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Laminated Glass Beams Subjected to Artificial Solar Radiation

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In the long run laminated glass interlayers are sensitive to weather conditions. Several studies have been carried out that aim at understanding the consequences of moisture and solar radiation on adhesion to glass and on the mechanical response of the composite pane. In particular, solar radiation seems to produce the strongest effects on the bulk properties of PVB, modifying the coupling capability of laminated glass plates exposed to the direct sunlight. Such problem has been already studied by the authors via dynamic tests on small laminated glass specimens subjected to artificial UV light; however, due to the methodology of these mechanical tests, it was not possible to repeat the experiment on the same specimens subjected to different exposition times, and it was not possible to investigate the laws of accumulation of the consequences of weathering actions. In fact, solar radiation could produce different effects on the structure of material, but only superimposed consequences can be observed. In order to better understand the time progression of the phenomenon, creep tests were performed on laminated glass beams subjected to four-point bending; the specimens were tested in correspondence of definite time intervals of UV exposure. The total amount of time will be defined according to the observed variation of test results with respect to the total exposure. The effects of UV radiation are highlighted directly comparing the displacement history diagram and successively evaluated analyzing the mechanical parameters that describe the rheological behavior.

Keywords: Laminated Glass, UV radiation, weathering action.

1. Introduction

It is known from the literature that polymers used as interlayer of laminated glass can be subjected to chemical modification in time, related to the ambient conditions they are exposed to: for example, Saad et al. (1995) measured dielectric parameters and dynamic mechanical properties of PVB after different time exposure to UV radiation; Safy El-Din and Sabaa (1995) investigated the causes of thermal degradation of PVB; Liu (2008) analysed the problem of thermal stability of PVB and possible stabilization by adding various bases. International standard (EN ISO 12543-4. 2001) proposes test methods to reproduce weathering action on laminated glass, focusing on thermal stability, UV radiation effect and consequences of absorption of moisture; these tests are mainly concerned with the visual consequences of the exposure action. However, the consequences on the mechanical properties or on the inner structure of material have recently drawn attention of researchers, mainly interested to the mechanical performances of structural laminated glass. Delincé et al. (2007) summarized the results obtained by some researchers on laminated glass subjected to UV radiation and moisture diffusion; Weller and Kothe (2011) and, successively, Kothe and Weller (2014) reported the results of a wide and systematic experimental investigation on glass laminated with PVB, EVA, TPU or ionomeric interlayer, even with combinations of environmental actions. Louter et al. (2012) focused their attention on the consequences of thermal and moisture actions on the interface of ionomeric interlayer. Serafinavicious et al. (2014) reported the results of an extensive experimental analysis performed on glass laminated with ionomeric, EVA and PVB interlayers as a consequence of moisture exposure, UV radiation and combinations; four point creep bending tests have been performed at different temperatures, but the results have not been elaborated as to represent the mechanical parameters of interlayer. Andreozzi et al. (2015) describe a wide experimental campaign in which the effects of different weathering agents are correlated to the rheological behaviour.

From the analysis of the literature it is evident that the exposure to UV radiation is one of the main degradation causes of laminated glass interlayer. Extensive exposition to solar radiation is however very common in architectural application, and can reach long time in the life of buildings, especially in some regions; for this reason the authors decided to focus on the consequences of UV radiation. Past experiences have suggested the possibility of different degradation phenomena, leading to different consequences on the inner structure of material and, consequently, on the mechanical properties; it is possible that such different effects prevail on the others in different times of the life of structural elements. For this reason, in order to monitor the progress of the degradation, not destructive tests were repeated on laminated glass beams at time intervals, during the exposition to artificial UV radiation.

The specimens used for the investigation and the artificial exposition to UV radiation are described in section 2. The mechanical tests are described in section 3. The first results are shown and discussed in section 4.

2. Artificial Exposition to UV Radiation

Seven small scale glass beams were laminated by Roberglass Srl (Calci, Pisa, Italy) using 6 mm float glass (Pilkington) and 152 transparent Trosifol (Kuraray) PVB interlayer (6-1,52-6). Four of these (specimens I1, I2, I3 and I4) were addressed to UV exposition to simulate the impact of solar radiation. Three out of the seven glass beams were kept shielded by UV radiation and used as a comparison (B1, B2 and B3). Before exposition, specimens I1, I2, I3 and B1, B2, B3 were tested in bending according to the procedure described in the following section.

