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Experimental Investigation Onflexural Behaviour of Glass Beams with Stainless Steel

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Abstract: Glass has been used as a non structural element in partition walls and windows, etc in the past centuries. Nowadays its use has been changed from non structural use to structural use which brings up light into the building due to its transparency and saves energy to the eco-friendly world and gives aesthetic view. The glass beams are used as a supporting member of the glass panels in the roof structures. Glass is a brittle material and has very high compressive strength compared to that of other building materials like concrete, etc and has very low tensile strength similar to concrete. To enhance its tensile strength, different types of reinforcement can be provided in the tensile zone of glass beams. The reinforcement for these type of composite glass beams are made of materials like steel, wood, etc in the form of hollow tube section or solid section. This study presents the experimental and analytical work of eight glass beams of size 550 mm X 21.5 mm X 50 mm of two glass type (annealed glass and toughened glass) with varying reinforcement percentage. The stainless steel plates are provided at the bottom of the glass beams in the form of a channel as reinforcement. Load deflection response of glass beams is studied. The analytical work was performed using ANSYS software. The experimental results are verified with the analytical results.
Keywords; Glass beam, low tensile strength, ANSYS, deflection.

I. Introduction

Glass is no longer considered as a non-structural element. It is increasingly called upon to constitute innovative structural components of a building, such as flooring, fins, beams or complete bolted glass assemblies in facades. Now it has been turned to use as the structural element which serves as a good building material to carry load. Glass has two opposite characteristics that transparent and impermeable for liquids and air. This combination of the behavior made the building to visually contact with the environment and day light access so it plays a vital role in architecture. Glass is the growing up structural field. Glass beams are used as the supporting member of glass panels in the roof of facade structures. Glass is a brittle material that is weak in tension because of its non-crystalline molecular structure. When glass is stressed beyond its strength limit, breakage occurs immediately without warning, unlike steel and aluminum where plastic mechanism can be formed. As glass is a brittle material that stress cannot be re-distributed and failure is assumed once crack occurs, the failure stress can only be referred as a probability of failure. Glass has very high compressive strength compared to other building materials like concrete, steel etc and has very low tensile strength similar to concrete. To enhance its flexural strength, different types of reinforcement can be provided in the tensile zone of glass beams. Different types of reinforcement is provided in the glass beams as stainless steel solid or hollow section, stainless steel plates in bottom in both sides, glass fibres in the interlayer of the laminated glass. Post tensioning process is also used in increasing the tensile strength of glass beams in bottom of the beams.

II. Literature Review

Laminated glass prevents glass shards from falling and flying and has strength equivalent to that of monolithic glass in resisting wind loadings[24].The technique for the modeling of laminated glass using finite element solver shows improved behavior. Shell elements with brittle failure for the glass components. Membrane elements to simulate the ultimate load carrying capacity of the PVB-interlayer which is nearly incompressible. It is numerically simulated with solver LS-DYNA it has good agreements with experimental results [28]. Analytical approach is helpful in determining the impact strength of laminated glass. A method is proposed for reducing material and energy consumption and the production cost of multilayer glass through the use of glasses with induced surface stresses.[21] The mechanical behaviour of laminated glass such as strength and creep post-glass breakage coupled with enhancements in durability and materials compatibility are achieved [27].The structural performance of laminated glass based on aspect ratio, slenderness factor and composition is analysed. During load tests conducted on laminated glass it was found that fracture generally occurred on one layer first. If the lateral load was maintained even after initial fracture then the second layer fractured.[14][10]

