Simulation of laminated windshield in automobile crash analysis

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***Abstract* - The objective of the present study is to investigate and create a methodology to study the mechanical behavior of laminated glass in the case of a pedestrian's head impact. Windshield models were set up using different combinations for the modeling of glass and PVB, with various connection types and mesh sizes. As the properties of glass are unknown during crash this test will help us understand the behavior of glass. Each glass model was impacted in different conditions of crash in an LS-DYNA simulation environment, and the results were compared with the experimental data performed in the test. The influence of glass fracture stress on the same model was investigated, and the cracked area and the peak value of the impacting layer's linear acceleration is to be determined by the critical fracture stress.**

***Index Terms* – crash analysis of laminated glass, ls-dyna, automobile glass failures**

I. INTRODUCTION

Today, crash simulations replace crash testing in the product development phase in the automotive industry. High quality simulations enable shorter product development time and higher competitiveness. However, increasing requirements regarding emissions and crashworthiness are demanding optimized material choice in the parts constituting the car body structure regarding the safety of the passengers. Of special interest for the automobile industry is a rational treatment of laminated glass in crash simulations.

In case of lateral car crash, the most frequent contact source is the side window. This side window is also the most frequent (40 %) apertures through which occupants are partially or fully ejected during a crash. Occupant ejection from vehicles is often considered to be a contributor to death and serious injury. The head/neck region is the most frequently injured body region of ejected occupants. In order to keep occupant within the vehicle during a collision, laminated side glass has been developed to gradually replace tempered glasses. This security glass is composed of two layers of heat strengthened glass (2.1 mm thick) with a plasticized interlayer membrane of Poly Vinyl Butyral or PVB (0.76 mm thick). This enhanced protective glass offers a good resistance for breaking and entering. It can resist an aggressive attack for 20-30 seconds compared to tempered glass which would resist the attack for only 1-2 seconds.

In the late 1980's, rollover tests on vehicle containing bi-layer glazing in the side window openings were conducted. The potential of glass-plastic glazing to significantly reduce ejections through motor vehicle windows were demonstrated. Clarke provides acceptable neck loads under severe glazing contact conditions. Advanced glazing systems may reduce partial and complete ejections through side window, according to the same authors. In 2002, Sances *et* al. simulated rollover accidents consisting of a Hybrid III dummy test device impacting side windows with three-layered laminated glazing. This glazing contained the dummy assembly. Head-neck biomechanical parameters were below the critical value injury tolerance limits value.

The dummy assembly never went through this security glazing. More recently, other authors stated that production laminated side glass is not an efficient barrier to occupant ejection during rollover (Kramer *et* al. 2006, Pierce *et* al. 2007). Evaluations were made against laminated glazing by drop tests on door-glass systems. Rollover accidents typically include multiple impacts and potentially long duration forces on the side glazing.

Data obtained from a crash simulation indicate the capability of the car body or guard rail structure to protect the vehicle occupants during a collision (and also pedestrians hit by a car) against injury. Important results are the deformations (for example, steering wheel intrusions) of the occupant space (driver, passengers) and the decelerations (for example, head acceleration) felt by them, which must fall below threshold values fixed in legal car safety regulations. To model real crash tests, today's crash simulations include virtual models of crash test dummies and of passive safety devices (seat belts, airbags, shock absorbing dash boards, etc.). Guide rail tests evaluate vehicle deceleration and rollover potential, as well as penetration of the barrier by vehicles.

I. EXPERIMENTAL SETUP

Total two series of experiments were performed on the laminated glass windshield. Brand new windshields of Maruti Omni van were used in each set of experiments. The first set of experiment consisted of a drop test and the second test was a quasi static loading test.

In the first set of experiment an ms rod was dropped on the windshield from a certain height. The objective of the test was to record the height of the drop object from which the crack generation starts in the windshield after impact. An ms rod 27 inches long and 28 mm diameter. The recorded weight of the rod was 3.4 kgs.

Fig. 1. Measuring drop height

Fig.2. Other assembly for drop test

The drop height of the rod was being increased gradually until the crack generation was observed in the windshield. Immense precautions were taken so that the rod axis remains parallel to the ground surface during impact. It was observed that the crack generation starts when the rod is dropped from a height of 21 inches from the surface of glass.

