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Durability of adhesive glass-metal connections for structural applications

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ABSTRACT

The use of adhesive bonds for structural glass-metal connections in the building envelope has increased in recent years. Despite the multiple advantages compared to more traditional bolted connections, long-term behaviour and durability of the adhesives have to be investigated accurately. Because, under service conditions, these products are exposed to factors, such as moisture, temperature and UV-radiation, which may influence their performance significantly. Sufficient data on the durability of adhesive glass-metal connections subjected to environmental factors is therefore essential, however, not always available. In an attempt to partially fill this gap, experimental tests were performed on three potential adhesives for structural glass-metal connections. During previous research, a stiff epoxy, 3M™ Scotch-Weld™ 9323 B/A, and a flexible MS-polymer, Soudaseal 270 HS, were selected for point-fixings, and a structural silicone, Sikasil® SG-500, for linear connections between glass and cold-formed steel. This paper reports on the effects of moisture, temperature and UV-radiation on the mechanical properties of structural point-fixings and linear glass-metal connections. According to the tests, both the epoxy and MS-polymer demonstrated limited resistance against moisture, while the performance of the silicone after exposure to moisture was outstanding. Thermal cycling did not significantly affect the 3M™ Scotch-Weld™ 9323 B/A and the Sikasil® SG-500. For the Soudaseal 270 HS, thermal cycling improved the mechanical properties. The exposure to UV-radiation had no effect on the MS-polymer and silicone, but did aggravate previous damage caused by moisture in case of the epoxy. Overall, it was concluded that the epoxy, 3M™ Scotch-Weld™ 9323 B/A, and the MS-polymer, Soudaseal 270 HS, are possible candidate adhesives from a durability point of view for point-fixings in façades as moisture can be easily controlled for this application. The structural silicone, Sikasil® SG-500, seems ideal for both indoor and outdoor applications. Moreover, its excellent adhesion to galvanised cold-formed steel under severe environmental conditions might give rise to the development of new structural concepts.

1. Introduction

When modernism started to rise in the beginning of the twentieth century, glass became one of the materials in building construction which was most appealing to the imagination, which it still is today. However, the use of glass as structural element is still a juvenile field of research, which is developing and expanding rapidly though. Applications of structural glass in beams, fins, canopies, structural sealant glazing systems, etc. offer hodiernal architects and engineers an entire new range of possibilities. Nevertheless, important practicalities to address are how to interconnect glass elements and how to connect glass components to an underlying structure. Glass by itself cannot be utilised due to its brittleness, limited toughness and strength, and laborious processing. Metal connectors on the other hand appear to be ideal; therefore glass-metal connections are introduced. These type of connections can be executed either mechanically or adhesively. Mechanical glass-metal connections, using bolts, clamps, or friction-grip fixings introduce peak stresses in the glass and often additional treatments of the glass panels, such as drilling and tempering, is required. Adhesive connections seem to be more appropriate from a mechanical point of view as forces are transferred more uniformly and as drilling of the glass is not necessary anymore. Moreover, thermal or acoustic bridges can be avoided, automation of prefab structural glass elements is possible, and the weight of the construction can be

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reduced. Adhesive connections between a glass element and the substructure exist in the form of linear bonds or point-fixings.

In the 19th century, combining glass with iron was an important milestone in the development of the use of glass as structural element. Together with the new building topologies from the Industrial Revolution, such as greenhouses, railway stations and galleries, iron-glass architecture became a symbol of this epoch. The connection of the two materials was regularly elaborated adhesively, hence the first linear adhesive connections between glass and metal originated. The slender primary load-carrying metal structure consisted of T-sections onto which glass plates were put into a bed of watertight putty made from linseed oil [1]. Fig. 1(a) illustrates the Royal Glass Houses of Laeken, Belgium, built between 1874 and 1876 by architect Alphonse Balat in which this technique is used. In the mid-1960s, the concept of linearly bonding glass panels to metal frames with an adhesive joint revived in the form of structural sealant glazing systems. The frame itself was often made of aluminium, but also (cold-formed) (stainless) steel was used, especially for larger spans as it stiffer. The concept of structural sealant glazing systems offered architects the possibility to build continuous façades with smooth glass planes, maximising lightness and transparency. Since then, the mechanical, thermal, acoustic and environmental performance of this system were improved by new concepts, such as the four-sided structural sealant glazing system, by new materials such as the two-component structural silicone, and by new products such as insulating glass units. Fig. 1(b) depicts the Charlemagne Building in Brussels, Belgium, built in the 1967 by Jacques Cuisinier and renovated between 1994 and 1998 by Helmut Jahn, replacing the concrete exterior by a four-sided structural sealant glazing system.