The characteristic strength for annealed, heat-strengthened ,fully tempered and chemically toughened glass were tested both in lying and standing positions. The result shows that the strength standing is about 67 % of strength lying[29].The empirical formula of the reinforced glass beams with the ABAQUS results for different types of failure is verified[4][20]. The behavior of the glass beams which is reinforced with the timber bonded in top and bottom of the beam with the adhesives forming I-shaped cross section is analysed[15]. Experiments were conducted to study about the concept of laminating the glass with relatively stiff polymer as interlayer to bond the metal to glass, the structural response of the composite beam at different temperature of -20 degree, 20 degree and 60 degrees with the pull out test[11].The Redundancy of reinforced glass beams with varying temperature, moisture and time dependent behaviour of the adhesive bond was studied. The ductility is provided between the glass & steel is by the adhesive bond between glass and reinforcement [7]. The difference in the failure mode of the glass beam reinforced with the flat bars and the round bars is observed [5][3].The mechanical characterization of laminated glass beams is done with different interlayer plastic sheets[2][26]. The structural response of the reinforced glass beams can be explained using the sequentially linear elastic analysis (SLA) scheme.[1]

The failure criterion for laminated glass under impact loading [23]. The steady-state cracking speed of PVB laminated glass is lower than that of pure glass and it also increases with higher impactor speed and mass [12][19]. The theoretical verification is done for the glass beams by reinforcing the glass with glued stainless steel profile increases its total resistance and supplies important residual resistance to the damaged glass structure [25]. Different polymeric interlayers used in the preparation of laminated glasses have been discussed and compared[16]. Analysation and determining the effects of the glass type such as annealed, heat-strengthened and fully tempered, reinforcement percentage as hollow section (1.4%) and full section (3.8%) and beam size with length variation of 1.5 and 3.2 m on the structural response of SG-laminated reinforced glass beams has been done[6][8]. The computational methods of the laminated glass was analysed[17].Development in strength and aesthetics is observed by using different polymeric materials for preparation of laminated glasses [18].

The effects of cross-section geometry, reinforcement geometry and glass-reinforcement bond on the structural behaviour of the beams has been investigated experimentally by bend tests on several small and large scale specimens [13][9].The behavior of a MRGB in bending can be subdivided into three stages the un-cracked stage, where no cracks are present in the glass and a perfect composite action between the glass and the reinforcement is assumed [22].

III Experimental and Analytical Study

3.1 Testing Methods for Determining the Strength of Glass

In practice, glazing panels are typically subject to out-of-plane bending when wind pressure is applied and when the load transferred to the beam, the beam also acts subjected to the out of-plane bending. Several test methods have been developed to examine the bending strength of glass. These test methods can be classified as (i) uni-axial bending tests and (ii) biaxial bending tests. With uni-axial bending tests, specimens are supported on two parallel sides and subject to one or two concentrated line loads causing bending in one direction(Figure 3.1).

The advantage of this test method is that only one principal stress is developed at all locations in the glass specimen. Hence, possible influences by other (minor) principal stress have been neglected. The uni-axial bending test with two concentrated line loads is also known as four-point bending test shown in Figure 3.1.

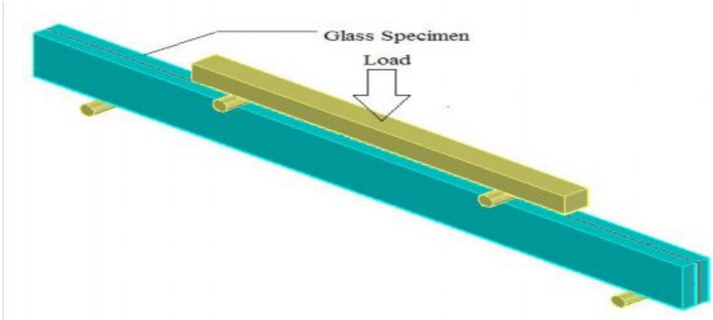


Figure 3.1 Four-point bending test

3.1.1 Details of Glass Beam Specimen

Two point loading is applied in the Glass beam in one third of the effective span. The glass beams used for the entire test have same geometry (550 mm x 21.52 mm x 50 mm) and glass type (annealed and heat strengthened).To minimize the variation in glass strength, all the specimens were purchased from the same supplier and were transported and stored before testing with methods and in conditions as similar as possible. The Glass beams are reinforced by the stainless steel. The stainless steel plates are folded in the form of channel of 22 mm x 10 mm and varying thickness.

