SYMPOSIUM GG

When Materials Matter–Analyzing, Predicting, and Preventing Disasters

April 26 – 27, 2000

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* Invited paper

SESSION GG1: FROM CHIPS TO CONCRETE
Chair: Marcel Ausloos
Wednesday Morning, April 26, 2000
City (Argent)

9:00 AM GG1.1
CAUSES AND PREVENTION OF CATASTROPHIC CHIP FAILURE. Andrea N. Grant and Robert F. Cook, University of Minnesota, Department of Chemical Engineering and Materials Science, Minneapolis, MN.

Almost never is the failure of an integrated circuit taken to mean the complete fracture of the silicon chip on which the circuits are built. Failures can be inherent (e.g., mis-processing, in which case the user never sees the chip), transient (e.g., radiation damage, in which case the user turns the machine off and on again to clear the soft error) or localized (e.g., electromigration damage, in which case the user perceives a degradation in machine performance with time), but never catastrophic. However, moves towards chip-scale packaging and greater temperature excursions during circuit operation lead to complete chip fracture as the possible dominant failure mechanism. While not as spectacular as an earthquake, the effects on transportation, telecommunications and commerce could be just as devastating. In this study, the stress on chips in small packages during thermal cycling is examined in the context of the mechanical damage generated in chips during processing and the likely fracture response of Si. In particular, sharp particle contact damage on the (100) and (110) surfaces of Si and the conditions for initiation of catastrophic cleavage fracture in chips mounted in small polymeric packages are considered. Consideration is also given to cases in which the catastrophic cleavage of Si might be a good thing.

9:15 AM GG1.2
Abstract Withdrawn.

9:30 AM *GG1.3
INFRASTRUCTURE AND ARCHITECTURAL SURETY^{SM}. Rudolph V. Matalucci, Sandia National Laboratories, Albuquerque, NM.

The mission of the Architectural SuretySM program at Sandia National Laboratories is to assure the performance of buildings, facilities, and other infrastructure systems under normal, abnormal, and malevolent threat conditions. Through educational outreach efforts in the classroom, at conferences, and presentations such as this one, public and professional awareness of the need to defuse and mitigate such threats is increased. Buildings, airports, utilities, and other kinds of infrastructure deteriorate over time, as evidenced most dramatically by our crumbling cities and aging buildings, bridges, and other facility systems. Natural disasters such as tornadoes, earthquakes, hurricanes, and flooding also stress the materials and structural elements of our built environment. In addition, criminals, vandals, and terrorists attack our federal buildings, dams, bridges, tunnels, and other public and private facilities. Engineers and architects are beginning to systematically consider these threats during the design, construction, and retrofit phases of buildings and infrastructures and are recommending advanced research in new materials and techniques. Existing building codes and standards do not adequately address nor protect our infrastructure or the public from many of these emerging threats. The activities in Sandia's Architectural SuretySM efforts take a risk management approach to enhancing the safety, security, and reliability of our constructed environment. The technologies and techniques developed during Sandia's 50 years as the nation's lead laboratory for nuclear weapons surety are now being applied to assessing and reducing the vulnerability of dams, to enhancing the safety and security of our staff in foreign embassies, and assuring the reliability of other federal facilities. High consequence surety engineering and design brings together technological advancements, new material requirements, systems integration, and risk management to improve the safety, security, and reliability of our as-built environment.

10:30 AM GG1.4
Abstract Withdrawn.

10:45 AM *GG1.5
CRITICAL MATERIALS ISSUES IN MODERN REACTOR SAFETY. Dana A. Powers, Sandia National Laboratories, Albuquerque, NM.

