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Assessment of Automobile Door Slam using Finite Element Method

Sunil S. Patil , Gautami U. Dhuri

Abstract: ***Automotive cars have various types of doors. The swinging door is the most common & complicated parts because they are doing both functions, general guidelines of car style, & passenger's safety by protecting humans from side crashes.***

With the advent of Computer Aided Engineering (CAE), Finite Element Analysis (FEA) has become a necessity for the automotive industry to improve and validate all manner of automotive structures. The use of FEA in the design procedure has increased significantly making validation of the FE Models used is essential. A comparison with experimental results of Door slam testing is a very effective method to evaluate the accuracy of the FE Models used.

The objective of the door slam testing is to determine acceleration, stress, strains & buckling energy induced while slamming action. In this door slam analysis carried out using CAE tools, Hypermesh-v12, Ls-Dyna. Door is slammed on rigid surface at velocity 1m/sec from opening angle 20 degree and results are evaluated for 0.35 seconds in the time step of 0.01second.Then predictability of the CAE method is examined through detailed comparison of experimental acceleration and strain results. While these results shows excellent agreement in CAE and test for accelerations on the outer panel. Also CAE predicts higher strains on the inner panel than the test. In addition, elastically buckling of outer panel is examined. These results of Acceleration, strain and buckling are also discussed in detail.

Keywords: Keywords: Computer Aided Engineering (CAE); Finite Element Analysis (FEA); Hypermesh-v12; LS-DynaExplicit; CATIA V5.

I. INTRODUCTION

The development of new automotive vehicles is a resource consuming and costly process. In order to reduce lead time and cost in the product development of vehicles more development will be made virtually. In an increasing pace of development and constant demands of cost reduction the building of prototypes is considered too expensive. Fewer and fewer prototypes are built in every prototype cycle of new automotive model development but the vehicle performance still need to be evaluated before the vehicles reach the market.

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Also Tight vehicle crash regulations and high quality and comfort standards continuously raise the bar in vehicle body and door design. The inclusion of additional crash safety structures as well as the usage of softer rubber elements increases the loading of components when doors are being closed. Also changes made to trim packages for increased passenger comfort, such as integrating new acoustic isolation materials, potentially impact the durability of doors and associated body components. When these components are not properly designed for durability, intensive use of the doors may cause obstructions when they are opened or closed. Such occurrences may generate undesired noise and rust, and may even lead to malfunctioning of the door lock mechanism. In order to avoid these problems and maintain reputation for extremely high quality, car manufacturer performs tests on physical prototypes to guarantee that the durability performance of door and body components is sufficient. This test approach delivers reliable results, although a number of disadvantages are associated with it. Expensive prototypes are required to perform the verification tests, and the evaluation of numerous door slam events consumes a considerable amount of time. And when discovering durability problems, the design needs to be adapted, prototypes modified, and tests rerun, adding both time & cost to the vehicle development process. [9]

Also the process of slam of a door assembly may cause the outer panel to experience buckling resulting in flutter or oil-canning. It could also induce localized strains in the inner panel which may cause fatigue damage. While these are the two phenomena during a slam event, damage could also be imparted in joints and reinforcements. Thus, a door slam test can identify several structural, durability and NVH issues in the door assembly design and material selection.

Experimental door slam test was conducted on the vehicle. In this the inner panel of the door was connected to the inner B-pillar at the opposite side with a spring. The opened door, resisted by the spring force, was released and the slam event was monitored using accelerometers on the outer panel and strain gages in the inner panel. The slam event is dynamic in nature resulting in geometric nonlinearities (at least on the outer panel), and material nonlinearities. An appropriate CAE procedure for simulating the slam event must take into account the material and geometric nonlinearities and the dynamic nature of the event. [1]

Door slamming is takes place at angular velocity 1 m/sec when door comes in contact with rigid surface. Total time span used for simulate results is 0.35 sec. And for it time step of 0.01sec is selected.

With these parameters acceleration - time history and stress strain graphs are plotted as an output results.

II. LITERATURE SURVEY

Enormous literature is available regarding the Finite Element analysis of automotive Door in the research papers and conference proceedings. Out of these a few noteworthy works are squeezed and briefly presented here.

S. Vinay Seeba1, S. Srikari2, V. K. Banthia, [5] in “Design & Analysis of Plastic Door Module for Car Body Application”(2010), studied Door module is preassembly of various components on a carrier plate which can be directly mounted onto the door inner panel. These door modules, when directly shipped to the OEM’s, save assembly time and cost in mass manufacturing. Long fiber reinforced thermoplastic polypropylene (PP-LFT) with glass filled fiber material is used for various automotive applications as it has improved structural and material properties over conventional materials like steel. Door modules made of PP-LFT material is manufactured using injection molding method. Although significant work was done on design and analysis of plastic door modules, there was no support information on how the final design of the door module was arrived at.

Topology and shape optimization were used in the present investigation to arrive at a design. 30 % glass filled STAMAX® PP-LFT door modules were used to replace the existing steel door module plate. Stress analysis and dynamic door slam analysis were carried out on the door module of new design to assess its performance under various durability loading conditions. Finally Mold flow simulation was performed on the door module part to check its manufacturability in mass manufacturing.

