Crash Analysis of the Frontal Structure of a Car Using Explicit Dynamics

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Abstract: Crash analysis is the primary test conducted to determine crashworthiness and eliminate safety concerns in a vehicle. The improvements in roadways and implementation of new design technologies in automobiles, has shifted a tremendous focus on vehicle safety in recent years. Deaths due to road accidents over the years have increased, primarily due to the inability of a car to withstand load and impact forces during collision. Multiple tests to assign passenger cars with a Global New Car Assessment Program rating (NCAP) have been conducted and the result is still inconsequential. This study presents a comparative outlook for a more structurally suitable material. Materials were selected based on previous research conducted. Three different velocities of 40 km/hr, 80 km/hr, 120 km/hr were considered and a simulation to calculate Total Deformation, Equivalent Plastic Strain and Equivalent Stress (Von Mises) was carried out using Explicit Dynamics in ANSYS. Values calculated at these velocities are presented in a tabular form and graphs were made. Inference was drawn and a suggestion for a better material is made.

Keywords: Car Frame, Crash Analysis, Metal Matrix Composite, Structural Strength

1. Introduction

Crashworthiness of a car determines its structural integrity. The increasing importance of safety of a passenger car becomes a relevant field of study, in terms of passenger safety, frame analysis and material selection. With the advent of Material Sciences and Composites, the selection of an appropriate material has become a difficult choice. Composites offer higher structural strength without increasing weight. The possibilities in terms of use in the automotive industry thus widen and open a broader scope of analysis. Over the years various studies have been conducted either on strength of frame or material analysis in different components of a passenger car. Studies have been mutually exclusive and are yet to offer a conclusive material for broader application in car frames and improvement of its strength. Another reason for improvement in structural strength is safety of the driver and pedestrian. This factor makes suitable simulations essential to conduct better analyses of the material selected.

AbolfaziMasoumi, Mohammad Hasan Shojaeefardand AmirNajeebi [1], in 2011 conducted a test for Material selection for automotive closures. The conclusion states that the safety is influenced by different factors such as cost, weight and structural performance. The paper offered an intricate analysis of distance between engine parts and front bumper which is important for head impact and highlights the importance of material selection. N. Bhaskar and P. Rayudu [2] in 2015 conducted a similar analysis for the design of a car bonnet. The material selected was Aluminium Alloy, which is a widely applied metal in the automotive industry. J. Schulz and H. Kalay [3] in 2016, incorporated composite material in car bonnets. The criteria behind choosing composite materials was stiffness and pedestrian safety. Energy absorption on frontal collision was also taken into account for selection of a suitable material. The main focus was the sandwich design for the car bonnet which inculcates a core design. The material of the core imparted more strength to the bonnet in addition to the outer material. Composites used were Carbon Fiber Reinforced Plastic (CFRP) with Polyvinyl Chloride as a suitable resin. Further analysis to reinforce the theme of this research was done by Vulavapoodi Narayana, L. Ramesh and K. Veeranjaneyulu [4] in 2016, which further solidified the introduction of composites in Car Bonnet. Martin Mohlin and Mikael Hanneberg [5] in 2016, Johan Karlsson [6] in 2016 and L. Kiran, ShrishailKakkeri and Shridhar Deshpande [7] in 2018, conducted weight reduction analyses by introducing materials.

Study on individual parts has also surged in previous years. From car bumpers to shock absorbers, the theory behind usage of better individual components to increase overall strength has been an area of massive speculation. R. Balamurugan and Dr. M Sekar [8] in 2017 designed a shock absorber to protect the car chassis from collision by absorption of energy. Although a material-based analysis was also conducted, the main purpose of the study was to improve the crashworthiness of the car bumper by introducing a new design. Alen John and Sanu Alex [9] in their 2014 review took a slightly different approach. The main focus behind the literature review was to increase fuel efficiency and thus suggest reduction in individual weight of components.

So far, the main focus of study in this area has been incorporating materials into different external components and thus increasing their structural strength which offers higher safety for passengers and to the internal components of the car. To provide more context to the purpose of this study, research done in adopting different methodologies have been unique and offer variability in terms of result. Energy Absorption characterization to determine crashworthiness of a car was first investigated by CC Ma , F. C. Lan, J. Q. Chen, J. Liu and F. B. Zeng [10] in 2015. The analysis was done on Aluminium Foam and porosity, which plays a major role in energy absorption was carefully observed. The suggestion for a better material was made by comparing ratios of porosity and energy absorption of Aluminium Foam. The loads applied were axial, which means that the collision analysis was done in one direction. This further validates how unidirectional impact is an accepted way of suggesting a suitable material to determine crashworthiness. Shalabh Yadav and SK Pradhan [11] in 2014 used crash simulation to verify why explicit dynamics is an advisable methodology.