Nuclear power currently supplies about 20% of the nation's electrical needs. The nuclear power production industry is going through evolutions that will lead to greater efficiency and competitiveness. Many changes in the nuclear power industry are limited by materials. Materials issues can be especially troublesome as efforts are made to extend the operating licenses of nuclear power plants. Some of these critical materials issues are discussed in the paper including fuel cladding for extended fuel burnup, flaw istributions used in probabilistic fracture mechanics analysis of reactor pressure vessels, void swelling in irradiated austenitic stainless steel, problems of detecting and sizing flaws in steam generators, and issues of predicting flow accelerated corrosion. The paper will conclude with a discussion of the > needs for better materials in future nuclear power plants.

11:15 AM GG1.6
PREDICTION OF THE ONSET OF REINFORCEMENT CORROSION IN CONCRETE BASED ON A MATHEMATICAL MODEL OF CHLORIDE ION TRANSPORT. Chee Burm Shin, Ajou Univ, Dept of Chemical Engineering, Suwon, SOUTH KOREA; Eun Kyum Kim, Seoul National Univ of Technology, Dept of Civil Engineering, Seoul, SOUTH KOREA.

Recently, premature reinforcement corrosion in concrete structures exposed to chloride containing environments has created an important problem. This is due to an increase of concrete construction in marine environments and increasing use of marine aggregate of chloride containing admixture at the mixing stage as well as the use of deicing agents in cold-weather area. Therefore, understanding the mechanism of chloride ion transport and establishing a theoretical model to predict the onset of reinforcement corrosion in concrete are very important for designing countermeasures against the damage of concrete structures. In this study, the behavior of chloride ions introduced into concrete from concrete surface by a marine environment and contained in admixture at the mixing stage was modeled. The physicochemical processes including the diffusion of chloride ion in aqueous phase of pores, the adsorption and desorption of chloride ions to and from the surface of solid phase of concrete, and the chemical reaction of chloride ion with solid phase were analyzed by using the finite element method. In order to validate the model, the calculated distributions of chloride ion concentration in concrete were compared with the measured data. The calculated results agreed favorably with the measured data. The results of this study may be used to predict the onset of reinforcement corrosion in concrete and to identify the maximum limit of chloride ions contained in concrete admixtures.

SESSION GG2: FROM BATTLESHIPS TO CONFLAGRATIONS
Chair: Alan J. Hurd
Wednesday Afternoon, April 26, 2000
City (Argent)

2:00 PM *GG2.1
EXPLOSION ABOARD THE BATTLESHIP USS IOWA. Richard L. Schwoebel.

An open breech explosion in a 16-inch gun aboard the battleship USS IOWA killed 47 crewmembers on April 19, 1989. An investigation by the US Navy concluded that the explosion could not have been an accident, and that it was most probably the result of an intentional act by a member of the gun crew. The Navy investigators supported these conclusions with evidence of foreign materials on the rotating band of the projectile. They associated these foreign materials with residues of an improvised chemical ignition device, and believed that this device was initiated by an intentional overram of the propellant into the breech of the gun. Committees of both the House and Senate held hearings on the Navy's investigation and questioned their conclusions. As an outgrowth of those hearings, the Senate Armed Services Committee asked Sandia National Laboratories to conduct an independent investigation of the explosion and the Navy's conclusions. The Sandia investigation determined that the foreign materials identified by the Navy were common to several areas of battleship turrets and 16-inch projectiles. This included residues of calcium, chlorine, various glycols and ion fibers. Furthermore, some of these same residues were found on regions of the projectile protected from the explosion. Sandia concluded that there was no explicit evidence that a chemical ignition device was present in the breech of the gun. The independent investigation also revealed that a high speed overram of the propellant could initiate an explosion by a previously unknown mechanism. This mechanism was related to the crushing of propellant pellets and the emission of burning particles from fracture surfaces. Full-scale experiments using a 16-inch gun configuration demonstrated that explosions would result with various probabilities depending on the overram speed. It was concluded that the explosion aboard the USS IOWA could have resulted from an inadvertent high speed overram of the propellant, perhaps asociated with confusion and inexperience of crewmen in the center gun room. Some 'lessons learned' from this investigation have been identified and will be discussed.

