PLENARY SPEAKERS

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University of Michigan, USA

From Defects to Microstructure Neighborhoods: A Review of Ultrasonic Fatigue Techniques in Assessing Very High Cycle Fatigue in Structural Alloys

Fatigue lifetimes in the very high cycle fatigue (VHCF) regime are controlled by fatigue crack initiation and, in some cases, small fatigue crack growth behavior. A fundamental aspect of this behavior is that a hierarchy of microstructure features can be identified that directly influences fatigue life through their influence on initiation and small fatigue crack growth behavior. In many commercial alloys features such as porosity or inclusions are critical. In other advanced alloys where such features are minimized microstructural variability and the characteristics of specific microstructural neighborhoods become the dominant influence on fatigue life. This presentation reviews research over the past 20 years at the University of Michigan that has used ultrasonic fatigue methodologies to investigate the influence of microstructure on fatigue behavior in the VHCF regime for a wide range of structural alloys.Alloys examined using ultrasonic fatigue include cast aluminum alloys, wrought magnesium alloys, titanium alloys and nickel base superalloys. Emphasis will be placed on how the research findings from this broad range of alloys can inform alloy design and fatigue life prediction.

Dipankar Banerjee
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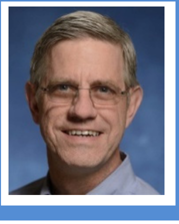
Aerospace Materials in India: Past, Present and Future

Materials and process engineering and product development efforts in India in aerospace have been driven by the Defence Research and Development Organisation (DRDO) and the Indian Space Research Organization (ISRO). Integration of these efforts with academics and national R&D Laboratories has been pursued through the Aeronautical Research and Development Board of the Government of India as coordinated by the DRDO. This presentation provides an overview of materials in aeroengine and airframe applications ranging from low to ultra-high temperature domains, with emphasis on emerging materials and processes and key application related technologies

Kevin J Hemker
Johns Hopkins University, USA



Advanced Micro-scale Mechanical Testing at Length Scales Relevant to Integrated Computational Materials Science & Engineering (ICMSE)

Advanced, multi-scale material models can now accurately predict the mechanical response of polycrystalline microstructures and facilitate rapid introduction of new materials into service. These microstructure-dependent models require detailed characterization and experimental benchmarks at salient length scales that are generally much smaller than conventional bulk samples. Micro-tensile and micro-bending fatigue experiments of a polycrystalline Ni-base superalloy, René 88DT, have been employed to elucidate microstructure-mechanical response linkages that can be used to guide and validate crystal plasticity finite element method (CPFEM) models. Recent advances in additive manufacturing allow for greater geometric complexity and flexibility in the design and fabrication of functional components, but the complexity of processing-structure-property relations is also increased. A parallel study, undertaken to characterize the location and processing dependent properties of Ni-based superalloy, IN625, lattices and thin-walled structures produced by selective laser melting (SLM) will also be used to illustrate the extension of multi-scale test techniques to additive manufacturing.

Micro-tensile experiments provide the full stress-strain behavior and quantitative mechanical benchmarks such as elastic modulus, yield strength, strain hardening, ultimate tensile strength, and strain to failure. But characterization of the transition from bulk polycrystalline behavior to single-crystalline response requires careful consideration of the interplay between specimen size and microstructure. Electrical discharge machining (EDM), focused ion beam (FIB) and femtosecond laser machining have been optimized and used to machine micro-tensile samples of multiple sizes. The variability in the measured strength of individual specimens was found to be greater for smaller specimens, while the average strength for a given specimen size decreased with size. The former is attributed to a finite sampling of grain orientations and the latter to a biased distribution towards grains with elevated Schmid factors. Femtosecond laser-machined samples with a tractable number of grains were found to provide clear benchmarks for CPFEM models. Local strain accumulation is mapped on the surface of these oligocrystals via digital strain correlation (DIC), and stain inhomogeneities highlight the role of microstructure and provide rich benchmarks for CPFEM simulations. The meso-scale samples also allow for the creation of explicit 3D datasets that can be reproduced in CPFEM models.

The effect of local microstructure on fatigue damage has been ascertained by resonance fatigue testing of miniaturized specimens in a novel micro-bending fatigue setup. Insights on how local microstructure (grain size, shape, orientation and neighborhood) influence local plasticity and subsequent crack formation have been collected and shown to involve slip initiation on {111} planes, micro-crack nucleation in large grains along twin boundaries experiencing high resolved shear stress and elastic incompatibility, and short crack growth along {111} planes in neighboring grains. In both tensile and fatigue testing, quantifying the microstructurally dependent response of oligocrysals opened a valuable pathway for model development and validation.

