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COMPREHENSIVE REVIEW OVER THE TESTING PROCEDURES, MATHEMATICAL AND SOFTWARE SIMULATION FOR THE ANALYSIS OF LAMINATED GLASS

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ABSTRACT

About $75 billion annual revenue is generated by global glass industry. Laminated glass has got a lot many proportions in it. In spite of increased use of the laminated glass (two monolithic layers of glass fused with an elastomeric interlayer—usually PVB to form a unit) as a structural material, facing material for architectural glazing applications, transparent insulating material for automobiles, material for wind shield, the structural capabilities and the mechanical properties of PVB laminated glass are not well recognized. Laminated glass has abundant potential of development and laminated glass industry has need of more responsiveness. This paper comprises of thorough review with inferences and further recommendations of about two hundred research articles and patents in the discipline of laminated glass. This research work aims at complete understanding of details of the laminated glass, data collection instruments, find a lack of consistency in reported results across the studies, identify gaps in the literature, flaw in previous research based on its design, interpretation and sampling.

Keywords: Laminated Glass, PVB, Wind Shield.

I. INTRODUCTION

Laminated glass is widely used for construction purposes and in automotive industry. Due to presence of Polyvinyl Butyral (PVB) even on applying impact force that could break the glass, no sharp-edged pieces are formed that might cause injury to nearby human beings. Wherever there may be an injury risk around, this important functionality of laminated glass forced the designers to use it. Due to being separated with PVB, it does not allow the ultraviolet radiation (UV) to penetrate. Also use of laminated glass dampens noise. All such significant purposeful and the architectural properties that are not stated above makes laminated glass suitable for use. The value of glass increases due to the use of glass in production of laminated glass. For Turkey, as being one of the biggest glass manufacturer country with numerous industrial plants committed for glass fabrication and employing many workers this is very important. Laminated glass contains two layers of glass and one layer of visco elastic polymer PVB film. Between two layers of glass one layer of PVB is sandwiched

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under pressure and heat. Sandwiched interlayer increases mechanical properties of the laminated glass up to a great extent. Firstly the area of impact increases which increases impact resistance. As specified earlier, interlayer keeps the broken pieces together that may rarely lead to dangerous accidents or incidents. When compared with monolithic glass structure, the laminated glass dampens more energy of impact. When the direction of projected resistance is taken in to consideration curved structure has more advantages compared with a straight beam. Curved beam resists more forces coming from outside particularly on an automobile glass. PVB aims at determining the mechanical properties of the laminated glass beams on different temperatures. The transition temperature of PVB produces a desired result on mechanical properties. PVB tends to become viscous when transition temperature exceeds. Jan Belis et al have done a research work on Experimental and analytical assessment of lateral torsional buckling of the laminated glass beams, he analytically investigated the effects of various geometrical and mechanical properties on typical lateral torsional buckling response of the laminated glass beams and stated that, type of glass is an significant feature that should be prudently taken into account. In his work due to its limited tensile strength the annealed glass samples cracked prematurely, subsequently based on few available test outcomes experimental load–displacement paths can easily be predicted with high accuracy using equivalent thickness analytical approaches.

J.O. Aguilar et al[2] have completed a research work on mechanical and optical properties of rich and solar control laminated glass in which he used thin layers of zinc sulphide and copper sulphide and further stated that the adhesion strength of laminated glass by about 20% is improved due to the presence of a layer of thin film (40–80 nm) of zinc sulphide which is applied on 2mm thick sheet of glass by chemical bath deposition. The optical transmission of laminated glass with thin film of zinc sulphide in visible region is approximately 80% basically the same as that of a simple glass (say PVB–glass laminate). The adding of 100–150 nm thin film of copper sulphide above the coating of zinc sulphide deliberates solar radiation control characteristics to the glass laminate such as visible transmission of 22% to 40% and very low transmission with the adhesion strength which is continued at 12–14 MPa that is beyond that of simple glass (say PVB–glass laminates).

Mahesh S. Shetty et al[3] have completed a research work on Failure possibility of laminated architectural glazing and window glazing due to collective loading of wreckage impact and wind. Finite element code ABAQUS is used for stress analysis, he detected that at higher impact velocities for both small, and large missiles of rounded end alignment, the failure possibility of aged glass panels is higher than that of new glass panels and, also the thickness ratio of outer to inner glass plies is significant for the small missile impact while it has no significance for large missile impact when glass thickness is kept constant.

