WORKSHOP PROGRAM
&
BOOK OF ABSTRACTS

[Zoom's link to the event]

Workshop Objectives:

The workshop will bring together scientists and engineers with expertise and research experience in the characterisation, modelling and design of ultralightweight materials and structures to discuss the state of the art and the current challenges in the field.

Workshop Chairs:

Prof. Federico Bosi
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LIGHTEN

Ultralight membrane structures towards a sustainable environment

H2020-MSCA-ITN ~ ITN - Innovative Training Network ~ EID - European Industrial Doctorates

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Thursday 12 May 2022
(Schedule is in UK time - BST)

8:45 - 9:00 Welcome and Introduction

9:00 - 10:30 SESSION 1

9:00 - 9:30 Davide S.A. De Focatiis
Uniaxial properties of unstretched and stretched ETFE films – experiments and some insights on modelling

9:30 - 10:00 Jörg Uhlemann, Felix Surholt, Dominik Runge, Natalie Stranghöner
Mechanical-technological behaviour of ETFE foils and their welded joints

10:00 - 10:30 Adrian Cabello, Adam C. Bown
Using a nonlinear thermo-viscoelastic constitutive model for the design and analysis of ETFE structures

10:30 - 10:45 Coffee Break

10:45 - 12:15 SESSION 2

10:45- 11:15 Fan Xu, Ting Wang, Yifan Yang
Mechanics of tension-induced membrane wrinkling and restabilization

11:15 - 11:45 Yibin Fu, Zhiming Guo, Shibin Wang
Localised bulging of an inflated rubber tube with fixed ends

11:45 - 12:15 Antonio E Forte
Inverse design of inflatable structures through modelling, optimization and machine learning

12:15 - 13:30 Lunch Break

13:30 - 15:00 SESSION 3

13:30 - 14:00 Benoît Roman, José Bico, Etienne Reyssat, Tian Gao, Antonio DeSimone, Emmanuel Siefert
A new concept of inflatable shell structures

14:00 - 14:30 Diego Misseroni, Phanisri P. Pratapa, Ke Liu, Glaucio H. Paulino
Experiments on origami metamaterials with tunable Poisson’s ratio

14:30 - 15:00 Kawai Kwok, Veli Bugra Ozdemir
Inflated Cone Experiment for High-Throughput Characterization of Time-Dependent Polymer Membranes

Thursday 12 May 2022

(Schedule is in UK time - BST)

15:00 - 15:15 Coffee Break

15:15 - 16:45 SESSION 4

15:15 - 15:45 Paolo Beccarelli, Roberto Maffei
New developments in ETFE envelopes

15:45 - 16:15 Christoph Paech
Design and development of membrane structures: case studies

16:15 - 16:45 Artem Holstov, Adam C. Bown
The Making of HOWL by Anish Kapoor: a Fitting Inflated Sculpture

16:45 - 17:00 Closing remarks

Uniaxial properties of unstretched and stretched ETFE films – experiments and some insights on modelling

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ETFE films are used in architecture, manufacturing and other more niche applications due to a range of unique properties. This talk will discuss insights gained from both thermal and mechanical charaterisation of a selection of ETFE films [1], as received from the manufacturers and following hot uniaxial pre-stretching. There are undoubtedly complexities arising from the specific crystal structures involved and their response to deformation, but there is also an underlying simplicity in the way that ETFE responds to hot stretching. This has implications for constitutive models as well as offering interesting opportunities to tailor some of the properties to specific applications.

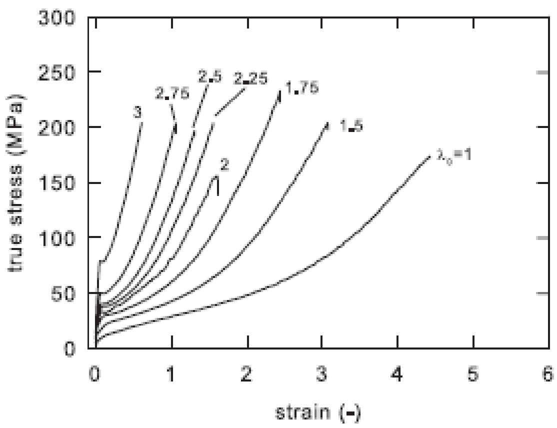

Fig. 1 Uniaxial true stress vs strain curves of DuPont 50μm ETFE films pre-stretched to a stretch of λ_0 (ranging between 1 and 3) as shown at 110°C and and frozen using a cold spray, and subsequently restretched in the same direction at 80°C. The strain rate was $0.03s^{-1}$ in both pre-stretch and restretch. Adapted from [1].

