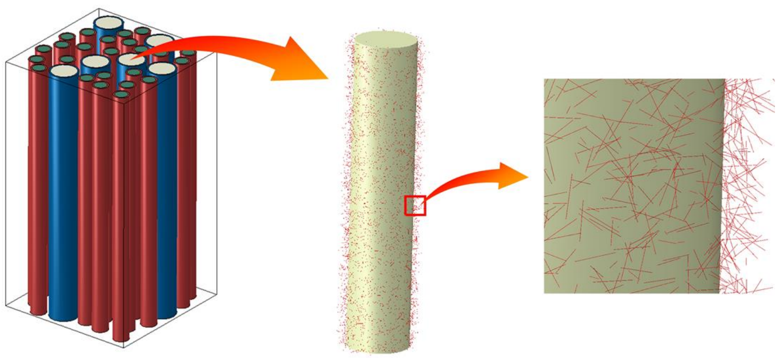
International Symposium on

NANOENGINEERED COMPOSITES:

Properties, Modelling and Applications

July 15-17, 2015, Roskilde, Denmark



PROGRAM AND ABSTRACTS

Overview and Objectives

Strong, highly reliable composites with enhanced service properties determine the perspectives of many key industries. Advances in nanotechnology opened new horizons in the improvement of these materials performances. Composites with nanoscale reinforcements, modified interfaces or tailored multiscale structures often demonstrate much better performances than neat composites.

The Symposium will bring together specialists in the areas of mechanics of materials, composite manufacturing and development, to discuss new frontiers in advanced materials for energy and structural applications, including hybrid, hierarchical, nano-, graphene and CNT reinforced composites.

Symposium Topics

- Graphene and CNT reinforced composites
- Nanocomposites and hierarchical composites
- Hybrid and carbon based composites
- Computational modelling and design of composites
- Processing, testing and characterization
- Interfaces and interphases

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Siegfried Schmauder, University of Stuttgart
Yoshinobu Shimamura, Shizuoka University
Bent F. Sørensen, Technical University of Denmark
Daniel Wagner, Weizmann Institute of Science
Tomohiro Yokozeki University of Tokyo

Day 1 - July 15, 2015

9:00- 9:30 ***Registration***

OPENING SESSION

9:30- 9:40	Opening, Leon Mishnaevsky Jr. (DTU, Denmark)
9:40- 9:50	Opening, Shinji Ogihara (Tokyo University of Science, Japan)
9:50-10:00	Welcome, Bent F. Sørensen (DTU, Denmark)
10:00-10:30	Yoshinobu Shimamura (Shizuoka University, Japan) Development of CNT/epoxy composite with high mechanical performance by using CNT spun yarn as preform

10:30-11:00 ***Coffee***

11:00-11:30	Povl Brøndsted (DTU, Denmark) Effect of resin curing kinetics on composite performance
11:30-12:00	Edith Mäder (Leibniz-Institut für Polymerforschung Dresden, Germany) Nanoscale materials for mechanical, electrical, hydrothermal and chemical functions in composite interphases
12:00-12:30	Nicola M. Pugno (University of Trento, Italy and Queen Mary University of London, UK) Hierarchical and self-healing bio-inspired graphene composites

12:30-14:00 ***Lunch***

SESSION I: MODELLING OF COMPOSITES AND NANOEFFECTS

14:00-14:30	Bent F. Sørensen, Technical University of Denmark, Cohesive laws modelling and large scale bridging in composites
14:30-14:50	Lars Pastewka (KIT, Germany) Contact, indentation, and scratching of a graphene-covered metal surfaces
14:50-15:10	Leon Mishnaevsky Jr. (Technical University of Denmark) Multiscale modelling of composites with secondary nanoreinforcement: Reserves of materials improvement
15:10-15:30	Liliana Sofia Melro (Aalborg University, Denmark) Mechanical properties of graphite and graphene and the influence of functional groups using molecular modelling

15:30-16:00 ***Coffee***

SESSION: NEW NANOCOMPOSITES AND STRUCTURES

16:00-16:30	Tomohiro Yokozeki (The University of Tokyo, Japan), CFRP using polyaniline-based conductive thermoset matrix
16:30-16:50	Woo Sik Kim (Tokyo University of Science, Japan), Development of ultra-high performance graphene-based composite: 3D, 2D and 1D architectures of graphene-based composite
16:50-17:10	Pooria Pasbakhsh (Monash University Malaysia), Halloysite nanotubes: Properties, modeling and applications of their polymer nanocomposites
17:10-17:30	Amnon Wolf (SP Nano Ltd, Israel) Improved interfacial properties of PAN/Phenolic-composites by coating of carbon fabric with SP1/CNT complex
17:30-17:50	Regina Bulatova (Technical University of Denmark) Organic-inorganic hybrid hydrogels with incorporated magnetite nanoparticles

18:30-22:30 ***Conference Dinner*** (Restaurant Bryggergården, Algade 15, Roskilde.)

Day 2 - July 16, 2015

SESSION: CHARACTERIZATION OF NANO-COMPOSITES

9:30-10:00 Satoshi Kobayashi (Tokyo Metropolitan University, Japan), Characterization of mechanical properties and fracture behavior of nano-particle dispersed textile CFRP composites

10:00-10:20 Vipin Kumar (The University of Tokyo, Japan) Synthesis and characterization of conductive CFRP & GFRP using pani-based electrically conductive thermoset polymer matrix

10:20-10:40 Homayoun Hadavinia (Kingston University, UK) Improving fracture toughness and strength of epoxy using graphene nanoparticles

10:40-11:00 ***Coffee***

SESSION II: MODELLING OF COMPOSITES AND NANOEFFECTS

11:00-11:30 Siegfried Schmauder (University of Stuttgart, Germany) Multiscale simulation of composites materials with view on nanoscale effects and reinforcements

11:30-11:50 Julian Schneider (QuantumWise A/S, Denmark) Atomic-scale simulations of mechanical and thermal properties of composite materials using the Atomistic ToolKit (ATK)

11:50-12:10 Junji Noda (Yamaguchi University, Japan) Basic FE analytical consideration about the size effect of fibers on mechanical properties for short fiber reinforced composites

12:10-12:30 Kristine Munk Jespersen (Technical University of Denmark) Modelling of micro-structure from 3D X-ray CT of Fiber Composite

12:30-12:50 Kawai Kwok (Technical University of Denmark) A micromechanical model for woven composites with viscoelastic matrix and interphases

12:30-14:00 ***Lunch***

SESSION: MECHANISMS OF STRENGTH AND DEFORMATION

14:00-14:30 Lars P. Mikkelsen (Technical University of Denmark) Small scale plasticity and compressive properties of composites

14:30-14:50 Kheng Lim Goh (Newcastle University, UK, and NU International Singapore, Singapore) On new interpretations of the basic mechanisms of nanoparticles reinforcing polymer-based composites and implications for composite design

14:50-15:20 Peng-Cheng Ma (Xinjiang Technical Institute of Phys & Chem, CAS, China), Behavior of load transfer in carbon nanotubes/polymer nanocomposites

15:20-15:40 Marta Korobeynikova (University of Stuttgart, Germany) The influence of graphene slices on the mechanical Properties of mono- and polycristalline α-iron

15:40-16:10 ***Coffee***

SESSION: NANOREINFORCED THIN LAYERS

16:10-16:40 Leif Nyholm (Uppsala University, Sweden) Paper based energy storage devices

16:40-17:00 Qingbin Zheng (Leibniz-Institut für Polymerforschung Dresden e.V., Germany),

