ABSTRACTS OF THE
57TH ACOUSTIC EMISSION WORKING GROUP
MEETING

MAY 13-15, 2015 UNIVERSITY OF ILLINOIS CHICAGO

HOST & PROGRAM CHAIR
DIDEM OZEVIN
University of Illinois Chicago
57th Acoustic Emission Working Group Meeting
May 13-15, 2015
University of Illinois Chicago

Host & Program Chair
Didem Ozevin, University of Illinois Chicago
Department of Civil and Materials Engineering

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Web Site
Jochen Vallen, Strategic Entrepreneurship Consulting

Local Meeting Organization Committee
Zeinab Abbasi
Minoo Kabir
James Kelly
Amir Mostavi
Hossain Saboonchi
Lu Zhang

Society Web Site
www.aewg.org
The first Acoustic Emission Working Group meeting was held in Idaho Falls on February 8, 1968. The AEWG meeting provides opportunities for the AE researchers, instrumentation developers, users, equipment and service suppliers to meet and discuss their research, development and application studies in the field of AE. The 57th AEWG meeting addresses current progress in AE including applications, new sensor/instrument development, and basic research results:

- New Acoustic Emission instrumentation and sensors (chaired by Mark Carlos)
- Acoustic Emission for materials/structure damage mechanics (chaired by Dr. Antonios Kontsos)
- Acoustic Emission applications for large scale structural and materials testing (chaired by Dr. David Kosnik)
- Acoustic Emission applications for damage detection in composites (chaired by Dr. Jonathan Awerbuch)
- Acoustic Emission applications in metals (chaired by Dr. Adrian Pollock)
- Wave propagation modeling of Acoustic Emission (chaired by Dr. Marvin Hamstad)
- Acoustic Emission for continuous source monitoring (chaired by Hartmut Vallen)

The presentations at the AEWG meeting represent cutting-edge research on AE, advanced instrumentation and current AE applications. In addition to technical presentations, the AE companies will present their state-of-the-art sensors and data acquisition systems.

The sponsors of the 57th AEWG meeting are:

- AE Corporate Sponsors: Vallen Systeme, Mistras Group (also known as Physical Acoustics Corporation), ATG (Acoustics Technology Group), Soundwel Technology Co. Ltd, and CTL Group
- Department of Civil and Materials Engineering, University of Illinois at Chicago

The organizers appreciate the support of the sponsors.

Didem Ozevin
Program Chair AEWG-57
### Tuesday, May 12, 2015 Chicago Marriott at Medical District/UIC

| 6:30–9:00 PM | AEWG Registration and Welcome Table |

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**Chairman Mark Carlos (Mistras Group Inc.)**  
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| S1-2 | 8:30-8:50 AM | Face-to-Face Calibration of AE Sensors: Modeling and Simulation. **J. Koduru and A. Pollock.** |
| S1-3 | 8:50-9:10 AM | Multi-sensor MEMS Device: Acoustic Emission and Strain Sensors. **H. Saboonchi and D. Ozevin.** |
| S1-4 | 9:10-9:30 AM | Fiber Optic Based Multi-Point Acoustic Emission Monitoring of Hybrid FRP Post Tensioned Concrete Beams. **Y. Liang and F. Ansari.** |
| 9:50-10:20 AM | Coffee Break |
| **10:20 -12:00 PM** | **Session 2 - Acoustic Emission for Materials/ Structure Damage Mechanics**  
**Chairman Professor Antonios Kontsos (Drexel University)**  
<p>| S2-1 | 10:20-10:40 AM | Microstructurally-Driven Validation &amp; Quantification of Acoustic Emission due to Twinning in Magnesium. <strong>M. Cabal, B. Wisner, K. Baxevanakis, J. Hochhalter and A. Kontsos.</strong> |
| S2-2 | 10:40-11:00 AM | A Forward Model for Fracture-Induced Acoustic Emission. <strong>J. Cuadra and A. Kontsos. Student Paper</strong> |
| S2-3 | 11:00-11:20 AM | The Forward and Backward Problems in Plates - Waveforms and Spectrograms. <strong>A. A. Pollock.</strong> |</p>
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<td>Z. Sun, N. Farace, W. G. Buttler and H. Reis.</td>
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**1:00-2:40 PM**  
**Session 3: Acoustic Emission Applications for Large Scale Structural and Materials Testing.**  
Chairman Dr. David Kosnik (CTL Group)

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**Special Session: Acoustic Emission Instrumentation Presentations**  
Chairman: Professor Tomoki Shiotani (Kyoto University)

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**4:10PM**  
**Departure for Boat Tour**

**5:15PM**  
**Chicago Architecture via Boat Tour**

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S7-3  Application of Wavelet on Acoustic Emission Location of Pipeline Leakage
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Sensor and Waveguide Characterization using a known Displacement Source

Kanji Ono¹ and H. Cho²

¹Department of Materials Science and Engineering, University of California, Los Angeles (UCLA), Los Angeles, CA 90095 United States
²Aoyama Gakuin University, Sagamihara, Japan

We have refined displacement-based characterization of AE sensors by using an impulse in lieu of step-down pulse. This change makes the low frequency response more reproducible. By using a broadband KRN sensor as a receiver, improved characterization of waveguides became feasible. Here, we report responses of waveguides of different diameters from 1/16” to ½”. It is found that the low-frequency part of L(0,1)-mode rod waves is increasingly suppressed above ¼” diameter, while stretching a short-duration (~1 µs) source into a long pulse of more than 100 µs. At larger diameters, F(1,1)-mode becomes the dominant one. To keep the pulse duration short, it is necessary to keep the waveguide diameter below 1/8”, preferably at 1/16”. Hamstad previously recommended this approach and the Harwell group used 1-mm diameter waveguide in the 1980s. However, in practice, it is inconvenient to mount a sensor. Thus, a compromise must be sought between pulse definition and convenience in the use of a waveguide.