Final design of STAMAX® PP-LFT based plastic door module is 33 % lighter than the existing steel door module plate and has improved strength, stiffness and manufacturability.

R. Mohan Iyengar, T.Chang, S. Laxman, S. Thirupathi, J. Powers, S. Perumalswami, [1] in “A comprehensive Study of Door Slam” (2004), did comprehensive study of door slam event as part of an ongoing technical collaboration between Ford and Rouge Steel Company. The experimental phase of the project involved measurements of accelerations at eight locations on the outer panel and strains on six locations of the inner panel. Slam tests were conducted with window up and window down.

There CAE phase of the project involve the development of suitable “math” model of the door assembly and analysis methodology to capture the dynamics of the event. The predictability of the CAE method is examined through detailed comparison of accelerations and strains. While excellent agreement between CAE and test results of accelerations on the outer panel is obtained, the analysis predicts higher strains on the inner panel than the test. In addition, the tendency of outer panel to elastically buckle is examined. The implications of the buckling of the outer panel are discussed. The effects of thickness distribution and plastic strains introduced on the inner and outer panels due to forming are studied. The results show that the strains on the inner panel can be significantly influenced when forming effects are accounted for.

Said Darwish, H. M. A. Hussein and Ahmad Gemeal, [2] “Numerical Study of Automotive Doors” (2012), in this Comparison between FEA results and targets led to the necessity to split lower opening of front door into two parts to increase stiffness. Also, thickness of window regulator engine fixing in both front and rear doors are increased. Predetermined values from previous works conducted on a similar existing SUV vehicle were used as targets to be achieved by Finite Element Analysis (FEA) of car doors. Mobile hinge fixing is duplicated for both front and rear doors Inner panel opening in front door window lower mechanism are also decreased.

Tan Wei, Wang Yan, Li Lingyang, Zhang Yu, [7] "Design of The Vehicle Door Structure Based on Finite Element Method, (2012)" they used finite element method in the development processes of the door assembly. The stiffness, strength, modal characteristic and anti-extrusion of a newly developed passenger vehicle door assembly are calculated and evaluated by several finite element analysis commercial softwares. The structural problems discovered by FE analysis have been modified and finally achieved the expected door structure performance target of this new vehicle. The issue in focus is to predict the performance of the door assembly by powerful finite element analysis software, and optimize the structure to meet the design targets. It is observed that this method can be used to forecast the performance of vehicle door efficiently when it’s designed.

III. METHODOLOGY

FE analysis of automotive door slam testing is carried out using the Altair Hypermesh v12 tool for meshing and LS-DynaExplicit Dynamic Solver for analysis. The behaviour of the acceleration, stress, strain & buckling energy of Door panel is studied & compared it with experimental data.

IV. GEOMETRICAL AND FINITE ELEMENT MODEL OF DOOR SLAM TEST

The geometric modeling of the door is carried out in the Computer-Aided Engineering software CATIA V5 and for FE, meshing carried out using Altair Hypermesh v12.

A. Geometric Model of the Door Slam Test

A geometric model is used to represent the physical door. The geometric modeling of the door is carried out in the Computer-Aided Engineering software CATIA V5 which is capable of producing precise solid and surface geometry. Finite element models associated with the geometric model of the door are created in order to analyze the strength of the door. The dimensions of the reference door were measured a close representation of the important geometric parameters to the physical door modeled. Detailed surface models of the major door structural members including the outer panel, inner panel, reinforcing components and rigid surface on which door slams were drawn in CATIA V5, see Figure 1- 2. For this study door latches and lock are excluded from model.

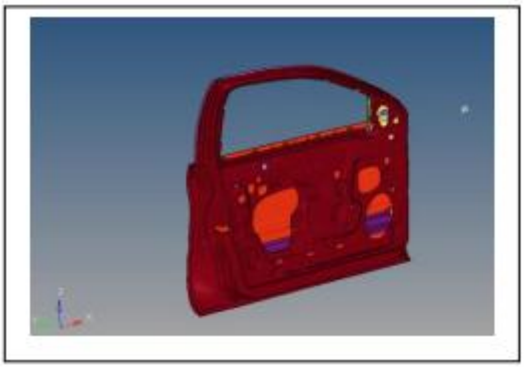

Fig. 1.Inner panel of Door

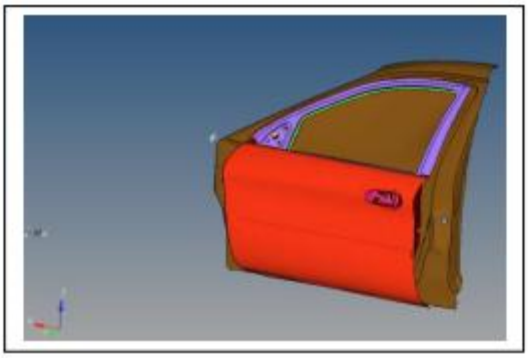

Fig. 2.Assembly Model of Door Slam Test with Rigid Surface

B. Meshing Geometry of Door Slam Test

After geometry cleanup, meshing was carried out using Altair Hypermesh v12. For meshing crash analysis criteria were followed.