	Graphene/carbon nanotube nanocomposite films for high-performance transparent conductive films
17:00-17:30	Ping Gao (Hong Kong University of Science and Technology, Hong Kong) Preparation of high-performance ultra-thin nanocomposite nafion membranes for proton exchange membrane fuel cells reinforced using Pt-nanosheet catalysts
18:30-20:30	***Dinner***

Day 3 - July 17, 2015

SESSION: APPLICATIONS OF NANOCOMPOSITES

09:30-10:00	Susanna Laurenzi (Sapienza Università di Roma, Italy) Multifunctional carbon/epoxy nanocomposites for aerospace structures
10:00-10:30	Peng-Cheng Ma, (Xinjiang Technical Institute of Phys & Chem, CAS, China), Polymer nanocomposites for wind blade materials: Perspectives and challenges
10:30-10:50	Jens Vinther (Carbon Nano Europe, Denmark) Vertically aligned CNT forests drawn to sheets.
10:50-11:10	Daria Sidorenko (National University of Science and Technology "MISIS", Russia) Carbon nanotube reinforced metal binders for diamond cutting tools: Effect of nanoparticles reinforcement on structure, properties and performances
11:10-11:30	***Coffee***
11:30-12:00	Ryosuke Matsuzaki (Tokyo University of Science, Japan) Cost effective open microwave heating of polymer resin with dispersed carbon nanotubes using interdigital electrode film
12:00-12:20	Yukihiro Kusano (Technical University of Denmark) Characterization of nano-fibrillar cellulose composites for industrial production processes
12:20-13:30	***Lunch***

SESSION: NANOCOMPOSITES: APPLICATIONS AND RISKS

13:30-14:00	Stein Dietrichson (Re-Turn AS and Icesolution AS, Fredrikstad, Norway) De-icing of windpower blades using microwaves and CNT-coatings
14:00-14:20	Zahra Rastian (Bushehr University of Medical Sciences, Iran) Carbon based nanomaterials for lipase immobilization: effect of geometry
14:20-14:50	Hanna M. Maes, (RWTH Aachen University, Germany) Release of carbon nanotubes from plastic composites: consequences for the environment
14:50-15:00	Closing Remarks, Shinji Ogihara (Tokyo University of Science, Japan)
15:00-15:10	Closing Remarks, Leon Mishnaevsky Jr (Technical University of Denmark)
15:10-16:00	***Coffee***

ABSTRACTS

(alphabetically, in the order of the presenter's family names)

Effect of Resin Curing Kinetics on Composite Performance

Povl Brøndsted

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The major design drivers for modern wind turbine blades are the fatigue properties (life-time) and stiffness to weight ratios (tip deflection, tower clearance). Compression strength and stability are also important in order to design against global and local buckling. The critical material properties are basically controlled by the fibres, the resin, the interface sizing performance, and the way these are assembled, i.e. the fibre architecture combined with the processing features.

The recent developments of the basic constituents are addressed with focus on the resin performance. Glass fibres have during the last years been in focus and improved with respect to stiffness at maintained density, and these high performance fibres have made it possible to manufacture cost efficient, longer blades with relatively lower weight. The focus on resin development has been on improvement of the fibre coherence, i.e. interface properties. However the curing kinetics of the resins are of vital importance to quality of the composite. During curing the resins are subjected to shrinkage which generates internal stresses in the composite blade materials. These internal stresses are causing damage which initiates fatigue damage and results in often highly reduced the performance.

The processing details are not fully understood, and the temperature curing cycles has a large effect on the quality of the final material. The internal stresses are causing damage which initiates fatigue damage and reduced the performance. Why?

ORGANIC-INORGANIC HYBRID HYDROGELS WITH INCORPORATED MAGNETITE NANOPARTICLES

Regina Bulatova

Department of Energy Conversion and Storage, Technical University of Denmark, Roskilde, Denmark

Organic-inorganic hybrid hydrogels (OIHH) with a large amount of immobilized water (hybrid hydrogel) and incorporated nanoparticles (inorganic part) have recently found extensive use as drug delivering systems, constructing materials and advanced cleaning gels for paintings and

sculptures. Such a wide application range of OIHH results from rich physics and synergy of polymeric properties and nano-inclusion's performance.

The goal of this work was to synthesize and characterize magnetosensitive OIHH with poly-N-vinylpyrrolidone (PVP), silica (SiO2) and magnetic nanoparticles building a gel network. The applied composition is of interest for the formation of "soft" manipulator, matrices for the targeted delivering and controlled release of drugs, matrices for stabilization and long-storage of prone to agglomeration and oxidation magnetite nanoparticles. Hence, the magnetic and physicomachanical properties as well as stability characteristics of OIGG to repeated cycles of sorption/desorption were studied. It was proven that the type of structural network and properties of the OIHH, namely, the change in the values of magnetization, shear modulus, and equilibrium degree of swelling, is determined by the concentration of incorporated magnetite nanoparticles

Preparation of High-Performance Ultra-Thin Nanocomposite Nafion Membranes for Proton Exchange Membrane Fuel Cells Reinforced Using Pt-Nanosheet Catalysts

Ping Gao

Department of Chemical and Biomolecular Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, HONG KONG.

We report the preparation and characterization of a Pt-layered double hydroxide/Nafion composite membrane with a thickness ~10 micron meters that exhibit a combination of desirable properties for the development of low cost and durable fuel cell technology. This is a self-humidifying membrane which exhibits fuel cross-over resistance and mechanical performance similar to a commercial membrane with thickness ~60 micron meter. Therefore, a drastic reduction in ohmic resistance and significant increase in power density (200%) are achieved. Our design is based on the homogeneous dispersion of Pt-anchored nanosheets inside solvent cast Nafion membranes. The exfoliated Pt-nanosheet catalysts were prepared via a chemical vapor deposition process using the nanosized double layer hydroxides as the anchoring sites to immobilize nano-Pt particles. The self-hydration is achieved through the Pt-catalyzed hydrogen oxidation in situ and the reinforcement is due to the dispersion of double layered hydroxide nanoparticles.

On new interpretations of the basic mechanisms of nanoparticles reinforcing polymer-based composites and implications for composite design

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2 NUInternational Singapore, Singapore 569830

Recent surge in the interest in the use of nanoparticulates for reinforcing polymer-based composites have led to many exciting findings concerning the potential possibilities of mechanical augmentation of these composites (see e.g. Fu et al. 2008; De Silva et al. 2013, 2014a). However, while it is well-known that particle loading (concentration) and particle type are key factors influencing the composite mechanical properties (Fu et al. 2008), little is known about the basic mechanisms underscoring how these nanoparticles provide reinforcement. As a follow-up from a recent paper (De Silva et al. 2014b), I shall discuss some of the key findings derived from simple mathematical models that lead to order-of-magnitude predictions of the contributions of elasticity and fracture processes to the response of the fibres, in the presence of varying particle concentrations (PCs, e.g. weight fraction or volume fraction). The mechanical properties are related to elasticity (i.e. yield strength, yield strain, stiffness, resilience) and fracture (i.e. extensibility, fracture strength and fracture toughness). I have compared the predictions with experimental results derived from tensile tests on wet-spun chitosan fibres for PC ranging 1 to 9 % (w/w) from a previous report. The comparative analysis reveals that (1) the mechanisms underlying the main effects of the fibre elasticity as well as effects arising from the interactions between PT and PC involve the stress transfer processes from the chitosan matrix to the particle and the yielding and initiation of rupture of the chitosan matrix; (2) the mechanisms underlying the main effects of fibre fractures involves the processes of particle rupture and particle pull-out (Mishnaevsky & Brøndsted 2009). More important, these processes can be understood quantitatively in terms of length scales bridging the structure and mechanical properties from molecular to particle-matrix and composite levels. The basic mechanisms lend to insights for new strategies for designing composite materials.

