Welding of thermoplastic interlayer - wider and combined interlayer

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Keywords:

1 Welding. 2 Interlayer 3. Combining 4. Laminated safety glass

Abstract

A new technology to widen or combine an interlayer like EVA, PVB; Ionoplast Interlayer, PET and many others by welding is introduced and the properties of the weld, using the example of EVA film is shown. Mechanical and chemical testing of the weld are introduced. The result is that no influence of the weld in a non-laminated or cross-linked EVA film could be determined. By combining different types of interlayers, such as transparent and translucent films, new possibilities for laminated safety glass arise for manufacturers and designers, which will be discussed.

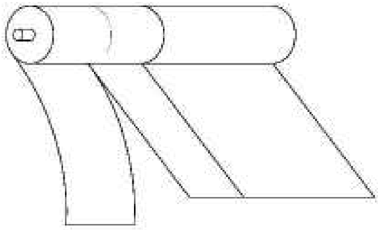


Figure 1: sketch of an oversized interlayer welded and cut to size

Figure 2 welded film role being delivered

Introduction

Laminating films, such as EVA, ionoplast interlayer, PET films and many other thermoplastic films such as some ETFE films, for example, are extruded in a relatively narrow format. The investment into film extruders is a real challenge for small manufacturers. In order to receive the film to the measurement specifications desired by the customer a welding technology has been developed, through which it is possible to weld most thermoplastic sheets together, so that the weld seam fulfils the requirements for processing and later use in a laminated glass. Through welding, the problems with installing the films are omitted for the processor. When installing laminated films, such as EVA or Ionoplast Interlayer, the film edges must neither overlap nor form a large gap, when placed on glass. This is already a tricky task with films of 0.76 mm thickness and with films of 0.38 mm thickness, specifically for larger formats, it is almost impossible to achieve. In addition, the individual laminate strips may slip when applying the upper disk. Even if everything was perfectly positioned with each other, the disk stack must go through the lamination process and is thereby normally moved or at least heated and pressed. Ionoplast in sheets with a thickness from 0.89 mm can be readily installed and have sufficient stiffness and adhesion to the glass so that they do not slip when placing the upper disk, yet, the impact after lamination may remain visible. During the lamination process, the two films "run" against each other at the hem. A welding of films ensures the mechanical transfer of one film strip to another. To better illuminate this transfer, examinations of welded sheets are necessary. What is true for installing films, also applies to welding. It is imperative that partial or linear duplication of the film, especially with thicker films, is avoided. This is because duplication can result in very high stress on the glass during lamination. An overlap welding of laminated glass films is therefore not practical. The films must be welded together in a butt joint, so that the welded film has the same thickness everywhere, if possible, and especially in the welded joint.

1. Welded joints

When welding films together, as in the welding of steel, a central area which has been welded through, as well as a heat-altered peripheral region is identified. The characteristics of the areas depend mainly on the thermal conductivity of the material, so that the welded joints for each material have a somewhat different appearance. So far, the following types of films have been successfully welded: EVA, PVB; Ionoplast Interlayer, PET and ETFE.

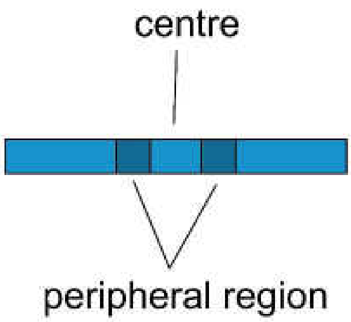


Figure 3: correct square butt joint and areas of a welded joint

Figure 4: manual stretch test of a welding joint during development of welding EVA interlayer

The welding of a laminated glass sheet is performed without filler material, so that a possible gap cannot be filled, and therefore the film may not have any spacing during welding. The challenge for edge-to-edge welding lies, for example, in the avoidance of air pockets and maintaining the parallelism of the films during the process. Very thin films can slightly overlap during welding (Figure 3) and thick films which are welded may be offset from each other (Figure 4).

