Bonding Quality of Joined Glass Components Exposed to UV and Fluidic Influences[1]

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Abstract

Components of structural glazing have to meet different requirements and resist various impacts, depending on the field of application. Within an international research project of the EU innovation program Horizon 2020, special glass panes with a fluid circulating in capillaries are developed exploiting solar energy. Major influences to this glazing are UV irradiation and the fluidic contact, effecting the mechanical and optical durability of the bonding material within the glass setup. Regarding to visual requirements, acrylate adhesives and EVA films are analyzed as possible bonding materials by destructive and non-destructive testing methods. Two types of specimen are presented for obtaining the mechanical behavior and the surface appearances of the bonding material.

Keywords: long-term examination, adhesives, material aging, climatic loading, destructive testing, non-destructive testing

1. Introduction

Due to the high solar transmission, large glass facades can be utilized to contribute to the energy supply of buildings and meet European climate regulations [1] by harvesting energy and introducing it to the building technology system [2]. For this purpose, capillary glasses produced in a rolling process are developed within an European research project as part of an insulating glass unit (IGU) shown in Figure 1-1 a. The setup of the capillary glass pane is presented in Figure 1-1 b, which allows a circulation of a glycol fluid through the capillaries and a heat and energy transfer to heat exchangers. The fluid is distributed to and collected from the capillaries by two channels arranged at the top and bottom of the pane being part of a circuit to the building technology system. Many fields of application are possible for the system integrated in the IGU as exemplarily shown in Figure 1-1 c. In addition, they can also be used as indoor partition walls or tunable shading devices [3].

As can be seen Figure 1-1 b, the setup of the capillary glass unit consists of two bonded glass panes. The bonding has to fulfill certain requirements of strength, durability and

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optical behavior in terms of transparency (Table 1-1). With regard to long-term behavior, these are strongly influenced by atmospheric impacts as for instance fluid contact and UV irradiation.

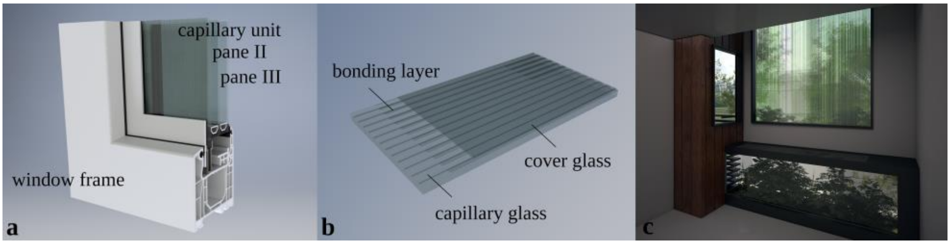

Figure 1-1 Capillary unit, a - components integrated in IGU, b - components of unit, c - indoor view of IGU with integrated, colored capillary unit.

Different suitable bonding materials are analyzed at the University of Weimar with respect to atmospheric influences. The focus of this article is set to the interaction of UV irradiation and permanent direct fluid contact. The mechanical and optical behavior of different artificially aged bonding materials are analyzed regarding these influences and the bonding quality for joining capillary and cover glasses is evaluated by means of destructive and non-destructive testing methods. The influence of other atmospheric load combinations – for example temperature changes and permanent fluid contact – are investigated in [4], [5].

Table 1-1 Required criteria of bonded glass-glass compounds.

Visual requirements	Long-term resistance against	Mechanical requirements
Transparent connection	Temperature	Durable load-bearing under climatic loading
Colorless/stable coloring	Fluid connection (glycol mixture)	High adhesion in temperature range of -20 °C to +80 °C
Non-porous	UV-irradiation	

2. Components and Bonding Materials

2.1 Bonding Components

The functional capillary unit (capillary glass, bonding layer and cover glass, Figure 1-1b) consists of a glass pane with a capillary structure made of soda lime silicate glass (produced in float process) [7] connected to a 0.75 mm thin glass made of modified and chemically prestressed aluminosilicate glass [8]. However, test specimens for analyzing conclusively consist of float glass.