2:30 PM *GG2.2
WEAPONS MATERIALS. Georges Micheels, Xavier Gavage, FN Herstal, Herstal, BELGIUM.

Since many years, firearm's design has been based on extensive use of traditional metallic materials. Regarding operating conditions severity, it was a comfortable position. In the last fifteen years, user's requirements were growing (weight budget, cost reduction, etc.) and designers had to consider potential use of new materials. During P90 sub-machine-gun design, introduction of reinforced fiber composites like polyarylamide IXEF induced design methodology reconsideration. It was he first use of a material having highly temperature sensitive mechanical characteristics. As environmental temperature became a key factor, failure modes analysis and performance assessment methods needed to be reviewed. Those changes brought use of new scientific tools during design stage like structural dynamic analysis (experimental and finite elements computation), fatigue computation, mechanical simulation, etc. Testing programs and methods were also adapted in order to put in evidence the environment effects on product performance. Thanks to this design process reengineering, performance goals have been achieved and user's safety was preserved.

3:30 PM *GG2.3

FORENSICS OF FIRE-EXPOSED MATERIALS. Ronald Gibala, University of Michigan, Ann Arbor, MI; David W. Powell, Sytek Consultants, East Syracuse, NY.

The determination of causes of fire damage to buildings and other large-scale structures often requires detailed materials analysis and characterization of individual fire-exposed components, ranging from massive structural members to the smallest constituents of electrical/electronic packages. Fire investigation includes not only examination of functional performance but also environmental exposure. Post-mortem reports of building fires have often implicated fluorescent lighting systems as a possible fire cause, especially the ballast components in which the transformer assembly steps up the 110-120V line voltage toward 200-220V for efficient but heat-producing operation. We have investigated dozens of fires in which blame has been initially associated with ballast components, but have found only one unusual case in which ballast performance was causative. Forensic examination, laboratory control experiments, and thermodynamic and kinetic analyses have demonstrated that growth of copper sulfide whiskers on copper transformer wires provides unambiguous evidence in cases in which ballasts are blameless. The legal, hence also financial implications of these results are profound.

4:00 PM *GG2.4

TOWARDS THE UNDERSTANDING OF THE THERMAL DEGRADATION OF COMMERCIALLY AVAILABLE FIRE-RESISTANT CABLE. Catherine Henrist, A. Rulmont, R. Cloots, Department of Inorganic and Structural Chemistry, University of Liege, BELGIUM; B. Gilbert, Department of Analytical Chemistry, University of Liege, BELGIUM; A. Bernard, Department of Geochemistry, University of Brussels, BELGIUM; G. Beyer, Kabelwerk Eupen, Eupen, BELGIUM.

Recent studies related to the processing of commercially available cables have been concerned by the effects of addition of zinc borate and alumina trihydrate to the polymer matrix in order to achieve good flame-retardant properties. We report results of microstructural investigations on such cables submitted to different heat treatments. This allows us to get information about the structural modifications and some understanding on the degradation of the electrical properties. We conclude with a short proposal to improve its efficiency.

4:30 PM *GG2.5

Abstract Withdrawn.

SESSION GG3/BB7: JOINT SESSION:
FROM AVALANCHES TO SANDCASTLES
Thursday Morning, April 27, 2000
Franciscan I (Argent)

8:30 AM *GG3.1/BB7.1

STATISTICS OF AVALANCHES AS FAILURE PRECURSORS. Stéphane Roux, Unité Mixte de Recherche CNRS/Saint-Gobain, Aubervilliers, FRANCE.

