NEWSLETTER 50

Summer 2020

EUROPEAN MECHANICS SOCIETY

Contents

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EUROMECH Conference Reports

ETC17 - 17th European Turbulence Conference

3-6 September 2019, Turin, Italy
Chairpersons: Prof. Guido Boffetta and Prof. Daniela Tordella

Brief summary

The 17th European Turbulence Conference took place at the Politecnico di Torino over 3-6 September 2019. Jointly organized with the University of Torino, this was the second time the ETC had taken place in Italy, having also been held in Siena in 1994.
The conference was organized into 8 parallel themes, offering a total of 66 sessions on 20 different topics. There was also a minisymposium on "Turbulence in the heliosphere and in the local interstellar medium", with 7 invited speakers.
Altogether, 625 abstracts were submitted to ETC17, of which 566 were accepted following review by two referees (drawn from the ETCC and the local committee).

Participants

A total of 530 participants registered from 31 countries, 67% in Europe. Some 12% of participants were female, and 38% of the participants registered as students (up to PhD).

Invited speakers

There were 8 invited speakers, whose talks were as follows.

- Dwight Barkley (University of Warwick), "The subcritical route to turbulence"
- Luca Brandt (KTH Mechanics), "Turbulent channel flow laden with finite-size particles"
- Claudia Cenedese (Woods Hole Oceanographic Institution), "Enhanced mixing and entrainment in turbulent plumes and gravity currents"
- Nicholas Hutchins (University of Melbourne), "Turbulent boundary layers developing over rough surfaces: from the laboratory to full-scale systems"
- Sylvain Joubaud (Ecole Normale Superieure de Lyon), "Toward internal gravity wave turbulence: an experimental approach"
- Eckart Meiburg (University of California at Santa Barbara), "Instabilities and High-Resolution Simulations of Particle-Laden Flows"
- Olga Shishkina (Max Planck Institute for Dynamics and Self-Organization), "Structures and scalings in natural thermal convection"
- Jerry Westerweel (Technical University of Delft), "Experimental investigation of turbulence and complex flows"

Young Scientist Awards

Some 63 participants applied for the award, of which 19 candidates were selected on the basis of the CVs they submitted with their applications. The talks given by the selected candidates were attended by two members of the ETCC committee, who chose the following two winners:

- Basile Gallet from CEA Saclay for his talk "Transition to the ultimate regime in a radiatively driven convection experiment"
- Davide Proment from University of East Anglia for his talk "Flying in a superfluid"

EUROMECH Colloquia Reports 2019

EUROMECH Colloquium 602
"Composite manufacturing processes: Analyses, modelling and simulations"
13 – 15 March 2019, Lyon, France
Chairperson: Philippe Boisse
Co-Chairpersons: Stepan Lomov

Introduction

Among the various lightweight materials, composites are very promising materials, and their development has attracted increasing attention in the transportation sector. The aviation industry was the first to introduce composite materials to replace conventional materials such as aluminium, and so now, for example, some 53% of the Airbus A350 consists of composites.

However, the properties of composite materials are not well-documented because they are a complex class of materials exhibiting highly anisotropic behaviour. They therefore need to be fully characterized, as for conventional materials like aluminium and titanium, but it is obvious that the methods developed for metals are not applicable to composites.

Composite materials are available in many forms and produced using a variety of manufacturing processes. These processes are numerous and often complex, but are essential for the quality of the final composite.

Manufacturing simulation enables an initial validation of a process and the determination of suitable process parameters. This can prevent a time-consuming and expensive "trial and error" process design. Furthermore, the fibre reorientation due to forming is predictable, which can be used as input data to structural analyses.

The simulation of composite manufacturing processes needs knowledge, experimental analysis and modelling of the physical phenomena involved. During the process, these phenomena and in particular the mechanics involve materials in large deformation, due to temperature, phase change, etc.

The experimental analysis, modelling and simulation of physical phenomena during composite forming were the subjects of EUROMECH Colloquium 602. It was an opportunity to establish the state of the art and to share the different approaches aimed at tackling tough problems related to the mechanics of composite materials at various scales during manufacturing.