References

1. De Silva RT, Pooria Pasbakhsh P, Goh KL, Chai S-P, Ismail H, Physico-chemical characterisation of chitosan/halloysite composite membranes, Polymer Testing, 32, 265–271 (2013)
2. De Silva RT, Pasbakhsh P, Goh KL, Mishnaevsky L, 3-D computational model of poly (lactic acid)/halloysite nanocomposites: Predicting elastic properties and stress analysis, Polymer, 10.1016/j.polymer.2014.09.057 (2014a)
3. De Silva RT, Pasbakhsh P, Quresh AJ, Gibson AG, Goh KL, Stress transfer and fracture in nanostructured particulate-reinforced chitosan biopolymer composites: influence of interfacial shear stress and particle slenderness, Composite Interface, 10.1080/15685543.2014.960334 (2014b)

Improving fracture toughness and strength of epoxy using graphene nanoparticles

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a Material Research Centre, SEC Faculty, Kingston University London, UK
b National Physical Laboratory, Hampton Road, Teddington, Middlesex, UK

Graphene nanoparticles can be used to produce advanced resin due to their excellent physicochemical properties and the natural abundance of their precursor, graphite. By exploring the growth, chemical modification, and doping of graphene and by using them in new configurations, more novel applications of graphene are emerging.

Incorporation of graphene as a nanofiller considerably contribute to higher stiffness and fracture toughness. In this work graphene nanoparticles at 0.1, 0.25 and 0.5 wt% loading are added to fabricate a series of epoxy/graphene nanocomposites. The stiffness and tensile strength are found from uniaxial tensile test. The fracture toughness (GIC) are evaluated by using three point single-edge notch bend (SENB) test. The stiffness, tensile strength and fracture toughness of nanocomposites at different graphene loading are assessed and they are compared with the neat epoxy resin. The fractographic analyses of the nanocomposites are carried out to establish the toughening mechanism.

Modelling of Micro-structure from 3D X-ray CT of Fiber Composite

Kristine Munk Jespersen
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Wind turbine blades are subjected to a high number of fatigue load cycles during their long life of 20-30 years. As a consequence, fatigue damage evolution in the uni-directional (UD) composite material, used for the main load carrying spars, is one of the main limiting factors against designing longer blades. Since fatigue damage evolution in UD composites is not well understood, this study considers gaining understanding on how to simulate fatigue damage in order to reduce the high safety factors in the future.

For the considered UD glass fibre composite, each UD layer is stitched to a thin transverse backing layer. The fatigue damage initiates in the backing layers, through debonding, and propagates into the UD bundles.

The cracks in the backing layer are mainly observed to propagate into the UD layer at locations where the backing bundles are intertwining and in direct contact with the UD bundles. For this reason a realistic model should include the presence of the thin backing layer, even though it does not have any particular effect on the material stiffness.

3D x-ray computed tomography (3D XCT) was used to obtain a 3D image of the internal micro-structure of the considered UD composite. The resolution in the considered scans is sufficient to visually distinguish single fibres, but too low to use a simple blob detection algorithm to locate them. Using a dictionary based segmentation algorithm makes it possible to extract the individual fibre centre lines, and transfer them into the finite element software ABAQUS for further analysis. From the 3D XCT scans it is possible to visualize individual broken fibres, opening the possibility of introducing broken fibres at realistic locations in the model. In addition, these observations can serve as a good way of validating micro-structural fatigue damage models.

Development of ultra-high performance graphene-based composite: 3D, 2D and 1D architectures of graphene-based composite

Woo Sik Kim[1], Shinji Ogihara[2] and Jun Koyanagi[1]

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[2]Faculty of Science and Technology, Department Mechanical Engineering, Tokyo University of Science, Japan

Graphene is comprised of a monolayer of hexagonally arranged sp2-hybridized C atoms. It has received much interest, because of its high electron mobility, thermal conductivity, elasticity, and stiffness. These properties make graphene attractive for application in nano electronic devices, sensors, functional composites, and energy storage.

In this research, graphene was prepared by unzipping of carbon nanotubes(CNTs), chemical exfoliation of graphite and electrochemical exfoliation of graphite rod. 3D foam like, 2D film like and 1D fiber like architectures of graphene composite were fabricated using various graphene-based nano materials.

3D architecture of graphene foams were developed via the in situ self-assembly of graphene and CNTs hybrid prepared by mild chemical reduction. The 3D architectures of graphene foam had low densities, high thermal stability, high electrical conductivity and high specific capacitance. 2D architecture of graphene films were fabricated via the various methods such as electro-spray deposition, spin / spray coating and etc. The electrical conductivity and transmittance of composite films were controlled. 1D architecture of graphene fibers were prepared via continuously spun from graphene oxide suspensions followed by chemical reduction at room temperature. By varying wet-spinning conditions and complex with CNTs, a series of graphene fibers were prepared. Their structural features, mechanical and electrical performances were investigated.

The fabricated graphene-based foams, films and fibers architectures, which make them candidates for potential applications in super capacitors, hydrogen storage, flexible/transparent electrode and thermal protection system at aerospace unit.

Characterization of Mechanical Properties and Fracture Behavior of Nano-Particle Dispersed Textile CFRP Composites

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Purpose of this study is to improve the inter-laminar fracture properties of the carbon fiber reinforced plastic laminates by addition of fine particle to brittle matrix resin. In this study, vinyl ester was used for the CFRP matrix and two types of particle, alumina and silicon rubber were used for the modifier. Three point bending test, tensile test, DCB test and ENF test was conducted to investigate the effect of mechanical properties of particle incorporated specimen. The mechanism of the difference in fracture behavior for these particle modified laminates was discussed on the bases of in-situ observation during the test. Addition of the rubber particle to the CFRP resulted in the increasing flexural strength due to the inhibition of the crack initiation and propagation and subsequent fiber buckling. Also the increasing Mode I fracture toughness was achieved though the Mode II fracture toughness decreased. Addition of the Al_2O_3 particle to the CFRP resulted in the increasing of flexural strength due to high matrix modulus compared with neat matrix which delays the occurrence of fiber buckling. However there was a slight decrease in mode I fracture toughness due to the insufficient toughening effect of matrix.

Synthesis and characterization of conductive CFRP & GFRP using pani-based electrically conductive thermoset polymer matrix

Vipin Kumar[* 1], Tomohiro Yokozeki[1], Teruya. Goto[2], Tatsuhiro Takahashi[2]

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The present work relates to PANI-based electrically conductive thermoset matrix used to prepare highly conductive thermoset CFRP and GFRP composites. The conducting component of the matrix is polyaniline, protonated with a protonic acid Dodecylbenzenesulphonic acid (DBSA). The thermoset matrix, for instance, Divinylbenzene (DVB) is used as a cross-linking polymer to enhance the rigidity. In this mixture, DBSA act as the dopant of PANI as well as the curing agent of DVB, this means that doping and curing of the composite occur simultaneously. More particularly, the present work reports the preparation of thermoset CFRP and GFRP composites which shows very high electrical conductivity in thickness direction as well as good mechanical properties. 3 CFRP & 3 GFRP samples of 1 mm and 2.5mm thickness with different PANI (9, 15 and 21 wt. %) and DVB (70, 50 and 30 wt. %) content have been prepared and their electrical & mechanical properties have been studied. Effect of sample thickness on conductivity is also studied. It has been found that the CFRP with the 21 wt. % of PANI & 30 wt. % of DVB content shows electrical conductivity of

1.19 S/cm in the thickness direction and a flexural modulus of 33.44 GPa. This conductivity is much higher than the Epoxy based conductive composite mentioned in available literature. CFRP with 50 wt.% of DVB content shows flexural modulus of 43.058 GPa, which is quite similar to the flexural modulus of bi-direction epoxy/CFRP composites.