Gianni Royer-Carfagni and Laura Galuppi[4] have done a research work on the Laminated beams using viscoelastic interlayer rationally to solve the time-dependent problems of a simply supported laminated beam, which is composed of the two elastic coatings joined by a viscoelastic interlayer, whose reaction is demonstrated by a Prony's series of Maxwell element, further achieved outcomes are deep-rooted by a complete 3D viscoelastic finite element mathematical study, which highlighted that there is a praiseworthy variance among the state of stress and strain which is calculated in case of the full viscoelastic or in the above mentioned ''equivalent'' elastic problem.

Christian Louter et al[5] have done a research work on Stability of SG-laminated reinforced glass beam: Effects of humidity, temperature, thermal cycling, and load period. During the study he examines the stability of the structural glass beams which are composed of the stainless steel reinforcement, annealed glass, and SG (Sentry

Glass) interlayer pieces. For this a series of pull-out tests and a series of bending tests have been done at various temperatures, after humidity exposure, after thermal cycling, and for long time loading 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. From humidity exposure investigations, it is determined that the humidity has an unpredictable but mainly slightly negative result on structural response of the SG laminated reinforced glass beams. From the long period loading checks, it is determined that the examined SG laminated reinforced glass beam provides outstanding post-fracture resistance for some important periods of time.

T. Pyttel et al[6] have done a research work on failure benchmark for the laminated glass in instance of impact. The main idea of this norm is that a perilous energy threshold should be reached during a finite expanse before failure can take place. Subsequently crack beginning and enhancement is established on a local Rankine (maximum stress) norm, to standardize the norm and estimate its precision, various tests with curved and plain samples of laminated glass were performed. The comparison between simulated and measured outcomes shows that the norm works very sound.

J. Belis et al[7] have done a research work on Failure mechanism & residual capacity of SGP laminated beams/annealed glass at room temperature, they achieve various series of uniaxial tensile tests on SGP samples and on annealed glass beams, in-plane four-point bending tests have been performed to estimate their failure mechanism and the post-fracture mechanical behavior at room temperature and set up that the residual load bearing ability of glass/SGP laminated beams might be considerably unlike in instance when fully tempered or heat strengthened glass is used. Much denser crack pattern is the main reason for this, which allows the interlayer to distort at various locations at the same time, keeping local stresses beneath the failure level. 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.

Jun Xu et al[8] have done a research work on 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.

Dong fang Wang et al[9] has done research work on Influence of middle weak layer on the impact behavior of the laminated structure. In his study, to define the dynamic response of an isotropic laminated circular plate which is impacted by a soft body, a calculation model based on minimum acceleration principle is established. The model holds good for the interlaminar shear effect that is induced by the middle weak layer and the difference between the model that is developed in this paper and that based on classical laminated theory generally be determined by three factors which are:, the radius of circular plate, the impact force and the elastic modulus of the glue.

Jun Xu et al [10] have done a research work on the mechanical performance of the PVB laminated glass under dynamic loadings and quasi-static, both of them uses dynamic Split Hopkinson Pressure Bar (SHPB) compression and quasi-static compression tests under various strain/loading rates to examine mechanical performance of the PVB laminated glass and 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. In MFO, stress and strain both will increase in higher strain rates in dynamic loading, however in quasi-static circumstances, main failure onset (MFO) strain increases with the loading rate while MFO stress remains constant.

M. Timmel et al[11] have done a research work on the finite element model for impact simulation with the laminated glass finite elements which are used to model layered setup of the laminated glass: Membrane elements to simulate ultimate load carrying capacity and shell elements with the brittle failure for glass components of PVB-interlayer. Two different methodologies are used to model the laminated glass: a smeared model and a physical model, this statistically stout 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.

M. Seshadri et al[12] have done a research work on Mechanical response of the cracked laminated plates. In this conduct, elastomer layer is characterized by an analytical connecting model, calibrated and validated through experimentations. An analytical model is developed to study the post cracking reaction of the laminated glass plates for simple steady crack designs.This model forecasts the yielding performance of cracked laminated plates as a function of the elastic and thickness properties of elastomer layer, adhesive strength and the size of wreckages and the number of the plate depending on the connecting performance of the elastomeric ligament, a bridging/interface finite element has been conveyed for the numerical models of broken laminates. 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.

F. Collombet et al[13] have done a research work on the impact behavior of the laminated mixtures. A clear finite element code is cast-off to model dynamic properties of impact loading. 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.