Discussion topics

The Colloquium was concerned principally with continuous-fibre composites for structural parts, and considered numerous processes including:

- Thermoset and thermoplastic prepreg forming;
- LCM (Liquid Composite Moulding) processes;
- RTM (Resin Transfer Moulding) processes;
- Infusion

Discussions fell under two main headings.

1 Draping of fibrous preforms and prepregs

Forming continuous-fibre reinforcements leads to specific mechanical problems arising from (i) relative slippage between the fibres and (ii) the quasi-inextensibility of the fibres. The following topics were discussed: Mechanical tests for fibrous reinforcements (in-plane and transverse shear, biaxial tension, bending, transverse compaction), constitutive laws for textile reinforcements (hyperelasticity, hyper-viscoelasticity, etc), simulations of preform deformation at macro-, meso- and micro-scale, specific finite elements, locking of textile materials, full-field strain measurements (DIC) and Micro CT analyses of internal geometry, generalized continuum mechanics for textile materials, second-gradient approaches.

2 Thermomechanics, thermokinetics and couplings

Composite forming processes are generally carried out at high temperatures, and the coupling between mechanical and thermal properties is important. The consolidation and crystallization of the resin are also coupled with the deformation during forming.
The following topics were discussed:
Multi-scale and multi-physics models and algorithms, curing, crystallization, polymerization, algorithmic coupling, advanced calculation strategies in couplings (model reduction, etc).

Conclusions

Following on from the Colloquium, some of the participants are aiming to bring the subject matter to a
wider audience:

- A group of participants are in contact with the CISM International Centre for Mechanical Sciences (Udine), to offer a course on composite forming.
- About twenty participants sent extended versions of their contributions to the journal *Composites A* for publication in a virtual special issue on the subject of the Colloquium.

EUROMECH Colloquium 604
"Fluid and solid mechanics for tissue engineering"
23 – 25 September, 2019, Oxford, UK
Chairperson: Sarah Waters
Co-Chairperson: Liesbet Geris

Summary

In this Colloquium, we presented state-of-the-art theoretical and experimental fluid and solid mechanics for tissue engineering (TE), and explored the transformative poten- tial of combined quantitative theoretical and experimental approaches to inform in vitro TE protocols. Delegates were drawn from the theoretical and experimental fluid and solid mechanics communities. To ensure the focus remained applicable to the TE challenges, we invited leading figures from the TE community, which also facilitated new opportunities for interdisciplinary collaboration.

Introduction

In vitro tissue engineering (TE) aims to create functional tissue and organ samples external to the body to replace damaged or diseased tissues and organs. By using cells (e.g. autologous or allogenic) in combination with natural or synthetic biomaterial scaffolds and biochemical factors, tissue engineered products have many advantages over traditional approaches such as donor tissue and organ transplantation that can elicit an adverse immune response. The development of the growing tissue construct, the combination of scaffold, cells, extracellular matrix (ECM) and biochemical factors, often occurs within a bioreactor that enables precise control of the bio-mechanochemical environment experienced by the cells within the growing construct.

This is particularly important in the development of mechanosensitive tissues, such as bone. Successfully engineering tissues in vitro has required the development of new smart biomaterials, new tissue growth strategies involving defined biological cues, and novel and bespoke bioreactor environments for growing tissue under physiological mechanical conditions. To date, only simple avascular tissues have been successfully generated to a standard where they can be used in a clinical setting, and research into methods for improving tissue viability is essential.

In TE systems, fluid and solid mechanics are used to provide mechanical load (e.g. via fluid shear, elastic deformation) to mechanosensitive tissues such as bone and vasculature, and a key challenge is to recreate the mechanical environment within the bioreactor system that is unique to the tissue under consideration. The fluid flows and solid deformations are intricate, requiring an understanding of novel fluid-structure interactions between the fluid flows, the cells and their ECM, and the (often deformable) biomaterial. Furthermore, successful tissue growth in bioreactor systems relies on appropriate solute delivery to and waste-product removal from the cells in the tissue construct. To promote transport (without recourse to agitation methods that can be damaging to cells in a tissue-engineering setting), fluid flows are exploited to enhance transport by advection.

