X International Conference on Textile Composites and Inflatable Structures
STRUCTURAL MEMBRANES 2021
K.-U.Bletzinger, E. Oñate, R. Wüchner and C. Lázaro (Eds)

INTEGRATION OF ETFE FOIL CUSHIONS INTO CONVENTIONAL GLASS FACADE SYSTEMS BY MEANS OF ADAPTED, SPACE-SAVING JOINING METHODS

ANDREAS KUNZE, THOMAS STEGMAIER AND GÖTZ T. GRESSER

Deutsche Institute für Textil- und Faserforschung Denkendorf (DITF)
Körschtalstraße 26, 73770 Denkendorf, Germany
e-mail: andreas.kunze@ditf.de, web page: www.ditf.de

Key words: ETFE, inflatable, facade, joining, welding, gluing

Summary. The current technology for producing a translucent facade is dominated by glazing, facade construction kits and a high degree of prefabrication. New technologies are discussed, that allow the integration of ETFE foil cushions into conventional, customary, modular glass facade systems on the market. A new facade element is presented, which consists of a rigid profile frame with integrated thermic separation, covered on both sides with ETFE foil. New edge formations have been developed and tested with regard to the industrial prefabrication of rectangular ETFE facade cushion elements. In particular three space-saving joining methods for joining ETFE foils with aluminium profiles are presented and discussed: gluing with cyanoacrylate adhesive, welding onto an ETFE coating and clamping in a mini keder, as well as the associated, necessary pre-treatment methods. An assessment of the joints is made through tensile tests and long-time outdoor weathering tests. All methods were applied in demonstrators and represent technical solutions.

1 INTRODUCTION

From 2018 to 2020 various joining methods were investigated and developed by the DITF for the LEICHT GmbH with the aim of creating a new type of inflatable ETFE cushion facade element with enhanced performance, which can be integrated into conventional, customary, modular glass facade systems on the market. The element consists of a rigid, rectangular profile frame with integrated thermic separation, covered on both sides with ETFE foil as outlined in Fig. 1. Since the focus of the investigation was on minimizing the installation space for the joint, there was a desire to realize an adhesive connection between the ETFE foil and the frame. This has been implemented. At the same time, due to the small number of adhesive systems on the market available for the material ETFE, alternative joining methods were investigated, namely welding the foil onto a coating and fastening the foil mechanically in a minimized keder rail system. The mechanical fastening was developed by the LEICHT GmbH for the facade system provider RAICO Bautechnik GmbH and is already available on the market. The alternative joining methods, gluing and welding, also represent interesting technical solutions and are therefore discussed in detail below.

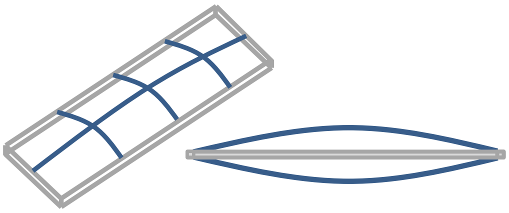

Figure 1: Inflated ETFE-facade element: rectangular rigid frame, both sides covered with ETFE foil

2 FACADE CONSTRUCTION

In order to implement a modular, scalable ETFE facade, integration possibilities into existing systems were sought. Mullion/transom systems of steel for glass facades offer several interesting construction details, that promise an increase in performance. Fig. 2 shows the cross-section of RAICO facade system elements, that were used for orientation: 1 mullion (Therm$^+$ FS1-System), 2 internal sealing plane, 3 pressure bar with sealing, 4 insulated glazing (drawing), 5 placeholder ETFE facade element frame, 6 cover strip, 7 air supply, 8 ETFE, 9 screw channel.