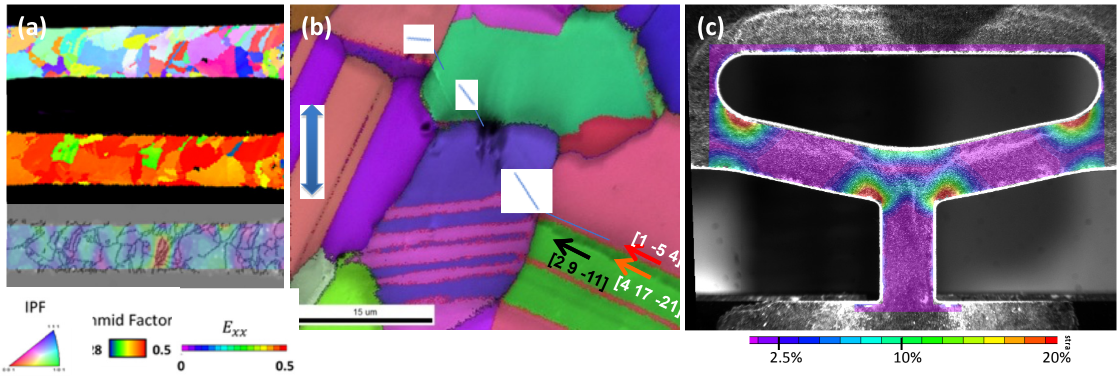


Fig. 1. Micro-scale mechanical testing provides multi-scale benchmarks for ICME modeling and design. (a) strain accumulation in a micro-tensile sample of Rene88DT, (b) crack nucleation and short crack propagation in a micro-bending fatigue sample of Rene88DT, and (c) an additively manufactured "T" element of IN625.

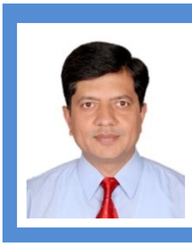
Current design of additive structures assumes homogeneous, isotropic properties, but additively manufactured alloys are neither. Characterizing the mechanical response of geometric "elements" provides a route for measuring the location and processing dependent behavior of SLM lattices and thin-walled structures. In situ mechanical testing and techniques are being used to study the effect of print conditions, geometry and location on the mechanical performance of IN625 "T" elements at room and elevated temperatures.

Kamanio Chattopadhyay
Indian Institute of Science, Bangalore, India

Can Cobalt Base Superalloys Compete with Nickel Base Superalloys? Developing a New Class of Alloys to Address the Challenge

Stabilisation of L12 structure in Co-Al based superalloys by the addition of Mo and Nb/Ta have enabled the community to explore and develop a host of new γ/γ' based superalloys in recent times. However, the high cost of Cobalt often makes them unviable in comparison to nickel based superalloys. A detailed study by energy dispersive spectroscopy (EDS) in transmission electron microscope (TEM) and atom probe tomography (APT) on solute partitioning behaviour across γ/γ' and their influence on the evolution of microstructure in these superalloys led us to design a new generation of low density Co-Al based superalloys that are not only Mo and W free but also having very high specific density at high temperatures that can overcome the difficulties of their adoption in commercial sphere. This talk will brief the adopted strategies and showcase the extraordinary mechanical properties (of the order of giga-pascal strength) and microstructures of some of these alloys.

Sudhir Kumar Misra
CEO, Brahmos Aerospace, India



TBD

Jean-Loup STRUDEL
Mines-ParisTech-CNRS, France

Creep Mechanisms in Advanced Superalloys

Nickel base superalloys are widely used to manufacture critical mobile and static components of the high-temperature jet engines, as well as ground turbines. The mechanical criteria which govern the dimensioning of high performance engineering parts are ever more demanding and must be taken into account when trying to improve the creep, fatigue and corrosion resistance of Ni or Co base superalloys.

The elementary physical mechanisms of plasticity and their evolution with temperature and strain rate will be summarized and related to microstructural patterns and their alteration during service. At low temperature, under high stress the creep rate goes through two minimum values, below 1% strain, in most Ni base superalloys with adequately low stacking fault energy. The first minimum is associated with the movement of a first generation of dislocations, confined to definite matrix channels, the essential function of them is to compensate and cancel out the elastic pre-strain of these channels, caused by the γ-γ' misfit. This mechanism, under very low stress, is responsible for negative creep. Under higher stresses, after several slip systems have been activated, shear and twinning of the ordered γ' precipitates can take place incompatibility with that of the matrix and the development of planar defects, on several slip planes, leads to the second minimum.

At high temperature, under low stress, the initially isotropic microstructures rapidly tend to become rafted. The origin of this phenomenon, the role of the misfit parameter in the development of rafted structures and the consequences of these patterns on the mechanical resistance of the material will be examined.

At intermediate temperatures, all the mechanisms described above can be simultaneously activated and interact with one another in various ways depending on the stress level and the strain rate.