Nabil M et al[14] have done a research work on the thermal degradation of poly(viny1 butyral) laminated protection glass effect of heat treatment on chemical structure of the plasticized poly(viny1 butyral) (PVB) laminated protection glass was examined in the temperature range from 50 to 200°C which used viscosity measurements and infra-red spectroscopy. The infra-red spectra displayed a large decrease in both the residual hydroxyl & acetate groups which are present in the PVB and composed with the whole disappearance of the cyclic acetal group.

P.A. Hooper et al[15] have done a research work on Blast resistance of the laminated glass. Blast loads were created using charge masses of 15 kg & 30 kg (TNT equivalent) at distances of approximately 10m to 16 m. Deflection and measurements/shape of distorting laminated glass were found using high speed digital image correlation. Between the frame and laminated glass measurements of loading at the joint were achieved using strain gauges in their learning shifts before failure of about 200 mm were noted. At the center of the pane peak, observed velocities and accelerations ranged from about 17 m/s - 31 m/s and 3 km/s^2 - 6 km/s^2 respectively. Strain in the fractured laminated glass was detected to reach the values of about 15% without tearing for a 1.5 mm interlayer.

Paolo Foraboschi has[16] done a research work on Analytical model for the laminated glass plates. In his research the performance of LG plate is replicated by a system of three systematic thorough (explicit) equations. Consequently it is both explicit and analytical, the model permits one to increase a superior understanding of the mechanical performance of the laminated glass plate.

Salvatore Aiello et al[17] have done a research on Compressive performance of the laminated structural glass members. In his study, the outcomes of twelve compressive experiments on glass column and panels are obtained. The key variables measured were fineness of the panels and shape and size of the cross-section of columns. The collapsing strength of the panels depends very much on the fineness restricting the fineness ratio in the glass columns did not make it possible to avoid quasi brittle breakdown. Definitely, local clasping takes place due to the low width of the projections that makes up the column.

J. Zangenberg et al[18] have done a research work on embedded adhesive joining for laminated glass plates. In his study, the structural performance of new linking strategy, the rooted adhesive joining used for laminated glass plates is examined. The joining shows auspicious potential as a upcoming clasp system for load transmitting laminated glass plates.

C. Amadio and C. Bedon[19] have done a research work on Clasping of laminated glass elements in out-of-level bending the load behavior ability of laminated glass beams in out-of-level bending is examined through a simple investigative model established according to Newmark's theory, concerning the flexural comeback of composite beams with deformable assembly. In this it was revealed that how load conditions, temperature variations, initial imperfections and additional external loads diminish the clasping resistance of LG beams that involves more distortions and putting forward their clasping breakage.

Chiara Bedon and Claudio Amadio[20] have done a research work on Buckling of the flat laminated glass panels in plane compression or shear. In their work, a systematic creation is projected for the approximation of the clasping resistance of the flat laminated glass panels under in plane compression or shear. Two dissimilar design tactics are compared: first one openly arises from the philosophy of sandwich panels while second one depends on the estimated theory of corresponding thickness and they catches that since of high fineness, the LG panels exposed to in-plane compression or shear can be affected by firmness difficulties.

Luigi Biolzi et al[21] have done a research work on progressive destruction and breakage of the laminated glass beams. In their work, a three-point bending examinations are obtained on the laminated glass samples which are completed with two outside equal tempered glass panels and an inside float glass.The laminated glass samples of same cross section were considered by three various mixtures of fully thermally tempered glass plies and annealed float.Also, two groups of samples were built with two varying interlayers that have meaningfully different mechanical characteristics. The gradual breakage sensed for the SGP beams/laminated glass is considerably different than what has been noted for the PVB beams / laminated glass.

Yao Koutsawa El Mostafa[22] Daya has done a research work on Static and free vibration study of the laminated glass beams on viscoelastic supports. For the stationary case, a logical way is settled for evaluating and optimization of the laminated glass beams with general limitations at the borders. In case of the free linear vibrations, modal possessions of the glass are steadfast by using a finite element process and they found that the corresponding stiffness demonstration of the viscoelastic boundary provisions lead in the static domain to two coupled linear differential equations that involve axial displacements and lateral displacement for the study of laminated glass beams.

Ivelin and Ivanov[23] have done a research work on Analysis, optimization and modeling of the laminated glasses as plane beam. In their study, a simply supported glass or polyvinyl butyral (PVB/glass beam) is shown by plane finite elements. Their study displays that the bending stress in glass layers is the determining factor for load bearing ability of the laminated glasses but the shear in PVB interlayer plays an key role for glass layer contact and the study illustrates that the simple bending concept is related to the single glass layer with accompanying by differential equations that describes the layer interface in their bending which is caused by shear of the PVB interlayer.

