Extrusion-Lamination Using Crosslinkable EVA for Advanced Adhesive Joints

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Abstract

Modern lightweight and multifunctional composites play a key role in sustainable building construction by enabling material-efficient structures and the realization of complex-shaped geometries. This, in turn, requires joining technologies that ensure durable and transparent load transfer while reliably compensating for geometric complexity and manufacturing-related tolerances. Conventional liquid adhesives are often unsuitable for such applications due to limitations in shape control, curing behavior and optical quality. To address these challenges, a new bonding technology was developed. Ethylene-vinyl-acetate (EVA) was selected as base polymer due to its excellent optical clarity, adhesion and aging resistance known from glass lamination. However, its use as a structural adhesive required a new processing concept leading to the development of a two-step extrusion-lamination process with controlled thermal crosslinking. EVA types with vinyl-acetate contents of 28 to 40 % were modified with organic peroxide and systematically characterized regarding extrusion behavior, degree of crosslinking and adhesive performance. In shear strength tests, the optimized formulation achieved up to three times higher adhesive strength than conventional hot melt adhesives. Furthermore, this EVA mixture demonstrated stable adhesion and transparency under heat and UV exposure in aging experiments.

Introduction

The construction sector contributes significantly to global energy consumption and CO_2 emissions. In this context, façade systems play a decisive role in the overall thermal performance, energy requirements and service life of buildings. In recent years, façade design has therefore shifted from a primarily architectural and structural approach to multifunctional, energy-efficient composite systems. These developments include dynamic glazing systems, energy generation integrated into the façade and lightweight modular structures, all of which aim to reduce material consumption while increasing functionality.[1]

Such systems have very high requirements for connection technologies, as they often combine materials with very different mechanical and thermal properties, such as glass, polymers and hybrid cores. They simultaneously require high optical quality, durability and geometric freedom.[2] Conventional mechanical joining techniques are often unsuitable due to stress concentrations, optical impairments and local material damage. Therefore, adhesive bonding has been identified as a key technology for such applications. Adhesive joints offer uniform stress distribution, reduced peak stresses and the possibility of creating lightweight, material-efficient structures with excellent surface quality. In addition, the wide range of commercially available adhesive formulations enables the mechanical, thermal and functional properties to be adapted to specific requirements. Adhesive joints offer uniform stress distribution, reduced peak stresses and the possibility of creating lightweight, material-efficient structures with

excellent surface quality. In addition, the wide range of commercially available adhesive formulations enables the mechanical, thermal and functional properties to be tailored to specific requirements. However, the production of reliable structural adhesive joints remains a challenge. Key quality factors for safety-relevant and long-term stable adhesive bonds are substrate compatibility, surface preparation, continuous process control and curing.[3],[4]

Several adhesive systems have been investigated for their suitability in transparent façade composites, including two-component epoxies, polyurethanes and UV-curing acrylates.[5] Although these liquid systems offer high initial strength and excellent transparency, they are subject to significant process limitations. The application is limited to flat surfaces, the substrates must remain fixed until the adhesive is sufficiently cured and, in some cases, aging under heat, UV or moisture has led to critical loss of performance.

An alternative solution are laminated joints using polymer interlayers such as SentryGlas® [6] or crosslinkable ethylene-vinyl acetate (EVA) [7] which have demonstrated excellent optical and aging performance. However, their use as adhesive layers is limited by the need for precise foil cutting and manual positioning which restricts flexibility and automation. A related approach was the formerly available DOWSIL™ Transparent Structural Silicone Adhesive (TSSA), a transparent silicone film designed for structural glazing applications. TSSA enabled simplified handling but also required predefined film geometries and a processing at elevated temperatures (120 to 140 °C) in an autoclave or vacuum-bag that was often integrated in single- or multi-stage glass lamination workflows.[8]

This paper presents the development of a new bonding technology based on crosslinkable EVA, which was specifically developed to overcome the described limitations. The approach combines automated EVA extrusion with a subsequent lamination step where thermal crosslinking occurs, combining the processing flexibility of hot melt adhesives with the mechanical performance and durability of crosslinked polymer networks. While EVA is applied in a molten state to enable precise and geometry-adaptable deposition, the final structural properties of the bond are intentionally developed during lamination. A key challenge of this procedure is the decoupling of application and crosslinking whereby the melting temperature of the EVA must remain well below the peroxide decomposition temperature. At the same time, the lamination temperature is limited by the thermal stability of the bonded substrates. These constraints necessitate a careful and systematic selection of EVA base polymers, crosslinker type and concentration as well as application and lamination parameters. Accordingly, the present study focuses on the experimental investigation and optimization of the material- and process-related parameters to establish a transparent and durable EVA-based adhesive system suitable for advanced structural bonding.

