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Design and Crash Analysis of Front Car Bumper to Achieve Material Optimizations

[1]Mr. Suhail Masud Patel, [2]Dr. Shashank Thakre, [3]Prof. Kishor Padghan

[1]Student, [2]Professor, [3]Assistant Professor

[1]Mechanical Engineering Department,

[1]Vidarbha Youth Welfare Society's Prof. Ram Meghe Institute of Technology and Research Badnera - Amravati 444701(MS), India

Abstract: Front can bumper not only provide aesthetic look to the car, but also it provides safety to the car passenger. It is generally made up by plastic, rubber, fiber material to withstand up to certain amount of impact. On higher impact it should collapse and should not create any damage on other car parts, body as well as passenger. Maximum impact force must be absorbed by the bumper. There are other several reasons why we use the plastic material for manufacturing car bumper.

The cost of the bumper is also an important factor which should be considered while the manufacturing. But the ultimate aim of the car bumper is to provide the maximum safety to the car passenger and other parts by absorbing maximum impact shock. While development of the bumper several tests are to be taken with different materials. Like vibration test, Crash test, Load test, Buckling Test etc. Results of these tests decide the usability of the bumper.

In this paper different bumper materials are to be tested with FEA Tool known as ANSYS 2020 R1. For this purpose, Maruti Wagon R car bumper is chosen with different materials from which it could be manufactured by considering all safety aspects. Virtual CAD Model is taken and imported into ANSYS Software to perform required analysis virtually. Further results are compared with each other and based on generated results, best suitable material is suggested to provide maximum safety with minimum cost.

Index Terms **- Car Bumper, ANSYS 2020 R1, Vibration test, Crash test, Load test, Buckling Test**

I. INTRODUCTION TO CAR BUMPER

Today, car bumpers can be made from anything from chrome-plated material to a variety of different rubber materials or plastics. This makes detailing car bumpers somewhat more complicated, as bumpers made from different materials require very different detailing treatments.

Bumper height from the roadway surface is important in engaging other protective systems. Airbag deployment sensors typically do not trigger until contact with an obstruction, and it is important that front bumpers be the first parts of a vehicle to make contact in the event of a frontal collision, to leave sufficient time to inflate the protective cushions.

Energy-absorbing crush zones are completely ineffective if they are physically bypassed; an extreme example of this occurs when the elevated platform of a tractor-trailer completely misses the front bumper of a passenger car, and the first contact is with the glass windshield of the passenger compartment. For this purpose, following material properties are needed in the bumper material.

Table 1: Required Material Characteristics for Bumper Material

Sr. No.	Material Characteristics
1	High impact resistance
2	Physical strength, specific toughness, light weight.
3	High heat resistance
4	High dimensional stability, low coefficient of thermal expansion, and low abrasion.
5	Good vibration damping, strength, and toughness.
6	Chemical inertness, high corrosion resistance
7	Easy serviceability

Today, numerical models reproduce all details of vehicles, and also include passengers. With such analysis and employing upwards of 1,000,000 elements, it may still take a few days to solve the problem even by the modern multiprocessor computers. Nowadays, with the development of the automobile technology, more and more light weighting materials like the Glass Material Thermoplastic (GMT) are applied to the automobile body. GMT provides a high strength to¬ weight ratio, chemical / corrosion resistance, and excellent impact properties at both low and high temperatures. Compared to metals, GMT offers greater design flexibility, lower tooling costs, and opportunities for part consolidation. Compared with thermoset composites, GMT improves productivity with shorter moulding cycle time, greater impact resistance, recyclability (melt reprocess ability), and elimination of controlled-storage requirements.

II. IMPACT MECHANISM

This kind of research on impact tests, the important point to be noted is the type of impact that we obtain elastic or plastic impact. Negligible quantity of energy will be losing in elastic impact in between two impacting bodies. Impact between two billiard balls can be considered as an example. Considerable amount of energy dissipation will be taking place in plastic impact. Impact between two automotive vehicles or at least between a rigid body and an automotive vehicle in which the vehicle gets crumple on an impact. It is also an example of an elasto-plastic impact.

