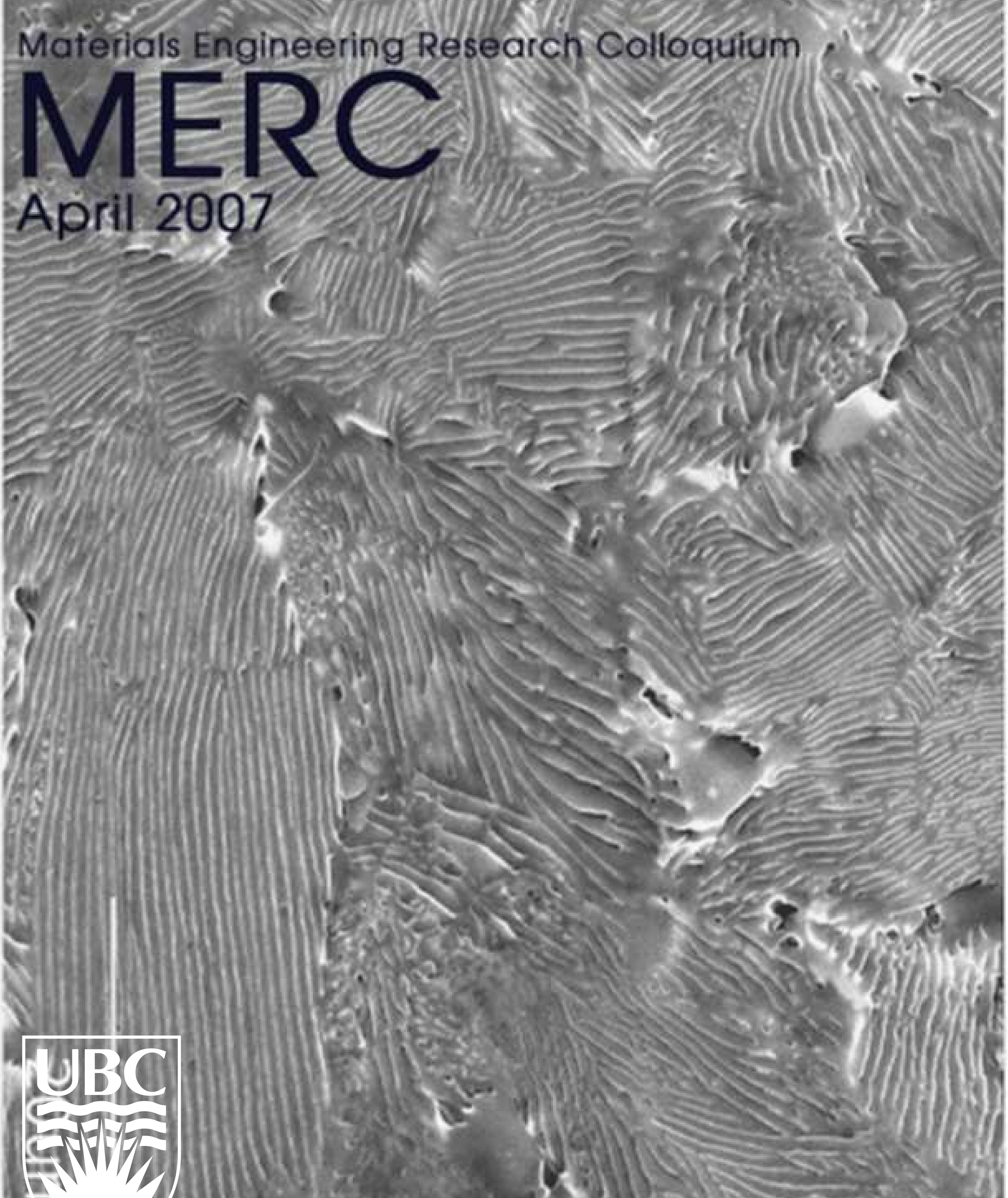
Materials Engineering Research Colloquium