We consider the development of damage in quasi-brittle heterogeneous materials, up to global failure. Various statistical models have been developed in this context, from one-dimensional or mean field models such as the fiber bundle model which can be solved analytically, to higher dimensionality models which can be studied numerically. Generically these models give rise to unstable breakdown events called "avalanches". The latters may display a statistical distribution which gives some information on the vicinity of the global failure of the system. In particular, avalanche sizes are power-law distributed with a universal exponent, up to a maximum avalanche size which diverges as the global failure point is approached. Such a behavior is formally reminiscent of critical phenomena where global failure plays the role of the critical point. This scenario is discussed in relation with the concept of self-organized criticality. Enlarging the scope of the models, such a statistics of avalanches can be applied to a wide variety of "depinning" phenomena, and traced back to the statistics of macroscopic driving force fluctuations. In this framework, two different features can account for the algebraic form of avalanches: one is the statistical distribution of the driving force itself, and the second is the time correlations which are present in the driving force signal. Extensions to crack propagation models are discussed. Other related models of thermally activated damage, which exhibits precursor signs to global failure, will also be discussed.

9:00 AM GG3.2/BB7.2

HUMIDITY-INDUCED COHESION EFFECTS IN GRANULAR MEDIA. Nathalie Fraysse, Luc Petit, Laboratoire de Physique de la Matière Condensée, Nice, FRANCE.

Despite the significance and the frequency of humidity effects on granular materials, the knowledge of these effects rests mainly on phenomenological and most of the time only qualitative observations. We have performed experiments under accurately-controlled humidity conditions in order to quantify such moisture-induced effects. We report the measurements of the maximal stability angle and the repose angle of a pile made of small glass beads, as a function of the relative vapor pressure, up to close to saturation. The influence of the wetting properties of the interstitial liquid on the grains was investigated; the comparison of the results obtained with water and heptane shows that the wetting properties have a strong influence on the cohesion of the non-saturated granular medium. In view of this, new experiments have been undertaken in order to obtain information on the liquid bridges that form between grains and give rise to cohesion of the granular medium. Our aim is to understand the close connection that exists, through interparticle forces, between microscopic properties such as wetting properties and surface roughness of the grains, and global-scale properties of the pile, as its stability and flowability.

9:15 AM GG3.3/BB7.3

EXPERIMENTAL STUDY OF INSTABILITY OF LARGE STRAIN FLOW IN DENSE GRANULAR MATERIAL. Vitali Nesterenko, Dept. of Mechanical and Aerospace Engineering, UC San Diego, CA; Richard Klopp, Donald Shockey, Donald Curran and Thomas Cooper, SRI International, CA.

Large strain flow of dense granular materials created by fracture (comminution) of initially solid ceramic is very important for ballistic performance of ceramic armor, penetration into dense rocks and concrete. There is a need for well characterized 2-D and 3-D experiments with dynamic flow of such materials to compare with existing theories and with the results of numerical modeling. Cavity expansion experiments (Klopp, Shockey et al., 1996) and collapse tube experiments - Thick Walled Cylinder (TWC) method (Nesterenko, Meyers et al., 1996) provide date with controlled low and large strain patterns under high dynamic pressures. They address initial and developed stages of penetration process correspondingly. This presentation is focused on the results obtained with the help of taped Thick Walled Cylinder method. In the experiments global hoop strains were in the range 0 - -0.12, and strain rates about 10-4 s-1. Shear localization was a primary mechanism accommodating large strains. Morphology of shear band was very different ranged from sharp crack-like to relatively broad area with large local shear strains accompanied by comminution. Number of localized shear bands does not depend strongly on overall hoop strain in experiments. Comparison of experimental results with results of numerical simulations based on FRAGBED model (Curran et al 1993, 1998) and the possibility to convert TWC approach into truly 3-D method by introducing a highly taped geometry of experiment with large angle of the central rod will be discussed.

9:30 AM GG3.4/BB7.4

DEM APPLICATION TO MIXING AND SEGREGATION MODEL IN INDUSTRIAL BLENDING SYSTEM. Kenji Yamane, Taiho Pharmaceutical Co, Ltd, Quality Control Dept, Tokushima, JAPAN.

