Influence of Environmental Factors on Mechanical Properties of Adhesive Joint

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Abstract: Shear adhesive connections are more frequently used in civil engineering. Load-bearing joints of glass structures belong to the one of the new important application of glued connections due to possibility of even stress distribution in joint, as compared with bolted connection. Semi-rigid or rigid adhesives are relatively new materials in façade engineering or the glass structures and durability is a very important factor to be taken into account to the designing of bonded connections. For this reason, comprehensive research focused on shear glued joints in glass structures was performed and the paper is dedicated to part of the research concentrating on the adhesive connections subjected to accelerated ageing condition effect together with brief discussion of methods used for laboratory ageing.

Keywords: Adhesive Connection; Environmental Effect; Laboratory Ageing; Durability; Artificial Ageing.

1 Introduction

Adhesive joint, as compared with bolted connection, provide numerous important benefits for usage in façade or/and civil engineering. Glued connection is able to eliminate stress concentrations in the joint depending on its stiffness and geometry, reduce thermal bridging due to low thermal conductivity of polymer, can increase efficiency of assembly and provide aesthetical qualities thanks to smooth surface of façade cladding without holes for screws and possible joining of unconventional materials often used in the facade design. Wide range of adhesives is available now, but only a little is known about long-term behavior of semi-flexible, semi-rigid or rigid adhesives in structural joints.

Structural adhesive connection must withstand not only mechanical loading but it must also resist service environment. Environmental effects may include moisture or high relative humidity, low and/or high temperatures, UV-radiation, influence of chemicals and solvents and corrosive effect of salt climates. Combined effect of several above mentioned influences that may also operate in real application of adhesive connection, e.g. in façade, is often worse than degradation effect of sum of each factors separately [1,2]. For this reason, it is also important to choose suitable method containing several these factors for ageing simulation in laboratory.

The recently finished research in adhesive connections for glass structures covered also environmental effect (combination of UV-radiation, high and freezing temperatures and high relative humidity) on structural adhesives applied in glass – to – glass or glass – to – metal joints.

2 Experimental Program

Five types of glue were selected for the experimental program. The selection goes from flexible polyurethane adhesives through semi-acrylate glue to stiff UV-curing ones. Shear loaded joint tests were performed for connections of glass-to-glass or glass-to-steel, stainless steel, and aluminium, testing setups are shown in Fig. 1 and 2. Glass in joints was used in two variants - with smooth, degreased surface and roughened surface by sandblasting. Particular set of specimens were exposed to conditions of accelerated ageing and after that they were tested to compare their shear load-carrying capacity.

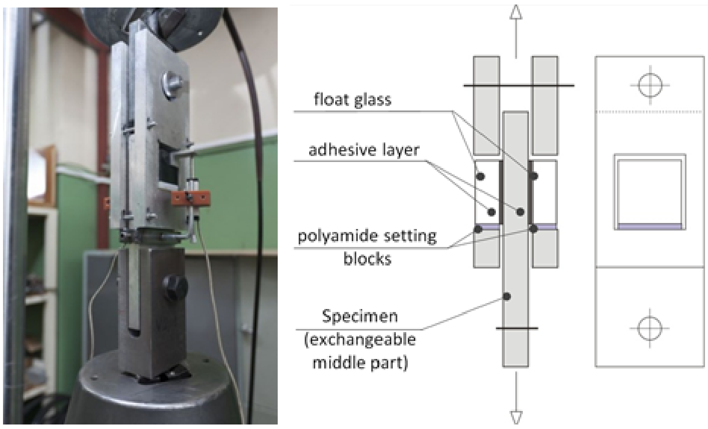

Fig. 1: Testing setup for glass-to-metal specimens.

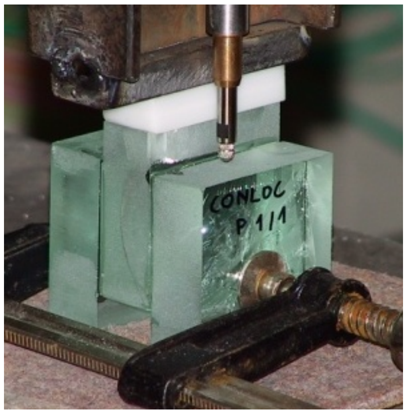

Fig. 2: Testing setup for glass-to-glass specimens.