Materials and Methods

Ethylene-Vinyl Acetate

EVA is a copolymer of ethylene and vinyl acetate, in which vinyl acetate (VA) units are randomly incorporated into the polyethylene backbone. The presence of polar acetate side groups disrupts the chain regularity resulting in lower crystallinity compared to polyethylene. As a result, EVA exhibits lower stiffness, increased flexibility and significantly improved optical transparency. In addition, thermal and oxidative stability are improved due to increased intermolecular interactions leading to restricted chain mobility and reduced oxygen diffusion. By varying the VA content, elongation at break and tensile strength as well as cohesive strength and adhesion can be adjusted which is particularly relevant for adhesive applications.[9]

Uncrosslinked EVA is often used as a thermoplastic hot melt adhesive due to its low processing temperature and broad substrate compatibility. Typical hot melt adhesive formulations contain 18 to 30 % VA and are modified with waxes, tackifying resins and stabilizers to control viscosity, solidification and adhesion.[10],[11]

In contrast, EVA is used as a crosslinkable interlayer material particularly in photovoltaic modules and in laminated safety glass.[12],[13] In these applications, EVA with typically 28 to 33 % VA is thermally crosslinked with organic peroxides during lamination resulting in high transparency and long-term durability. Compared to the standard interlayer polyvinyl butyral (PVB), EVA offers improved moisture resistance and simplified processing especially for glass laminated with integrated functional components.

The selection of the EVA to be used in this study was driven by the need to achieve low extrusion temperatures in order to prevent premature peroxide decomposition during adhesive application. The melt flow rate (MFR, DIN EN ISO 1133-1 [14]) was therefore a decisive selection criterion. A high MFR value indicates EVA with a low molecular weight (low VA content) and thus good flowability at relatively low processing temperatures. This is particularly advantageous for adhesive extrusion as the material can be processed without high thermal energy input. Conversely, a low MFR value indicates a higher molecular weight (high VA content) and thus higher viscosity. After crosslinking, these EVA compositions offer higher network density and correspondingly high mechanical stability but require significantly more precise temperature control during extrusion. The MFR is also controlled by the addition of additives meaning that this value on its own does not specify the degree of crosslinking after lamination.

For these investigations EVA base granulates from Arkema were taken (EVATANE® 28-05, 28-25, 33-25 and 40-55) which cover VA contents of 28 to 40 % and a wide MFR range. In the following, the VA content and MFR are used as sample specifications for EVA types (e.g., EVA 28-05 for EVATANE® 28-05).

Crosslinking of EVA was achieved using ALPHA-EVA-Compound 28-25 natural from Ravago, containing 4 % Tert-Butylperoxy-2-ethylhexylcarbonate (TBPEHC) as radical initiator along with processing and stabilization additives. To precisely adjust the peroxide concentration, Zebra-flow® T177, a functionalized EVA masterbatch containing 25 % TBPEHC was additionally employed enabling controlled modification of crosslinking kinetics and network density.

EVA Extrusion

Adhesive application was performed using a Mahor V4 pellet extruder which enabled continuous extrusion of small quantities of EVA. The EVA granulate was transported by a rotating screw in a 20 mm long, temperature-controlled cylinder, melted, homogenized and extruded directly onto the substrate through a 1.1 mm nozzle. The extrusion unit was integrated into the portal system of a Creality Ender-5 3D printer providing precise two-dimensional control of adhesive application. The most suitable extrusion temperature was determined in advance based on the EVA base granulate.

Sample preparation for substance analyzing

EVA base polymers and EVA-peroxide mixtures were processed by extrusion. The development of a reproducible mixing procedure was part of the present investigation and is described in the results. The extruded filaments were cut to a length of approximately 5 cm and pressed between Teflon-coated glass plates preheated to 80 °C using 1 mm spacers to ensure a constant and reproducible film thickness. These uncrosslinked films were subsequently used for thermal

and spectroscopic characterization. For DSC measurements, circular specimens with a diameter of 5 mm were punched from the EVA films and placed into the crucibles with full bottom contact. For FTIR analysis, the EVA film could be examined directly on the ATR crystal without further preparation. Samples intended for characterization after crosslinking remained between the glass plates and were subjected to the lamination process described below.

