both microtexture and α_2 precipitates increase the SCC susceptibility. SCC susceptibility was well tackled by implementing the hot isostatic

pressing and post heat-treatment processes through eliminating both microtexture and α_2 precipitates.

There was a fracture mode transition from ductile dimples during pre-crack to flat facets during SCC. In order to understand the SCC mechanisms, T-EBSD and TEM analysis were applied on FIB lift-out lamellas cut from pre-cracking and SCC fractured regions to investigate the difference in the dislocation substructure underneath the fracture surface.

It has been found that:

- In pre-cracking region, basal $\langle a \rangle$ slip was the dominate slip system. While, basal $\langle a \rangle$ and $\langle c + a \rangle$ slip were observed underneath SCC facets.
- An increase in dislocation density was observed underneath SCC facets compared to that below the pre-crack dimples.
- A combined AIDE and HELP could be the SCC mechanism.

H2 M.A. Javed, W.C. Neil, G. McAdam, S.A. Wade: Swinburne University of Technology, Australia Defence Science and Technology Group

Evaluation of microbiologically influenced corrosion performance of different metal types exposed to sulphate reducing bacteria

It is well known that the rate and form of corrosion in a particular environment can vary substantially depending on the type of metal used. The type of metal can also influence the attachment of microbes and the level of any subsequent microbiologically influenced corrosion (MIC). In the present study a range of different engineering alloys including carbon steel, stainless steels, copper-nickel alloys, inconel and titanium were evaluated with respect to MIC susceptibility. Lab-based studies were conducted to investigate the early stages of bacterial attachment and subsequent longer-term corrosion. Polished coupons were exposed to the sulphate reducing bacteria (*Desulfovibrio desulfuricans*) in modified Baar's medium. A range of techniques including 3D optical profilometry, light microscopy, scanning electron microscopy and energy dispersive x-ray spectroscopy were used to study the bacterial attachment and subsequent corrosion. The results indicate that the rate and magnitude of initial attachment of the bacteria depended on the type of alloy substrate. Longer-term immersion studies showed accelerated corrosion of carbon steel and copper-nickel alloys in biotic condition compared to abiotic conditions. No evidence of corrosion was observed on any of the stainless steels, inconel and titanium alloys for any of the test conditions (i.e. either biotic or abiotic) used in this study.

H3 A.K Martin, A.S.M. Ang, W. Ganther, P. Cook, D. Fullston: CSIRO, Kwik-Coat Australia, Swinburne University of Technology

Corrosion of zinc alloys with small compositional differences exposed to salt spray testing corrode at different rates

Copper and titanium are added, in small quantities (both less than 1%), into zinc to produce the alloy which is rolled to make architectural zinc sheeting. The same commercially available zinc sheeting is used as 150×100mm corrosion coupons to measure atmospheric corrosion. It has long been assumed that all zinc sheeting with small compositional differences corrode at the same rate. This is reflected in ISO atmospheric exposure standards that specify that corrosion coupons prepared from zinc sheeting are required to be a minimum of 98.5% pure zinc, and without any other qualifications. Three zinc alloys, with varying amounts of copper and titanium, were exposed to a Neutral Salt Spray Test (ASTM B117-11) for 216 hours to determine if the presence of differing amounts of Copper and Titanium produced different corrosion rates. The preliminary results, presented here, suggest that zinc alloys with different amounts of copper and titanium do corrode differently. CR4 Steel corrosion coupons were used as reference samples. The impact that enables the selection of

corrosion coupons with different zinc alloys, and hence different corrosion rates, on Australian and international Standards is discussed.

H3 A. Somers, G. Deacon, A. Chong, B. Hinton, D. MacFarlane, M. Forsyth: Deakin University, Monash University

Recent developments in organic corrosion inhibitors for mild steel

Historically, chromates have been very effective inhibitors of corrosion for metals such as mild steel. We are now aware of the dangers associated with chromate use and researchers are seeking more benign alternatives. Our group and collaborators have for some time been investigating the use of rare earth carboxylates to replace chromates. In 2004 Blin et al. reported lanthanum 4-hydroxycinnamate, $\text{La}(4\text{-OHCinn})_3$, as a promising compound from a range of such compounds [1]. More recently we have been investigating alternative structures closely related to $\text{La}(4\text{-OHCinn})_3$. A totally organic complex, imidazolium 4-hydroxycinnamate (Imn 4-OHCinn) was investigated with the aim of developing a compound with the purpose of inhibiting both corrosion and microbial growth. This compound was found to inhibit mild steel corrosion across a wide pH range and was particularly effective at a pH of 2[2].

We have also been investigating a rare earth compound with an alternative carboxylate structure to the cinnamate; 4-(para-methylphenyl) 4-oxobutyric acid (PMPOB). This ligand differs by having a carbonyl group present, which may give an extra anchor point to a metal surface when forming a barrier coating [3]. A range of rare earth PMPOBs were investigated, with $\text{Y}(\text{PMPOB})_3$ resulting in the largest reduction in corrosion current density and the fewest pits.

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H3 Y. Peng, T. Hughes, G. Deacon, B. Hinton, M. Forsyth, A. Somers, J. Mardel: Deakin University, CSIRO, Monash University

Corrosion inhibition of mild steel by rare earth carboxylate compounds

Metal corrosion costs billions of dollars annually worldwide due to premature failure and maintenance of infrastructure. The use of environmentally benign corrosion inhibitors is an effective and economical method to mitigate corrosion. In recent years, rare earth carboxylate compounds have demonstrated effective corrosion inhibition for mild steel in aqueous chloride solutions, with lanthanum 4-hydroxy cinnamate ($\text{La}(4\text{OH-Cin})_3$) showing particular promise.

Here we are currently investigating a novel range of rare earth salts based on 4-(para-methylphenyl) 4-oxobutyric acid (PMPOB) as inhibitors for AS1020 mild steel in aqueous chloride solutions. Cerium, lanthanum, neodymium and yttrium salts were investigated by potentiodynamic polarization experiments, revealing that REM-PMPOB salts were effective as anodic inhibitors. Moreover, $\text{Y}(\text{PMPOB})_3$ showed the most pronounced inhibiting performance, with a significant reduction of the corrosion current density. Electrochemical impedance spectroscopy (EIS), as a semi-quantitative approach, was also employed to interpret the speciation and evolution of protection on the metal surface. The electrochemical equivalent circuit (EEC) was created from basic electronic components (resistor, capacitor, inductor, etc.) to explain specific changes involved at the

electrolyte/film/metal interfaces. Surface characterization methods such as SEM, EDS, FTIR and profilometry have been applied to immersed samples to gain a better understanding of corrosion mitigation mechanism and surface speciation.

H3 W. Xu, M. Ferry, N. Birbilis, G. Sha: Nanjing University of Science and Technology (China), UNSW, Monash University

A high-specific-strength and corrosion-resistant ductile Mg alloy

Ultra-lightweight alloys with high strength, ductility and corrosion resistance are desirable for applications in the automotive, aerospace, defence, biomedical, sporting and electronic goods sectors. Ductility and corrosion resistance are generally inversely correlated with strength, making it difficult to optimize all three simultaneously. Here we design an ultralow density (1.4 g cm^{-3}) Mg–Li-based alloy that is strong, ductile, and more corrosion resistant than Mg-based alloys reported so far. The alloy is Li-rich and a solute nanostructure within a body-centred cubic matrix is achieved by a series of extrusion, heat-treatment and rolling processes. Corrosion resistance from the environment is believed to occur by a uniform lithium carbonate film in which surface coverage is much greater than in traditional hexagonal close-packed Mg-based alloys, explaining the superior corrosion resistance of the alloy.

H3 M. U. Manzoor, A. Salman, T. Ahmad, M. Kamran, A. Farooq, H. Sajjad, H. Zafar, N. Ali: Department of Metallurgy & Materials Engineering, CEET, University of the Punjab (Pakistan)

Electrochemical characterization of PVDD coated AlTiN on stainless steel substrate for biomedical implant

Physical Vapour Deposition (PVD), LARC (lateral arc rotating cathodes) technology was used to deposit AlTiN coating on stainless steel samples. The corrosion resistance of the coating and the substrate was investigated using Electrochemical Impedance Spectroscopy (EIS). The commercially available and biocompatible, Ringer Lactate solution as an immersing medium was used at 25°C temperature over the period of days. The coating and substrate were characterized by Scanning Electron Microscopy (SEM) with Energy Dispersive x-ray Spectroscopy (EDX) and Surface profilometry. The SEM and EDX analysis revealed a dense and consistent coating with a coating thickness of $2.58 \mu\text{m} \pm 0.14 \mu\text{m}$ at cross section of substrate and the film. The surface profilometry showed better surface roughness after coating. The EIS tests indicated that corrosion resistance of the coated sample was better than the uncoated substrate and behaved like cathodically protected coating and showed more resistivity. The EIS results varied because of the hydration of the coating in the aqueous medium after the interval of 20 and 40 days. Overall the behavior of the coating showed more corrosion resistance than the uncoated samples.

Symposium I: Light metals design

I1 A. Lodh, I. Samajdar, C. Hutchinson: IIT-B (India), Monash University

The correlation between dislocation density, arrangement and residual stress evolution

Plastic deformation of metals occurs through the motion of dislocations and results in dislocation accumulation within the material. Dislocations exhibit a long range strain field and their accumulation within a metal results in the development of incompatibility stresses throughout the microstructure. These incompatibilities may be affected by both the total dislocation density as well as the arrangement of dislocations. In this work, an attempt is made to decouple the effects of total dislocation density and their arrangement on the residual stress development in two commercial aluminum alloys (AA1050 and AA3003). The dislocation arrangement and density are controlled

using both cold rolling followed by thermal recovery, and cyclic deformation experiments. Selected conditions corresponding to similar total dislocation densities but different dislocation arrangements are compared. X-ray diffraction is used to estimate the residual stress ("sin² ψ " method) and dislocation density. This study summarizes how these two features of a dislocation microstructure contribute to the overall residual stress development in solid solution Al alloys.