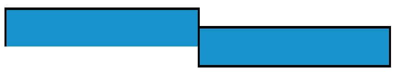


Figure 5: incorrect Lap joint

Figure 6: incorrect mutually offset

The behaviour of the film during welding is dependent upon the type of material and thickness and therefore requires very precise control of the welding equipment during the entire welding process. This is the only way to weld sheets of different thicknesses and different types of films with the same welding equipment. To find the correct welding parameters for each type of material, it is not enough to just weld the film together. The welded joint must be checked before and after lamination in order to check its usability. We carry out a series of tests on samples with different welded joint variants, in order to find the appropriate welding parameters. If a sample fails a test, these welding parameters will

be withdrawn. We repeat the process until we have samples with welding parameters that have passed all tests.
This method for optimization is described in the following sample tests for evguard ®, EVA laminated safety glass film presented by the Wolfen film factory from Germany. Some tests were also carried out by the independent testing laboratory Friedmann & Kirchner, a company for material and component testing mbH. The series of tests presented here precede attempts by the Wolfen film factory, where none of the samples had passed all tests. The welding parameters used resulted in a high pre-cross-linking of EVA film. Pre-cross-linking should be avoided, due to the danger of poor adhesion of the film to the glass, among other things. However, these first tests could be used to limit the welding parameters and prepare samples with different welding parameters for the second series of tests.

2. Rheological and mechanical examinations of welded EVA film from the Folienwerke Wolfen

2.1 Studies with the Rheometer

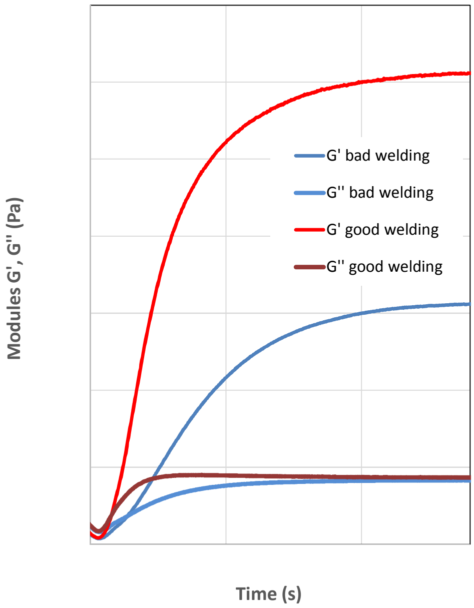
With a Rheometer, Figure 7, it can be determined whether and to what extent an incipient cross-linking exists in an EVA sample. Rheological studies were carried out on eight different welding samples with sample numbers ecg-5 to ecg-12. The specimens were die-cut with a central welded joint and had a diameter of 30mm by approx. 0.8 mm thickness, Figure 8. The specimens were examined with a rheometer by an isothermal measurement of cross-linking at 140C ° with a frequency of 1Hz and a sheer strain of 0.6%. Through comparative analysis with non-welded samples, the degree of cross-linking can be determined by the identified storage modulus and loss modulus respectively.
The analysis showed that no sample shows pre-crosslinking.

Figure 7: The used Rheometer is a shear rheometer which can be used both in rotational and in oscillatory mode. It is used to measure the storage modulus *G'* and the loss modulus *G''* which determine the crosslinking behaviour of the studied EVA-Film.

To investigate the influence of the welding process on the crosslinking behaviour of the film, the rheological properties were determined at a temperature of 140°C. The modules are shown as a function of time in Figure 8a, for a EVA film with bad welding (red), and for a EVA film with good welding line (blue).
EVA can be crosslinked by peroxides. At a typical temperature, the peroxide will decompose and create free radicals. The radicals will be transferred to the polymer chains. Combination of two radical points of the polymer chain will create the polymeric network. This process can be analysed by means of a rheometer. Generally, the crosslinking of the EVA will lead to an increase of both elastic and viscous module G' and G''.
Samples from the first test run have shown insufficient crosslinking. Due to high temperatures during the welding process, the peroxide inside the EVA film starts crosslinking already during this step. A certain amount of the peroxide was decomposed already. On the other hand, the temperature of the welding process was too low for creating a polymeric network. However, the decomposed peroxide is terminated, and can't be used for a further crosslinking. Consequently, the increase of the modules at 140°C is low.