Face-to-Face Calibration of AE Sensors: Modeling and Simulation

Jaya Koduru and Adrian Pollock

MISTRAS Group Inc., Princeton Junction, NJ 08550

Calibration of Acoustic Emission (AE) sensors is essential to ascertain the fitness of the sensors for AE testing and also for quality assurance in a production environment. Pressure calibration, following the reproducibility standards set in ASTM E 976, enjoys widespread support from several AE sensor manufacturers for its simplicity and insight it provides into a sensor’s frequency response. The technique employs the impingement of longitudinal waves on the sensor face; its frequency response (power spectrum) is plotted. The waves impinging on the sensor face are usually swept in frequency, typically with a chirp signal of a prescribed bandwidth. The calibration process can be modelled utilizing Finite Element Modeling (FEM) techniques. This leads to a better understanding of the process and the sensor response. The simulation tools can help to simplify the design of sensors for present and future requirements, and can also help to establish the technical merits of the calibration process employed. In this presentation, the setup of the simulation tools for replicating the calibration process will be discussed, and a comparison will be made between the model-simulated and experimentally measured sensor responses.

Multi-sensor MEMS Device: Acoustic Emission and Strain Sensors

Hossain Saboonchi and Didem Ozevin

Department of Civil and Materials Engineering, University of Illinois at Chicago, Chicago, IL, USA

Micro-electro-mechanical systems (MEMS) have diverse manufacturing capabilities to design and manufacture various sensing elements in order to monitor various mechanical behaviors in structures. In this study, piezoresistive strain sensors are integrated with capacitive acoustic emission sensors on a small footprint device. The integrated sensing allows redundant data measurement from a given point in order to increase the reliability of Structural Health Monitoring.
(SHM). In this study, the strain sensor is designed with the principle of piezoresistivity property of polysilicon, and has superior gauge factor as compared to conventional metal gauges. For the design of strain sensor, trenching concept is implemented to increase the strain transfer, and strain-free resistance is limited near to 350 Ω in order to use conventional Wheatstone bridge data acquisition systems designed for foil gauges. The strain transfer through the layers of MEMS package is evaluated using numerical models. The responses of strain sensor under monotonic and cyclic mechanical loads are evaluated in comparison with conventional metal gauges. The temperature sensitivity of strain sensor is evaluated using thermal load cycles. The acoustic emission sensors are designed with the principle of capacitance change under dynamic excitation, and tuned to 60 kHz and 150 kHz via changing spring geometry. The MetalMUMPs (Multi-User-MEMS-Processes) are implemented to manufacture the sensors on 1 cm x 1 cm device area. The concurrent performance of MEMS strain sensors and acoustic emission sensors is tested under cyclic loading of notched aluminum specimen. The strain sensor strengthens the interpretation of complex acoustic emission data via monitoring driving force and allowing on-chip data filtering in order to process the data recorded from high stress levels.

S1-4 Fiber Optic Based Multi-Point Acoustic Emission Monitoring of Hybrid FRP Post Tensioned Concrete Beams

Yujin Liang and Farhad Ansari

Department of Civil and Materials Engineering, University of Illinois at Chicago, Chicago, IL, USA

Development of a serially multiplexed fiber-optic acoustic emission (AE) sensor is described. The sensor detects AE events in real time at two different points along a single length of an optical fiber. The time-domain waveform contains signals from the two locations, and a method is introduced for identification of the signals. Detection and identification of signals along a single data stream reduces the data-acquisition rigor and provides for rapid real-time damage location detection in materials. The sensor consists of two optical fiber coils along an arbitrary length in a Michelson interferometer arrangement. The experimental program involved proof of concept tests by way of damage location detection along the lengths of individual hybrid FRP rods. The experimental program included direct tension tests for detection of damage locations in the FRP rod as well as tests on post tensioned concrete beams with FRP rods. Conventional piezoelectric transducers were also employed for comparison of results.

S1-5 Wireless Remote Monitoring of Alkali-Silica Reaction using Acoustic Emission

Mohamed K. ElBatanouny1, Marwa Abdelrahman2, Paul Ziehl2, Jeremiah Fasi3, Carl J. Larosche3, and John Fraczek1

1Wiss Janney Elstner Associates Inc., 330 Pfingsten Road, Northbrook, IL 60062
2Department of Civil and Environmental Engineering, University of South Carolina, 300 Main Street, Columbia, SC, USA, 29208
3Wiss Janney Elstner Associates Inc., 9511 N. Lake Creek Parkway, Austin, TX 78717

Alkali-silica reaction (ASR) is a degradation mechanism that generates internal cracks in concrete material as a result of volumetric expansion. Many structures in the United States are currently affected by ASR including the Seabrook Nuclear Power Plant which brought this type of degradation of reinforced concrete to the attention of the general public. ASR depends on material selection of the concrete matrix and permits few mitigation techniques once the structure is in service. Therefore, there is a pressing need for a health monitoring method that is capable of detecting and quantifying the rate of ASR induced degradation.
Acoustic emission (AE) has the ability to detect micro-cracks as it is highly sensitive to stress waves emitted from sudden release of energy. AE is a passive method of structural health monitoring that enables real-time monitoring which makes it a suitable candidate for ASR detection both in periodic maintenance inspection and long-term monitoring and prognosis. This presentation discusses the results of an ongoing wireless remote monitoring test program that is conducted in collaboration with Texas Department of Transportation. The test includes four specimens with dimensions 14x14x14 inches. Three specimens were cast using specially designed concrete mix to accelerate ASR damage while the last specimen served as control. The specimens are placed in field setting to examine the effect of ambient environmental conditions (rain, wind, and others) on the AE data. ASR damage is examined using expansion measurements along with continuous AE monitoring. The results of this study show that AE can detect micro-cracks forming as a result of ASR damage and classify the degree of damage in the specimens.