I1 C. Todaro, M. Qian, M. Easton, D. StJohn: University of Queensland, RMIT University
The effect of ultrasonic treatment on the formation and segregation of primary intermetallic compounds and primary silicon in an Al-19Si-4Fe foundry alloy

It is difficult to obtain microstructurally homogeneous castings of hypereutectic Al-Si based alloys by conventional foundry processes, because of the propensity to form macrosegregation defects during solidification. This study evaluates the effect of ultrasonic melt treatment (UST) on the microstructure formation and segregation of primary iron-containing intermetallic compounds and primary silicon in a slowly cooled Al-19Si-4Fe alloy (in wt pct). The major findings include: (1) Without UST massive macrosegregation occurs due to an increase of primary phase constituents near the mould wall and near the melt surface and their depletion near the central region of the ingot; (2) Applying UST in the temperature range of 973 to 903 K effectively eliminates macrosegregation, accompanying the uniform distribution of refined primary phase constituents along the cross section of the ingot; (3) The microstructure of the conventionally solidified alloy revealed the presence of β -Al₅FeSi coexisting with δ -Al₄FeSi₂ in contrast to the presence of only β -Al₅FeSi in the ultrasonically-treated solidified alloy, suggesting UST promoted the formation of β -Al₅FeSi; (4) The UST microstructural refinement of the precursor δ -Al₄FeSi₂ ensures the peritectic transformation of δ -Al₄FeSi₂ to β -Al₅FeSi is completed by dramatically reducing the size of the δ -Al₄FeSi₂ particles, allowing their complete dissolution into the β -Al₅FeSi envelope covering the δ -Al₄FeSi₂ particles; and (5) Microstructural modification is primarily observed below the cylindrical radiating face of the sonotrode. The potential mechanisms for these observations are discussed.

I1 Q. Zhang, X. Gao, L. Wang, C. Hutchinson: Monash University
Enhanced fatigue performance in underaged Al alloys

Aluminium alloys are widely used in moving structures due to their high specific strength, stiffness and environmental resistance. However, the fatigue behavior is also extremely important in these applications and is often the cause of component failure. In Steels, the fatigue ratio (σ_f /UTS) is ~0.5. For precipitate strengthened Al alloys it is closer to 0.3. It is now known that this comparatively poor fatigue response is due to an instability in the precipitate structure of Al even when cycling at room temperature. Under low cycle fatigue (LCF) conditions it has been recently shown that cyclic loading can be exploited to catalyze profuse dynamic precipitation in underaged Al alloys which can drastically strengthen the alloys. Under high cycle fatigue (HCF) conditions it will be shown that the fatigue lifetime of underaged alloys can exceed that of the peak aged state by more than an order of magnitude and the role of dynamic precipitation in this enhancement will be discussed. The results of both LCF and HCF tests on 2xxx and 7xxx series alloys are reported in this study. Small angle x-ray scattering (SAXS) and transmission electron microscopy (TEM) has been used to characterize the evolution of the precipitate state during cyclic loading. The conditions leading to fatigue crack nucleation have been studied by examining the evolution of surface topology and the fatigue crack growth behavior has been monitored with dedicated fatigue crack growth experiments.

I1 E. Farabi, P.D. Hodgson, H. Beladi: Deakin University

The role of thermomechanical processing on the martensitic transformation characteristics in pure titanium

In the current study, the effect of cold deformation on the characteristics of subsequent β -to- α martensitic phase transformation (i.e. texture and variant selection) was studied in a pure titanium alloy using plain strain compression testing in conjunction with electron backscatter diffraction technique. The deformation appeared to alter the transformation texture and variant selection mechanism; resulting in distinct misorientation angle distribution. At strain free condition, the misorientation angle distribution of martensite revealed four main peaks, which consistent with the intervariant boundaries expected from the ideal Burgers orientation relationship. The two highest peaks were characterized as $63.26^\circ/[(10)\bar{5}53]$ and $60^\circ/[112\bar{0}]$ misorientations. The deformation was progressively widened the misorientation angle peaks and reduced the fraction of the intervariant boundaries associated with Burgers orientation relationship.

I1 D. Qiu, M. Easton: RMIT

Duplex grain refinement of beta and alpha Titanium through inoculation

Grain refining titanium and its alloys during solidification can significantly reduce casting defects, enhance mechanical properties and improve formability in the following thermomechanical process. The potent grain refiner also plays a key role to convert columnar grains to equiaxed grains in additively manufactured Ti components. Unlike other light metals, such as Mg and Al, there is no commercial grain refiner for Ti available to date. This is mainly because very limited inoculants can survive in the molten titanium with very high chemical activity at the temperatures above 1670 degree Celsius. By addressing this great challenge, this paper will present our recent discovery of a new inoculant, which can effectively grain refine both beta and alpha Ti grains. The strategy of devising the potent inoculant rests on two criteria, peritectic reaction induced grain refinement and good crystallographic matching between inoculant and titanium. The potency of designed inoculant was experimentally validated in a 10 gram, arc melted button ingot. By adding optimum amount of the inoculant into pure Ti, equiaxed beta dendrite with the size around 150 μm can be obtained. In addition, fine and uniformly distributed equiaxed alpha grains with the grain size of 15 μm were found within each prior beta dendrite. It is proposed that the remaining inoculant from peritectic reaction promotes the heterogeneous nucleation of alpha Ti grains as well. This mechanism is supported by reproducible orientation relationship between the inoculant and the surrounding alpha Ti grains, which is also consistent with the prediction from edge-to-edge matching model.

I1 P.Sh. Naseri, D.R.G. Mitchell, M. Ahmed, E.V. Pereloma: University of Wollongong

The microstructure evolution in a near-beta Ti-10V-3Fe-3Al alloy during compression deformation

A near- β Titanium alloy with a nominal composition of Ti-10V-3Fe-3Al (wt.%) was produced using a blended elemental powder metallurgy (BEPM) technique. After solution treatment in the β phase field, it was heat-treated in the $\alpha+\beta$ phase stability region (675°C) to form a bi-modal microstructure. A series of interrupted compression tests (interrupted at 0.1, 0.2 and 0.4 strain) was conducted to study the microstructure evolution. The microstructures were characterised using X-ray diffraction, optical and scanning electron microscopy.

Stress-strain curves showed a stress plateau due to the formation of stress-induced twins and martensite. Triggering stress associated with this plateau was calculated to be 117 MPa.

Results showed that stress-induced products (SIPs) appear as either thick laths or thin lines in the microstructure. They nucleate at grain boundaries or at intergranular α . Microstructural studies

revealed that SIP formation is dependent upon both grain-size and grain-orientation, as only a subset of grains display SIPs, especially at lower strains. At higher strains, the density of SIPs and the number of grains containing them increase simultaneously. Finally, further straining resulted in the emergence of intersecting thin lines and in the formation of secondary deformation products within the initial thick laths.

I1 A. Dehghan-Manshadi, M. Qian, M. Dargusch, D. StJohn: University of Queensland, RMIT University

Metal Injection moulding of non-spherical hydride-dehydride Ti powder

Metal injection moulding, MIM, which is an adaptation of powder metallurgy into the plastic injection moulding technique, is an advanced and low cost method for manufacturing many metallic and non-metallic materials including Ti alloys. This process combines the most useful characteristics of powder metallurgy (low cost, simplicity, flexibility of composition selection and inexpensive raw materials) and plastic injection moulding (ability to manufacture complex parts and rapid production). Such combinations enable MIM to be used for economic manufacturing of engineering parts with high degree of geometrical complexity and high production volume.

The aim of the current work is to study the manufacturing of Ti parts by the MIM process using inexpensive non-spherical hydride-dehydride (HDH) Ti powders. Through a series of laboratory tests, the essential parameters for successful metal injection moulding of titanium parts using HDH powders were studied. The results indicate that manufacturing of quality Ti parts is possible through accurate control of MIM parameters including slow heating rate during de-binding and sintering, high vacuum and correct sintering time and temperature.

I1 H. Watari, Tokyo Denki University (Japan)

Development of hot forging process high aluminum content magnesium alloys manufactured by horizontal twin-roll casting

In order to clarify the possibility of practical use of high tensile magnesium alloys manufactured by a rapid solidification process, hot forging behaviors of relatively high aluminum content magnesium alloy sheets that were fabricated by a horizontal twin roll casting process was investigated. Although the range of aluminum contents of magnesium alloys which are commercially available is 3~9 %, high tensile strength magnesium alloys containing 10 to 12% aluminum, such as AZ101, AZ111, and AZ121 have been manufactured for the hot forging test by the use of press machine with a novel servo die cushion system.

Firstly, relationship between casting parameters and microstructure, mechanical properties of cast sheet in twin roll casting were investigated. Secondary, manufacturing parameters, such as types of lubricant, forging temperature and magnitudes of back pressure during hot forging were investigated. It has been found that twin roll casting of thick magnesium alloy sheet was possible at roll speeds of 2.5~10 m/min. Obtained thickness of cast sheets were 5~10 milli meters. It has been clarified that the diameter of the microstructure of the high tensile strength magnesium alloy that contains relatively high aluminum content, was about 30 micro meters due to microscopic observation. Finally, it has also been confirmed that hot forging of high tensile magnesium alloys that contain relatively high aluminum content is possible without cracks at 300-350 centigrade. By applying appropriate back pressure during hot forging was effective for successfully forging of cast magnesium alloys.

I2 Z. Zeng, M. Bian, Y. Zhu, S. Xu, C.H.J. Davies, N. Birbilis, J-F. Nie: Monash University; Baosteel Company (China)

Texture evolution in magnesium alloys during cold rolling and annealing

Formability and mechanical properties of Mg sheet alloys are closely related to texture, and therefore an improved understanding of texture and its evolution is important. As for the texture evolution during sheet fabrication, there are two areas that have not been systematically studied. Firstly, the texture development during cold rolling has not been in-situ monitored, thus the details of how the basal texture is developed is not fully understood. Secondly, there is a lack of in-situ observation of texture evolution in the early stages of recrystallisation, e.g. within 100s annealing at 350°C. The lack of these information makes it difficult to reveal the origin of basal texture weakening caused by some specific alloying additions. In this study, we use a quasi-in-situ EBSD method to monitor in real-time the evolutions of texture and microstructure during cold rolling and annealing in the range 290-350°C. The influence of alloy composition and thermomechanical processing conditions on texture and microstructure development during cold rolling and annealing will be discussed in this presentation.

I2 S.C.V. Lim, K.V. Yang, J.F. Sun, C.H.J. Davies, X. Wu: Monash University; Baosteel Company (China)

Microstructure evolution characterization of hot deformed and post-annealed Ti alloy using double cone samples

Compression tests on double cone samples were conducted to characterize the effects of strain and deformation speed on globularization of the lamellar microstructure and crystallographic texture development. Hot deformation tests were carried out at temperatures of 850°C to 950°C with constant cross head speeds of 0.125, 1.25 and 12.5mm/s while post heat treatment were conducted at 900°C for 1 hour for the deformed samples. Globularization is enhanced as strain increases and by post-deformation heat treatment. The morphology and crystallographic texture of the lamellae varies with strain: the lamellae gradually orientate perpendicular to the deformation direction, as do the basal planes. Post-deformation annealing has little effect on the texture for both the non-broken lamellar and globularized grains but it does increase the texture intensity of both structures and sharpen the basal transverse texture for the globularized grains. A simple processing design chart was also established with respect to percentage of reduction for hot compression.

