

WATER-INDUCED AGEING MODIFICATION FACTOR FOR PTFE-COATED GLASS FIBRE FABRIC

H. ASADI^{*}, J. UHLEMANN^{*}, N. STRANGHOENER^{*} AND M. ULBRICHT[†]

^{*} University of Duisburg-Essen, Institute for Metal and Lightweight Structures, Universitaetsstr. 15, 45141 Essen, Germany
Email: hastia.asadi@uni-due.de, joerg.uhlemann@uni-due.de, natalie.stranghoener@uni-due.de - Web page: www.uni-due.de/iml

[†] University of Duisburg-Essen, Lehrstuhl für Technische Chemie II, Universitaetsstr. 7, 45117 Essen, Germany
Email: mathias.ulbricht@uni-essen.de - Web page: https://www.uni-due.de/tech2chem

Key words: Tension Fabric Structure, Glass-PTFE Materials, Water Impacts, Uniaxial Tensile Strength, and Water-Induced Ageing Modification Factors

Summary. *The negative impact of water must be considered during the design of architectural coated woven fabrics which are sensitive to water attacks. It is known that the uniaxial tensile strength of glass-PTFE materials does degrade with water attack. This contribution quantifies the possible tensile strength reduction of different types of glass-PTFE materials under various water exposure conditions. This includes not only water exposure of unsealed cutting edges, as they, e. g., exist in weld seams, but also water exposure of the glass fibres through the PTFE coating. Experimental results show that both water exposure methods lead to similar degradation effects. From the acquired values of degradation, strength modification factors have been derived using the principles of the new European Technical Specification prCEN/TS 19102:2021-04 “Design of tensioned membrane structures”.*

1 INTRODUCTION

Water in various forms of air humidity, rain, snow, hail, dew, and/or frost can deteriorate materials by chemical reaction and/or mechanical stress originating from sequences of swelling-deswelling. Glass-PFE material as a composite polymer is composed of a high-strength glass fibre fabric and high-performance polytetrafluoroethylene (PTFE) coating. Glass yarns are embedded in the PTFE coating layer due to their sensitivity to water effect. The insufficient intrinsic protective functionality of the PTFE layer was proved by Asadi et al.¹ hence, water can reach the middle layer of glass-PTFE polymer, i.e. fabric yarns, thorough surface pinholes. Additionally, water content fluctuation causes compressive and tensile stresses which results in cracking². Over time, ageing cracks develop and the protection of the coating is reduced. Water movement through the uncovered edges and through the thickness of fabric is called in-plane and out-of-plane water seepage, respectively. In this paper, the impact of water in both shapes of in-plane and out-of-plane watering on the tensile strength of different types of glass-PTFE fabrics were assessed experimentally. Furthermore, the degradation rate of the uniaxial tensile strength was evaluated in line with the recently drafted design rules of tension fabric structures, based on the principles of the

Eurocodes, the new European Technical Specification prCEN/TS 19102:2021-04 “Design of tensioned membrane structures”³.

2 WATER IMPACT ON GLASS-PTFE FABRICS

Glass-PTFE composites consist of E-glass fibre, finish layer, silicon-based primer, unfilled PTFE or glass-filled PTFE coating, and top coating layers. By assuming the ideal performance of each layer, glass-PTFE fabrics can be regarded as one of the most durable architectural coated woven fabrics with a life expectancy of more than 30 years. The existence of some local defects such as pinholes in the final coating can lead to water contact with glass fibres which causes tensile strength deterioration¹. The influence of water on the mechanical properties of glass-PTFE composites first was studied by Ansell et al.⁴. They immersed several glass-PTFE fabrics (weighted between 750-1600 gm⁻²) in a flask containing distilled water (conditions of 85 °C / 85 % RH (relative humidity) and 5 °C / low RH every 12 hours) and observed the retaining tensile strength of about 62 % of the virgin value. They also dried samples at 20 °C / 65 % RH which partially recovered the tensile strength reduction. 12 years later, Toyoda et al.⁵ submerged uncoated glass fibre fabric and glass-PTFE fabrics in a hot water bath at 20 °C, 30 °C, 50 °C, and 90 °C for maximum of two weeks and reported 31 % for uncoated glass fibre fabrics and 62 % for glass-PTFE fabrics (belonging to 90 °C). Scanning electron microscope of 90 °C specimens illustrated micro-holes, micro-cracks, and partial failures on the surface of uncoated glass fibres while some indentations and adhesion of fine particles were visible on the glass-PTFE surfaces. Asadi et al.^{1, 6} investigated the temporary and permanent tensile strength deterioration of glass-PTFE type II fabrics for different time periods. They observed a recovery of the tensile strength from the temporary to permanent states whereas a decrease of the tensile strength was obvious by comparing the permanent and virgin situations. In their research, the temporary and permanent conditions mean the tensile strength measurement after watering and one water-dry cycle, respectively. They also detected ink penetration through the intact coating of glass-PTFE type IV in the direction and opposite direction relative to gravity.