Programmes

The Colloquium had 8 sessions organised around themes. Each session stimulated excellent levels of discussion (we ensured the timetable allowed plenty of time for discussion). The sessions were complemented by lively poster sessions, and excellent discussion in all breaks, etc. The engagement between the different communities was fantastic.

Session 1: Introduction

In the introductory session, **El Haj** gave an excellent opening keynote by showcasing the ways we grow tissues in vitro and highlighting how multidisciplinary teams with mathematicians, engineers and biologists can combine efforts to address challenges in the field. **Waters** then showed how mechanistic mathematical modelling can be used to provide insights into the fluid and solid mechanics environments encountered by cells in a tissue engineering setting, considering scales ranging from a scaffold pore to a bioreactor system. **O'Dea** showed how a multiphase modelling approach together with multi-scale homogenisation techniques can be employed to inform scaffold design and functionalisation by understanding how scaffold pore design, nutrient transport and distributions of BMP2 may be tailored to promote osteogenesis and thereby to guide ongoing in vitro experiments.

Session 2: Materials

The focus of the second session was on materials. **Callanan** demonstrated how experimentation and modelling can be used together to unlock the full potential of biomaterials. **Cameron** described how ice-templating and electrophoretic deposition technologies can be exploited to create novel, complex and biomimetic 3D environments for the control of tissue growth. The approach is adaptable to a wide range of medical applications, including osteochondral repair, cardiac patches, dermal grafts, breast cancer diagnostics and bioreactors for platelet generation. **Mullin** presented the results of experimental investigations into the motion of light spheres in a rotating horizontal drum filled with viscous fluid, with applications to biological scaffolds.

Session 3: Soft tissue modelling

In the soft tissue modelling session, **Mouthuy** spoke about a novel type of dynamic bioreactor system that makes use of musculoskeletal humanoid robots to apply realistic mechanical stresses to tendon tissue constructs in vitro. Such a system can be used for pre-clinical testing of novel biomaterials, including degradable biomaterials made of submicron electrospun fibres. **Lally** spoke about tissue engineering of vascular grafts, showcasing in vitro experiments to quantify the influence of different levels of cyclic tensile strain on the orientation and growth of vascular smooth muscle cells. **Loerakker** spoke about tissue engineered heart valves and how computationally-inspired changes in valve design can improve the in vivo remodelling of such valves. Finally in this session, **Contera** talked about the use of atomic force microscopy to quantify viscoelasticity of extracellular matrices/tissue e gineering scaffolds across temporal and spatial scales.

Session 4: Films and fluids

The films and fluids session opened with **King** speaking about multiphase models for tissue growth. **Wagner** spoke on free boundary problems of active and driven hydrogels. **Cummings** presented a mathematical model for ischemia-reperfusion injury and postconditioning therapy. The session closed with a talk by **Dalwadi** on the development and solution of a mathematical framework for the optimisation of freezing protocols in cryopreservation.

Session 5: Bioreactors

The next session focused on bioreactors. **Ye** discussed the translation of regenerative medicine for human benefit in the context of the associated enabling technology, the bioreactor. The operation and application of bioreactor systems developed from within industry and academia to translate regenerative medicine to patients was delineated. **Oliver** discussed a mathematical model for a novel class of microfluidic device which can be rapidly fabricated by printing a fluid onto a solid substrate with flows generated passively via surface tension. **Zhao** presented a computational model to show how fluid flow induced cell stimulation in bone tissue engineering changes due to interstitial tissue formation in vitro. Finally, **Papantoniou** spoke on developmental engineering of callus organoids as predictively functional micromodules for designed bone organ formation.

Session 6: Tissue growth and scaffold design

In the tissue growth and scaffold design session, **Barzegari** presented an HPC-based simulation of biodegradation behaviour of magnesium-based biomaterials. **Nasehi** showcased how stem cell morphology controls the nuclear import of transcription factors within a bioengineered 3D niche. **Mukherjee** presented an in silico model of scaffolds for repair of large articular cartilage defects in the human knee joint. **Dunlop** closed the session demonstrating how surfaces of biomaterial scaffolds can shape and influence tissue form.

