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FLEXURAL BEHAVIOR OF LAMINATED GLASS BEAMS WITH T CROSS-SECTIONS

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Key words: Laminated glass, Glass beams, flexure, Buckling

Abstract. *This paper examines the behavior in flexure of glass beams having rectangular and tee (T) transverse cross-sections. Results of flexural testes on beams with rectangular cross-sections tested along the weakest and the stronger axis and object of previous studies of the authors [1-3] are here briefly presented and discussed. Detailed experimental program in progress referring to flexural test of glass beams with T transverse cross-section is here presented. The work highlights the issues recurring in the design of glass beams in rapid diffusion in the transparent architecture such as: - flexural and torsional buckling; - connections between glass panels with steel devices; - glued connections between single panels.*

Sommario. *Questo articolo esamina il comportamento a flessione di travi in vetro avente sezione rettangolare ed a "T". I risultati delle prove di flessione sulle travi a sezione rettangolare lungo l'asse forte e lungo l'asse debole sono oggetto di un precedente studio degli autori [1-3] e sono brevemente presentati e commentati. E' presentato nel dettaglio il programma sperimentale con riferimento alle prove di flessione sulle travi in vetro con sezione a "T". Il lavoro mette in evidenza i problemi di progettazione delle travi in vetro, come ad esempio: instabilità flessio-torsionale, collegamento tra i pannelli di vetro e ancoraggi in acciaio, incollaggi tra i singoli pannelli.*

1 INTRODUCTION

Several studies were addressed to analyze the effects of the shape and of the dimension of the transverse cross-section of beams often constituted by laminated glass (LG) panels assembled together by two components based glue or epoxy resin. In some other cases rectangular [1-3] and tee (T) [3-5] cross-sections were utilized to form glass beams to be tested in flexure. Single rectangular glass panels have also to be excluded because of their slenderness that limits the load carrying capacity a T section can be utilised. However, T section is shape sensitive to torsion and could fail by buckling before reaching tensile strength of material. Therefore, as shown in Fig. 1, stiffeners could be required to reduce buckling phenomenon.

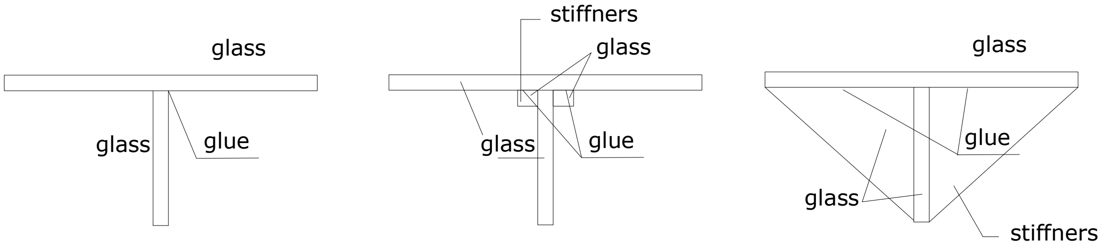

Fig. 1 – Multilayered glass panel and glued connection in T cross-sections.

One important aspect to take into account in glass columns design is the connection between two or more panels. In this case the connections transfer the forces from one element to the other. The material glass behaves elastic and, therefore, it is not able to redistribute stresses. A connection in glass members causes stress concentrations and, as a consequence, it should to be designed with great care to prevent brittle failure. Currently, techniques and products for connecting either glass-to-glass or glass to other materials are available. In the paper examined cases refer to glued connections between single panels. Therefore, tensile or compression forces are transferred by friction. It has to be stressed that the strength of a glued connection depends not only on the intrinsic strength of the bond material, but it is based also on: - bonding material (i.e. adhesive and cohesive properties); - design of the joint (e.g. geometry of the bond, governing forces to be transferred); - aspects relating to workmanship and curing. Most of the studies refer to single panels subjected to flexure or compression and only few studies refers to compressive or flexural tests on glass columns or beams with open cross-section such those having T or X cross-section. In the present paper, after a brief review of the experimental researches recently developed by the authors referring to single glass panels in flexure loaded both along the weakest and the stronger plane of inertia, an experimental research in progress on the flexural behaviour of glass beams with T transverse cross-section is presented. The target of these researches was the characterization of the instantaneous behavior of laminated glass members with T cross-section loaded from the top and from the bottom as shown in Fig. 2 to individuate the best shape and dimensions and loading configuration of the T cross-section.