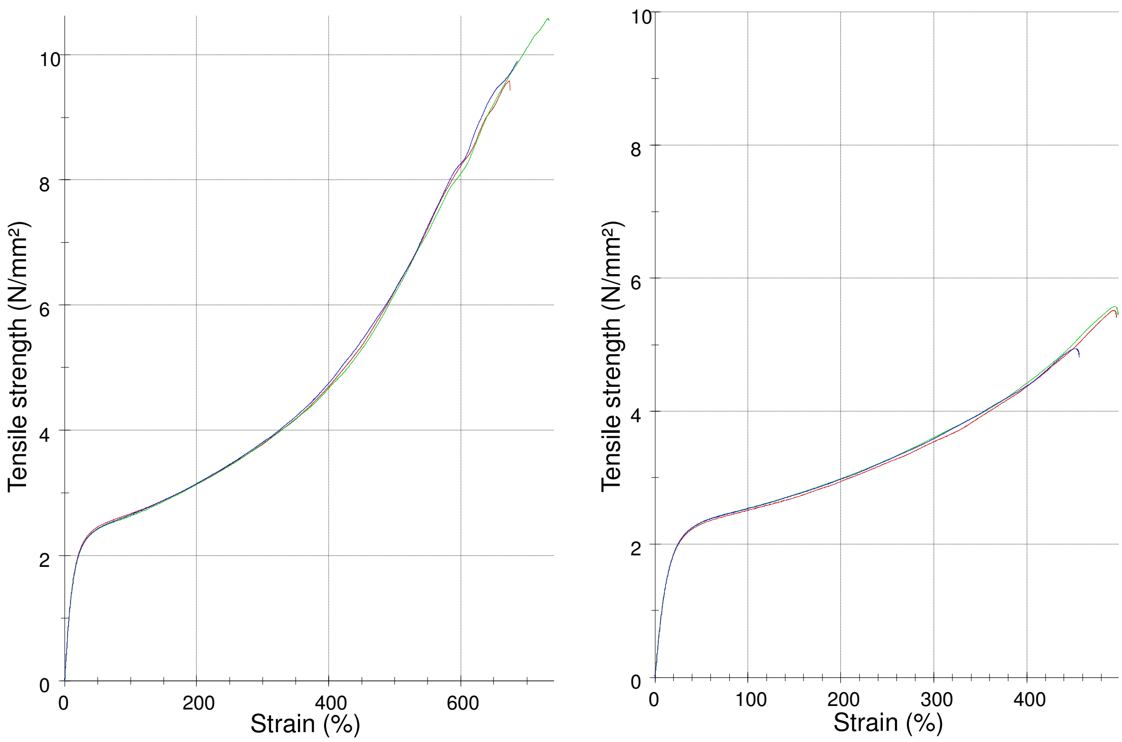
During the second test run, the welding process was optimized. As result, the rheological properties of the welded samples are different. As can be seen, the increase of the modules G’ and G’’ is much higher than for the samples with “bad” welding. The nominal values of the modules are the same as for standard values for evguard film. All samples of the second run show similar rheological properties, the welding can be classified as “good”.

Figure 8a: Rheological characterization of a „good“ and „bad“ welding line, measured at 140°C on a plate-plate rheometer, Malvern Kinexus



2.2 Mechanical Investigations

Through mechanical tensile tests, it was determined whether the welding joints met the manufacturer's minimum tensile strength requirement, so that they can be processed into laminated safety glass in a lamination line or in a factory. In the lamination, the films are always drawn manually or by machine and possibly even bent. The film manufacturer specifies a minimum tensile strength of 5 MPa and a fracture elongation of at least 700% for the tested EVA film. Tensile tests were performed by Wolfen on the eight samples numbered 5 to 12, with a transverse welding joint, in accordance with ISO 527-3, on a Zwick material testing machine BZW 2.5.. In addition, 3 specimens per sample were clamped across the seam and measured. The stress – strain diagrams of samples evguard-5 and evguard-6 are shown in the next Figure 8b.



Figures 8.b: Stress-Strain diagram of sample evguard-5 (left) and evguard-6 (right), measured according to ISO 527-3. Zwick Materialprüfmaschine BZW 2.5

The results of the tensile tests in Figure 9 show that the welding parameters of the samples with the number five satisfied the requirements for the tensile strength and fracture elongation. With studies carried out by the manufacturer of Wolfen, an adjustment of the welding parameters, which have no material damage, can at least be identified and sufficiently well sealed.

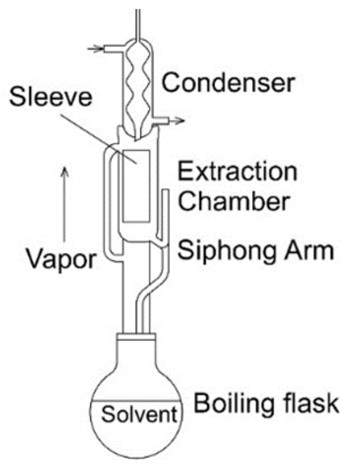
		sample No.							
	setpoint	**5**	6	7	8	9	10	11	12
tensile strength (MPa)	> 5	**10**	5,3	2,8	2	2	2,5	2,2	1,5
elongation at break (%)	> 700	**698**	484	109	42	21	46	24	13

Figure 9: Results of tensile tests by the Wolfen film factory in accordance with ISO 527-3 on a Zwick material testing machine BZW 2.5 and on welded EVA laminated films with a transverse welding joint.