3 EXPERIMENTAL INVESTIGATION

3.1 General

The presented experiments scrutinized the tensile strength reduction of glass-PTFE at two different watering conditions: out-of-plane watering and a combination of both in-plane and out-of-plane watering, as is shown in Figure 1.

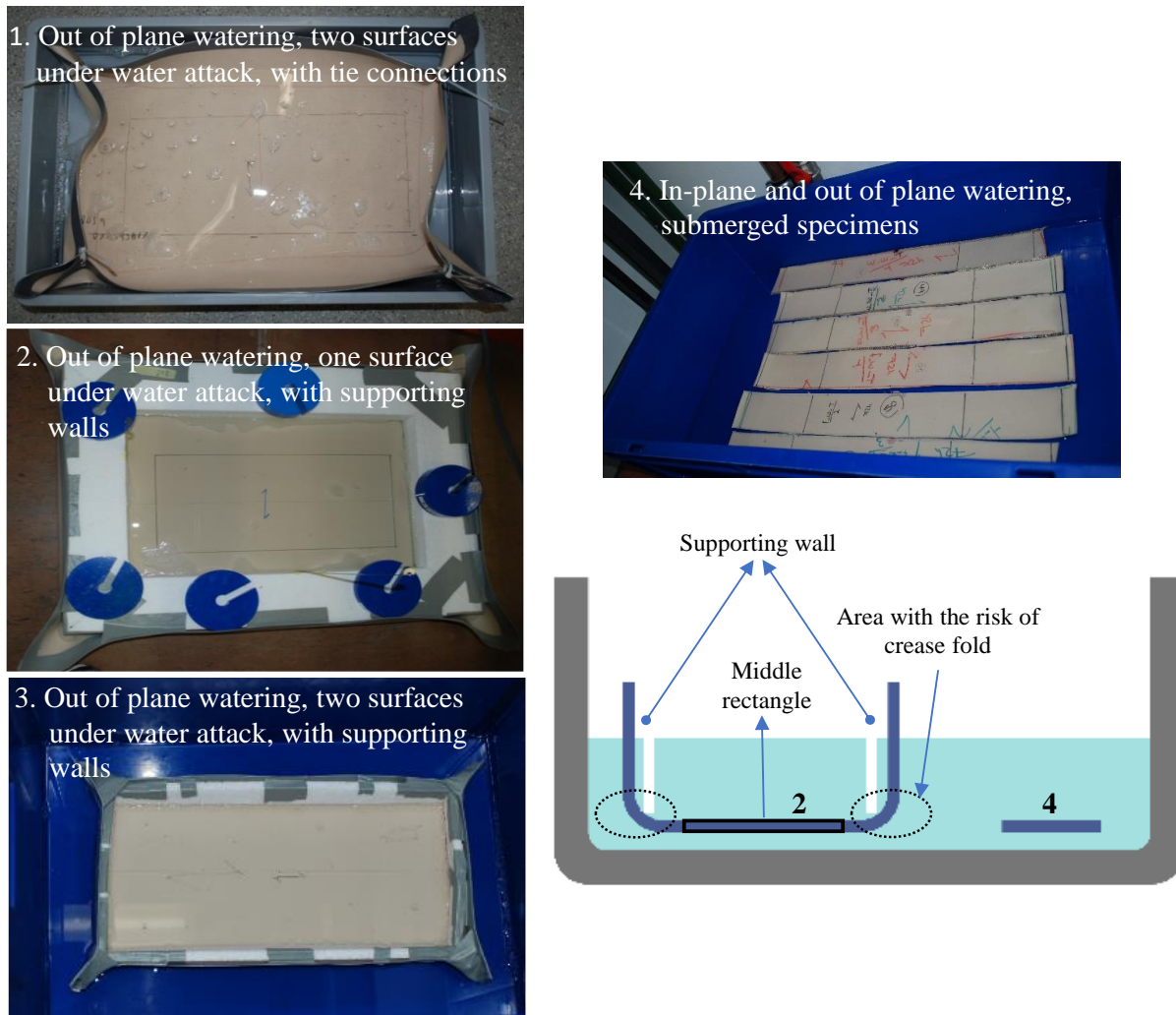


Figure 1: Different mechanisms of water seepage through glass-PTFE fabrics

3.1 Material

In this investigation, glass-PTFE types II, III, and IV classified based on prCEN/TS 19102:2021-04³ were utilized. Technical specifications are provided in Table 1. The classification is based on the tensile strength provided in producer's datasheets; all materials belong to a German producer which is well known for manufacturing architectural membrane fabrics.

Table 1: Specification of investigated materials

Sample	Number of batches	Total weight [gm ⁻²] ^{**}	Thickness [mm] ^{***}	Yarn density warp/weft [dtex] ⁺	Yarn count warp/weft [cm ⁻¹] ⁺⁺
Glass-PTFE type II (III) [*]	Two	1291	0.73	1360/1360	13/11
Glass-PTFE type III	Two	1153	0.66	2040/2040	11/13
Glass-PTFE type IV	Five	1641	0.94	4080/4080	8/10

^{*}Type II according to datasheets, type III according to measured tensile strength, ^{**} mean of all batches, measured based on DIN EN ISO 2286-2:2017-01⁷, ^{***} mean of all batches, measured based on DIN EN ISO 2286-3:2017-01⁸; ⁺ mass per unit length [0.1 g/km], taken from producers' datasheets; ⁺⁺ mean of all batches, measured based on DIN EN 1049-2:1994-02⁹.

3.2 Methods

The combined water specimens, state 4 of Figure 1, were standard strips ($50 \pm 1 \times 420$ mm²) based on EN ISO 1421¹⁰, while out-of-plane watered samples were individually formed samples of bigger pieces of the fabrics (350×620 mm² or 450×620 mm²), see states 1, 2, and 3 of Figure 1. The extra edges (100 mm from each side) of the out-of-plane samples were bent up to form walls that can stay higher than the water level with the help of the supporting walls or by tie connections. In the latter configuration to avoid crease fold, corners should be set far from