Session 7: Cell level

In the cell level session, **McCue** spoke about a morphoelastic model for contraction and expansion of fibroblast populated collagen lattices. **Yeo** presented a mathematical model for magnetically targeted stem cell delivery. **Preziosi** merged the results of continuum mechanics models and individual cell-based models that take into account cell adhesion mechanics and nucleus mechanical properties to deduce a macroscopic model able to describe the motion and growth in dense fibrous environments.

Session 8: Conclusion

In the closing session, **Korin** showed how in order to utilize engineering approaches in the design of vascular targeting nano-medicines, various in silico and in vitro microfluidic models can be employed, as well as real size arterial models which emulate both the biological and physical environment relevant to vascular disease conditions. **Geris** showcased the state of the art in multi-physics and multi-scale modelling in skeletal tissue engineering. Finally **Kamm** closed the meeting with a fascinating keynote talk showcasing vascular networks on chips and their applications.

Conclusions

This was an exciting and stimulating meeting that has already led to several new research initiatives in fluid and solid mechanics and their applications. We would like to thank everyone who attended and made the event so enjoyable and successful, and of course to EUROMECH for their excellent support and funding.

EUROPEAN MECHANICS SOCIETY

EUROMECH Colloquium 605[1]
"Damage and failure of engineering materials under extreme loading conditions"
21 – 24 May, 2019, Madrid, Spain
Chairperson: José A. Rodríguez-Martínez
Co-Chairpersons: Sébastien Mercier

Introduction

Damage and failure of deformable solids is a constantly evolving scientific field that poses a real challenge in terms of understanding, modelling and control. Indeed, since the early notes of Leonardo da Vinci circa 1500 CE, where possibly the first mechanical tensile test was described, scientists still seek to understand, characterize and model fully the mechanical behaviour of materials under various loading and environmental conditions.

Solid structures, especially those subjected to extreme loading conditions, such as various aerospace components, or protective armour elements in military applications, have to be designed to delay potential damage and failure in service. The material may experience intense physical phenomena, leading to, for example, a sudden increase of temperature, microstructural transformations, geometrical changes, or internal instabilities driven by inertial loads.

As experimental capabilities allow ever-deeper observation of the physical behaviour of the structures under extreme loading conditions, modelling efforts need to keep pace. Furthermore, research in this area concerns many different types of engineering materials – metals, polymers, ceramics and composites – as it is driven by different industrial sectors (defence, automotive, aerospace).

Nevertheless, despite the significant efforts of scientists to improve understanding of the processes of strain localization, damage and failure, it is apparent that a number of questions remain open, notably on the origin of strain localization or dynamic fracture, and how to control and prevent it.

Participants and programme

The goal of EUROMECH Colloquium 605 was to discuss the latest achievements on the subject of dynamic failure of materials, and was held at the Universidad Carlos III de Madrid. The 49 participants from 13 different countries and 3 continents (Europe, America and Asia) attended 36 presentations over 4 days, sharing their latest (mainly unpublished) results and advances on the topic. Fruitful and informal discussions between well-known researchers in the field and novice researchers were also encouraged.

Discussion topics

The main topics discussed during the talks at the Colloquium were as follows.

[1] Acknowledgements
It is noted that the Vice-President for Scientific Policy of the Universidad Carlos III de Madrid opened the Colloquium.
We thank the Universidad Carlos III de Madrid for the very professional organization and support. We also thank EUROMECH for selecting this topic, which has provided a nice opportunity for fruitful exchan- ge between scientists.

