Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2009, Valencia
Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures
28 September – 2 October 2009, Universidad Politecnica de Valencia, Spain
Alberto DOMINGO and Carlos LAZARO (eds.)

Sticky Glass - Structural bonded Joints with Acrylates

Bernhard WELLER*, Iris VOGT

*Technische Universität Dresden
Institute of Building Construction
01062 Dresden, Germany
bernhard.weller@tu-dresden.de

Abstract

UV and light curing acrylates present a whole host of possibilities for designing glass construction with adhesively bonded joints. Their clear and colourless appearance produces a transparent and lightweight construction. Short curing times consisting of no more than mere minutes allow for quick production with minimal downtime within the overall process. Processing can resume immediately once bonding has occurred. The advantages of acrylates can be silhouetted against the characteristics and properties of adhesive silicone which has been widely approved by German building authorities for specific façade applications.

These adhesives are analysed both generally as bulk material and in applications as a joint between glass and metal. The use of dog bone shaped specimens is recommended to analyze the material behaviour under a variety of influential factors such as temperature and testing speed. The bonded joints of test specimens provide an opportunity to examine the interaction between the adhesive and the materials to which they are adhered. Constructions having punctually bonded joints are tested to demonstrate the potential use of acrylic joints in glass treatments. Some components are exposed to natural weathering in order to examine the affects of ageing on the adhesive.

Finally in short form commendations can be given to plan and design glass constructions with adhesively bonded joints of UV and light curing acrylates.

Keywords: Glass, Bonded Joints, Acrylates, Adhesive, Dog Bone Shaped Specimen, Material Properties, Bulk Material, Natural Weathering

1. Introduction

Attractive applications for the potential use of transparent joints in glass construction are presented in Tasche [1]. Particularly attractive uses to apply these joints are glass safety barriers and overhead glazing like canopies. The last-mentioned ones are located outdoor in order to observe the material durability under real conditions.

Figure 1+ 2: Bonded overhead glazing under natural weathering

Safety barriers out of glass are built up to be classified under category C1 per TRAV [2]. Test examinations considered the monolithic tempered safety glass bonded by polished, stainless steel fittings as may be found in such an application situation. For the bonding a UV and light Acrylate, PHOTOBOND® 4468 (later referred to as PB 4468) [3], was used. By the use of a special lamp the curing was done within few minutes. Glass panes and brackets were loaded with a static load to simulate wind loads in exterior applications.

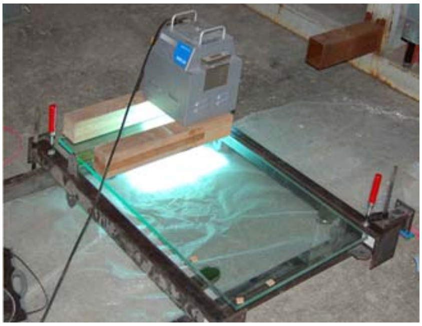

Figure 3+4: Safety barrier. The curing process with a special lamp and the simulation of static loads by sand sacks

Simulating a slipping person, which falls against the glazing, pendulum impact tests, based on TRAV [2], were conducted from a height of 450 mm at three different locations on the specimen. The resulting strains were measured by several strategically placed strain gauges located near the support-brackets and impact points. Due to first examinations the connection to the substructure was changed to compensate for constraints that appeared after initial test readings. In the end, glass breakage occurred as a result of deformation and stiff construction as well as a result of joint failure. Modified adhesives should, therefore, be used in these particular types of applications (Vogt [4]).

Figure 5+6: Pendulum impact test of the safety barrier

2. Determination of Material Properties

2.1 Bulk material

Two methods are available to determine the material properties of the adhesive material used in bonded glass joints, either determination at the bulk material or at bonded specimens. Both methods have advantages and limits. By using specimens of the adhesive material absent any adherend, the material properties of the bulk material can be determined. The material behaviour and properties, as described by Young’s modulus and Poisson’s ratio, can be determined by the application of a tensile load. It is also possible to simultaneously measure the axial and transversal strains, contact-free, with the help of a biaxial video extensometer.

Figure 7: Specimen being stretched to the capacity of the climate chamber.

The specimens were tested with varying rates of strain based on the requirements set forth under ISO EN 527 [5]. These requirements include a wide band of test results ranging from 1 mm/min up to 500 mm/min. ETAG temperatures ranging from, -20 up to +80 °C were used in order to reflect extreme conditions when bonded joints are used in façades or exposed to variable temperatures (ETAG 002 [6]). The tensile modulus - the inclination of the tensile stress-strain-relationship at initiation - is shown in a three-dimensional diagram based on the temperature and the rate.