Christian Louter et al[24] have done a research work on Structural response of the SG laminated strengthened glass beams: investigational inquiries on the effects of beam size, reinforcement percentage and glass type. In their study, they investigated the special effects of glass type (fully tempered, heat-strengthened and annealed), reinforcement quantity (full section and hollow section) and also beam size (about 1.5 to 3.2 m) on the structural sense of the SG laminated protected glass beams. It is done by bending tests on 8 different series of beam samples and they found that the applied glass type has an important consequence on both the preliminary failure strength: due to a difference in superficial strength of the glass types (the post breakage performance) & due to a difference in fracture pattern of the glass types of the reinforced glass beams.

Mehmet Zulfu Asik and Selim Tezcan[25] have done a research work on accurate model for the performance of the laminated glass beams. In their study, a scientific model for behavior of the laminated glass beams is presented. The least total potential energy norm is used in evolving the precise model, they found that the laminated glass beams having fixed end shows nonlinear performance while the simply supported beams show linear performance.

Laura Galuppi and Gianni Royer Carfagni[26] have done a research work on effective thickness of the laminated glass: Variation of the preparation in a design of the EN standards. In their study, typical examples display that this method leads to the unreliable outcomes. They found that Enhanced Effective Thickness (EET) method appears to signify a precise and great tool for the applied calculation of the laminated glass. The suggested theory is useful, because it can be useful to a package made by an arbitrary number of coatings of any thickness under the furthermost different loads and boundary condition.

K. De Belder et al[27] have done a research work on Estimation of equivalent complex modulus of the laminated glass beams and its use for sound conduction with loss expectation in their study. This technique is useful to regulate the equivalent complex modulus E (jo), with its insecurity bound of multilayer glass beams from transversal vibration experimentations in free boundary conditions. In their study, it has been displayed that, the equivalent complex modulus E(jo) of multilayer glass beams can be dignified precisely via broadband flexural vibration test for free boundary conditions.

Claudio Amadio and Chiara Bedon[28] have done a research work on buckling verification methodology for the monolithic and laminated glass elements under the combined in plane bending and compression. In their study, mathematical static incremental models are done with a finite element model that is able to forecast the buckling strength of the imperfect glass elements eccentrically compressed and are based on a large mathematical forecasts, an interaction investigative curve is projected to be used in daily practice as a balanced resistant domain for buckling verification of the glass elements.

H.D. Hidallana Gamage et al[29] have done a research work on Failure study of the laminated glass panels which are subjected to the blast loads. In the study, they granted a hard and a trustworthy analytical technique that used finite element (FE) methods to study the blast response of the laminated glass (LG) panels and forecast the failures of its components and found that, the tensile strength (T) of the glass has an important influence on behavior of LG panels. Glass panes absorb about 85% of the blast energy for the treated blast load. Glass pane absorbs maximum of the blast energy and is likely to flop during a blast making a high danger.

Zhijun Feng et al[30] have done a research work on the structure of a macro porous silica film as an interlayer of the laminated glass. In their study, a macro porous silica film (MSF) was presented as a buffer layer of material which was between a silicate glass (SG) film and a polyurethane (PU) film to form a very new aeronautic laminated glass. The structure simulation of MSF was achieved using ANSYS software and their consequences specify that pores in the MSF should be as far as through pore or the pore on MSF–PU edge. The pore would reduce the shear stress on MSF–PU interface.

Laura Galuppi et al[31] have done a research work on the practical terms for the design of the laminated glass in his work, an assessment is made with the classical method by Wolfel Bennison and they found that when load is not uniformly spread the standard Wolfel–Bennison method gives outcomes that are not safe. Better estimates can be completed with the improved effective thickness method.

Laura Galupp Gianni and Royer Carfagni [32] have done a research work on Design of the laminated glass under the time dependent loading. In their work, they logically solved the time dependent problem of the simply supported three-layered sandwich beam with a linear viscoelastic interlayer under an unloading/loading antiquity which shows that its gross comeback is strongly posh by the rheological possessions of polymer which is modeled by Wiechert Maxwell units. In their study, they found that the overall comeback of laminated glass is strongly affected by viscoelastic properties of polymeric interlayer because this is accountable of the shear coupling of glass plies, an effect that significantly effects the strength and stiffness of composite set.