Similarly GFRP with the 21 wt.% of PANI content shows electrical conductivity of 0.09 S/cm in the thickness direction and a flexural modulus of 11.12 GPa. Significant improvement in the electrical conductivity of the samples is observed with the increase in PANI content. Highly conductive thermoset FRP composite have been reported in this work. This research will lead to more areas of application of conductive FRPs like structural super capacitor, sensors and conductive FRP ducts and pipes. The comparison of the electrical conductivity and flexural modulus of the conductive CFRP & GFRP has been shown in the Figure 1 and Figure 2 respectively.

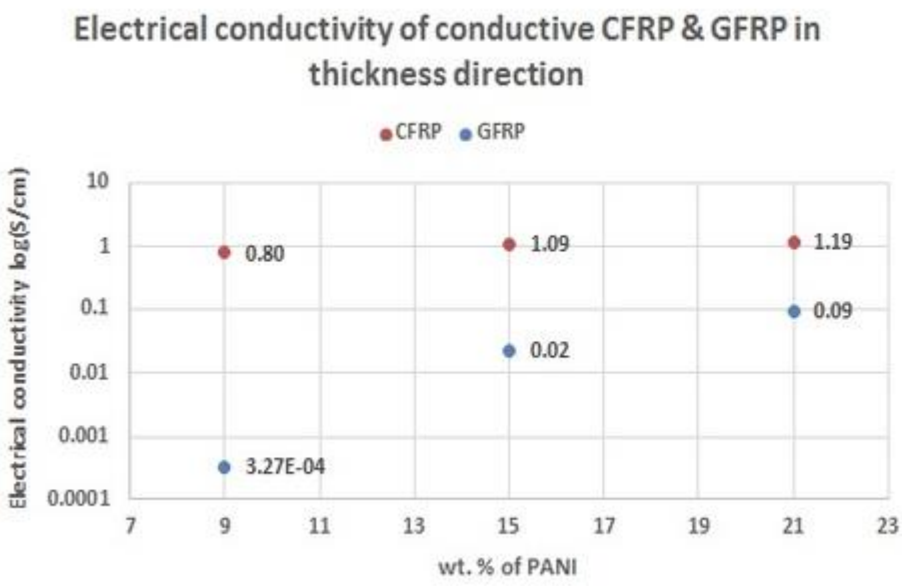

Figure 1. Electrical conductivity of CFRP & GFRP of 1 mm thickness w.r.t PANI content

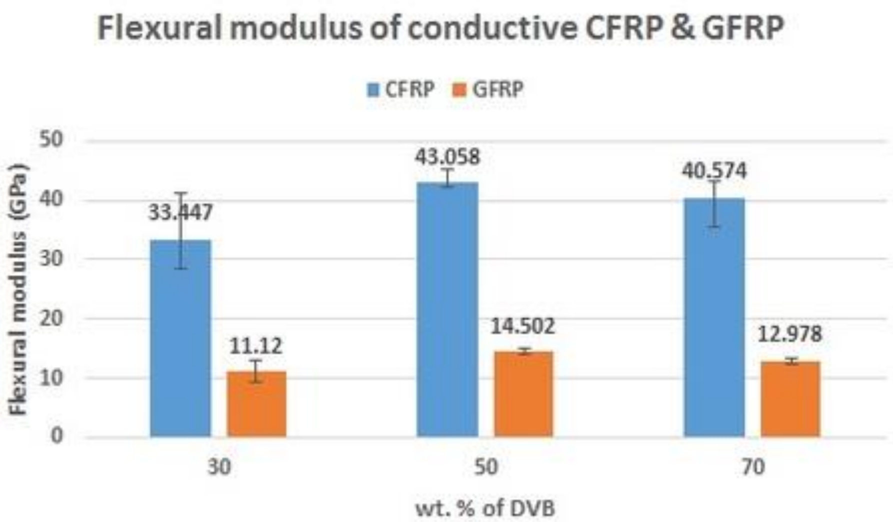

Figure 2. Flexural modulus of CFRP & GFRP 2.5 mm thickness w.r.t DVB content

Characterization of nano-fibrillar cellulose composites for industrial production processes

[1*]Yukihiro Kusano, [2]Mannila Juha, [2]Virtanen Sanna, [1]Bo Madsen

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Cellulose is renewable, nontoxic, and biodegradable, and is known to be the most abundant biopolymer on earth. It has been extensively studied in terms of biological, chemical, and mechanical properties. In particular, nano-sized cellulose attracts significant interests due to its high strength, high modulus, high surface area and unique optical properties. The EU project "Industrial Production Processes for Nanoreinforced Composite Structures" focuses on studying and developing industrially feasible production methods of nano-fibrillar cellulose (NFC) polymer composites for lightweight structures which can be used for packaging, vehicles and aeronautical applications. The scope of the project includes NFC production and modification, composite processing, mechanical testing and modelling of NFC composites, and lifecycle assessment. In the present work, NFC-epoxy composite plates were manufactured and their mechanical properties were evaluated. The result shows correlation to the precisely measured densities of the composites, supported by microscopic observation of the fractured surfaces after the mechanical test.

Atmospheric pressure plasma processing for structural applications

Yukihiro Kusano

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A plasma is an ionized gas. Plasma surface treatment is attractive for the application to adhesion improvement, because cleaning, roughening and addition of polar functional groups can be expected at the surfaces simultaneously. Such a plasma is often operated at low gas pressures, but can be stably generated at atmospheric pressure. One of the challenges in the development of atmospheric pressure plasma processing is to demonstrate high treatment efficiency and productivity. Gliding arc can fulfill the requirements, generated between diverging electrodes in a gas flow. It is shown that gliding arc is preferably used for adhesion improvement of glass fibre reinforced polyester plates, and that the treatment effect highly depends on temperatures of the electrodes and the discharges. Furthermore, the gliding arc can be extended up to several cm so that 3-D complicated surfaces can be easily treated. Plasma processing can be also improved by ultrasonic irradiation into a plasma. It is indicated that ultrasonic irradiation can enhance oxidation at the glass fibre reinforced polyester surfaces, suppress arcing and improve treatment uniformity. Potential application for plasma surface functionalization of nanoparticles will also be discussed.

A micromechanical model for woven composites with viscoelastic matrix and interphases

Kawai Kwok

Department of Energy Conversion and Storage, Technical University of Denmark

Woven fabric reinforced polymer composites are attractive materials for use in large space structures because of their multi-axial load-bearing capacity in a single lamina and mass efficiency. Space structures made from composites suffer from long-term dimensional instability because of the inherent time- and temperature- dependent behavior of the matrix and the interphases. Accurate characterization and modeling of the viscoelastic behavior are hence important for analysis of load and deformation of composite structures over time. This work presents a study of the effective viscoelastic behavior of woven composites based on computational homogenization and experimental characterization. A viscoelastic shell model is formulated based on the Kirchhoff theory and results in a viscoelastic ABD matrix characterizing the effective viscoelastic behavior. The viscoelastic ABD matrix is obtained by homogenization at the fiber level and the lamina level, taking into account the fiber, matrix and interphase properties as well as the weave geometry. The computed effective properties are compared against experimental creep measurements. Finally, the model is implemented in a structural simulation of a typical spacecraft structure component for prediction of its long term behavior.