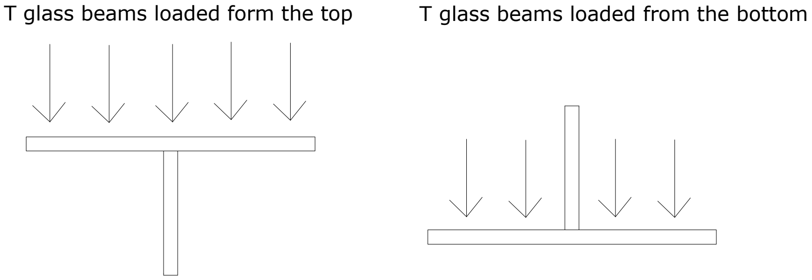

Fig. 2 - T cross-sections loaded from the top and from the bottom.

2 PREVIOUS EXPERIMENTAL RESEARCHES

In this section the results of experimental researches based on bending test on laminated glass panels are presented and briefly discussed. Researches are those of Campione et al. [2] and Campione et al. [4] and Aiello et al. [1]. These results are relative to bending tests on laminated glass panels loaded along the stronger plane of inertia and having different dimensions and composition. The first research mentioned is Campione et al. [2] in which bending tests were carried out on laminated and monolithic glass panels loaded along the maximum inertia. The material utilized for the glass beams was a multilayer composite glass having 10 mm total thickness and dimensions equal to 500x1000 mm. Glass kinds considered were: float glass, slowly annealed in temperature-controlled kiln, without residual stresses and with low mechanical features; fully tempered glass (FTG), obtained from float glass via a thermal tempering process and with enhanced strength properties; heath-strengthened glass (HSG), produced using the same process as for fully tempered glass but with a lower cooling rate and consequently with mechanical properties intermediate between the standard float glass and the fully tempered glass. Concerning the interlayer, two different chemical components were considered: polyvinyl butyral (PVB) and polycarbonate (PC). In both cases (glass + PVB and glass + PC) two glass sheets having thickness equal to 4 mm were assembled with an intermediate foil, which was 2 mm thick; in such a way a total thickness equal to 10 mm was obtained (4 + 2 + 4). Bending tests were performed using the scheme of three point bending tests. The test setup is shown in Fig. 3. Special steel clamps were adopted in the support and in the loaded sections to prevent flexural instabilities during the test. The load was transmitted by a universal displacement controlled machine, with a rate of 0.5 mm/min, while a system of bearing steel plates and cylindrical supports were adopted at the loading point and in the supports, allowing rotations and avoiding out-of-plane buckling of the panels. Fig. 3 shows the load–deflection curves for the 500x1000 mm panels tested in flexure for the different cases examined. For each typology examined, two panels were tested but, for clarity’s sake, only one result is reported. It has to be observed that the two specimens in the same series showed similar results.

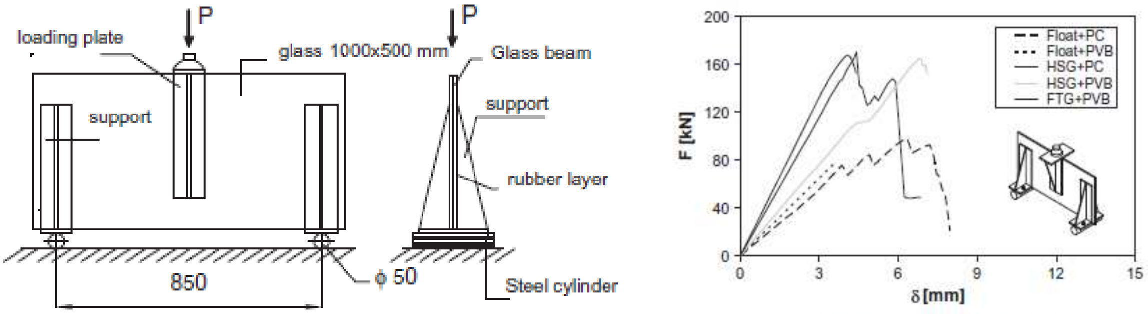

Fig. 3 - Load scheme and load deflection curves for glass beams Campione et al. [2]).