References:

[1] De Focatiis D.S.A. and Gubler L. (2013) Uniaxial deformation and orientation of ethylene - tetrafluoroethylene films. Polymer Testing, 32(8):1423-1435.

Mechanical-technological behaviour of ETFE foils and their welded joints

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The thermoplastic fluoropolymer ethylene/tetrafluoroethylene, ETFE, has been increasingly used in membrane structures in the construction industry since the 1980s. The plastic ETFE exhibits a nonlinear, viscoelastic material behaviour that has not yet been fully investigated. However, when building lightweight membrane structures with ETFE foils, knowledge of the nonlinear, viscoelastic material behaviour is essential to be able to build wide, open and at the same time safe and economical structures. The material behaviour can be divided into short-term tensile behaviour and long-term behaviour, both under monoaxial stresses and biaxial stresses. For the assembly of the surface structures, the welding of the individual cut length is essential, since the basic material is only available in a limited product width. So far there have only been a few studies on the load-bearing behaviour of welded ETFE foils.

This presentation provides a brief overview of the material behaviour of ETFE foils in short-term tensile tests as well as long-term tests in monoaxial and biaxial stress conditions. In addition, material models are presented which describe the material behaviour in the above-mentioned tests and stress-states. Furthermore, first insights into the fracture behaviour of welded ETFE foils are given.

Using a nonlinear thermo-viscoelastic constitutive model for the design and analysis of ETFE structures

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A nonlinear, time dependent thermo-viscoelastic material model has been developed at Caltech [1] to represent thin polyethylene-based films, typically used as the shell for high altitude balloons. This material model has been implemented in the aerospace industry for several years in support of the design and analysis of stratospheric balloons. Viscoelastic material models have already been successfully applied in a finite element (FE) environment [2] for modelling of such balloons.

Ethylene tetrafluoroethylene (ETFE) is fluorine-based plastic which also shows a significant time-dependent and temperature-dependent response under load. The Caltech material model can therefore be factored and calibrated to be used for the design and analysis of ETFE films. In doing this a more precise and controlled analysis of this type of structures can be achieved. The most remarkable advantage of having such a complete tool is how the design process gets simplified on one hand but at the same time better understood and more accurate. This gained precision may be critical for some extreme cases, as will be exemplified in this paper. This comprehensive approach can also dispense the designer with some of the factors currently required to account for biaxial stress, temperature variation and long-term effects. A yield locus can be also defined [3] to aid in the design and analysis tasks.

References:

[1] F. Bosi, S. Pellegrino, "Nonlinear thermomechanical response and constitutive modeling of viscoelastic polyethylene membranes", Mechanics of Materials, vol. 117, pp 9-21, 2018.

[2] D. Wakefield, "Non-linear viscoelastic analysis and design of Super-pressure Balloons: stress, strain and stability", AIAA Balloon Systems Conference, 2009.

[3] F. Bosi, S. Pellegrino, "Molecular based temperature and strain rate dependent yield criterion for anisotropic elastomeric thin films", Polymer, vol. 125, pp 144-153, 2017.

Mechanics of tension-induced membrane wrinkling and restabilization

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Wrinkling of thin membranes under tension is omnipresent in nature and modern industry (see Fig. 1), a phenomenon which has aroused considerable attention during the past two decades because of its intricate nonlinear behaviors and intriguing morphology changes. In this talk, we review recent advancements [1-5] in the mechanics of tension-induced membrane wrinkling and restabilization, by identifying three major stages of its progress: small-strain (<5%) wrinkling of stiff sheets, finite-strain (up to 30%) wrinkling and restabilization (isola-center bifurcation) of soft films, and the effects of curved configurations and material properties on pattern formation. Growing demand for fundamental understanding, quantitative prediction, and precise tracking of secondary bifurcation transitions in morphology evolution of thin films helps to advance finite-strain plate/shell theories and sophisticated modeling methods. This progress not only promotes our insightful understanding of complex instability behavior, but also reveals novel phenomena and sheds light on developing wrinkle-tunable membrane structures and functional surfaces.

