Lifetime Prediction for Fatigued Sheet Moulding Compounds (SMC)

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Composite materials for lightweight applications such as cars and airplanes are subjected to vibrations and therefore a reliable prediction of their lifetime is required. Since the lifetime of composite structures typically exceeds the experimental time for fatigue tests in the laboratory, experimental shortcuts like time/temperature-shifting are applied. However, is shifting a proper method for composites, where the fiber component is not a time-dependent material?
For homogeneous materials, fatigue is characterized by processes like the initiation of a crack and subsequent propagation of the crack up to the complete fracture of the material. Heterogeneous materials can exhibit both, single crack formation and, depending on the volume fraction and the strength of the components, the formation of multiple cracks. The fatigue process then consists of the formation of more and more cracks until one component is fully saturated with cracks, leading to delamination between the components and final fracture of the entire structure.
An experimental method based on “fatigue load/number of cycles-shifting” is proposed and a stiffness based failure criterion will be introduced. Fatigue experiments under varying loads have been performed on short glass fiber reinforced resins (sheet molding compound, SMC) and the number of cycles up to the complete fracture of the specimens was measured. Lifetime data for different loading histories were then shifted to obtain a master load/lifetime-curve for the prediction of a lifetime for different loading histories.

Unlocking Materials Mysteries: Harnessing Language Models for Knowledge Extraction

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Large language models have emerged as powerful tools for knowledge extraction from Mechanics and Materials journal papers, offering a novel approach to enable the robust gathering of datasets and making inferences about structure-property relationships. By leveraging their natural language processing capabilities, these models can automatically extract relevant information, such as experimental results, material compositions, and mechanical properties, from vast collections of academic papers. This process streamlines data acquisition, reducing the manual effort required for dataset creation.

Furthermore, large language models excel at identifying complex patterns and relationships within the extracted text, allowing researchers to uncover valuable insights into the structure-property relationships of materials. Through the analysis of textual information, these models can reveal hidden connections, trends, and correlations that might have been challenging to identify using traditional methods. This abstract highlights the potential of large language models in revolutionizing the way researchers extract knowledge from Mechanics and Materials literature, ultimately facilitating more efficient and data-driven advancements in the field.

This abstract was written by chatGPT

Full-field Deformation Measurements via Atomic Force Microscopy: What has changed in the last 25 Years?

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Although Atomic Force Microscopes (AFM) are widely used for high-resolution imaging and to probe the contact properties of surfaces, fast and quantitative in-plane mechanical deformation mapping, especially of highly deformable media, is still lacking. Towards this goal, a novel miniature experimental apparatus was developed for *in-situ* acquisition of microscale and nanoscale in-plane mechanical deformation fields with the aid of a high-resolution AFM and Digital Image Correlation (DIC). This experimental system was shown to produce accurate results for AFM scanning rates up to 20 Hz, which is a twentyfold improvement in speed compared to the pioneering studies by Wolfgang Knauss and his students in the late 1990s. Higher scanning rates, e.g. 40 Hz, are also shown to be possible via photoexcitation of the AFM cantilever, which reduced the acquisition time of high-resolution AFM images from 17 min to just 25 sec. This presentation will discuss AFM hardware advances in relation to the AFM cantilever dynamics, which made such fast strain mapping capabilities possible.

Artskin Nano-Structured Membranes Based on _Force-Network Technology_ - Theoretical Background and Applications

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The use of the new generation nanoporous membranes in medicine will be presented. "*ArtSkin*" membranes represent a technological breakthrough and will change the healing procedures for burns and other major wounds as we know them today. Membranes "*ArtSkin*" are made of Chitozan and are fully biocompatible and biodegradable. They are manufactured using the so-called *Force-Network* spinning technology, which allows precise control of fiber thickness and membrane porosity.