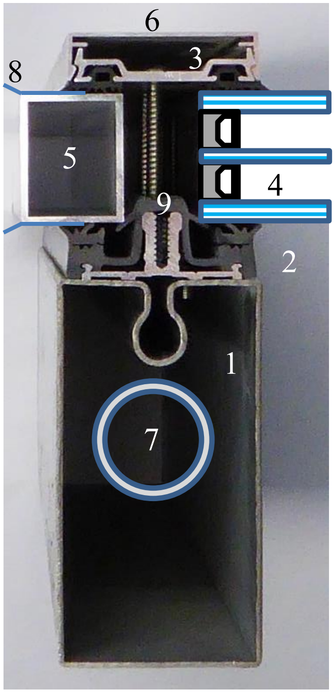

Figure 2: Cross-section of a RAICO facade system

Advantages over common special solutions in ETFE construction are: the ETFE cushion panel can be prefabricated and integrated like and, if desired, next to a glazing, no additional supporting structure is required, the mullion/transom system stabilizes the ETFE facade element and ensures its static stability, there are two separated sealing lines and there is a fold drainage, the air supply is invisible and a narrow face width is possible (cover strip 55 mm, mullion 60 mm).

3 BASIC FRAME CONSTRUCTION

If the ETFE cushions are to be installed parallel to insulated glazing, as shown in Fig. 2, an alignment of the component thicknesses is necessary. Furthermore, despite of the support of the mullion/transom system, a minimum flexural strength of the rectangular frame, to which the ETFE foil is fastened, is required for handling purposes. The aimed at maximum frame dimensions were 1,5 m x 3 m (now 5,9 m), so that the frame can be covered with material off the role, without a cutting pattern seam in the membrane surface. The approximate dimensions of the frame profile, shown in Fig. 2 (element 5), are 30 mm x 40 mm. The resulting available space for the desired joining process was absolutely sufficient. The width required for the targeted joints for fastening the ETFE foil was only 10 to 15 mm.

The simple frame profile shown in Fig. 2 does not provide any thermal separation between the panel surfaces in the region of the frame, compared to the triple-paned insulating glass, which uses insulating spacers. In order to increase the insulation performance of the aluminum frame profile, a thermal separation was sought. The first drafts were based on a full cross-section sandwich construction, Fig. 3 left side, where aluminum surface profiles are separated by an insulating block. The detailed versions took up a well-established technology in profile construction: two aluminum profiles, connected by two thermally insulating webs, Fig. 3 right side. As a result, for all joining processes examined and described below, the joining partners were aluminum and ETFE.

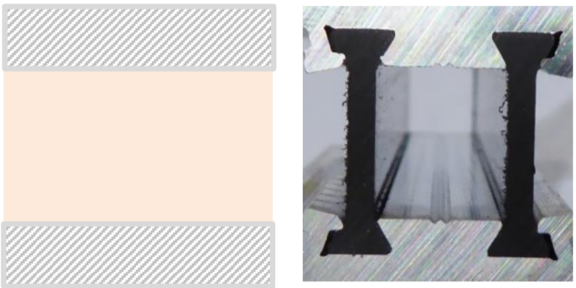

Fig. 3: Profile cross sections: sandwich construction (left), two insulating webs (right)

As can be seen in Fig. 2, the ETFE foil exits the frame surface in an angle, that creates peel loads. The idea of designing the frame cross-section according to the exit angle was rejected, because the angle is not the same along the frame, changes with varying loads and material strain, destroys the joining plane and contradicts the modular use of identical parts.

4 BOUNDARY CONDITIONS OF THE MEMBRANE CONSTRUCTION

The joining partner and the occurring loads are essential for determining the specifications of the joining seam and for identifying suitable joining methods.

4.1 ETFE Foil

One approach, to determine the required seam strength, is to base it on the maximum permissible membrane tension. Assuming a permissible load up to the second yield point, the beginning of plastic deformation, which was taken as 20 N/mm² (uniaxial testing at 22°C) and with definition of a maximum foil thickness of 0,25 mm, a maximum membrane tension of 5 kN/m results. The advantage of such a high seam strength is, that the material working range of the ETFE foil can be fully utilized. For material testing, the product NOWOFLON ET 6235 Z from NOWOFL with a material thickness of 0,25 mm was selected. Seam tensile tests were carried out in the manner of strip tensile tests, as through this the deformations and forces were easy to quantify.