middle rectangles. The provisions for wet specimens based on EN ISO 1421 require that the distilled water volume is equal to 20 times the total sum of the specimens' volumes either for the combined water seepage or out-of-plane watered specimens while the soap surfactant (as surface tension decreasing agent) volume is 0.1 % of the distilled water volume. For one test series, water without surfactant was also used. For the two-sided out-of-plane watered specimens, state 1 of Figure 1, the water volume on each side was equal to the aforementioned amount. After finishing the water cycle, samples were rinsed and dried between two sheets of blotting paper, and then the uniaxial tensile behavior of the material was measured by a uniaxial constant rate extension machine (CRE) according to the strip test method of EN ISO 1421.

4 RESULT AND DISCUSSION

4.1 Combination of in-plane and out-of-plane watering - different watering time period

The mean tensile strength (evaluated from three or five specimens for each test series) of in-plane and out-of-plane watered specimens, see state 4 of Figure 1, with watering periods of 24 h, 48 h, 72 h, 144 h, 147.5 h, and 720 h are illustrated in Figure 2. Considering this Figure, the decrease of the tensile strength is dominant for all watered cases even after 24 h. But no general trend of the higher rate of tensile strength deterioration by extending the watering time period is recognizable. This happens maybe because the mechanism of the tensile strength degradation reaches a steady state at early watering stages. The magnitude of the residual tensile strength for each single glass-PTFE specimen shows a scatter value between 80.0 % to 99.0 % for a watering time period maximum of 30 days, see Table 2.

Table 2: Residual tensile strength of glass-PTFE after different watering time periods

Watering time period [h]	Residual tensile strength [%]	
	Warp	Weft
24	82.8 to 99.0	80.0 to 98.5
48	86.1 to 94.1	83.8 to 94.9
72	83.4 to 94.7	81.0 to 93.3
144	81.5 to 94.9	77.7 to 96.7
720	81.8 to 93.8	83.4 to 94.7