The welding parameters with the number five are used for the preparation of samples for tests at Friedmann and Kirchner. These experiments should verify the results of Wolfen and furthermore illuminate the mechanical behaviour of cross-linked film, and the laminated welded joint.

3. Chemical and mechanical studies on welded EVA film by Friedmann and Kirchner

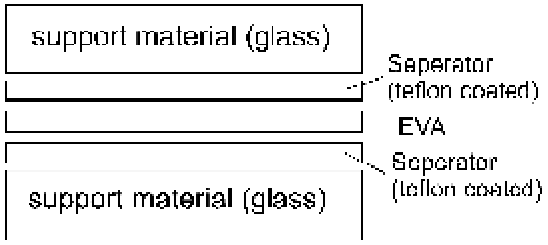
3.1 Studies using Soxhlet extraction



With the Soxhlet extraction, the degree of cross-linking of EVA can be determined. The Soxhlet method rinses all soluble components from the sample with a solvent (xylene) at about 70C °. The material, which remains behind is cross-linked material. To determine the degree of cross-linking in the welding joint, approximately 5g of material was taken directly from the centre of the welding joint.

Figure 10: Principle of Soxhlet extraction for determination of Gel Rate: non cross-linked parts are extracted from the curved EVA by a solvent (xylene), at a temperature of 70C °. Distilled and cooled solvent is used, no change of solving rate due to concentration, no oxidation of EVA, only a small sample of ≈ 0.5 g is required by a high precision ≈ 1%.

To verify the results of the measurement, cross-linked material was also taken from a film, which was laminated on both sides with Teflon and extracted. Due to the Teflon sheet, EVA laminating film can be removed irrespective of the laminate. Fig. 11 The manufacturing process corresponds to the manufacturer's instructions and was carried out in a vacuum ring method.



Through comparative weighing of the mass before and after extraction, the degree of cross-linking can be determined. However, this method is only suitable for cross-linking levels above a certain gel rate. Low levels of cross-linking cannot be determined, because very small structures can be flushed through the lattice structure of the extraction sleeve.

Figure 11: Preparation of gel sample rate by using Teflon-coated separator

From the results in Fig. 12, it can be seen that no negatively acting pre-cross-linking of the material could be verified in the welding joint and that for the material of the counter sample, taken from the laminated specimens PK 2, a higher degree of cross-linking could be detected.

sample	Parameter	mass	sleeve	Sleeve + mass before	Sleeve + mass after	Final weight	GelRate [%]
Weld EVA by Customer	n.a.	0,428g	14,226g	14,654g	14,26g	0,03 g	0,08 %
ex PK 2 sample 1 by F&K	45min:95°C 70min:135°Call VAC	0,5236g	14,4714g	14,995	14,9579	0,4865	92,90 %

Figure 12: Determination of Gel Rate, comparing the masses by weighing

3.2 Mechanical studies on welded EVA film

To obtain statements on the strength of the cross-linked and uncross-linked welding joint and the adhesion of the welding joint to the glass, two mechanical testing methods were used by Friedmann and Kirchner. One the one hand, the tearing behaviour in accordance with DIN 53363 was investigated on trouser samples with uncross-linked and cross-linked material, and on the other hand, the adhesion to determine the pulling force in accordance with the ASTM D903 was investigated in the area of the welding joint.

3.2.1 Studies of tearing behaviour of cross-linked and non-cross-linked film

We investigated whether the tearing behaviour in the area of the welding joint. compared to tearing behaviour in the rest of the film, changed significantly. For this purpose, a trouser-shaped test piece of 40 x 100 mm was cut from the welded film. The two legs of the trouser-shaped specimen are pulled apart in a testing machine, wherein the welding joint is arranged across the pulling direction and torn.

Figure 13: Mounting of *Trouser-tear test specimen* A mounted sample of a combined film of a clear

Figure 14, the measured values of a cross-linked (PK 5) and an uncross-linked sample (PK 6) are compared. After initial elongation of the material, both samples show the typical jerky tear behaviour with subsequent elongation phase and repeated tearing. In the area of the welding joint (between 96mm to 102 or 107mm), noticeable behaviour can neither be found on cross-linked nor on uncross-linked material. This means that the tensile strength of the material was obviously not or not significantly affected by the welding. To determine the tear strength, the characteristic values presented in measurements in Figure 14 are listed in Figure 15.