4.2 Loading conditions

In order to estimate the maximum loads and their direction, the company LEICHT carried out FEM calculations, with an isotropic, linear-elastic material model for typical load cases. The frame dimensions were 1,5 m x 3 m. The loads were factored: max. inflation pressure 300 Pa x 1,35 and max. wind suction -780 Pa x 1,5. These resulted in a local max. foil tension of 2,81 kN/m, which is in the elastic range and far below the 5kN/m derived above. Based on the resulting foil exit angle of 17°, the load can be devided into a shear load of 2,68 kN/m acting in the joining plane and a peel load of 0,82 kN/m acting perpendicular to it. Since the seam exit angle changes with the load and since this is difficult to reproduce in a uniaxial strip tensile test, the seam tests were carried out with two fixed exit angles: pure shear load (0° exit angle) and shear-peel load (15° exit angle) Fig. 4.

Fig. 4: Lower holding device in clamp with foil exit angle of 15°

The tests were carried out in an air-conditioned laboratory at 22°C and 50% relative humidity. All test specimens were adjusted to the climate for 24 hours before their loading. The tensile tests were carried out on a Zwick Z020 material tester. The test speed was 100 mm/min. The profiles were clamped in lower holding devices, producing a fixed foil exit angle. The free end of the foil strip was clamped between the upper clamping jaws. The most promising joining processes were then implemented in inflated cushion element demonstrators and exposed to long time outdoor weathering.

5 COLD BONDING

5.1 Adhesives and pretreatment

Four different adhesive systems were tested (Table 1). In all cases the substrate was a bare aluminum flat profile (30 mm x 2 mm) which was sandblasted for pretreatment and cleaned with the LOCTITE SF 7063 cleaner. The adhesive length was 10 mm for the reactive adhesives and 15 mm for the adhesive tape.

Table 1: Compilation of the adhesive systems

foil	primer/adhesive/activator
NOWOFLON ET 6235 Z 50 mm width, Corona treated	primer: LOCTITE SF 770 on ETFE adhesive: cyanoacrylate LOCTITE 401 on aluminum
NOWOFLON ET 6235 Z 50 mm width, Corona treated	primer: LOCTITE SF 770 on ETFE adhesive: cyanoacrylate LOCTITE 414 on aluminum
NOWOFLON ET 6235 Z 50 mm width, Corona treated	primer: LOCTITE SF 770 on ETFE adhesive: acrylate LOCTITE AA330 on ETFE activator: LOCTITE SF 7388 on aluminum
CMC Type 77701 (adhesive tape) 30 mm width	polysiloxane (pressure sensitive adhesive, part of the adhesive tape)

The primer could be applied with a brush and aired off within seconds. The cyanoacrylates are superglues. They were dripped onto the aluminum profile and flowed into the entire joint gap when the joining partners were brought together. After curing, the adhesive was transparent.

The activator SF 7388 is sprayed and has an intense odor. The AA330 adhesive is applied from the tube and also has an intense odor. After curing, the adhesive is yellowish. The yellow coloration is not particularly noticeable under the attached foil, but adhesive residues that have escaped from the joining zone have an intense yellow color.

The adhesive tape CMC type 77701 can be peeled off and stuck on again repeatedly. For the tensile test the tape was stuck on once.

All joined samples were stored for at least 24 hours before tensile testing, so that the reactive adhesives had sufficient time to cure.

5.2 Tensile tests

The force-strain curve of a 50 mm wide ETFE foil strip of the sample "LOCTITE 414/2, 0°" serves as a reference (Fig. 5, orange). The characteristic curves of the other foil strips attached to the profiles essentially follow the characteristic curve, so that only the maximum tensile strengths achieved are entered in the Fig. below for the sake of clarity. The sample CMC generates higher values because it has different dimensions.