Differential Scanning Calorimetry (DSC)

Thermal characterization of the EVA compounds was carried out using differential scanning calorimetry (DSC) on a DSC 204 F1 Phoenix® (NETZSCH). Measurements were performed in closed aluminum crucibles under argon atmosphere. Samples were cooled to 0 °C using liquid nitrogen followed by heating from 0 to 200 °C at a constant rate of 10 $K \cdot min^{-1}$. DSC was used to analyze melting behavior, peroxide decomposition and crosslinking reactions enabling determination of suitable temperature windows for extrusion and lamination as well as estimation of the degree of crosslinking.

Fourier Transform Infrared Spectroscopy (FTIR)

Chemical characterization of EVA samples was performed by FTIR spectroscopy using a PerkinElmer Spectrum 400 equipped with an ATR diamond crystal. Spectra were recorded in the range of 4000 to 750 cm^{-1} at a resolution of 4 cm^{-1} averaging 32 scans per specimen. ATR-FTIR enabled non-destructive analysis without sample preparation with a penetration depth of approximately 5 µm. The technique was used to quantify the peroxide content allowing an estimation of the homogeneity of the EVA mixture and the degree of crosslinking particularly in comparison with data derived from the DSC.

Preparation of bonded compression shear specimens

Adhesive strength was evaluated using compression shear specimens (Figure 1) consisting of polyamide and glass substrates. The polyamide (PA12 reinforced with 35 % glass fibers, PA2200-GF35/C5015 SITRAPLAS GmbH) was 3D printed as a plate, milled and cut to test specimen size. The substrate geometry was selected in accordance with DIN EN ISO 13445 [15] at dimensions of 25 mm × 25 mm × 6 mm. The adhesive bond width was set to 3 mm. Reproducible joint thicknesses were ensured by specially designed laminating devices with 3D-printed spacers which enabled controlled positioning and uniform pressure. The influence of the adhesive joint thickness was part of the investigations.

Figure 1 Compression shear specimen - shown here is the version made of two glass plates. For this study, one of them was replaced with polyamide. (© Felix Hegewald)

To compare the crosslinkable EVA adhesive with similarly applicable adhesive systems, reference specimens were prepared using a conventional hot melt adhesive (3M™ Scotch-Weld™ 3748

TCQ) which is being investigated for lightweight additively manufactured glass composites [16] and a manually cut EVA interlayer (evguard®).

Lamination Process

Lamination and thermal crosslinking were conducted in a temperature-controlled convection oven (Memmert UFP 400) using a multi-step heating profile. Samples were first heated to 80 °C for EVA melting followed by an isothermal hold of 5 minutes. Subsequently, the temperature was increased to 145 °C and held isothermally for 30 minutes to induce peroxide decomposition and EVA crosslinking. Controlled linear cooling to room temperature was performed over 6 hours.

Shear Strength Testing

Compression shear tests were performed using a universal testing machine (Instron 5581) in accordance with DIN EN ISO 13445 [15]. The specimens were loaded at a constant test speed of 1.5 mm · min^{-1} until failure using a 5 kN load cell. For each parameter set, 6 to 8 specimens were tested. Engineering shear stress at failure was calculated based on the measured initial adhesive bond geometry. The failure behavior was documented.

Aging Procedures

The durability under façade-relevant conditions was evaluated under dry environmental conditions as the glass-polymer adhesive bond investigated is intended for an application in hermetically sealed glass units [16] that prevent moisture penetration. UV aging was performed according to DIN EN ISO 12543-4 [17], test procedure A, using simulated solar radiation for 2000 hours. Thermal cycle testing was conducted in accordance with DIN EN ISO 9142 [18] in a Feutron KPK 600 climate chamber with specimens stored in closed boxes containing desiccant to prevent humidity. Long-term thermal aging was carried out at +60 °C in accordance with DIN EN 15434-1 [19] using a Memmert UFP 400 oven. After aging, compression shear tests were repeated to quantify changes in adhesive performance.