The physics and mechanics of adiabatic shear bands

Characterized by areas of intense shear localization, such as those found in high-speed machining chips, the onset of failure by adiabatic shear banding (ASB) is still debated. On the one hand, the high temperature rise developed in the localized area may soften the material and precede fracture. On the other hand, the microstructural evolution – such as dynamic recrystallization – may play an important role and precede the latter phenomenon. The state of the art on numerical approaches and new experimental techniques was presen- ted and discussed during the Colloquium. It is still unclear whether temperature elevation induces the softening or whether microstructural changes, associated later with temperature increase, induce the localization. Based on detailed observation of various alloys, some assumptions were discussed, but the origin is clearly material-dependent. Under dynamic loading, the localization process leads to a narrow zone of intense deformation. This very thin area needs specific treatment when modelled numerically. Several approaches were discussed at the Colloquium, showing the regularizing effect of thermal conductivity in the numerical results, allowing prediction of shear bands of finite thickness. It was concluded that the shear band width can be linked to the thermal conductivity of the material. Ne- vertheless, some other physical mechanisms that may lead to regularization (introducing a length scale) were discussed as well. In particular, further research is needed to elucidate the regularization mechanisms in dynamic problems dominated by inertia.

The effect of combined (shear-dominated) loading was also discussed extensively. Indeed, it was shown that prescribing a pure shear mode of deformation is almost impossible in ex- periments using the hat sample or the butterfly sample. A new device combining torsion and confinement was presented, which opens new perspectives for the dynamic analysis of the mechanical behaviour of metallic materials under shear-dominated dynamic loading. From a modelling standpoint, it was shown that a compressive component added to the principal shear loading may prevent localization to a large extent, delaying the onset of shear banding.

Inertia-driven structural instabilities

The formation of structural instabilities – e.g. necking, buckling or wrinkling – strongly depends on the rate of loading. Under static conditions, a circular bar subjected to uniaxial tension, develops a neck in the weakest section of the specimen, while under dynamic loading the role of stress wave propagation, or inertia itself, determine the number of necks and the location of failure, which can occur away from the weakest section of the specimen. For instance, the number of necks and fragments in rings subjected to dynamic expansion depends on the applied velocity, as extensively discussed in some of the talks. The influence of anisotropy on the formation of dynamic necks in metallic shells was also investigated.

In this regard, new analytical, numerical and experimental approaches were presented to monitor and identify the loading conditions and material behaviour that control necking at high strain rates. For instance, a new two-zone model was presented to model necking under biaxial loading. This model, which accounted for the stress triaxiality in the necked section using Bridgman approximation, was validated with finite element calculations. Nevertheless, the two-zone model predefines the shape of the defect, which raised several questions regarding the effect of the imperfection on the results.
Necking is a geometric instability and as such depends on the specific structure investigated, which leads to the question of what is the specific contribution of materials properties and boundary conditions on the formation and growth of dynamic necks. The problem of multiple necking under uniaxial tension was also addressed with a new linear stability approach that, unlike most of the currently available analytical models, captures the scatter in the dominant wavelengths that dictates the multiple necking pattern at high strain rates. Interestingly, the model uses theory developed in other fields of physics – such as analysis of noise and wave propagation on the ocean – offering new ways to bring to light the role of surface roughness in the formation of necking instabilities in dynamic problems.