Contact modeling is used to simulate the interaction between parts in the Door which may bear against each other during deformation under load. Separation of surfaces is allowed after two parts come in contact during an analysis. Contact is also defined for the rigid body form coming in contact with the Door. Contact within the Door structure is defined in order to simulate joints between Outer panel, reinforcing components and inner panel.

Table I: Meshing criteria

Sr. No.	Comment	Criteria
1	Element Length - minimum	≥5mm
2	Aspect ratio	≤2.0
3	Warpage	≤10°
4	Jacobian	≤0.6
5	Skewness	≤45°
6	QUAD element minimum internal angle	≥45°
7	QUAD element maximum internal angle	≥135°
8	TRIA element minimum internal angle	≥30°
9	TRIA element maximum internal angle	≥120°
10	Total number of triangles	≤5%

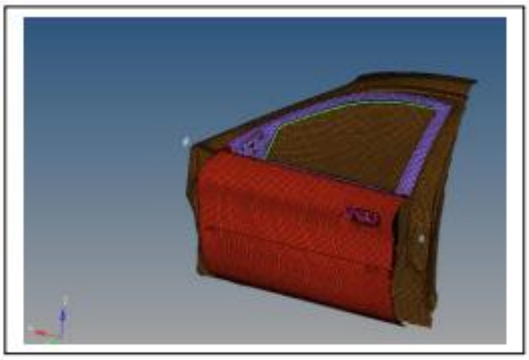

Fig. 3.Meshed model of Outer panel of Door

C. Assign Properties

Properties were assigned to all components as per car door component properties

Table II: Material &Thickness assigned to different components

Sl. No	Part Name	Material Name	Thickness (mm)	Section Type
1	Outer Door Panel	Cold Rolled sheet	0.70	Sectshll
2	Inner Door Panel	Cold Rolled sheet	0.68	Sectshll
3	Horizontal Reinforcing Member (Purple color)	FRP	1.56	Sectshll
4	Vertical Reinforcing Member (Green color)	FRP	1.00	Sectshll
5	Vertical Reinforcing Member (yellow color)	FRP	2.30	Sectshll
6	Rigid member	Mat_Rigid _Free	2.68	Sectshll

Table III: Properties assigned to Material

Sl. No	Part Name	Density, ρ	Young's modulus, E	Poisson's ratio, υ
1	MATL24	7890	210	0.3
2	MATL20	3310	210	0.3

D. Boundary conditions

The function of the boundary conditions is to create and define constraints and loads on finite element models.

The local axis is created at position of door hinge about which door revolves while closing and opening. Rotational degree of freedom is given to door about local axis, which allows door to rotate. All degrees of freedom of rigid surface are locked on which door slams.

V. RESULTS AND DISCUSSION

Results are mentioned in two stages. In first LS-Dyna results are given and also these LS-Dyna results are compared with experimental results for validation and discussion.

A. Acceleration-Time history at Outer Panel

Measurement of acceleration- time history is done at 8 locations on Outer panel of Door. These 8 locations are same as that of locations where accelerometer is attached to measure acceleration-time history experimentally as shown in Figure 4

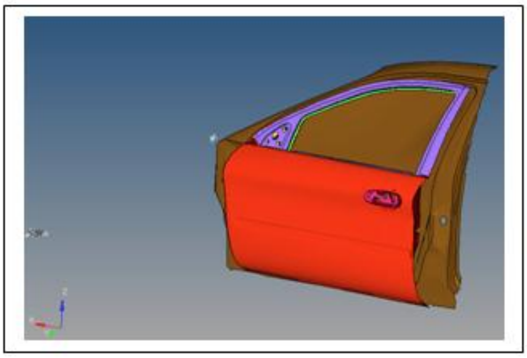

Fig. 4.Location at which acceleration-time history simulated.

Table IV: Acceleration-Time history at various locations (CAE)