Stefan H. Schulze et al[33] have done a research work on the analysis of the laminated glass beams for the photovoltaic submissions. In their study, a three layered beam with glass skins and a polymeric core is smeared as a model structure to evaluate mechanical belongings. They found that for the beams with EVA core films, the outcome of simulations agrees well with the investigational facts.

Yuki Shitanoki et al[34] have done a research work on the practical and nondestructive technique to conclude the shear relaxation modulus performance of the polymeric interlayers for the laminated glass. In their study, they used a technique which is based on the direct quantity of laminate effective thickness which used four point bend trial geometry or the uniform pressure loading of the laminate plates. In their study, they found that this new methodology to be precise over an inclusive range of the test circumstances. Also, it is established that the method is used with other the laminate test geometries, such as the uniform pressure loading of simply supported laminate sheets.

Mostafa M. El Shami et al[35] have done a research work on the stress analysis of the laminated glass with various interlayer constituents. In their study, the new advanced order finite element model using 9 nodded quadrilateral elements was applied to examine the laminated glass plates with both dissimilar interlayer materials and an investigational load testing program is defined. Two types of the interlayer materials, a steady polyvinyl butyral and strong making of polyvinyl butyral were used. In their study, they observed that the effect of interlayer material on the transferred shear between two glass plates is declining as the temperature rises for the PVB interlayer.

Laura Galuppi and Gianni F. Royer Carfagni [36] have done a research work on the effective thickness of the laminated glass beams: New manifestation via a variational method. In their study, a variational method to the problem is presented. By choosing suitable shape functions for laminated beam distortion, minimization of strain energy functional results in new terms for current thickness under any constraint and the load conditions, according to the improved approach, it presents no further difficulty with respect to traditional Wolfel Bennison formulation, but also gives much better outcomes when the beam is not simply supported and load is not uniform, especially when the interlayer is lenient.

Yong Peng et al[37] have done a research work on the finite element modeling of the crash examination performance for the windshield laminated glass. In their study, the windshield FE models were set up by using the different combinations for modeling of glass and the PVB, with numerous connection types and two mesh sizes (about 5 mm and 10 mm). In their study, they found that the G-P-T (about 5 mm mesh) model is the most precise for demonstrating the windshield model. Such a kind of laminated glass model comprises of two layers of a shell element with a tied element connection namely the shell element layer that represents the glass and membrane element layer say PVB.

Martin Larcher et al[38] have done a research work on the experimental and numerical surveys of the laminated glass subjected to blast loading. In their study, some numerical models are studied and used to simulate the failure of glass and also the interlayer. Layered shell elements with special failure conditions are efficiently engaged in the simulations. In their study, they found that the failure of PVB cannot be characterized in the smeared model. Only the performance of panel with at least one not broken glass ply can be measured.

Jingjing Chen et al[39] have done a research work on the different driving devices of in-plane cracking on the two brittle layers of the laminated glass. In their study, both the high speed photography structure and drop weight platforms are employed to examine the in-plane crack propagation performance in the laminated glass plates. It is found that the fracture of PVB laminates subjects to impact loading follows some rules: the supported glass layer would always start before the loaded layer. And the final morphologies of the radial crashes on both sides are completely overlapped even if they transmit at different time.

Wei Gao and Mengyan Zang [40] have done a research work on the simulation of the laminated glass beam impact problem by emerging fracture model of the spherical DEM. In their study, a fracture model fit to spherical discrete element method (DEM) is presented that is based on the concept of cohesive model and found that the developed code is useful to study the fracture process of the automobile laminated glass beams.

Mehmet Zulfu et al[41] have done a research work on a mathematical model for the behavior of the laminated uniformly curved glass beam. In their study, three nonlinear coupled partial differential equations that govern the true behavior are derived in the polar coordinates by applying variational and energy principles. In their study, they found that the simply supported curved laminated glass beam has higher shifts and stresses compared to the fixed one. But the difference in stresses is not large which means that the support conditions have more effect on the displacements than stresses.

Paolo Foraboschi et al[42] have done a research work on the hybrid laminated glass plate: Design and assessment. In their study, a theoretical study conducted on the products available on architectural market that include various glass structural applications. The results of the study show that the type of the interlayer material commands the operative failure mode of LG plate.

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Zemanova et al[43] have done a research work on the numerical model of the elastic laminated glass beams under finite strain. In their study, they introduced an efficient and reliable finite element method to the simulation of immediate response of the laminated glass beams. In their study, they found that the method provides outcomes with correctness comparable to the detailed 2D large strain finite element models.