S2-1  Microstructurally-Driven Validation & Quantification of Acoustic Emission Due to Twinning in Magnesium

Michael Cabal¹, Brian Wisner¹, Kostantinos Baxevanakis¹, Jake Hochhalter², and Antonios Kontsos¹

¹Department of Mechanical Engineering & Mechanics, Drexel University, Philadelphia, PA 19104, USA
²Durability, Damage Tolerance, & Reliability Branch, NASA LaRC, Hampton, VA 23681, USA

To understand microstructure-specific mechanisms responsible for local (micro) plasticity, as well as crystallographic reorientations in magnesium alloys caused by mechanical loading, Acoustic Emission (AE) monitoring and in-situ mechanical testing were combined inside a Scanning Electron Microscope (SEM). Two modified textures were developed by an in-house thermomechanical process in order to provide twin-prone and twin-free samples upon tensile loading. Controlled specimen geometry provided an a priori defined strain localization zone that assisted in minimizing the unknowns and validating/quantifying the in situ recorded AE data. Using electron back scattered diffraction (EBSD) measurements, quantification of surface twins inside the strain localization zone is reported, which provided the means to implement a microstructurally-validated and feature-based AE analysis, including classification.

S2-2  A Forward Model for Fracture-induced Acoustic Emission

Jefferson Cuadra¹, and Antonios Kontsos²

¹Ph.D. Candidate and ²Assistant Professor
Mechanical Engineering & Mechanics Department, Drexel University, Philadelphia, PA

The characteristics related to crack initiation and other similar acoustic emission (AE) sources are potential indicators of the material damage state and the associated structural integrity. However, these micro- and macro-mechanisms result, given the current state of available acquisition equipment, in convoluted AE signals due to complex geometrical effects, material nonlinearities, in addition to other unwanted noise sources. Thus, development of advanced tools for understanding and quantifying AE is of great importance to address current challenges including the insufficient evaluation and validation of experimentally recorded AE signals. In this context, the forward problem of simulating AE activity is addressed herein by proposing computational finite element models (FEM) for fracture-induced AE generation and propagation. To this purpose, AE is viewed as part of the dynamic process of energy release caused by crack
nucleation which includes the stages of incubation and initiation but not subsequent crack growth. To form the computational approach, full field experimental information including material point coordinates and related deformation maps obtained by using the Digital Image Correlation (DIC) method is used to construct constitutive laws, such as a cohesive law used as crack initiation criterion, and to define other damage related parameters (i.e. plasticity zone size ahead of the pre-existing notch). Subsequently, 3D FEM simulations based on such experimental data are implemented using the extended finite element method (XFEM) to create an initial failure. Numerically simulated AE signals from the dynamic response due to the onset of damage are then evaluated in the setting of the inverse problem of source identification and localization, creating in this way the tools for AE signal processing similar to experimental investigations. The results successfully demonstrate material and geometry effects in fracture-induced wave propagation simulations and create a pathway for the quantitative comparison between experimental and theoretical predictions of AE. Furthermore, investigations on the effect of plasticity on simulated travelling waves ahead of the crack tip were performed and revealed nonlinear interactions that had been postulated to exist. Finally, the computational model is used to provide quantified measures of the energy release associated with crack initiation.

S2-3 The Forward and Backward Problems in Plates - Waveforms and Spectrograms

Dr. Adrian A. Pollock

MISTRAS Group Inc., Princeton Junction, NJ 08550

Presented here is an exploration of theoretical waveforms in plates, generated by a program called PlotRLQ, and their spectrograms. Program variables include not only the plate material, thickness and source-sensor distance but also the through-thickness position of the source and the moment tensor. The solution of the forward problem (implemented for out-of-plane motion) can be a valuable tool for addressing the harder, backward problem (i.e. how to determine the source’s through-thickness position and moment tensor from the observed waveform). In this presentation, waveforms and spectrograms will be shown for a variety of cases, along with comments on the backward problem.

S2-4 Reliability and Sensitivity of Acoustic Emission Sensing Systems for Damage Detection

Afshin Zahraee, Mehdi Modares, and Jamshid Mohammadi

Department of Civil, Architectural and Environmental Engineering, Illinois Institute of Technology, Chicago, IL, USA

Acoustic Emissions (AE) is the most used nondestructive technique for monitoring large structures. While AE can physically be measured with a high degree of accuracy, reliable algorithms that process raw data and produce information for decision making are still under investigation. Two components are required in an acoustic monitoring system: a material deformation that becomes the source and the transducers that receive the stress waves generated from the source. While the AE technique yields advantages of local, global, remote and continuous monitoring, the disadvantage and uncertainty of separating real-time background noise is prominent. Due to variations between sensors along with proximity sources of measurement, improvements on the signal to noise ratio must be achieved. Damage induced acoustic emission signals contain frequencies around 150 kHz, while environmental noise produces less than 50 kHz. Through proper filtering and accurate probabilistic modeling, damage induced acoustic emission is likely to be detectable even in the presence of environmental noise. The ambiguity in measurements causes a systematic uncertainty as well. Increase in computation performance has allowed researchers to include uncertainty in numerical models. Additionally, a
framework based on multisensory data fusion algorithm has been proposed by researchers for the real-time AE source localization and wave velocity estimation in the isotropic plate-like structures, in a highly noisy environment. This paper provides an overview of significance of these sources of uncertainties specific to fatigue damage. The review of uncertainty covers those that pertain to the AE measurements as well as to the host system mechanical properties.

