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REVIEW ARTICLE

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EXPERIMENTAL STUDY FOR BENDING BEHAVIOUR OF LAMINATED GLASS WITH DIFFERENT TYPE OF INTERLAYER AND THICKNESS

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ABSTRACT

Laminated glass (LG) is used as windshields in automotive industry. They are also widely spread in buildings as architectural glazing. LG consists of two or more layers of glass plies adhered by an interlayer. Two soda-lime glass plies are separated by an adhesive polymer that prevents the glass plies from shattering. In this paper presents the results of experiments of three point bending test with structural laminated glass plate. For experiments laminated glass with three different interlayer thickness and two different types of interlayer material polyvinyl butyral (PVB) and ethylene vinyl acetate (EVA) are used.

INTRODUCTION

Laminated glass is a type of safety glass that holds together when shattered. In the event of breaking, it is held in place by an interlayer, typically of polyvinyl butyral (PVB), between its two or more layers of glass. The interlayer keeps the layers of glass bonded even when broken, and its high strength prevents the glass from breaking up into large sharp pieces. This produces a characteristic "spider web" cracking pattern when the impact is not enough to completely pierce the glass.

Laminated glass is normally used when there is a possibility of human impact or where the glass could fall if shattered. Skylight glazing and automobile windshields typically use laminated glass. In geographical areas requiring hurricane-resistant construction, laminated glass is often used in exterior storefronts, curtain walls and windows. The PVB interlayer also gives the glass a much higher sound insulation rating, due to the damping effect, and also blocks 99% of incoming UV radiation.

Literature review-

Serafinaviciusa et. al. [1] performed a long term laminated glass, four point bending test with PVB, EVA and SG interlayers at different temperatures they find that Sentry Glass (SG) interlayer has more load bearing ability as compared to PVB and EVA.Louter et. al. [2] performed the stability test on SG-laminated reinforced glass beam under the effects of humidity, temperature, thermal cycling, and load period and he noted that from the temperature tests it is determined that on increasing and decreasing temperature both negatively influences residual resistance of the SG laminated reinforced glass beams and it is determined that the humidity has an unpredictable but mainly slightly negative result on structural response of the SG laminated reinforced glass beams. Pyttel et. al. [3] presented a failure criterion for laminated glass in case of impact. To calibrate the criterion a wide range of experiment with curved and plain samples of laminated glass were performed. The comparison between simulated and

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measured outcomes shows that the norm works very sound.

Belis et. al.[4] experimentally investigated the failure mechanism & residual capacity of sentry glass plus (SGP) laminated beams/annealed glass at room temperature, they achieve various series of uniaxial tensile tests on SGP samples and on annealed glass beams It should be clear that also a varying serviceability temperature will affect the characteristics of SGP and therefore, also those of laminated beams made with it and the failure mechanisms observed were significantly different from those of glass/PVB beams

Xu et. al. [5] have done a experimental & macroscopic study of dynamic crack patterns in the PVB laminated glass sheets subjected to light weight impacts, they use high speed photography that carry out some impact fracture experiments to examine the crack propagation manners of the PVB laminated glass when it is exposed to light weight impacts. It is noted that the steady-state cracking speed of pure glass is higher than that of PVB laminated glass, and also increases with higher impact mass and speed.

Wang et. al. [6] developed a model based on the subsection displacement theory and the large deflection analysis is developed to describe the dynamic response of isotropic laminated circular plates impacted by a soft body. The model takes into account the interlaminar shear effect induced by the middle weak layer. It is proved that the interlaminar shear effect plays an important role in the performance of the laminate

Xu et. al. [7] experimentally studied the mechanical performance of the PVB laminated glass under quasi-static and dynamic loading. Outcomes show that the PVB laminated glass is a very strong rate dependent substance having nonlinearity in its constitutive performance under both dynamic loading and quasi-static conditions. Timmel et. al. [8] developed a finite element model for impact simulation with the laminated glass. Two different methodologies are used to model the laminated glass: a smeared model and a physical model, this statistically robust model is able to simulate qualitatively genuine fracture performance of the laminated glass and leads to good settlements with investigational results in a roof crush simulation manner.