2.2 Bonding Materials

Two types of bonding materials are chosen for testing, namely an UV-curing acrylate and an EVA film (ethylene vinyl acetate copolymer). The acrylate meets the visual requirements stated in Table 1-1, which is one of the highest priorities in the selection of the bonding materials. On the other hand, EVA film is a suitable and mechanical proofed material for glass lamination in safety glass [6]. In comparison, the acrylate is a more brittle and stiffer material while the EVA film is characterized by its high elongation capacity and thermal stability - characteristic properties are given in Table 2-1.

Table 2-1 Characteristic properties of adhesive materials [9], [10].

Property	Acrylate	EVA foil
Density [kg/m³]	1.0	0.95 – 0.97
Tensile strength [N/mm²]	33	>20
Elongation at tear [%]	4	>700
Young´s Modulus [N/mm²]	1600	No specification
Refraction index	1.503	1.480

Information on aging of EVA films used in applications like PV modules or as greenhouse films can be found in [11], [12], [13] and [14]. However, the focus in this paper is the clarification of the changes of the mechanical properties (cohesive and adhesive changes depending on the bonding partner) under the influence of climatic loading like UV-radiation, fluidic-storage and temperature changes. UV-curing Acrylates are already used as structural adhesives. The material behavior and information on designing with Acrylates are presented in [15], [16]. It was shown, however, long-term water storage in combination with UV-radiation leads to a decrease in strength parameters. [16], [17]. The investigations in the research project want to evaluate the mechanical properties in the specific application shown in Figure 1-1.

2.3 Specimen preparation

Two specimen types are prepared for the artificial aging process shown in Figure 2-1.

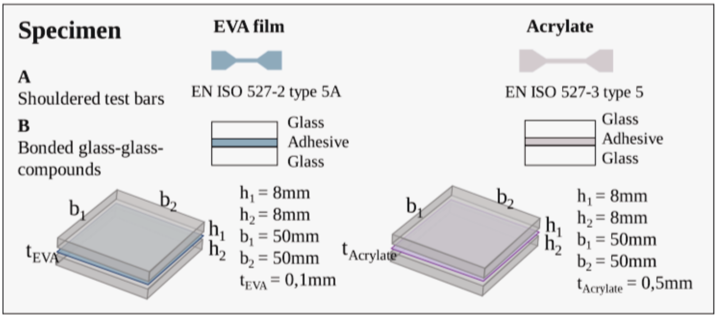

Figure 2-1 Specimen specifications – measurements of shouldered test bars and bonded glass-glass-connections.

To evaluate the material behavior, shouldered test bars (specimen type A) are produced. For the EVA, corresponding specimens are cut out of the basic material (DIN EN ISO 527-2 type 5A [18]) and bonded in a vacuum laminator (Meier Vakuumtechnik GmbH) at 125 °C. For the fabrication of acrylate shouldered bars, the material is casted into prefabricated silicone molds (DIN EN ISO 527-3 type 5 [19]) and cured for 10 minutes by an UV-lamp. The second type of specimens (specimen type B) consist of two glass plates bonded by the different adhesive materials. For EVA film, the lamination process corresponds to the shouldered specimens. Regarding the acrylate specimens, spacers are placed between the glass plates to provide an unchanging layer thickness of the filled in adhesive. The specimens are cured under an UV-lamp for 3 minutes afterwards.

3. Experimental Approach

Various methods are distinguished to characterize and quantify aging [20], which represents the totality of physical and chemical material changes over time. For experiments, accelerated artificial impacts adapted from realistic environmental influences are induced to specimens in the sense of a time lapse. Figure 3-1 presents the experimental scheme applied to determine the material behavior of bonded specimens and adhesive materials. The artificial aging is customized to the environmental conditions of the capillary glass unit. A main climatic influence is provoked by UV-irradiation. Since all materials/components are in direct contact with the fluid (glycol mixture), this is an additional influence to be considered. For this reason, three different climatic settings are defined in this research: UV-irradiation (UV), Fluidic contact (F) and UV-irradiation and permanent fluidic contact (UV/F).