M. Lopez Aenlle et al[44] have done a research work on the effective thickness concept in the laminated glass elements under static loading. In their study, equations for effective thickness of the laminated glass beams are derived from analytical model which is proposed by Koutsawa and Daya and they found that all the simulations provided like results (with error less than 1%) for the deflection and stress effective thickness of a simply supported beam under the distributed loading. With respect to the simply supported beam under the concentrated loading, the error was less than 2% for the deflection effective thickness.

Wei Xu and Mengyan Zang[45] have done a research work on four point combined FE/DE algorithm for the brittle fracture study of the laminated glass. In their study, the penalty method is applied to calculate the interface force between two sub domains, the finite element (FE) and the discrete element (DE) sub domains and they found that on comparing the impact fracture tests with the simulation results, they noticed that there are changes in the amount of the cracks of upper and lower glass, but the location of cracks and propagation paths are similar to the investigational outcomes. So the theory stated in this paper is effective to forecast some macroscopic fracture features such as the crack location and the crack transmission.

Bedon et al[46] have done a research work on assessment of the existing logical models for lateral torsional buckling analysis of the PVB and SG laminated glass beams via viscoelastic simulations and the experiments. In their study, they investigated the correctness of existing logical models in the forecast of elastic critical load and the load lateral displacement path of these elements and the comparisons showed that the analytical methods based on the concept of equivalent flexural and torsional stiffness can also be used to forecast the elastic critical load of PVB or SG laminated glass beams in well-defined temperature and under load-time conditions.

M. Overend et al [47] have done a research work on the mechanical performance of the laminated hybrid glass units. In their study, the experimental surveys on the novel laminated hybrid glass units subjected to the quasi-static out-of-plane loads and which represents the corresponding analytical models developed to describe the load–deflection response of the units, both in the fractured and post-fractured states. Investigational data showed that the laminated hybrid glass units can achieve significantly by post-fracture stiffness and their post-fracture strength can be equal or can also exceed the strength at first fracture.

Tomas Serafinaviciusa et al[48] have done a research work on the long term laminated glass, four point bending test with PVB, EVA and SG interlayers at different temperatures. In their study, they carried out four point bending tests on the laminated glass with three different types of interlayer and find that Sentry Glass (SG) interlayer has more load bearing ability as compared to PVB and EVA.

Laura Galuppi et al[49] have done a research work on the enhanced effective thickness of multi-layered laminated glass. In their study, the enhanced effective thickness method, earlier proposed for two glass layer composites is extended to the case of the laminated glass beams made (i) by the three layers of glass of arbitrary thickness, or (ii) by an arbitrary number of equally thick glass layers. The main result of this article is to provide the non trivial extension of the enhanced effective thickness (EET) method proposed in the case of multi-layered laminated glass beams. The formulae allow one to estimate the deflection and stress effective stiffness for a composite package of the three glass layers of any thickness with no particular effort.

Richard Behr et al[50] have done a research work on load duration and interlayer thickness properties on the laminated glass. In their work, the laminated glass units were subjected to a pressure of 0.2 psi for 3500 seconds with two interlayer thicknesses (0.76 and 1.52 mm) tests were performed at 22° C, 49° C, and 77° C. In their study, they found that slight reduction in stiffness in the laminated glass units having thicker interlayers, stresses increase as temperatures rise and increase in corner stress(around 20%) and center deflection(around 10%) as a function of time and load.

Paolo Foraboschi [51] has done a research work on the behavior and failure strength of laminated glass beams. In their study, a logical model that forecasts stress growth and ultimate strength of the laminated glass beams that involve a multilayered system that allows displacements in the shear flexible interlayers. The model can be applied to laminates of the arbitrary shape and size under usual uniaxial bending. No specific simplifying hypothesis is made in expressing the procedure so the modeling inexactness is low, as proved by comparing imaginary model forecasts with experiment results and they found that architectural LG may perform in a manner similar to that of monolithic glass of same nominal thickness: (1) neither under short term lateral pressure at and below the room temperature, (2) nor under long term lateral pressure representative of snow loads at temperature of 0°C, and (3) around 50°C and even under long term lateral pressure, LG behavior may not significantly alter towards the coated units.

C. V. Girija Vallabhan et al[52] have done a research work on the properties of the PVB interlayer used in laminated glass. In their study, specially made laminated glass specimens 50 mm x 50 mm x 9.5 mm with two interlayer thicknesses of 0.76 mm and 1.52 mm are tested in a direct shear box testing device and they find that the interlayer shear modulus of PVB interlayer is very dependent on the amount of the total average shear strain in the interlayer but not on its thickness.