S.N	Time (in Sec)	Acceleration (in 1 × G) unit at location							
		1	2	3	4	5	6	7	8
1	0	0	0	0	0	0	0	0	-0.12
2	0.01	-0.2	-0.08	-0.26	-0.34	-0.45	-0.34	-0.34	-0.43
3	0.02	-0.1	-1.09	-0.2	-1.2	-0.56	-0.43	-0.23	-0.2
4	0.03	0.1	0.1	-0.45	-0.65	-0.65	-0.23	-0.46	-0.29
5	0.04	-0.17	-1.34	-0.76	-0.94	-0.36	-0.45	-0.65	-0.27
6	0.05	-0.03	-0.12	-0.4	-1.11	-0.78	-0.37	-0.43	-0.14
7	0.06	-0.23	-0.98	-0.03	-0.09	-0.53	-0.42	-0.29	-0.46
8	0.07	0.03	0.18	-0.8	-1.09	-0.63	-0.27	-0.28	-0.65
9	0.08	0.08	-0.76	-0.45	-0.93	-0.47	-0.13	-0.19	-0.42
10	0.09	-0.14	0.46	-0.9	-0.34	-0.78	-0.1	-0.15	-0.83
11	0.1	0.1	0.13	-0.29	-1.67	-0.14	-0.43	-0.21	-0.93
12	0.11	-0.13	-1.23	-1.8	-0.56	-0.43	-0.26	-0.04	-0.43
13	0.12	-0.07	-0.54	-0.1	-0.14	-0.67	-0.84	-0.19	-0.34
14	0.13	0.03	0.84	0.75	-0.83	-0.78	-0.72	-0.12	-0.15
15	0.14	0.2	-1.2	0.18	-1.62	-0.25	-0.03	-0.19	-0.24
16	0.15	0.12	-0.7	-0.2	-0.09	-0.3	-0.45	-0.25	-0.27
17	0.16	-0.24	0.1	-0.54	-0.06	-0.53	-0.31	-0.01	-0.26
18	0.17	-0.13	-0.32	0.1	-0.76	-0.52	-0.04	-0.4	-0.24
19	0.18	-0.17	-0.45	-1.35	-1.61	-0.47	-0.13	-0.52	-0.16
20	0.19	-0.24	0.08	-0.9	-0.03	-0.93	-0.09	-0.73	-0.96
21	0.2	0.1	-0.08	-1.09	-0.45	-0.87	-0.05	-0.71	-0.24
22	0.21	0.13	-0.2	-0.6	0.98	-0.05	0.19	-0.92	3.44
23	0.22	0.06	-0.65	-0.78	1.4	-0.46	0.39	-0.83	5.47
24	0.23	-0.13	0.74	-0.2	1.23	5.45	-0.93	-0.81	12.59
25	0.24	-0.22	-1.87	-0.6	11.35	12.68	8.43	9.34	0.04
26	0.25	1.2	0.5	3.7	10.34	5.02	6.59	7.62	-9.36
27	0.26	5.3	5.65	7.34	-1.89	-7.39	1.51	-4.23	-4.23
28	0.27	7.6	1.4	1.65	-11.09	-3.54	-9.16	-8.94	-3.96
29	0.28	-11	-16	-9.34	1.2	-0.04	0.84	0.62	-2.43
30	0.29	2	1.5	10.4	9.5	-0.24	3.45	3.54	-5.83
31	0.3	0.98	14.2	0.3	1.5	0.45	3.98	3.94	-5.75
32	0.31	-7.8	-6.4	-7.48	-6.54	2.48	-4.05	-4.12	-0.26
33	0.32	5	9.38	4.92	-3.04	-4.39	-0.29	0.43	-0.65
34	0.33	1.3	0.6	0.26	6.43	0.95	2.04	4.56	3.05
35	0.34	-5	-8.8	-5.8	-0.75	1.3	2.84	3.09	1.4
36	0.35	-3.2	-4.26	-4.25	4.52	2.43	-0.98	-0.98	-0.04

Figure: 5 shows comparison of predicted FEM results of Accelerations-Time history and experimentally measured results of Accelerations-Time history at location 2

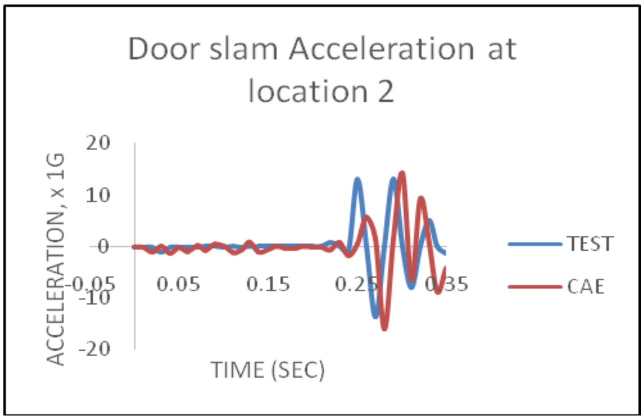

Fig. 5.Comparison of FEM & Experimental results of Acceleration-Time historyof Door slamming at location 2

The maximum accelerations occur at Location 2 and that acceleration is 14.2×G. This location is near the center of the outer panel. This is because location 2 is at the center of the panel and will have less reinforcing effect from the inner and other reinforcements. In contrast, regions closer to the door edges, such as locations 5-8, experience less acceleration. The accelerations at these locations dampen at a faster rate compared with the response at locations1-4.

B. Elastic Buckling/ Oil-canning of the Outer Panel of Door during Slam

The outer panel displacements relative to the closed position of the door are calculated by subtracting the displacements of the door when closed quasi-statically from the displacements when closed dynamically. The resulting relative displacements of the outer panel reveal its elastic buckling/oil-canning behavior during the last stages of the slam event. When the buckling is severe enough to cause plastic deformation, oil-canning phenomenon may result.

The contours of relative displacement (in the y-directions – perpendicular to the door outer panel) of the outer panel are shown in Figures 6- 7 at various times. The time values are chosen to approximately correspond to the peaks and valleys of accelerations on the outer panel during the last stages of the slam event.