To predict the motion of powders and grains is important in pharmaceutical industries. Many pharmaceutical engineers have studied granular flows related to powder mixing. In this study, DEM (Discrete Element Method) approach is presented as an industrial application to investigate the behavior of granular flows. The granular motion in a rotating cylinder was focused on the basic study of DEM for industrial application. Rotating cylinder is a fundamental system for commercial blenders widely used in many industrial processes. In addition, segregation of particles in a rotating cylinder is very interesting phenomena. Not only industrial engineers but also physicists study this segregation mechanism. DEM simulation showed radial segregation of two different size particles in a rotating cylinder. From the viewpoint of calculated granular temperature, radial segregation system was analyzed. Particle migration in axial direction, which is the source for axial segregation, was also shown by DEM simulation.

9:45 AM GG3.5/BB7.5
HOW SANDCASTLES FALL: THE CRITICAL ANGLE OF WET SANDPILES. Thomas G. Mason, Deniz Ertaş, Thomas C. Halsey, Exxon Research and Engineering, Annandale, NJ; Alex J. Levine, University of Pennsylvania, Dept. of Physics, Philadelphia, PA.

Capillary forces induced by small quantities of liquid significantly affect the stability of sandpiles, which makes possible the construction of sandcastles at the beach. We determine the maximum angle of stability of sandpiles as a function of liquid content, theoretically and experimentally. This angle becomes system size dependent in the presence of cohesive forces, as is well known in soil mechanics. The increase in the critical angle with increasing fluid content is controlled by the surface roughness of the particles, as well as by the surface tension of the added fluid, and exhibits three regimes as a function of the added-fluid volume. Theoretical results are in good agreement with experimental observations, which include confocal microscopy of the fluid-filled particle contact regions.

10:30 AM *GG3.6/BB7.6
NEW METHODS FOR SNOW AVALANCHE RISK MANAGEMENT AND FORECASTING. P. Bartelt, Swiss Federal Institute for Snow and Avalanche Research, SLF/ENA, Davos Dort, SWITZERLAND.

The Swiss Federal Institute for Snow and Avalanche Research is responsible for developing technical and organizational measures to prevent avalanche disasters. The institute is divided into two basic sections. The first is the operational avalanche warning service. This unit not only determines the avalanche danger on a day-to-day basis but is also responsible for developing information transfer tools that can be used by avalanche professionals at the local level. The second unit is a research group that studies physics of snow and avalanches. As part of this research, avalanche dynamics models have been developed that track the motion of flowing and powder snow avalanches. These risk management models are used by local communities to prepare hazard maps that delimit land into red (high danger), blue (medium danger) and white (no danger) zones. Numerical models have also been developed to track the development of the snowpack over time. In this presentation we will give a brief overview of the institute and talk about new methodologies (numerical models, forecasting models) that are being applied to prevent catastrophic avalanche disasters.

11:00 AM *GG3.7/BB7.7
WETTING-INDUCED EFFECTS IN GRANULAR MEDIA. P. Schiffer, R. Albert, A.-L. Barabasi, Dept. of Physics, University of Notre Dame, Notre Dame, IN; P. Tegzes, T. Vicsek, Department of Biological Physics, Eotvos University, HUNGARY.

While most studies of granular media focus on the properties of dry materials in which the intergrain forces are purely repulsive, the addition of a thin layer of a wetting fluid adds an attractive force to the system, and therefore a new dimension to the underlying physics. The physics of such a wet granular system is relatively unexplored, and there is no basic understanding of how interstitial liquid affects the granular properties. This problem is of great scientific interest and also practical importance since granular materials relevant to many industrial applications often contain significant liquid between the grains. We investigate the effect of interstitial liquid on the physical properties of granular media both theoretically and experimentally by measuring the angle of repose as a function of the liquid content in a spherical granular medium. We find that that large changes in the physical properties of granular materials can be induced by even a nanometer-scale layer of liquid on millimeter-size grains. The liquid-induced adhesive forces lead to three distinct regimes in the observed behavior as the liquid content is increased: a granular regime in which the grains move individually, a correlated regime in which the grains move in correlated clusters, and a plastic regime in which the grains flow coherently. The qualitative properties of the different regimes can be understood within the framework of two different proposed theories: the surface stability theory of Albert et al. and the bulk stability theory of Halsey and Levine.