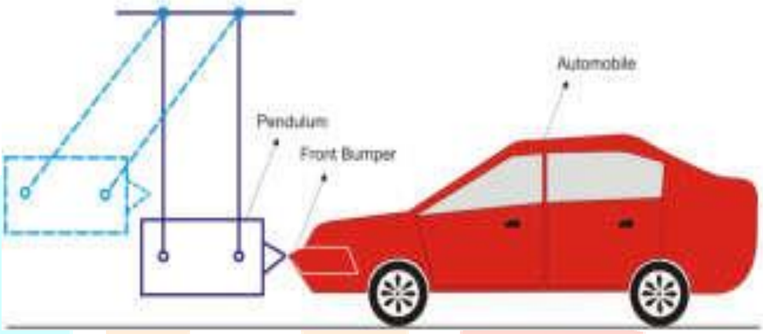


Fig. 1: Low-Speed Impact Test

Since the impact between the front bumper and an impactor is nonlinear and transient analysis are involved, this phenomenon can be very complicated in low-speed crashes. Therefore, the automobile manufacturers insist that material failure or crash should not occur in bumper system while designing the bumper. Such that the total energy will be conserved throughout the duration of impact.

Here, the impactor is considered as rigid body and the front bumper is made of composite and metallic materials, the load of the impact distributed irregularly along the connecting area over the connecting region of the bumper beam.

III. AIMS AND OBJECTIVES OF STUDY

1) Material Optimization for Front Car Bumper through virtual crash analysis.
2) FEA Analysis of Car Bumper and CAD Tool Learning.
3) Performance of Crash Analysis, Buckling and Vibration Analysis of Bumper.
4) FEA Tool learning and study.
5) Material Comparison (PC-ABS, Polyurethane, Poly-Vinyl-Chloride) with each other to find best material.

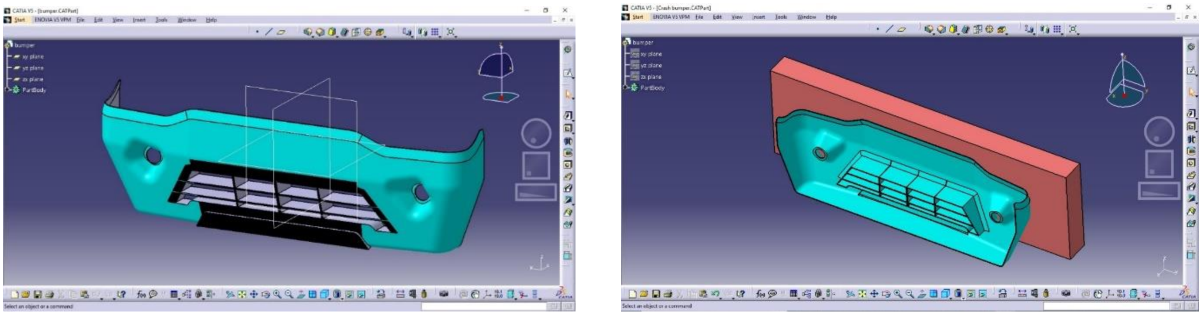
IV. LITERATURE REVIEW

Dharmateja Kruthiventi, 2 M. Venkaiah, “Modelling and Impact Analysis of Four-Wheeler Car Bumper: An Empirical Study”. In his study, the most important variables like material, structures, shapes and impact conditions are studied for analysis of the four-wheeler car bumper beam. [1] T.Krishnamoorthi, R.Girimurugan, M.Vairavel, S.Elango, D.Karthick, V. Muthurathnagiri, 7S.Velusamy, “Design and Impact Analysis of Automobile Front Bumper Beam by Varying Materials”. In their study, impact analysis on a typical automobile front bumper beam was carried out successfully by varying the materials. [2]

Nitesh joshi*1 Rupesh tiwari 2 G.V.R.Seshagiri Rao3, “Design and analysis of Front Bumper for Light Passenger Vehicles”. The aim of their study is to analyse and study the structure and material employed for car bumper in one of the car manufacturer. [3] Lu Weia, Yao Jiab,* Liu Xiangdongc, Xing Leid, Lv Xingwange, Yao Jingf, “Optimization Design of Inner Structure and Material of Cars Front Bumper Based on Finite Element Method”. In their paper, the bumpers with different inner structure (circular cross section form and honeycomb cross section), different materials (Al alloy, structural steel and polyethylene) have been researched by finite element method. [4]

V. CAD MODELLING OF CAR FRONT BUMPER

In this study we have chosen the Maruti Wagon R 2019 model hatchback car which is most popular and largest selling vehicle of his segment in India. Front car bumper is to be modeled on CATIA V5R21 Software. Fig. 3.2 shows the CAD model developed in CATIA V5R21 software. For this purpose, sketcher and part modules are used. Several commands from part module like pad, pocket, multi section solid, removed multi section solid, chamfer, fillet, shell etc are used.



(a) (b)

Fig. 2: Front Car Bumper CAD Model Developed in CATIA V5R21 Software

Fig. 2 (b) shows the front car bumper with obstacle. To perform Crash test with different speed such model is developed. Both bodies are different from each other and their collusion with some specified speed can provide strength, behavior of bumper material and shape.