S2-5  **Quantitative Evaluation of Rejuvenators to Restore Embrittlement Temperatures in Oxidized Asphalt Mixtures using Acoustic Emission**

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Towards developing a method capable to assess the efficiency of rejuvenators to restore embrittlement temperatures of oxidized asphalt binders towards their original, i.e., unaged values, three gyratory compacted specimens were manufactured with mixtures oven-aged for 36 hours at 135 °C. In addition, one gyratory compacted specimen manufactured using a short-term oven-aged mixture for two hours at 155 °C was used for control to simulate aging during plant production. Each of these four gyratory compacted specimens was then cut into two cylindrical specimen 5 cm thick for a total of six 36-hour oven-aged specimens and two short-term aging specimens. Two specimens aged for 36 hours and the two short-term specimens were then tested using an acoustic emission approach to obtain base acoustic emission response of short-term and severely-aged specimens. The remaining four specimens oven-aged for 36 hours were then treated by treating their top surface with rejuvenator in the amount of 10% of the binder by weight. These four specimens were then tested using the same acoustic emission approach after two, four, six, and eight weeks of dwell time. It was observed that the embrittlement temperatures of the short-term aged and severely oven-aged specimens were -25 °C and -15 °C, respectively. It was also observed that after four weeks of dwell time, the rejuvenator-treated samples had recuperated the original embrittlement temperatures. In addition, it was also observed that the rejuvenator kept acting upon the binder after four weeks of dwell time; at eight weeks of dwell time, the specimens had an embrittlement temperature about one grade cooler than the embrittlement temperature corresponding to the short-term aged specimen.

S3-1  **Acoustic Emission Testing Services – Success over Decades in the LPG Business**

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The way of performing the requalification of liquefied petroleum gas (LPG) tanks has improved tremendously with the help of acoustic emission testing in past decades. In the old days the common practise for this activity consisted in Europe mostly of a combination of traditional methods like hydraulic testing, visual inspection (inside and/or outside), wall thickness measurements and others. Those procedures were far away from being convenient for the tank operator/owner and led to substantial interruptions of tank operation. Just to give an example, it was routine in some countries - and maybe it is still routine in some others - to excavate underground tanks located in backyards at the time when the service period was about to expire and exchange them with new or refurbished ones. Beside the inconveniences caused by the
application of traditional methods, the economic drawback was considerable high (long duration, manpower, disposal of polluted water, transport of tanks, etc.). Thus, the LPG companies were the main drivers to identify an alternative solution, which is cost-effective, leads to less interference of service and at the same time results in improved safety of the installation. Since the LPG tank population is huge and the design of the tanks is similar, acoustic emission testing was identified to be a candidate for such an alternative. And it was proven by hundred thousands of successfully performed tests over the decades that it was the choice. TÜV AUSTRIA was among the first testing organisations, which developed a testing technique in the late 1980s for LPG tanks with a capacity till to 13 m³. The experience gained in the field during the first years of application on small tanks supported the improvement of the technique so that it was suited for testing tanks - even underground - with a capacity up to 1000 m³ and more.

This contribution highlights the key features of the employed testing techniques being in line with the European standards EN 12817 and EN 12819, shows some examples of acoustic emission tests performed in the past and gives an overview on statistical evaluations of data gathered from tests performed in Portugal, Spain, Italy, Austria, Germany and many other European countries.

**S3-2 Challenges and a Solution Approach for Permanent AE Monitoring of an Aboveground Storage Tank**

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Detection and location of leakage and corrosion at the floors of aboveground storage tanks (AST) is a more and more establishing application of the acoustic emission testing (AT) method. In some countries this type of testing is carried out as a substitution of an internal inspection. In fact, the results of an AT is sometimes influenced by randomly occurring external disturbances, like wind, rain, temperature change, and more. The reliability of the results of a short time AT, that usually lasts only one or few hours, is still disputed. It can be improved, when acoustic emission equipment for leak and corrosion testing is permanently installed. A permanent installation of equipment with the ability to continuously collect and analyse not only AE data but also environmental conditions, like weather, wind speed, temperature, etc., creates new challenges for the autonomous operation of hardware and software.

This presentation is based on the realisation and a one year operation of a prototype permanent monitoring installation for leak and corrosion detection of an aboveground storage tank.

**S3-3 Evaluation of Aggregation Areas in RC Decks with Secondary AE Activity**

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In bridge decks asphalt-paved RC slabs have been employed commonly in Japan as well as on the east coast of US. Deterioration of the RC bridge deck appeared to commence through the initial cracks with numerous traffic loads. Rainfall and resultant permeation of water via the cracks evolve the damage of RC decks. In addition spray of antifreezing agent containing calcium chloride during winter accelerates the damage of RC decks as it introduces corrosion of reinforcing iron bars leading to numerous tensile cracks around rebar. As for the final form of this deterioration, punching shear failure can be found in the bottom surface of the decks. Based on
these failure processes of the RC decks, replacement program for the deteriorated RC decks has been proposed. However, as known currently this kind of corrective maintenance takes much more cost than that of proactive, evaluation of early deterioration, specifically with non-destructive ways, is becoming a crucial issue. Aggregation of surface concrete just beneath the asphalt layer can be a clue to know the earlier deterioration form than final one. In this presentation preliminary study to examine or visualize the aggregation areas with secondary AE activity will be demonstrated. Model RC decks w/wo aggregation is subjected to uniaxial compression with attaching different resonant frequency types of AE sensors. Applicability of AE technique for on-site investigation of aggregation areas is discussed in terms of applied load, energy of AE and attenuation depending on the sensors’ type.

S3-4  A Proposed Methodology for the Real Time Monitoring of Concrete Fracture using Quantitative Acoustic Emission

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Advisor: Thomas Schumacher, PHD

The world-wide ageing and deteriorating civil infrastructure network has necessitated the development of new Structural Health Monitoring (SHM) approaches that are capable of producing quantitative feedback on fracture mechanisms in critical civil structures such as bridges in real-time. In this paper, a methodology that combines techniques applied in quantitative seismological analyses with the enabling capabilities of the Acoustic Emission (AE) technique in order to gain insight into ongoing fracture processes in concrete structures is presented. The proposed methodology employs the technique of Moment Tensor Inversion (MTI), a key analysis tool in seismology, in order to develop a full understanding of the physics of the source of fracture and infer its properties. The MTI technique is a quantitative method used to invert recorded surface displacements generated within a test specimen due to ongoing rapid internal strain releases in order to identify and characterize the sources of AE within this specimen.