Specimens I1 to I4 were kept suspended on a grid in horizontal position, in front of an array of six lamps Ultra-Vitalux® 300W (Osram) at a distance of 25 cm (Fig. 1); the spectrum of the emitted radiation is considered to well reproduce the spectrum of solar radiation. This was measured using a Pyranometer (LSI-lastem) at various distances from the lamps, in the position where the specimens should be placed. Interpolating the measured values of radiation, it was verified that 25 cm was the proper distance to produce an average irradiance level in the plane of about 900 ±100 W/m^2, that is the condition proposed in UNI EN ISO 12543-4 (Fig. 2). Note that the radiation condition used in the experimental campaign is not exactly as described in UNI EN ISO 12543-4 where a wider array of lams is suggested, put at a wider distance from the specimens, that produce overlapping of the ligth beams and a more uniform radiation on the surface of the specimens. Despite these differences, the radiation condition considered in the experimental program can be considered effective.

Specimens of I series were irradiated for 28 days (about 672 hours). Temperature of specimens exposed to radiation was not monitored but only controlled at time intervals; when it was observed in summertime that the temperature of the specimens exceeded 50°C the exposition to UV radiation was suspended as recommended by UNI EN ISO 12543-4; the high temperature could have produced some influence but the limited amount of hours should have limited the damage in comparison to the damage produced by radiation. After this period, a second loading-unloading cycle (see Section 3) was performed both on specimens I and B. Successively, specimens I were subjected to UV radiation for about 21 days (about 528 hours) and then both specimens I and B were subjected to a third loading-unloading cycle. Comparing the behaviour of specimens I with specimens B allowed to exclude the influence of ambient temperature on interlayer response.

The average solar irradiance on a definite plane orientation and in a definite position of Italian territory can be evaluated with the interactive software made by Italian Agency ENEA (http://www.solaritaly.enea.it/CalcRggmmIncl/Calcola.php), according to Italian standard UNI 8477/1 "Calcolo degli apporti per applicazioni in edilizia. Valutazione dell'energia raggiante ricevuta". Using this application it was calculated that the total irradiance on a sloping surface facing south in Florence (Italy) during one year is about 1602 kWh/m^2. On this basis it is possible to conclude that the two time periods of artificial irradiation should correspond respectively to the energy irradiated by sunligth in 4.5 months, and to 8 months on a roofing in Florence facing south.

3. Creep bending tests

The small scale laminated glass beams are 55 cm long and 5 cm wide, with a thickness of 6-1.52-6 mm (fig. 3). Supports were put at a span of 50 cm and two point loads were applied at 5 cm from the beam center so to permit the easy measurement of deflection. The vertical displacements at midspan and at the supports were monitored during the test with strain gage displacement transducers. 14.41 kg dead load was applied at midspan, divided on the two point load, in about 20” time, avoiding dynamic effects; the load was left on the specimens for about 24 hours. The value of load was determined so to produce a tensile stress on the lower beem less then 25 MPa in the hypotesis of layered beams (uncoupled); the specific value was determined by the weight of the device used to distribute the load on the beam, plus two dead weights of about 1kg. Temperature was recorded during the test; it is worth noting that, being impossible to control properly room temperature, a certain difference was always recorded between day and night, when heating system is not active in the laboratory. After the dead load was removed, the displacement recovery was recorded for at least 24 hours. Both the deflection due to the elastic response and to the successive creep were registered. The timetable of the mechanical tests is reported in Table 1. Tests 1 were performed at the end of May and at the beginning of June on three I specimens and on the three B specimens, none of which subjected to artificial irradiation; Tests 2 were performed after about 28 days both on blank specimens (B) and on the I01, I02 and I03 specimens irradiated for about 28 days; Tests 3 were performed after about 56 days both on blank specimens (B) and on the I01, I02 and I03 specimens irradiated for about 56 days. The comparison between the creep diagram of specimens subjected to UV radiation and of the blank specimens permits to evaluate the evolution of the bulk properties of interlayer subtracting the influence of temperature.

In fig. 4 a photo of the experiment is reported; in fig. 5 the diagrams of deflection versus time are reported for the six beams recorded during tests number three.