Seshadri et. al. [9] developed an analytical model to study the post cracking reaction of the laminated glass plates for simple steady crack designs.They noted that the mechanical performance of broken laminated plates depends mainly on response of the polymer deposit that joins the broken pieces of the glass.Collombet et. al. [10] developed a model for taking into account the physics of damage events occurring during impact of composite structures Two approaches are used for modeling the damage phenomena: (1) Contact techniques and the averaging model (2) modest norms for defining damage beginning and noted that by using tools depending on the explicit finite-element dynamic codes, this method offers a means of investigating the tentative situations and to model the events which cannot be identified experimentally in real time.

Material used in research

Laminated glass with PVB interlayer-Samples of laminated glass are prepared with PVB (Polyvinyl butyral) interlayer. The glasses are prepared by two annealed glass plates with polyvinyl butyral interlayer in between. The interlayer thickness in the laminated glass are-5mm+0.38mm+5mm, 5mm+0.76mm+5mmand

5mm+1.52mm+5mm,fig no-1 shows upper and lower glass plate with interlayer.

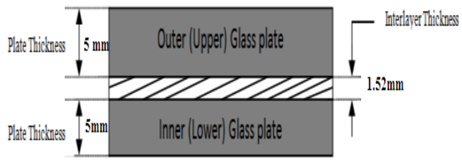


Fig No-1 Upper & lower glass plate

Fig No-2 View of laminated glass plate

In the research work total 30 laminated glass samples were tested with two different types of interlayer and three different types of thickness of each type of interlayer i:e 0.38mm 0.76mm and 1.52mm.Sample of laminated glass plate is shown in fig no-2

PVB-(Poly vinyl butyral)-Poly[(2-propyl-1,3-dioxane-4,6-diyl)methylene].Molecular formula $(C_8H_{14}O_2)_n$. Non chlorinated vinyl was invented in 1930's and is formed by reaction of polyvinyl alcohol with butyraldehyde with further is conducted under heat and pressure. Manufacturing of laminated safety glass panels is one of the main PVB appliances in attempts to achieve strong binding between glasses, optical clarity, toughness and flexibility. Furthermore, PVB has excellent adhesion with many materials such as glass. As well PVB is widely used as a film sandwiched in a safety glass.

EVA- (Ethylene vinyl acetate) The copolymer consisting of ethylene and vinyl acetate monomers. The material possesses the characteristics of high tensile strength, excellent transparency, sufficient cohesion, low-temperature toughness, stress-crack resistance, hot-melt adhesive, water proof properties and resistance to UV radiation that allows it to use in the photovoltaic industry as an encapsulation material for silicon cells. One of the major applications of EVA film is making laminated glass panels requiring safety and also moisture and UV radiation resistance. This lamination film is especially used for decorative glasses when some painted pictures or pattern should be put on it. EVA can be used as a substitute in many applications.

TEST METHOD

Three-Point Bend Testing: The bend test is a simple and inexpensive qualitative test that can be used to evaluate both the ductility of a material. The three point bending test is widely used to characterize mechanical behavior of materials. It provides values for the flexural modulus, flexural stress and flexural strain of the material. It is often used as a quality control test having the advantage of simplicity of both the test piece and equipment. The bend test uses a sample that is bent in three point bending. The test is carried out in accordance with ASTM D790-03. A small beam of rectangular cross section is placed on two supports. A force is applied at its center and the resulting displacement is recorded. Flexural modulus is used as an indication of a material's stiffness when flexed. Since the physical properties of many materials (especially thermoplastics) can vary depending on ambient temperature, it is sometimes appropriate to test materials at temperatures that simulate the intended end user environment.