This shows an interesting buckling phenomenon resulting in the alternate inward and outward buckling of the panel during the slam event. A similar phenomenon, called flutter, occurs due to aerodynamic loads under driving conditions. In Figures 6- 7, positive values of relative displacement are in the inward direction while the negative values represent the outward relative displacement.

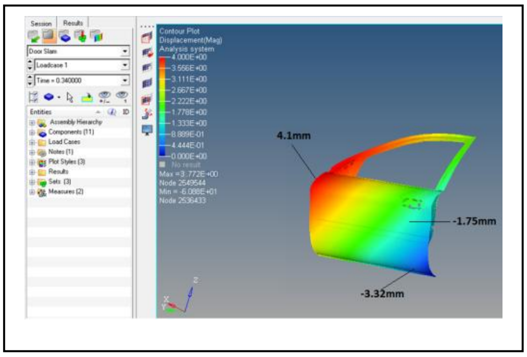

Fig. 6.Contours of displacement revealing the displacement of the outer panel during the slam event relative to the closed position of the door, at time, t =0.34 seconds

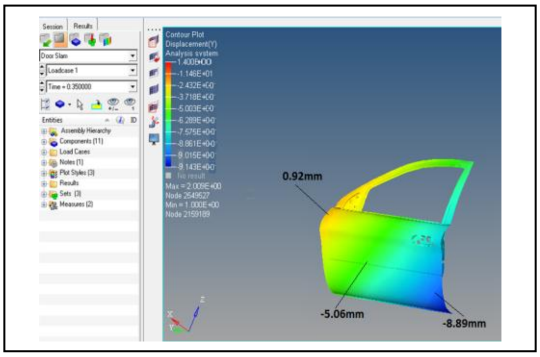

Fig. 7.Contours of displacement revealing the displacement of the outer panel during the slam event relative to the closed position of the door, at time, t =0.35 seconds

At t=0.25 Sec we can see one outward buckling area in weaker area of outer panel. As time progresses at t=0.27 Sec the same area of outer panel reverse the buckling mode and pop in. This alternating sequence of buckling modes may also imply that the panel would experience "flutter" during vehicle driving conditions.

The buckling regions indicate regions of weakness and hence braces need to be used to strengthen these regions. Also, these regions may pose NVH issues when the vehicle reacts to aerodynamic loads, by causing flutter and accompanying noise.

C. Surface strains & stresses on Inner Panel of Door during Slam

Certain regions of inner panel are more prone to fatigue failure as a result of repeated slam cycles. The evolution of fatigue damage, particularly under low-cycle fatigue conditions, depends on the strain levels and amplitudes experienced by the panel during representative slam cycles. Thus, as a first step toward developing a CAE based fatigue prediction methodology, it is important to examine the predictability of surface strains.

Filtered results of major principal strains are obtained at location 1 and 2, also Filtered results of major and minor principal stresses are obtained at all 6 locations as shown in Figure 8. These 6 locations are same where micro-strains are measured experimentally.

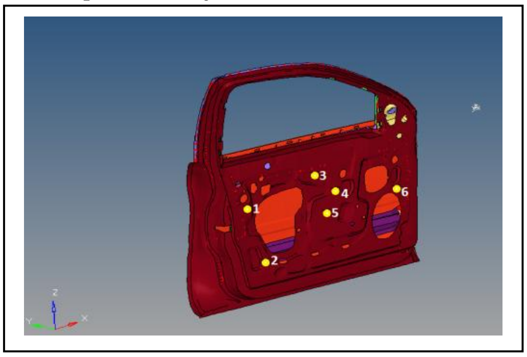

Fig. 8.Location at which strain-time & stress-time history simulated

Table V: Major Principal Strain -Time history at various locations (FEM)

S.N	Time (in Sec)	Major Principal strain at location	
		1	2
1	0	0	0
2	0.01	0.00015	0.0011
3	0.02	0.00012	0.0023
4	0.03	0.00014	0.00102
5	0.04	0.00013	0.00321
6	0.05	0.00024	0.00104
7	0.06	0.00014	0.00205
8	0.07	0.00016	0.00311
9	0.08	0.00045	0.00063
10	0.09	0.00049	0.00169
11	0.1	0.00036	0.00127
12	0.11	0.00032	0.00153
13	0.12	0.00046	0.00218
14	0.13	0.00051	0.00127
15	0.14	0.00042	0.00202
16	0.15	0.00052	0.00285
17	0.16	0.00054	0.00125
18	0.17	0.00074	0.00052
19	0.18	0.0013	0.00051
20	0.19	0.0015	0.00041
21	0.2	0.0018	0.00023
22	0.21	0.00094	0.00053
23	0.22	0.00067	0.00063
24	0.23	0.00094	0.00359

25	0.24	0.00751	0.00498
26	0.25	0.00459	0.0149
27	0.26	0.0043	0.0135
28	0.27	0.00485	0.0156
29	0.28	0.00367	0.0103
30	0.29	0.0024	0.0174
31	0.3	0.00394	0.0145
32	0.31	0.00482	0.0206
33	0.32	0.00138	0.00975
34	0.33	0.00315	0.00931
35	0.34	0.00254	0.00858
36	0.35	0.00485	0.0097