I2 H.Q. Ang, T. Abbott; D. Qiu, C. Gu, S. Zhu, M. Easton: Monash University, RMIT University, Magontec

The strain rate sensitivity of HPDC Mg-Al alloy

There is growing interest in magnesium alloys from the automotive industry for light weighting and emissions reduction. However, relative to aluminium alloys, the applications of magnesium alloys in automotive vehicles remain limited, mainly due to their inadequate mechanical properties. To improve the mechanical properties of existing magnesium alloys and to develop new alloys, an improved understanding of mechanical behaviour and deformation mechanisms of magnesium alloys is required.

In this work, the tensile properties of high pressure die cast Mg-4Al-4RE (AE44) and Mg-6Al-0.3Mn (AM60) under strain rates ranging from 10^{-6} to 10^{-1} s^{-1} were investigated. The flow curve of AE44 was consistently shifting higher with increasing strain rate, giving rise to higher yield strength and ultimate tensile strength. In contrast, the shift in flow curve of AM60 was a lot more modest, especially at higher strain rates above 10^{-5} s^{-1} . The strain rate sensitivity, which tended to decrease with increasing strain rate, was significantly higher in AE44 than in AM60. The observed difference

in strain rate sensitivity between AE44 and AM60 is considered to be related to the level of Al solute in the Mg matrix.

I2 N.J. Edwards, W. Song, G. Lu, S.J. Cimpoeeru, D. Ruan: Swinburne University, Defence Science and Technology Group

Dynamic testing of 2024-T351 aluminium using a Hat-shaped specimen

Adiabatic shear bands are a phenomenon that can result from ballistic impact in susceptible materials. They may result in plugging failure of the targeted material due to the sudden drop in flow stress of the material once they begin to form. This work presents an ongoing study observing the flow localization and formation of adiabatic shear bands at different strains and strain rates. Initial compressive tests at quasi-static are conducted on an MTS universal testing machine, whilst a split Hopkinson pressure bar is used for higher strain rates. The dynamic material properties found are compared to previously established data to confirm validity of the test method and data. Microstructural examination of tested specimens is presented using optical and scanning electron microscopy. At higher strain rates the material shears adiabatically allowing further study of adiabatic shear bands resulting from ballistic impact. Hardness testing results are presented for different regions of the material including within an adiabatic shear band showing a rise of hardness within the adiabatic shear band.

I2 H. Izui, S. Kamegawa, K. Toen, Y. Komiya, Nihon University (Japan)

Wear behavior of TiB/Ti and TiC/Ti composites with different Ti powders

Wear behavior of TiB/Ti and TiC/Ti composites with different Ti powders were investigated. Hydride-dehydride (HDH) and gas-atomized (GA) pure Ti powders with a particle size of <20 μm or <45 μm were used as a matrix, and TiB₂ or TiC powders were used as a reinforcement. The composites were sintered by the spark plasma sintering (SPS) process. The composites using the HDH powder with a particle size of <20 μm showed higher ultimate tensile strengths and Vickers microhardnesses than the other composites. The TiC-reinforced Ti with the GA powder having a particle size of <45 μm exhibited good wear resistance. The results show that the addition of TiC improved the wear resistance of the composites.

Symposium J: Thermal-mechanical and processing

Keynote J1 X. Wu, K. Yang, N. Perevoshchikova, T. Jarvis, P Rometsch, D. Tomus, Monash University

Selective Laser Melting (SLM) of aerospace materials, its quality control and certification

Selective Laser Melting (SLM), also called 3D printing, is being considered for aerospace and biomedical applications where quality, including consistency and repeatability are essential. This presentation describes the recent activities associated with Monash University in terms of research and development, powder production and the status in achieving international aerospace certification for SLM'd parts. Different materials, including Al, Ti and Ni alloys have different issues in the SLM process, due to their metallurgical and crystallographic differences. Whilst elimination of cracking and retaining high temperature properties are critical for SLM Ni alloys, optimisation of post heat treatment becomes more significant for Al alloys as defined by the nature of the sensitive response of precipitates of Al alloys during heat treatment. Achieving aerospace certification requires controlling the quality from powder to SLM'd products as is demonstrated here using Ti64 alloy. To achieve equivalence to current international aerospace standards for wrought products, 9 batches of powder atomised from 3 lots of Ti bars, each lot weighing >3 tonnes, were used to make SLM

samples using a laser powder bed system (EoS-M280). More than 3000 SLM samples have been tested. It has been found that using appropriate quality of barstock followed by rigorous control of the atomisation and SLM processes, outstanding mechanical properties coupled with consistency and repeatability have been obtained in SLM'd Ti64 parts and this has led to the qualification of Falcontech Ti64 powder and SLM'd parts for civil aerospace applications. Some NDE results also will be reported including the influence of defect shape and location on the minimum detectable defect size during x-ray and synchrotron examination.

J1 A. Zafari, K. Xia: University of Melbourne

Uniform distribution of fine β grains in a beta titanium alloy achieved by multiple forging-annealing cycles

A Ti-5553 β alloy with an initial β grain size of ~ 1 mm was subjected to multi-axial forging (150 °C) and multiple forging (150 °C)-annealing (900 °C) cycles. Formation of shear bands and accumulation of strain in the bands from forging contributed to a heterogeneous microstructure and catastrophic fracture. In contrast, performing an annealing step after each forging led to the formation of fine grains (~ 50 μm) in the shear bands thanks to recrystallisation. The strengthening effects of these fine grains prevented the localisation of strain in the shear bands, enabling the accommodation of further strain in the coarse grains outside the bands. The experimental results were consistent with simulations by finite element analysis (FEA). Repeated forging-annealing led to a uniform structure with β grains of ~ 50 μm

J1 J. Cornu, T. Dorin, N. Stanford, P. Hodgson: Deakin University, Monash University

Phase transformations in nano-bainitic steels produced by direct-strip-casting

Direct strip casting (DSC) is an innovative near-net-shape process for the formation of thin steel sheets which drastically simplifies the conventional process, allowing significant energy savings. In the current era of producing green technologies with reduced environmental footprint, DSC is the ideal candidate for steel sheet production and has thus been taken to the industrial stage in the past decades. The materials produced by DSC undergo extreme cooling rates, resulting in non-equilibrium conditions of solidifications and further phase transformations. The current challenge is to be able to predict the final microstructure under such processing conditions as a function of the steel composition.

Nano-bainitic steels have been increasingly studied in the past decades as they offer unprecedented mechanical properties but their upscaling to industrial applications has not been possible due to the high processing costs of these alloys using the conventional steel processing method. The aim of the current project is to explore the use of DSC to process nano-bainitic steels by understanding the phase transformations and the effect of minor alloying additions on the microstructure and resulting mechanical properties of DSC nano-bainitic steels. Five compositions were carefully selected to study the influence of chemistry (carbon, silicon and chromium content) on the microstructure development during DSC. The microstructure and segregation behaviour are investigated using SEM, TEM, XRD and EDS, and kinetics data are obtained by means of dilatometry experiments. The impact of each element on microstructural development will be presented.

J1 A. Prasad, L. Yuan, P. Lee, M. Easton, D. StJohn: University of Queensland, General Electric, University of Manchester (UK), RMIT

Inoculant undercooling induced nucleation and growth during equiaxed solidification: Numerical studies

Predicting grain size in castings has remained a major challenge. The Interdependence Model provides a simple analytical model to predict the grain size during equiaxed solidification of a casting. Simultaneously, the mMatIC model has been used to confirm some of the predictions from the Interdependence Model (Acta2013). The mMatIC model is a numerical solidification model which simulates the growth of individual or multiple equiaxed grains which uses the alloy liquidus as the grain nucleation temperature. This model has now been extended to assign values of nucleation undercooling to the location of an inoculant particle. This work describes preliminary results obtained from this updated model. In particular, inoculants with user-defined values of undercooling were placed at specific points in front of an already growing grain (placed in the centre of the computational domain). The success/failure of user-placed inoculants to trigger a nucleation event was studied and the model outputs are presented and explained. The results further validate the Interdependence Model predictions.

J1 Y. Bai, X. Zhang, K. Xia: The University of Melbourne, CSIRO

Hardwood composites produced by equal channel angular pressing

Previous research has shown the advantage of equal channel angular pressing (ECAP) in producing bulk composites from hardwood (HW) flour with wheat gluten as additive. In the present study, the composites were produced by ECAP of hardwood flour with addition of polyethylenimine (PEI) to improve processing, binding and mechanical properties. Fully densified bulk material was obtained with HW particles well bonded to each other. With a constant back pressure of 70 MPa, the effects of processing speed, temperature and friction condition were investigated. It was found that higher friction between the channel and particles led to a significant improvement in strength, with higher processing speed and temperature also contributing. The highest flexural strength of ~50 MPa was achieved when the particles were extruded at 200°C and 50 mm/min, and with high friction. The outcome has further demonstrated the potential of ECAP for producing wood flour based composites.

J1 M. Zhang, Y. Ali, Q. Huang: The University of Queensland

Revisiting the effect of solidification cooling rate on microstructure of cast magnesium alloys

Microstructure of as-cast metals is governed by solidification cooling rate, chemical composition (solute additions), effective heterogeneous nucleation sites and associated external forces. It is generally considered that higher cooling rate results in finer and equiaxed grains due to the large undercooling. Considerable research in the last a few decades also indicates that additions of solutes and/or proper nucleants can also promote the formation of fine and equiaxed grains. However, the combined effects of two or more these factors are more complicated. Significant grain coarsening and increase fraction of columnar structure were observed in some Mg binary alloys at high cooling rate in our recent work. In these alloys, fine and equiaxed grains were more easily obtained at slow cooling. In addition, it was also found that adding some solutes or particles into the binary Mg alloys may lead to chemical reaction before the solidification starts. The as-cast microstructure of Mg alloys is closely related to these reaction products. The possible mechanisms of grain coarsening and refining will be discussed in the presentation.

Symposium K: Nanostructured and nanoscaled materials

Invited K1 M. Bhaskaran, P. Gutruf, S. Sriram: RMIT University

Transparent oxide thin film stretchable devices

Functional oxides are known for their versatility and high performance but are notorious for their brittleness and high temperature synthesis. With the demand for stretchable electronics, the challenge remains in the integration of these functional oxides with polymeric substrates. Our research focus has been to realise stretchable electronic devices with highly functional characteristics while being optically transparent.

Our research has addressed this key bottleneck with a ubiquitous transfer process which allows us to combine high temperature processed oxide with biocompatible polymeric base. This process utilised the naturally weak adhesion of platinum to silicon, and this allows us to create electronics on a rigid substrate such as silicon and then peel off the layers to transfer onto a flexible substrate. This process also results in a unique 'micro-tectonic' surface, creating opportunities to explore new stretchable device applications. This process has been successfully demonstrated using transparent indium tin oxide, zinc oxide thin films, and titanium dioxide thin films with stretchability of up to 15% which is exceptionally high for a brittle oxide. The transfer technique can also be combined with micro and nanofabrication techniques to create versatile applications. With this process, we have also demonstrated room temperature gas and UV sensors, mechanically tunable diffraction gratings as well as optical metasurfaces.