They are the worldwide first membranes with a porosity of less than 50 nm (fifty nanometers). Therefore, they are air-permeable and water vapor permeable and at the same time 100% waterproof. A porosity of 50 nm also ensures that the "*ArtSkin*" membranes stop all bacteria, as well as viruses. In the case when they are made of chitosan or polyamide, they present an "artificial skin", which allows easy and quick treatements of large-scale skin injuries, which are most often mortal.

The lecture will present the physical background of the technology of making such membranes and several examples of the *in-vivo* use of *ArtSkin* membranes for the treatment of burns and wounds.

Surface Patterns in Cyclically Loaded Gel using Frontal Polymerization

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Frontal Polymerization is a process in which a self-sustaining polymerization wave initiated by a thermal trigger propagates through a thermoset monomer or gel to convert it to polymer. In this project, we develop a coupled thermo-chemo-mechanical model capable of describing within the framework of nonlinear kinematics the evolution of deformation and temperature fields during frontal polymerization of a dicyclopentadiene (DCPD) gel. Underlying the model is the concept of eigenstrains corresponding to the phase transformation prompted by the frontal curing process.

After a description of the theoretical model and its numerical implementation, I will discuss its application a bio-inspired stress-induced patterning technique in which we form thermoset polymeric materials with periodic surface topography patterns by applying oscillatory uniaxial loads to a partially cured DCPD gel during frontal polymerization. 3D numerical results of this process will be compared with experimental measurements of the surface patterns.

Advances in Ruga Mechanics and its Applications to Biomedical Science and Technology

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Over the past decade, ruga structures, i.e., large amplitude corrugated structures, have been extensively studied for their morphing morphology and physical property variations. This talk will present two examples of ruga-mechanics applications in biomedical science and technology. One is the advancement in understanding the mechanics of hyperelastic creasing, and it is applications to cardiovascular disease monitoring technology. The other is the discovery of flexoelectric graphene crinkle ruga and its applications in chromatin sequencing of nucleosome arrays self-assembled along graphene crinkles for molecular epigenetic studies.

Progressive Failure Analysis of Composite Materials – Application on Airplane Structures

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Large notch damage resistance of composite panels is one of the major design drivers for airplane primary structures (e.g. wing skin panels) as per FAA CFR 25.571 requirements. Damage progression and the residual strength analysis are typically done by using Progressive Failure Analysis (PFA). Many different PFA methods have been developed by academia and research institutes. In this presentation, practical aspects and issues of PFA applications on aircraft primary structures are discussed.

Growth and Dry Transfer of Graphene on Sapphire

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The rate at which graphene is used in different fields of science and engineering has only increased over the last decade and shows no indication of saturating. At the same time, the most common source of high-quality graphene is through chemical vapor deposition (CVD) growth on copper foils with subsequent wet transfer steps that bring environmental problems and technical challenges due to the compliance of copper foils. To overcome these issues, thin copper films deposited on silicon wafers have been used, but the high temperatures required for graphene growth can cause dewetting of the copper film, and consequent challenges in obtaining uniform growth. In this work, we explore sapphire as the substrate for the direct growth of graphene without any metal catalyst at conventional metal CVD temperatures. Firstly, we found that annealing the substrate prior to growth was a crucial step to improve the quality of graphene that can be grown directly on such substrates. The graphene grown on annealed sapphire was uniformly bilayer and had some of the lowest Raman D/G ratios found in literature. In addition, dry transfer experiments have been carried out that have provided a direct measure of the adhesion energy, strength, and range of the interactions at the sapphire/graphene interface. The adhesion energy of graphene to sapphire is lower than that of graphene grown on copper, but the strength of the graphene/sapphire interaction is higher. The quality of the several centimeter-scale transfer was evaluated using Raman, SEM and AFM as well as fracture mechanics concepts. Two-step dry transfer will also be addressed. Based on the evaluation of the electrical characteristics of the graphene synthesized in this work, it has implications for potential biosensing applications.