Multifunctional carbon/epoxy nanocomposites for aerospace structures

Susanna Laurenzi

Department of Astronautic Electrical and Energy Engineering, Sapienza Università di Roma

Rome, Italy

The embedding of carbon-based nanoparticles, such as carbon nanotubes and more recently graphene nanoplatelets, are investigated as a possible solution for a large number of challenges related to the application of aerospace structures. In particular, the current trend is creating multifunctional composite materials to carry out tasks generally performed by several elements.

However, the industrial employment of such nanocomposite structures is still far from common due to the limitations in the manufacturing. For instance, a good dispersion of nanoparticles inside the polymer matrix is crucial to obtain a structure with homogeneous properties. Our work is focused on epoxy polymer matrices, which are largely used in high performance composite structures. In this context, we study the relation between the process technology, in particular liquid composite molding, and the mechanical, electromagnetic and thermal properties of the final nanocomposites.

From the mechanical point of view, the nanoindentation technique is used to determine the hardness and the modulus of carbon nanotube reinforced-epoxy at the nanoscale, whereas the toughness is investigated by low energy impact tests. To understand the contribution of the carbon nanotubes to the toughness of nanocomposites, we perform high-resolution scanning electron microscopy and Raman spectroscopy on the fractured surfaces and we determine the failure modes of the carbon nanotubes after impact.

Polymer Nanocomposites for Wind Blade Materials: Perspectives and Challenges

Peng-Cheng Ma

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The global market for wind energy has increased exponentially in the past few decades, and there is a continuous effort to develop cost-effective materials with higher strength to mass ratios for wind blades. Polymer nanocomposites, materials consisting of polymer matrix and nano-scale fillers, have attracted much interest for various applications ranging from aerospace to civil engineering. Ongoing progress shows that polymer nanocomposites deliver exceptional mechanical properties and multi-functional characteristics. In light of the author’s previous experience in composites and nanotechnology, this presentation will offer a systematic scheme on the principles and technical practices for the fabrication of polymer-based nanocomposites. We will analyze the suitabilities and advantages of polymer nanocomposites for wind blade materials. Special emphasis will be placed on the effect of nanofillers on mechanical, damping, electrical, thermal and barrier properties of polymer composites, which are important considerations when selecting suitable materials for wind blades with larger rotary radius. The application of nanocomposites as sensory materials for advanced warning of defects in composite structures will be discussed as well. Finally, based on the progress made so far, some suggestions paving the way for the large commercialization of these nanocomposites for wind blades will be presented.

Behavior of Load Transfer in Carbon Nanotubes/Polymer Nanocomposites

Peng-Cheng Ma

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Knowledge and understanding on the nature and mechanics of interface between the carbon nanotubes (CNTs) and polymer are critical to predict and prepare mechanically enhanced CNT/polymer nanocomposites. The characterization of CNT-polymer interface, however, is a challenging task because of the technical difficulties associated with the manipulation of nano-scale objects.

This seminar will present our findings on the behavior of load transfer in CNT/polymer nanocomposites. Nanocomposites consisting of epoxy and CNTs with/without functionalities were prepared and characterized to evaluate the CNT-matrix interactions using *nanoscale* fibre pull-out experiment and Raman spectrometry. The results show that physical interaction and chemical bonding are two main interfacial mechanisms between the polymer matrix and CNTs. Qualitative analysis using Raman spectrometry show that nanocomposites filled with functionalized CNTs exhibit a noticeable G'-band shift upon mechanical loading, suggesting a more efficient load transfer between the matrix and CNTs. An interesting observation is that the slope of the G'-band shifts can be either positive or negative, depending on the functional groups on CNTs and the created interfacial structures. The mechanisms behind this observation will be discussed with reference to fractography (*Microscale*) and mechanical properties (*Macroscale*) of nanocomposites. The application of nanocomposites as sensory material for the warning of defects in fibre-reinforced polymers (FRPs) will also be presented.

Nanoscale materials for mechanical, electrical, hydrothermal and chemical functions in composite interphases

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Nanoscale materials (CNTs, GNPs) have been employed into composites' interphase in order to implement multiple functions, such as mechanical, electrical, hydrothermal and chemical.

They were deposited onto electrically insulating glass fibre surfaces, leading to the formation of semiconducting CNTs-glass fibres and in turn multifunctional fibre/polymer interphases.

First, the CNTs-glass fibre demonstrated a high sensitivity towards strains by simultaneous determination of electrical resistance under tensile loading, which highlights a potential as in-situ micro sensor in materials. Secondly, the interfacial shear strength of single fiber composites exhibited more than 30 % improvement. Third, an in-situ strain sensor was manufactured to realtime monitor the microcrack in composites instead of external sensors.

Finally, the CNTs-glass fibre was used as an in-situ physical-chemical sensor to characterize the processes of curing or crystallization of polymers. The glass transition was interpreted by the resistance measurement.

Furthermore, the influence of polymeric coatings on CNT fibers was investigated in order to vary the interfacial interaction with epoxy matrix. The pull-out tests and SEM study revealed different interfacial failure mechanisms in CNT fiber/epoxy systems for untreated and coated fibers compared to epoxy resin treated ones. The epoxy matrix penetrated between the CNT bundles in the uncoated or coated fiber, forming a relatively thick CNT/epoxy composite layer and thus shifting the fracture zone within the fiber. In contrast to this, shear sliding along the interface between the matrix and the outer fiber layer impregnated with the resin was observed for epoxy resin coated fibers.

Release of carbon nanotubes from plastic composites: consequences for the environment

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Due to disposal of plastic products, all kinds of synthetic polymers are found in the environment. Plastic debris was shown to be taken up by many different organisms and to negatively affect for example fish and seabirds. It is to be expected that composites containing nanoscale additives, i.e. nanomaterials, will be treated and disposed in the same way and eventually end up in soils and aquatic systems. Therefore, it is of utmost importance to study the release of nanomaterials from polymer matrices, in which they are embedded. This research is still at its infancies, especially in the case of carbon nanotubes (CNTs) that are difficult to detect and quantify with available analytical methods. By producing plastic plates containing radiolabelled CNT (^{14}C-CNTs), we are able to track CNT release from polymer (polycarbonate, polypropylene, and epoxy resin) composites under weathering conditions. The CNT-containing materials (up to 2.5 weight percent CNTs) were exposed to simulated sunlight radiation and thereafter transferred to different environmental media (freshwater, saltwater, soil, and sediment). Afterwards, the amount of radioactivity released from the plates was measured. It was shown that up to 1% of the embedded CNTs were released from irradiated samples whereas release from non-irradiated control samples was much lower. Information on the ecotoxicity of CNTs and possible CNT-polymer particles is still scarce. We found that CNTs can be taken up by algae, waterfleas, sediment worms, and fish. Although acute toxicity of CNTs is rather low, we showed that the material can reach muscle tissue and the blood current of fish. As a consequence, this nanomaterial might become available for human consumption via food transfer. Hence, further research on the long-term effects of CNTs to organisms is required in order to assess the risks associated with these carbonaceous nanoparticles.