Invited K1 P. Sharma: UNSW

Ferroelectric domain walls as novel nanoelectronic elements

Interfaces and boundaries between competing phases (ferroic domain walls, phase boundaries), and materials (for e.g. LaAlO_3 and SrTiO_3) have gathered immense interest as potential reconfigurable nanoelectronic elements. IBM is currently developing 'race-track memories' in which the high-density digital information is encoded in the form of magnetic domain walls, which can be injected and moved controllably along 3 dimensional (3D) ferromagnetic nanowires. Only recently, analogous research in ferroelectric materials has seen tremendous interest, because of much smaller domain wall sizes and the potential of electric field induced wall movement that could enable ultralow-power electronics.

Ferroelectrics are an important class of functional materials that possess spontaneous polarization and exhibit two or more thermodynamically stable equilibrium states. Zero-field cooled ferroelectrics form regions with the same orientation of the polarization called domains, which are separated by sharp (few nanometer wide) interfaces called domain walls (DWs). Ferroelectric DWs thus represent abrupt 2D interfaces, which are about two orders of magnitude sharper than the corresponding magnetic DWs. The electronic and structural environment at these ferroelectric DWs is very distinct from the domains that they delineate, resulting in exciting new functionalities not present elsewhere in the material, which among others include electrical conduction and magnetism. In this talk, I will present results which demonstrate the concept of a resistive switch based on nanoscale ferroelectric domain walls.

K1 J. Wang, N. Stanford: Deakin University, Monash University

Mechanical twinning and slipping in twinning-induced plasticity steel by micropillar compression

Twinning-induced plasticity (TWIP) steels have an excellent combination of ultimate tensile strength (>1 GPa) and elongation to fracture (>50%). At room temperature, the deformation mechanism of TWIP steel is composed of a complex combination of mechanical twinning and

dislocation slip. However, it is still unclear how twinning and slipping contribute to the high strength and work hardening rate. In this work, mechanical twin and slip behaviour of a TWIP steel were investigated by compression of micropillars in twin-preferred orientations, i.e. [1 1 1] and [4 4 33], and slip-preferred orientation, i.e. [1 0 0] and [20 2 9]. This method removes some of the complexity of studying a system where twinning and slip can occur concurrently in polycrystals during plastic deformation. The critical resolved shear stresses for dislocation slip or mechanical twin have been determined according to the stress-strain curves extracted from micropillar compression. The activation of mechanical twin and slip in micropillars were characterized by scanning electron microscopy (SEM), transmission electron microscopy (TEM) and transmission Kikuchi diffraction (TKD). The results suggest that mechanical twin requires a much higher resolved shear stress than dislocation slip in TWIP steels. Mechanical twin can accommodate a significant amount of plastic deformation, but it has little contribution on work hardening. Multiple slip can provide the most promising way of enhancing work-hardening rate. The understanding of twin and slip behaviours in single crystal from this study is valuable for designing bulk TWIP steels with enhanced mechanical properties.

K1 E.J. Oghenevweta, D. Wexler, A. Calka: University of Wollongong

Mechanisms of reaction between titanium and graphite during mechanically induced self-propagating reaction synthesis of titanium carbide

The mechanism of mechanically induced self-propagating reactions (MSRs) during sudden ignition of ball milled elemental powders is not well understood. We employed High Resolution Electron Microscopy, and Raman and X-ray Photoelectron Spectroscopies to determine the reaction sequence during milling of titanium (Ti) and graphite (C) powders in stoichiometric Ti₅₀C₅₀ proportions and interpret results in terms of nucleation and growth theory. Prior to the exothermic ignition, off-stoichiometric Ti_(1+x)C_(1-x) nuclei, approximately 2-4 nm in size, form by reaction at the interface between the severely deformed Ti particles and graphite milling debris. After ignition, both rapid growth of existing nuclei, and nucleation and growth of additional off-stoichiometric Ti_(1+x)C_(1-x) occurs. Local product morphologies after the ignition vary, depending local heat flow and restrictions on the rate of diffusion of carbon into the TiC as it grows. After extended milling increased 1:1 stoichiometry in the TiC product is observed.

Invited K2 S. Sriram, T. Ahmed, J. Kim, H. Nili, S. Walia, M. Bhaskaran: RMIT University

Transparent resistive switching electronic memories based on amorphous SrTiO_(3-x)

Transparent electronics is of increasing interest for the next generation of electronic circuitry that can enable devices capable of displaying information on surfaces such as windshields of cars. For a fully transparent integrated circuit, high transparency is also desirable in its important circuit element: the memory unit. For optical transparency without compromising memory density, inherent transparency is needed in a single memory unit. That requires transparency in both the active switching material and the electrodes. As the mechanisms governing many resistive switching systems are not yet fully understood and well-established, they are still part of ongoing research. As a result, assessment of any potential application in transparent electronics depends on the actual demonstration of a working system.

Here, we report transparent resistive switching memories (t-ReRAMs) that feature high transparency (>85% in the visible range). Amorphous SrTiO_(3-x) (a-STO) is chosen as the switching material owing to its excellent bipolar resistive switching performance. The t-ReRAM are fabricated in a bilayer a-STO stack, with varying concentrations of oxygen vacancies, sandwiched between indium tin oxide (ITO) electrodes. The bipolar resistive switching characteristics of our t-ReRAM showed

switching ratio over 2 orders of magnitude and retention over 105 s, under the ambient conditions. The devices also showed optical modulation in their high resistive state using UV and visible light excitations. The materials and electrical characterisation are used to explain the bipolar resistive switching mechanism in our bilayer t-ReRAM.

K2 Z. Liu, P. Koshy, J. Hart, C.C. Sorrell: UNSW

Preparation of ceria nanoparticles by precipitation method and investigation of their defect characteristics

Ceria nanoparticles were synthesised by the simple precipitation method without any additional heat treatment at high temperatures. The synthesis involved initially the formation of cerium hydroxide by precipitation of cerium nitrate with sodium hydroxide. The effect of parameters such as the reaction temperature, time of reactions, and the volume of the solutions were studied. The reaction temperature was varied from 30°C to 90°C and the volume of the reaction solution was varied from 20 mL to 80 mL. X-ray diffraction (XRD) and high resolution transmission electron microscopy (HR-TEM) were used to analyse the crystallinity and morphology of the samples. The average size of the particles was ~ 5 nm and the particles were of a mixed morphology (octahedral and rod shapes). Laser Raman spectroscopy and X-ray photoelectron spectroscopy (XPS) were conducted to determine the characteristics and volumes of the defect sites on the surface of the particles.

K2 H. Ren, P. Koshy, C.C. Sorrell: UNSW

Effect of crystal structure and grain morphology on the photocatalytic performance of BiVO₄

BiVO₄ is an emerging photocatalytic material with promising characteristics such as a narrow band gap, high stability, and low cost. The present work reports data for the mineralogical, nanostructural, optical, and photocatalytic properties of BiVO₄ powders. X-ray diffraction, laser Raman spectroscopy, scanning electron microscopy, and transmission electron microscopy were used to determine the mineralogical and morphology characteristics of the powders. These powders were fabricated using hydrothermal method involving Bi(NO₃)₃ and NH₄VO₃ solutions under varying pH values and reaction times. Differences in grain morphologies and sizes as well as the crystal structures were obtained by varying the pH values and the reaction times. The differences seen in the grain morphology and crystalline structure were expected to produce variations in the electronic structure and hence to influence the generation and recombination rate of charge carriers, resulting in different photocatalytic performance. Thus the present work aims to establish a correlation between the processing parameters and the resultant photocatalytic activity of these materials.

K2 A. Zafari, K. Xia: University of Melbourne

Precipitation of equiaxed α in severely deformed beta titanium alloys

High pressure torsion and shear punch were performed on a Ti-5553 metastable β alloy followed by aging at 600 °C for different times ranging from 30 seconds to 6 hours. In contrast to the conventional microstructure of β Ti alloys where α precipitates as needle-shaped plates with the Burgers orientation relationship (BOR), randomly oriented equiaxed α particles formed in the severely deformed Ti-5553 alloy. Extensive transmission electron microscopy (TEM) and high resolution TEM (HRTEM) were carried out to shed light on such a change in the morphology of the α phase. It was revealed that the equiaxed α particles precipitated in three steps: β phase recrystallisation, α precipitation in β grain boundaries with the BOR, and finally grain growth leading to the replacement of coherent α/β interfaces with the BOR by irrational, high angle α/β interfaces.

K2 P. Chandran, A. Zafari, E.W. Lui, K. Xia: University of Melbourne

Mechanically alloyed Al-5 at.% Nb consolidated by equal channel angular pressing

Mechanically alloyed Al with immiscible elements such as Nb can lead to a uniform distribution of nanoscaled precipitates which are highly stable compared to conventional alloying and with excellent interface, resulting in significant increase in strength without problems associated with nano ceramic particles in metal matrix composites. Although immiscible, Nb can be alloyed with Al through mechanical milling, forming trialuminide (Al_3Nb), either directly or upon subsequent precipitation, which possesses high strength, stiffness and stability at elevated temperatures. In the present study, Al-5 at.% Nb supersaturated solid solution was formed after prolonged ball milling and Al_3Nb was precipitated in the form of nano particles after ageing at 530°C for one hour. The milled Al-Nb powder was heat treated and consolidated by equal channel angular pressing (ECAP) at 400°C , resulting in a uniform distribution of nanoscaled Al_3Nb particles in the Al matrix.

K2 K. Pancholi: Robert Gordon University (Scotland)

Nonlinear process of self-assembly in formation of nano-structure

The properties of material is a result of the structures at multiple length scales. Emergence of such structure through self-assembly of molecules or nano-particles is inherently non-linear dynamic process. This natural dynamic process when perturbed by external stimuli, the resulting pattern can be entirely different. If the self-assembly or any other material processing technique is analysed in its parametric space, the set of natural guiding principle for nano-structuring can be derived, which is useful in natural material design.

In this work, the graphene nano-particle infused polymeric foam with monodispersed sized bubbles was produced. Prepared foam is exposed to various stimuli such as laser, ultrasound and plasma to prepare the nano-structure. Using the 3D computer tomographic images, the self-assembly in response of various parameters such viscosity, temperature, particle size, degree of hydrophobicity and power of external stimuli is analysed. The emerging patterns is analysed in nonlinear control theory to derive general guiding principles of the self-assembly for the studied case. Resulting patterns suggests that change in kinetics of particle agglomeration in response to change in various properties affects formation of the super lattice structure. It is envisaged that systematic nonlinear optimisation can yield the material with desired properties.