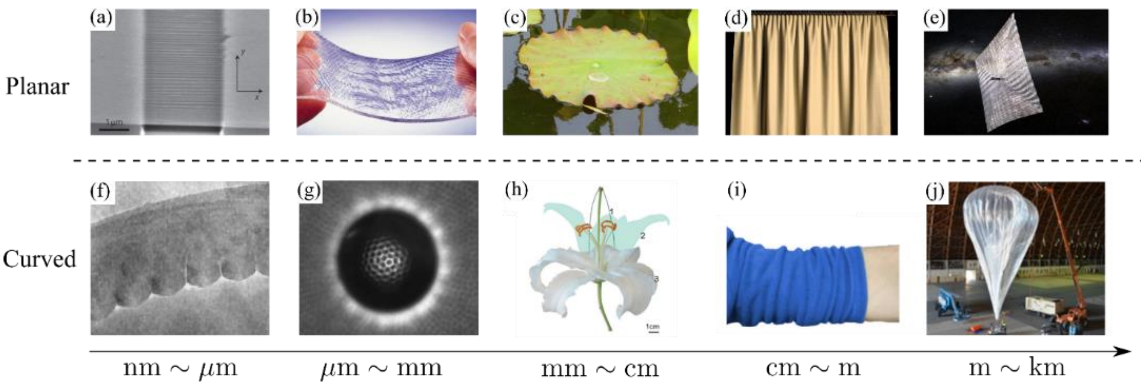

Fig. 1. Abundant membrane wrinkling phenomena in nature and modern industry across length scales.

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References:

[1] T. Wang, Y. Yang, C. Fu, F. Xu. Competition between Mullins and curvature effects in the wrinkling of stretched soft shells. ***Int. J. Solids Struct.***, 241: 111473-1–111473-9, 2022.

[2] T. Wang, F. Liu, C. Fu, X. Zhang, K. Wang, F. Xu. Curvature tunes wrinkling in shells. ***Int. J. Eng. Sci.***, 164: 103490-1–103490-20, 2021.

[3] T. Wang, Y. Yang, C. Fu, F. Liu, K. Wang, F. Xu. Wrinkling and smoothing of a soft shell. ***J. Mech. Phys. Solids***, 134: 103738-1–103738-20, 2020.

[4] T. Wang, C. Fu, F. Xu, Y. Huo, M. Potier-Ferry. On the wrinkling and restabilization of highly stretched sheets. ***Int. J. Eng. Sci.***, 136: 1–16, 2019.

[5] C. Fu, T. Wang, F. Xu, Y. Huo, M. Potier-Ferry. A modeling and resolution framework for wrinkling in hyperelastic sheets at finite membrane strain. ***J. Mech. Phys. Solids***, 124: 446–470, 2019.