Micromechanics of dynamic ductile fracture

Dynamic ductile fracture is usually characterized by a three-stage process: nucleation, growth and coalescence of voids. To study the related phenomena, analytical yield criteria at moderate strain rates have been commonly used in recent decades. Thus, micro-inertia effects are frequently neglected, which in the case of high loading rates could be very important (up to taking full control of the fracture process). Participants presented very recent progress in analytical modelling and finite element simulations of dynamic void growth in porous materials, and the role of cavitation and internal pressure in the nucleation of voids in initially defect-free materials. The interaction between neighbouring voids was also investigated with various numerical approaches. Depending on the spatial distribution of initial voids, different modes of deformation develop, which dictates the dissipation of energy in the material and thus the damage and fracture processes. There was a talk devoted to analysing the formation ofn void-growth-driven damage at intercepting beam devices used at CERN. These devices, usually made of heavy alloys, are exposed to high-intensity X-ray beams, which generate a large increase of temperature in the material, leading to enormous variation in hydrostatic pressure and the rapid growth of voids. In this application, the interplay between temperature rise and high stress variations makes the problem particularly challenging. Moreover, there were several discussions on the application of additive manufacturing to building metallic protective structures. This subject is currently attracting the attention of many researchers, who are modelling these materials with porous-plasticity theories to account for the internal porosity that 3D printing induces during the manufacturing process. Modelling dynamic behaviour of 3D-printed metals was identified as a new subject of research for the next few years. The void-growth process in single crystal materials was also discussed during the Colloquium.
Some presentations were focused on the influence of anisotropy and tension-compression asymmetry on the development of damage in dynamically loading specimens. Some other talks revealed the effect of hydrogen embrittlement, which is an important issue in many industrial applications, and a micro-mechanical model to capture the formation and propagation of cracks due to hydrogen embrittlement was presented. Moreover, it was shown that when a honeycomb-like structure faces dynamic loading, the porosity evolution is governed by two length scales that strongly influence the mechanical behaviour of the part. This type of honeycomb structure presents interesting dissipation properties at very large strain rates, which is an important issue requiring further investigation and experimental validation. The role of grain boundaries and grain orientations on dynamic damage in various metals and alloys was illustrated by different numerical approaches. Intergranular fracture was modelled by considering cohesive elements. Weak and strong boundaries were modelled. It was shown that the dynamic toughness is strongly linked to microstructural features of the material. It was concluded that by controlling the strength of the grain boundaries, the energy dissipated during dynamic loading process can be tailored.

Dynamic mechanical and thermomechanical behaviour of metals across scales

It is well known that the dynamic mechanical response of a ductile material depends on the microstructural evolution (density and type of defects) during deformation. However, little is known about the thermomechanics surrounding these events. During the Colloquium, it was shown that under dynamic (adiabatic) conditions the amount of energy stored by internal defects (microstructure) during deformation can be related to the macroscopic thermomechanical (heat to work ratio) response of the material. As discussed during the meeting, further numerical and experimental work to link thermomechanics across scales is still needed. At very large strain rates, the method of dislocation,dynamics is a very promising tool. In fact, results obtained at the level of dislocation dynamics can be used to feed into meso-scale models. This upscaling is not yet widespread in the community and needs additional research. On the other hand, industry demands ready-to-use models that are reliable and can provide predictions rapidly. For materials presenting complex microstructural changes during loading, e.g. multi-phase steels used in the automotive industry, the current models show significant limitations predicting fracture for wide ranges of loading rates and stress states. In this regard it was suggested that machine learning may provide an effective solution for the previously mentioned industrial demands, as an alternative to traditional mathematical modelling. Nevertheless, it was concluded that further developments in machine learning are needed for results to be more physically credible. Another key topic discussed in the Colloquium was the dynamic effects found in high cycle fatigue (gigacycles). In such scenarios, quasi-static tests cannot be performed, since it requires cyclic tests at large frequency and very low strain amplitude. It was shown that measuring self-heating du- ring such tests can help to predict the material behaviour in high cycle fatigue. An overview of all experimental difficulties that are being encountered in this problem was presented and some preliminary results discussed.

Dynamic failure of brittle materials subjected to shock and impacts

Experimental and numerical techniques to study brittle failure under impact loading were presented. Multi-scale modelling of the behaviour of silica glass at high temperatures and pressures was the core of another presentation, which made apparent the importance of considering the microstructure of a material when modelling dynamic brittle fracture and crack propagation in ceramics, polymers and rocks. There was another talk devoted to multi-scale modelling of dynamic fracture in brittle materials, including thermal effects at the crack tip. A comparison with some earlier experiments showed that the temperature field measured during fast crack propagation can be quantitatively reproduced. The dynamic mixed-mode fracture of steel fibre-reinforced concrete was investigated and (also) modelled using a multi-scale approach. The performance of metaconcrete subjected to blast loading was discussed. It was shown that this material provides advanced protective capabilities that may not be obtained with classical fibre-reinforced concrete. Moreover, there was another presentation that showed that, while deep earthquakes can sometimes be considered as a slow process, inertia is playing a role, showing a link between earth sciences and traditional mechanics of materials. The constitutive behaviour of foams, polymers and laminates under dynamic conditions was also discussed. There was a talk that illustrated the influence of the specimen, the boundary conditions and the pre-stretch of the sample on the propagation of dynamic cracks in rubber. Using DIC, it was possible to measure the crack velocity and elucidate the loading conditions that lead to dynamic fracture of the structure.