K2 J. Wandiyanto, V.K. Truong, X.M. Xu, V.T.H. Pham, A.S.M. Ang, C.C. Berndt, R.J. Crawford, E.P. Ivanova: IMEC (Belgium), RMIT, Swinburne University

Antibacterial activity of highly ordered nano-arrayed silicon surfaces

Much inspiration has been drawn recently from naturally occurring mechano-bactericidal surfaces such as wings of cicada *Psaltoda claripennis* and dragonfly *Diplacodes bipunctata* in fabricating their synthetic analogues with nano-patterned features of similar surface topologies. Here we employed electron beam lithography to fabricate highly ordered low and high aspect ratio nano-arrayed black silicon surfaces with constant surfaces wettability. The antibacterial effect of five types of the nano-arrays with 220 nm, 330 nm, 420 nm, 470 nm and 510 nm height nanopillars against *Staphylococcus aureus* 65.8T and *Pseudomonas aeruginosa* ATCC 9027 bacterial cells have been investigated. It was found that the high aspect ratio surfaces with the high elastic modulus were most effective against *P. aeruginosa*, whereas the low aspect ratio surfaces and low elastic modulus exhibited the highest antibacterial activity against *S. aureus* cells. These data provide useful insights into design and fabrication of mechano-responsive antibacterial surfaces.

Symposium L: Geopolymers & use of waste materials

L1 E.O. Garce, J. Hoppe Filho, M.R. Garcez, L.C.P. Silva Filho, G.C. Isaia: Federal University of Bahia (Brazil), Federal University of Rio Grande do Sul (Brazil), Federal University of Santa Maria (Brazil), Deakin University

Evaluation of residual rice husk ash reactivity

Rice husk ash (RHA) produced without burning control presents atomic arrangements characteristic of quartz and cristobalite, and a vitreous silica structure which may interact with calcium hydroxide to form calcium silicate hydrate. The depolymerisation of amorphous silica and the following precipitation of hydrated compounds depend on the pH of the aqueous solution, controlled by the dissolution of portlandite. The use of RHA in the production of pozzolanic cement requires prior understanding regarding the interaction of pozzolan with calcium hydroxide without the presence of Portland cement. This system establishes the maximum consumption of lime per vitreous unit of RHA. In this work mixture substitution of 15% and 25% of Portland cement by RHA was investigated. The evolution of the pozzolanic activity up to 182 days was measured and indicates the existence of remaining portlandite in both pozzolanic systems, regardless of the RHA content. However, the reaction rate of the pozzolan was higher in the system with higher calcium hydroxide content. The pozzolanic activity is not dependent on the ratio between portlandite and pozzolan though, emphasizing the importance of the BET surface area in the reaction kinetics.

L1 B. Lynch, A. Nazari, S. Wade: Swinburne University of Technology

Corrosion of steel fibre reinforced mortars - A microstructural investigation

Fibre reinforced mortars (FRM's) and concrete are growing in demand as specialised applications evolve. Evaluation of steel fibre reinforced mortars (or concrete) where common cementitious binder types are compared directly with geopolymer (the most researched cement alternative) has been strangely absent from the research literature. In this paper, steel FRM's made with three binders (Ordinary Portland Cement, a blended cement with 30% fly ash and geopolymer) are directly compared when immersed in a corrosive environment – aerated seawater- for 6 months.

Changes in electrical resistivity are used as an indicator of corrosion resistance differences between the materials with each showing distinctive characteristics – OPC increases linearly, blended cement increases curvilinearly and geopolymer remains unchanged. Physical corrosion changes were tracked by degradation of fibres on polished specimens removed from immersion at regular intervals. Micrographs from an optical microscope showed that the OPC and blended cement samples degraded at similar rates but the fibres in the geopolymer sample corroded at a slower rate. Voids in each material were evaluated by 3D profiling with similar results for OPC and blended cement but a much higher mean diameter of voids for geopolymer.

These results indicate that the fibres in each matrix assessed will corrode at varying rates after extended exposure to a corrosive environment with the geopolymer being starkly different to OPC and the blended cement. The electrical resistivity differences between the two cements, however, suggests they will vary but over a much longer period and not as dramatically to each other as they are to geopolymer.

L1 M. Berndt, J. Sanjayan, R. Pathmanathan, K. Pasupathy: Swinburne University of Technology

Service life modelling for geopolymer concrete in atmospheric environments

Understanding and predicting the long-term durability of geopolymer concrete is key to gaining acceptance of this material within the construction industry. Laboratory tests typically measure a single property and do not consider the multiple effects of real life exposure conditions. In order to

address these deficiencies, an investigative study has been performed on geopolymer concrete subjected to a range of environments throughout Australia. One such environment was atmospheric and the carbonation of geopolymer concrete was compared with ordinary Portland cement (OPC) concrete. It was found that the geopolymer concrete was more susceptible to carbonation. Similar behaviour has been reported in other studies. However, the pH reduction associated with carbonation is not as great for geopolymer concrete. The implications of these findings on the service life of reinforced concrete were examined. Carbonation models were used to predict the progress of a carbonation front versus time for geopolymer concrete and a range of OPC concretes with different levels of cement replacement by supplementary cementitious materials. The predicted service life in context of AS 3600 and durability planning for major structures was considered.

L1 A. Bagheri, A. Nazari, J.G. Sanjayan, P. Rajeev, W. Duan: Swinburne University of Technology, Monash University

Experimental and atomistic study of boroaluminosilicate geopolymers

Geopolymers are cement-free construction materials which are produced by mixing an aluminosilicate source such as fly ash with an alkali activator. Despite their eco-friendly nature, the negative impact of the sodium silicate part of the activator of geopolymers on the environment is undeniable. The use of borax, one of the eco-friendly salts of boric acid, as an activator can potentially lead to the production of more environmentally-friendly geopolymer. However, a better understanding of their theoretical properties could be a milestone to produce new generations of geopolymers with high performance. A growing interest in the prediction of the macroscale properties of geopolymer compounds was the most compelling motivation for this study. For this purpose, the current study focused on both points to apply borax as a potential replacement for silicate-based activators and model all the experiments by Molecular Dynamics (MD) simulation. Substituting boron atom with aluminium in the structure of geopolymer was the core idea of the simulation. Compressive strength, density and elastic modulus tests were conducted, and the results were compared with the MD simulation outcomes. Increasing the content of borax in the mixture led to a decrease in all of the properties, although the range of 10% to 30% of replacement eventuated in acceptable results. A fair agreement between simulation and experimental results was achieved through which the best fitting parameters for atomistic modelling of geopolymers were found.

L1 R. Shabbar, Z. Wu, P. Nedwell: University of Manchester (UK), University of Kufa (Iraq)

Mix proportioning of lightweight aerated concrete using response surface methodology

The effects of cement, water and aluminium powder content on the density and compressive strength of lightweight aerated concrete with silica fume were investigated by statistical modelling. A two-level factorial design method and Response Surface Methodology (RSM) were applied. The three independent variables were evaluated at a minimum, maximum and midpoint of the experimental domain. The results show that the characteristic performance of lightweight aerated concrete was significantly affected by their interactions. The statistical models developed in this study can facilitate optimizing the mixture proportions of lightweight aerated concrete for target performance by significantly reducing the number of trial batches required.

L1 S-W. Tsao, T-W. Cheng, K-L. Lin, Y-C. Ding, W-H. Lin, C-P. Huang: National Taipei University of Technology (Taiwan), National Ilan University (Taiwan), Institute of Nuclear Energy Research (Taiwan)

A study on solidification of simulated radionuclide ion exchange resins using geopolymer technology

Ion exchange resins are widely used in the nuclear reactor to remove the radioactive contaminants such as neutron activation products and fission products which may leak from fuel element. The loaded ion exchange resins is considered as low-level radioactive waste and must be properly treated and disposed by solidification. Due to resin's hydrophobic properties, cement hydration process is incompatible with the resin's surface for solidification purpose. Therefore, the geopolymerization could be a solution for the solidification of low-level radioactive wastes loaded resin.

The objective of this study is to use geopolymer process with blast furnace slag, wollastonite powder as raw materials and alkali solution to solidify simulated radionuclide ion exchange resins at ambient condition. The viscosity was controlled between 6000~7000 mPa·s. The quantities of simulated radioactive ion exchange resins for geopolymer solidification are 10, 15 and 20% (wt.) by volume. According to test results, optimal geopolymerization parameters were determined and the properties of solidification product also in compliance with the set in standards fuel cycle and materials administration atomic energy council of Taiwan.

L1 T-C. Li, T-W. Cheng, K-L. Lin, Y-C. Ding, H-S. Wei: National Ilan University (Taiwan), National Taipei University of Technology (Taiwan)

A new process for fabrication geopolymer

Geopolymer, similar to natural zeolite minerals, is a class of three-dimensionally networked alumino-silicate materials. Due to its superior mechanical and physical properties, such as non-combustible, heat-resistant, fire/acid resistant, easy to make it, and formed at low temperatures, geopolymer have been gradually attracting world attention as potentially revolutionary green materials. Conventionally, geopolymers are synthesized from a two-part mix, consisting of an alkaline solution (often soluble silicate) and solid aluminosilicate materials.

The purpose of this study is to simplify the geopolymerization process by reacting sodium metasilicate with Na_2CO_3 and $\text{Ca}(\text{OH})_2$ to form NaOH which can act as alkali solution for geopolymerization. This alkali solution was then mixed with coal fly ash and blast furnace slag to produce geopolymer. Experimental results show that the geopolymer prepared with the new process has a compressive strength of 25 MPa after 28 days curing.

L1 P. Godonou: Uppsala University (Sweden)

Steel cell reinforcement: an alternative and sustainable material for buildings and civil works

During the past century or so, Reinforced Concrete (RC) has consolidated its position as the material of choice for primary structural bearing components in buildings and civil works. RC are mainly used with steel rebar carrying tensile and bending loads. While steel, timber, masonry or Fiber Reinforced Polymers (FRP) are good alternatives in many cases, RC using rebar is still regarded as the best option, despite some negative sustainability aspects.

Cell reinforcement made of steel sheets or plates with specially engineered profile and geometry, is a novel material designed to be an alternative or a complement to steel rebar or steel plates and sheets in many applications. The use of cell reinforcement generally results in 20 to 60% lower need for steel, better strength and durability as well as better handling for workers in-situ or during prefabrication.

In this paper, some examples of structural components such as beams, slabs and walls for buildings or civil works using this innovative reinforcement are presented. A comparison of performance for similar structural components made of conventional RC is also undertaken. It is shown that cell reinforcement is in many cases a better alternative to more established RC, with respect to structural, environmental and economic considerations.

Acceptance of this innovative material in design codes is the next step needed to highlight and further promote its use in the building and construction sector.