Fig.3. Glass cracks after the test

The second test performed was the buckling test. A fixture was designed in such a manner that it holds the windshield and applies load vertically over it. The fixture consisted of two grooved wooden logs, an ms c-channel and two ms pipes. The pipes were welded to the c-channel such that they are perpendicular to the channel surface. Both the wooden logs were drilled on both the ends in such a manner that they could pass easily through the vertically welded ms pipes in upward and downward direction. Four metal strips were welded on the bottom of the c-channel to provide support to the fixture during loading.

The first wooden log was slid down through the vertically welded pipes such that its groove is exposed. After proper placement of the log, the smaller edge of the laminated windshield is placed in the groove. The second wooden log is then slid through the vertical pipes and placed over the windshield such that the upper edge of the windshield is placed exactly into the groove of the log. Arrangements are made that the windshield is properly held between the two logs.

Fig.4. Bucling test fixture

Fig.5.Wooden log used for holding Laminated glass

Table 1. Load v/s. deflection.

Load (kg)	**Deflections (mm)**	
	Windshield 1	**Windshield 2**
39.05	5	5
17.86	8	7
14.18	9	9
13.35	1	11
5.4	11	12
5.2	13	14
5.1	15	14
3	15	15
2.25	16	17
2.15	16	17
1.65	18	19
Total=109.19		

Fig.6. Glass buckles after loading discreetly

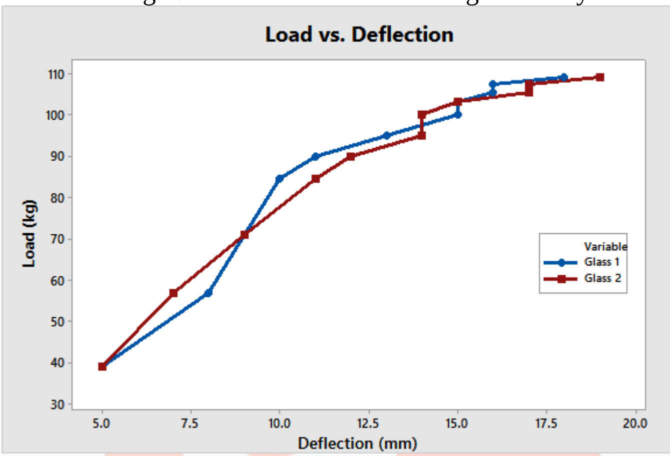


Fig.7. Various loading condition for both the glasses

II. SIMULATION RESULTS

For simulating the experiment we first have to develop exact models of the components used in the testing. These models are then meshed to create finite elements over them for the analysis. After the meshing process loading conditions and degree of freedom constraints are applied to the model. Later the models are loaded in a solver software for the simulation process.

Siemens Unigraphics 9 or NX-9 was the tool used for basic modelling of the components. For meshing and application of loading condition Altair Hypermesh 12.0 was used. A high end analytical simulation software LS-DYNA is used for the process of simulation.

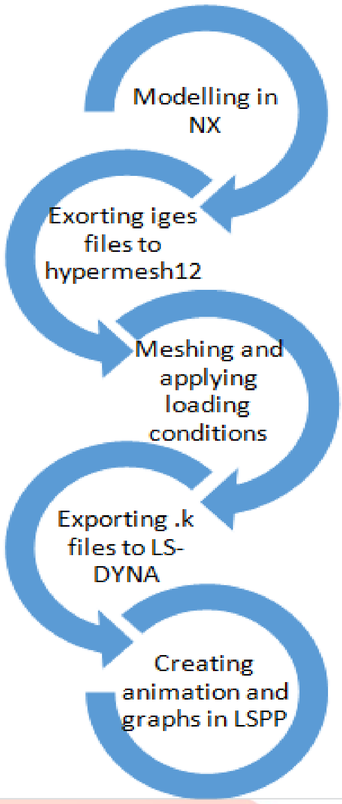


Fig.8. Simulation procedure adopted

Drop Test:

In the beginning, the basic element of the project, the windshield is modelled in the NX-9 software. The exact dimensions of the windshield are noted by actual measuring the sheet after placing it on the ground. After developing the model, the nx file is converted into iges (*Initial Graphics Exchange Specification). The iges format files are accepted by almost all the new modelling as well as analysis softwares).*

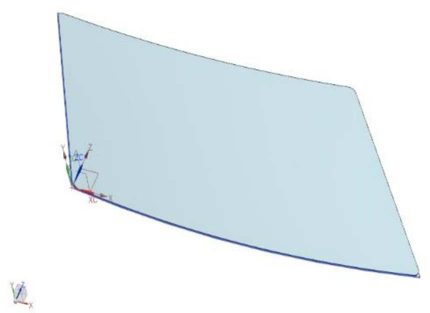


Fig.9. Glass Model created

After creating the model in nx-9 it is saved as an iges file. This iges file is then loaded in the hypermesh 12.0 software. The rod is designed in the hypermesh software itself. The glass model is meshed in 2d option i.e. after meshing the glass only shell elements are obtained on the surface.

In case of the rod, first the cross section of the rod is created and meshed using shell elements. This profile of the rod is then dragged along the length of the rod which is 27 inches long for creating the model.

For assigning the material properties the glass is assigned MAT_L_32 card and the rod is assigned MAT_L_20 card. The MAT_L_20 card is defined as a rigid material. The properties like density, Young's modulus, Poisson's ratio can be assigned manually to the applied card.

The velocity of the rod can be calculated by the formula:

$v^2 = u^2 + 2as$

Where,

v: final velocity

u: initial velocity

a: acceleration due to gravity

s: displacement

Thus we get the value of v as

$$v = \sqrt{(2as)}. = 3.22 \text{ m/s}$$

And the kinetic energy will be calculated as

$$k.e. = 0.5*m*v^2 = 17.627 \text{ joules.}$$

V =where m is the mass of the rod (3.4 kg).

After assigning the constraints and the loading values to the glass and the rod, the model is exported into the LS-DYNA format (.k file). The high end solver LS-DYNA is opened and the converted file is loaded into the solver. The process of simulation is started. The solver generates output files and stores in the folder created by the name of the model.

LS-DYNA has a preprocessor and a post processor called as the LS PREPOST (LSPP). The preprocessor is used for modelling but is not generally preferred because of its complexities. To view the animation of the experiment the d3plot file generated by the solver is opened in the LSPP. As the file opens in LSPP, the animation toolbar opens where we can set the fps and the animation speed.

he screenshot of the animation can be seen in Fig.10. below

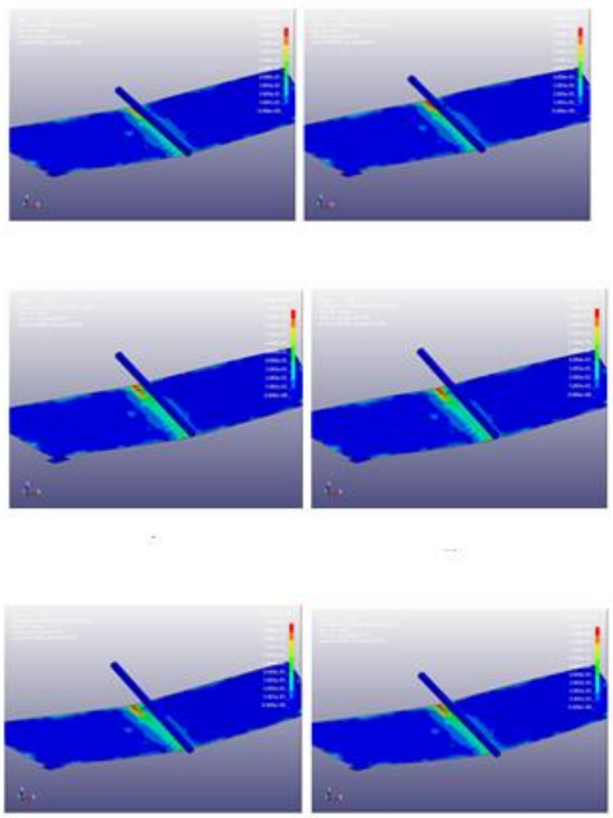


Fig. 10 Screenshot of drop test animation showing plastic strain

The card only defines the material behavior. A number of iterations are done by changing the properties of the card allotted to the elements until the simulation matches to the experimental results accurately.