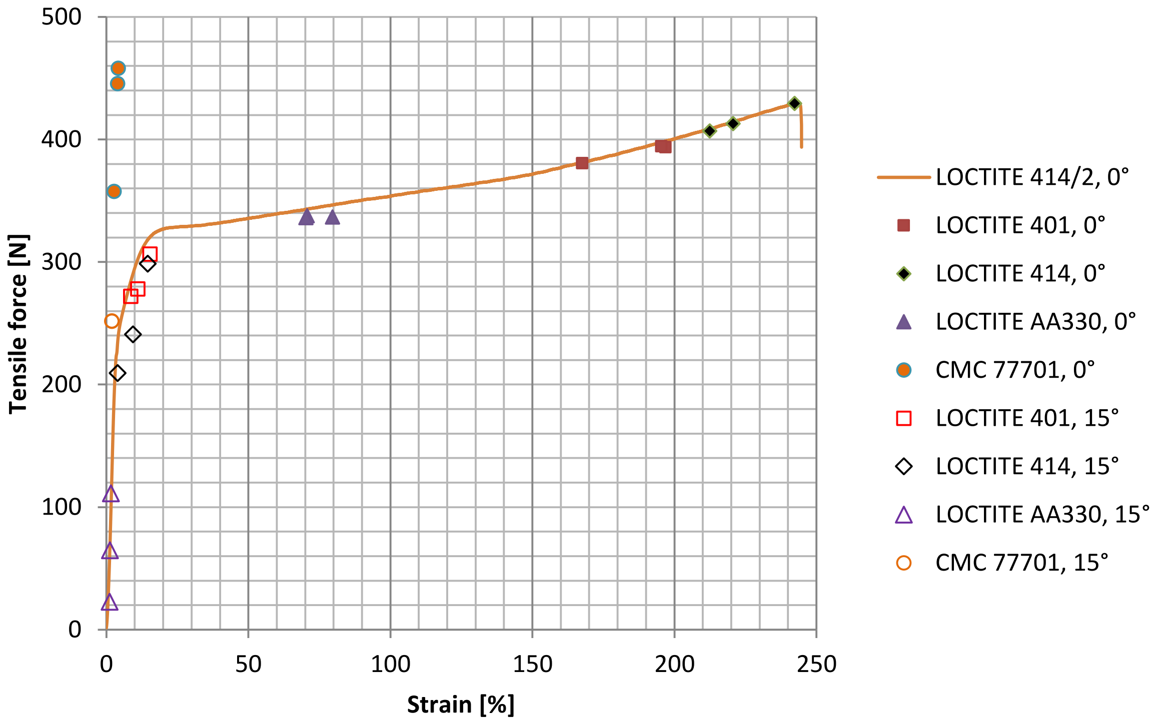

Fig. 5: force-strain curve of the reference foil strip (orange) and max. values of the glued ETFE samples

In all bonds, a significantly lower load capacity occurred under 15° loading due to peeling, compared to the 0° loading direction, which reaches far into the plastic deformation region. It is therefore recommended to prevent the peeling load by constructive countermeasures. The foil could easily be peeled off by hand for all tested adhesive bonds.

In the case of the adhesives LOCTITE 401 and LOCTITE 414, the plastically deformed foil tore off at the edge of the seam under a 0° load. Under 15° loading condition a mixed fracture occurred: in 50% of the samples the adhesive detached from the aluminum and in 50% of the samples the foil developed a lateral tear due to asymmetrical deformation.

The adhesive LOCTITE AA330 detached from the foil in all cases.

The CMC adhesive tape developed longitudinal folds under unidirectional stress in 0° direction, due to the transverse contraction and peeled off in transverse direction. Under 15° loading the tape also peeled off. The high test-speed does not allow any statements to be made about the long-term resilience of the adhesive tape. Fig. 5 shows the tensile forces achieved.

Since the adhesive LOCTITE 414 achieved the highest seam strength, a cyclical test was carried out under 0° loading. This was carried out in a force-controlled manner at a loading speed of 66,7 N/s, between the force limits of 0 and 200 N (in 3 seconds from 0 to 200 N). The aim of 1000 load cycles was achieved without premature failure.

5.4 Demonstrator

The adhesive system based on LOCTITE 414 was tested on 2 small demonstrators with the dimensions of 70 cm x 70 cm. For the assembly, the ETFE foil was pretensioned on a wooden frame (Fig. 6 left), which was lowered onto the aluminum frame after the adhesive and the primer had been applied. The adhesive had to be applied quickly, and therefore was applied in the form of a bead of glue. During the pressing process, it spread over the entire adhesive gap. The excess foil was cut off directly on the frame with a knife and a protective flat profile strip was screwed over the adhesive connection to prevent peeling loads. Fogging occurred in the cavity of the demonstrator, which is noticeable by a whitish precipitate, as shown in Fig 6, right side, on an air inlet that originally looked bare.