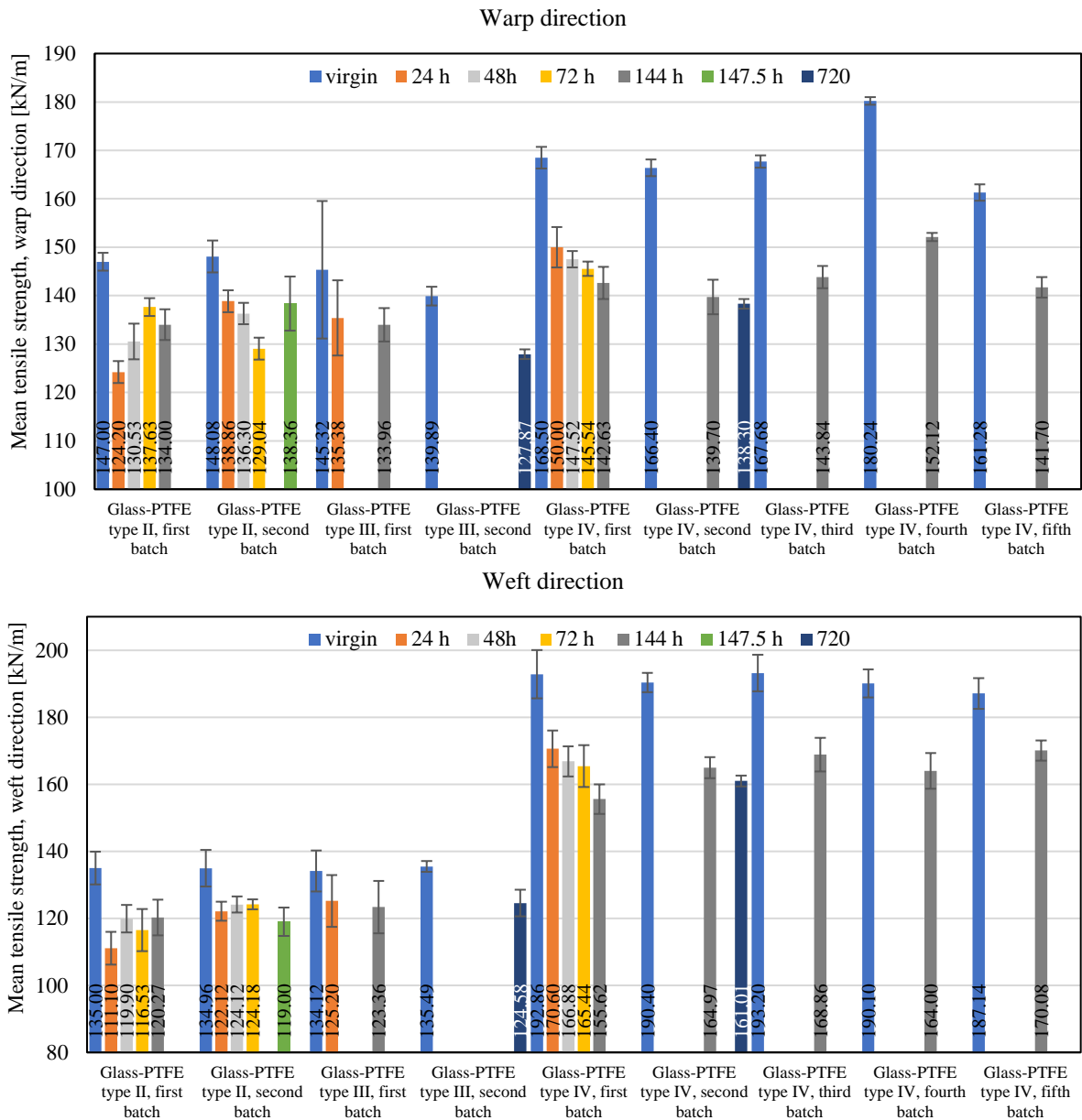


Figure 2: Mean tensile strength of glass-PTFE samples, different watering time periods

4.2 Comparison of different water seepage mechanisms

Figure 3 plots the mean tensile strength taken from three to five test specimens to compare the water penetration via either coating and uncovered edges or via coating only.