In the drop test, the first crack was generated when the rod was dropped from a height of 21 inches (53 cm). In the simulation process the rod is not dropped from the height, instead the kinetic energy that the rod gains just before the collision is assigned to the rod. For calculating the kinetic energy we need the velocity of the rod just before coming into contact with the windshield.

Buckle Test:

In the buckle test simulation only two main elements are required i.e. the windshield and the wooden logs. As mentioned in section 2.3.3 grooves are created on the wooden log and a chamfer is provided on one of the edge of the groove. Considering the same, a cad model is developed in NX-9 using the available tools.

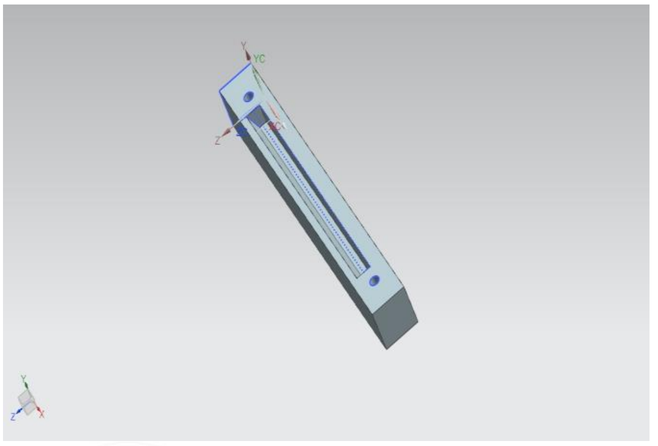


Fig.11. View showing champher on the groove edge

Below is shown the simulation results of buckling test.
The same procedure is followed here. The fixture assembly is loaded in the Altair hypermesh 12 software. Glass is meshed using shell elements. The loading conditions are applied on the upper wooden log. The bottom wooden log is to be kept fixed.

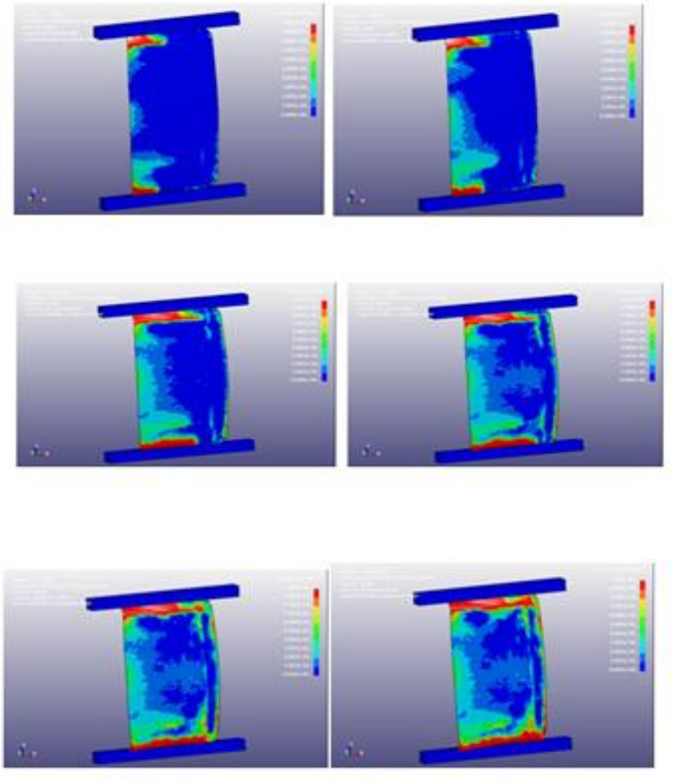


Fig.12. Screenshots of Buckling test simulation showing plastic strain.

A graph of load v/s deflection is plotted with the help of excel files generated by the LSPP.