The crack patterns of the two panel types examined at failure are shown in Fig. 4 a) and Fig. 4 b). In both cases, failure occurred without any chip. In the case of float glass with PC there were fewer cracks than in the case of float glass with PVB; in general, cracks started from the bearing zone and propagated to the supports, with an "arch effect" strength mechanism.

For float glass with PVB, a wider zone of glass was included in the strength mechanism, as shown by the crack pattern experimentally obtained.

(a) Float + PC (b) Float + PVB

Fig. 4 - Cracks patterns at failure of glass beams a) PC b) PVB. (Campione et al. [2]).

The second research mentioned is Campione et al. [3]. The experimental program consisted in four-point bending tests was conducted on monolithic and laminated panels to evaluate the ultimate tensile stress of the glass and the effective level of connection between the glass foils. Specimens were manufactured with laminated glass, composed by two foils of float glass with 4 mm thickness and connected by a PVB film with a thickness equal to 0.76 mm. Two different series of specimens were considered (S and U series). The two series were manufactured from different producers, and consequently, they had different levels of connection between the glass panes, which were experimentally evaluated. The dimensions of the specimens were 300 × 100 mm, whereas the thickness was 4 mm for monolithic specimens and 9 mm for multilayer panels. Bending tests were performed adopting the configuration shown in Fig. 5.

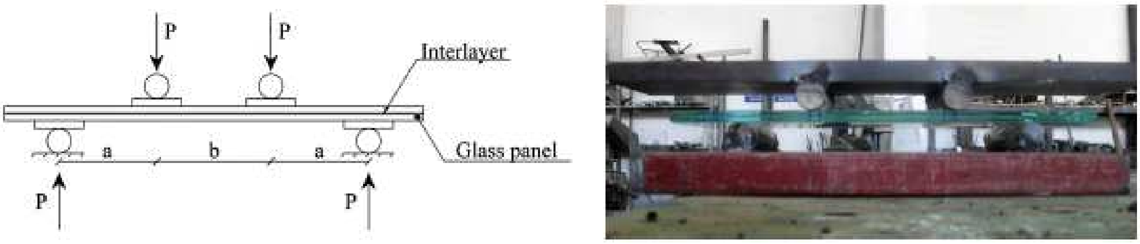

Fig. 5 - loading scheme for flexural tests (Campione et al. [3]).

A universal testing machine with a capacity of 600 kN with a rate of 1 mm/min was used to perform the tests. The machine was controlled by an electronic control unit, which was interfaced with software furnished by the producer. The top crosshead could move with a maximum velocity of 200 mm/min by means of two threaded frames with a large diameter. Furthermore, its position was controlled by a transducer. The bottom crosshead was kept fixed during the tests and it was linked to a load cell with a capacity of 600 kN. Bending tests were performed in a controlled environment with a temperature value equal to 18°C and humidity of 50%. The average ultimate stress values of monolithic glass specimens were 37.57 and 36.99 N/mm^2 for the S and U series, respectively. The values were similar, with an average stress equal to 37.28 N/mm^2, because the same kind of glass was used for manufacturing both specimen series. Figs. 6 (a, b) show the load-deflection curves relative to both monolithic and multilayer glass panels and for each series under investigation.