3.2 Test Setup

The glass beam of size 550 mm x 21.52 mm x 50 mm with simply supported edges where tested under two point loading.

Figure 3.2 Test setup

Loading arrangements are done in such a way that the load is transferred to the distribution beam and then to the loading rods in the point of loading and then to the beam. The test setup is shown in the figure 3.2.The applied load was measured using load cell and the deflection of the glass panel was measured using deflection dial.

3.3 Test Results of Specimens

Four samples of glass beams were tested up to failure and the results are reported. The eight specimens are tested by placing the glass in the vertical portion as that it is to be placed in the field to transfer the point load in by the spider arms. Among eight specimens, four specimens are annealed glass type and other four specimens are toughened type. Among four specimen of one type of glass, one specimen is of unreinforced and other three specimens are reinforced in the tensile zone to prevent the brittle failure with varying thickness of the stainless steel plates as 0.36 mm , 1.2 mm and 1.5 mm. The load is given in the interval of 0.1 kN and the deflection is measured using the deflection gauge. The samples are tested and the results are tabulated.

3.3.1 Observation

The experimental testing is carried out in the UTM with the capacity 1000kN. The load applied in the interval of 0.1 kN. The observations during the testing of the glass beams are listed below.

3.3.2 Annealed Glass

The annealed glass without reinforcement fails suddenly without any warnings and its load carrying capacity suddenly drops to zero. The glass at the loading point starts to fail at the failure load and glass particles spreads in around area. The glass still remains in the support. The glass fails suddenly when the loading steel comes in contact with the glass. Reinforced glass beams with reinforcement of 0.36 mm thickness plate, the stainless steel plate starts to buckle and detached from the glass at the failure point of the glass. In the reinforced glass beams with reinforcement of 1.2 mm and 1.5 mm thickness slip failure occurs. The failure pattern of unreinforced glass beams is shown in figure 3.3.

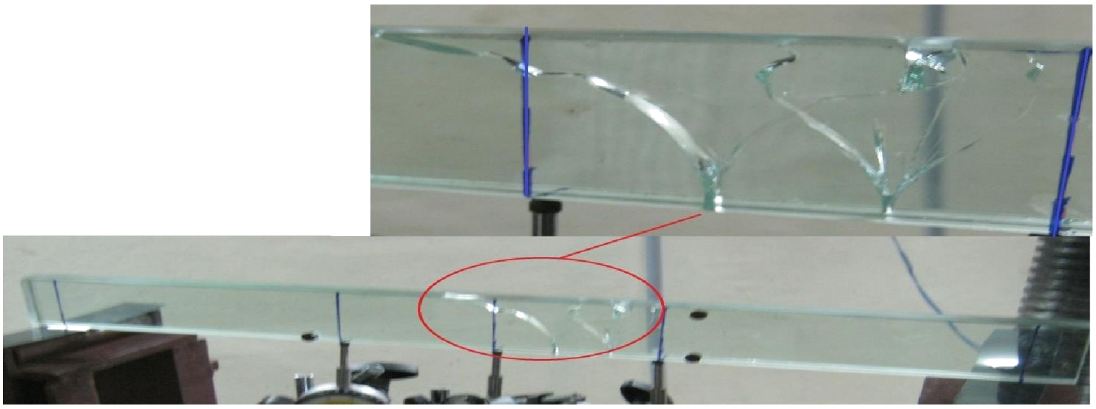


Figure 3.3 Failure pattern of annealed glass

3.3.3 Toughened Glass

The toughened glass without reinforcement fails suddenly without any warnings and its load carrying capacity suddenly drops to zero.The glass at the loading point starts to fail at the failure load and glass particles do not spread around the area and slips from the support.