Localised bulging of an inflated rubber tube with fixed ends

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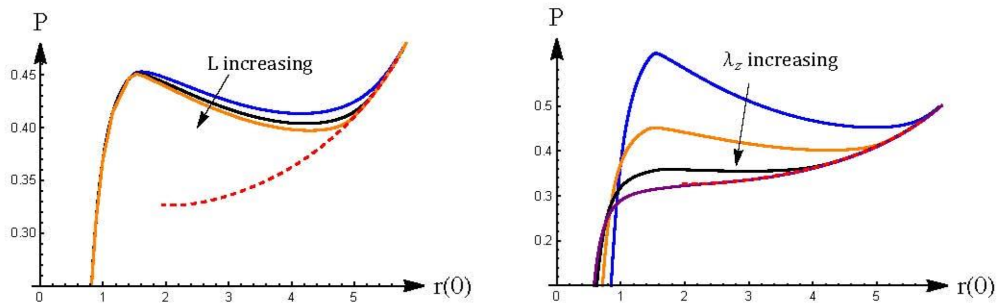
When a rubber tube with free ends is inflated under volume control, the pressure will first reach a maximum and then decrease monotonically to approach a constant asymptote [1]. The pressure maximum corresponds to the initiation of a localised bulge and is predicted by a bifurcation condition, whereas the asymptote is the Maxwell pressure corresponding to a “two-phase" propagation state [2-6]. In contrast, when the tube is first pre-stretched and then has its ends fixed during subsequent inflation, the pressure versus bulge amplitude has both a maximum and a minimum, and the behaviour on the right ascending branch has previously not been fully understood. We show that for all values of pre-stretch and tube length, the ascending branches all converge to a single curve that is only dependent on the ratio of tube thickness to the outer radius (see figures below). This curve represents the Maxwell state to be approached in each case (if Euler buckling or axisymmetric wrinkling does not occur first), but this state is pressure-dependent in contrast with the free-ends case. We also demonstrate experimentally that localized bulging cannot occur when the pre-stretch is sufficiently large and investigate what strain-energy functions can predict this observed phenomenon.



Acknowledgements: This work was supported by the National Natural Science Foundation of China (Grant Nos 12072224, 12002067).

References:

[1] Kyriakides S, Chang YC. 1990 On the inflation of a long elastic tube in the presence of axial load***. Int. J. Solids Struct.*** 26, 975–991.

[2] Fu YB, Pearce SP, Liu KK. 2008 Weakly nonlinear analysis of localized bulging of an inflated hyperelastic tube of arbitrary wall thickness. ***Int. J. Non-linear Mech.*** 43, 697–706.

[3] Fu YB, Liu JL, Francisco GS. 2016 Localized bulging in an inflated cylindrical tube of arbitrary thickness – the effect of bending stiffness***. J. Mech. Phys. Solids*** 90, 45–60.

[4] Wang SB, Guo GM, Zhou L, Li LA, Fu YB. 2019 An experimental study of localized bulging in inflated cylindrical tubes guided by newly emerged analytical results. ***J. Mech. Phy. Solids*** 124, 536–554.

[5] Chater E, Hutchinson JW. 1984 On the propagation of bulges and buckles. ***ASME J. Appl. Mech.*** 51, 269–277.

[6] Yin WL. 1977 Non-uniform inflation of a cylindrical elastic membrane and direct determination of the strain energy function. ***J. Elast.*** 7, 265–282.

Inverse design of inflatable structures through modelling, optimization and machine learning

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When a rubber balloon is inflated its shape changes. This property has been exploited in the design of inflatable structures and soft robots. Harnessing the dramatic deformation resulting from the inflation of a soft membrane, scientists have been able to transform flat objects into shelters [1], storm surge barriers [2] and space modules [3].

For most application, controlling the final inflated/actuated shape of the device is of paramount importance. Therefore, across fields of science, researchers have increasingly focused on designing soft devices that can morph into target shapes to achieve functionality.

Here, I present different approaches for the inverse design of inflatable structures. Kirigami [4], soft pixelated membranes [5] and multistable origami [6] are powerful design platforms to create functionality through shape-changing capabilities. Classical optimization approaches and machine learning methods can be used to solve ill-posed inverse problems where a target shape in input is given and the optimal design to achieve that target shape upon inflation (or deflation) is obtained as result.

Acknoledgements: This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 798244

References:

[1] D. Melancon, B. Gorissen, C. J. García-Mora, C. Hoberman & K. Bertoldi. Multistable inflatable origami structures at the meter scale. Nature

[2] A. Niewiarowski, A. Rock, S. Adriaenssens, M. Chiaramonte. Pneumatic storm surge barriers subject to hydrodynamic loading. IASS 2018: Creativity in Structural Design, Massachusetts, 2018.