11:30 AM GG3.8/BB7.8
TRANSPORT THROUGH PARTICULATE MATERIALS LIKE CONCRETE. Piet Stroeven, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, THE NETHERLANDS.

Cementitious composites are based on a particulate skeleton of a wide range of particle sizes, from the sub-millimeter into the decimeter range. Ideally, the open space between such particles is filled up by a cementitious binder, which is in the mixing stage a slurry of particles dispersed in water. Size of the (blended) cement particles can range from 1 to 100 μm, or more. Due to size seggregation of the binder particles at the aggregate surfaces at the initial (fresh) state, a so called interfacial transition zone (ITZ) is formed around the aggregate particles. Consequently, the grading of the cement particles (i.e., the particle size distribution function) is a function of the distance to the aggregate particle's surface. A relatively porous ITZ is resulting, a feature maintained in the hardened state. Ingress of harmful substances in hardened concrete (gas, fluid) is promoted by the relatively high porosity in the ITZ. i.e. the presence of dense aggregate particles increases the path length, but the low density makes this the favorable route. Presently, computer-simulation studies are underway to study the character (such as the contiguity) of the porosity in the interphase (as a function of water to cement ratio, cement fineness, etc). But even when technological measures are taken to improve the density (such as in high performance concrete), the substances have to circumvent the particles. This paper will therefore focus on the common problem in transport phenomena in a granular material like concrete, i.e. the *tortuosity* in the transport route. An analytical solution based on stereological notions will be presented. A similar solution could be used in aggregated matter of dense particles where the matrix is absent, like in sand, or sandy soils. It is interesting to note further, that the presented solution also describes the roughness of fracture surfaces in concrete, which are similarly governed by the relative weakness of the ITZ. Hence, this solution can be on the base of (fracture) mechanical estimates of strength properties.

SESSION GG4: FROM ENGINES TO ASTEROIDS
Chair: Michael P. Marder
Thursday Afternoon, April 27, 2000
City (Argent)

1:30 PM *GG4.1
STRUCTURAL FAILURE BY FATIGUE: PROBLEMS IN GAS-TURBINE ENGINES AND CARDIAC DEVICE PROSTHESES. Robert O. Ritchie, Department of Materials Science and Mineral Engineering, University of California, Berkeley, CA.

It is estimated that over 80% of all structural failures can be traced to mechanical fatigue, invariably in association with cyclic plasticity, sliding or physical contact (fretting or rolling contact fatigue), environmentally-assisted damage (corrosion fatigue), or elevated temperatures (creep-fatigue). Many of these failures, such as aircraft crashes or medical implant fractures, incur enormous financial costs and can involve significant loss of life. Indeed, the annual cost of such fatigue fractures has been estimated to be between one and two billion dollars. In this presentation, we focus on the role of cyclic fatigue in two quite diverse safety-critical applications, namely the premature failure of metallic engine components, e.g., blades and disks, in gas turbines in military aircraft due to high-cycle fatigue, and the mechanical fracture of ceramic heart valve prostheses implanted in the human body. Specifically, we will examine how such fatigue failures can be analyzed, from a materials (microstructure), mechanical (fracture mechanics) and chemical (corrosion) standpoint, and how a rational basis for design and life prediction can be developed to minimize the risk of further failures.

2:00 PM *GG4.2
DAMAGE AND FRACTURE IN COMPLEX MICROSTRUCTURES. Elisabeth Bouchaud, SRSIM, CEA-Saclay, Gif-sur-Yvette, FRANCE.