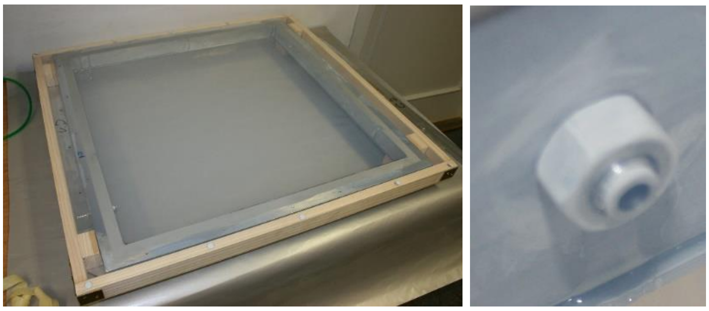

Fig. 6: assembly with additional tensioning frame (left), precipitation due to fogging (right)

The demonstrator panels have been installed at the outdoor weathering site of the DITF since September 2020 (Fig 7) and inflated to the pressure of 190 Pa.

Fig. 7: outdoor installation of ETFE cushion bonded by adhesive

So far no damage has been identified. The temperature range of the ambient air was between -15,8 °C to +31°C and the max. wind speed was 13,9 m/s.

6 WELDING

The welding concept was developed from the idea of activating an adhesive layer when joining by heat or light. One pursued solution was, to coat the aluminum profiles with an ETFE powder coating and then to thermally weld the ETFE foil to the coating.

6.1 ETFE powder coating

The aluminum profiles were prepared and coated at a local provider in the following steps: degreasing, corundum blasting, primer, ETFE powder coating in several passes until the desired layer thicknesses of 200, 400 or 600 µm were achieved. Additional efforts arose for surfaces that were not to be coated. They had to be masked off. The high melting point of ETFE has a significant impact on production and cost. For example, thermally insulating webs with a low melting point can only be installed after coating.

6.2 Welding tests

The welding was carried out using available welding technology by the manufacturer Novum Membranes. The first tests were run on ETFE coated, flat aluminum profiles with the dimensions of 30 mm x 3 mm, using a continuous belt circulating welding machine and a speed of 0,4 m/minute. The seam width was 10 mm. The welding machine had to be operated with high power settings, as the aluminum strongly dissipated the heat. In case of thicker coatings, these obviously have a thermally insulating effect and an acceptable joint pattern and quality was only achieved with a minimum coating thickness of 600 µm. At 400 µm, only short sections of acceptable seams could be produced. At a coating thickness of 200 µm a weld could not be made.

6.3 Tensile tests

Strips were cut from the joined samples and were tested in a strip tensile test at a foil exit angle of 0° and 15°. In no case did the coating peel off the profile. If the weld seam is produced notch-free, then the seam is significantly stronger than the foil and the test samples fail in the plastic region. Fig. 8 shows the results of a few tensile tests. The tensile test of a foil strip serves as a reference (blue line). Onto this, failure points of the seam tests are plotted for 0,4 mm and 0,6 mm thick coatings and two different profile materials: bare aluminum and anodized aluminum.

