# Track 2:
# Thermomechanics and Infra-Red Imaging

*Organized by:* Janice Dulieu-Barton, University of Southampton; Fabrice Pierron, Arts et Métiers ParisTech; Rachel Tomlinson, University of Sheffield; David Backman, National Research Council Canada

## *Sponsored by the SEM Thermomechanics and Infra-Red Imaging Technical Division*

The track marks the launch of the Thermomechanics and Infra-Red Imaging Technical Division. There are 23 papers in the track including three Keynote Presentations from leaders in the field. In recent years the applications of infra-red imaging techniques to the mechanics of materials and structures has grown considerably. The expansion is marked by the increased spatial and temporal resolution of the infra-red detectors, faster processing times and much greater temperature resolution. The improved sensitivity and more reliable temperature calibrations of the devices have meant that more accurate data can be obtained than were previously available. The purpose of the track is to bring together novel work on all aspects of thermomechanics with the focus on the application of infra-red imaging approaches. The main thrust of the session will be on the analysis of thermomechanical behavior of materials and using this behavior to elicit information on material characteristics, stresses and failure. Of particular interest are strong thermomechanical couplings that result in nonlinear behavior such as viscoelasticity, diffusivity and material phase changes. An objective is to share experience on how data-rich experimental mechanics can help scientists and engineers to better understand and simulate the behavior of materials and structures. It is also envisaged that papers utilizing other imaging techniques in conjunction with infra-red approaches will be a key part of the track program enabling cross-fertilization over disciplines and applications. The track takes place over six sessions covering high speed thermography, multiscale thermodynamic couplings, thermography in fatigue and damage assessment, application to composite materials and thermoelastic stress analysis. In the final two slots of the track there will be a wrap up and future research directions panel discussion session.

## Keynote Presentation:

**Guruswami "Ravi" Ravichandran**
California Institute of Technology

Wednesday, June 15 • 9:00 AM • Session 52

### *High Speed Thermal Imaging in Dynamic Behavior of Materials*

A review of high speed thermal imaging techniques including point, line and full-field infra-red measurements and their applications in studying problems related to dynamic behavior of materials is presented. The development of a full field infra-red thermal imaging systems capable of taking 1 million frames/s is described and is contrasted with the existing commercial systems. Several examples of applications of thermal imaging in dynamic fracture and shear banding are discussed. The temperature field evolution in real time during the initiation and propagation of cracks and shear bands in ductile metals is highlighted. Such measurements have provided quantitative and qualitative insights concerning the dynamic failure of metals at high loading rates. The challenges and opportunities in high speed thermal imaging for applications in experimental mechanics are discussed.

**Guruswami Ravichandran** is the John E. Goode, Jr. Professor of Aerospace and Professor of Mechanical Engineering, and Director of the Graduate Aerospace Laboratories (GALCIT) at the California Institute of Technology. He received his B.E. (Honors) in Mechanical Engineering from the University of Madras, Sc.M. in Engineering and Applied Mathematics, and Ph.D. in Engineering (Solid Mechanics and Structures) from Brown University. After a year of post-doctoral work at Caltech, he joined the faculty of the University of California, San Diego in 1987 and returned to Caltech in 1990 as a faculty member. He is a Fellow of the ASME and SEM. His awards and honors include, B.J. Lazan and M. Hetényi Awards from SEM and Charles Russ Richards Memorial Award from Pi, Tau, Sigma and ASME. He is the recipient of a Doctor honoris causa (*Dhc*) from Paul Verlaine University (Metz, France). His research interests are in dynamic behavior of materials, micro/nano mechanics, shock waves, composites, active materials, biomaterials and cell mechanics, and experimental methods. He has served as an associate editor of SEM's Journal, *Experimental Mechanics,* and ASME's *Journal of Engineering Materials and Technology*.