For the artificial aging under UV-irradiation (UV) and the combined climatic loading (UV/F), the experiments resemble specifications of the ETAG 002 [21] as follows: duration of 550 h, average radiation intensity of 42 W/m², humidity of 50 %, constant temperature of 40 °C over time. The specimens of load case UV and UV/F are embedded in glass basins and set into a climate chamber with UV irradiation. For the load case F, the specimens are placed in UV-blocking boxes at room temperature. After 550 h of artificial aging, the specimens of load cases UV, F, and UV/F are subsequently evaluated by tensile tests on shouldered bars. Furthermore, the quality of the bonding connection is non-destructively analyzed from a visual point of view (evaluation of appearance and surface characteristics of the bonded glass-glass-connections) to evolve und facilitate deeper comprehension of aging processes in artificial simulations. The results of all tests are compared to specimens tested without aging effects representing the basis for the evaluation of the bonding quality.

4. Results

4.1 Non-destructive Method

Based on the criteria chosen in [20] (yellowing, overcasting, darkening, crack formation, dimensional stability), specimens B (glass-glass-specimens) show no visible and critical changes after the climatic loading. This is exemplified in Figure 4-1, where the specimens are placed in front of a picture theme for reasons of better perceptibility. The air pockets – visible for the acrylate connected specimen – are a result of manufacturing processes and not connected to the climatic loading.

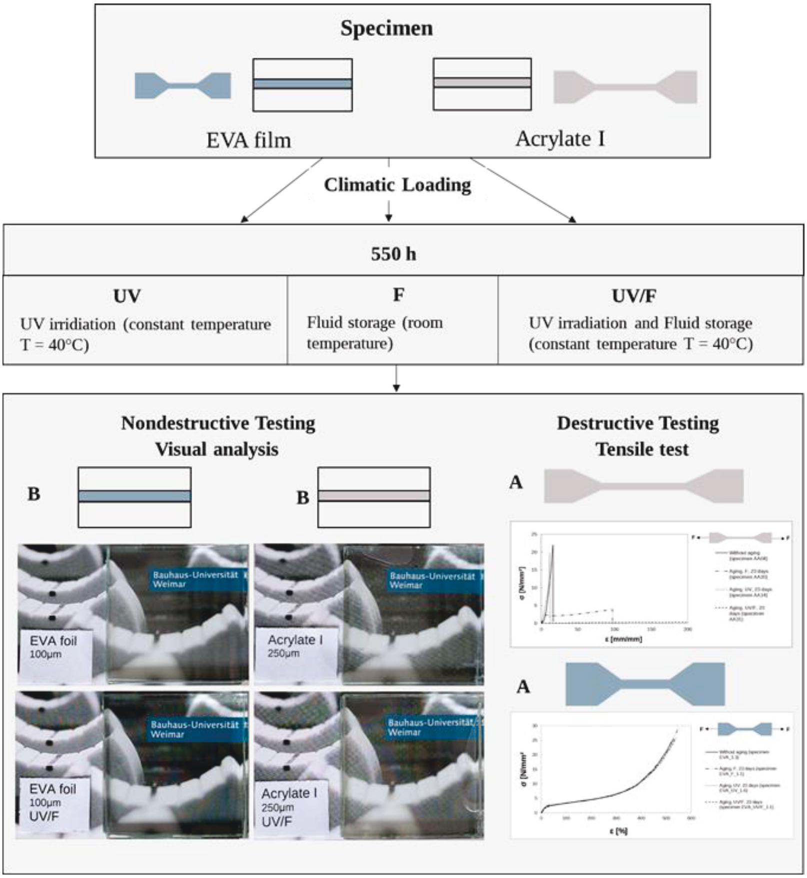

Figure 4-1 Experimental approach – evaluation of bonding quality of glass-glass compounds.

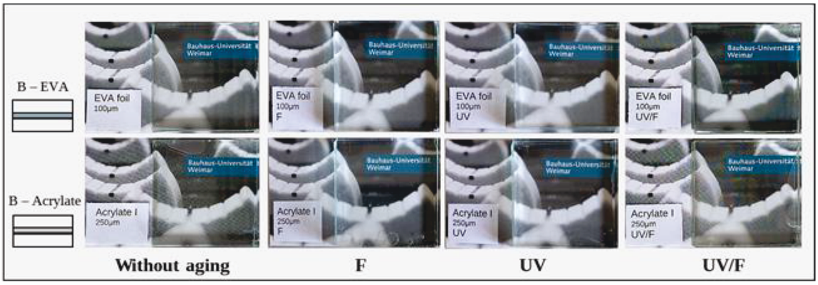

Figure 4-2 Evaluation of bonding quality of glass-glass compounds – visual analyses of specimens B.