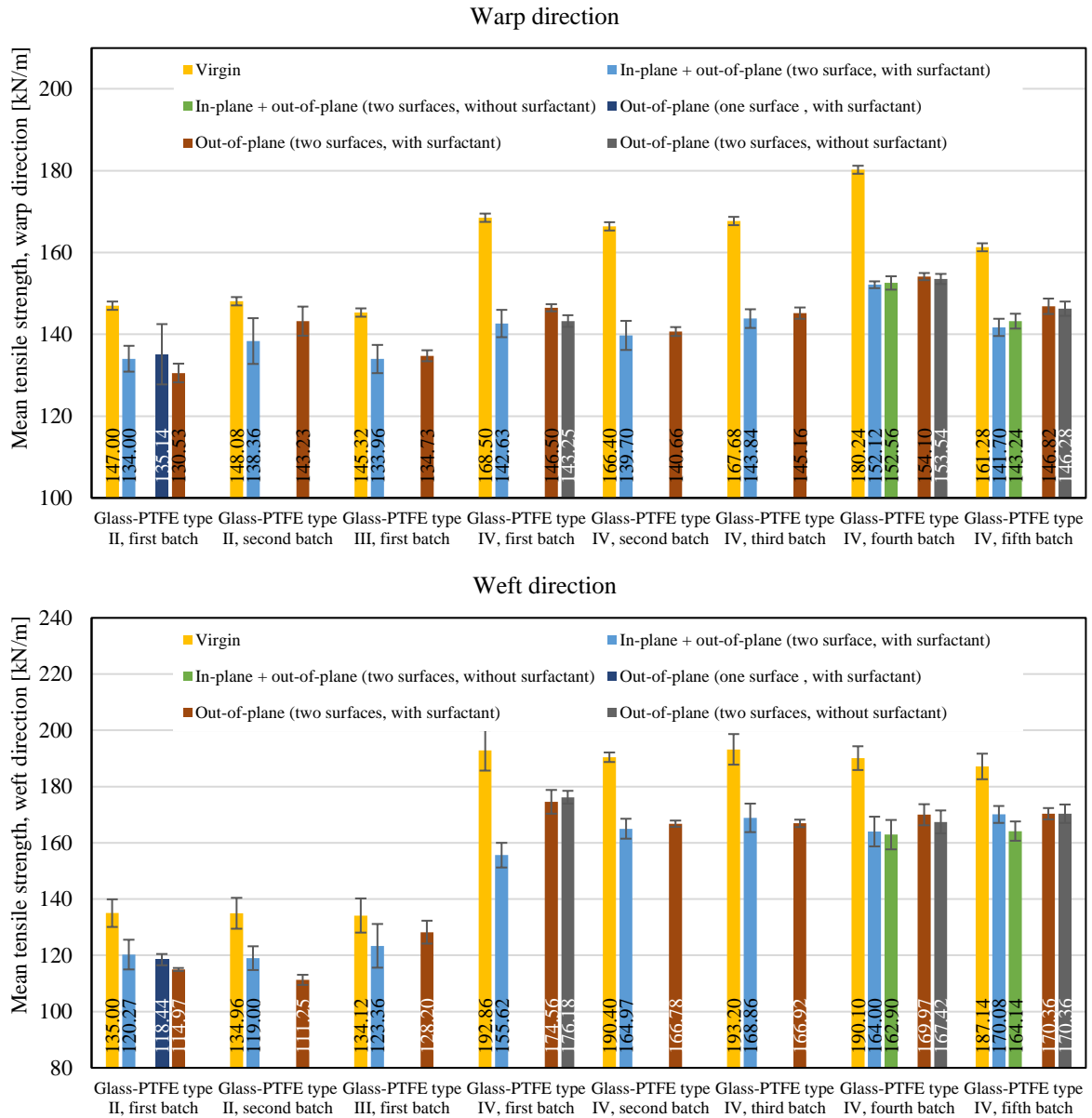


Figure 3: Mean tensile strength of glass-PTFE fabrics, different watering mechanisms

Compared to the virgin state, the tensile strength decrease governs all watered states while no stringent trend ruled the change of the tensile strength due to various water seepage mechanisms. The variation range of the residual tensile strength obtained from each single watered specimen is shown in Table 3. Based on this table, all watering mechanisms result in

almost the same variation domain. From a practical point of view, it can be stated that the mechanisms of water attack played no role on the tensile strength reduction rate. It is also implicitly comprehended that as soon as the glass-PTFE fabric is exposed to water, degradation has to be expected.

Table 3: Residual tensile strength of glass-PTFE for different water seepage mechanisms.