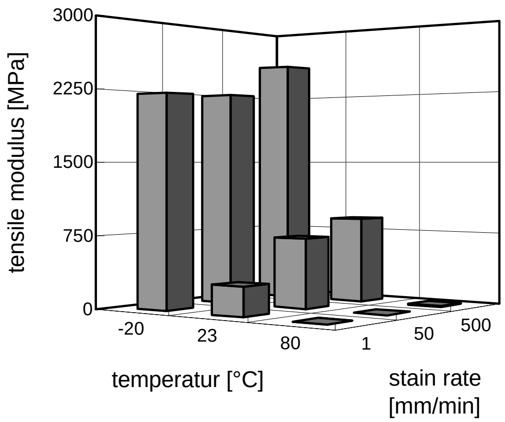

Figure 8: Tensile modulus based on the temperature and the rate

Looking at the resulting tensile modulus, this particular adhesive material becomes very flexible at high temperatures and very stiff at low temperatures. The tensile modulus increases steadily as the strain rate increases. If bonded joints with UV and light curing acrylates will be used in configurations in which varying temperatures and rates (for example snow and storms) are estimated, then this specific material behaviour must be taken into consideration.

2.2 Butt bonded hollow cylinder

To determine the material properties of bonded joints, different specimens with varying geometries can be used. In the case of glass construction configurations, the butt-bonded hollow cylinder, depicted in accordance to DIN EN 14869-1 [7], is particularly suitable for determining such material properties. A closed ring-shaped geometry produces a constant state of stress in contrast to the frequently used single-lap joints which cause a stress distribution with stress peaks.

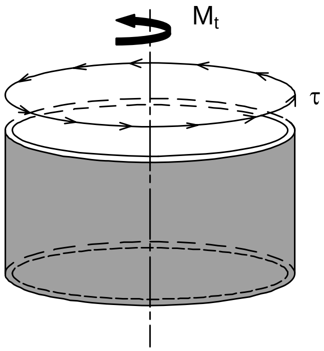

Figure 8: Stress distribution for tension

$$\tau = \frac{M_t}{W_p} = \frac{16 \cdot M_t \cdot d_a}{\pi \cdot (d_a^2 - d_i^2)} \tag{1}$$

In DIN EN 14869-1 [7], the butt-bonded hollow cylinder is designed for metal joints. Therefore, this construction must be modified for joints connecting glass components. As such, a circular pane of glass was bonded to the initial hollow cylinder by the use of a ring-shaped light- and UV-curing acrylate. The adhesive thickness of 0.5 mm was set using glass beads, and the UV-lamp was placed directly above the configuration to allow for radiation to penetrate the glass at right angle to the adhesive. A second hollow cylinder, using a plane auxiliary bonding, was affixed to the front on the opposite side of the glass. In this case an epoxy resin was chosen since it produces more resistance than the acrylate; this joint had no effect on the results. The displacements were measured by eddy current sensors which were placed above the acrylate joint. This configuration was loaded with both tensile and torsional forces in order to determine the elastic material properties. Experiments were conducted at temperatures of -20 °C; +23 °C; and +80 °C according to ETAG 002 [6].

The elastic material properties were determined based upon experimental results obtained under the assumption of a restricted lateral strain (Schlimmer *et. al.* [8]); the validity of this assumption was verified by experiments and calculations. As evidenced by the tensile stress-strain diagram, the acrylate PB 4468 [5] shows a nearly linear behaviour at the onset that flattens prior to breaking. The shear stress-strain diagram shows a nearly bi-linear curve with an easily distinguishable yield point. In most cases there was an adhesive failure in the metallic substrate as determined in Tasche [1].

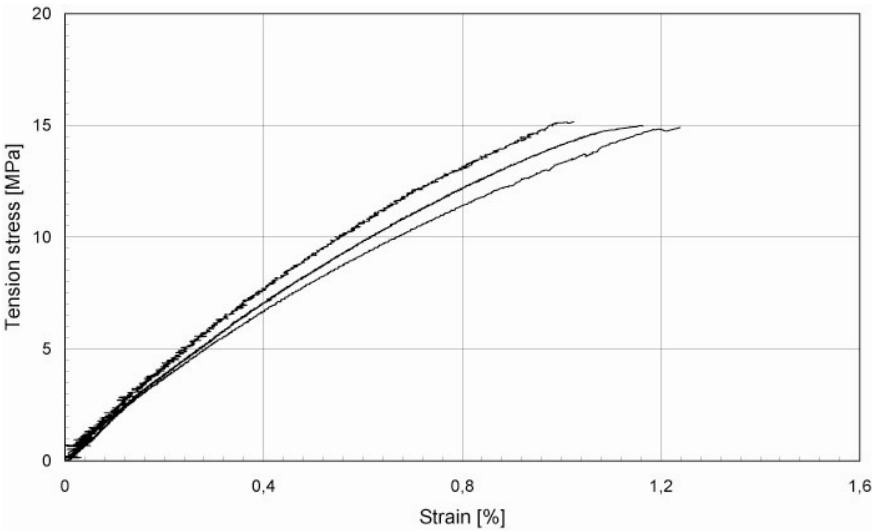

Figure 9: Tensile stress - strain diagram for PB 4468, +23 °C; adhesive thickness 0.5 mm