S3-5  AE Leak Rate Prediction: Some New Applications to Control Valves

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For decades, acoustic emission measurements with handheld leak rate meters have been used to identify valves in need of repair or replacement by determining if internal leaks are above the allowable tolerance for the valve. However, in-service control valves (i.e., throttling, as opposed to open/closed valves) generate AE through other mechanisms that have implications for valve performance. In this talk, studies on two other potential applications of AE leak rate meters to control valves are discussed: (1) reversal of spring-loaded seal rings, and (2) leakage through valve body castings.

Certain control valve seals include directional springs to enhance sealing. These springs are typically replaced multiple times over the valve’s service life; occasionally, springs are installed backward by mistake. While such installation errors are rare, they have substantial consequences because the error is typically not detected until after the installation team has departed. Results from correct and opposite seal direction show dramatically different AE responses. Use of AE measurements to immediately correct such installation problems will be discussed.

Control valve bodies are typically castings that are much more robust than the surrounding pipe. Due to complex geometries, weld repair on the casting is usually required. Some valve body
designs are susceptible to leakage due to specific characteristics of the casting and weld repair. In evaluation of different screening methodologies, AE leak detection behavior and leak rate prediction methods were employed. These studies differ from typical AE valve leak detection in two ways: (1) the valves are blocked, and thus leak rate is determined from pressure loss, and (2) helium, a fluid more commonly used in leak detection than in commercial application of control valves, is used to test the castings. This method will be compared to conventional leak rate predictions.

S4-1  Modeled Transverse Surface AE Signals from Buried Dipole Sources in a Polymer Rod

Marvin A. Hamstad

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Finite element modeling (FEM) was used to study the AE signals generated from internal radially-oriented dipole sources in a long PVC rod. The rod had a diameter of 8.5 mm and a total length of 600 mm. A large number of cells (9.2 x 10^6) were required to provide the necessary resolution. The out-of-plane AE signals versus time (up to 280 µs) were obtained at 90 mm and 120 mm from the sources. At each propagation distance, a total of 16 pseudo sensors were equally spaced around the circumference. A pencil lead break on the end of the rod was used to partially validate the FEM results and to determine appropriate filtering for the signals. Group velocity curves were calculated for both symmetric and antisymmetric modes. The antisymmetric modes are more complicated for a rod having both a circumferential order as well as a series of modes for each circumferential order. After filtering with a 8 kHz high pass filter, a 80 kHz low pass filter was applied to correspond to expected results from such a polymer. Along with the signals, fast Fourier transform (FFT) and Choi Williams distribution (CWD) results were obtained. Three dominant modes were identified using the group velocity curves: L(0,1) symmetric, F(1,1) antisymmetric and F(2,1) antisymmetric. The relative dominance of these modes changed with the angle from the radius to the source to the sensors. By use of the results from the multiple sensors the modal pattern of the outside surface was determined for each dominant mode along with the amplitude dependence as a function the angles to the sensors. Also, the dependence of the signal amplitudes of the modes was determined by placing the dipole center at four different distances from the axis of the rod.

S4-2  Two-dimensional Elastic Wave Velocity Tomography and AE-Tomography for Anisotropic Materials

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The authors have been studied on tomographic techniques as well as AE-Tomography for the evaluation of structural integrity. We have focused on structures of the isotropic materials in these techniques since the materials on civil engineering, e.g. concrete, have been handled as the isotropic materials in general. However, in recent, the use of anisotropic materials, e.g. FRP, are spreading to the field of civil engineering as thin and tough materials, and its evaluation of integrity is now a significant challenge to keep its safety and serviceability during its service period. Thus, the authors propose new techniques of elastic wave velocity tomography and AE-Tomography for the evaluation of integrity of anisotropic materials in this study. Anisotropic elastic
wave velocity profile is used to represent the anisotropy, and the profile is applied for ray-trace. This enables to consider the anisotropy on the computation of first travel time as well as the identification of AE source location and elastic wave velocity distribution on elastic wave velocity tomography and AE-Tomography. The proposed technique is verified by executing a series of numerical investigations, and its applicability is discussed with regards to the accuracy of the identified elastic wave velocity distribution.

S4-3 Using Acoustic Emission and Electrical Resistivity to Assess Freeze-Thaw Damage in Concrete

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This paper discusses a series of electrical measurements made on cementitious mortars containing water-NaCl solutions (0% to 23.3% concentration by mass) over temperatures in the range of 23 °C to -35 °C. Electrical impedance spectroscopy, acoustic emission, and thermal measurements were made during cooling and heating to detect phase changes and resulting damage. The influence of the degree of saturation (DOS) and NaCl solution concentrations are examined. Three phase changes were detected: 1) eutectic phase change (~ -24 °C), 2) ice/water phase change (~ -4 °C to -4 °C), and 3) chemical phase change (~ -4.5 °C to -5.5 °C). While the resistivity is highly dependent on changes in temperature, a drastic increase in resistivity is observed during freezing. Additionally, a comparison of specimens above and below the critical DOS (i.e., the DOS required for damage to occur) shows that resistivity measurements may be used to quantify damage in addition to acoustic emission measurement.

S4-4 Ultrasonic Scattering Measurement of Air Voids Distribution in Early-Stage and Hardened Concrete Samples

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The size distribution of air voids in concrete has significant impacts on freeze-thaw damage. Some deteriorations are caused by the filling of air voids with secondary cementitious materials or the lack of smaller entrained air voids, and thus leading to inadequate spacing factors. This study presented a non-destructive ultrasonic scattering technique to determine the air void size distribution in early-age and hardened concrete. The ultrasonic scattering theory were applied to calculate the theoretical attenuation of concrete by including the effects of viscoelastic matrix and different sizes of air voids and aggregates. The air void size distribution will be obtained by using inverse analysis to minimize the difference between theoretical and experimental attenuation of concrete. The air void measurement on hardened concrete was favorably compared with the petrography-based ASTM C 457 method. The logarithm normal distribution for entrapped air
voids and normal distribution for entrained air voids were selected to better represent the air void size distribution in concrete. The air void content of early-age concrete were also favorably compared with the gravimetric-based ASTM C138 for fresh concrete. The evolution of air void size distribution of early-age concrete showed that the total air content reduced and the sizes of some small air voids increased with curing time. These results indicated that the developed ultrasonic scattering technique can measure the size distribution of air voids in concrete and can be potentially applied as a quality control tool of concrete construction for reduced freeze-thaw damage.