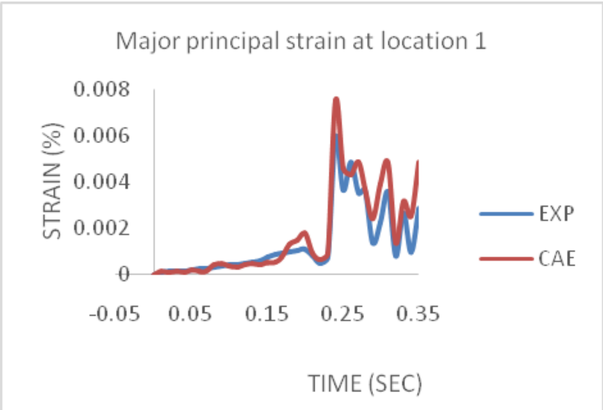

Fig. 9.Comparison of FEM & Experimental results of Major Principal Strains- time history of Door slamming at location 1

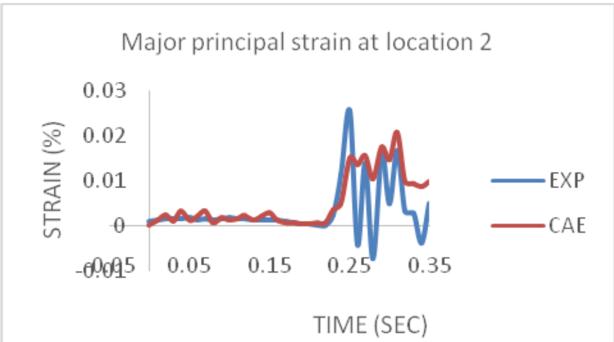

Fig. 10. Comparison of FEM & Experimental results of Major Principal Strains- time history of Door slamming at location 2

Table VI: Major Principal Stress -Time history at various locations (FEM)

S.N	Time (in Sec)	Major Principal Stress at location (in MPa)					
		1	2	3	4	5	6
1	0	0	0	0	0	0	0
2	0.01	0.32	0.09	0.45	0.54	0.12	0
3	0.02	0.84	0.54	0.12	0.68	0.44	0.09
4	0.03	0.69	0.34	0.18	0.56	2.3	1.23
5	0.04	0.2	0.51	0.09	0.34	1.23	0.09
6	0.05	0.54	1.4	0.04	1.76	3.32	3.34
7	0.06	0.49	0.04	0.18	0.43	0.21	6.54
8	0.07	0.67	0.35	0.67	1.4	2.3	0.08
9	0.08	0.26	2.2	0.27	0.54	2.98	2.2
10	0.09	0.49	0.87	0.23	0.67	1.12	1.12
11	0.1	0.78	0.05	0.72	0.23	0.98	7.32
12	0.11	0.49	6.59	0.17	0.65	0.02	5.4
13	0.12	0.94	0.5	0.98	0.87	0.43	2.45
14	0.13	0.2	8.41	1.34	0.32	0.98	4.34
15	0.14	0.63	0.03	1.09	0.54	0.09	8.43
16	0.15	0.94	0.54	0.83	0.54	0.32	2.5
17	0.16	0.23	0.19	0.43	0.25	0.55	9.83
18	0.17	3.52	0.93	1.02	1.65	0.43	2.09
19	0.18	0.05	1.45	0.87	0.06	1.03	8.32
20	0.19	2.54	7.02	0.58	0.09	0.3	6.43
21	0.2	5.43	4.8	1.83	0.87	2.34	0.98
22	0.21	2.62	2.45	2.49	0.98	0.04	4.98
23	0.22	8.62	0.95	0.75	0.48	5.5	9.43
24	0.23	3.57	5.2	-10.34	3.54	1.3	15.32
25	0.24	16.5	13.63	49.55	0.54	0.3	39.43
26	0.25	9.75	12.42	71.34	5.43	8.6	6.43
27	0.26	10.34	34.54	-38.6	13.79	1.87	40.32
28	0.27	15.39	0.43	-26.59	7.65	3.54	1.5
29	0.28	9.73	23.43	-10.43	5.76	1.3	134.3
30	0.29	10.75	12.94	-26.34	6.87	9.89	6.5
31	0.3	10.94	13.23	65.34	2.45	4.5	123.34
32	0.31	14.5	16.52	35.43	13.56	4.1	5.54
33	0.32	7.54	5.49	10.06	11.45	2.65	84.43
34	0.33	15.43	0.04	-20.47	5.67	3.4	0.54
35	0.34	5.02	15.93	29.87	3.56	0.45	123.32
36	0.35	10.73	5.49	24.51	9.65	9.45	6.76

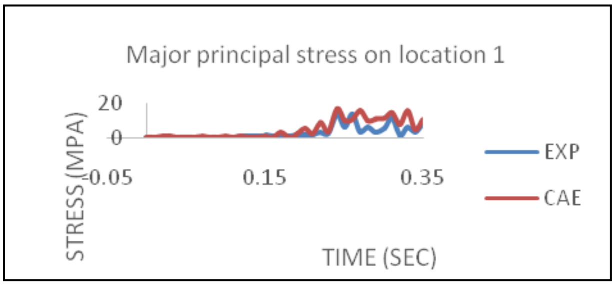

Fig. 11. Comparison of FM & Experimental results of Major Principal Stress- time history of Door slamming at location 1