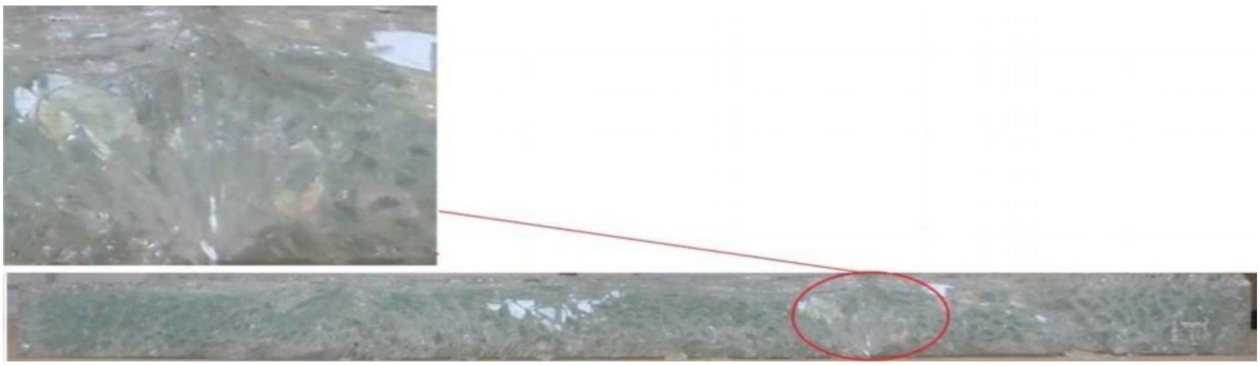
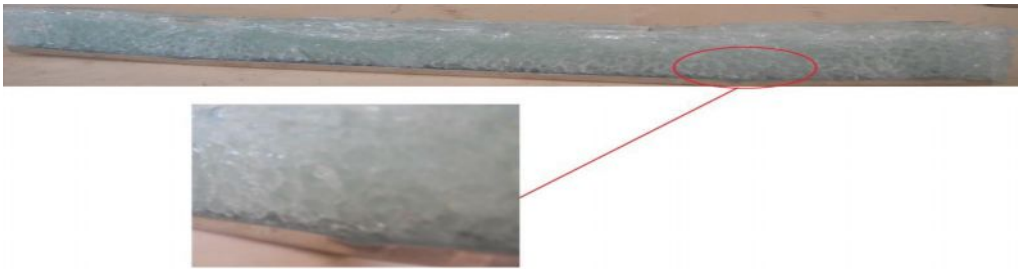


Figure 3.4 Failure pattern of toughened glass

The glass fails suddenly when the loading steel comes in contact with the glass. Reinforced glass beams do not slip from the support. Reinforced glass beams with reinforcement of 0.36 mm thickness plate, the stainless steel plate starts to buckle and detached from the glass at the failure point of the glass. In the reinforced glass beams with reinforcement of 1.2 mm and 1.5 mm thickness slip failure occurs.

(a)



(b)

Figure 3.5 Failure pattern of reinforced glass beam with 0.36 mm thick stainless steel reinforcement (a) Annealed glass (b) Toughened glass

3.4 Brief description of ANSYS and its features

ANSYS is FEA software used in engineering field for the analysis of the product or material which are newly developed. It is used as a tool, solver, for finding the behaviour of materials for extreme conditions like high loads, variation in temperature, fatigue, etc.,

These are some of the analysis that can be performed by using ANSYS.

- Static Analysis
- Modal Analysis
- Harmonic Analysis
- Transient Analysis
- Spectrum Analysis
- Buckling Analysis
- Sub structuring Analysis

3.4.1 Graphical user interface window

The GUI allows several levels of customization, ranging from a simple change in the sizes of the GUI and the areas in it to a more complex change in the menu hierarchy and design of the dialog boxes. GUI attributes you can change include these items:

- The size of the GUI and the areas in it
- Colours and fonts
- The menus shown at GUI start-up
- The mouse and keyboard focus
- The menu hierarchy and dialog boxes.