The differences in chemical composition of alloys and the various engineering microstructures obtained after optimized thermo mechanical treatments or single crystal growth will be considered in relation with their ability to enhance or deteriorated the creep resistance of a number of currently used and/or recently developed high-performance alloys.

Rajiv S Mishra
University of North Texas, USA

A Perfect Storm: Opportunities Created by Intersection of Alloy Design and Disruptive Manufacturing Technologies

Periodically we come across disruptive manufacturing technologies that signify major advancement. Often such technologies are referred as 'enabling technology'. A recent example is additive manufacturing (AM) which has caught imagination of designers and materials scientists. A key attribute of AM technologies is the ability to create complex unitized structures. Similarly, friction stir welding (FSW) emerged as an enabling joining technology for high strength aluminum alloys which were classified as 'non-weldable' by fusion techniques. For any advanced manufacturing process, the cost of implementation has to be justified by gains in performance. This paradigm does not apply to enabling technologies because they shift the landscape of what is possible. In this overview talk, we will take an anatomical approach to analysis of disruptive technologies. What are the key features of the process and how these impact the microstructure-property-performance relationships? Among the fusion AM technologies, laser based powder bed technologies (LBPBT) have become very popular because of the extraordinary design advantages. Topological optimization of a component based on the stress analysis can lead to significant weight saving. While design of complex shapes with intricate lattice structures and process optimization to accomplish such parts have advanced significantly, most of the work is done with legacy alloys. Similarly, performance of FSWed high strength aluminium alloys is limited by loss of properties in heat affected zone. How can we overcome such losses? The answer lies in alloy design for specific process to create the perfect storm of breakthrough advances!

Somnath Ghosh
Johns Hopkins University, USA

Parametrically Homogenized Constitutive Models (PHCMs) for Predicting Fatigue Failure in Metallic Materials Coupling Multi-Scale Modelling with Machine Learning and Uncertainty Quantification

Fatigue failure in structural materials has been a topic of interest to researchers for decades. However, with the advent of recent research initiatives like the Integrated Computational Materials Engineering (ICME) and Materials Genome Initiative (MGI), research in this field has taken an exciting new dimension. By coupling sophisticated tools of Computational Mechanics and Computational Materials Science, these initiatives are enabling computational models to probe into the origins of cracking at multiple scales due to inhomogeneous plastic flow and follow their evolution to failure. This talk will introduce an approach to the development a multi-scale computational framework for physics-based modeling of fatigue crack nucleation and evolution, in polycrystalline metallic materials. Titanium alloys will be a specific focus in this study.

This talk will discuss a bottom-up and top-down multi-scale modeling framework for predicting fatigue crack nucleation in structures of Titanium alloys, e.g. Ti-7Al [1-4]. A parametrically homogenized constitutive model (PHCM) and a parametrically homogenized crack nucleation model (PHCNM) are developed from computational homogenization of crystal plasticity finite element simulation results performed on microstructural statistically equivalent RVEs. Bayesian inference and machine learning methods are employed to derive microstructure-dependent functional forms of PHCM and PHCNM coefficients. The PHCM is augmented with uncertainty quantification to account for model reduction errors and microstructural uncertainty. Macroscopic FE models for test specimens of Ti alloys are created by matching correlation functions of microtexture in EBSD scans. Nucleation hot-spots are identified by PHCNM in macroscopic simulations of stress-controlled dwell loading, then top-down microscopic simulations are performed to probe into the crack nucleation process. The computed distributions of nucleation life and locations follow experimentally observed characteristics of dwell effect in Ti alloys.

References

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Hamish Fraser

The Ohio State University, USA

Combining Materials Characterization and Modeling to Optimize Additive Manufacturing of Titanium Alloys

Additive manufacturing of components made of metallic alloys are produced using a feedstock (usually powders or wire) of conventional alloys. In the case of titanium alloy components, the application of essentially all industrially competitive techniques for additive manufacturing result in characteristic defects, being coarse columnar grains (in the direction of deposition), porosity, and residual stresses. This paper addresses the first of these, where the solution sought involves the development of modified/new alloys specifically for the given manufacturing process. The proposed solution involved the application of computational thermodynamics to identify which alloying additions to titanium alloys result in an increase in the freezing range of the given alloy base, such that a columnar to equiaxed transition (CET) may be effected. These alloying additions, mainly eutectoid formers, have been found, at critical concentrations, to cause a CET to occur, resulting in a relatively fine equiaxed microstructure.

Of course, the amount of required solute additions for these elements usually exceeds their solubility limit in the various titanium alloys, and, therefore, a further effort involving alloy development through heat-treatment has been required. Two types of alloys are being developed, the first with essentially identical properties as the (given) base alloy, and the second, alloys with enhanced properties. Unusually refined microstructures may be developed, and the origins (phase transformation pathways) of these have been studied. The influences of the pseudo-spinodal mechanism, metastable phases, and massive transformations are compared and contrasted. The mechanical properties of samples produced using additive manufacturing and subsequently heat-treated have been measured, and the active mechanisms of strengthening have been identified from knowledge of microstructure/property relationships developed with the aid of machine learning. These various efforts will be described during this presentation.