MERC

April 2007



UBC

Materials Engineering Research Colloquium
April 2007

Schedule:

Time	Presenter		Title
10:30	D. Waldbillig		Suspension plasma spraying of solid oxide fuel cell electrolytes
10:45	M. Breakey		Co-deformation of an Aluminum Zinc Alloy
11:00	A. Phillion		Hard-To-Measure Mechanical Properties: The Case of Semi-Solid Materials
11:20		Break	
11:40	P. Chan		A Study of Boiling Heat Transfer on Steel Strip at Low Coiling Temperatures
11:55	T. Li		Banding in remelted ingots
12:10		Lunch	
13:15	V. Ebacher		Strain Redistribution and Cracking Behavior of Human Bone during Bending
13:30	W. Lo		Corrosion Mechanism of Basic Refractories in Non-Ferrous Converters
13:45	K. Siggers		Feasibility of Calcium Polyphosphate as a bone scaffold for Revision Hip Surgeries
14:00		Break	
14:15	J. Skrovan		Accelerated Corrosion of Aluminum for Hydrogen Generation
14:30	H. Azizi-Alizamini		Microstructural Evolution and Mechanical Properties of Ultrafine Grained Low Carbon Steels

Abstracts

Suspension plasma spraying of solid oxide fuel cell electrolytes

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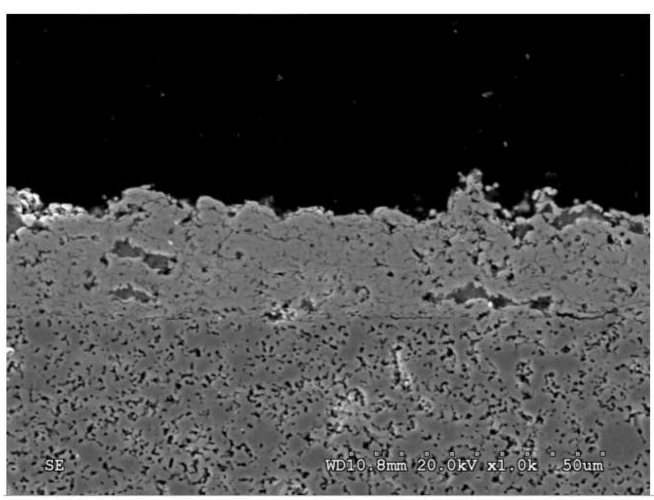
Research Summary:

Suspension plasma spraying (SPS) is a promising modification to traditional plasma spray techniques that may allow plasma sprayed layers with finer microstructures and better porosity control to be produced. The fine microstructures and controlled porosity of these layers combined with plasma spraying's ability to produce layers rapidly without requiring a post-deposition heat treatment makes this an interesting new manufacturing method to produce solid oxide fuel cell (SOFC) active layers. This study uses an axial injection suspension plasma spray system to produce thin layers of fully stabilized yttria-stabilized zirconia (YSZ) for use as an SOFC electrolyte.

The primary objective of this project is to improve the understanding of the relationships between substrate, feedstock, and plasma spraying parameters and the resulting coating characteristics such as thickness, porosity, deposition efficiency, and adhesion through the use of a series of systematic experimental investigations, and to correlate the coating microstructural and physical properties to the resulting fuel cell electrochemical performance.

The improved understanding of the processing-property-performance relationships will be used to improve the performance of SPS deposited SOFC electrolytes by decreasing their thickness to < 25 micrometers while minimizing porosity.

Figure: SEM image of the polished cross-section of a SPS deposited YSZ coating.