[3] Bigelow's next-generation inflatable space habitat is shoting fort he moon, The Verge. https://www.theverge.com/2019/9/13/20863143/bigelow-aerospace-b330-inflatable-space-habitat-nasa-nextstep-astronauts

[4] L. Jin*, A. E. Forte*, B. Deng, A. Rafsanjani, K. Bertoldi. Kirigami-inspired inflatables with programmable shapes. Advanced Materials

[5] A. E. Forte, P. Z. Hanakata, L. Jin, E. Zari, A. Zareei, M. C. Fernandes, L. Sumner, J. Alvarez, K. Bertoldi. Inverse Design of Inflatable Soft Membranes Through Machine Learning. Advanced Functional Materials

[6] A.E. Forte*, D. Melancon*, L.M. Kamp, B. Gorissen, K. Bertoldi. MuA-Ori: Multimodal Actuated Origami. arXiv

A new concept of inflatable shell structures

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Inflatable structures are often obtained by sealing together patches along their border, programming the 3D shape as a taylor would do, with pressure only providing structural stiffness.

We present here a different concept of inflatable shells where inflation is turning a flat double layer into a shell. It is obtained through a very simple manufacturing process: two superimposed flat fabric are heat-sealed along well-chosen path. When the resulting maze of inflatable tube is inflated, it imposes an effective lateral contraction of distances [1].

The distortion of the metris leads to non developable shapes when inflated [1,2,3]. Still, the deflated fabric is a simple planar double fabric, that can be simply folded or rolled. The stiffness of the shell is very anisotropic, depends primarily on the internal pressure, and could possibly be used at the architectural scale.

Fig. 1. An inflated planar pattern leads to a dome shape when inflated.

References:

[1] E.Siéfert, J.Bico, E.Reyssat, B.Roman**.** Programming stiff inflatable shells from planar patterned fabrics. ***Soft Matter*** 16, 7898-7903, 2020.

[2] T.Gao, A. DeSimone, E.Siéfert, B.Roman. Shape Programming: Shape Programming by Modulating Actuation over Hierarchical Length Scales. ***Advanced Materials,*** 32, 2004515, 2020.

[3] J. Panetta, F. Isvoranu, T. Chen, E. Siefert, B. Roman and M. Pauly. Computational inverse design of surface-based inflatable. ***ACM Transactions on Graphics SIGGRAPH*** 40, pp 1–14, 2021**.**

Experiments on origami metamaterials with tunable Poisson's ratio

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Origami metamaterials display highly tunable Poisson's ratio values depending on their folded state. Usually, Poisson's effect is formulated theoretically under the assumption of rigid panels. Nonetheless, origami metamaterials are often fabricated with non-rigid panels so that their mechanical properties could differ from those predicted theoretically. Here, we present a novel experimental setup, shown in Fig. 1, suitable to study the Poisson effects in deployable metamaterials that undergo simultaneous deformations in both the applied and transverse directions. Using this setup, we conduct Poisson's ratio measurements of the standard Miura-ori, the standard Eggbox, and the recently proposed Morph origami metamaterials [1]. We experimentally observe the Poisson's ratio sign switching capability of the Morph pattern, along with its ability to exhibit either completely positive or completely negative values of Poisson's ratio by virtue of topological transformations. Our results demonstrate the agreement between the theory, the simulations, and the experiments on the Poisson's ratio measurement and its tunability in origami metamaterials.

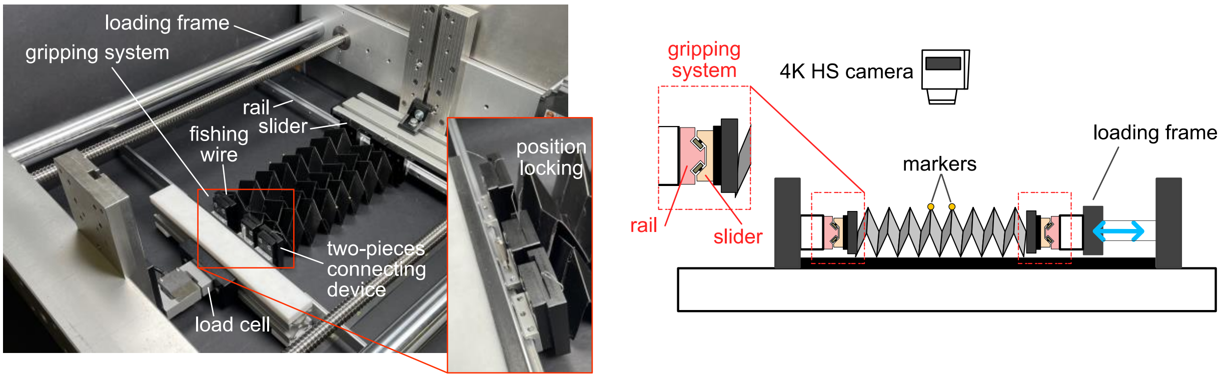

Fig. 1. Experimental setup designed and realized to perform the Poisson's ratio experiments on three different origami patterns: the standard Miura-ori, the standard Eggbox and the Morph.