By default, the main areas of the GUI (Utility Menu, Main Menu, Standard Toolbar, ANSYS Toolbar, Input Window, Graphics Window, and Output Window) display when you activate the GUI. ANSYS supports graphical user interface, which is easy to understand and reduce the working time for modelling and analysis of the product or materials.

3.4.2 Metal reinforcement

The metal used for the reinforcement is stainless steel as it has the exposed to the atmosphere it will not get corroded and the strength of the metal is similar to that of steel. The yield strength of stainless steel metal is of 210 Mpa. The elastic properties of stainless steel with young's modulus of 200 pa and poisson's ratio of 0.3.The analysis of the reinforced glass beams includes the static linear analysis. The glass beam is the thin plate so large deflection theory and geometrical non linearity are used for the analysis. The difference in the mesh size results in the result variation. The finite element analysis gives better accurate results compared to that of the experimental results. The element choosen for the reinforcement is four node general-purpose shell. The geometry and nodal location of the element is shown in figure 3.7.

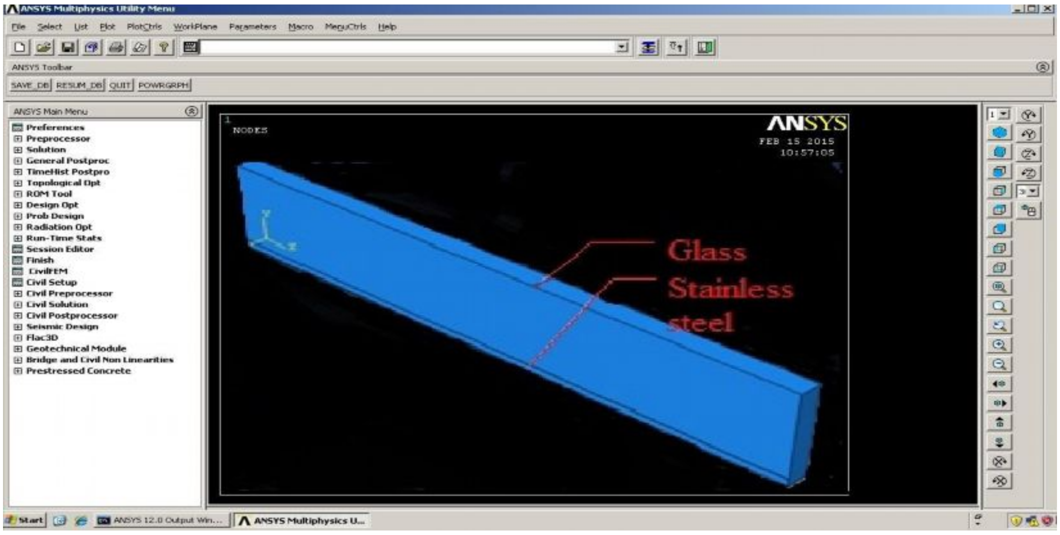


Figure 3.7 Four noded shell element

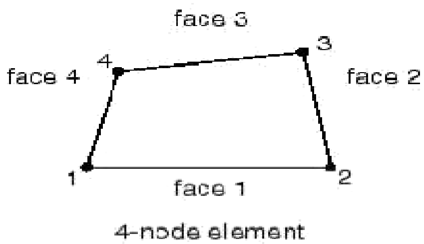


Figure 3.8 Global co-ordinate axes for the FEM analyses

3.4.3 Meshing

The density of the element mesh has a great influence on the results of the geometrically nonlinear analysis. Since increasing the amount of elements in the model rapidly increases the computational cost of the analysis, it is reasonable to find an optimal combination between the accuracy of the results and the size of the model. The meshing is of done as fine meshing with the approximate size of 1mm. The element type chosen for glass is the continuum three dimensional eight noded stress linear elements and for reinforcement is shell four noded element.