Results and Discussion

Minimum extrusion temperature

For the development of an extrusion-based bonding process using crosslinkable EVA, the minimum extrusion temperature had to be kept as low as possible to ensure a sufficient temperature difference to the subsequent crosslinking reaction. The thermal properties of the EVA base polymers were therefore first analyzed by DSC to identify processing-relevant temperature ranges. The final temperatures of melting were determined depending on the vinyl acetate content with potential minimum extrusion temperatures between 78 and 92 °C, as published in [20]. Beyond melt formation, the application behavior after extrusion proved to be a critical factor for adhesive suitability. The temperature that was finally considered to be the application temperature was determined by the condition that the EVA flowed out of the nozzle as a stable and continuous filament (Figure 2). In addition, it had to be possible to apply both linear and free-form adhesive paths to substrates (Figure 3). Only by considering melting and application properties, the minimum extrusion temperature for each EVA type could be defined resulting in 80 °C for EVA 40-55 and EVA 33-25, 85 °C for EVA 28-25 and 90 °C for EVA 28-05.

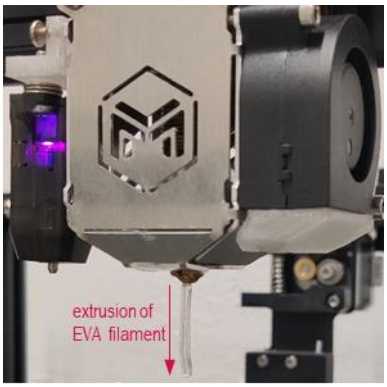

Figure 2 EVA extrusion from the nozzle as a uniform filament, demonstrating stable melt flow at low processing temperature as required for controlled adhesive application.

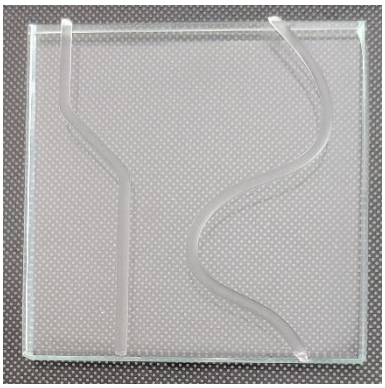

Figure 3 Extruded EVA, which is applied as continuous paths in free geometries onto a glass substrate and shows precise, geometry-adaptable adhesive application.

Homogeneity of EVA-peroxide mixtures

For crosslinkable EVA systems used in thin adhesive layers, a homogeneous distribution of peroxide and additives is an absolute prerequisite as local concentration variations may lead to insufficiently crosslinked regions and thus reduce both structural performance and long-term durability. While EVA interlayers for glass laminates are produced in large-volume mixing processes and minor inhomogeneities across the large foil area are negligible, this cannot be transferred to the proposed small-scale EVA adhesive joints.
To investigate the homogeneity of the EVA mixture after extrusion, EVA 33-25 was mixed with 25 % Ravago compound and extruded linearly onto glass substrates. A visual inspection with a colored masterbatch showed significant inhomogeneities (Figure 4) which were confirmed by DSC measurements (Figure 5 left). For this purpose, a sample was taken from each path and five of these were examined at random. A wide range of crosslinking enthalpy (H_c = 6.6 to 27.6 J g^{-1}) and crosslinking initiation temperatures between 115 and 140 °C were observed indicating an inhomogeneous peroxide distribution.

Several strategies for improving homogeneity were evaluated. The use of a cutting mill to fine-crush the base EVA granulate as well as the compound for better mixing did not work with the round granulates. The use of a manually cut standard EVA interlayer ensured good peroxide distribution (H_c = 13.5 ± 1.6 J g^{-1}) but the shape of the pieces (3 mm x 3 mm x 0,38 mm) hindered continuous feeding and stable extrusion. The most effective approach was a double extrusion process in which the EVA mixture was first extruded, pelletized and then extruded again. This resulted in significantly improved homogeneity (H_c = 19.5 ± 2.9 J g^{-1}, Figure 5 right). A repeated extrusion step was not beneficial as it led to premature crosslinking.

Figure 4 EVA adhesive paths extruded onto a glass substrate from EVA 33-25 containing 25 % Clariant Renol Green used as a visual tracer to assess mixing quality and peroxide distribution. The pronounced color inhomogeneity along the applied EVA stripes illustrates the insufficient suitability of manual premixing and single extrusion.