The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the sample. These parameters are based on the test specimen thickness and are defined differently by ASTM and ISO. For ASTM D790-03, the test is stopped when the specimen reaches 5% deflection or the specimen breaks before 5% of deflection. For ISO-178, the test is stopped when the specimen breaks. If the specimen does not break, the test is continued as far as possible and the stress at 3.5% (conventional deflection) is reported. A variety of specimen shapes can be used for this test, but the most commonly used specimen size for ASTM D790-03 is 3.2 mm x 12.7 mm x 125 mm (0.125" x 0.5" x 5.0") and for ISO-178 it is 10 mm x 4 mm x 80 mm. Flexural stress at yield, flexural strain at yield, flexural stress at break, flexural strain at break, flexural stress at 3.5% (ISO) or 5.0% (ASTM) deflection, flexural modulus. Stress/Strain curves and raw data can be obtained from this test.fig no-3 shows simple three point bending set up.

Fig No-3 Three-point bending test

Conduction of 3-point bending test- The 3-point bending test on laminated glass is conducted at MNNIT Allahabad on a Q set software bending test machine shows in fig no-4

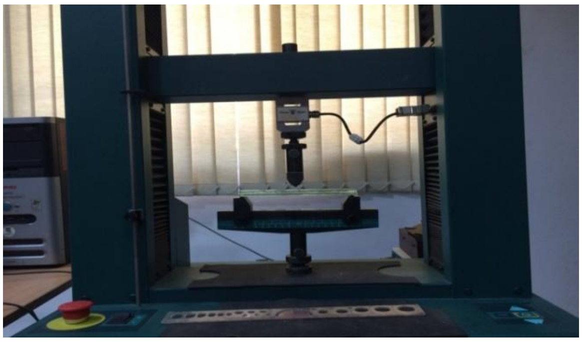


Fig No-4 Q-set bending test machine

RESULTS

a- Results of 3-point bending test with interlayer thickness of 0.38mm(PVB)-

The three point bending tests were performed on a laminated glass plate shown in fig no-5,5-Test specimen were produced with two 5mm thick annealed glass Both the glass are laminated each to other with PVB (Polyvinyl butyral) interlayer of 0.38mm.3-point bending test is carried out as per ASTM D790-03 and the deflections were measured. A laminated glass plate after test is shown in fig no-6.

Fig No-5 View of laminated glass sample

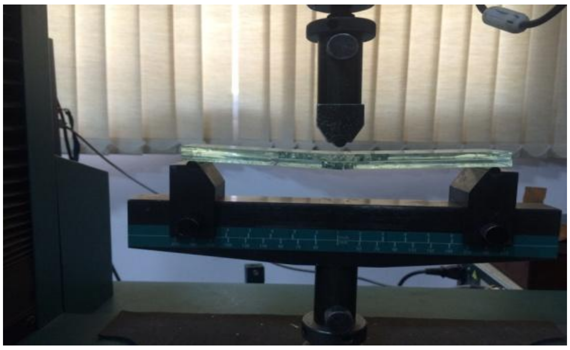


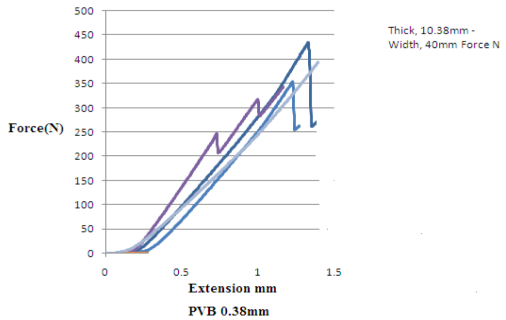
Fig No-6 View of laminated glass after test

Graph no-1 shows the deflection in mm in a laminated glass plate of PVB interlayer with 0.38mm thickness in a laminated glass plate of PVB0.38mm we observed a max load of 434N with a deflection of 1.4mm and min load of 344.4N with a deflection of 1.5mm as shown in table no-1, fig no-7 shows laminated glass samples after test. In the laminated glass plate the crack generated across the width of the specimen, all the cracks occur near the mid span region. It is seen that the crack pattern on the two glass plate are nearly overlapped as shown in fig no-7