S4-5  Damage Characterization in Dimension Limestone Cladding using Non-Collinear Wave Mixing of Critically Refracted Longitudinal Waves

Megan McGovern and Henrique Reis
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A method capable of characterizing artificial weathering damage in dimension stone cladding using access to one side only is presented. Dolomitic limestone test samples with increasing levels of damage were created artificially by exposing undamaged samples to increasing temperature levels of 100, 200, 300, 400, 500, 600, and 700 °C for a ninety minute period of time. Using access to one side only, these test samples were nondestructively evaluated using a nonlinear approach based upon non-collinear wave mixing, which involves mixing two critically refracted dilatational ultrasonic waves. Criteria were used to assure that the detected scattered wave originated via wave interaction in the limestone and not from nonlinearities in the testing equipment. Bending tests were used to evaluate the flexure strength of beam samples extracted from the artificially weathered samples. It was observed that the percentage of strength reduction is linearly correlated (R²=98) with the temperature the specimens were exposed; it was noted that samples exposed to 400 and 600 °C had a strength reduction of 60% and 90%, respectively. It was also observed that results from the non-collinear wave mixing approach correlated well (R²=0.98) with the destructively obtained percentage of strength reduction.

S4-6  On the Legitimacy of Acoustic Emission Methods to Identify Failure Mechanisms in Large Composite Aerospace Structures

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The propensity of large composite structures used in aerospace applications to develop a large number of internal (nonvisual) localized failures during service loading requires reliable nondestructive testing (NDT) and inspection (NDI) methods that could support damage tolerance testing and studies of such structures. The acoustic emission (AE) method relies on propagating elastic waves released by active flaws, i.e., during crack formation. This method has the potential to offer a unique advantage over other NDI techniques. The primary advantage of AE monitoring is that it could serve, in real-time, as an early warning system to alert onset of internal failures (e.g., cracks), indicate the rate of damage accumulation, and aid in approximately locating the site of damage. The overwhelming majority of studies over the past four decades on AE with small scale (laboratory) testing of composites dealt with the ability of the AE method to identify the source
mechanisms that generated AE signals. The obvious and overarching goal is to assess the state-of-damage and damage criticality at any given load level, or cycle number, thus, to estimate, in real time, residual strength, remaining life, and safe load limits. Accordingly, a great deal of effort has been placed on the ability of the AE method to identify the source mechanisms (e.g., fiber fracture, matrix cracking, delamination) that generate such AE signals embedded in big data set. The latter requires detailed waveform and wave propagation analyses. This presentation will address the difficulties confronted in interpreting the AE data generated during loading of large composite structure. These include, for example, the voluminous amount of data generated, the high rate of data accumulation, extraneous emission, and data interference. Further, depending upon circumstances, AE signals generated from identical sources may be recorded as emanating from different sources and vice-versa. The presentation will focus on these difficulties with the goal of understanding the current limitations and future opportunities.

S5-1 The Challenges of Acoustic Emission in Diagnostics AND Prognostics
Antonios Kontsos

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Acoustic emission (AE) as a nondestructive evaluation (NDE) method implemented across time and length scales, from fundamental science to demanding engineering applications, continues to spark strong enthusiasm in addition though to equally strong, in many cases, skepticism on its capabilities to both diagnose and predict existing, incipient and/or developing damage. Although this could be generally stated for several NDE methods, the advent of high resolution material characterization and structural inspection techniques combined with the increasing post-processing and computational modeling power, create (to the author’s opinion) the appropriate framework to pose a timely question: “What are the grand challenges of AE today?”. In this talk, a brief presentation of some of the important scientific origins of the AE method in conjunction with an enumeration of some of the most stimulating problems that AE has been proposed to give answers, are provided. Examples are drawn by several fields ranging from materials science to aerospace engineering, while the talk intends to create a necessary condition for a “self-check” of the related research and engineering community on the potential of the method in diagnostics and prognostics.

S5-2 Use of AE to Analyze Fatigue Induced Damage Events in Cr-Mo Steel
S. Wayne and G. Qi

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There is a critical need to develop an alternative method to understand the response of materials to random damage, especially those that occur in the early loading stages and subsequently during fatigue loading. Fracture is usually described in three stages: crack initiation, slow crack growth and fast fracture, so the first two stages in many ways determines the useful life of the material system. Microstructural damage accumulates and leads to fracture as stress is applied to the materials through various load sequences, which determines the fatigue life. Crack initiation is difficult to quantify, so the concept of threshold strength (a value below which cracks do not propagate) is typically used for safe designs. Thus a major challenge in predicting the behavior of materials under stress is relating the early stages of microstructural damage to crack initiation and growth.

To address this need, we have developed a framework of data-enabled science that is based on captured AE signals from active damage events obtained when materials are subjected to static
and dynamic loading. Evaluating the state of material damage centers around a global damage variate \( D \), which is a multivariate data matrix of random damage information with its rows and columns being observations and scale vectors, respectively, that quantifies the microstructural damage. This variate can then be analyzed by means of multivariate statistics and data mining techniques, allowing for data-enabled decision-making concerning material failure. In this presentation we present recent research findings concerning the damage response of 4340 steel to static and fatigue loading and provide some insight into the ever-changing damage state, from initiation to final fracture.