Cost effective open microwave heating of polymer resin with dispersed carbon nanotubes using interdigital electrode film

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Tokyo University of Science, Japan

Conventional microwave heating requires an expensive facility and its enclosed-type oven limits the size of curable products. This article proposes an open-type microwave heating of a polymer resin using microwaves produced by an interdigital electrode array film positioned between the composites and the mold. The proposed method has the advantages of reduced facility cost and applicability to large composite structures. The dispersion of carbon nanotubes (CNTs) in the resin also enables the use of a relatively low applied voltage for the heating. This is because the CNT-filled resin has a high dielectric loss tangent. The generated heat was observed to increase with the CNT content and a heating efficiency of 70% was achieved. It was particularly observed that a significant temperature increase occurred at 0.08 wt% CNT content owing to the electrical percolation phenomenon. Moreover, selective microwave heating using an electrode array also enabled the achievement of a much larger increase in temperature.

Mechanical properties of graphite and graphene and the influence of functional groups using molecular modelling

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Polymer composites have shown improved performance as a result of the combination of their constituents. Graphene and carbon fibres, the latter modelled as graphite, are common and efficient fillers providing composites with high strength and stiffness. Carbon fibres in particular, are often functionalised in order to afford a good adhesion from the polymer and therefore an efficient stress transfer from the matrix to the fibres, as it is in the quality of the bond between these two components that the transfer is more or less efficient. In this study, molecular dynamics simulations are carried out to investigate the influence of functional groups on the mechanical properties of both graphene and graphite. The effect on the bonds between the carbon atoms that form the layer, and the influence of an extra layer, in the presence of those groups will be accessed through the determination of the elastic properties of each model system.

Multiscale modelling of composites with secondary nanoreinforcement: Reserves of materials improvement

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Mechanical properties and strength of materials can be enhanced by modifying the structures of the materials at micro- and nanoscales. One of the promising directions of the materials modification for the properties enhancement is based on the control and modification of interface properties. Interfaces, phase and grain boundaries represent often relatively instable and deformable regions of materials. The introduction of geometrical structural inhomogeneities (e.g., defects or nanoparticles) into instable phases allows to control the local stress concentration and to channels the deformation energy into the lower scale level. Thus, nanomodification of weak regions and structural defects can be used to influence the damage evolution and improve the damage resistance of the material. A series of computational micromechanical studies of the effect of nanostructuring and nanoengineering of interfaces, phase and grain boundaries of materials on the mechanical properties and strength of composite materials was carried at the DTU Wind Energy. We considered several groups of materials (composites, nanocomposites, nanocrystalline metals, wood) and explored (using numerical experiments [1-4]) how the interface structures influences the properties of the materials. In the simulations, it was demonstrated that the availability of special structures in grain boundaries/phase boundaries/interfaces represents an important and promising source of the enhancement of the materials strength.

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Basic FE analytical consideration about the size effect of fibers on mechanical properties for short fiber reinforced composites

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Basic two-dimensional finite element analyses for the short fiber reinforced composites were conducted in order to investigate the size effect of fibers on the mechanical properties. In this model, the elastic deformation of fibers and the elasto-plastic deformation of matrix were considered. Three kinds of fiber alignment including the staggered fiber array were prepared. Three kinds of fiber aspect ratio under constant fiber volume fraction were additionally prepared. The boundary condition of FE analyses were implemented under an infinite and a finite length in width. In order to clarify the effect of miniaturization in fiber size on the deformation resistance under strain levels in elastic and plastic deformation of matrix, four kinds of fiber size under constant fiber volume fraction were arranged. Consequently, it was confirmed that the deformation resistance during plastic deformation of matrix increased only under the boundary condition of a finite length in width for all cases. Moreover, the increase ratio of deformation resistance was high in the case of uniform fiber alignment as well as the case of high aspect ratio of fibers. The plastic deformation of matrix near edge fiber depends on the fiber alignment and fiber aspect ratio causes such increase of deformation resistance.

De-icing of windpower blades using microwaves and CNT-coatings

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Since 2011, Re-Turn AS investigates deicing of wind power blades using microwaves. R&D efforts are also undertaken in cooperation with SP in Sweden, VTT in Finland and Aarhus University, e.g. in the context of the TOPNANO program aiming at passive anti-icing coatings, and also in the context of EU and national programs in Norway and Sweden. Certain R&D programs, such as with SP, aim at finding combinations of microwave-absorbing coatings and suitable e.g. hydrophobic topcoats, for colour and stability reasons.

The concept is enabled by coating technology involving very efficient microwave absorbers such as carbon nano-tubes (CNT) on the one side, and modern microwave technology (semiconductors) on the other side. Both technologies are developed by Re-Turn and now transferred to a new start-up company, Icesolution AS.

The deicing solution involves microwave emission inside the blade, complete coverage of the blade by a thin coating comprising CNT and a conventional top coat for erosion stability. Results are presented regarding

a) fundamental studies such as microwave absorption, suitable materials, relevant testing protocols and deicing trial tests of a 3 m wing segment,

b) coating development, and

c) practical implementation aspects including potential risks, e.g. HSE and technical challenges.

Compared with alternative solutions such as hot air and heating foils, the “wireless” microwave concept promises to be robust, simple, energy-efficient and possibly suitable even for anti-icing during operation. Efforts focus now on implementation on the first larger wind turbines in cold climate. Practical challenges on different markets, i.e. retro-fit of existing turbines and new blades, and business challenges, such as cost-benefit calculations, are discussed.

Paper based energy storage devices

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There is currently a strong need for the development of inexpensive, flexible, light-weight and environmentally friendly energy storage devices. This has led to the development of a range of new paper-based electrode materials, batteries and supercapacitors. In this presentation it will be shown that flexible nanocellulose and polypyrrole composites, manufactured by chemical polymerization of pyrrole on a nanocellulose substrate, can be used as electrodes in water-based charge storage devices [1-3]. The latter paper-based devices exhibit both high charge storage capacities and excellent power capabilities due to the combination of the large surface area (up to 250 m^2/g) of the nanocellulose and the thin (i.e. 50 nm) layer of polypyrrole on the nanocellulose fibres. The composite synthesis method and the electrochemical properties of the composites will be discussed, as well as the possibilities of using polypyrrole coated nanocellulose fibres in the manufacturing of free-standing, high active mass paper electrodes [4-7]. With the latter approach, devices with unprecedented cell areal capacitances at high current densities during thousands of cycles in aqueous solutions can be readily realised. The present type of composites provides new exciting possibilities for the development of green and foldable devices for a range of novel applications, many of which are incompatible with conventional batteries and supercapacitors.