Table No-1

Laminated glass(PVB) with interlayer thickness 0.38mm			
Samples	Total Thickness	Max load(N)	Deflection (mm)
1.	10.38mm	434	1.4
2.	10.38mm	430	1.39
3.	10.38mm	354.8	1.3
4.	10.38mm	344.4	1.5
5.	10.38mm	394.4	1.16

Graph-



Graph No-1 Force vs Extension

Fig No-7 PVB (0.38mm) Glass samples after test

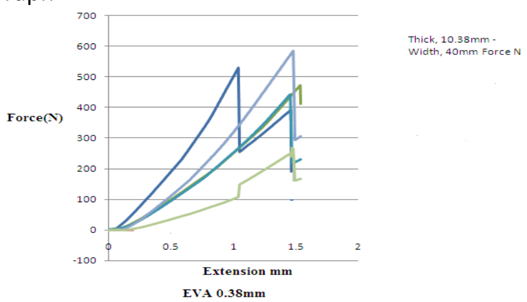
b- Results of 3-point bending test with interlayer thickness of 0.38mm(EVA)

The three point bending tests were performed on a laminated glass plate. Test specimen were produced with two 5mm thick annealed glass, both the glass are laminated each to other with EVA (Ethylene vinyl acetate) interlayer of 0.38mm.3-point bending test is carried out as per ASTM D790-03 and the deflections were measured.

Table No-2

Laminated glass(EVA) with interlayer thickness 0.38mm			
Samples	Total Thickness	Max load(N)	Deflection (mm)
1.	10.38mm	531	1.46
2.	10.38mm	473	1.14
3.	10.38mm	442	1.11
4.	10.38mm	585	1.27
5.	10.38mm	531	1.06

Graph-



Graph No-2 Force vs Extension

Fig No-8 EVA(0.38mm) Glass samples after test

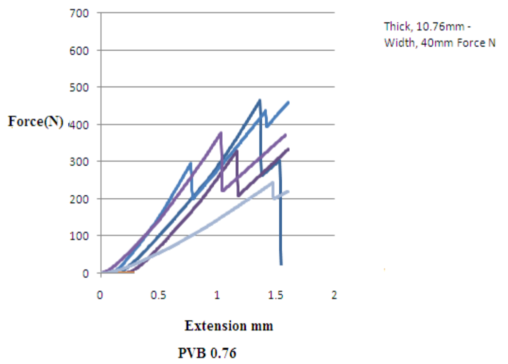
Graph no-2 shows the deflection in mm in a laminated glass plate of EVA interlayer with 0.38mm thickness in a laminated glass plate of EVA0.38mm we observed a max load of 585N with a deflection of 1.27mm and min load of 442N with a deflection of 1.1mm as shown in table no-2 and fig no-8 shows laminated glass samples after test in the laminated glass plate the crack is initially generated in the lower glass plate and travelled across the width of the glass plate and as the load increased fracture similar to the initial fracture occurred in the lower glass plate at various point and on further loading the fractures occurs on the top laminated glass plates at various points and travels across the width as shown in fig no-8

c- Results of 3-point bending test with interlayer thickness of 0.76mm(PVB)

The three point bending tests were performed on a laminated glass plate.5-Test specimen were produced with two 5mm thick annealed glass, both the glass are laminated each to other with PVB (Polyvinyl butyral) interlayer of 0.76mm.3-point bending test is carried out as per ASTM D790-03 and the deflections were measured, Graph no-3 shows the deflection in mm in a laminated glass plate of PVB interlayer with 0.76mm thickness in a laminated glass plate of PVB 0.76mm we observed a max load of 464.5N with a deflection of 1.53mm and min load of 261 with a deflection of 1mm as shown in table no-3 and fig no-9 shows laminated glass samples after test in the laminated glass plate it is observed that the first crack was not generated at the middle of the laminated glass plate where actual loading was done but it was generated near to that point and when the load is increased the cracks similar to the first crack also generated at mid point as shown in fig no-9