Symposium M: Nuclear waste & fuel

Keynote M1 C.L. Corkhill, S.T. Barlow, A.J. Fisher, C. Mann, C.L. Thorpe, C. Murray, C. Tang, N.C. Hyatt: University of Sheffield (UK), Diamond Light Source (UK)

The materials science of wasteforms for a UK geological disposal facility

The decommissioning of ageing nuclear facilities in the UK and final disposal of $> 650,000\text{m}^3$ of nuclear waste in a geological disposal facility presents significant challenges, and opportunities, for materials science. These range from wasteform design for problematic wastes, to understanding the behaviour of wasteforms and other repository materials in contact with groundwater on timescales of tens of thousands to millions of years. In this presentation, the findings of a number of recent and ongoing studies that aim to evaluate and understand the long-term behaviour of glass, ceramic and glass-ceramic materials developed to immobilise problematic UK radioactive wastes are highlighted. Briefly, the characterisation of these materials is discussed, including an overview of the application of synchrotron X-ray facilities to understand composition-structure-dissolution relationships under conditions relevant to geological disposal. The results from batch and flow-through experiments, designed to quantify the kinetics of dissolution and understand corrosion mechanisms, are described, in addition to complementary surface-sensitive chemical and morphological characterisation of materials during, and after dissolution.

Invited M1 E.R. Vance, D. Gregg, C. Grant, K. Oluson: ANSTO, University of Cambridge (UK)

Immobilisation of radioactive Cs in ceramics

The most dangerous radioactive isotope of Cs is ^{137}Cs ($t_{1/2} \sim 30\text{y}$) and we have looked at various ceramics for its immobilisation on the basis of PCT tests. These materials are $\text{Cs}_2\text{TiSi}_6\text{O}_{15}$, $\text{CsAlSi}_2\text{O}_6$, $\text{CsFeSi}_2\text{O}_6$, and $\text{CsAlSi}_5\text{O}_{12}$. The first of these appears to be preparable by hot isostatic pressing (HIP) only over a narrow temperature range (1050-1090°C), but the other materials are easily prepared by sintering at $\sim 1350\text{-}1400^\circ\text{C}$, although hot isostatic pressing would very likely give even better results. Other factors considered were potential to accommodate the $\text{Cs} \rightarrow \text{Ba}$ transmutation on decay, waste loading in relation to heat-loading, effects of in-can HIP atmosphere.

M1 E.R. Vance, E. Maddrell, D. Gregg, C. Grant, A. Stopic: National Nuclear Laboratory (UK), ANSTO

Immobilisation of ^{129}I

The long-lived ^{129}I isotope requires a very long immobilisation time because of its very long half life and several options exist. We have focussed on AgI sodalite, $\text{Ag}_4\text{Al}_3\text{Si}_3\text{O}_{12}\text{I}$, but CuI could be promising. We found that although the AgI sodalite exhibits considerable leach resistance in water, as exhibited by its performance in PCT tests, the presence of strong reducing agents such as Fe metal in the water leads to rapid decomposition of the sodalite with attendant I dissolution. However the material is quite resistant when Cu and Ni powders are added to water, leading to the credibility of

hot pressing in Cu or Ni cans at temperatures in the range of 750-900°C. CuI however is unaffected by the presence of Fe in water. It can readily be precipitated from solution, although only half the I is precipitated at a time. However finely divided CuCl reacts with iodide to form CuI.

M1 C. Cheung, S. Deen, N. Scales, D. Gregg, E.R. Vance, C. Grant, G. Triani: ANSTO

A study of radionuclide volatilisation during calcining and consolidation of nuclear waste forms

This study was conducted to support fundamental understanding of how to evaluate volatile off-gas constituents derived through thermal processing of materials used in nuclear waste management. In Synroc process technology, calcination is necessary to ensure that liquid feed waste stream is transformed and placed into canisters for hot-isostatic consolidation (i.e. HIPing). In general, calcining and HIPing processes are typically conducted above 600°C and 900°C, respectively. During calcination conditions, radionuclides such as caesium, ruthenium and tellurium, in different valence states can become volatiles and may require careful engineering to suppress their volatility and thereby reduce the quantities of these chemicals in the off-gas system.

Waste form components (i.e. additives) and potential volatiles often form very complex systems. In this parametric study, different simulated waste forms (in ceramic and amorphous structures) were studied empirically. The impact of different variables on the level of volatility is presented. Design implications and important engineering information are discussed.

M1 D. Gregg, E.R. Vance, K. Olufson, J. Veliscek-Carolan, I. Watson, N. Webb, T. McLeod, M. Jovanovic, I. Kurlapski, C. Grant, T. Palmer, K. Lu and G. Triani: ANSTO

Waste forms for the immobilization of waste streams from Mo-99 production

Tc-99m, the most commonly used radioisotope in nuclear medicine is produced from the decay of Mo-99 which is predominantly produced in reactors by irradiation of enriched uranium targets. This results in a uranium filter cake containing fission products. This filter cake could itself be treated as a waste stream, or processed to retrieve the uranium for further use, thus producing additional waste streams during reprocessing. Here we consider glass, glass-ceramic, ceramic and geopolymer waste form options for the various waste streams formed in uranium reprocessing as well as for the filter cake itself. All waste forms have been characterised by XRD and SEM and their compressive strength and durability determined by standard methods. For the uranium waste streams the waste forms have been assessed for their proliferation resistance. Consideration has been given to the most suitable solutions for the immobilization of wastes that meet non-proliferation objectives.

Symposium P: Posters

P-01 C.Y. Chen, J.R. Sellar: Pyrotek Products, Monash University

Electron Diffraction from Micro- and Nano-structured cubic zirconia

Pure zirconia (ZrO_2), when alloyed with ~ 10 mole % or more of lower-valent metal oxides like CaO or Y_2O_3 can "stabilize" its high-temperature cubic form down to room temperature. Known as cubic-stabilized zirconia (CSZ) it is a hard, toughenable ceramic frequently employed as the electrolyte in large-format solid oxide fuel cells (SOFC).

For a long time, however, the structure of CSZ was a controversial topic. Originally thought to be atomically disordered, a consensus has recently converged on the Allpress-Rossell model, where the crystalline constitution of CSZ is cubic only on average, with each alloy now considered to be a random two-component mixture of ~1 or 2nm fragments of a fluorite-based superlattice line phase coherently intergrown on an average fluorite lattice, plus a distorted fluorite-like ion-conducting component. Though containing most of the dopant cations and formal crystallographic vacancies,

the small fragments are considered not to conduct oxygen ions. Essentially all the ionic conduction in SOFCs with a CSZ electrolyte is instead judged to be via the pure distorted fluorite component, as evidenced by the reduction of conductivity with increased dopant.

In the present experiments we demonstrate that a much larger micro-structural feature also exists in CSZ on a 500 Angstrom scale, giving rise to electron diffraction effects hitherto unexplained but foreshadowed in a report published by Carter and Roth (1968), linking the Allpress-Rossell model to the larger microstructural feature under discussion herein.

P-02 A. Hasegawa, H. Nakamura, M. Sato, Y. Kadoma, O. Okada: NIT Hachinohe College, Renaissance Energy Research Co. (Japan)

Preparation and characterization of a novel heat resistance alumina using coprecipitation method

Alumina with a large specific surface area such as γ -alumina are useful as catalyst supports for automotive catalyst or steam reforming catalyst. However, conventional porous alumina with a large specific surface area, for intense γ -alumina, undergo easily transition to the α -phase, very quickly at a high temperature of 1000°C or higher. The present study describes a process for preparation of heat-resistant alumina using a coprecipitation method. We have succeeded in the preparation of heat resistant alumina by the coprecipitation from ethanol solution containing tetraethylorthosilicate and aluminum nitrate nonahydrate using ammonia solution as the precipitant. In the standard γ -alumina, α -alumina was formed in 20 hours at 700°C in a 18 MPa steam atmosphere. Industrial heat resistant γ -alumina was transformed to α -alumina completely at 1200°C for 30 hours in air. On the other hand, in the novel heat resistant alumina comprising 5 mass% silica, virtually it was impossible to observe any peaks, which derived from the α -phase under steam atmosphere or at 1200°C for 30 hours in air. The heat resistant alumina with 5 mass% of silica exhibited superior heat resistance in that a high specific surface area of about 40 m²/g was retained even after 720 hours of calcination at 1200°C. High heat resistance of the novel heat resistant alumina, was considered to be due to silica is highly dispersed in the alumina by a coprecipitation method.

P-03 A-M. Paniagua-Mercado, P. Estrada-Diaz, J. Reyes-Martínez, G. Gomez-Gasga, H. Dorantes- Rosales, C. Mejía-García, E. Diaz-Valdes: Instituto politécnico Nacional (México)

Formation of iron carbide as protect surface of chemical corrosion, by carbon nanoparticles in refractory mixes of Al₂O₃ SiC-C

Nanoparticles of carbon were obtained by mechanic milling, at different sizes, pouring these in mixes of Al₂O₃-SiC-C refractory mixes, water and Fenolic resin, pressed in bricks and drying at 240°C for developing the bonding, the bricks were kept in a laboratory before chemical attack with steel slag by aluminothermy, to simulate the corrosion by slag. Then were performed physical and chemical characterization, by X-ray diffraction, EDS, SEM and optical macrographs. The bricks were kept in laboratory. After days, some oxidation due to humidity was present on the surface, decreasing this with the nanoparticles size. After aluminothermy, the formation of iron carbide Fe₅C₂ was detected on the bricks surface by EDS, this carbide protected the bricks surface of slag attack and chemical corrosion by humidity, when the nanoparticles of carbon had 21.78 nm and 17.25 nm sizes.

P-04 A-M. Paniagua-Mercado, A. Mauro-Nolasco, E. Díaz-Valdés, J. Ibarra-Báez, C. Mejía-García: Instituto politécnico Nacional (México)

Properties characterization of impregnated nanoparticles of titanium oxide in surfaces of textile fibers ceramics

Samples of textile fiber ceramics with fiberglass insert which supports 640°C were characterized, with two percentages of nanoparticles of titanium oxide (5% and 10%), by the method of impregnation with starch and water, then were burned at different temperatures of 400°C, 700°C, 800°C and 1100°C for 24 hours, weight before and after of each treatment, observed that some of them lost more weight than others and the fibers surfaces too change the physical properties. Friction tests were conducted to evaluate resistance and the result was that samples with 5% of nanoparticles of titanium oxide are eroded partially than others. After samples were burned above 800°C, a light opaque and diffuse film slightly yellowish is formed, at 1100°C this film is more colored, this was observed by macroscopic lens camera, and by X-ray diffraction, this changes corresponding to a transformation of clinoenstatite to $MgSiO_3$, because the insert glass was fused, samples have the mechanical properties by insert glass, with nanoparticles of TiO_2 at 700°C no present fusion of insert and the fibers properties are same than 400°C, with more temperature; at 800°C and nanoparticles the surface of ceramic fibers is almost the same that 700°C, lost mechanical properties and are brittle and glassy totally at 1100°C. The nanoparticles of titanium oxide are benefices the fiber ceramics and fiberglass maintain the properties for more temperature.

