Towards new engineering standards for ETFE roofs – from mono- to biaxial stress/strain characterization based upon physical properties of ETFE-foils

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Abstract

To date the commonly used method for determining the ULS and SLS of ETFE foils in roof and facade structures is based upon mono-axial tensile strain [1] and creeping [2] tests, which only reflects one-dimensional properties of the ETFE material. However, in all roof structures, where inflatable ETFE-cushions has been used so far, membranes are exposed to biaxial stress. This is in clear contrast to mono-axial measurements, which are still suggested to be taken as reference for the determination of limits of ETFE-foils [3]. The mono-axial stress is an idealized case, which neglects completely the contribution of transverse contraction, i.e. Poisson's ratio. There is also no derivation available so far, which is giving evidence for the applicability of the mono-axial case in bi-axial stress scenarios. A negative example is the determination of the tensile strength of ETFE with a nominal value of 50 N/mm^2. Taking into account the reduction of the test stripe width from 20 mm to 9.1 mm and the thickness from 250 µm to 140 µm, the tensile strength results as 196 N/mm^2.

In order to get the elastic and viscoelastic properties of the ETFE foils including the time constants for creeping we have conducted biaxial tensile stress tests as a combination of oscillatory, retardation and relaxation experiment with stress ratios of 1:1 and 1:2 for both axis. These measurements reflect a more realistic view on an ETFE-foil under biaxial stress, e.g. for a static wind load, which is additionally influenced by short-time gusts of wind. For a biaxial stress ratio of 1:1 the machine direction MD and transversal direction TD was determined to be more than 10%. In addition, the creeping of the foil shows an exponential saturation behaviour with a time constant of approximately 200 seconds. In addition, it has to be noted, that the ETFE-foil remained elastic within short-time load changes even at high static loads resulting in stress of 20 N/mm^2. During the relaxation period the biaxial stress was reduced to a value of 4 N/mm^2, leading to an incomplete relaxation of the material, however, the strain is reduced furthermore with a considerable higher time constant than in the case of creeping under higher loads.

References

[1] DIN EN ISO 527-1:2018-08 & DIN EN ISO 527-03:2019-2

[2] DIN EN ISO 899-1:2018-03 .

[3] *N. Stranghöner, J. Uhlemann et.al.*, Prospect for European Guidance for the Structural Design of Tensile Membrane Structures, JRC Report: Eurocodes Scientific and Technical Report, Publications Office of the European Union, Luxembourg (2016)