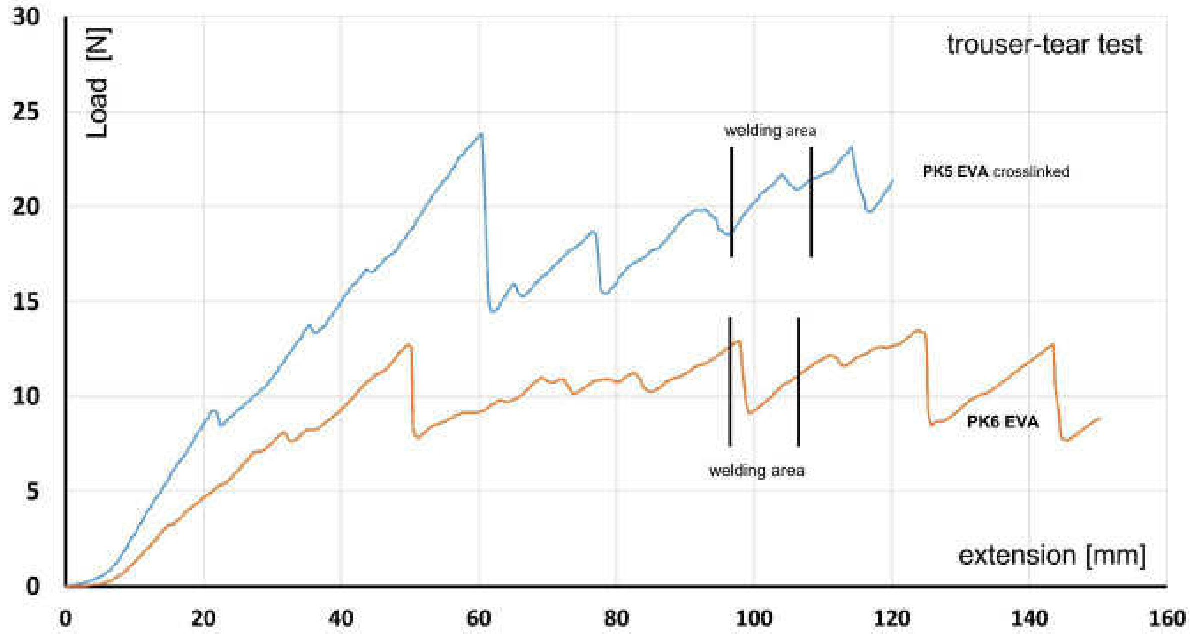


Figure 14: Extract from the results of tear behaviour in the area of the welding joint in cross-linked and uncross-linked EVA. A noticeable behaviour in the area of the welding joint cannot be detected.

sample	welding area between	Film	speed [mm/min]	thickness [mm]	force min [N]	force Median [N]	force max [N]
PK5	96 and 107 mm	EVA cross-linked	60	0,84	9,24	18,65	21,83
PK6	96 and 102 mm	EVA	60	0,62	0,00	10,74	13,47

Figure 15: Supplementary representation of the characteristic values of the measurements to calculate the tear resistance of studied films, shown in Figure 14.

3.2.2 Peel test

The peel test method covers the determination of the comparative peel or stripping characteristics of adhesive bonds in accordance with ASTM D903. The EVA film is laminated on one side on a float glass and peeled back at an 180 degree angle to measure average peel strength, especially in the area of the welded joint. Figure 17 shows a test in which a black mark of the welding joint can clearly be seen.

Figure 16: mounted specimen 2, a black mark of the welding joint during the peel test of Tape 2 can clearly be seen.

With each tensile test, the material strip is clamped at some other point in the pulling mechanism, and clearly different regions of the welding joint inspection arise. The peel tests with tape 3 and tape 4 began much closer to the welding joint than in previous experiments. For better legibility, tests 1 and 2 were presented in Figure 17, and tests 2 and 3 were presented in Figure 18. The experiments show that apparently a smaller but insignificant influence of the welding joint on the adhesion can be found. This arises over the course of the peel tests, which can clearly be seen in Figure 18, as can similar or even lower values outside of the welding joint.