Table No-3

Laminated glass(PVB) with interlayer thickness 0.76mm			
Samples	Total Thickness	Max load(N)	Deflection (mm)
1.	10.76mm	464.5	1.53
2.	10.76mm	383	1.7
3.	10.76mm	430	1.78
4.	10.76mm	372	1.58
5.	10.76mm	261	1



Graph No-3 Force vs Extension

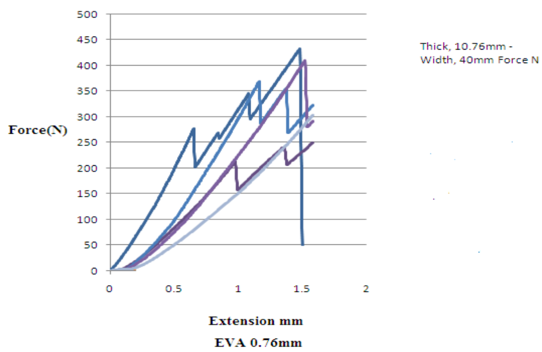
Fig No-9 PVB (0.76mm) Glass samples after test

d- Results of 3-point bending test with interlayer thickness of 0.76mm(EVA)

The three point bending tests were performed on a laminated glass plate.5-Test specimen were produced with two 5mm thick annealed glass, both the glass are laminated each to other with EVA (Ethylene vinyl acetate) interlayer of 0.76mm.3-point bending test is carried out as per ASTM D790-03 and the deflections were measured

Table No-4

Laminated glass(EVA) with interlayer thickness 0.76mm			
Samples	Total Thickness	Max load(N)	Deflection (mm)
1.	10.76mm	433	1.58
2.	10.76mm	276	1.16
3.	10.76mm	435.5	1.489
4.	10.76mm	309.5	1.03
5.	10.76mm	331	1



Graph No-4 Force vs Extension

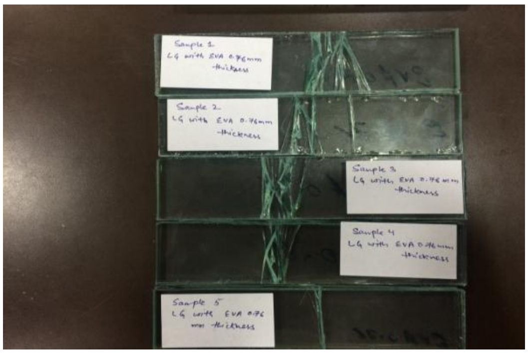
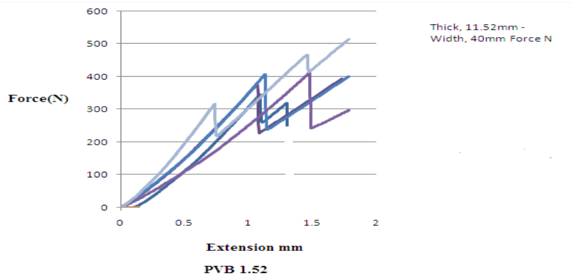


Fig No-10 EVA (0.76mm) Glass samples after test

Graph no-4 shows the deflection in mm in a laminated glass plate of EVA interlayer with 0.76mm thickness in a laminated glass plate of EVA 0.76mm we observed a max load of 435.5N with a deflection of 1.489mm and min load of 276 with a deflection of 1.1mm as shown in table no-4 and fig no-10 shows laminated glass samples after test in the laminated glass plate the crack is initially generated in the lower glass plate and travelled across the width of the glass plate and as the load increased fracture similar to the initial fracture occurred in the lower glass plate at various point and on further loading the fractures occurs on the top laminated glass plates at various points and travels across the width. In the glass plates of EVA 0.76mm we seen that in two glass samples the cracks were not generated on the mid span region were actual loading was done but it was generated near the mid span as shown in fig no-10

e- Results of 3-point bending test with interlayer thickness of 1.52 mm (PVB)

The three point bending tests were performed on a laminated glass plate. Test specimen were produced with two 5mm thick annealed glass, both the glass are laminated each to other with PVB (Polyvinyl butyral) interlayer of 1.52mm.3-point bending test is carried out as per ASTM D790-03 and the deflections were measured.