## Keynote Presentation:

**André Chrysochoos**
Montpellier University

Wednesday, June 15 • 2:30 PM • Session 68

### *Energy Balance Properties of Steels Subjected to High Cycle Fatigue*

This paper presents an experimental protocol developed to locally estimate different energy balance terms associated with the high cycle fatigue (HCF) of steels. Deformation and dissipated energy are respectively derived from displacement and temperature fields obtained using digital image correlation (DIC) and quantitative infrared thermography (QIRT) techniques. The combined processing of visible and infrared images reveals the precocious, gradual and heterogeneous development of fatigue localization zones. It also highlights the plastic character of dissipative heat sources (i.e. proportional to the loading frequencies), and the progress of fatigue dissipation, observing the drift of the mean dissipation per cycle for a given loading. The substantial of internal energy variations during HCF loading are finally underlined. The paper ends with a discussion on the consequences of such energy balance properties in terms of HCF modeling.

**André Chrysochoos** is currently Professor of Mechanical Engineering at the Montpellier University. He received his PHD in 1983 from Montpellier University and defended his "state thesis" in 1987. After a six years period of work at the National Center of the Scientific Research (CNRS), he joined the University of Montpellier in 1989. His awards and honors include, the CNRS Bronze Medal for Excellence in Research and the Applied Research Award ADER-ANVAR for innovative research technology, both in 1988. He became a member of the "Institut Universitaire de France" in 1997 and received the Ernest Dechelle Prize awarded by the French Academy of Sciences in 2002. His research concerns experimental and theoretical aspects of thermomechanical behaviour of solid materials. He developed a quantitative infrared analysis of dissipative and coupling phenomena and used, in parallel, digital image correlation techniques to perform local energy balance associated with heterogeneous deformation processes. He currently serves as a member of the editorial board of the journal *Annals of Solid and Structural Mechanics*.

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Keynote Presentation:

**Takahide Sakagami**
Kobe University

Thursday, June 16 • 9:00 AM • Session 84

## *Successful Application of Thermoelasticity to Remote Inspection of Fatigue Cracks*

A new remote nondestructive evaluation technique based on thermoelastic temperature measurement by infrared thermography was developed for the evaluation of fatigue cracks in steel bridges. Fatigue cracks were detected from localized thermoelastic temperature changes at crack tips due to stress singularities generated by wheel loading from traffic on a bridge. Self-reference lock-in data-processing technique and motion compensating technique were developed to improve the thermal images obtained in the crack detection process. Advantages and limitations of the proposed nondestructive evaluation technique were discussed based on results of field experiments for highway bridges.

Thermoelastic stress analyses in the vicinity of crack tips were also carried out after the crack detection process by self-reference lock-in thermography. The stress distribution under wheel loading by traffic was measured by infrared thermography. Stress intensity factors were evaluated from measured stress distribution. It was found that these fracture mechanics parameters can be evaluated with reasonable accuracy by the proposed technique, enabling the assessment of structural integrity based on the evaluated fracture mechanics parameters.

**Takahide Sakagami** is a professor in the Department of Mechanical Engineering, Graduate School of Engineering, Kobe University. Prof. Sakagami graduated from Osaka University in 1983, and received his PhD from Osaka University in 1988. He has held JSPS Research Fellowships for Young Scientists from 1987 to 1988, was a Research Associate of Osaka University from 1988 to 1994, Associate Professor of Osaka University from 1994 to 2009, and Professor of Kobe University from 2009. Prof. Sakagami is a Fellow of JSME (The Japan Society of Mechanical Engineers). He has been Chairman of Research Committee on Infrared Thermographic NDT in JSNDI (1996-2000, 2006-2010), Chairman of Research Committee on Tank Global Diagnosis Optimization from 2004 to 2005, and Chairman of Research Committee on Tank Strategic Maintenance System in 2006. Prof. Sakagami's Research interests are: Nondestructive evaluation by infrared thermography, Inverse problems related to nondestructive evaluations, Material evaluation based on dissipated energy and thermoelastic stress measurement using infrared thermography, Nondestructive material evaluation based on terahertz wave and infrared spectroscopy.