Watering time period [h]	Residual tensile strength [%]	
	Warp	Weft
In-plane + out-of-plane (two surfaces)	81.5 to 96.7	77.7 to 96.7
In-plane + out-of-plane (two surfaces) without surfactant	83.3 to 90.8	81.3 to 89.9
Out-of-plane (one surface)	83.1 to 95.3	86.0 to 89.6
Out-of-plane (two surfaces)	83.8 to 99.4	80.9 to 97.5
Out-of-plane (two surfaces) without surfactant wetting	84.3 to 92.1	85.2 to 93.8

5 STRENGTH REDUCTION FACTOR

The deteriorative effect of water on glass-PTFE as construction material must be considered in every design situation owing to the omnipresence of water. The current draft standard of prCEN/TS 19102³ proposes a value of 1.10 as the weathering-induced ageing modification factor for glass-PTFE materials. In this paper, a strength modification factor k_{hum} is proposed to describe the deterioration effect of water or humidity on glass-PTFE fabrics by equation (1), where $f_{k,23,virgin}$ and $f_{k,23,watered}$ represent the 5 % fractile values of the short-term tensile strength in virgin and watered states at room temperature. The maximum values for the investigated glass-PTFE type II, III, and IV are 1.20 (warp)/1.25 (weft), 1.12 (warp)/1.15 (weft), and 1.25 (warp)/1.20 (weft), respectively. It should be noted that k_{hum} cannot be implemented in the design solely; the combined effect of all possible environmental impacts is required.

$$k_{hum} = \frac{f_{k,23,virgin}}{f_{k,23,watered}} \quad (1)$$

6 CONCLUSIONS

In this paper, the degradation effect of water on the uniaxial tensile strength of glass-PTFE materials was assessed experimentally. Permitting the ingress of moisture can lead to glass fibre failure even at ambient temperature. The decrease of the tensile strength occurred with the first 24 hours of watering with the highest deterioration rate of 17.2 % in warp and 20.0 % in weft directions. More prolonged exposure to water had only a marginal further influence. Water attacks glass fibres not only via in-plane watering at unsealed cut edges but also in almost the same tensile strength damaging magnitude via out-of-plane watering through the coating. The highest observed rate of tensile strength degradation in out-of-plane watering states was 16.9 % for warp and 19.1 % for weft directions. For this reason, the destructive effect of water on glass-PTFE materials should be considered in the design of membrane structures. This decrease of the uniaxial strength can be evaluated by k_{hum} , which acts as a

strength reduction factor under humidity effect and was determined as a maximum 1.25. It must be emphasized, that this value cannot be utilized alone in the design of membrane structures. The impact of other environmental influences, as e. g. UV radiation, have to be included, as well.

REFERENCES

- [1] Asadi, H., Uhlemann, J., Stranghoener, N., and Ulbricht, M. Water influence on the uniaxial tensile behavior of polytetrafluoroethylene-coated glass fiber fabric. *Materials MDPI* (2021), **14**:1-22.
- [2] A. Davis and D. Sims, *Weathering of Polymers*, Springer, 1983rd edition, 1983.
- [3] prCEN/TS 19102:2021-04, Design of tensioned membrane structures (unpublished draft, publication expected 2022).
- [4] Ansell, M.P., Hill, C.A.S., and Allgood, C. Architectural PTFE-Coated Glass Fabrics- Their Structure and Limitations. *Text. Res. J.* (1983) **53**:692-700.
- [5] Toyoda, H., Sakabe, H., Itoh, T., and Konishi, T. Degradation of polytetrafluoroethylene-coated glass fiber fabrics by hot water treatment. *J. Fiber Sci.* (1995) **51**:282–286.
- [6] Asadi, H., Uhlemann, J., and Stranghöner, N. Water infiltration impact on tensile strength and breaking strain of architectural fabrics. *Adv. Struct. Eng.* (2018) **21**:2605-2616.
- [7] DIN EN ISO 2286-2:2017-01, Rubber- or plastics-coated fabrics - determination of roll characteristics - Part 2: Methods for determination of total mass per unit area, mass per unit area of coating and mass per unit area of substrate; German version EN ISO, 2017.
- [8] DIN EN ISO 2286-3:2017-01, Rubber- or plastics-coated fabrics - determination of roll characteristics - Part 3: Method for determination of thickness; German version EN ISO 2286-3:2016, 2017.
- [9] DIN EN 1049-2:1994-02, Textiles; woven fabrics; construction; methods of analysis; part 2: determination of number of threads per unit length; German version EN 1049-2:1993, 1994.
- [10] DIN EN ISO 1421:2017-03, Rubber- or plastics-coated fabrics – determination of tensile strength and elongation at break; German version EN ISO 1421:2016, 2017.