Graph No-5 Force vs Extension

Table No-5

Laminated glass(PVB) with interlayer thickness 1.52mm			
Samples	Total Thickness	Max load(N)	Deflection (mm)
1.	11.52mm	345.2	1.6
2.	11.52mm	394.8	1.73
3.	11.52mm	425	1.88
4.	11.52mm	323.5	1.44
5.	11.52mm	567.75	2.1

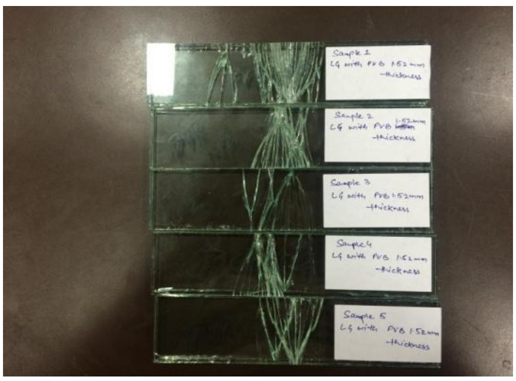


Fig No-11 PVB (1.52) Glass samples after test

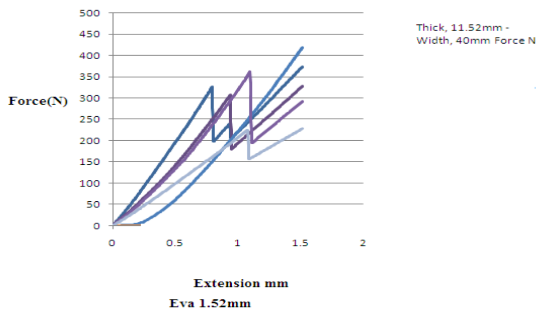
Graph no-5 shows the deflection in mm in a laminated glass plate of PVB interlayer with 1.52mm thickness in a laminated glass plate of PVB 1.52mm we observed a max load of 567.75N with a deflection of 2.1mm and min load of 323.5 with a deflection of 1.4mm as shown in table no-5 and fig no-11 shows laminated glass samples after test In the laminated glass plate the crack generated across the width of the specimen, all the cracks occur near the mid span region. It is seen that the crack pattern on the two glass plate are nearly overlapped as shown in fig no-11

f- Results of 3-point bending test with interlayer thickness of 1.52 mm (EVA)

The three point bending tests were performed on a laminated glass plate.5-Test specimen were produced with two 5mm thick annealed glass ,both the glass are laminated each to other with EVA (Ethylene vinyl acetate) interlayer of 1.52mm.3-point bending test is carried out as per ASTM D790-03 and the deflections were measured

Table No-6

Laminated glass(EVA) with interlayer thickness 1.52mm			
Samples	Total Thickness	Max load(N)	Deflection (mm)
1.	11.52mm	374.4	1.51
2.	11.52mm	378	1.27
3.	11.52mm	314	1.16
4.	11.52mm	345.6	1.29
5.	11.52mm	300	1



Graph No-6 Force vs Extension

Graph no-6 shows the deflection in mm in a laminated glass plate of EVA interlayer with 1.52mm thickness in a laminated glass plate of EVA1.52mm we observed a max load of 378 N with a deflection of 1.27mm and min load of 300 with a deflection of 1mm as shown in table no-12 and fig no-12 shows laminated glass samples after test in the laminated glass plate the crack is initially generated in the lower glass plate and travelled across the width of the glass plate and as the load increased fracture similar to the initial fracture occurred in the lower glass plate at various point and on further loading the fractures occurs on the top laminated glass plates at various points and travels across the width. In the glass plates of EVA 1.52mm we seen that in two glass samples the cracks were generated on the mid span region were actual loading was done and also near the right corner of laminated glass plate as shown in fig no-12