Co-deformation of an Aluminum Zinc Alloy

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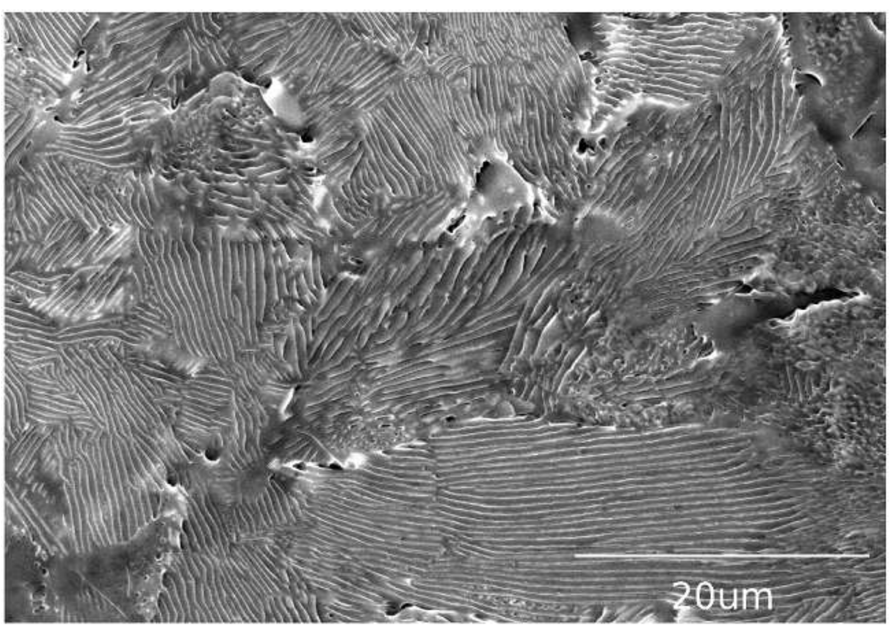
Research Summary:

As the phase scale of a material changes, so does its mechanical properties. Many fine-scale binary composites, including copper chromium and copper niobium, have shown strength increases far exceeding the prediction by rule of mixtures. The mechanism causing this anomalous increase in strength is not well understood. Very little research has been focused on the co-deformation of fine scale FCC-HCP composites and it is unclear how materials with such different individual deformation mechanisms will deform together.

A model aluminum zinc system was developed and characterized. Aluminum zinc can be discontinuously precipitated to produce a fine scale lamellar microstructure which can be manipulated by processing conditions. The discontinuous precipitation reaction transforms the entire microstructure producing a regular structure of a simple geometry. This model material can then be tested using well developed and accurate mechanical tests to determine how the two phases co-deform.

The model system was tested at various temperatures and strain rates using monotonic tensile tests, baushinger tests, and load/unload tests. The microstructure was then analyzed using SEM, TEM and XRD to determine how the material codeformed.

Figure: Al-18.5at.%Zn discontinuously precipitated.



Hard-To-Measure Mechanical Properties: The Case of Semi-Solid Materials

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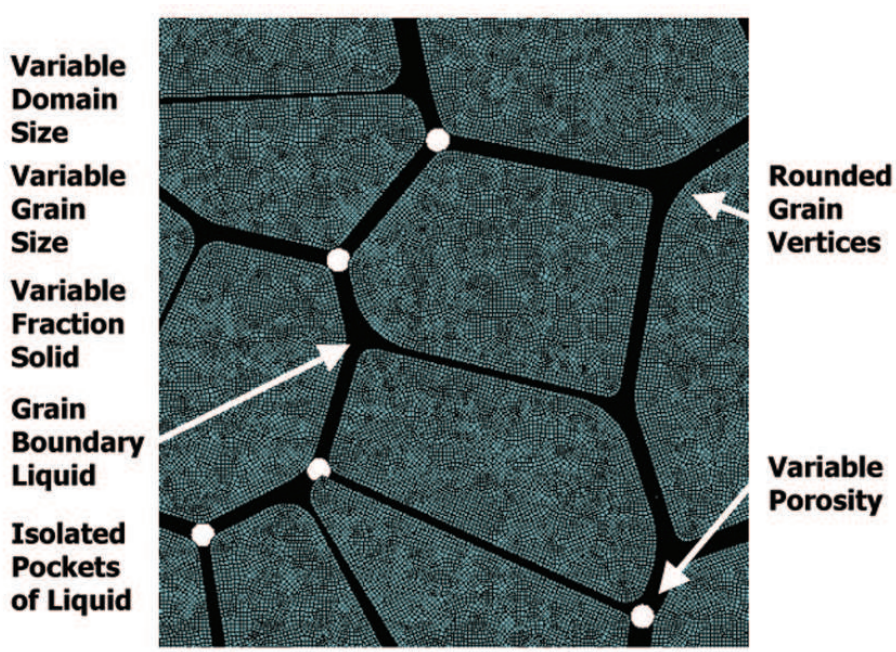
Research Summary:

Hot tearing is a major casting defect in which cracks form and propagate in the semi-solid phase leading to downstream product rejection. Accurate mechanical property data in the semi-solid state is critical for the development of predictive models for hot tearing reduction. Unfortunately, determining this material behaviour is challenging due to the difficulty of reproducing casting-like conditions in a controlled setting.

In this work a technique is presented that enables measurement of semi-solid tensile constitutive behaviour via a series of finite-element-type virtual experiments conducted on the commercial aluminum alloy AA5182. This microstructural model is first validated against actual experimental data at high fraction solid. Subsequently, the validated model is used to provide the material's stress-strain response in the range $0.75 < fs < 0.98$, and allows for the effect of porosity to be quantified. From the results, an empirical constitutive law was developed that is useful for both industrial process models and criteria for prediction of hot tears.

Figure: Semi-solid microstructural phenomena captured by the virtual experiments.



A Study of Boiling Heat Transfer on Steel Strip at Low Coiling Temperatures

Phillip Chan
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Research Summary:

Cooling of hot strip steel on the runout table is a critical step in determining the final microstructure and properties. With the advent of new high strength steels such as transformation induced plasticity (TRIP) steels and dual-phase (DP) steels, it is imperative to control and enhance runout table cooling to ensure that the final desired microstructure is produced; which may entail coiling at temperatures close to room temperature. The purpose of this study is to develop a fundamental understanding of jet impingement cooling at low coiling temperatures. This study is performed by using three different jet impingement entry temperatures: 350^{o}C, 500^{o}C and 600^{o}C. Another parameter studied was the effect of strip speed, as this can affect residual stress formation and dimensions of the strip. Four different speeds were studied for each temperature: 0.3, 0.6, 1.0 and 1.3 m/s.

Experimental trials were run on a pilot scale runout table, using a single nozzle water jet impinging on the top surface. The use of a single nozzle water jet may allow for visual analysis of the jet impingement surface and acquisition of temperature data without interference from neighbouring water nozzles. Thermocouples were instrumented from the bottom surface, 1 mm from the impinging surface to record the temperature profile. The temperature data was further processed using an inverse heat conduction model to generate heat flux at the impingement surface and boiling curves.

Banding in remelted ingots

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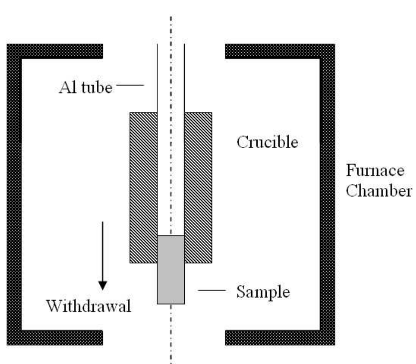
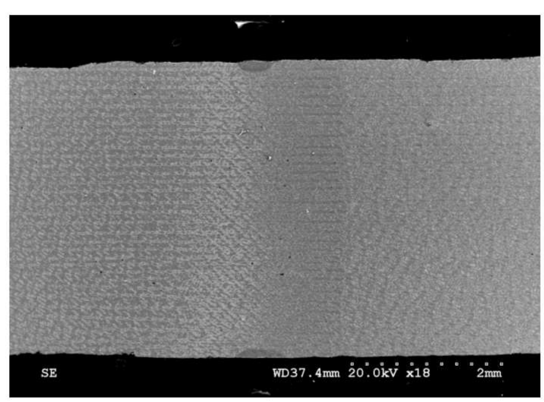
Research Summary:

Process irregularities in remelting furnace operation have an impact on the ingot solidification structure which depends on the local thermal conditions and the alloy concerned.In this presentation,a brief introduction to the remelting process as well as its instabilities is made. And we also present the results of a laboratory investigation into the structures resulting from interruptions in solid growth under thermal conditions which are similar to those in the mid-radius region of a remelt process. The results demonstrate the range of structure, segregation and precipitation changes which are experienced by a range of alloys including IN718,Nimonic80, Waspaloy, M50 and SAE4340. In the case of alloys which form primary precipitates, the interruption period is shown to give rise to structure changes which would not be eliminated by subsequent heat treatment: In the single phase solidification alloys the changes are largely cosmetic due to changes in dendrite shape and size. Conclusions are drawn as to the rules which may be developed for process control based on solidification instabilities of this nature.

Figure: Left - Description of the equipment and the experimental procedure Right - The banding structure produced by the interruption of solidification.





Strain Redistribution and Cracking Behavior of Human Bone during Bending

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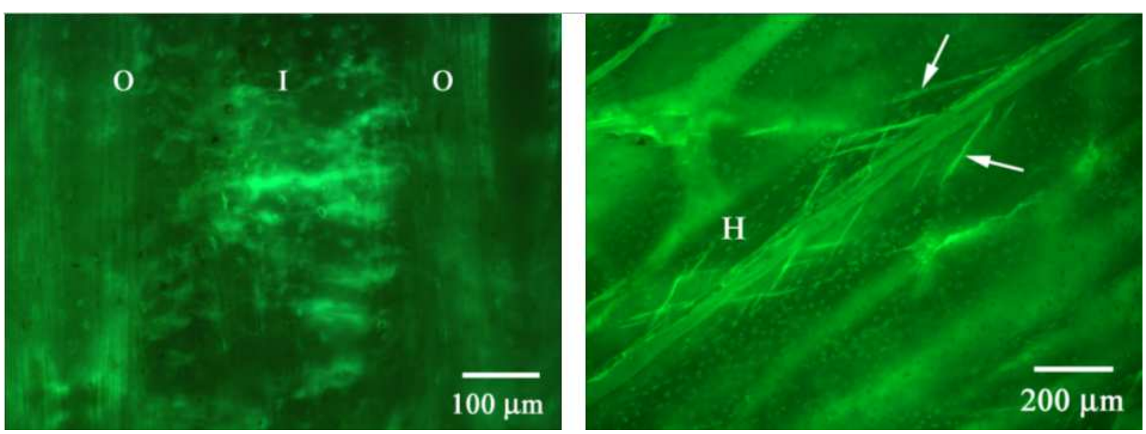
Research Summary:

Long bones often fail due to bending loads. Understanding the fracture process during bending is of great importance to the prevention and treatment of bone fractures. In this study, we investigated the origin of long bone's bending strength through the study of the dynamic strain redistribution happening during the post-yield stage of deformation and its relation to microdamage at the microstructural level. This was accomplished by comparing the behaviors of human long bones with standard cortical bone specimens in terms of strain redistribution, Poisson's ratios, microdamage morphologies, and macro-scale fracture patterns. It was found that human tibiae failure in bending was very similar to that of standard beam cortical bone specimens with respect to the four previous aspects. Also, the examination of bone's Poisson's ratio indicated very different inelastic deformation mechanisms under tension and compression: bone volume expanded in tension but was nearly conserved in compression. Finally, as a result of strain redistribution, bone's bending strength mainly depended on its compressive strength, which was significantly influenced by the osteonal "porous" microstructure of human bone as compared to its tensile behavior. Hence, we concluded that bone microstructure at the Haversian system level plays an important role in bone deformation and fracture. Further work is thus needed to understand the origins of the compressive microcracks within the secondary osteons.