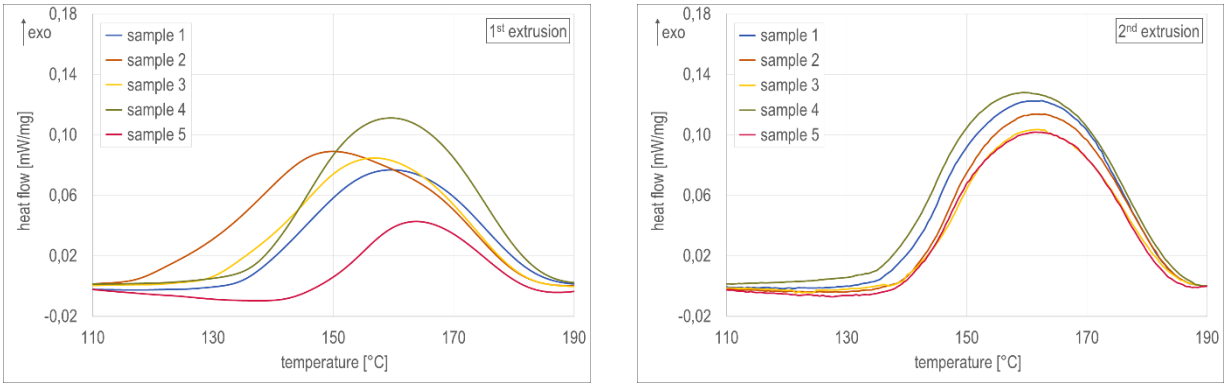

Figure 5 DSC thermograms of the EVA mixture (33-25 with 25 % compound) after manual premixing and a single extrusion step (left) and after double extrusion to improve peroxide distribution and mixing homogeneity (right).

Peroxide content and crosslinking

The development of a structurally applicable EVA adhesive requires precise control of the crosslinking reaction as the peroxide concentration directly governs network density and thus stiffness, strength and long-term stability. In contrast to conventional EVA interlayers used in glass lamination which typically contain about 1 % peroxide, this study systematically investigated elevated peroxide contents for higher crosslinking. The crosslinking behavior of EVA formulations can be analyzed by DSC which provides quantitative information on reaction enthalpy and conversion. But the applicability of DSC is limited by long measurement times and extensive sample preparation particularly for DSC systems without an autosampler. At a typical heating rate of 10 $K \cdot min^{-1}$, a single crosslinking measurement including cooling requires approximately half an hour. For mixtures with high peroxide contents, even longer measurement times with reduced heating rates are necessary, since the highly exothermic crosslinking reaction introduces additional heat beyond the programmed heating rate. This causes the instrument to counteract resulting in poorly resolvable and difficult peak evaluation (Figure 6). In addition, crosslinking brings the polymer chains closer together and the temperature-driven molecular mobility causes more physical interactions. This can lead to endothermic relaxation during subsequent heating which distorts the enthalpy signal. Additionally, the crosslinking reaction is influenced by accelerators which complicates direct comparability and the calculation of crosslinking degree.

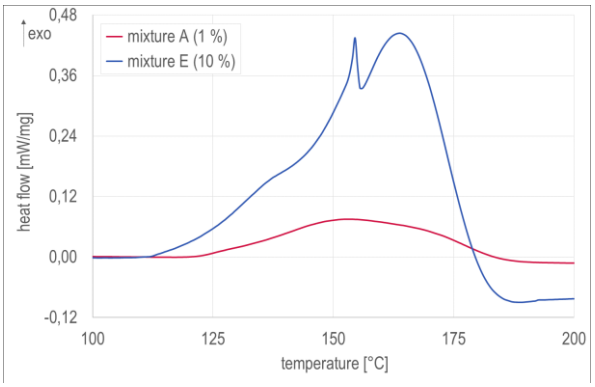

Figure 6 DSC thermograms of EVA mixtures containing 1 and 10 % peroxide. For the higher peroxide content, a two-part crosslinking enthalpy peak is evident due to a strong exothermic contribution from the peroxide transfer to the accelerator followed by EVA crosslinking. After cross-linking, the baselines shift significantly as a result of the change in thermal conductivity resulting from the polymeric structural transformations. This is clearly visible for the mixture with 10 % peroxide due to higher cross-linking. Under these conditions, quantitative evaluation of the enthalpy area becomes difficult.

To enable a faster quantification of peroxide concentration in EVA mixtures ATR-FTIR spectroscopy was evaluated as an alternative to DSC. After screening the full EVA spectrum, absorption regions associated with the peroxide crosslinker were identified (Figure 7). The integrated absorption of the characteristic band at 1185 cm^{-1} caused by the C-O-vibration connected to the peroxyl group was selected for quantitative analysis.