Figure 17: Peel test results of tape 1 and tape 2. A non-significant influence of the welding joint on the adhesion by a slight decrease in the peel force can be determined, which then somewhat increases again and however adopts similarly low values at the end of the experiment.

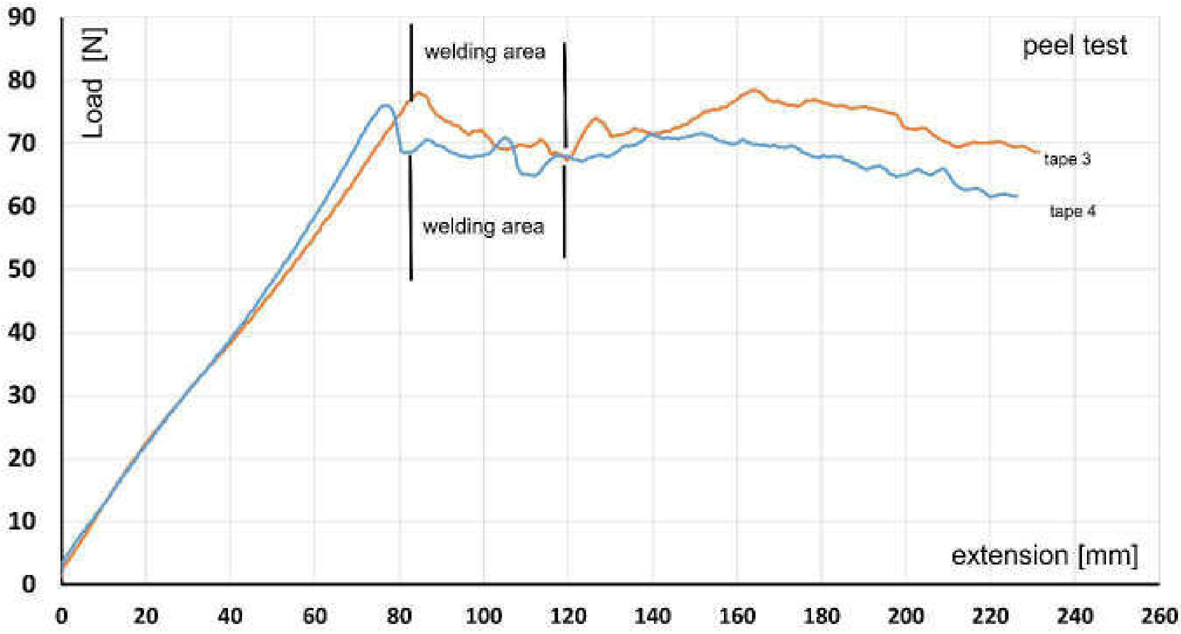


Figure 18: Peel test results of tape 3 and tape 4. A non-significant influence on the adhesion of the welding joint by a slight decrease in the peel force can be determined. However, the peel values fall away below the welding area in the further course of the studies.

line No.	welding area between	with [mm]	orientation [°]	speed [mm/min]	pull-off force [N/cm]
1	148 und 188 mm	20	180	100	33,79
2	158 und 193 mm	20	180	100	37,84
3	84 und 120 mm	20	180	100	35,86
4	84 und 120 mm	20	180	100	33,86
5	50 und 88 mm	20	180	100	29,68

Figure 19: Supplementary representation of the experimental parameters and numerically determined peel strengths to the peel test, shown in Figure 17 and Figure 18.

Through the studies on adhesion behaviour of EVA film, it could be shown that no significant influence of the welding joint on the adhesion and the peel force is detected. Assuming compliance with all important parameters for the lamination of laminated glass with EVA, a welded sheet can be used with confidence. However, the welding parameters must first be determined by a suitable series of tests for each film thickness and for each type of film.