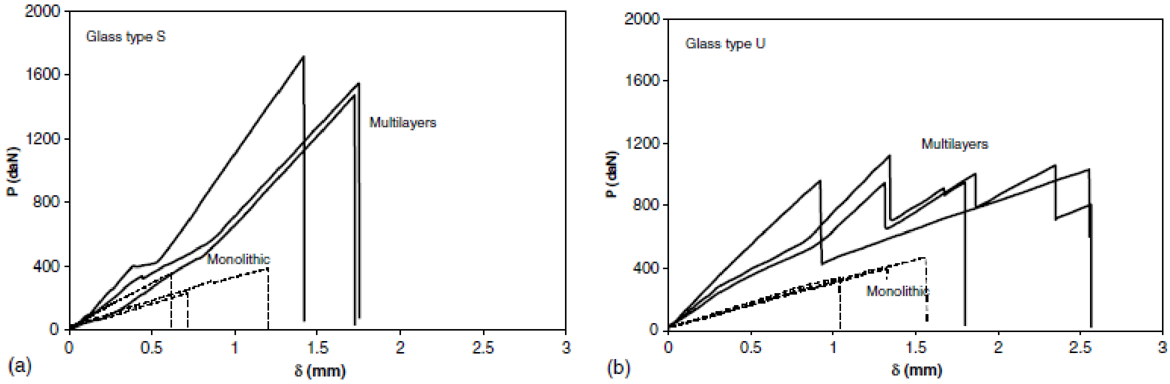

Fig. 6 - Load –delfection curves for glass types: a) S and b) U (Campione et al. [4]).

The failure load of laminated glass panels was always more than twice the failure load of monolithic specimens, highlighting the role of the connection ensured by the interlayer. If a perfect connection is ensured, the failure load of the multilayer glass panel should be approximately four times greater than that relative to monolithic specimens; if no connection is provided, it would be approximately twice. For specimens in the S series the connection level was high, and its effect could be observed in terms of both peak load and flexural stiffness. Curves were not linear from the start because of progressive cracking occurring in each glass foil. The failure modes of the glass panels under testing are shown in Fig. 7.

Fig. 7 Bending tests: a) monolithic glass specimen; b) laminated glass specimen (Campione et al. [4]).

Monolithic specimens showed brittle behavior; panels broken in two with the formation of large fragments [Fig. 7a]. A brittle but safer failure mode was observed in laminated panels [Fig. 7b]. Different cracks opened on the bottom side with the formation of little fragments that were glued to the interlayer, whereas the two glass foils remained connected even after failure. The third research mentioned is that of Aiello et al [3] which refers to laminated glass made with two 4 mm thick float glass layers bonded together with apolyvinylbutyral (PVB) layer with a thickness of 1 mm. For this study six four-point bending tests were performed for material characterization. Specifically, three 300 × 100 × 4 mm panels of float monolithic glass and three 300×100×9 mm panels of laminated glass were tested in flexure under four point bending tests loading beams along the weakest plane. Three tests were performed for each type of specimen and the respective bending-tensile strengths were deduced. Afterwards, knowing the ultimate stresses in each case, the connection level due to PVB was evaluated. The average value of the failure load for monolithic glass specimens was 37.81 MPa. In the case of multilayered panels the average value of the failure load for laminated glass specimens was 1.5 time the tensile strength of monolithic panels highlighting the importance of the PVB interlayer.

3 EXPERIMENTAL PROGRAM

On the basis of the results shown in the previous sections it emerges that the behavior of laminated multilayered glasses is better than that of the monolithic one. The load-carrying capacity of the beam loaded along the strong axis is much higher than that of glass beam loaded along the weakest axis if the phenomena of buckling are avoided by the presence of torsional stiffeners. Elements of greater importance require the formation of cross-sections in T or double T or X cross-section.

In this paper, the focus is on elements with a T section to be loaded from the top of from the bottom (see Fig. 2). From the theoretical point of view it is preferred to load beams with T cross-section for bottom loading for the following reasons: - the largest area in the tension zone where the material has a lower strength (tension strength lesser than compression one); - it is more easy to support roof panels; - the beam is more stable torsionally because the center of the section is on the bottom. In order to experimentally validate these aspects an experimental program is in progress regarding glass beams with interlayer in PVB and made of laminated glass having thickness 4-4-1.52 mm. Cross-section had T shape and dimensions of flange 200x9.52 mm and wed 200x9.52 mm and overall length 2400 mm.

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