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References:

[1] Pratapa, P.P., Liu, K., Paulino, G.H., "Geometric mechanics of origami patterns exhibiting Poisson's ratio switch by breaking mountain and valley assignment", Physical review letters, 122.15, 155501 (2019).

Inflated Cone Experiment for High-Throughput Characterization of Time-Dependent Polymer Membranes

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Long-term behavior of polymer membranes in the nonlinear regime are probed by strain histories under various stress levels. Current characterization methods for polymer membranes impose a uniform stress field and hence require a series of long-duration tests to be conducted, which poses a significant experimental challenge. Here we present the inflated cone method to generate a continuous spectrum of strain histories under various stresses in a single experiment. By imposing a known stress gradient and utilizing full-field strain measurement technique, the inflated cone method provides a high-throughput approach for extracting time-dependent data of polymer membranes. The method is suitable for studying nonlinear time-dependent deformations under biaxial stress state. The stress range and ratio can be easily modulated by cone geometry design. We demonstrate the utility of the method through creep-recovery tests carried out on a thin polyethylene film. The proposed experimental method is highly beneficial for development of nonlinear viscoelastic and viscoplastic models.

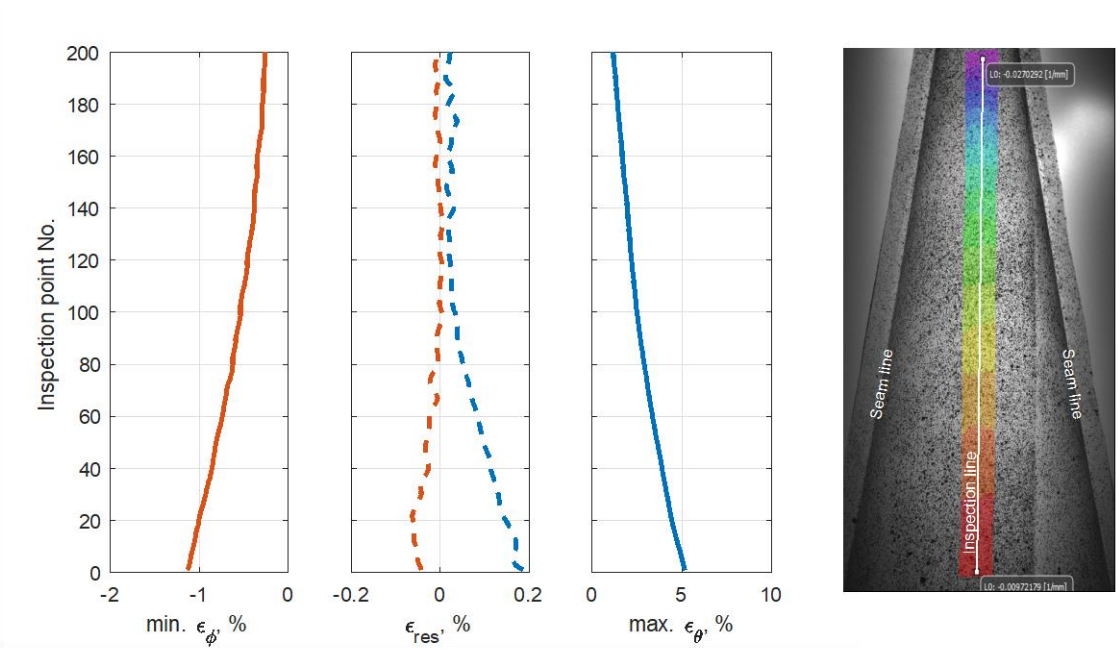

Fig. 1 Meridional and hoop strain distributions on the inflated cone.