3.3.7 Loads and Boundary Conditions

The glass beam is simply supported on both ends and subjected to two point loading on compression edge. When the beam is loaded, the central part of the beam deforms and when the maximum tensile stress is the glass exceeds the tensile stress, the glass starts to crack.

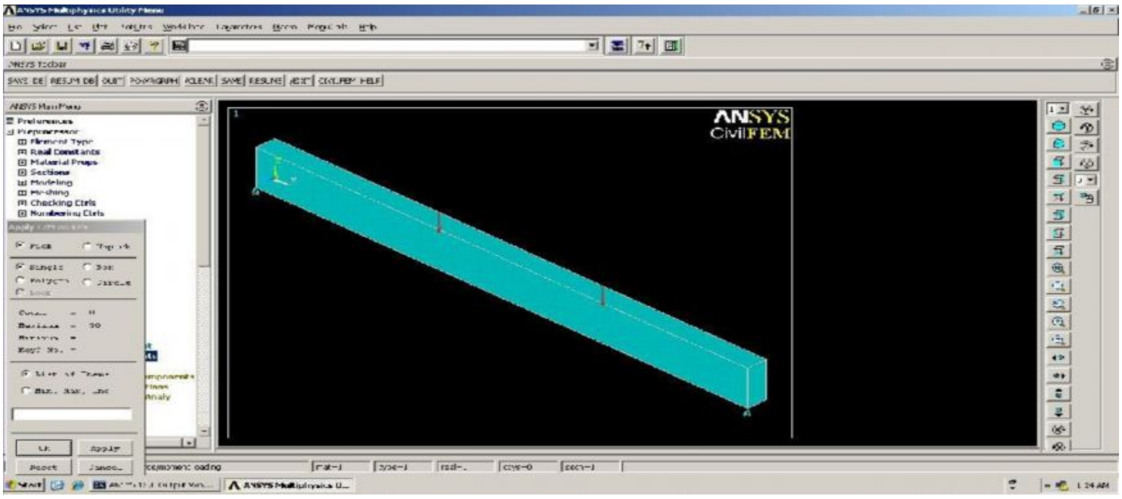


Figure 3.9 Boundary condition and loading condition for unreinforced glass beam

After the glass cracks, the stainless steel carries the load until the yielding of the stainless steel. The glass beam size of 550 mm x 21.52 mm x 50 mm is analyzed. Load is applied at a regular interval . Load is acting on the thickness of the glass whereas the steel is fixed at the bottom of the glass beams. The flexural beam testing is carried out in a simply supported beam.