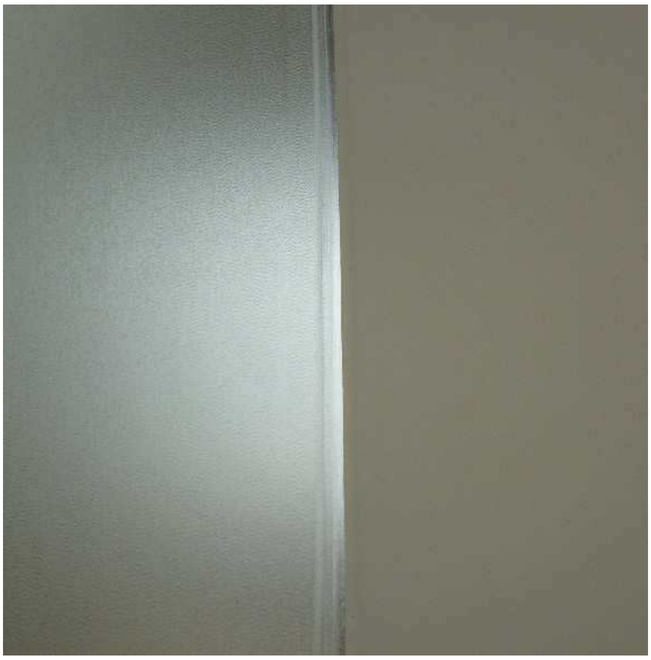
4. Combination of interlayer

In order to obtain a wider film, the welding of thermoplastic films for a variety of materials is an interesting alternative for manufacturers of film and laminated glass. For the many applications of glass, it is useful to design a portion of the disk to be opaque or coloured and another part transparent (Figure 20). Parapet panes or glass doors are partially printed, e.g. with stripes or dots, not only for artistic reasons but also for better visibility. Some of these applications require mandatory use of laminated safety glass.

Figure 20: Laminated glass pane, made from a film combination of milky and clear film

Therefore, there are always attempts to make the glass in some parts transparent, through consolidation of laminated filmstrips, and to make other parts translucent or opaque. The consolidation of different films from edge to edge is, as explained earlier, a difficult and error-prone task. Entirely new possibilities arise with butt welded film combinations of different types of films such as milky and transparent film.

Studies on PVB film show that the welding of milky and transparent film, also, has no effect on the film or the laminate. Figure 13 shows a sample of a combined film of a clear and a milky PVB film, mounted by Friedmann and Kirchner in a trouser-tear test, and Figure 22 shows a welding joint in such a combination foil.



The tear tests on combination films were on the one hand carried out on the milky to the clear (PK7) and on the other hand carried out from the clear to milky film (PK8). Figure 22 shows the stress-strain diagrams of two such experiments compared to one another. When ripping the clear to milky film, the welding joint could be identified by significant fluctuations in the transition from one material to another. When tearing in the opposite direction, the welding joint can hardly be identified. What is essential, however, is that in no sample was there a decrease in strength in the transfer of the welding joint.

Figure 21: Welding joint of a milky and clear PVB film combination

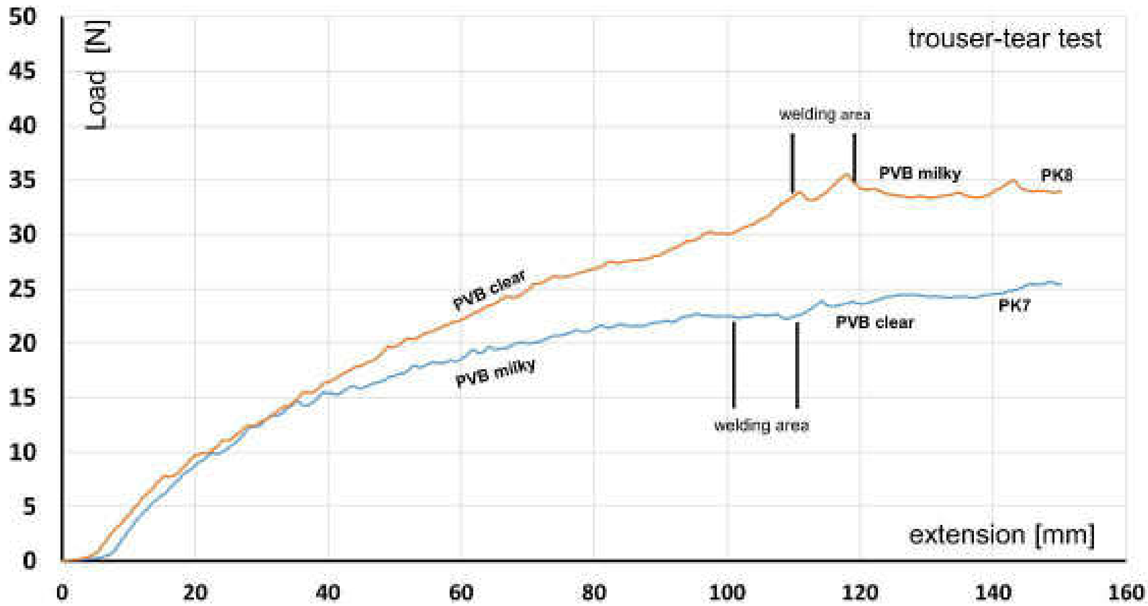
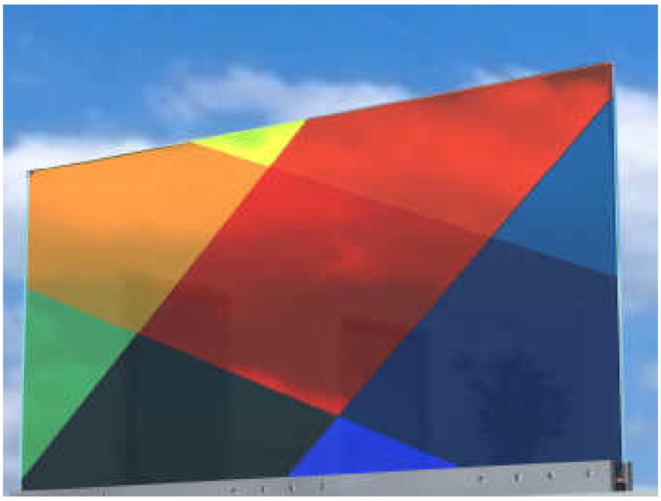