2.1 Laboratory Ageing Cycle

There are several methods to test ageing effect on glued joint. Firstly, there is possibility to use natural environment and expose specimens to real environmental conditions. The greatest disadvantage of natural ageing is time consumption. For this reason, there are few laboratory ageing tests and related codes, e.g. ISO 9142 "Adhesives - Guide to the selection of standard laboratory ageing conditions for testing bonded joints", ISO 11431 "Building construction - Jointing products - Determination of adhesion/cohesion properties of sealants after exposure to heat, water and artificial light through glass", ISO 11997-1 "Paints and varnishes - Determination of resistance to cyclic corrosion conditions - Part 1: Wet (salt fog)/dry/humidity", DIN 53287 "Testing of adhesives for metals and adhesively bonded metal joints - Determination of the resistance to liquids", ISO 9227 "Corrosion tests in artificial atmospheres - salt spray tests", Xenon test, Cataplasma test or even many different tests used by manufacturers of glues (e.g. climate cycling test VW PV 1200). But none of them provides comparison of artificial ageing effect with real environmental degradation and also none of them includes all the most common environmental factors (UV-radiation, high relative humidity, high temperatures and also low temperatures effects) in one cycle.

Therefore, accelerated ageing cycle used for the research included moisture, UV-radiation, high and freezing temperature effect, see Fig. 3. The cycle lasted one week (168 hours) and was repeated 9 times to simulate 5 years in exterior condition effect in Czech Republic climate. In view of the fact that there is no satisfactory technical guide or standard how to expose glued joint in structural glass to laboratory ageing, typical cycle for simulation of external conditions was assumed from TP VVÚD 3.64.001, which was developed by Research and Development Timber Institute's originally for polymer coatings on metal surfaces and it was used for adhesive joints in glass for the first time.

3 Results

3.1 Modifications Caused by Laboratory Ageing

After artificial ageing all specimens were assessed with the naked eye to find out modifications. All PU-adhesives specimens had no significant changes. Both types of PU-adhesives (SikaFlex 265 + Booster and SikaForce 7550) have low UV-resistance, but this problem was solved successfully by primer coatings to the glass surface.

The specimens glued by a 2-component acrylate adhesive (SikaFast 5211) showed adhesive faults at the glass surface and also there were small bubbles and small surface cracks at the adhesive layer edge, see Fig. 5. These faults were probably created due to temperature changes which the adhesive had to withstand because glass transition temperature T_g is around +50 °C and it is within the temperature range of the laboratory ageing cycle. Probably, specific volume changes due to temperatures repeatedly going over T_g, caused the small bubbles, cracks and adhesion faults in glue.

All specimens glued by UV-curing adhesive RiteLok UV50 with a smooth glass surface were unsealed spontaneously during artificial ageing, see Fig. 6. The specimens with this adhesive and a surface roughened by sand-blasting had no observable modifications. There is an assumption that the adhesion weakening and subsequent peeling off was caused by high relative humidity in the weterometer. The second type of UV-curing adhesive (Conloc 685) also had no noticeable changes, which can affect the mechanical properties.