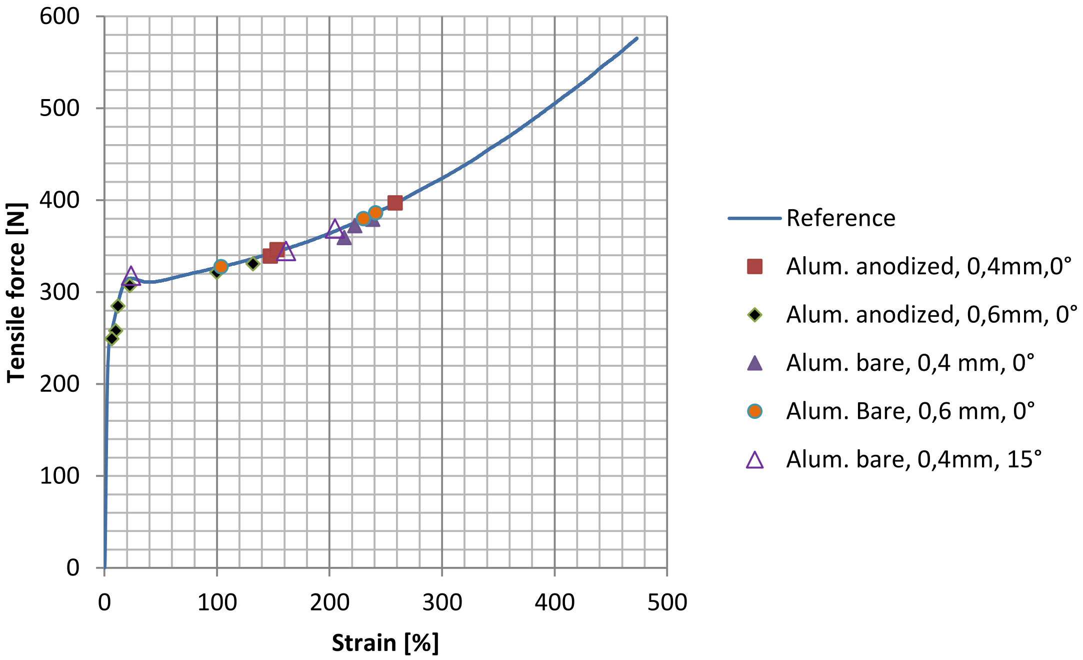

Fig. 8: Tensile test of welded samples

6.4 Assembly

The welding process was also tested in two small demonstrators measuring 70 cm x 70 cm. As available welding technology was used, only flat aluminum frames were coated and welded with ETFE (Fig 9). Two covered flat frames were then screwed onto a frame made of rectangular hollow profiles

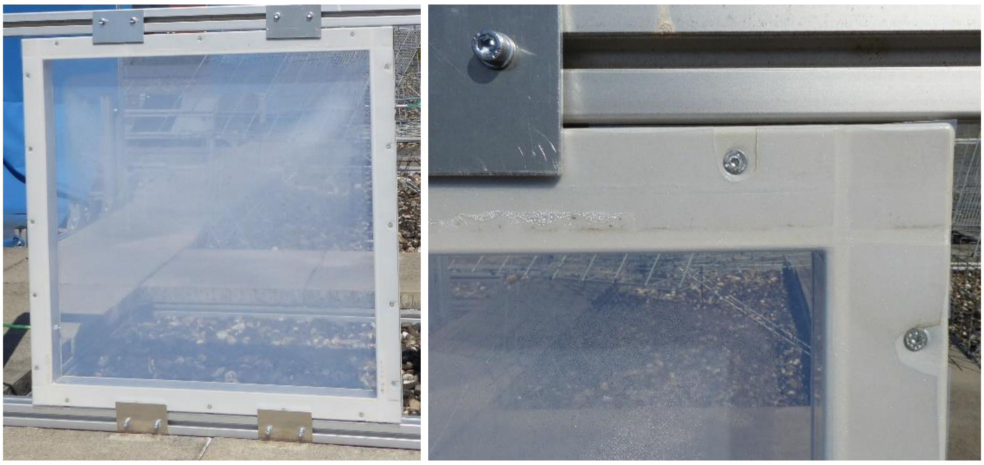

Fig. 9: welded ETFE demonstrator and detail of the seam

If a specially built joining machine were used, the joining process could take place directly on the frame and in a very efficient and automated way.

One demonstrator panel has been installed in the outdoor weathering site of the DITF since January 2021. So far no damage has been identified. The temperature range of the ambient air was between -15,8 °C to +31°C and the max. wind speed was 13,9 m/s.

7 CLAMPING

7.1 Profile

Since the clamping system is already available on the market and information is available, it will be listed below mainly for comparison purposes. A description can be found in Fig. 10 and in reference [1].

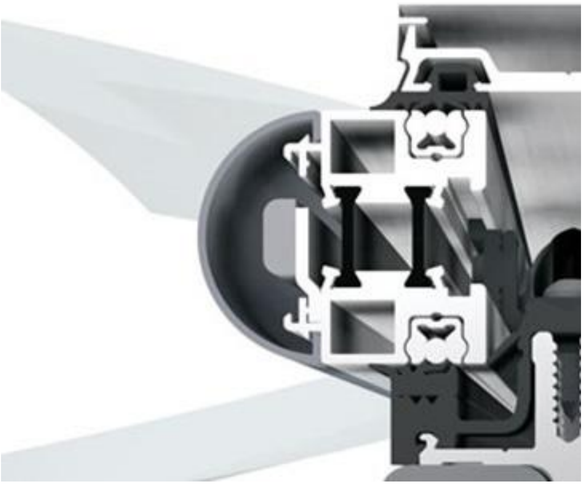

Fig. 10: Clamping system profile ETFE_THERM^{+}

Two plastic webs thermically separate two aluminum profiles. Inside the ETFE cushion there is an LED strip. The ETFE foil is clamped into a system of keder profiles.