P-05 E. Diaz-Valdes, C. Mejía-García, G.S. Contreras Puente, T. Molina Mil: Instituto politécnico Nacional (México)

Processing and characterization of semiconductor-superconductor composite materials (CdS-Bi-based composites)

Current research on the generation, transportation, storage, consumption and energy saving, is of great importance, because conventional energy sources are declining. Therefore, it is considered to semiconductors as the basis for non-conventional energy generation, on one hand, and on the other, to the superconducting materials as carriers and to store energy. Both play an important role in the development of possible semiconductor-superconductor devices. In this work the processing and characterization of semiconductor-superconductor composites CdS-Bi-Pb-Sr-Ca-Cu-O is reported. The superconducting material was prepared by the method of solid state reaction. The composites were prepared by two ways: 1) by mixing superconducting and semiconducting materials and sintering them; and 2) synthesizing nano-CdS on the superconducting material by chemical bath deposition technique. The influence of the synthesis conditions in the composites is determined through electrical, structural and morphological characterization. In the composites processed by mixing and sintering, the addition of CdS in the superconducting material does not affect its phases and crystal structures, but the heat treatment applied to each composite, to prepare them in pill form, caused changes. On the other hand, The semiconductor-superconductor processing composite through synthesis of CdS by chemical bath technique, with the superconductor embedded in the chemical bath, produces growth of CdS nanoparticles in the pores of the superconductor and its surface. Reaction times of 10 min produce CdS growth in amounts covering the superconducting material and shorter reaction times favor the coating pores only, and therefore the study of the behavior in the superconductor-semiconductor interface.

P-06 C. Mejía-García, A.M.P. Mercado, E. Diaz-Valdes, A. Cruz-Orea, M.L.R. Morales: M.A.A. Ibarra: Instituto politécnico Nacional (México), Lab. LaNSE (México)

Synthesis and characterization of clay with sawdust and Ag nanoparticles

We present the synthesis of clay with the incorporation of sawdust with different sieving (0.425, 0.84 and 1.41mm) using an oven at 890°C by 9 hours, some samples were immersed in a solution of Ag nanoparticles. The samples were analyzed to obtain their physical, structural and morphological properties. The densities for each sample were obtained in the range of 3.44 and 2.673 (g/ml) and the volumetric absorption between 16.06 and 45%. The XRD pattern shows the three main characteristic phases of the clay as quartz (SiO_2), kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) and goethite (HFe_2). The morphology of the samples was analyzed by SEM, showing various pore sizes depending on the sieves used for casting sawdust.

P-07 A. Antony, Deakin University; D. Fabijanic, Deakin University; N. Stanford, Monash University; P.D. Hodgson, Deakin University

Model alloy approach to study the evolution of microstructure in deep cryogenically treated martensitic steels

Deep cryogenic treatment (DCT) is a sub-zero treatment that is carried out at a temperature below -125°C to produce material with exceptionally high wear resistance. The combined effect of austenite–martensite transformation and the precipitation of ultrafine carbides during subsequent tempering could be attributed towards the improved wear resistance after DCT. It was proposed that clusters of carbon were formed around dislocations during the DCT and on subsequent tempering these sites act as nuclei for the formation of fine carbide particles. The present work was focused on studying the role of dislocations in increasing wear resistance during deep cryogenic treatment on martensitic steels. Advanced characterisation on Fe-0.6C binary alloy that was subjected to deep cryogenic treatment at -196°C, revealed an increase in the dislocation density. The effect of this scenario on wear resistance was studied on Fe-0.6C binary alloy, with respect to the amount of retained austenite before DCT and the addition of alloying elements.

P-08 S. Matsuura, M. Nanko, M. Kutata: Nagaoka University of Technology, Nuclear Science and Engineering Directorate Japan Atomic Energy Agency (JAEA)

Disappearance of ZrO_2 scale formed on zircaloy fuel rods with molten control rods during severe accident of boiling water reactor

Boiling water reactor consist of fuel rods and control rods in the pressure vessels. When severe accident occurs, water coolant circulation is halted, leading to increase temperature of these fuel rods by thermal radiation from the fuel rods. Subsequently, the control rods comprised of stainless steel (SS) and B_4C will be melted. The SS- B_4C melt will react with Zircaloy (Zry) cladding of the fuel rods. The melt will contact to oxide scale made from ZrO_2 on Zry tubes by steam oxidation in the severe accident. The ZrO_2 scale may protect Zry cladding tubes from the SS- B_4C melt. However, the ZrO_2 scale will disappear by reduction with Zry because oxygen supply from the surrounding was stopped by covering the Zry cladding with molten SS- B_4C . In order to study reaction behavior of Zry cladding with molten control rods, the soaking experiments of Zr into molten Fe- B_4C were conducted.

Zr plates were heated for 12 h at 900°C in Ar-10% H_2O atmosphere for forming ZrO_2 scale with 20 μm in thickness. The samples were soaked to melted Fe- B_4C at 1200, 1225 and 1250°C for 0 to 20 min. Thickness of the ZrO_2 scale was measured by using an electron probe micro analyzer. The value of thickness reduction of ZrO_2 scale increased with increasing the soaking time. ZrO_2 scale with 20 μm in thickness disappeared after soaking at 1250°C for 2 min.

Acknowledgement: This study was performed partially in “Advanced Multi-scale Modeling and Experimental Tests on Fuel Degradation in Severe Accident Conditions”, Ministry of Economy, Trade and Industry on 2015.

P-09 K. Mester, T. Dorin, M. Barnett, M. Weiss: Deakin University

Effect of Sc and Zr additions on microstructure and properties of extruded parts of Al-Cu-Li alloys

Al-Cu-Li alloys are widely used in the aeronautic sector due to their exceptional combination of low weight and high strength. One of their main use is as extruded product where texture control is extremely important in order to retain an optimal strength. The addition of Zr is traditionally used in these alloys as they lead to the formation of fine Al_3Zr dispersoids that pin grain boundaries and avoid recrystallisation. An alternative well known recrystallization inhibitor is Scandium which leads to the formation of fine Al_3Sc dispersoids. These dispersoids have also the advantage to significantly strengthen the alloys with as much as 100 MPa increase per 0.1at%Sc added. The main disadvantage of these dispersoids is their poor thermal stability during the solution heat treatment which leads to their coarsening and dissolution.

This project explores the addition of both Zr and Sc which leads to the formation of hybrid $\text{Al}_3(\text{Sc}_x\text{Zr}_{1-x})$ dispersoids. These dispersoids have the advantage of both strengthening, inhibiting recrystallization whilst being thermally stable and thus have a high potential for use in the next generation of Al-Cu-Li alloys. In order to fully understand the effect of Sc addition, four compositions were carefully selected:

- 1) 0.12wt%Zr,
- 2) 0.12wt%Sc,
- 3) 0.07wt%Zr+0.05wt%Sc and
- 4) base alloy free from Zr and Sc.

Hardness is used to follow the age-hardening kinetics induced by precipitate formation. Scanning electron microscopy is used to observe the bulk microstructure and evaluate the fraction of recrystallised grains as a function of Sc and Zr content.

P-10 X. Li, W. Xu, M. Ferry: UNSW

Precipitation behaviour of 2205 duplex stainless steels during thermal processing

The secondary precipitation behaviour of as-cast, hot-rolled and solution treated 2205 duplex stainless steels were investigated, revealing the elemental distributions in austenite, ferrite, different secondary phases and their local area. Discrepancy of preferred elemental distribution can be observed between the austenite and ferrite. After solution treatment, chromium and nickel are enriched in both ferrite and austenite. Further, manganese distributes evenly in ferrite and austenite, which is not in accordance with the literature, whereby manganese prefers to distribute in austenite. Trace elements such as carbon and nitrogen etc. were also found to play an important role in secondary precipitation in duplex stainless steels, which can result in severe matrix impoverishment of key alloying elements.

P-11 A. Alsubaie, P. Sharma, J. Seidel: UNSW

Nanoscale ferroelectric domain structure of bismuth ferrite BiFeO_3 under different strains

The effect of induced epitaxial strain on ferroelectric properties of thin films has received increased research interest in recent years. Researching studies have shown that the polarization[1], piezoelectricity[2], domain structure[3], and phase stability[2] of these materials in thin films can

be modified by strain because of the inherent coupling between the elastic and ferroelectric phenomena [4].

Ferroelectric domain structure under mechanical tensile stress in bismuth ferrite (BFO) was observed using piezo response force microscopy (PFM) under different strain conditions. For this purpose a newly designed bending stage has been developed for tensile and compressive bending stress application. We have found that the ferroelectric domain structure changes under tensile stress and domain walls are displaced along the uniaxial strain direction. The change of domain structure is clearly seen in PFM with and without applied stress. Furthermore, in-plane polarization-electric field (P-E) hysteresis loops are recorded under different strains. We found that the positive coercive voltages are slightly changed in contrast with the negative coercive voltages under moderate tensile strain of the BFO film.

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P-12 A. Bagheri, A. Nazari, J. G. Sanjayan, P. Rajeev, W. Duan: Swinburne University of Technology

Role of boron as an eco-friendly replacement in alkali-activated materials and fly ash-based geopolymers

In this work, the effect of boron ions on the strength of geopolymers and alkali-activated slag (AAS) was investigated. The samples were produced by replacement of borax, an eco-friendly salt of the boric acid, with sodium silicate in the alkali activator solution. Class F fly ash and blast furnace slag were used to produce geopolymer and AAS specimens respectively. The substitution of boron ions in the structures of geopolymer and AAS meant to decrease the negative impact of silicate compounds on the environment. Outcomes showed that formation of B-O bonds in the geopolymer matrix prevented an unexpected behaviour of the strength derived from an imbalance in the alkali activator solution. Furthermore, the compensatory role of boron in the strength of AAS was undeniable.

P-13 A. Mehjabeen, M. Qian, W. Xu: RMIT University

The developments of Zirconium (Zr) and it's alloys in orthopaedic & dental implants

Zirconium (Zr) and it's alloys and their developments in orthopaedics and dental application are discussed in this study. Generally Zr is always added to Ti alloys as an alloying element to improve the mechanical properties. However, it is well established that biological behaviours and corrosion resistance of pure Zr and pure Ti are similar. Although the mechanical properties of pure Zr and pure Ti are slightly different. Zr has lower hardness and lower Young's modulus compared to Ti. However, the advantage of Zr based alloys is it's usage in medical devices under magnetic resonance imaging (MRI) because of its low magnetic susceptibility. Magnetic susceptibility of Zr is about half of that of Titanium. This is why; Zr has become a favourable non-toxic implant material with excellent biocompatibility and good mechanical properties. Zr based alloys are most commonly used in total knee replacement (TKR) and total hip replacement (THR) procedures. Recently high strength zirconia (zirconium oxide, ZrO₂) ceramics are widely used as new materials for dental implants. In

this study, basic properties and mechanical properties of Zr and its alloys, their corrosion resistance, biocompatibility and magnetic susceptibility are explained.