4.2 Destructive Method

The evaluation of the material behavior is shown in Figure 4-3. Upon reaching a certain stress level, the acrylate specimen without any aging effects shows an elastic, quite linear behavior. When effected by UV-radiation, the stiffness increases connected to a slight decrease of maximum stress and strain levels. However, the influence of fluid storage leads to a completely different behavior, where plasticizing effects of the specimen are apparent. Upon reaching a certain strain level, strong increase of elongations is connected to an only slight increase of stress and a much less brittle behavior. The effect of material softening is even stronger for climatic load case UV/F, where the specimen provides very low stiffness and an elongation at tear of approx. 200 %. The influence of the aging process is much smaller for EVA-specimens as presented in Figure 4-4. A high non-elastic material behavior is detected without as well as for all aging influences with quite congruent stress-strain-curves.

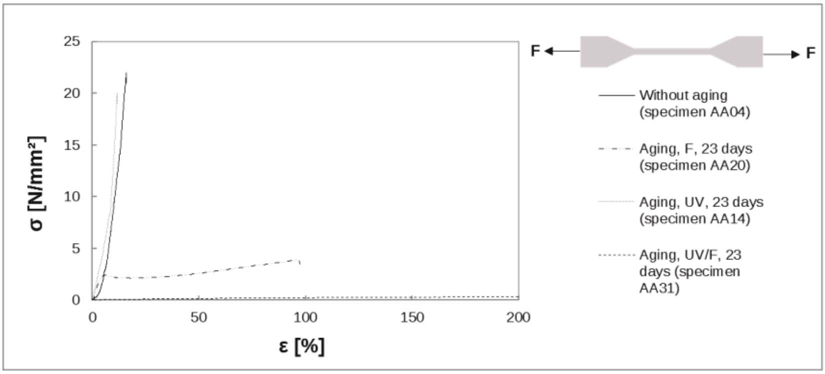

Figure 4-3 *Evaluation* of bonding quality of glass-glass compounds under climatic loading – tensile test, connection means – acrylate.

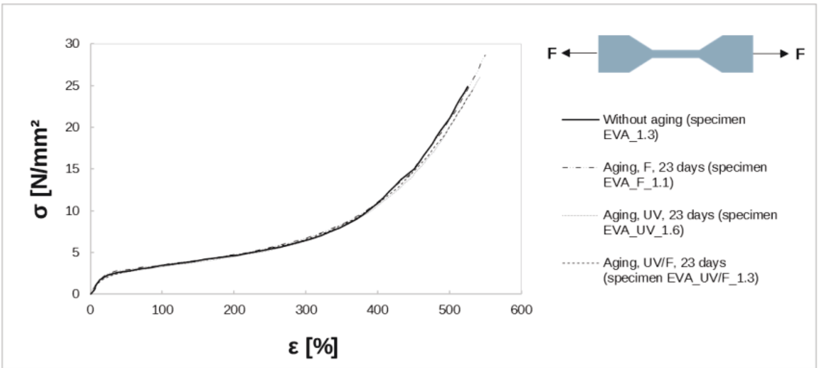

Figure 4-4 *Evaluation* of bonding quality of glass-glass compounds under climatic loading – tensile test, connection means - EVA film.

5. Conclusion

For the development of a new façade system, glass-glass compounds are to be bonded. Physical and chemical aging processes occur in plastic materials when climatically influenced leading to mechanical and visual material changes. For detection, tensile tests and visual analyses are performed using different specimens. For acrylates, the material behavior is strongly influenced by UV irradiation and fluid contact (embrittlement, softening). On the other hand, EVA films do not show such a diversity in material behavior under climatic loading. In the visual analyses of bonded compounds, aging effects due to UV irradiation and fluid contact cannot be detected for the specimens of this research. Based on diverse testing series, the EVA films are chosen as functional bonding material for the glass compounds.

6. Acknowledgements

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