7.2 Tensile tests

Tensile tests were carried out on foil strips of different ETFE types. In all cases, the foil failed in the plastic region as can be seen in Fig. 11 for a white and a translucent ETFE material.

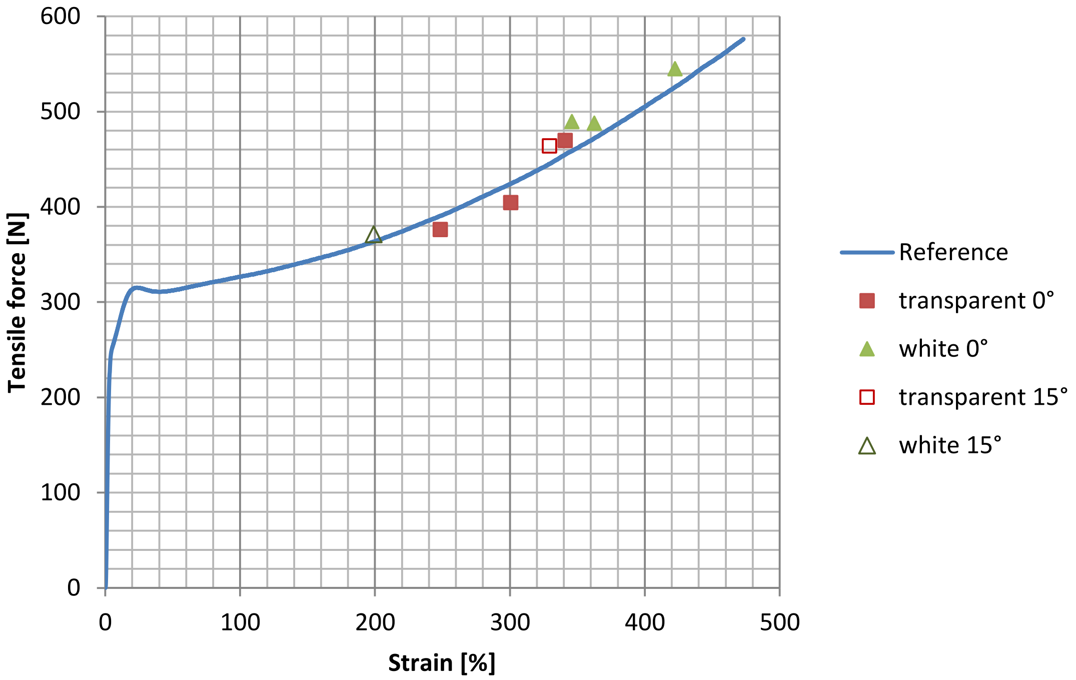

Fig. 11: Clamping system profile ETFE_THERM+

8 COMPARISON AND CONCLUSION

For all three joining methods: cold bonding, welding and clamping, technical solutions for joining ETFE onto a modular frame have been shown. However, there is a major difference in the number of preceding processing steps, which must be considered in terms of cost.

With regard to recycling and reuse, the clamping process offers easy material separation. The glued foils can also simply be peeled off and the profiles cleaned by sandblasting. So far, the ETFE coated surfaces can only be welded over. The welding technology is particularly interesting for the automatic covering of frames in a production line. Whether the cost savings generated in this way compensate for the coating effort would have to be investigated further.

REFERENCES

[1] https://www.raico.de/magazin/lifestyle/etfe-neu-gedacht/

Acknowledgement

The authors like to thank the “Bundesministerium für Wirtschaft und Technologie” for funding the research project “Verschattungssysteme” within the framework of the “Zentrales Innovationsprogramm Mittelstand (ZIM)” by mandate of a “Deutsche Bundestag” resolution. We would also like to thank the supporting companies: LEICHT GmbH, NOWOFOL and Novum Membranes.