DiogoMontalvao and Magnus Moorea [12] in 2014 conducted a study to determine the importance of test protocols and why they are becoming stricter by the day to improve a car's performance in crash situations. He came up with an idea to replicate real time surroundings to study deformations in the frontal structure. GD Lohith Kumar, H. S. Manjunath, N. Shashikanth, Venkatesh Reddy [13] in 2018, computed crashworthiness of the scaled down Sedan car model. Computational approach and ANSYS Explicit Dynamics tool were used. It was seen that the extent of plastic deformation of the car increased with increase in velocity, the frontal part of the car absorbs a major portion of the impact energy. The velocities and the result on energy absorption hold importance to assess any result.

Steel and Aluminium prove to be the two metals which are widely used in automotive applications. There are two main material groups widely applied in car manufacturing: various grades of high strength steels and lightweight metallic alloys. Alloys of these metals are very cost effective in terms of manufacturing and availability. The use of these materials is not only for external frame and chassis components, but also for internal components like engines, brakes, transmission systems, etc.

Composite materials have a unique place in the manufacturing industry because of their properties such as high strength and stiffness, wear resistance, thermal and mechanical fatigue and creep resistance. Metal matrix composite (MMCs) is an advancement in production of composites.

The importance of review in the field of materials is necessary to justify the selection for this study. Aluminium Metal Matrix Composites have been a topic of wide interest in the field of Material Science because of their light weight, high stiffness and moderate strength. They meet safety and operational standards of various applications and also have proven to be cost effective. S. T. Mavhungu, E. T. Akinlabi, M. A. Onitiri and F. M. Varachia [14] in 2017 researched AMMC and its industrial application. The review states AMMC as “high performance substitutes” and versatile. RajanVerma, Saurabh Sharma, Dinesh Kumar [15] in 2017, conducted research on how reinforcements like Silica or Alumina make AMMC more desirable for applications in the automobile or aerospace industry. Comparison was made and Aluminium with reinforced Alumina proved to be a better material in terms of Impact Toughness and Compressive Strength which prove to be important factors in analysing a frontal collision.

Affordability also plays an important role in incorporating a new material into the automotive industry. Cost becomes an deciding factor in the automotive industry when it comes to material selection for vehicle components. David R Cramer, David F Taggart and Hypercar Inc. [16] in 2002 studied the “Design and Manufacture of an Affordable Advanced-Composite Automotive Body Structure”. The industry increasingly uses high-strength steel, aluminium, magnesium, plastics, and composites, all to varying degrees, to achieve modest weight savings. But more technical progress is required in order to improve fuel economy significantly and reduce emissions fleet-wide. They concluded that a body designed with composites offers 60% weight reduction with higher structural performance.

The above mentioned research papers focus on incorporating materials into individual components of the frontal structure of a car. Study conducted on alternate materials has not been applied to the entire frame of the car; tests for crashworthiness were done on the entire car frame but composite materials were not taken into account. This research paper aims to fill the gap between the exclusivity of Crash Analysis, Composite Materials and Structural Strength of a car frame.

2. Materials

Materials selected for this study were Aluminium Alloy 6061, AISI 1045 Steel and Aluminium Metal Matrix composite with Alumina. The selection of these materials was based on a variety of applications in the frontal structure of a car as well as on the research which has been conducted previously.

The material properties mentioned below were used as metrics when importing the material data into the ANSYS material directory to conduct Explicit Dynamics on the frontal structure of a car.

Table 1. Mechanical Properties

	Al 6061	AMMC Al	AISI 1045 Steel
Density (kg/m3)	2770	3900	7870
Specific Heat(J/kg-k)	875	831	486
Poisson's Ratio	0.33	0.33	0.29
Young's Modulus(MPa)	71000	350000	20000
Yield Strength(MPa)	280	238	310
Ultimate Tensile Strength (MPa)	310	380	565

The mechanical properties of these materials were collected from previous research and compiled together in MS Excel. These properties were later input into the ANSYS materials directory for analysis and comparison.

3. Methodology

For this study, SOLIDWORKS and ANSYS were used for design and simulation, materials were added to the ANSYS directory and the Modal Settings for Explicit Dynamics were specified. The final report was generated from ANSYS which contained required numerical values and graphs for each of the tested parameters. These values and graphs were inferred and the consolidated data is presented in this study.