Reinforcing Spread Tow Carbon Fiber Laminate via Ultrathin Aligned Carbon Nanotube Sheets

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Spread tow carbon fiber composites are receiving an increased attention in recent years for diverse applications in space exploration, aircraft, and sports gear due to thin forms, and their high tensile strength compared with tow carbon fiber composites. Their compressive strength, however, is much lower than their corresponding tensile strength. Herein we report a facile technique to enhance their compressive strengths through interlaminar insertion of 2-4 ultrathin aligned carbon nanotube (CNT) sheets. As an added functionality, the inserted well-aligned CNT sheets also provided electrical conductivity in the composites even at a CNT loading below the electrical percolation threshold for other CNT filled composites. Mechanical and electrical characterization was made on the CNT sheet inserted composites and the baseline composites. Results show that the CNT sheets increase the compressive by 14.7% compared with the baseline. Such an increase is attributed to a 33.0% enhancement of the interlaminar shear strength, and the interfacial fracture toughness (mode II fracture toughness increases by 34.6%), provided by the inserted CNT sheets compared with the baseline. The electrical conductivity increases by up to 64.7%. The findings indicate that the insertion of well-aligned ultrathin CNT sheets in the interlaminar region of a spread tow carbon fiber composite can significantly enhance mechanical and electrical performance, paving path towards applications where both mechanical and electrical performance is crucial, such as for structural health monitoring, lightning protection, and de-icing in aircraft and wind blades.

Crack Tip Fields in Fiber Reinforced Materials at Finite Strain

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Recent work on crack tip fields in fiber reinforced materials at finite strain will be presented [1-6]. We begin with linear fibers in a neo-Hookean matrix and then extend to consider nonlinear fibers in a Generalized neo-Hookean matrix. Novel aspects of path-independent integrals will also be presented. Some observations on crack tip fields in a damaged-neo Hookean material will also be made.

1. Liu, Y., Moran B., 2023. Tearing a neo-Hookean sheet. Part II: asymptotic analysis for crack tip fields, *International Journal of Fracture*
2. Liu, Y., Moran, B., 2023. Tearing a neo-Hookean sheet. Part I: insights into the crack tip fields by a phase field damage model *International Journal of Fracture*
3. Liu, Y., Moran, B., 2021. Crack tip fields in a neo-Hookean sheet reinforced by nonlinear fibers. *Journal of the Mechanics and Physics of Solids* 152, 104406
4. Liu, Y., Moran, B., 2021. Hodograph Transformation for Asymptotic Crack-tip Fields in Isotropic Hyperelastic Sheets: Higher Order Eigenmodes and Path-independent Integrals. *International Journal of Fracture* 229 (1), 77-94
5. Liu, Y., Moran, B., 2020. Large deformation near a crack tip in a fiber-reinforced neo-Hookean sheet. *Journal of the Mechanics and Physics of Solids* 143, 104049.
6. Liu, Y., Moran, B., 2020. Asymptotic path-independent integrals for the evaluation of crack-tip parameters in a neo-Hookean material. *Int J Fract* 224, 133-150.

Predicting Distortion and Reducing Residual Stresses in Additively Manufactured Parts

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Minimization of residual stresses and the associated part distortion at minimum damage of the material are major objectives in additive manufacturing of metal and polymer parts. Progress was made through a department´s research collaboration by labs of design, manufacturing, material science as well as engineering mechanics and simulation focusing on Selective Laser Melting (SLM) applied to stainless steel. Thermo-mechanical modeling and FEM simulation has been used to predict displacements inverse to the distortion from manufacturing based on the calibration by standard cantilever specimen. Application to fabricated prototypes showed coincidences up to 70% of ideal target geometry. As residual stresses up to failure level, localized near support structures, are strongly affected by the laser energy and laser paths patterns across the part, devised scan-strategies applied in simplified mechanical FEM models subject to inherent strains proved as important precursor for the manufacturing process. Annealing procedures reduce part-scale distortions, like bending or twisting, and recover the mechanical properties of the stainless steel after the high energy laser exposure. Finally, an outlook to warpage simulations of semi-crystalline PA-12 disks is given.