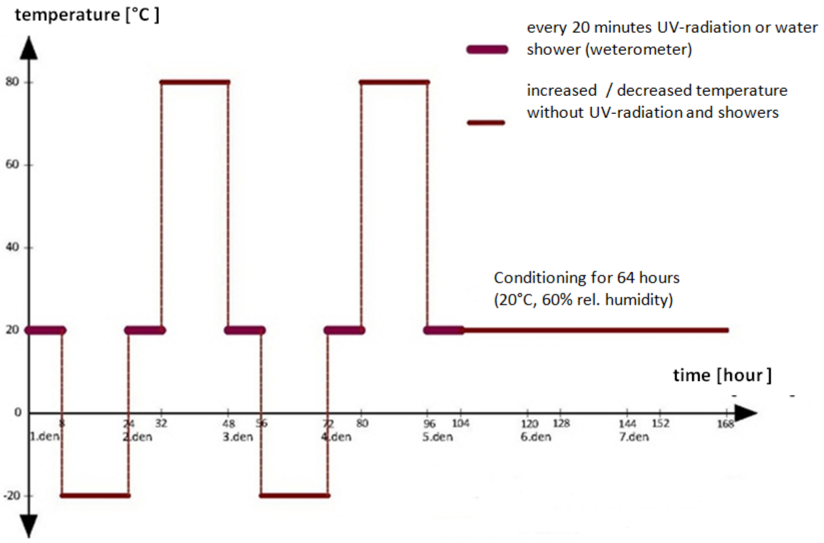

Fig. 3: Typical cycle of laboratory ageing.

Fig. 4: Testing setup for glass-to-metal specimens.

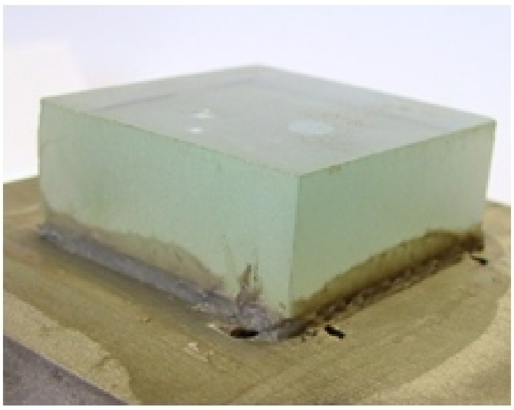

Fig. 5: Faults caused by artificial ageing in 2C-acrylate adhesive.

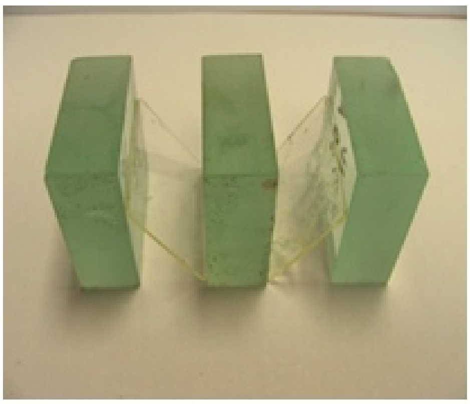

Fig. 6: Unsealed specimen of RiteLok UV50.

3.2 Mechanical Behavior of Joints After Exposure to Ageing

Shear test results in stress-strain relationship graphs, including comparisons with specimens unexposed to the ageing effect, are shown in Fig. 7, 8 and 9. The continuous line in the graphs marks the results of laboratory aged specimens, while the dashed line provides comparison with the results of specimens which were not exposed to ageing. For PU-adhesives no worsening was observed, even for 2-component PU (SikaForce 7550) higher strength of all joints was measured. There is an assumption that this glue needs a longer time for curing than is stated in technical data sheet. 2-component acrylic adhesive showed similar shear strength values like the specimens without artificial ageing, no negative effect of small bubbles or adhesive faults developed due to laboratory ageing was observed. The average shear strain values were measured by 15 % higher and deformation had a more plastic nature. UV-curing adhesives showed worsening of mechanical properties which could be solved by water/moisture resistant sealing of the adhesive edge for Conloc 685 glue. RiteLok UV50 glue was assessed as unsuitable adhesive for load-bearing joints due to its spontaneous unsealing during laboratory ageing and significantly worsening of unsealed specimens (with roughened surface)