P-14 K. Beggs, D. Gunzelmann, L. O'Dell, L. Servinis, T. Gengenbach, B. Fox, L. Henderson: Deakin University, CSIRO Manufacturing, Swinburne University

Optimising Surface Functionalisation of Carbon Fibre to Enhance Interfacial Adhesion

Carbon fibre reinforced composites are used across a range of industries where there is a requirement for light-weight material such as in the Boeing Dreamliner and BMW i3. However, performance is undermined by failure mechanisms such as fibre-polymer matrix de-bonding. Building on previous work¹ which shows the introduction of pendent amines onto the fibre surface enhances fibre-to-matrix interaction (Fig. 1), this study seeks to optimise existing surface grafting methods and use novel techniques to examine the chemistry at the surface and interface of the modified carbon fibre. Figure 1. General scheme showing improved fibre/matrix interaction following functionalization (Editor's note: No figures are included in this compilation of abstracts.)

In this study, the surface of the carbon fibre has been modified through in situ diazonium formation under both conventional heating and microwave irradiation.^{2,3} Electrochemical functionalisation with diazo salts has also been undertaken and offers the fastest reaction rate and superior surface coverage. The modified fibres have been evaluated by XPS and solid state NMR to determine chemical composition. Other key performance parameters (modulus, tenacity, coefficient of friction and interfacial shear strength) have also been determined and compared to control commercial fibres.

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P-15 N. Haghdadi, P. Cizek, P.D. Hodgson, G.S. Rohrer, V. Tari and H. Beladi: Deakin University, Carnegie Mellon University (USA)

Effect of transformation path on the austenite-ferrite interface characteristics in the duplex stainless steel

A thorough characterization of austenite-ferrite interfaces was carried out in a duplex stainless steel for two distinct microstructures (i.e. equiaxed vs. Widmanstätten) produced through different phase transformation mechanisms (i.e. diffusional vs. semi-displacive). Misorientation angle/axis analysis showed that a considerable amount of interphase boundaries obey Kurdjumov-Sachs (K-S) orientation relationship (OR) followed by Nishiyama-Wasserman (N-W) independent of the transformation path. The fraction of both K-S and N-W interfaces was, however, higher in the case of the Widmanstätten microstructure. The plane distribution analysis showed a relatively high anisotropy for the both microstructures with K-S and N-W interfaces tending to terminate on (111)FCC and (110)BCC planes. This is in line with both crystallographic constraints and the tendency to adopt low-energy interface configurations. Other austenite-ferrite interfaces which corresponded to neither K-S nor N-W ORs, however, tended to terminate on (111)FCC and (111)BCC planes. This is believed to be due to the nucleation of austenite with irrational ORs on (111)/(111) initial ferrite-ferrite boundaries, or due to a gradual deviation of ferrite planes from (110) towards (111) plane while austenite irrationally grows.

P-16 E. Farabi, P.D. Hodgson, H. Beladi: Deakin University

The role of thermomechanical processing on the martensitic transformation characteristics in pure titanium

In the current study, the effect of cold deformation on the characteristics of subsequent β -to- α martensitic phase transformation (i.e. texture and variant selection) was studied in a pure titanium alloy using plain strain compression testing in conjunction with electron backscatter diffraction technique. The deformation appeared to alter the transformation texture and variant selection mechanism; resulting in distinct misorientation angle distribution. At strain free condition, the misorientation angle distribution of martensite revealed four main peaks, which consistent with the intervariant boundaries expected from the ideal Burgers orientation relationship. The two highest peaks were characterized as $63.26^\circ/[(10)\bar{5}53]$ and $60^\circ/[112\bar{0}]$ misorientations. The deformation was progressively widened the misorientation angle peaks and reduced the fraction of the intervariant boundaries associated with Burgers orientation relationship.

P-17 M. Parvizi, S.P. Ringer, M. Eizadjou: The University of Sydney

Transverse rolling and sequence heat treatment of ultra-fine grain duplex steel

Our work is focussed on the development of novel thermo-mechanical processing schedules for the production of third generation advanced high-strength steels (G3 AHSS). This particular study explores the effect of the sequence of cold rolling (CR) and intercritical annealing (IA) on the microstructure and mechanical properties of a new G3 AHSS with an ultrafine duplex (austenite + ferrite/austenite) microstructure. It has been shown that IA on a novel fully martensitic low-carbon medium manganese steel produces ultrafine duplex microstructure with high strength and high ductility. Subsequent CR of this duplex microstructure triggered a transformation-induced plasticity (TRIP) process and transformed more than 95% of the austenite to α' -martensite. This deformed microstructure (deformed ultrafine ferrite and α' -martensite) was the base material for this study. Various IA heat treatments were applied to explore the microstructure and mechanical properties of this steel alloy. The effect of IA on microstructure (grains size, phase fractions and chemical composition of different phases) was investigated by means of SEM-transmission Kikuchi diffraction (TKD), atom probe microscopy (APM) and X-ray diffraction (XRD). The microstructure-property relationships of these steels is discussed in terms of a pathway for enhanced strengthening.

P-18 D.S. Ward: Adelaide Polymer Consultancy

Investigation of premature cracking failure in amorphous thermoplastic components

This paper discusses two cases where the author has investigated premature failure and cracking of thermoplastic components. In each case, the presence of low molecular weight species in intimate contact with an amorphous thermoplastic (ABS) has initiated cracking and failure at lower stress levels than would otherwise be expected. The techniques used in these investigations include microscopy, thermal analysis (Thermo Gravimetric Analysis and Differential Scanning Calorimetry), FTIR (Fourier Transform Infra Red Spectroscopy) and accelerated testing techniques. This failure mechanism, often abbreviated to ESC or Environmental Stress Cracking, is not widely understood or considered when selecting materials and the chemicals in contact with them. A greater awareness and understanding could help to avoid interactions leading to premature component failure.

P-19 R. Shabbar, Z. Wu, P. Nedwell: University of Manchester (UK), University of Kufa (Iraq)

Mix proportioning of lightweight aerated concrete using response surface methodology

The effects of cement, water and aluminium powder content on the density and compressive strength of lightweight aerated concrete with silica fume were investigated by statistical modelling. A two-level factorial design method and Response Surface Methodology (RSM) were applied. The three independent variables were evaluated at a minimum, maximum and midpoint of the experimental domain. The results show that the characteristic performance of lightweight aerated concrete was significantly affected by their interactions. The statistical models developed in this study can facilitate optimizing the mixture proportions of lightweight aerated concrete for target performance by significantly reducing the number of trial batches required.

P-20 P. Godonou: Uppsala University (Sweden)

Steel cell reinforcement: an alternative and sustainable material for buildings and civil works

During the past century or so, Reinforced Concrete (RC) has consolidated its position as the material of choice for primary structural bearing components in buildings and civil works. RC are mainly used with steel rebar carrying tensile and bending loads. While steel, timber, masonry or Fiber Reinforced Polymers (FRP) are good alternatives in many cases, RC using rebar is still regarded as the best option, despite some negative sustainability aspects.

Cell reinforcement made of steel sheets or plates with specially engineered profile and geometry, is a novel material designed to be an alternative or a complement to steel rebar or steel plates and sheets in many applications. The use of cell reinforcement generally results in 20 to 60% lower need for steel, better strength and durability as well as better handling for workers in-situ or during prefabrication.

In this paper, some examples of structural components such as beams, slabs and walls for buildings or civil works using this innovative reinforcement are presented. A comparison of performance for similar structural components made of conventional RC is also undertaken. It is shown that cell reinforcement is in many cases a better alternative to more established RC, with respect to structural, environmental and economic considerations.

Acceptance of this innovative material in design codes is the next step needed to highlight and further promote its use in the building and construction sector.

P-21 J-Y. Cho, W. Xu, M. Qian: RMIT University

Microstructural homogeneity of Ti-6Al-4V alloy manufactured by selective laser melting technique

As one of the additive manufacturing technologies to make metallic components, selective laser melting (SLM) is the techniques which have been used a lot in research and industry area. However although the fact that each layer has experienced repetitive heating and cooling leading to different and complex heat history, can make it hard to get homogenous microstructure, the homogeneity of microstructure of SLM built Ti-6Al-4V components has not been reported. Therefore, herein the microstructural homogeneity has been studied.

The 20mm long and 12mm wide Ti-6Al-4V cylinder sample manufactured by SLM technique with 60 μ m of layer thickness and 50.62 J/mm³ of energy density, was investigated. With image analysis, it was found that the lower part of the sample consists of α / β phase while upper region of the sample is composed of α' martensite phase. Furthermore, volume fraction of beta phase and alpha plate thickness gradually decrease as approaching top of the sample. Moreover, the region between top

and below 3.5mm from top which corresponds to α' martensite region shows much lower elastic modulus than lower part but the hardness is not significantly changed in different position. In addition, by analysis the diffraction pattern acquired from micro XRD instrument, it was confirmed that there is no significant variation in lattice parameters of α' or α phase in different position of the sample and that of β phase formed in the α / β region is relatively constant. From these results, the conclusion that even though lattice parameter of each phase is not significantly changed, the microstructure and micro-mechanical property of Ti-6Al-4V parts fabricated by SLM is varied with different position, especially top side of the part because the upper region has less influence of the heat generated by deposition of new layer, can be drawn.

P-22 S.H. Islam, M. Qian, D. Parker, R. Chen: RMIT University

Characterisation of the intermetallic layer of 55Al-Zn-Si-Mg hot dip coated steel strips using Focussed Ion Beam (FIB) and Transmission Electron Microscopy (TEM)

Coated steel strips have a very wide range of applications and are an integral part of our daily life. The coating process is realized by hot dipping the steel strips into a coating bath of an Al-Zn based alloy. An alloy or intermetallic layer up to 1 mm thick forms during the hot dip coil coating process between the steel substrate and the final coating overlay. The alloy layer not only provides essential metallurgical bonding between the two but also acts as the last barrier against corrosion. Despite being an established coating process, the phases present in this thin intermetallic layer have not been fully characterised as yet. Relevant information in the literature is largely based on data produced using scanning electron microscopy. In this research, TEM samples are prepared using the FIB technique from the intermetallic layers observed in both industrially coated steel strips and those coated on a laboratory scale steel strips. The intermetallic layers are characterised using the FIB and TEM assisted with selected area electron diffraction (SAED) and Energy-dispersive X-ray spectroscopy (EDS). The various phases present in the intermetallic layers are identified.

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