Microstructure is known to be the key to toughening, and hence, a good understanding of damage and fracture mechanisms at the microstructural scale should help design tough materials. In this range of length scales - which is strongly material dependent - one has to look at the material as a disordered medium, and many interesting attempts have been performed to reach a good statistical understanding of damage and fracture. Particular focus has been put on the statistical study of fracture surfaces, the morphology of which has been shown to exhibit some universal characteristics. These observations have motivated a significant theoretical effort, and models of lines moving through randomly distributed arrays of obstacles have shown to compare qualitatively well to experiments. However, their validity concerns a limited range of length scales, above which distributed damage has to be taken into account. The importance of damage in the understanding of the scaling properties of cracks is shown through various experiments and numerical simulations. Damage cavities have been observed in metallic alloys, and their morphology has been compared to the ones observed in molecular dynamics simulations on amorphous materials (glass and ceramics). This morphology fits the small length scales morphology of fracture surfaces, which may be the result of stress waves induced along the crack front by the microstructural heterogeneities. The large length scales regime is argued to be the result of a strong correlation between damage cavities. This assumption is supported by numerical simulations of damage and fracture in quasi-brittle model materials and by experiments.

3:00 PM *GG4.3

IMMOBILIZING MATERIALS. Jean-Marie Liégeois, Universitè de Liège, Chimie Macromoléculaire at Multimatériaux, Liège, BELGIUM.

Injuries of muscles or tendons, and limb fractures have been treated for over hundred years with plaster of Paris. The lightweight alternative was born twenty five years ago, in the form of a low temperature moldable thermoplastic bandage. Yet, the first generation material had some drawbacks that needed to be addressed. Generally low temperature softening polymers are based on semi crystalline aliphatic polyesters. By alloying with some polyacrylates, a wide range of specific material behaviors is now available, from very stiff to mildly soft still keeping a character of self bonding after a short heat treatment. The shape setting time is dependent upon polymer composition and molecular weight. It has been analyzed by DSC and SAXS monitoring the size and global volume of spherulites formed during crystallization. The ability of such new resins to be processed on open mesh fabrics make the new bandages unique in that they breath just as the skin does.

3:30 PM GG4.4

AN IMPROVED MAGNETIC TECHNIQUE FOR THE NON-DESTRUCTIVE DETECTION OF FAULTS IN EMBEDDED STEEL REINFORCEMENT. Peter Haycock, Simon Brown, Nick Tomlinson, Keele Univ, School of Chemistry and Physics, Staffordshire, UNITED KINGDOM; Matthew Hocking, Magnon Inspection, Keele, Staffordshire, UNITED KINGDOM.

The ability to locate precisely, by non-invasive means, faults in steel reinforcement embedded within another material is highly desirable, but often not readily attainable. A few years ago, the catastrophic collapse of a car park deck in Wolverhampton, the day before a scheduled visit by the heir to the throne, brought home to the UK the need for monitoring of the condition of such structures. Shedding of tires and blowouts on highways are phenomena which indicate the potential value of similar monitoring of vehicle tires. We have addressed the latter issue by means of a technology that is applicable also in other situations where structural steel is inaccessible. Steel is a magnetic material and, hence, can be magnetized by application of an external magnetic field. Uniform, homogeneous steel can be magnetized uniformly. However, any irregularities in the steel lead to corresponding non-uniformity in the magnetization. This forms the basis of methods for the monitoring of various structures, including mineshaft cables and oil pipelines. However, the precise magnetic state of the piece under test can yield more information than just the position of a fault. We have investigated the use of a series of applied magnetic fields and corresponding matched modes for detection and analysis of magnetization anomalies. Our initial work on tires has culminated in a prototype instrument capable of determining the position of corrosion to the steel reinforcement, the layers of steel cord that are affected and the degree of rusting that has taken place. In principle a tire can be scanned in 10 seconds, which means that, including handling time, a rate of better than one tire tested per minute can be sustained. We are currently working on extending the applicability of the technique to reinforced concrete.