4. First results and discussion

In Andreozzi et al. (2015) the mastercurves of shear modulus of specimens subjected to UV radiation was reported. In particular, from the experimental results it is apparent that both storage modulus G’ and loss modulus G’’ encrease evidently; however, the first 912 hours seem not to produce consequences.

Regarding the experimental campaign here described, as can be seen in Fig. 4, the differences in behaviour of specimens I and B are not very accentuated. However, it can be noted that the delayed deflection, main consequence of the viscous share of interlayer deformation, seems to increase with the exposition to UV. For this reason, a more careful analysis was performed. An evaluation of the elastic share of deformation was made, determining the value of deflection after about 5 seconds that load was put on the beams. Such elastic share was then subtracted from the total deflection displayed after 24 hours so to evaluate the delayed share of deformation. The values of displacement obtained on specimens I was then related to the average values obtained from specimens B. In fact, the different temperatures in tests 2 and 3 can strongly affect the deformative behaviour of materials (temperatures ranged from 25 to 28°C for tests number 2 and from 12 to 16°C for tests number 3). Note that the range of the experimental temperatures probably include the glass transition temperature T_g of PVB.

The results of this analysis have been reported in Fig. 6.

After 672 hours of exposition to UV radiation, the I specimens show an increase of stiffness with reference to the specimens B not exposed to UV radiation. The ratio is about 0.7 for the elastic share and 0.5 for the delayed deflection. On the contrary, after 1200 hours the total deflection of specimens I is almost equal to the deflection of specimens B; however, it appears that the elastic share is decreased while the delayed deflection is increased. This observation induces to suppose that the radiation influences the rheological behaviour of interlayer, modifiyng the inner structure of material.

Since the specimens did not exhibit a clear trend, reliable results will be available at the end of a prolonged exposition, when a higher number of tests will better describe the phenomenon and eventually will confirm the results presented here.

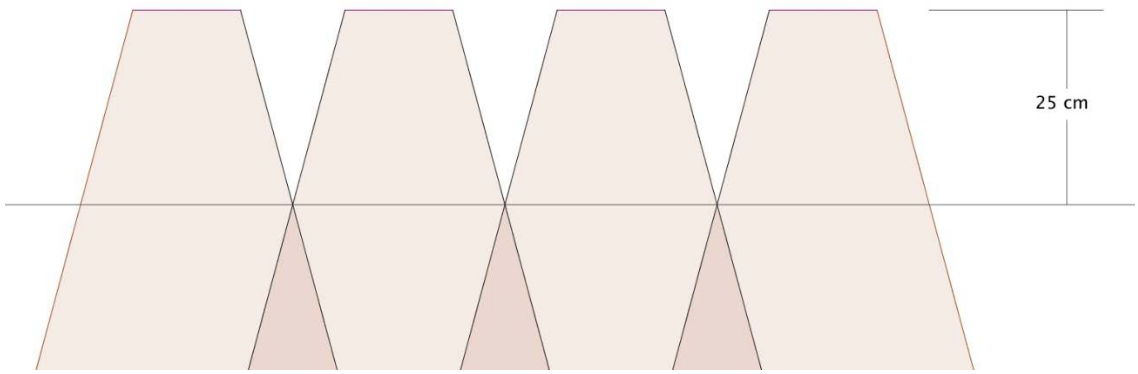

Fig. 1 Front view of the lamp array.