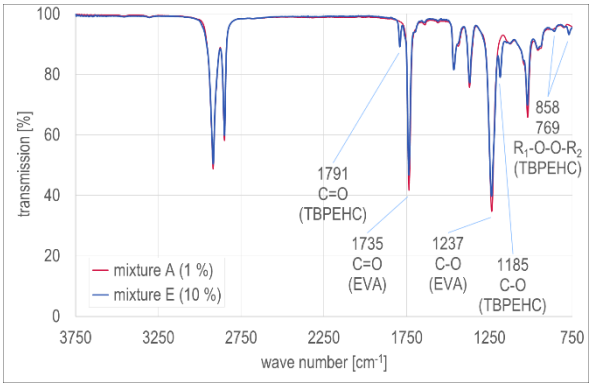

Figure 7 FTIR spectra of EVA mixtures containing 1 and 10 % peroxide, highlighting characteristic EVA and peroxide-related absorption bands and the corresponding vibrational modes. The band at 1185 cm^{-1}, attributed to the C–O vibration associated with the peroxyl group, was selected for quantitative analysis, as it exhibits the highest intensity among the peroxide-related bands and is therefore most suitable for reliable quantification.

Both methods showed linear relationships for uncured EVA mixtures. Regression analysis yielded coefficients of determination of R^2 = 0.982 for DSC-based crosslinking enthalpy and R^2 = 0.999 for FTIR band integration (Figure 8). After crosslinking, the residual peroxide content was also determined by FTIR, enabling an estimation of crosslinking degree. However, at peroxide concentrations below 1 % the characteristic absorption band becomes weak and increasingly difficult to evaluate. For consistent comparability across the investigated concentration range, a fixed integration interval of 1190 to 1178 cm^{-1} was chosen. Although this window does not capture the full band area at high peroxide contents, it prevents the spectrum from cutting through the baseline at low concentrations which would otherwise lead to erroneous area calculations. Since the band minimum remained constant at approximately 1185 cm^{-1} independent of concentration, this procedure was considered appropriate. Based on the calibrated peroxide content before and after curing, the degree of crosslinking was calculated and found to increase systematically with increasing initial peroxide concentration.

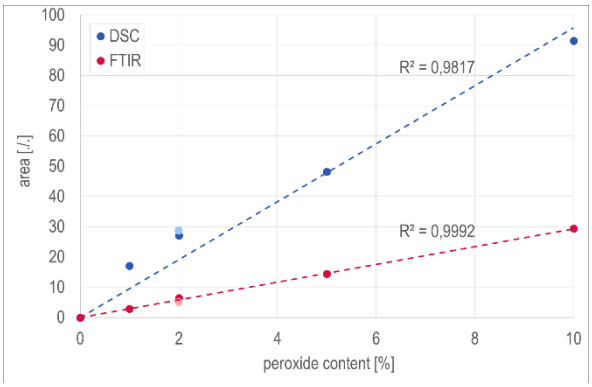

Figure 8 Calibration of peroxide concentration in EVA by comparison of DSC crosslinking enthalpy peak areas and FTIR peroxide-related band integrals. Data points and corresponding trendlines are shown. At 2 % peroxide, two formulations are included prepared with constant and doubled accelerator content, respectively (lighter marker).

The DSC analysis of the crosslinked samples showed a clear influence of the accelerator contained in the EVA mixtures. It significantly changed both the initial temperature and the shape of the crosslinking enthalpy peak. The mixtures used for calibration were fully crosslinked within a single DSC heating run during which the accelerator promotes radical transfer to the polymer backbone and thus initiates crosslinking at lower temperatures. This behavior could be seen in a typical double-peak pattern in the thermograms.[21] In contrast, thermograms of already crosslinked specimens no longer exhibited the initial exothermic contribution indicating consumption of the accelerator during sample lamination. Consequently, the remaining crosslinking reaction started at higher temperatures altering the enthalpy signal and limiting comparability. The crosslinking degrees calculated from DSC differed from the FTIR-based results by approximately 5 %. More noticeable deviations were observed for the sample containing 5 % peroxide where DSC indicated about 20 % lower conversion. However, this observation is based on a single measurement.