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Contact, indentation, and scratching of a graphene-covered metal surfaces

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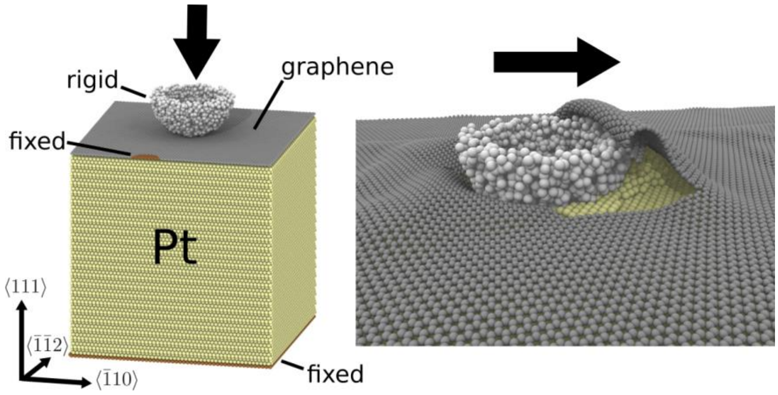

We study nanoindentation and scratching of graphene- covered Pt(111) surfaces in computer simulations and experiments with smooth and rough indenters of radius 1.5 to 10 nm. Our simulations show approximate agreement with continuum prediction for the load N vs penetration h up to the point where surfaces yield. Yield of bare surfaces strongly depends on indenter roughness, but covering surfaces with graphene regularizes this response to the results obtained for ideally smooth indenters. Further penetration after yield leads to eventual rupture of the graphene sheet. Friction, low before rupture, then jumps to values also found for bare Pt(111) surfaces. While graphene substantially enhances the load carrying capacity of the Pt substrate, the substrate's intrinsic hardness and friction are recovered upon graphene rupture.

Halloysite Nanotubes: Properties, Modeling and Applications of their Polymer Nanocomposites

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There have been many studies carried out to reinforce polymers such as polylactic acid (PLA) and chitosan using different nanofillers such as carbon nanotubes (CNTs), montmorillonite (MMT), nanosilica and nanocrystalline cellulose (NCC) while in recent years natural mineral nanotubes such as halloysite, sepiolite and palygorskite have gained much attention to use as nanofillers to significantly enhance the thermo-mechanical characteristics of polymers by lowering the cost and using more sustainable materials in order to compete with petro-chemical based plastics in different applications. Among these novel fillers, halloysite nanotubes (HNTs) have been found to be the suitable candidate for this purposes especially in those applications where loading an agent or drug is needed into their hollow lumen structure. In this study, properties, modeling and applications of different types of polymer/HNT nanocomposite structures will be discussed. Among those there are fabrication and modeling of PLA/HNTs nanocomposites prepared by solvent casting and melt blending methods which have been discussed and reviewed in order to give some comparative and explanatory outputs of these nanocomposites versus to the other types of fillers. PLA/HNT membranes prepared in this study has been proven to have significant antimicrobial activity to be sued as high performance multifunctional active food packaging.

In another effort the preparation and characterization of chitosan/HNTs composite films/membranes prepared by both electrospinning and solvent casting methods have been discussed. According to our recent findings and literature incorporating HNTs into the chitosan has resulted in significant improvements in mechanical, thermal and barrier properties. Chitosan/HNTs composites can be used for applications such as tissue engineering, waste-water treatment, drug delivery and wound healing. Most of these studies have shown that HNTs are non-toxic and are safe for use in the above mentioned applications. HNTs offer advantages of biocompatibility and lower cost compared to other fillers such as carbon nanotubes.

As part of our study in this area FE simulations were carried out to predict the elastic modulus of PLA/HNTs composites. Idealized and a real-structure based models were compared with experimental data and it has been found that compared to idealized model, real-structure based model led to accurate results.

Carbon based nanomaterials for lipase immobilization: effect of geometry

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Carbon-based nanomaterials have been recognized as potential support for lipases immobilization applied as biocatalysts and biosensors. The hydrophobicity character of carbon materials could induce active conformational change of immobilized lipases which is the major concern. Different carbon-based nanomaterials including multi-walled carbon nanotube (MWCNT), graphene nano plate (GNP) and mesoporous carbon nanopowder (MCNP) with carboxyl functional group were applied as carrier for lipase immobilization. Morphology of carrier's effect on immobilization of *Thermomyces lanuginosus* (TLL) and *Candida antarctica* B lipases (CALB) was studied and their performances in organic solvent were investigated. Immobilization efficiency of 98 and 100% were observed for TLL and CALB immobilized on carboxylated MCNP. Functionalization of carbon-based nanomaterials and enzyme immobilization were confirmed by Raman and X-ray Photoelectron Spectroscopy (XPS). Morphology of the immobilized TLL on functionalized carriers was observed by Transmission Electron Microscopy (TEM). Significant increase in synthetic activities of immobilized TLL was observed in compared to free lipases (5-26 fold) where retained activity of immobilized CALB was 0.64-1.8.

Multiscale Simulation of Composites Materials with View on Nanoscale Effects and Reinforcements

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Multiscale modelling of composites including atomistic, micro- and mesomechanical numerical studies supported by advanced experiments are reviewed. The general concept of multiscale modelling and computational design of composites [1] is formulated. The linkage of atomistic and micromechanical (finite element) models is discussed for several cases [2]. An example of micromechanical modelling of the nonlinear behaviour of nanodispersed elastomeric copolymer particle-modified PA 6 [3] is discussed in detail. A 3D self-consistent embedded unit cell model was used in these simulations. In the model a spherical inclusion is surrounded by the PA 6 polymer matrix, which is again embedded in the PA 6/elastomer composite. The mechanical behaviour is determined iteratively in a self-consistent manner using updated elastic–plastic data as new input. The future perspectives of multiscale modelling as applied to composites and nanocomposites are discussed.

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Atomic-scale simulations of mechanical and thermal properties of composite materials using the Atomistic ToolKit (ATK)

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The Atomistix ToolKit (ATK) offers a broad range of tools to simulate atomic-scale mechanical, thermal, and electronic properties of materials. Combined with its graphical user interface Virtual NanoLab (VNL), a powerful and easy-to-use package for both industrial and academic researcher project is provided, which is used for example by most of today's major semiconductor companies.

In this talk, I will guide through some examples of simulations of composite and carbon-based materials using VNL-ATK. I will for instance present calculations of the microscopic behavior of

boron-nitride-nanotubes in an amorphous matrix, as well as carbon-nanotubes under various external deformations and their thermal conductivity. Furthermore, I will show how the growth of thin amorphous selenium films from vapor-deposition can be simulated on the atomic-scale. Finally, I will present the new adaptive kinetic Monte-Carlo (aKMC) functionality in ATK, which enables the simulation of growth or diffusion processes on much longer time-scales than accessible in conventional molecular dynamics simulations.

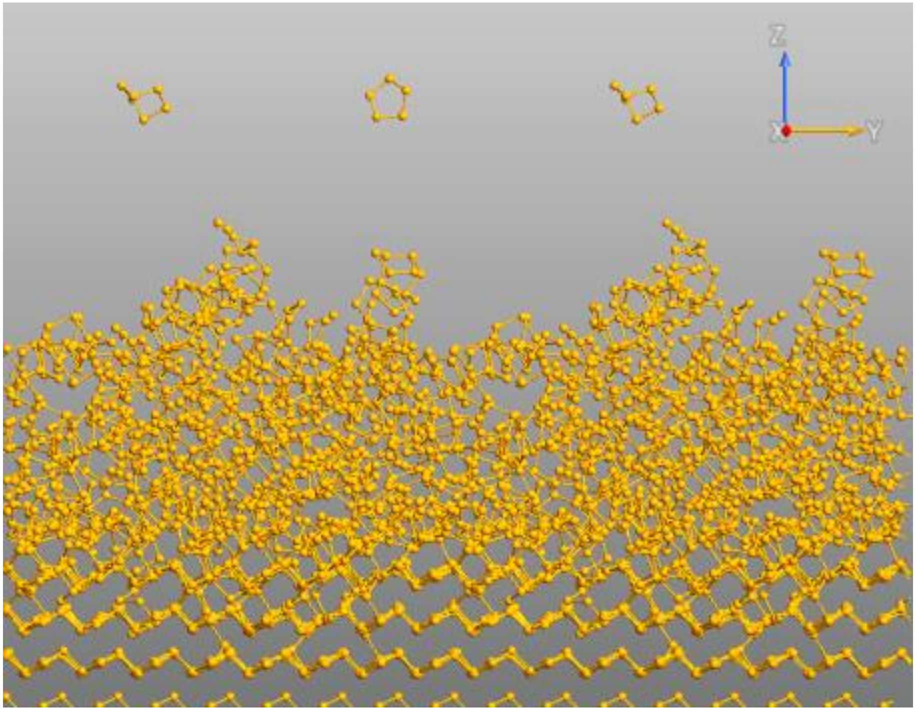

Figure 1: Snapshot of a deposition simulation of selenium vapor onto a crystal substrate.