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VI. DISCRETIZATION/MESHING OF CRASH TEST SET-UP

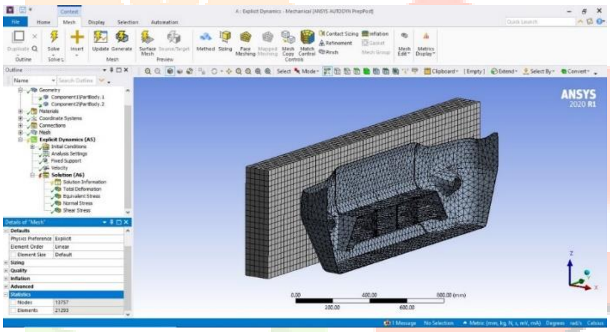


Fig. 4: Meshed view of Crash Test Set-up

Table 2: Nodes and Elements

Type of Element	3D Tetragonal
No. of Elements	21293
No. of Nodes	13757
Type of Elements	Square and 3D Tetragonal

Table 3: Properties of different materials for Crash Test Analysis

Property	**PC-ABS**	**Polyurethane (PUR)**	**Poly-Vinyl-Chloride (PVC)**
Young's Modulus (E)	1916.74 MPA	2410 MPA	3275 MPA
Poisson's Ratio (μ)	0.36	0.389	0.4
Density (ρ)	1150 kg/m3	1660 kg/m3	1400 kg/m3

VII. BOUNDARY CONDITIONS

To simulate the proper physical condition, velocity and obstacle fixing are to be attached properly. In case of Crash Test Set-up, it is fixed at the end of the obstacle where it actually comes in contact with Car Bumper. A car with 60 km/Hr, 65 km/hr and 70 km/hr velocities are in the consideration. Hence the velocity which is to be applied on Crash Test Set-up is considered including thrust and torque. Hence the Actual Boundary Conditions are as follows.

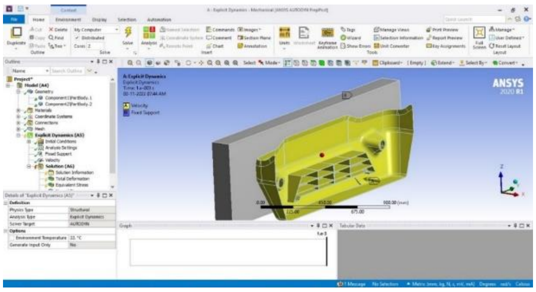
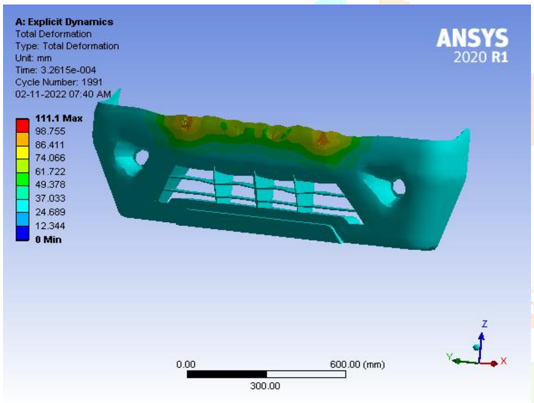


Fig. 5: Boundary Conditions applied on Crash Test Set-up for analysis

VIII. CRASH TEST RESULTS FOR PC-ABS MATERIAL

Crash Test Results for 60 km/hr Car Velocity (PC-ABS Material)



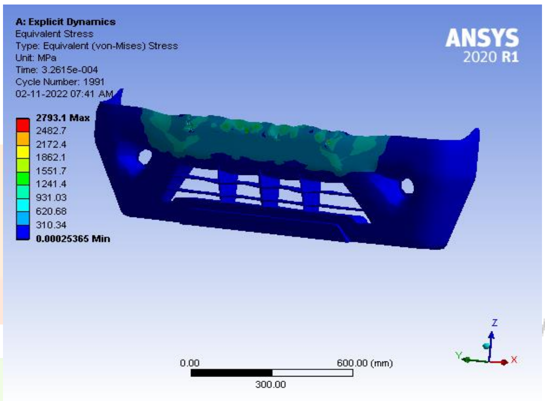
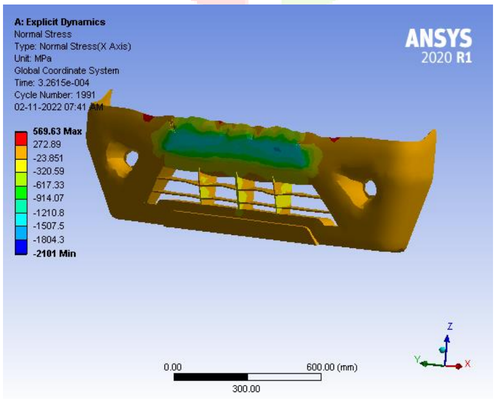