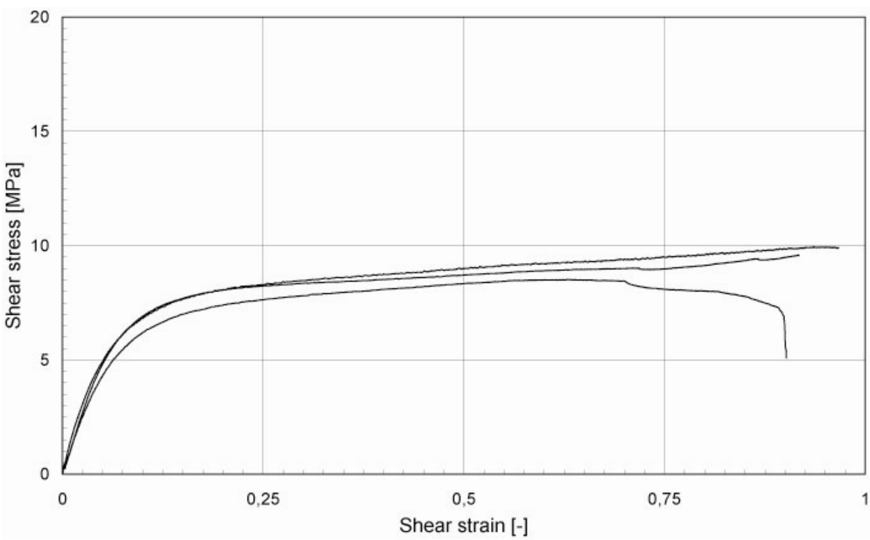

Figure 10: Shear stress - shear strain diagram for PB 4468, +23 °C; adhesive thickness 0.5 mm

3. Results

Comparing both methods variances are seen in the results of the material properties. Results from the use of the butt-bonded hollow cylinder led to higher mechanical properties when the results from both testing methods were compared. Such results reflect the stiffer behaviour of the material in a joint. Interactions between adhesive and adherend occur at a very thin interface and produce very small changes in the adhesive glue used. Increased mechanical properties result when the average of the thicknesses is taken into account (Vogt [4]).

	E [MPa]		
temperature	**-20 °C**	**+23 °C**	**+80 °C**
dog bone shaped specimen	2202	298	2
butt-bonded hollow cylinder, d_K =0,5 mm	2348	349	4

Figure 11: Young's Modulus for the PB 4468 at room temperature

4. Conclusion

Finally commendations can be given to plan and design glass constructions with adhesively bonded joints of UV and light curing acrylates. Depending on the requirements of the application, the choice of adhesive should be carried out. The construction of the assembly as well of the detail should account on the particularise of this adhesive (Vogt [4]).

Acknowledgments

A special thank goes to KL Beschläge Karl Loggen GmbH, Delo Industrieklebstoffe GmbH & Co. KG and the Institut of Material and Beam Technology, Fraunhofer Gesellschaft. Thanks is also given to the German Federal Ministry of Economics and Technology and the Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" e.V. for supporting this research project.

References

[1] Tasche, Silke: *Strahlungshärtende Acrylate im Konstruktiven Glasbau*, Dissertation. Dresden: Technische Universität, 2007.

[2] TRAV: *Technische Regeln für die Verwendung von absturzsichernden Verglasungen.* Fassung 2003. In: Mitteilungen des Deutschen Instituts für Bautechnik, Ausgabe März 2003. Berlin: DiBt, 2003.

[3] DELO Industrieklebstoffe: *Technische Information DELO-PHOTOBOND® 4468*, Landsberg 2006.

[4] Vogt, Iris: *Strukturelle Klebungen mit UV- und lichthärtenden Acrylaten*, Dissertation. Dresden: Technische Universität, 2009.

[5] ISO EN 527: *Kunststoffe - Bestimmung der Zugeigenschaften.* Deutsche Norm. Berlin: Beuth, 1996.

[6] ETAG 002: *Leitlinie für die europäische technische Zulassung für geklebte Glaskonstruktionen (Structural Sealant Systems - SSGS), Teil 1: Gestützte und ungestützte Systeme*. Berlin. Bundesanzeiger, 1999.

[7] DIN EN 14869-1: *Strukturklebstoff - Bestimmung des Scherverhaltens struktureller Klebungen - Teil 1: Torsionsprüfverfahren unter Verwendung stumpf verklebter Holzylinder (ISO 11003-1: 2001, modifiziert).* German version EN 14869-1: 2004. Berlin: Beuth, 2004.

[8] Schlimmer, Michael; et. al.: *Berechnung und Auslegung von Klebverbindungen, Teil 1* - *9*, Adhäsion - Kleben und Dichten, Jahrgang 48 (2004) Heft 5 - 12.