Figure 22: stress-strain diagrams of tear tests on the tensile directions from the clear to milky film (PK8) and from the milky to clear film (PK7). What is essential, however, is that in no sample, was there a decrease in strength in the transfer of the welding joint.

PVB welding is more or less easy, because a thermoplastic material can withstand many cycles of heating and cooling. The same applies to the combination of transparent and translucent PVB. The welding joint is very homogeneous and also runs homogeneously together in the lamination process. In film combinations, a clean transition is formed, incidentally also in subsequent studies.

5. The future of welding interlayer thermoplastic



Films such as EVA and PVB can, to date, be welded from about 0.5 mm thickness. Initial laboratory experiments show, however, that the welding of thinner films with 0.38 mm is possible. This is especially interesting for coloured PVB films, as many colours are offered only in 0.38 mm thickness. Combinations of transparent, translucent or coloured welded foil strips initiate numerous colour effects in the composite. This is especially true when the films are arranged on several levels above one another (Figure 25). Thus we may soon encounter laminated safety glass disks through the combination of films in rainbow colours as a door, partition, or in a facade.

Figure 24: coloured PVB films, twisted and stacked against each other

The previously developed technology is available for the welding of two film strips with up to 3600 mm width in one operation. More than two filmstrips can currently be welded only with experimental equipment. Figure 26 shows a film reel with four simultaneously welded strips of film, approximately 100mm width.

In the future, the welding of three films in an industrial welder will be possible in one operation. The middle strip of film should be able to be varied from a width of 150 mm to a width of 2000 mm. The maximum width of the film combinations of three filmstrips is planned at 4000 mm.

Figure 25: Film web of four welded foil strips

The development of welding technology has been underway for two years at an extensive and accelerated rate, so that some other film types such as ETFE, PET and especially PVB can already be welded - either to achieve excessive widths or to manufacture film combinations from different filmstrips.

PET films are used in a variety of ways and laminated in laminated glass for various purposes, such as for colouring or for a better post-cracking behaviour between two EVA films. ETFE films are usually lap-welded and inserted into the facade or as an air cushion or membrane. It makes sense that the edge to edge welding process is therefore, for example, for decorative films, since the overlapping welding is not desirable for optical reasons.

Figure 26: Welded multi-coloured ETFE decorated film for use in the facade

Welding of the films is a promising new technology, which can not only be used for laminated glass sheets. Once the correct welding parameters for a film are determined and are safeguarded through experiments on the film, but also by experiments with laminated film, nothing will stand in the way of the application of this technique. Thermoplastic films, which are not extruded in sufficient width, appear in many industries. Regardless of the on-going developments to weld various types of film, we are excited to see which future challenges our welding technology will face.

6. References

1 Dr. Steffen Bornemann; Research & Development; Wolfen film factory GmbH, Report 15-StB-002 tests on welded evguard film 03/2015
2 Robert Kirchner, Friedmann & Kirchner; company for materials and component testing mbH D - 76865 Rohrbach: Investigation Report glass laboratory -04/2015-welded evguard and PVB film
3 Sastré Hanno, show the flag with laminated safety glass, Glaswelt 04.2015, p.54 / 55

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