**S5-3  Acoustic Emission Events Characterization during Low Cycle Fatigue Experiments**

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The acoustic emission (AE) events during fatigue experiments are caused by various sources. Besides the fatigue crack, other sources such as noise, vibration, rubbing, and clacking may cause AE events that can be captured by the AE instrument. The objective of this study is to develop the science and understanding of how crack-generated AE wave signals can be extracted from non-crack wave signals during AE monitoring under actual operational conditions. To achieve this objective, an AE testing hardware and software platform to perform fatigue experiments with AE events capturing capability was built. The testing platform incorporates functions for monitoring, recording, and examination of fatigue loading parameter, AE event waveforms, and video of the test specimen. In the beginning of the study, low cycle fatigue experiments were carried out to understand the performance and capacity of the testing facility. During the first group of experiments, we have identified crack and non-crack AE events using multi-sensor time of flight triangulation method. The crack AE signals were coming from a 1-mm stress-concentration hole. The non-crack AE signals were coming from the grips. The triangulation done on multi-channel AE waveforms allowed the location of the AE event source on the specimen or grips. Signal analysis algorithms, such Fourier transform, short time Fourier transform, and wavelet transform are being investigated for characterizing crack and non-crack AE events in the time-frequency domain.

**S5-4  Microstructure-Sensitive Investigation of Fracture using Acoustic Emission Coupled with In Situ Electron Microscopy**

Brian Wisner, Mike Cabal, Prashanth A. Vanniamparambil, Jacob Hochhalter, William P. Leser and Antonios Kontsos

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A novel technique using Scanning Electron Microscopy (SEM) in conjunction with Acoustic Emission (AE) monitoring is presented to investigate, in a microstructure-sensitive framework, both early plastic deformation and fracture of metals. The coupling between quasi in situ microscopy with actual in situ nondestructive evaluation falls into the recently proposed Integrated Computational Materials Engineering (ICME) framework and the idea of quantitative and data-driven characterization of material behavior. To validate the use of AE monitoring inside the SEM chamber Aluminum alloy sharp notch specimens were tested both inside and outside the microscope using a small scale mechanical testing device. Load data were correlated with both AE information and microscopic observations of microcracks around grain boundaries as well as
secondary cracks, voids, and slip bands. The preliminary results are in excellent agreement with similar findings at the mesoscale following ASTM standard testing. Extensions on the application of this novel technique are discussed.

S5-5 The Busyness Concept for Checking Data Quality at High Hit Rates
Adrian A. Pollock
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In conventional hit-based AE systems, the hit process ends when the signal has been below the detection threshold for a predetermined time (the hit definition time or HDT). Ideally, each detected event in the structure will cause one hit on each channel that detects it. An undesirable situation, arising at high data rates, is when a second signal crosses the detection threshold before the end of the previous signal’s HDT. This leads to corruption of some or all of the feature measurements. “Busyness” is a useful way to estimate whether this is happening and to tell how severe is the condition. Within a given time segment of a test, “Busyness” is defined as the fraction of its time for which a channel is “busy” measuring signals. It is the sum of the accumulated duration and the accumulated dead time, divided by the length of the time segment. Busyness can be equated to the probability of a new incoming signal being falsely measured. It is thus a useful indicator of data quality. Also, it is easily plotted. Examples of the use of this concept will be presented.

S6-1 Source Types, Signal Length and Source Location (2D) Studied in a Long PVC Rod by use of Modeled AE Signals
Marvin A. Hamstad
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A study was conducted by use of finite element modeling to examine the AE signals generated by four different internal dipole source types. These sources were a radial dipole, a axial dipole and a tangential dipole, as well as, three mutually perpendicular dipoles to create a dilatation (explosion) source. The PVC rod had a diameter of 8.5 mm and a total length of 600 mm. A large number of cells (9.2 x 10^6) were required to provide the necessary resolution. The out-of-plane AE signals (up to 280 µs) were obtained at 90 mm and 120 mm from the source. The signals versus time were obtained at a total of 16 sensors spaced at 22.5 degree increments on the outer surface of the rod. Fast Fourier transform (FFT), waveform and Choi Williams distribution (CWD) results were obtained for the different source types when they were all located with their center at a nominal 1 mm from the rod axis. Also, the effect of the length of the processed signal on the FFT and the CWD results were examined. The peak amplitudes for each source type were compared to determine the relative detectability of the signals. By use of the modal shape of the F(1,1) antisymmetric mode around the circumference and its mathematical dependence on the angle to the sensors, an approach was developed to determine from just two sensors the angle of a diameter along which the source was located. The use arrival times determined by the CWD at a fixed frequency were found to correspond to the group velocity for the L(0,1) mode. Thus, sources could also be located along the length of the rod.

S6-2 Accurate Prediction of Acoustic Sensor Spacing for Leak Detection and Localization
Amir Mostavi¹, Didem Ozevin¹ and Long Feifei²
Long-range pipes can be monitored using the AE method using a limited set of sensors. The prediction of acoustic sensor spacing requires the attenuation curves of particular frequency and pipe geometry, and the input signal amplitude. The attenuation curves can be obtained using experimental or numerical models. However, modeling 3D geometry to study wave propagation in pipes due to leak requires extensive computational effort. In this paper, the axisymmetric geometry of the pipe is simplified by reducing the problem to 2D while the non-axisymmetric loading is represented by the summation of Fourier series. The numerical model allows modeling high frequency wave propagation for long-range pipes. Using the developed numerical model, a parametric study is conducted using different pipe dimensions and frequencies (from 5 kHz to 200 kHz) in order to understand the wave characteristics and the attenuation profiles. A steel pipe is built in the laboratory to understand the acoustic characteristics of different frequencies under different leak rates. The numerical results are linked with the experimental results in order to identify the accurate prediction of acoustic sensor spacing.