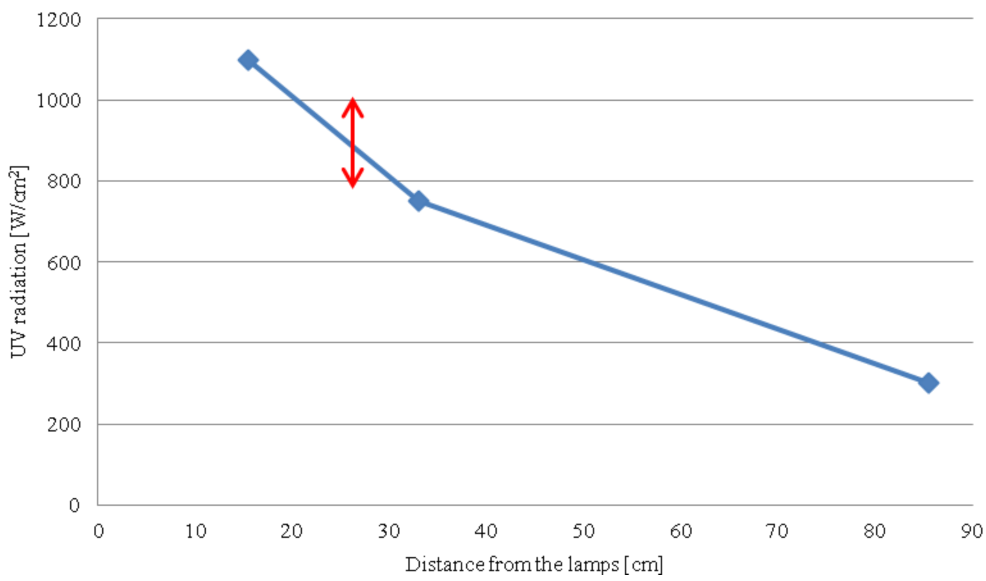

Fig. 2 Optimal distance from the lamps to obtain about 900 ±100 W/m^2.

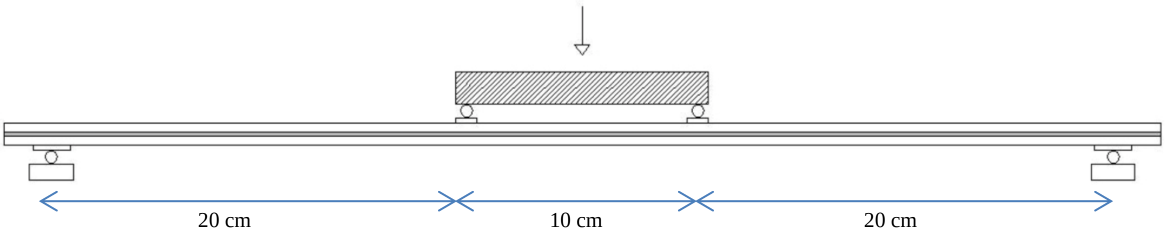

Fig. 3 Small scale laminated glass beam for creep test.

Table 1 Timetable of the mechanical tests

	TEST 1	TEST 2	TEST 3
B01	05/06/17	05/07/17	14/12/17
B02	07/06/17	10/07/17	19/12/17
B03	12/06/17	13/07/17	21/12/17
I01	23/05/17	27/06/17	04/12/17
Hours of exposition	0	672	1200
I02	29/05/17	29/06/17	06/12/17
Hours of exposition	0	672	1200
I03	31/05/17	03/07/17	11/12/17
Hours of exposition	0	672	1200

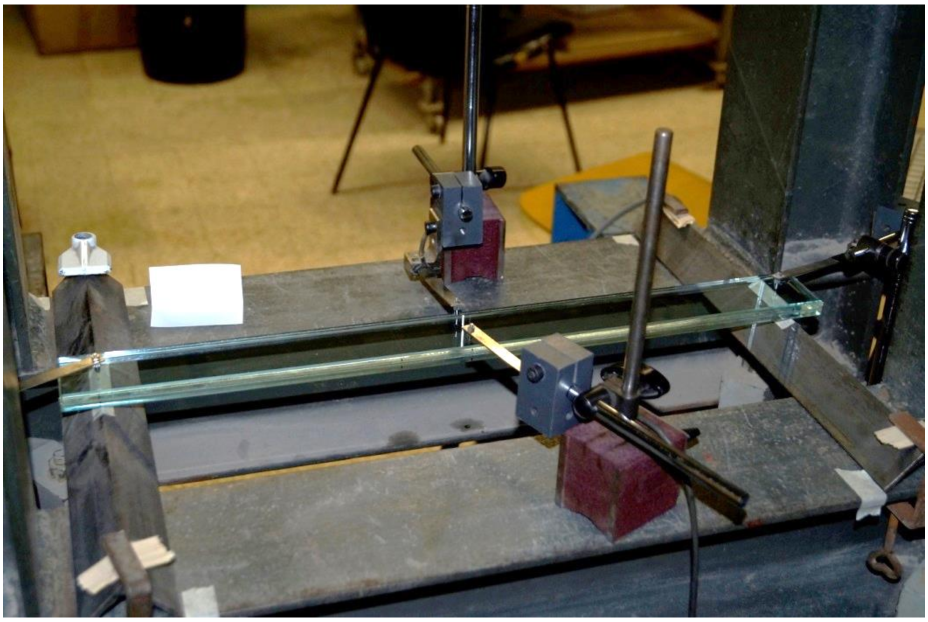

Fig. 4 Specimen B 02 during the recovery phase of test number 3.