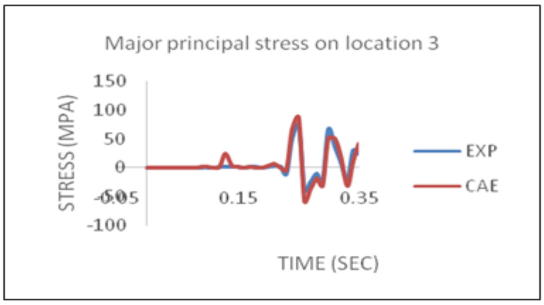

Fig. 12. Comparison of FEM & Experimental results of Major Principal Stress- time history of Door slamming at location 3

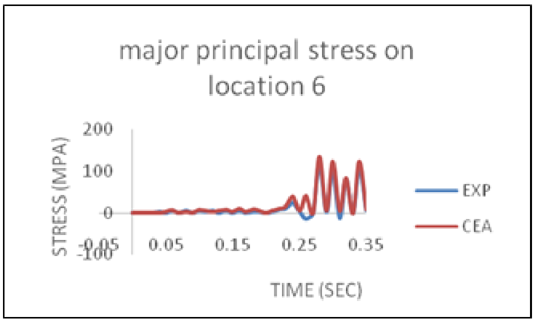

Fig. 13. Comparison of FEM & Experimental results of Major Principal Stress- time history of Door slamming at location 6

Table VII: Major Principal Stress -Time history at various locations (FEM)

S.N	Time (in Sec)	Minor Principal Stress at location (in MPa)					
		1	2	3	4	5	6
1	0	0	0	0	0	0	0
2	0.01	-0.45	0.01	-0.05	-0.12	0.31	0
3	0.02	-0.58	-0.04	-0.07	-0.13	0.34	0
4	0.03	-0.85	-0.42	-0.03	-0.34	0.94	0.1
5	0.04	-0.83	-0.12	-0.23	-0.98	-4.5	0.12
6	0.05	-0.24	-0.83	-1.45	-1.3	-0.23	-0.12
7	0.06	-0.96	-1.2	-2.43	-0.03	-5.56	-2.22
8	0.07	-0.96	-0.97	-0.09	-0.43	3.4	1.2
9	0.08	-0.73	-0.43	-3.45	-1.43	-2.34	-1.32
10	0.09	-0.19	-0.54	-6.54	-2.3	-4.43	-1.2
11	0.1	-0.67	-3.45	-8.47	-0.02	-0.43	-0.11
12	0.11	-0.29	-6.45	-0.05	-0.23	-4.3	-3.3
13	0.12	-2.4	-7.54	-9.45	-1.2	-8.5	-4.4
14	0.13	-0.35	-8.43	-12.3	-0.05	-8.7	-5.66
15	0.14	-2.75	-8.98	-0.07	-0.98	-0.45	-2.3
16	0.15	-0.03	-8.23	-0.08	-0.56	-75	-0.34
17	0.16	-0.28	-6.43	-14.93	-0.98	-10.54	-3.3
18	0.17	-3.59	-8.43	-0.04	-0.05	-8.7	-4.44
19	0.18	-0.3	-7.43	-0.05	-0.19	-0.6	1.2
20	0.19	-0.53	-10.43	-0.02	-0.21	-0.01	-2.2
21	0.2	-0.95	-11.43	-1.48	-1.2	-8.54	-9.4
22	0.21	-2.44	-12.3	-5.37	-3.4	-13.5	-3.45
23	0.22	-6.39	-12.98	-27.59	-2.3	-6.4	-3.1
24	0.23	-2.47	-0.32	-0.04	-2.8	-23.3	-17.2
25	0.24	-0.05	-56.34	-2.45	-4.4	-18.34	-20.2
26	0.25	-9.47	-0.49	-1.54	-4.6	-29.43	-32.3
27	0.26	-4.62	-25.54	-15.43	-2.3	-16.3	-10.2
28	0.27	-13.56	-0.9	-23.43	-13.4	-0.32	-14.4
29	0.28	-15.94	-32	-4.59	-2.3	19.32	5.5
30	0.29	-4.75	-0.04	-0.06	-8.4	-1.34	-0.1
31	0.3	-19.654	-48.4	-3.56	-8.5	-12.3	8.98
32	0.31	-21.67	-0.9	-6.28	-5.5	-3.4	-59.09
33	0.32	-3.72	-0.67	-0.05	-3.4	-15.4	-15.5
34	0.33	-7.42	-0.54	-43.71	-8.6	0.76	3.2
35	0.34	-8.69	-0.07	-25.09	-2.3	-15.5	0.3
36	0.35	-4.27	-41.43	-24.86	-7.6	-3.4	-16.6