Fig No-12 EVA (1.52) Glass samples after test

Conclusion

The highest values of middle span deflection are obtained with a PVB laminated glass plates**.** Type of interlayer and thickness of interlayer plays an important role in increasing the strength of laminated glass**.** During the test it is observed that the crack initially generated in the lower glass plate**.** It is observed that the first crack was not generated at the middle of the laminated glass plate where actual loading was done but it was generate near to that point**.** It is seen that the crack patterns on two glass plates are nearly overlapped**.** In all the laminated glass samples the first crack was generated in the lower glass plate and on increased loading fracture similar to lower glass plate occurs in the upper glass plate .The analytical model and the simulation technique can be useful tools for the design of laminated glass structures. The fracture strength of the glass used in the glass ply of the laminate combined with the knowledge of the loading conditions can be used along with a model for the description of glass fracture to determine the failure probability at various locations in the glass ply. Nevertheless, modeling LG used for primarily structures presents several challenges, since glass-PVB laminates respond in a complex manner due to the large mismatch in stiffness, strength, and thickness of glass and polymer, the additional stiffening and strength effects of the polymer, effects of interface, and polymer visco elasticity, including temperature and loading rate

REFRENCES

[1]. Tomas Serafinaviciusa, Jean-Paul Lebeta, Christian Loutera, Tomas Lenkimasc, Artiomas Kuranovas on Long-term laminated glass four point bending test with PVB, EVA and SG interlayers at different temperatures published by Elsevier in Procedia Engineering 57 (2013)

[2]. Christian Louter, Jan Belis, Frederic Veer, Jean-Paul Lebet on Durability of SG-laminated reinforced glass beams: Effects of temperature, thermal cycling, humidity and load-duration published by Construction and Building Materials 27 (2012)

[3]. T. Pyttel, H. Liebertz, J. Cai on Failure criterion for laminated glass under impact loading and its application in finite element simulation published by Elsevier in International Journal of Impact Engineering 38 (2011)

[4]. J. Belis, J. Depauw, D. Callewaert, D. Delince, R. Van Impe on Failure mechanisms and residual capacity of annealed glass/SGP laminated beams at room temperature published by Elsevier in Engineering Failure Analysis 16 (2009)

[5]. Jun Xu Yueting Sun, Bohan Liu, Mengyi Zhu, Xuefeng Yao, Yuan Yan,Yibing Li, Xi Chen on Experimental and macroscopic investigation of dynamic crack patterns in PVB laminated glass sheets subject to light-weight impact published by Elsevier in Engineering Failure Analysis 18 (2011)

[6]. Dong fang Wang, Jialing Yang and Yux in Sun on INFLUENCE OF THE MIDDLE WEAK

LAYER ON THE IMPACT BEHAVIOR OF LAMINATED STRUCTURES Published by AMSS Press, Wuhan, China Acta Mechanica Solida Sinica, Vol. 26, No. 3, June, 2013

[7]. Jun Xu, Yibing Li, Bohan Liu, Mengyi Zhu, Dongyun Ge On Experimental study on mechanical behavior of PVB laminated glass under quasi-static and dynamic loadings published by Elsevier in Composites: Part B 42 (2011)

[8]. M. Timmel, S. Kolling, P. Osterrieder, and P.A. Du Bois on A finite element model for impact simulation with laminated glass published by International Journal of Impact Engineering 34 (2007)

[9]. M. Seshadri, S.J. Bennison, A. Jagota,and S. Saigal on Mechanical response of cracked laminated plates published by Acta Materialia 50 (2002) www.actamat-journals.com

[10]. F. Collombet, X. Lalbin & J. L. Lataillade on IMPACT BEHAVIOR OF LAMINATED COMPOSITES: PHYSICAL BASIS FOR FINITE ELEMENT ANALYSIS published by Composites Science and Technology 58 (1998) Elsevier Science Ltd