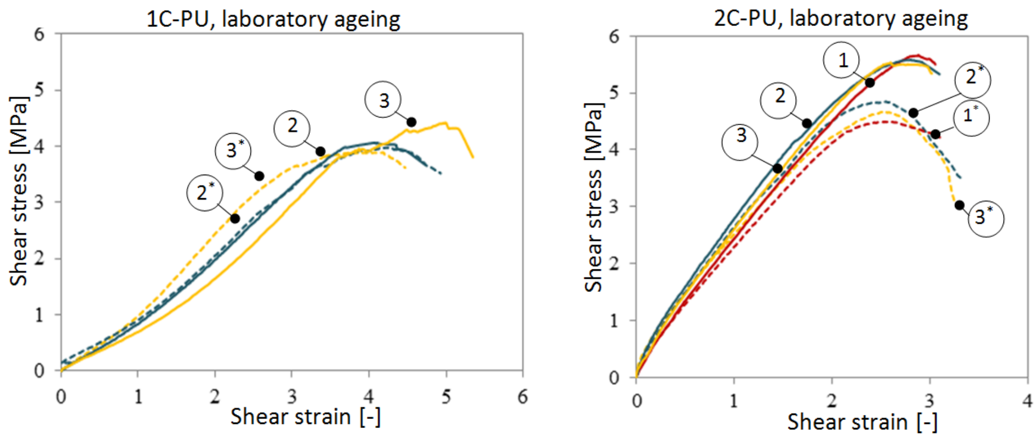

Fig. 7: Shear stress-strain relationship laboratory aged PU adhesives. 1 = steel + glass + ageing, 1* = steel + glass, 2 = stainless steel + glass + ageing, 2* = stainless steel + glass, 3 = aluminium + glass + ageing, 3* = aluminium + glass.

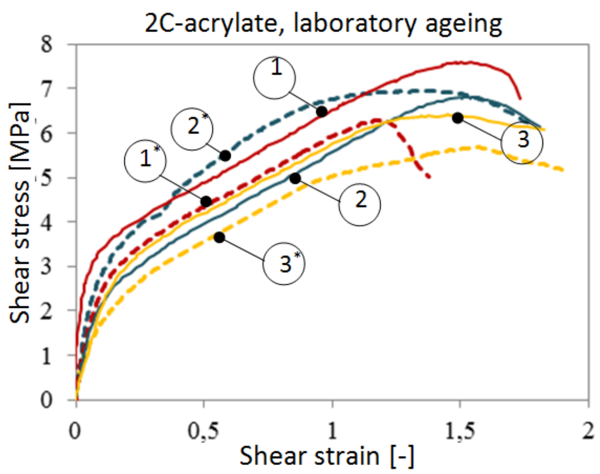

Fig. 8: Shear stress-strain relationship – laboratory aged 2C -acrylate adhesive. 1 = steel + glass + ageing, 1* = steel + glass, 2 = stainless steel + glass + ageing, 2* = stainless steel + glass, 3 = aluminium + glass + ageing, 3* = aluminium + glass.

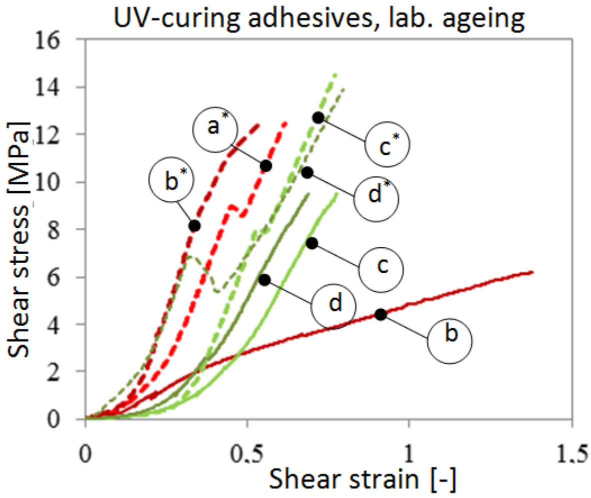

Fig. 9: Shear stress-strain relationship laboratory aged UV-adhesives. a* = RiteLok UV50 + smooth glass, b = RiteLok UV50 + sand-blasted glass + ageing, b* = RiteLok UV50 + sand-blasted glass, c = Conloc 685 + smooth glass + ageing, c* = Conloc 685 + smooth glass, d = Conloc 685 + sand-blasted glass + ageing, d* = Conloc 685 + sand-blasted glass.

4 Conclusion

Ageing can significantly change mechanical properties of glued joint and there is a necessity to investigate these changes with emphasis to special requirements of joint application.

Acknowledgement

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