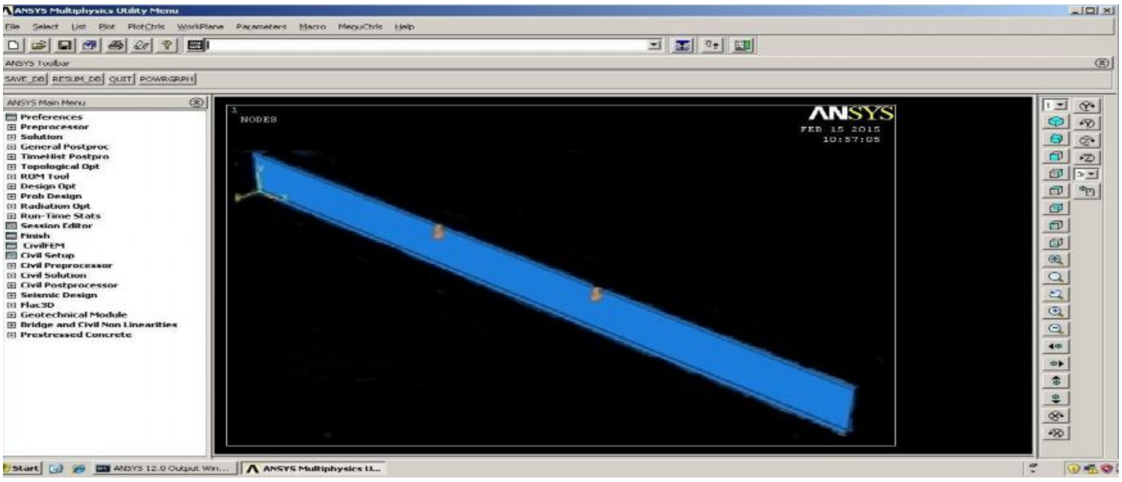


Figure 3.10 Boundary condition and loading condition for reinforced glass beam

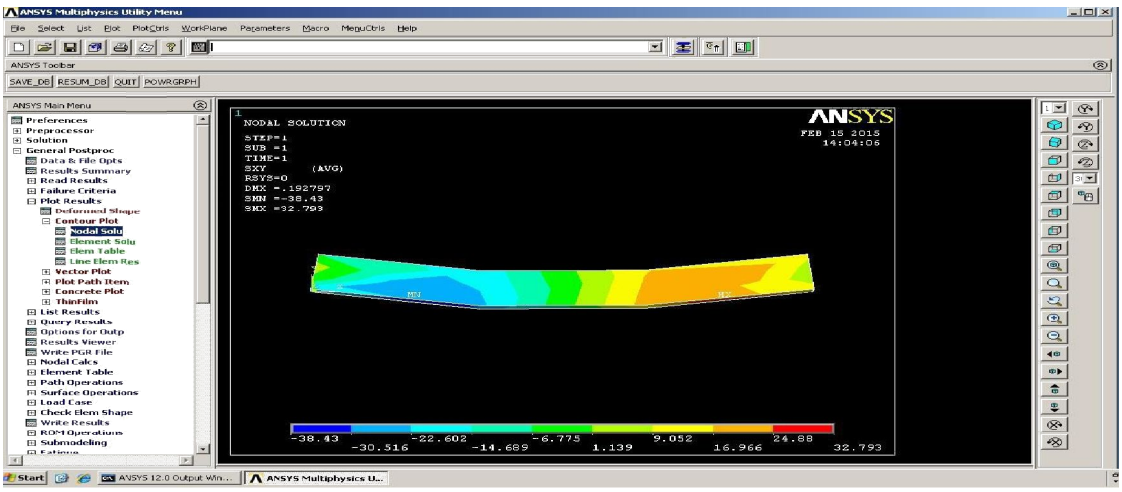


Figure 3.11 Stress pattern of unreinforced glass beam

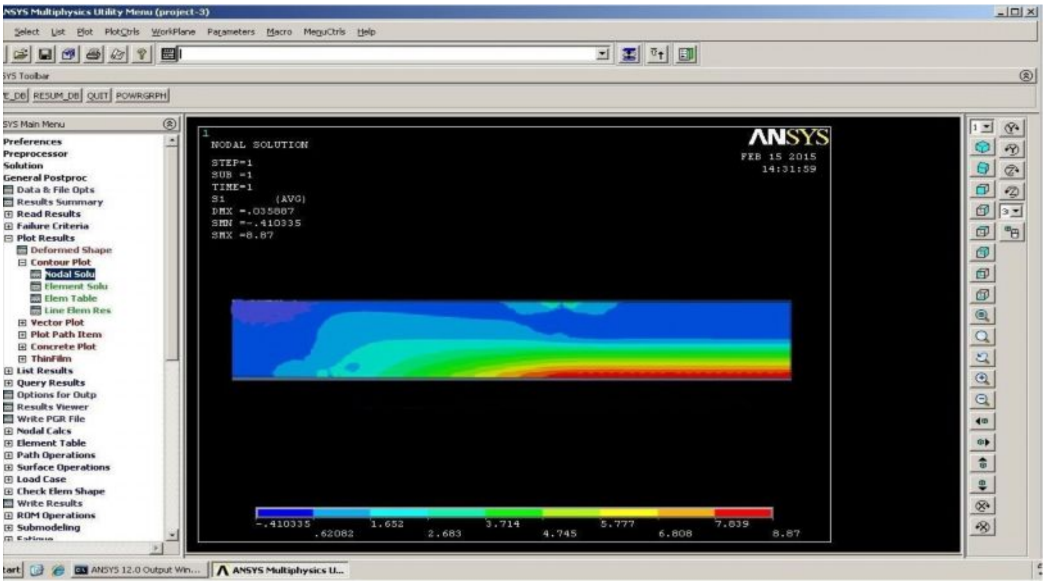


Fig 3.12 Stress pattern of reinforced glass beam

In stress contour, red colour denotes high stress and blue colour low stress. In the non linear analysis the relative distribution of the total tensile stress on the surface varies as the applied load is increased and increase in the reinforcement percentage. At low loads the membrane stresses are negligible and simple bending theory may be used to give the same results. At high loads the membrane stresses become significant and the maximum stresses lie at some point on the bottom of the tensile zone, moving closer to the support of the glass beam as the load increases.

Iv. Results and Discussion

4.1 Experimental Results

Eight specimens of glass beams were tested in the laboratory upto failure with two point loading to study their behaviour. The glass specimens used in all of the tests have the same geometry as 550 mm × 21.52 mm × 50 mm and two glass type as laminated, annealed and toughened glass panels. The first four samples are of annealed type and other four samples are of toughened type at the loading rate of 0.1 kN respectively to study the behaviour of glass beams with varying percentage of reinforcement used as 0, 1.40, 4.68, 5.85 by varying the thickness of the stainless steel plates. The load Vs mid deflection for annealed type and toughened type specimens is presented in Figure 4.1 and 4.2 respectively.

4.2 analytical results

Analytical modeling results for two glass type with varying reinforcement at the tensile zone of the glass beam modeled as quarter model and was carried out using non-linear finite element analysis ANSYS software.