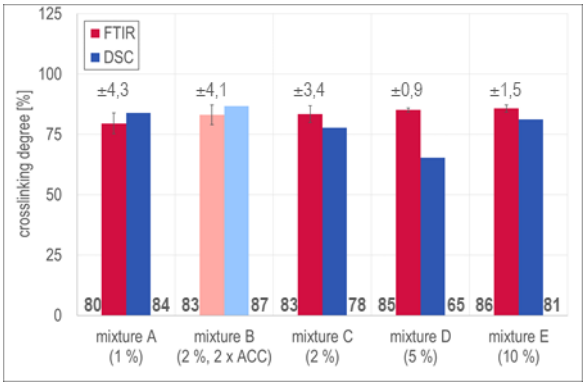

Figure 9 Crosslinking degrees of EVA samples cured with peroxide contents ranging from 1 to 10 % determined by FTIR and DSC evaluation using the corresponding calibration curves. Mixture B was formulated with the double amount of accelerator. The DSC measurements are based on single measurements.

These findings demonstrate that DSC is not well suited for quantitative crosslinking assessment in EVA systems containing variable contents of peroxide and accelerator. However, ATR-FTIR offered a robust, fast and cost-effective method for investigating crosslinking, supporting formulation development and process control of crosslinkable EVA adhesive systems.

Adhesive Strength

The mechanical performance of the developed crosslinked EVA adhesive system was first evaluated using compression shear specimens prepared from different EVA base granulates, each modified with 25 % compound corresponding to 1 % peroxide. Independent of the VA content, all specimens achieved comparable shear strengths of approximately 4 MPa, as published in [20].

Thereafter, the influence of peroxide concentration was investigated in order to enable effective crosslinking at reduced lamination temperatures which is essential for temperature-sensitive substrates. Formulations containing 1 % (mixture A) and 2 % peroxide were therefore compared. The higher peroxide level was achieved either by increasing the compound fraction (mixture B) which simultaneously doubled the concentration of crosslinking accelerator or by keeping the compound content constant and adding additional peroxide via masterbatch (mixture C). Regarding compressive shear strength, no significant differences were found between specimens with different peroxide concentrations, as also published in [20]. However, additional DSC analyses (Figure 10) showed clear differences in crosslinking kinetics. The higher peroxide content shifted the start of crosslinking by about 10 K to lower temperatures and led to an earlier completion of the reaction. In addition, the higher accelerator content led to a faster increase in the heat flow curve resulting in an earlier reaction maximum. Increased peroxide and accelerator contents are therefore advantageous in order to achieve effective crosslinking at reduced lamination temperatures without compromising adhesive strength.

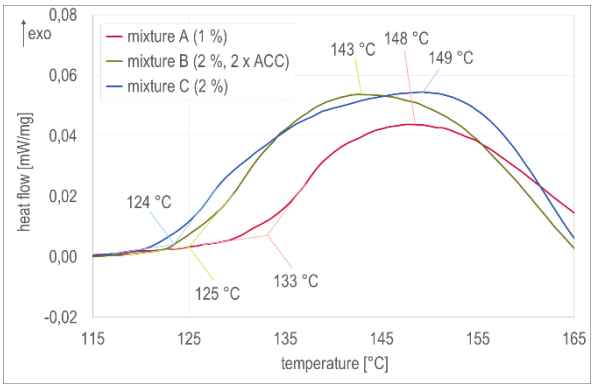

Figure 10 DSC thermograms of EVA mixtures with peroxide contents of 1 % (A) and 2 % (B and C). Formulations A and C contained 25 % compound, whereas formulation B contained 50 % compound corresponding to a doubled concentration of crosslinking accelerator (2x ACC).

Adhesive joint thickness was identified as a more significant parameter than EVA type or peroxide concentration. An increase in thickness led to a continuous reduction in shear strength (Figure 11) along with a shift in the failure mode from predominantly adhesive to more cohesive failure patterns.

Follow-up benchmark tests were performed to position the crosslinkable EVA adhesive relative to hot melt and EVA interlayer bonding methods. Material-specific adhesive layer thicknesses of the respective technologies were considered. Under these conditions, the cross-linkable EVA adhesive exhibited significantly higher shear strengths achieving three times (hot melt) respectively twice (EVA interlayer) the value.