The increasing architectural trend of maximising lightness and transparency in buildings during the last 30 years resulted in the development of new glass connections, such as bolted point-fixings developed in the 1980s and 1990s, which minimise the visual impact of the glass supports [2]. However, direct contact between the glass and the bolts, made from harder materials such as steel should be avoided due to the glass' brittle behaviour. This also makes the glass sensitive to stress concentrations introduced using this type of connections. For this reason, the concept of adhesive point-fixings was introduced a few years ago. These connections offer a more efficient way of load transfer through the glass and eliminate the necessity of drilling and tempering. The adhesive used to fabricate such connections is either a soft elastic material, such as a structural silicone or an MS-polymer, or a rigid material such as an epoxy or acrylic. In the Dow Corning warehouse in Feluy, Belgium, built by architect Werner Aenspeck in 2012, stainless steel connectors were affixed to insulating glass units (IGU's) using a transparent structural silicone adhesive (TSSA).

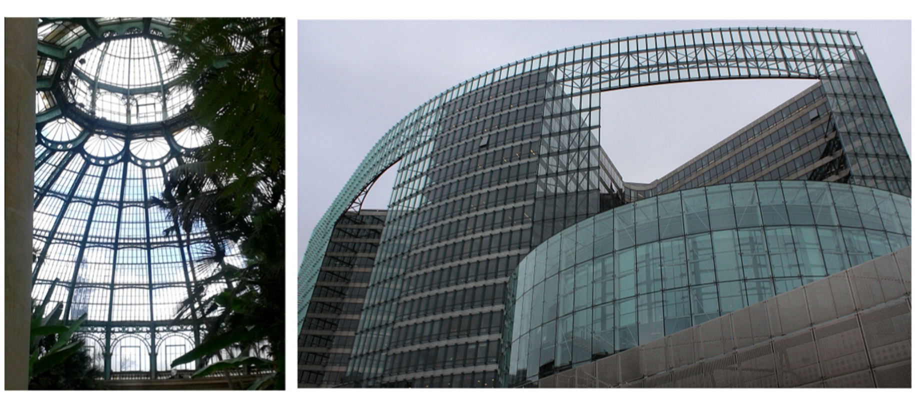
Adhesive bonds are very promising for structural glass connections. Structural silicones, for instance, show high potential for structural adhesive bonds in glazing systems, because of their good physical properties, such as high movement capability, good resistance to UV-radiation and low water absorption. Still, long-term behaviour and durability of adhesives for either linear bonds or point-fixings have to be investigated meticulously, as under real outdoor conditions these products are exposed to a wide range of factors which may affect their performance significantly. Indeed, structural adhesives used in exterior façades of buildings are subjected to arduous conditions, such as humidity, UV-radiation, and thermal cycling, which may cause degradation of the mechanical properties. Adhesives are chemical substances, susceptible to ageing to a level depending on the adhesive type and external factors. In the spirit of times, maintenance and repair costs are reduced as much as possible. Consequently, to ensure a service lifetime of 20–25 years for structural bonds in façades, the durability of these connections should be as high as possible. Therefore, sufficient data on the long-term performance of adhesive glass-metal connections subjected to environmental influences is indispensable. However, a lack of such quantitative data together with the deficiency of reliable accelerated ageing procedures has most likely impeded the use of adhesives in building construction.

The aim of this research is first to determine an artificial ageing schedule for structural adhesive point-fixings and structural linear adhesive glass-metal connections based on available standards, technical specifications and guidelines. In such a scheme, the most important environmental factors, i.e. moisture, temperature, and UV-radiation, influencing the mechanical properties of the connections should be included. Next, two candidate adhesives for structural adhesive point-fixings, namely the stiff epoxy 3M™ Scotch-Weld™ 9323 B/A and the flexible MS-polymer Soudaseal 270 HS, and one adhesive for structural linear adhesive connections, namely the structural silicone Sikasil® SG-500, are investigated for their durability by imposing the proposed artificial ageing procedures. For these, the effects of individual and combined influential factors on the mechanical properties are assessed by performing experimental tests.

2. Artificial ageing

2.1. Parameters and design

During their service life, adhesive connections are subjected to various environmental and operational conditions [3–8]. The external environment of a façade exposes structural adhesives to humidity, water absorption, temperature, thermal cycles, daily thermal movements, UV-radiation, acid rain, cleaning products,



(a) (b)

Fig. 1. (a) Royal Glass Houses of Laeken, Belgium and (b) Charlemagne Building in Brussels, Belgium.