Conclusion

There was tremendous positive feedback from the participants during the Colloquium, who readily forged new bonds with colleagues, both during the presentations and at the so- cial gatherings, which we expect will lead to new international collaborations in the future. The dynamic behaviour of materials was shown to be a hot topic in the field of mechanics, and further work is still needed to elucidate the physical phenomena that precede material failure.

Acknowledgements

It is noted that the Vice-President for Scientific Policy of the Universidad Carlos III de Madrid opened the Colloquium. We thank the Universidad Carlos III de Madrid for the very professional organization and support. We also thank EUROMECH for selecting this topic, which has provided a nice opportunity for fruitful exchange between scientists.

EUROMECH Colloquium 607
"Marine Ageing of Polymers"
28-29 August, 2019, Brest, France
Chairperson: Peter Davies
Co-Chairperson: John Summerscales

Introduction

Polymer-based materials are extensively used in marine applications, from pleasure boat hulls to deep sea thermal insulation of offshore risers. As a result they are subjected to a very wide range of mechanical loading conditions, but the essential feature of all these applications is the permanent presence of water. The first step in developing safe, reliable marine structures is therefore the integration of water diffusion effects into their design. This is usually based on results from accelerated test methods, whose validity may be questioned. Even if this step is valid, recent work has clearly shown that this is not sufficient: water interacts with applied stress, so coupling must also be considered. These two aspects, test acceleration and water/stress coupling, must be fully understood if they are to be used to predict service lifetimes.

The goal of EUROMECH Colloquium 607 was to bring together actors from different marine application areas who are confronted by these problems, in order to exchange on qualification methodologies, with a particular emphasis on laboratory characterization methods and lifetime prediction.

This is an area that has been studied for over 50 years, with the most widespread approach being immersion of samples in water at elevated temperatures and periodic mechanical testing. The limitations of this approach have been highlighted in recent years, and as polymer applications become more critical, so the need for more accurate predictions of mechanical behaviour becomes more pressing. There is a particular requirement for validated models that are able to include coupling between water diffusion and mechanical stress.

Programme and discussion topics

Four key material areas were identified::

- Unreinforced polymers
- Polymer foams
- Polymer fibres
- Fibre-reinforced polymers

One half-day session was devoted to each, with a keynote lecture from a recognized expert introducing each session.

Unreinforced polymers

The Polymer session was introduced by Professor Richaud of ENSAM Paris, who described recent work to integrate wet ageing and oxidation in a modelling framework. This underlined the multi-disciplinary nature of research on ageing: it is essential to include polymer chemistry in any simulation but this is not intuitive for mechanical engineers and researchers.

Further examples were given in two subsequent presentations in which low temperature ageing and microplastic formation were discussed. The traditional accelerated ageing approach cannot account for environments in which UV exposure, seawater exposure and variable mechanical loads (due to wind, waves and currents) occur simultaneously. One avenue to explore is the development of new instrumentation which allows the actual loading conditions to be measured in service. The application of new portable NMR techniques and the integration of fibre optic sensors could both provide information on the chemical and physical state of the polymer, so that models can focus on the dominant mechanisms. The presentation of these two techniques with examples of their application stimulated considerable discussion.

The session concluded with a study that included a chemistry-based model linked to mechanical properties, which allows lifetime predictions to be made for thermoplastic elastomers. This showed what is possible when the dominant mechanisms can be isolated – chain scissions in the case presented – and its kinetics can be linked to environmental conditions even when an Arrhenius expression is not valid.

Polymer foams

The session on polymer foams focused on polymers filled with hollow glass spheres. These are widely used both for buoyancy and thermal insulation, so the main loading case is hydrostatic pressure directly linked to the water depth. A keynote from G. Stewart, the technical director of a Scottish industrial company producing these foams, provided information on current qualification procedures and their limitations. The common polymer test methods are not suitable to characterize these materials, which require highly specific equipment, notably large pressure vessels. The large dimensions of samples result in long ageing times, while deeper water applications (>4000m) and longer durability requirements (>30 years) are adding to the cost of qualification.