Figure: Different deformation mechanisms under different stress states: tensile diffuse microdamage (left) and confined compressive cross-hatched microdamage (right); O: osteonal bone; I: interstitial bone; H: Haversian system.



Corrosion Mechanism of Basic Refractories in Non-Ferrous Converters

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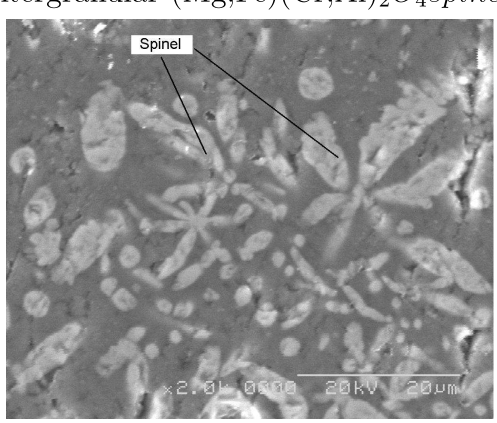
Research Summary:

The current research is to understand the complex corrosion mechanism occurring at the interface, surface and penetration layer between basic refractories and fayalite slags from converting furnaces. Currently, refractory bricks in non-ferrous furnaces contain a mixture of magnesia and chromite ore in various ratios. The oxides, spinels and the solid solutions of various magnesia spinels with chromia, alumina and iron oxides (Fe2+ and Fe3+) are the basic components in the refractories used in non-ferrous converters. The corrosion mechanisms were studied using laboratory testing techniques and post mortem failure analyses on industrial trial brick samples. Dynamic-type tests were carried out in a rotary furnace and static tests were performed in crucibles. These microstructures and phase compositions of the corroded refractories, in the lab and industrial experiments, were tested using the Scanning Electron Microscopy/Energy Dispersive Spectroscopy and respectively X-Ray Diffraction and the results are discussed versus the initial microstructures and phase compositions of the un-used refractories.

A potential environmental risk in using magnesia-chrome and chrome-magnesia bricks is the disposal of bricks after a process is shutdown and re-lined. Bricks exposed to fayalite slags, in theory, could potentially cause the trivalent chromium (Cr3+) in the chrome ore to transform to hexavalent chromium (Cr6+), which is carcinogenic. The Cr6+ has not been established hazardous unless it is in solution. Potential leaching of the used bricks by rain could contaminate water streams resulting in allergic contact dermatitis (ACD) or even cancer. An investigation on the possible leaching Cr6+, if eventually formed during use in the non-ferrous converters, will also be investigated.

Figure: SEM image of Intergranular (Mg,Fe)(Cr,Al)$_2O_4spinel$



The Feasibility of Calcium Polyphosphate as a bone scaffold for Revision Hip Surgeries

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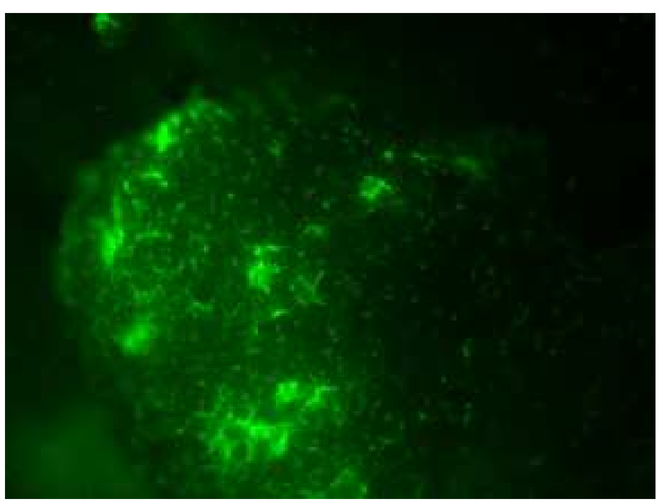
Research Summary:

Revision hip surgery commonly uses the addition of morsellized cancellous bone (MCB) for filling bone defects and to encourage new bone growth around the hip implant. Problems associated with using MCB, which include its availability, disease transmission and implant migration, have prompted the search for replacement materials. Through mechanical and biological testing, this study looks at the feasibility of using a synthetic ceramic, Calcium Polyphosphate (CPP), as a substitute material. Confined compression and direct shear tests carried out on MCB, particulate CPP and a series of spherical particles of different materials were used to compare the mechanical properties of MCB and CPP but also to define an upper bound of properties attainable for particulate constructs of this kind. Real-time PCR and MTT were the biological assays used to quantify the influence of different substrate materials (bone, CPP and hydroxyapatite) on the growth and differentiation of the mesenchymal stem cells seeded on the particles. Results of this testing suggest that CPP is a suitable candidate for the replacement of MCB in revision hip surgeries.

Figure: GFP+ Stem cells seeded on CPP particles at a magnification of 5X



Accelerated Corrosion of Aluminum for Hydrogen Generation

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Research Summary:

With the current concern with global warming, air pollution, and diminishing reserves of fossil fuels, there has been increased emphasis on transitioning to a hydrogen economy. However, if hydrogen is to be widely used as a future energy carrier, storage will be needed to meet time-varying demands for fuel and allow for mobile energy sources. By far the most common storage solution for small systems is currently steel pressure cylinders and industry has set a target of a cylinder with a gravimetric storage density of 6 mass % and a volumetric storage density of 30 kg/m3. Aluminum being a reactive metal will readily form aluminum hydroxide when placed into water with a resulting release of H2 gas. Looking at a mass balance equation we can calculate that aluminum could have an equivalent storage density of 11 mass%, well above current storage targets. However in practice Al is almost always found with a protective Al2O3 oxide layer covering the bulk material due to reaction with oxygen in the atmosphere. This layer is non-soluble and prevents the Al-water reaction. In near neutral pH pure water systems, aluminum is reported to form various aluminum hydroxides depending on water temperature and pressure all of which form a passivating layer that grows to at most a couple of microns thickness before the reaction stops. For this reason aluminum has not traditionally been viewed as a practical source for hydrogen generation. Current work has been focused on the effect of Ball-Milling, oxide addition, and high temperature and pressure to allow for complete corrosion of aluminum powders in commercially feasible timeframes. Results from this work will be discussed along with future work planned for a high pressure reactor that has just been completed to allow for testing at up to 10,000 psi.

Microstructural Evolution and Mechanical Properties of Ultrafine Grained Low Carbon Steels

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Research Summary:

Ultrafine grained (UFG) steels with improved strength and toughness have become of interest as a new class of high strength steels which are particularly demanded for construction applications. However, heterogeneous deformation features like lüdering and limited ductility are the main drawbacks of these materials. Bimodal distribution of the grains and/or second phase particles can potentially improve the combination of strength and ductility in UFG low carbon steels. Recently, martensite straining which is based on cold rolling and subsequent annealing of martensitic structures has been proposed as a simple route to produce UFG structure in low carbon steels with a lean chemistry. In this research, the effect of chemical composition and processing parameters such as rolling reduction and annealing time and temperature on the microstructure and mechanical properties of low carbon steels processed via martensite straining was studied. Furthermore, a new method for developing bimodal grain size distribution in low carbon steels through cold rolling and appropriate annealing of dual phase structures is introduced. Recovery/recrystallization of ferrite and recrystallization of martensite together with pinning by carbides yield a heterogeneous microstructure with deliberate distribution of coarse and fine grains. The effect of geometrical arrangement of fine and coarse grains in these composite type structures on the mechanical properties is currently under investigation. Moreover, microstructural modelling will be used to provide helpful information on the interaction between different microstructural mechanisms in these processes.

Figure: SEM micrograph of a plain low carbon steel with a bimodal grain size structure. Process: Dual phase structure (40% martensite+ 60% ferrite) cold rolled for 50% reduction followed by annealing at 525^o C for 1200min.