Nucleation and Growth of Cracks in Elastomers

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We explore the nucleation and propagation of cracks within a transparent polydimenthylsiloxane elastomer using the “poker-chip” specimen. This is accomplished not just through the usual macroscopic load and displacement data, but also with synchronized optical images at high spatial and adequate temporal resolution to resolve the evolution of the failure processes. This is augmented with interrupted tests and x-ray computed tomography-based reconstruction of the three-dimensional geometry of cavities and/or cracks. These experiments and observations reveal that nucleation of multiple cracks dominates when the thickness to diameter ratio is small, because the incompressibility of the material induces substantial hydrostatic tension nearly uniformly in the specimen. In contrast, the specimens with larger thickness to diameter ratio tend to nucleate fewer cracks, and are dominated by the growth of cracks. At even greater thickness to diameter ratios, uniaxial tensile stress conditions are approached, and failure is then dominated by surface flaws. Analysis and numerical simulations are performed to understand the observed transitions in the cavitation/fracture process evolution and to extract the criterion for nucleation of cavities/cracks.

Increasing Role of Integrated Photonics and Criticality of Advanced Packaging Technologies to Extend Moore's Law

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Lightmatter, Boston, MA

With explosive growth in the AI market coupled with slowing down of Moore's law and end of Dennard Scaling, is leading to a major shift in the semiconductor industry. The emergence of the chiplet ecosystem and rise in demands of advanced packaging technologies is a testament of these changes. Furthermore, there are growing concerns from service providers that increasing power consumption by the data centers will soon be unsustainable. Addressing the need to continue to meet ever increasing computing demand in a power efficient manner is of paramount importance. This talk will focus on the role of Integrated Photonics and adv. Packaging technologies in addressing some of the challenges faced by the semiconductor industry.

Anisotropic Plasticity Modeling Using Constitutive Artificial Neural Networks

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Constitutive artificial neural networks (CANN) have recently been developed for automated model discovery of soft matters such as gray and white brain matters and skin tissues. Instead of using a classical off-the-shelf neural network, a constitutive artificial neutral network with specifically designed activation functions inherently satisfies general kinematic, thermodynamic, and physical constraints and trains robustly. In this talk, the possibility of adapting this constitutive modeling approach to anisotropic plasticity model discovery of sheet metals is explored. Possible activation functions related to anisotropic plasticity are discussed.

Advanced Measurement of Thermomechanical Properties of Polymer Composites

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Thermoset polymer composites are used as structural materials in a wide range of applications in the aerospace, automotive, energy and construction industries. To improve the toughness of the brittle glassy polymer matrix (e.g. epoxy resin), block copolymers (BCP) have recently been used as structure-forming elements during polymerization as an alternative to the commonly incorporated ceramic fillers. The block copolymers are dissolved in the liquid epoxy resin, mixed with hardener and accelerator and thermally cured. During curing, phase separation of the BCP occurs and characteristic structures such as nano- or microscale particles are formed. These induce mechanisms during fracture processes that increase the fracture toughness of the matrix, such as void formation and plastic deformation. The degree of toughness enhancement is highly dependent on the BCP concentration. Another key to improving and controlling morphology and properties is the manufacturing process of the material itself, since associated parameters such as temperature, heating rate, and reaction turnover affect the size of the resulting particles and other morphological features. To elucidate the relationships between the processes, the resulting material structure, and the properties, we can now use advanced analytical techniques that complement fractographic methods (SEM). Recently developed atomic force microscopy techniques allow the measurement of mechanical, thermal, and dynamic mechanical properties, and provide access to chemical properties using nanoscale infrared spectroscopy at the same specific location on the sample. Temperature modulated refractive index measurements can provide insight into the genesis of structure formation and morphological changes such as cross-linking, phase transitions, and material aging during curing, which is usually not readily available. Morphological changes during polymerization can be monitored by changes in thermal volume expansion, even under constant temperature conditions and even in anisotropic fiber-reinforced composites.