Fig. 6: Total Deformation Due to 60 km/hr speed. Fig. 7: Equivalent stresses developed due to crash

Figure 6 shows the total deformation due to hitting an obstacle with a speed of 60 km/hr. It is found that deformation is 111.1 mm which is too large and it will damage bumper as well as car front surface as shown in figure. The maximum deformation is observed at the bumper surface. Due to this deformation the engine parts are safe and able to absorb maximum shock due to impact.

Figure 7 shows the equivalent stresses due to crash. The stresses developed in this result is high (2793 MPa). It is due to the velocity applied and obstacle impact. The damage portion shown in the Fig. 5.4 is at the hitting surface.



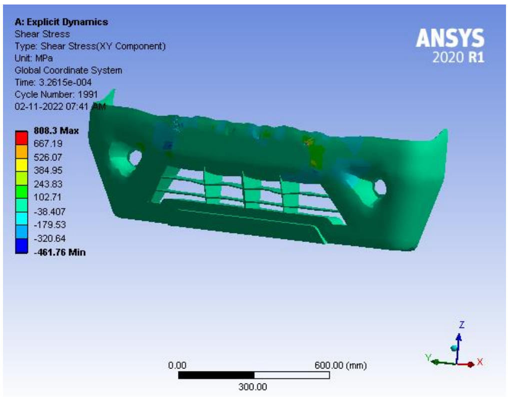


Fig. 8: Normal Stresses observed at 60 km/hr speed Fig. 9: Shear Stresses at 60 km/hr speed

Figure 8 shows the normal stresses which are 569.63 MPa. These stresses are also at higher value. Having higher stresses is desirable in the case of car bumper. It indicates the absorption of maximum impact forces. Figure 9 shows the shear stress value at 60 km/hr speed. As compare with normal stresses it is found higher (808.3 MPa). But the concentration of such higher stresses are at few spot only. This stress value provide shearing from specific location as shown in figure.

By observing all above results for 60 km/hr speed crash test, we found that, Bumper is itself capable to withstand on this speed and able to protect engine parts from maximum damage. It is able to absorb maximum shock.

Table 4 shows all the tabulated results from crash test analysis performed. By observing all the results, we found that increase of velocity also increase bumper damage. But athe speed of 60 km/hr, bumper damage is at considered level. But as speed increases the bumper damage increases and also tress values are beyond acceptable range. This may damage engine parts. Hence the speed level of 60 km/hr is found safer for engine parts protection and passengers also.

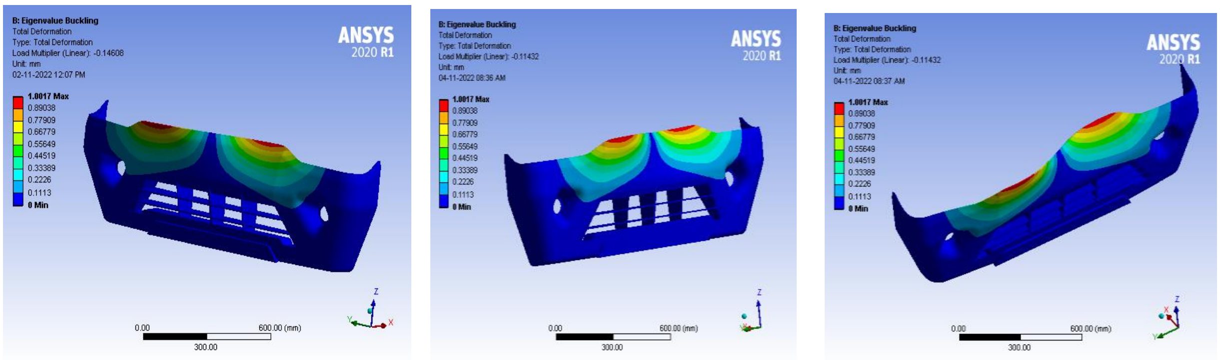
Table 4: Tabulated Results for PC-ABS Material in all the Crash Test Analysis