F. W. Flocker1 and L. R. Dharan[53] have done a research work on the low velocity impact resistance of the laminated architectural glass. In their study, finite element algorithms are used to study the effect of the glass ply geometry on low velocity, small missile impact resistance of the laminated architectural glass and also in their study it is revealed that glass ply geometry can meaningfully affect impact resistance of the laminated glass. Three layer laminates are revealed to offer better impact resistance than five layer and seven layer laminates for same overall thickness. For three layer laminates of same overall thickness, those with thin outside glass plies gives better impact resistance than those with thick ones.

Richard A. Behr et al[54] have done a research work on the performance of the laminated glass units under simulated windborne debris impacts. In their study, laboratory studies have been showed to examine the resistance of various laminated glass units to inner glass ply fracture when subjected to the simulated windborne debris impacts and also in their study they found that fabricating the interlayer with a PVBIPET composite (in place of monolithic PVB) had a uncertain effect on lowering the probability of inner glass ply fracture but similar profits could probably be achieved at lower material costs by making a monolithic PVB interlayer thicker and a fully tempered inner glass ply had a somewhat lower probability of fracture due to missile impacts than that of a heat strengthened inner glass ply of the same thickness.

Lokeswarappa R. Dharani et al[55] have done a research work on the breakage forecasting of the laminated glass using the “Sacrificial Ply” Design Concept. In their study, a mechanics based logical model is established to forecast the cumulative probability of inner glass ply fracture in the laminated architectural glass subjected to simulated wind borne debris impact on the outer glass ply. A nonlinear dynamic finite element study is employed to calculate stresses in each layer of laminate due to the impact and they found that the selection of parameter n has a negligible effect on the forecast cumulative probability of inner glass ply fracture if parameter k is suitably selected.

M. L. Aenlle and F. Pelayo[56] have done a research work on the frequency response of laminated glass elements: Investigative modeling and effective thickness. In their study, it is showed that Ross, Kerwin, and Ungar's model can be deliberated as a particular case of the Mead and Markus model when the exponential deterioration rate per unit length is neglected.

Laura Andreozzi et al[57] have done a research work on the dynamic torsion tests to describe the thermo viscoelastic properties of the polymeric interlayers for the laminated glass and also in their study a test process is scheduled to perform dynamic experiments on polymer interlayer that revels to be more simple and more reliable than the ways presently in use and they find that the mechanical behavior of the laminated glass strongly depends on the thermo viscoelastic behavior of the polymeric interlayer.

Chiara Bedonand and Claudio Amadio[58] have done a research work on Flexural torsional buckling: Experimental analysis of laminated glass elements. In their study, buckling tests are performed on the laminated glass beam columns that have rectangular cross section and are subjected to combined uniaxial compression and bending and they found that the buckling strength of the laminated glass specimens looked strongly dependent on the applied load eccentricities due to the interacting bending moments and on the mechanical possessions of the PVB-films.

H.D. Hidallana-Gamage et al[59] have done a research work on the numerical modeling and study of the blast performance of the laminated glass panels and the effect of material parameters. In their study, they presents a comprehensive numerical technique to treat the blast response of the laminated glass (LG) panels and studies the effect of significant material factors and they found that the tensile strength of the glass largely influences blast response of the LG panels, while the interlayer material belongings have a key impact on response under the higher blast loads.

Konstantin Naumenko and Victor A.Eremeyev [60] have done a research work on a layer wise model for the laminated glass and photovoltaic panels. In their study, a layer wise concept for the structural examination of glass and photovoltaic laminates is established. Starting from governing equations for the single layers, appropriate interaction forces, kinematical constraints, a twelfth order structure of partial differential equations is formulated and they found that the type of additional boundary state for example free edge or framed edge, has an important effect on the deflection for the laminates with very soft core layer.

Bong Hwan Kim et al[61] have done a research work on low velocity impact performances of a laminated glass. In their study, a finite element simulation founded on a higher order beam finite element and a PVB interlayer concept is applied to find the dynamic responses of the laminated glass panels and they found that the laminated glass faces less destruction compared to the monolithic glass of same thickness.

Michele Guida et al[62] have done a research work on FE testing of wind shield subjected to high velocity impact. In their study, FE study were carried out so as to evaluate the influence of geometrical limitations such as panel measurements, the thickness as well as the impact limitations and they find that the PVB gives help to glass because if the glass breaks, interlayer preserves the glass wreckages.