The following talks in the session addressed some of these issues. Acceleration of tests by increasing temperature is valid over a limited range – then hydrolysis can occur. Increasing pressure can also accelerate water ingress but again there is a limit beyond which diffusion mechanisms change. Finally, the most practical approach is to reduce the sample dimensions, which is very effective for pure syntactic foams (microspheres). For foams with mini- and macro-spheres the difficulties remain, as specimens must be large enough to constitute a representative volume.

An additional keynote was added at the end of this session as the programme committee considered that the extensive experience of ageing for a very wide range of applications at the KTH Polymer group would provide a focus for discussion on transverse application of test techniques. This was indeed the case, with examples shown from the nuclear industry through to packaging. The difficulty in accelerating radiochemical ageing effects was highlighted by profiling techniques, which revealed very different effects when accelerated test results were compared with results for samples aged in service for 21 years. Automotive fuel line qualification tests were also critically analysed, and the role of different degradation mechanisms (plasticizer loss, internal cavitation, swelling), for different polymer formulations, was clearly shown.

Polymer fibres

The session on polymer fibres started with a keynote from M. Vlasblom of DSM Dyneema. He focused on creep behaviour of HMPE fibres, but developed a methodology to apply creep modelling to predict fatigue behaviour of fibre yarns, and then to include temperature effects in predicting rope fatigue behaviour.

Water and UV exposure are not of primary importance for HMPE but may be critical for other fibres, and the papers that followed focused on accelerated tests. Autoclave test procedures were described in studies to obtain data to predict oxidation of PP fibres. Then the effect of water was shown for polyamide fibres, followed by a description of long-term creep and fatigue tests performed in water on ropes. The session ended with a detailed case study of the qualification of such materials for floating wind turbine mooring lines.

Fibre-reinforced polymers

The session on fibre-reinforced polymer composites started with a keynote by Professor Echtermeyer of the Norwegian Technical University. He presented a state of the art on the determination of long-term properties for marine and offshore applications. Their approach is to examine the sensitivity of the constituents to the environment individually, both chemically and mechanically, then to develop specific tests to study interfaces within the resulting composite. He concluded that substantial savings in testing costs are possible.

The papers which followed in this session mostly described a more traditional approach (influence of immersion alone), but a range of tests was examined, in particular those focusing on specific failure mechanisms. One example is the study of the influence of seawater ageing on interlaminar crack propagation under different loading modes, the aim being to introduce appropriate strain energy release rate values (and their ageing sensitivity) into structural calculations of complex composite parts. Results from a European project underway to develop more environmentally friendly bio-composites were also presented.
Finally, a paper from the University of Nantes described very recent modelling work, which outlined a methodology to integrate the various composite ageing mechanisms into a coupled water/stress environment simulation. This is the Grail for many researchers, and is attracting considerable current interest. Several elements are now available.

Modelling of water ingress is now common: many authors rely on Fick, but more complex models can be implemented. The effect of water on swelling and local stresses has also been developed and an example was shown here. A considerably more difficult next step is to include damage, and here the introduction of a crack and its influence on water ingress was discussed for both homogeneous and heterogeneous (composite) materials. Deterministic and stochastic approaches were shown. The results are very promising and may enable damage/water/stress interactions to be simulated.

Conclusions

The main benefit of this Colloquium was to make researchers working on particular materials and applications aware that many researchers in parallel communities are confronted by very similar problems.

Paradoxically, accelerated testing is a central part of research both to develop new high technology marine applications and to understand plastic pollution. These methods are included in qualification procedures across industry but the fundamental understanding of the influence of accelerating parameters on degradation effects remains insufficient.

This is even more relevant for applications where strong coupling (water plus pressure, water plus temperature, etc) induces its own accelerating effects. Several of the papers presented at the Colloquium showed original results in this area.