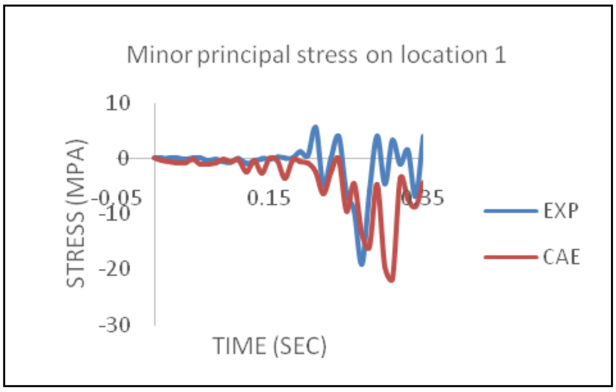

Fig. 14. Comparison of FEM & Experimental results of Minor Principal Stress- time history of Door slamming at location 1

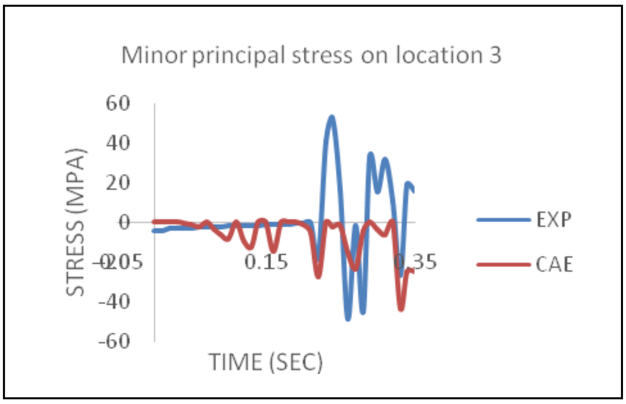

Fig. 15. Comparison of FEM & Experimental results of Minor Principal Stress- time history of Door slamming at location 3

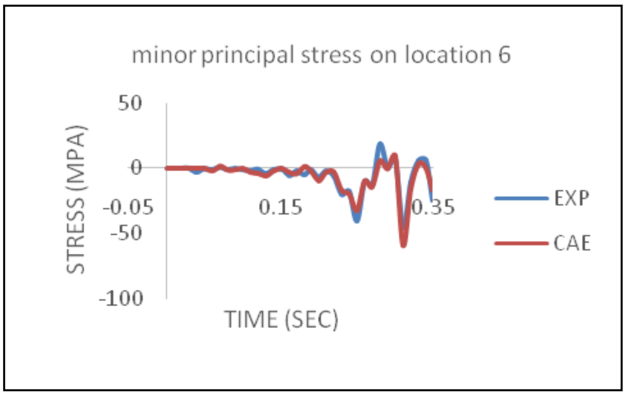

Fig. 16. Comparison of FEM & Experimental results of Minor Principal Stress- time history of Door slamming at location 6

Similar to strain results, for location 1 and location 2 from Figure 9 - 10 FEM results are comparable to that of Experimental results. And at the end of slam event FEM values are high compared to experimental due to rigid surface consideration in simulation. The comparison of stress histories for locations 3, 4, 5 and 6 shows higher values of FEM stress results as compare to experimental. Reason for this variation of result is the presence of window regulator mechanism, motor, window glass and speaker system in the Door which is used for obtaining experimental results. Due to these component distributions of stress would be altered. Thus the local stress and strain value affect by approximation made in FEM. The maximum principal stress is at location 6 and it is 123.34 MPa.

VI. CONCLUSION

The swinging doors which are the most common are almost the most complicated parts in a car since they not only determine the general guidelines of car style, but also are vital for passenger's safety by protecting humans from side crashes. So it needed to be designed by considering aesthetic, ergonomic and safety aspects. By checking these design ability to withstand working conditions various methods are developed. In this work used FEM method for checking Acceleration, buckling energy, principal strains and principal stress related to slam event.

As FEM results are input dependent those results are validated with experimental results. From this work certain outputs are found out which are mentioned below.

From time history of acceleration simulation results on outer panel we found out maximum acceleration occurs at location 2 and value of maximum acceleration is14.2×G at 0.30 sec. This happens because this location is at the center of the panel and will have less reinforcing effect from the inner and other reinforcements.

Simulation results of displacement of the outer panel during the slam event shows that the outer panel goes through a complex buckling pattern during the slam event. The buckling of the outer panel can cause undesired flutter and result in NVH issues.

From major principal strain- time history results we conclude maximum principal strain is at location 2. Maximum principal strain is 0.0174% at 0.30 Sec.

Also from principal stress- time history simulations, maximum principal stress is found out at location 6. Maximum principal stress is 123.34 MPa at 0.31 Sec.

From comparison with Experimental results we can say that FEM results holds good with experimental results. Some variations occur due to various considerations in FE analysis. Reasons for variations are consideration of rigid surface for slamming in FEM in place of vehicle body for experimental test. Also other reason is window regulator mechanism, motor, window glass and speaker system in the Door which is used for obtaining experimental results are not modeled in FEM. these variations are small so we can say FEM results are validated with that of Experimental results.

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