Stephen benison[63] has done a research work on the high performance laminated glass for anatomically well-organized glazing. In the study, he examined the mechanical performance of the laminated glass at various temperatures with the help of the finite element and actual thickness process and found that enhancement in the performance may be attained with the use of the PVB interlayer.

Mr.Nayeemuddin and Mr. Abdul Nazeer[64] have done a research work on the effect of low velocity impacts on the composite material by using the finite element study software LSDYNA in their study**.** Firstly, the study is carried out on a steel plate which is impacted by a rigid impactor for various mesh density of the plate and impactor. So it is noted that, as mesh density increases the accurateness also increases.

Ignatius Calderon et al[65] have done a research work on analysis of effective thickness approach for the design of the laminated glass. In their study, an evaluation of data from investigation programs in which the laminate effective thickness has been measured directly and compared to the simplified calculation methods that are based on effective thickness method and he found that the effective thickness technique is a best useful method for calculating the glass stress and deflection of the laminated glass.

Ivelin V. Ivanov and Tomasz Sadowski [66] have done a research work on mechanical response of the laminated glass subjected to low velocity impact. In their study, the mechanical response is examined by tests and finite element models for better understanding and they found that, the radial cracks come from non-impacted sides of glass coatings and they could transmit through the whole thickness of the films.

Mohammad a Torabizadeh[67] have done a research work on compressive, tensile and shear characteristics of unidirectional epoxy/glass composite that is subjected to the mechanical loading and low temperature facilities. In the study, he conferred an investigational study on the compressive, tensile and in plane shear performance of unidirectional glass fiber reinforced polymeric composite beneath motionless and low pressure loading circumstances and they noticed that low temperatures have a important result on composite failure manner. It is also analyzed that the modulus and strength of unidirectional composites both increases with decreasing the temperature in all cases including compressive, tensile and shear load.

Sebestian heimbs-siven heller and peter [68] have done a research work on simulation of low velocity impact on the laminated plate’s with-out and with preload. In their study, low velocity impact performance of the laminated glass with and without preloading was examined and they found that an increased deflection and energy absorption for pre load composite plates was noticed.

M. Y. Zang et al [69] have done a research work on investigation of impact fracture performance of the automobile laminated glass by 3D discrete element technique. In their study, a 3D discrete element model of the laminated glass plane is obtainable and a 3D mathematical analysis code, which can simulate the impact fracture performance of an automobile laminated glass is established and they found that PVB plays an significant role for appeasing the impact.

O. Alsaed and I. S. Jalham[70] have done a research work on Ethyl Vinyl Acetate (EVA) and Polyvinyl Butyral (PVB) as a binding material for laminated glass. In their study, the result of the type of the bonding interlayer on the mechanical performance of the laminated glass was calculated and they found that the failure strength of the laminated glass bonded with either EVA or PVB decreases as the thickness of interlayer increases.

Furthermore, the failure strength of glass bonded with the PVB is lesser than that for EVA ones for the same situations. Also, it was detected that with the increase of the glass plate thickness & the increase of interlayer thickness, the ability of laminated glass to absorb energy increases Shelton and Mauro [71] have done research on Simple model for forecasting the post-breakage behavior of the laminated glass. In their study, they formed a simple model of a four point bending test and compared the outcomes with FE study and they find that the models presented are able to be used for forecasting the post-breakage behavior of the laminated glass. Jan Belis et[1] al have done a study on Experimental and analytical assessment of lateral torsional buckling of laminated glass beams he investigates analytically the effects of various mechanical and geometrical properties on the typical lateral torsional buckling response of laminated glass beams and initiate that, The type of glass is an important factor that should be carefully taken into account In his work annealed glass specimens cracked prematurely due to their limited tensile strength; consequently, based on few available test results experimental load–displacement paths can be in general predicted, with good accuracy, by means of equivalent thickness analytical approaches

II. CONCLUDING REMARKS

It is clearly noted from the above assessment that in the field of laminated composite a lot of research effort is done that includes experimental studies and analytical models out of which some fixated on the comparison between the strength of the laminated glass and monolithic glass and did not take into concern the thickness of bonding interlayer, and thickness and the position of the glass plates. Some of them have given the theory of effective thickness. Also, PVB is the chief bonding material in this study. This study varies from the above stated ones in the way that it focuses on how the glass type & thickness and how the dissimilar laminated deposits (EVA,PVB,BOPP,PU) and the number of laminated interlayers affect the insulating, mechanical and other properties of the laminated glass. The art of laminated glass still has a wide scope of enhancement to serve the world in an enhanced manner.

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