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New developments in ETFE envelopes

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ETFE is one of the most stable chemical compounds and its films are largely employed in the building industry due to the very good long-term stability, resistance to soiling and high light transmittance. The mechanical strength is relatively good, especially considering that the material is not reinforced by a woven support, and make ETFE foils suitable for load-bearing envelopes characterized by small spans or supported by cables.

ETFE foils are traditionally used for multilayer pneumatic cushions, however, in recent projects the application of single skin ETFE foils has been successfully investigated. This innovative application opens new areas of interest in the area of the building envelope, such as a protective secondary facade. In addition, the growing demand for reducing the heating\cooling costs has recently increased the demand for ETFE foils with pigments or surface treatments able to improve the environmental performance of lightweight envelopes based on ETFE foils.

Fig. 1 Monitoring of an ETFE envelope, Maco Technology.

This presentation describes the recent developments in this field through a series of built projects which include a retrofitted ETFE roof, a temporary pavilion and a permanent ETFE Façade. The analysis of the case studies provides a unique opportunity to highlight the advantages and disadvantages of ETFE envelopes and the promising new developments in this field.

Design and development of membrane structures: case studies

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Lightweight membrane and foil materials are used for various purposes in modern architecture. Especially in long-span structures lightweight membrane and foil materials often provide benefits compared to other building materials. Freedom in form and a high tensile strength combined with a growing selection of available materials make their application very popular and versatile. By having a very low dead load compared to other cladding materials, structural membranes and foils allow structures with minimal mass and contribute to significanly reduce the overall CO_2 footprint of a building structure. In today's architecture and even more so in the future, increasing demands are and will be placed on the functionality and aesthetics of these building skins.

The presented case studies show a variety of solutions where structural membranes and foils are used for the building envelope. The projects include standard materials as for example ETFE foils, glass/PTFE or PVC/PES membranes on the one hand but also project specific material developments are shown.

Figure 1: M11 Memorial Madrid

Figure 2: special woven membrane

References:

[1] C. Paech: Structural membranes used in modern building facades. Proceedings of the 2016 Tensinet Symposium, Newcastle. Procedia Engineering Volume 1552016 Pages 61-70.
[2] K. Göppert, C. Paech: *Memorial in Madrid*, Detail, 10/2007, S.1160-1166
[3] C. Paech: Moveable membranes - smart solutions in the field of architecture. Proceedings of the TensiNet Symposium 2019.

The Making of HOWL by Anish Kapoor: a Fitting Inflated Sculpture

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Contemporary art is often abstract and enigmatic. In many cases, it is not meant to be understood, but rather is experienced. Contemporary artists employ symbolic, sometimes, instinctive associations to certain colours, shapes and patterns to instigate an emotional response from the viewer. To achieve this, their works can be purposefully distanced from realism and be devoid of superfluous details. However, this minimalistic approach does not always apply to the scale of the artworks. One of the most influential contemporary artists, Anish Kapoor, is famous for his monumental installations that blur the boundaries between architecture and sculpture. His latest work, entitled “HOWL”, is a site-specific inflated fabric form installed in the Rotunda of the Pinakothek der Moderne, Munich, Germany in September 2020 to mark the 18-year anniversary of the museum opening. At 21.5m in diameter and 14.3m in depth, the burgundy-coloured ellipsoidal form is the largest exhibit that has ever been displayed in the museum. It fills the Rotunda and is seemingly squeezed between its columns extending naturally into the spaces between them and hanging at the height of 2.75m over the ground. This creates a powerful visual and formative interaction between the art object and the building, which has been a focal design intention.

The enormous pneumatic sculpture had to be tailored perfectly to the building to convey this effect. Any deviations from the desired form could lead to wrinkles, overstressed or slack fabric areas and loss of symmetry, which would impact the fine art work aesthetically and could even prevent its installation. Tensys have been tasked to realise the artist’s vision of HOWL, undertaking fabric analysis and patterning. This paper presents the methods used to address the engineering challenges in this project, including parametric CAD and FEA tools for optimisation of the shape and the consideration of material behaviour and the effects of inflation pressure and contact with the columns on the form and material stresses.