4.3 Theoretical Results

Glass is linear Elastic material and it is considered as the main load carrying capacity of the beam. The theoretical results are calculated based on the formula calculated and the experimental ,analytical and theoretical deflection are compared are tabulated in table 4.1 .

Table 4.1 Maximum deflection of glass beams

Glass Type	Reinforcement percentage %	Maximum load carrying capacity (KN)	Experimental deflection (mm)	Analytical deflection (mm)	Theoretical deflection (mm)
Annealed	0	5.9	0.91	0.903	0.834
Annealed	1.40	10.5	1.65	1.532	1.484
Annealed	4.68	17.2	2.68	2.541	2.431
Annealed	5.85	20	2.92	2.873	2.827
Toughened	0	19.5	2.78	2.812	2.756
Toughened	1.40	23.3	3.44	3.475	3.294
Toughened	4.68	29.1	4.54	4.374	4.114
Toughened	5.85	31.7	4.69	4.673	4.481

V. Conclusion

- Flexural behaviour of laminated annealed and laminated toughened glass beams samples are tested by varying the reinforcement percentage.
- The strength of toughened glass is 58.5 % more than that of annealed glass.
- The cost of toughened glass is 15.47 % more than that of annealed glass.
- Load carrying capacity of the reinforced glass beams are higher compared to unreinforced glass beam.
- Initial height of the uncracked compression zone increases with increase of percentage of the reinforcement.
- Ductility of the glass beams is improved by providing reinforcement in the tensile zone of the glass beams.
- The safety of the structural glass beams are improved by providing the reinforcement.
- Load carrying capacity of the reinforced glass beams increases with increase in percentage of reinforcement.
- Deformation calculated analytically and theoretically is less than the experimental results whereas the analytical and theoretical results do not over estimate.

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