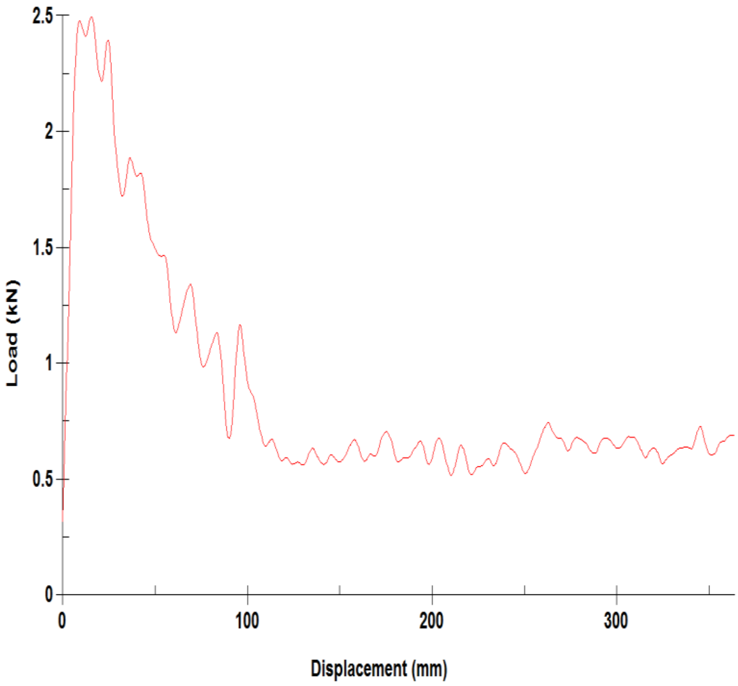
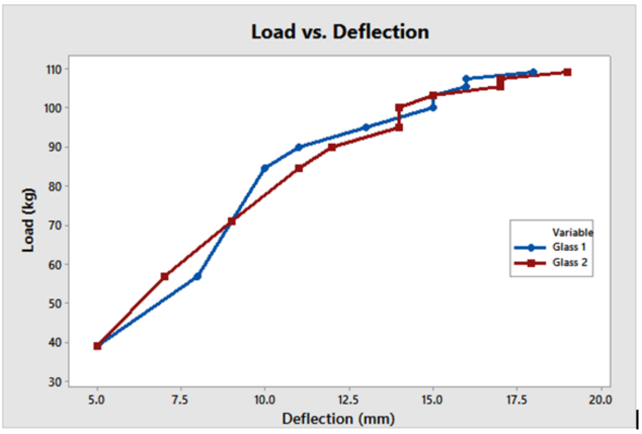


Fig. 13 Load vs Deflection graph

III. OBSERVATIONS

Comparing the experimental data and the simulation results, it can be seen that the behavior of glass matches in both the cases. A good correlation is observed between the simulation and experiments. The simulation and experimental graphs of buckling test shows same deflections before breakage.



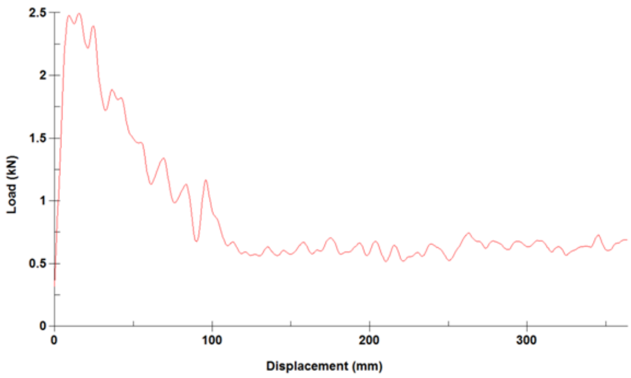


Fig. 14 Comparison between experiment and simulation.

IV. CONCLUSION

A simple windshield investigation and material model has been developed for crash analysis of the windshield. Experimental tests were conducted for Saint Gobain Laminated windshield for Maruti Omni van to determine the plastic strain responses under static and dynamic loading conditions. The test data was used to identify the material properties used to model the adhesive bond layer. The methodology has been validated by simulating the same tests with proper boundary conditions in Hypermesh and LS-DYNA solver. The CAE simulation correlated well with the test data.

To include failure of laminated windshield into FE models will significantly improve the accuracy of the results in crash simulations and the correlation to the actual performance. The improvement of CAE tools for laminated glass in automotive design and its continuous optimization will help to extend the use of glazing in the future.

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