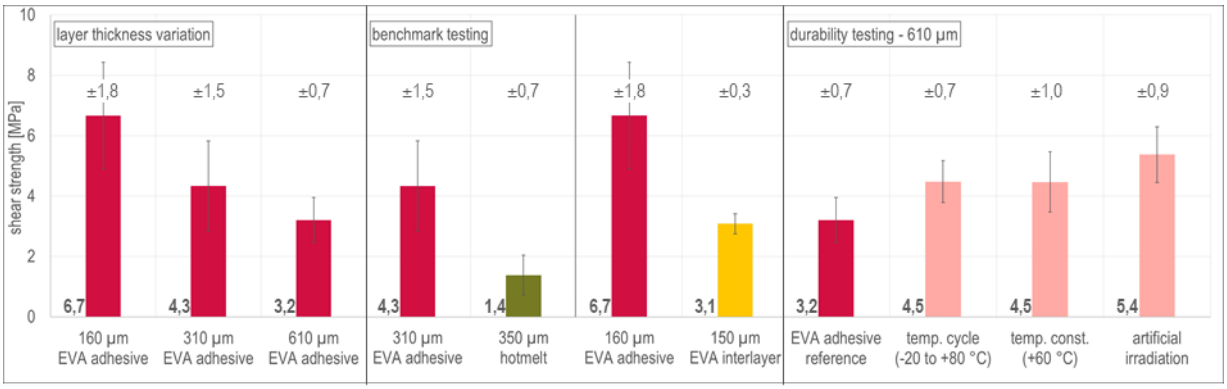

Figure 11 Results of compression shear tests summarizing the influence of adhesive layer thickness, benchmark testing and durability testing.

Finally, specimens with crosslinked EVA adhesive of base granulate 33-25 modified with 25 % compound were subjected to thermal aging and artificial irradiation followed by compression shear tests. The shear strengths after aging increased by at least 40 % compared to the reference. After the mechanical tests, EVA samples were extracted from the joints and analyzed by DSC showing almost complete crosslinking of the adhesive after all aging scenarios. This behavior is attributed to post-crosslinking as the samples were exposed to temperatures of at least 60 °C for several weeks. However, extending the lamination process in manufacturing to achieve similar initial crosslinking is economically unfavorable and higher lamination temperatures are not possible due to the limited thermal stability of polymer substrates. Consequently, the previously identified effect of increased peroxide concentrations in combination with a higher accelerator content offers an effective way to achieve improved crosslinking and adhesive performance at the same or even reduced processing temperatures.

Summary and Conclusion

This study focuses the development of a structural adhesive system based on crosslinkable EVA using an extrusion-lamination process to enable transparent and durable adhesive joints for advanced façade composite applications. EVA was selected due to its proven optical quality and long-term stability in glass lamination. However, as a structural adhesive, it required a controlled processing concept that combined extrusion-based application with subsequent thermal crosslinking during lamination.

A systematic experimental approach was applied to define suitable processing parameters and formulation strategies. DSC measurements enabled the determination of minimum extrusion temperatures for different EVA types ensuring sufficient separation between melt processing and peroxide activation. Beyond thermal criteria, extrusion stability and the ability to apply continuous adhesive paths were identified as essential requirements for adhesive suitability.

Homogeneous peroxide distribution was found to be critical for thin adhesive layers. Initial manual mixing resulted in strong variations in crosslinking enthalpy whereas a double-extrusion process significantly improved mixture uniformity without premature curing. To accelerate formulation screening, ATR-FTIR was established as a fast alternative to DSC for peroxide quantification showing good correlation with crosslinking enthalpy and enabling estimation of crosslinking after curing.

Mechanical tests demonstrated shear strengths of up to 6.7 MPa for an optimized formulation with thin adhesive layers highlighting layer thickness as a critical parameter for the structural performance of the EVA adhesive. However, the reported values are based on engineering stresses and further investigations considering large deformations and true stress–strain

behavior are required. Increasing peroxide and accelerator contents did not significantly alter shear strength but shifted crosslinking onset to lower temperatures supporting reduced lamination temperatures for temperature-sensitive substrates. Comparison with conventional hot melt adhesives and EVA interlayers showed that the developed crosslinked EVA compound had significant potential for improved load-bearing capacity within the limits of the evaluation performed.

Thermal and UV aging confirmed durability with increased shear strengths due to post-crosslinking at elevated aging temperatures. Overall, the results highlight the potential of crosslinkable EVA formulations as transparent structural adhesive with adjustable processing and robust mechanical performance.

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