S6-3 Wave Propagation in Complex Geometry with Effective Finite Element

Lu Zhang and Didem Ozevin

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The spline component of gearbox structure is a critical and non-redundant element that requires early detection of flaws for preventing catastrophic failures. In this study, two Nondestructive Testing (NDE) methods (acoustic emission and ultrasonics) are combined in order to detect the presence of flaw in gearbox spline component with the improved reliability. The AE method is a direct way of detecting active flaws; however, the method suffers from the influence of background noise and location/sensor based pattern recognition method. The ultrasonic method can be implemented when the gearbox is not operational; however, the method is limited by the flaw size and orientation. The gearbox spline geometry is simplified as a planar geometry, and dynamic finite element model is conducted. In the FE model, piezoelectric sensor model was introduced. Electricity signal generated by PZT sensor was used as input, which is the same as the experiment. The multiphysics process between mechanics (flattened bevel) and electrical (PZT sensor) was simulated. The influence of notch on the propagating elastic waves is numerically shown, and experimentally validated. Once the model is validated, the wave propagation and transfer properties in the complicated geometry could be obtained numerically.

S6-4 Integration of Metamaterials and MEMS to Block Friction Emissions

Minoo Kabir and Didem Ozevin

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A new innovative technique for detecting sub-millimeter crack growth in large-scale structural systems is introduced, based on focusing the wave energy released by the newly formed crack surfaces. The wave field focusing will be accomplished by newly designed-artificially created and acoustically tuned-metamaterial passive device, patched to the monitored structure. This metamaterial patch will provide stop bands to restrict propagation of selected frequencies, by its optimal periodic structural/material arrangement. The new generation of Micro-Electro-Mechanical Systems (MEMS) sensors are used to detect propagation elastic waves, taking the advantage of miniaturization, mass fabrication and narrow band frequency. The MEMS device...
includes a set of out-of-plane and in-plane sensors with a specific resonant frequency tuned to 50 kHz-200 kHz. The metamaterial patch consists of a periodic arrangement of cylinders on a plate, is numerically studied to present a band gap of the desired frequency range of the MEMS sensors. The integration of metamaterial patches and MEMS sensors provide a field focusing to reduce wave attenuation and prevent interference of secondary waves sources, such as friction, with the primary waveforms.

S7-1 Continuous Monitoring of “Clashing” in Combustion Turbines Using Acoustic Emission

Obdulia Ley and Adrian Pollock
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Clashing is a term used to describe contact between rotating blades and stationary vanes in GE F-Class gas turbines. Clashing has been an important topic in at meetings of the 7EA User Group for several years. Currently there is uncertainty as to when during the gas turbine operation cycle the clashing takes place, and uncertainty about the time evolution of the damage. To minimize unsafe operation conditions and minimize the damage to the compressor, boroscope inspections are performed at more recent intervals. This paper presents our efforts monitoring turbine operation using acoustic emission to detect clashing, and using AE features to identify damage location, level and viability of keeping the turbine in operation. We will discuss the characteristics of the clashing signals, their occurrence during the operation cycle, and detected activity accumulated in time and space and its correlation with visual observations during maintenance of the unit.

S7-2 Acoustic Emission (AE) as a Diagnostic Method for Hip Implant Performance in Orthopedics: Perspective Review and Initial outcomes

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Total hip replacement is a major surgical achievement which has helped many patients to overcome the hip joint pain and restore day to day functions with little restrictions in lifestyle. This surgery has technologically advanced from time to time with improved implant design, introduction of newer material, better understanding of the complex behavior and the complexity of the working environment. Even with sophisticated primary Total Hip Replacement (THR) surgery and with the latest improved implants it has not been able to avoid the necessity for secondary surgery.

In general, any mechanical system is considered to be failed when it cannot perform the intended function. In this context, the failed hip implant performs the intended function but there will be change in the way it executes the function. While executing the normal function if the patient feels pain or if the patient is feeling uncomfortable then that particular implant is considered as failed even though it executes the required function. It is no way related to the technology used while performing primary THR but is dependent on the behavior of the implant after primary THR. So it is clear that, there is a great need for the monitoring of the hip implant after primary THR as secondary operations are not only difficult to perform but also carry more risk of increase in
complications with reduction in prognosis. There are many challenges associated with the monitoring of hip implant. The main challenge is not only associated with the monitoring technique but also to answer the questions, (1) Will the monitoring of hip implant after primary THR and provide early prediction of its failure? (2) Can any clinical measure be provided to the patients to avoid the secondary hip replacement surgery?

Many techniques have been proposed for monitoring hip joints like post mortem examination, arthrography, digital radiography, Dual Energy X-ray Absorptiometry (DEXA) and Roentgen Stereophotogrammetric Analysis (RSA), vibration signals based technique, etc. But use of Acoustic Emission (AE) for monitoring of hip joint has proved its potential to be an effective technique for hip joint monitoring and also the need for further study. Many attempts have been made to check the feasibility of AE for monitoring hip joint both for in vivo and in vitro analysis. In our study, we made an initial attempt to a hip simulator (tribocorrosion) and AE sensing system, and we found promising results, particularly the evolution of current and AE (energy data).

Hence, in this paper, a review about the state of the art in the use of AE for hip monitoring and the preliminary data from hip simulator, will be presented. A detailed discussion will be made on the limitations of such techniques and a future roadmap for its successful use.

**S7-3 Application of Wavelet on Acoustic Emission Location of Pipeline Leakage**

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Pipelines are important components of utility service and industry field. The instable or stable leakage can detrimentally include environment and society. Acoustic Emission (AE) method enables detecting and locating the leak site with a spatially distributed sensor array. The original waveforms obtained from laboratory scale leak testing show that the leakage signals are combinations of many frequencies in different modes, which introduce error in source localization input of wave velocity. Wavelet decomposition is applied on the analysis of waveforms to differentiate different modes, and the source localization is applied to higher order decomposed signals. The experimental results show that the Gaussian wavelet provides the best approach for decomposing leakage waveform to be used for accurate leak localization.
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