M Zimmermann
Fraunhofer IWS Dresden, Germany

Microstructure and Fatigue Behavior of the Laser Welded Nickel-Based Alloy 617 occ

The Nickel-based alloy 617 occ belongs to the class of high-performance materials with its high strength in combination with high ductility, high corrosion resistance and its high temperature phase stability. The alloy is generally suitable for fusion welding processes, however the thermal impact during processing can have a significant influence on the microstructure and as a consequence on the strength properties. Both carbides located at grain boundaries as well as homogeneously distributed gamma'-precipitates determine these properties. In case of the innovative process technology of laser-multi-pass-narrow-gap welding only restricted areas around the weld seam are subject of thermal impact. Hence, no severe changes in microstructure occurred. However, with increasing seam depth (> 70 mm) flaws in the form of porosities and incomplete fusion could be detected. While these type of weld defects might not necessarily be detrimental regarding the static strength of the welded joint, they certainly affect the cyclic strength. An innovative test methodology – the so-called high frequency fatigue testing – was used in order to determine the fatigue behavior of laser-multi-pass-narrow-gap weld seams. Fatigue samples were extracted from circumferential joints with the weld seam being positioned at the highest stressed volume of the sample. Load-controlled tests were executed with a resonance test system working at a test frequency of f = 1000 Hz and a stress ratio R = 0. The load levels applied were chosen according to the cyclic strength of the base material in order to reach the very high cycle regime (N ≥ 10 Mio. cycles) at room temperature. After testing all samples were subject to in-depth fractographic analyses. A good correlation between fatigue life and defect type and size could be determined. In case of flaws smaller than 0.1 mm2 the cyclic strength of the welded joint is only 10% below that of the base material.

Vikram Jayaram
Indian Institute of Science, Bangalore, India

Cantilever Bending for Accelerated Creep Testing

Creep of a cantilever in bending under steady state conditions allows the extraction of secondary creep parameters such as the stress exponent and activation energy. With the addition of digital image correlation, the potential of the technique is vastly increased. A single test is now capable of generating both primary and secondary uni-axial creep data-sets at different stresses. Tension-compression asymmetry is immediately apparent and, under certain conditions, can be quantified. Samples as small as 0.2 – 0.4 mm thickness can be readily fabricated and tested, making the technique particularly suited to residual life extension of high temperature components in service, to evaluating the effect on creep resistance of changes in alloy composition and heat treatment and, finally, to reducing the cost associated with sample weight in situations where expensive alloying elements are involved. This talk will illustrate some of the above using recent results on ferritic-bainitic boiler steels after years of service exposure, pure aluminium, titanium – aluminium alloys and lead.

B S Murthy
Indian Institute of Technology, Hyderabad

TBD

T S Sudarshan
President & CEO, Material Modification Inc., USA

Materials Solutions for Warfighter Survivability

Warfighter survivability has taken on an increasing emphasis due to the tremendous innovations that have been made in materials, processing and manufacturing techniques over the past two decades. Many difficult and traumatic situations can now be mitigated or controlled with the advances in new generations of materials, tools such as additive manufacturing and the ability to deliver solutions through nanotechnology. In this talk, various solutions for hemostasis to woundcare and pain management along with materials innovations for the warfighter in the areas of tents, uniforms, chemical resistant materials and coatings for wearables will be provided with the possibility of translating these developments for civilian use.

George F Vander Voort
Vander Voort Consulting L.L.C., USA

Determination of the Degree of Thermal Exposure to the Lower Head of the Three-Mile Island Unit 2 Nuclear Reactor Using Metallography

The accident at Unit No. 2 of the Three Mile Island nuclear reactor (TMI-2) on March 28, 1979 was the worst nuclear accident in US history and crippled the nuclear industry. An international Vessel Investigation Project was formed to assess the integrity of the vessel. But, it was not possible to remove specimens from the lower head until January – March 1990. Fourteen of the fifteen specimens removed by electrical discharge machining were from under the debris pile that accumulated on the lower head due to melting of ~19,000 kg (~45%) of the core. Specimens were previously cut from the lower head of a cancelled reactor of very similar size and design destined for Midland, Michigan. These specimens were subjected to controlled heating cycles with peak temperatures from 800 to 1100 °C for periods of 1 to 100 minutes. The initial study qualitatively compared the structures in the 15 specimens from TMI-2 to the control specimens from the Midland lower head. The writer used the same specimens and employed micro-indentation hardness traverses, electron microprobe analysis and selective etching followed by quantitative metallography (by image analysis) to obtain a far more detailed description of the thermal exposure experienced.

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