Development of CNT/epoxy Composite with High Mechanical Performance by Using CNT Spun Yarn as Preform

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Carbon nanotubes (CNTs) possess excellent mechanical properties; thus, CNTs may have great potential for use with reinforcing polymer resin. Recently, CNT spinning techniques using long CNTs for producing CNT spun yarns have been developed. CNT spun yarns have higher nanotube packing fractions and better fiber alignment in spite of using long CNTs. These characteristics are ideal for the preform when fabricating high-performance composite materials. In this study, epoxy-based composites were fabricated with a bundle of single-ply spun yarns as a preform using the pultrusion technique. The tensile properties of the composites were explored by using quasi-static tensile tests, and SEM observation of the fracture surface was conducted. In order to discuss the role of CNTs in reinforcement, a simple mechanical analysis was conducted using the rule of mixtures.

Carbon nanotube reinforced metall binders for diamond cutting tools: Effect of nanoparticles reinforcement on structure, properties and performances

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Diamond composite materials are widely used as cutting tools. Performance of such composite materials depends on characteristics of diamonds, mechanical and tribological properties of the matrix and the matrix / diamond interface. Modification of metal matrix composite (MMC) with even a small amount of reinforcing nanoparticles can significantly increase hardness and bending strength of materials.

This work demonstrates effects of the dispersion strengthening by nanoparticles of tungsten carbide, zirconium dioxide and carbon nanotubes on mechanical and tribological properties of MMC based on iron and copper. Nanoparticles doped conventional MMCs show higher values of hardness, bending strength and wear-resistance. Besides, diamond/binder adhesive force is of great importance for cutting performance. Adhesion between diamond grains and the binder strongly depends on diamond graphitization. Raman spectroscopy studies have shown that WC nanoparticles decrease graphitization level up to 30%. The computational studies were carried out to clarify the mechanisms of the nanoparticles material strengthening.

Furthermore our findings indicate that tungsten carbide can be deposited onto diamond crystals directly during sintering of MMC with nano-modified metal matrix. The coating is formed via the gas-transport mechanism and chemisorption of volatile tungsten oxide WO_3 onto local areas of the diamond surface graphitization followed by reduction and carbide forming.

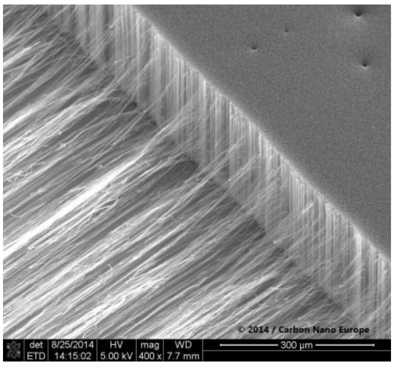
Simultaneous improvement of mechanical and tribological properties of the matrix and increasing of adhesion of diamond grains is a promising method to enhance the diamond tool performance.

Vertically Aligned CNT Forests Drawn To Sheets.

Jens Vinther, Carbon Nano Europe, Denmark

This work builds on the discoveries of the Baughman group in Dallas, USA. Please see: http://bakerinstitute.org/media/files/event/fa9dd012/Nano_2005_Baughman_.pdf

In 2013 my company, Carbon Nano Europe, bought an RF-CVD system from Dallas and build a laboratory in Denmark in order to commercialize the technology of vertically aligned CNT forests in Europe. I am currently working with optimizing the quality of the CNT forest. The interconnection of the individual CNT's in the forest determines the ability to pull the forest into macroscopic meter long sheets of 18 µm high aerogel with approx. 2.6m CNT's per mm^2. Fabrication, properties, applications and challenges will be discussed.



Improved Interfacial Properties of PAN/Phenolic-Composites by Coating of Carbon Fabric with SP1/CNT Complex

Amnon Wolf[1], Asa Eitan[1], Tamir Fine[1], Lea Elmaleh[1], Ido bramovitch[3], Nerya Hoter[3], Hagit Levy[3] and Oded Shoseyov[1,2]

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PAN/phenolic composites display excellent in-plane properties but perform poorly when out-of-plane, through-thickness properties are considered. Composite architectures with carbon nanotubes (CNTs), either dispersed within a matrix or bound to a fabric, can potentially alleviate this weakness. However, effective reinforcement of composites using CNTs is difficult, due to poor dispersion and interfacial stress transfer and has thus far met limited functional success and is associated with high costs. This work describes an innovative and cost-effective means of improving these inferior mechanical properties by using SP1, an exceptionally stable, plant-derived protein featuring 12 graphite-specific binding peptides, allowing for multivalent bi-facial CNT attachment to PAN fabric, forming a reinforced structure. This work demonstrates remarkable improvements in interlaminar shear strength and through-thickness tensile strength of SP1/CNT-reinforced PAN composites.

CFRP using polyaniline-based conductive thermoset matrix

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The present work aims to develop carbon fiber reinforced plastics (CFRP) using polyaniline (PANI)-based electrically conductive thermoset matrix to enhance the electrical properties of CFRP. The authors develop conductive thermosetting resin using Dodecylbenzenesulphonic acid (DBSA) as dopants and Divinylvenzene (DVB) as crosslinking polymer to enhance the rigidity. Thermal and electrical properties of PANI-based thermosetting resin are characterized. The developed resin is utilized to fabricate CFRP by the prepreg-based hot press method. This paper reports the electrical and mechanical properties of the fabricated CFRPs, which suggests excellent electrical conductivity in thickness direction of developed CFRP. Finally, lightning strike damage of the developed CFRP is evaluated in comparison to traditional CF/Epoxy composites, and superior damage resistance of the developed composite is demonstrated.

Graphene/carbon nanotube nanocomposite films for high-performance transparent conductive films

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Transparent conductive films (TCFs) have been used in a wide variety of optoelectronic and photovoltaic devices, such as touch panels, flat displays, solar cells, optical communication devices and solid-state lighting. TCFs composed of ultra-large graphene oxide (UL-GO) and functionalized single-walled carbon nanotubes (SWNTs) are assembled by using the Langmuir–Blodgett (L–B) technique. After thermal reduction, the reduced UL-GO/SWNT nanocomposite films on quartz substrates deliver remarkable sheet resistance ranging 180–560 Ω/sq with optical transmittance ranging 77–86% depending on the number of hybrid layers. To produce flexible TCFs, UL-GO/SWNT nanocomposite films were also assembled onto poly(ethylene terephthalate) (PET) substrate, providing excellent optical and electrical properties with a remarkable sheet resistance of 8.1 kΩ/sq at a transmittance of 90.3% after reduction by hydriodic (HI) acid. The L–B assembly technique developed here is capable of controlling the film composition, structure and thickness. It is highly suitable for fabrication of transparent conducting optoelectronic devices on a large scale without extra post-transfer processes.