3:45 PM *GG4.5

LONG-TERM CORROSION PROTECTION OF INFRASTRUCTURAL STEEL BY THERMAL SPRAY TECHNOLOGY-AN APPROACH WHOSE TIME HAS COME. Herbert Herman, SUNY Stony Brook, Dept of Materials Science and Center for Thermal Spray Research, Stony Brook, NY.

The repair and maintenance (R&M) of transportation-related infrastructural steel is one of the most compelling challenges facing industrialized nations. Governmental funding for infrastructure remediation will increase dramatically, but means through which R&M are to be implemented remain mired in political and technical indecision. This problem has now become urgent due to catastrophic failures and from an arising recognition that bridges and related components of the transport system are inextricably tied to societal economics. Similar challenges are faced by military organizations, where tremendously increased expense and time are expended in maintenance. There is thus an almost feverish activity aimed at addressing R&M questions. Coupled with the deterioration of structural steel is the removal of rust and previously applied paint. Traditional grit blasting results in unacceptable environmental lead pollution hazards and, repair programs designed to avoid these problems are costly, leading to severe delays in the repair cycle. It is essential to establish Strategies for Reduced Maintenance. Effective programs are limited by institutional barriers, which are difficult to overcome, but must involve education and clear demonstrations of long-term cost effectiveness for non-traditional technologies, and commercial barriers, which must be converted to opportunities, allowing for recognition by approving authorities. There exist largely unrecognized highly effective coating systems for decades-long infrastructure corrosion protection. Thermal spray technology, used with appropriate automation, can form corrosion/erosion resistant coatings, such as galvanically active zinc and aluminum-zinc alloys, and hi-molecular weight polymer blends as low-VOC (volatile organic compounds) compliant barrier coatings. In addition, lead oxide/rust vitrifying glasses can be thermally sprayed to mitigate against the severe environmental problems associated with conventional surface preparation methods. Advanced corrosion protection systems will be outlined and discussed with reference to civil and military infrastructure survivability.
This work is supported by NSF's MRSEC Program, No. DMR-9632570.

4:15 PM GG4.6

THE IDENTITY OF FRACTURE MODES AT VARIOUS LENGTH SCALES: FROM CORROSION, DIELECTRIC BREAKDOWN TO EARTHQUAKES AND ASTEROID IMPACT. Valery P. Kisel, Institute of Solid State Physics, Chernogolovka, Moscow District, RUSSIA.

The remarkable finding of this work is the universal correlation between the starting stresses (currents) for different stages of plastic flow and fracture at various length scales of observations (from atomic-scale internal friction, electromigration, etc. to macroscopic yield stress [1], then from the starting stresses for the first microcrack nucleation (corrosion) up to macrocrack nucleation (dielectric breakdown), geotectonic and planet faults, etc., in single or polycrystalline, disordered, composite or polymer samples, films, superconductors and ceramics, asteroids, etc. under various tests (from the corrosion up to shock stresses and asteroid impact) and environments. The universal scaling of stresses (stressing currents) allows to forecast the safety margins of materials and points to the crucial role of deformation stress in mechanisms of plasticity and to the strict chain of deformation stages: atomic/microscale dislocation motion/multiplication and full stop, cell and grain boundary origin, the first micro-crack nucleation and microcrack coalescence into macrocracks (macrofracture) up to the planet faults. It is the change in dislocation cross-slip parameters versus deformation stress that explains the above scaling and deformation structures up to fracture: at low stresses and high temperatures, in extremely pure samples or at low stress rates the wavy or diffuse slip originates the so-called ductile mode of failure with rough rupture surfaces; at high deformation stresses and low temperatures, in impure/disordered (polymer) crystals, at high stress rates the straight slip lines promote the so-called brittle fracture mode: the smooth surfaces with atomic-scale cleavage steps, kinks, river patterns, vacancy clusters or microdimples, etc.

1. V.P. Kisel, Mater. Sci. Engr., 1993, 164A, p.356.