Sr. No.	Velocity	Result	PC-ABS	Polyurethane (PUR)	Poly-Vinyl-Chloride (PVC)
1	60 km/s	Total Deformation	111.1 mm	135.12 mm	140.32 mm
2		Equivalent Stress	2793.1 MPa	2940.17 MPa	3010.22 MPa
3		Normal Stress	569.63 MPa	614.12 MPa	630.65 MPa
4		Shear Stress	808.3 MPa	920 MPa	950.22 MPa
5	65 km/s	Total Deformation	652.64 mm	702.03 mm	720.35 mm
6		Equivalent Stress	3018.2 MPa	3125.12 MPa	3150.87 MPa
7		Normal Stress	475.33 MPa	540.58 MPa	560.78 MPa
8		Shear Stress	644.64 MPa	699.34 MPa	705.32 MPa
9	70 km/s	Total Deformation	602.36 mm	675.41 mm	695.44 mm
10		Equivalent Stress	3012.4 MPa	3285.66 MPa	3300.74 MPa
11		Normal Stress	1023.5 MPa	1112.55 MPa	1188.29 MPa
12		Shear Stress	663.83 MPa	663.83 MPa	690.42s MPa

Table 4 also shows the results generated through Polyurethane and Poly-Vinyl-Chloride (PVC) material. To compare materials with each other, their crash test analysis results are generated and tabulated in above two tables. Summery and detailed conclusion about above tables are given in conclusion.

IX. BUCKLING ANALYSIS

Buckling phenomenon can be defined as the structural instability that is usually associated with high compressional loading which results in a failure mode of structural element that is long and slender. Although, only compressive strength is the failure criteria for any short column, some more criteria are also to be considered in the failure of long columns like: Length of the column, Elasticity of the material used, second moment of area of the cross section, and how rigidly both the ends are supported. Bumper will lose its shape after the application of impact load which give the possible buckling deformation at 1 mm only as shown in figure 5.17. By observing below result, it is found that the buckling deformation will be observed at 1.03 mm.



(a) (b) (c)

Fig. 10: Buckling Deformation observed in Car Bumper for PC-ABS, Polyurethane and PVC Material

By observing Fig. (a), (b) and (c) for buckling analysis in all three materials, it is found that the buckling deformation all three materials is same i.e. 1 mm. Hence the buckling of car bumper will not offer a damage on bumper as well as engine parts.

Table 5: Vibration Analysis Results for car bumper considering all Materials

Sr. No.	Mode Shape	PC-ABS		Polyurethane (PUR)		Poly-Vinyl-Chloride (PVC)	
		Deformation (mm)	Frequency (Hz)	Deformation (mm)	Frequency (Hz)	Deformation (mm)	Frequency (Hz)
1	Mode 1	27.65	31.43	25.12	28.23	26.33	29.12
2	Mode 2	28.80	43.51	26.33	35.36	27.45	34.32
3	Mode 3	33.50	46.86	28.12	38.33	28.45	40.21
4	Mode 4	30.79	60.86	31.14	42.33	32.55	43.10
5	Mode 5	34.68	69.37	36.12	48.11	35.89	48.33
6	Mode 6	39.14	76.01	28.66	54.01	30.12	55.11

It is said that more the frequency safer the object. But in case of bumper the maximum frequency value is up to 77 Hz. If we compare this value with engine generated frequency (i.e. 30 Hz) then we found that bumper is quite safer at this frequency range.

X. CONCLUSION

By observing all the results generated at 60, 65 and 70 km/hr speed of vehicle for both PC-ABS, Polyurethane and Poly-Vinyl-Chloride material, it is found that at 70 km/hr speed value of equivalent stresses is maximum. Also, the normal stress value and shear stress values are greater than other two stresses. All these stresses developed indicates the failure of the bumper with higher speed. At speed 65 Km/Hr speed normal stresses are less. But the equivalent stresses are more and it will be responsible for failure of bumper with possible damage on engine parts. 60 Km/Hr speed is found better speed as the damage produce is less as deformation is less. Engine parts will have minimum or negligible impact penetration. Hence the 60 Km/Hr speed is found better for the car bumper allowable damage and ultimately engine parts and passenger safety.

Considering Buckling Analysis all three materials provide buckling deformation on similar value. Hence the buckling of bumper is found safer for engine parts and passengers.

Vibration analysis results are obtained with less frequency value in all three materials (76 Hz for PC-ABS, 54 Hz for Polyurethane and 55 Hz for Poly-Vinyl-Chloride material). But the maximum vibrations generated by car engine will not go beyond 30 Hz. Hence the bumper is safe for all three materials.

On the basis of material, it is observed that the PC-ABS Material is having better analysis results than the Polyurethane and Poly-Vinyl-Chloride material. Hence the PC-ABS material is found best suitable for the manufacturing of bumpers.

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