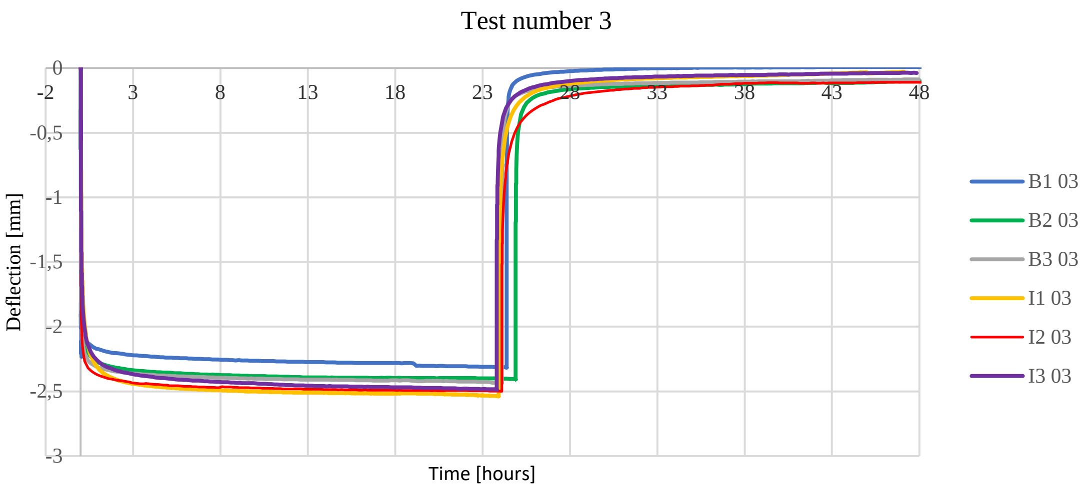

Fig. 5 Deflection versus time diagram for the six specimens tested; test number 3.

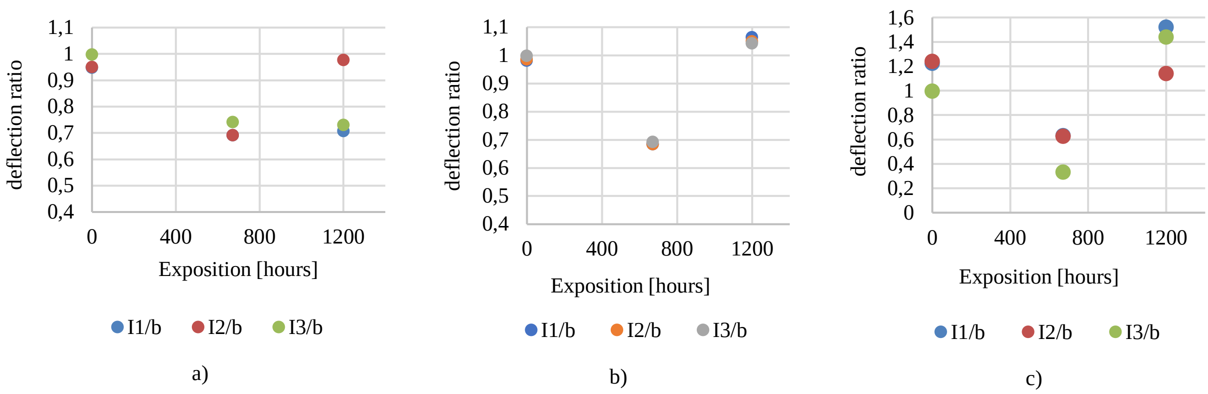

Fig. 6 Ratio between deflection of I1 I2 I3 specimens and average deflection of specimens B as a function of exposition time to UV radiation: a) elastic share of deflection; b) total deflection; c) delayed deflection.

Acknowledgements

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