3.1. CAD Design

A CAD model was chosen consisting of a wall of dimensions 210×170×100 cm3 and a car of dimensions 270×120×100 cm3. Both parts were joined in an assembly and the same was imported into ANSYS.

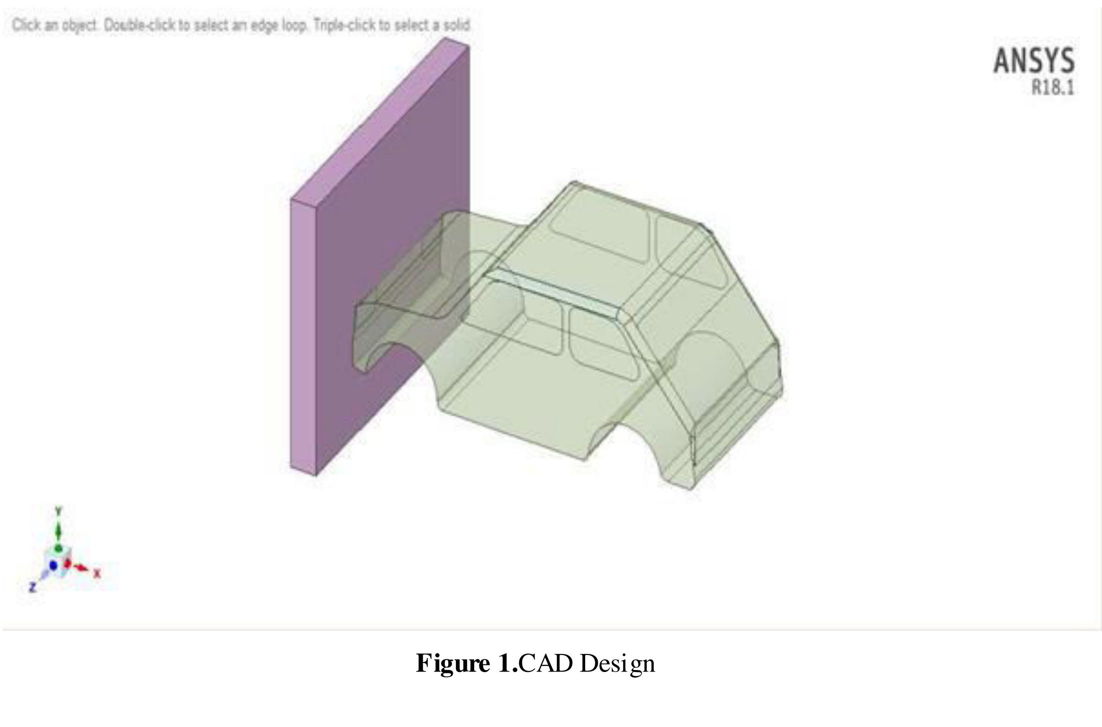

Figure 1.CAD Design

3.2. Adding new material

ANSYS Explicit Dynamics was used for this study. The Engineering Data was updated. Concrete (non-linear) was chosen as an additional material. Al 6061, AMMC and AISI 1045 were added to the material library and the following properties for the same were input for each material: Density, Isotropic Elasticity (Young's Modulus and Poisson's Ratio), Bilinear Isotropic Hardening (Yield Strength and Tangent Modulus) and Specific HeatFirst Paragraph: use this for the first paragraph in a section.

3.3. Modulation / Simulation settings

The geometry was imported into ANSYS and the Modal was opened. Geometry settings were updated. Concrete material was assigned to the wall and the stiffness behaviour was changed from the default ‘flexible’ to ‘rigid’. Different materials were assigned to the car (Al 6061, AMMC and AISI 1045 case-wise) and a thickness of 3 mm was given to the car body.

Meshing involved division of the entire model into small pieces (elements). To mesh the model, element type is decided first. A course mesh was generated with 10331 nodes and 9649 elements.

Velocity was added in the Initial Conditions of Explicit Dynamics. To justify the suggestion of a material, three different velocities 40 km/hr, 80 km/hr, 120 km/hr were taken along the negative X-direction such that the car would collide with the wall with these velocities.

End Time was taken as 0.001 seconds in the Analysis Settings and a fixed support was added and the output was calculated at 20 Result Number of Points. The entire body of the wall was chosen as a rigid fixed support.

The testing was done on three major parameters: Total Deformation, Equivalent Plastic Strain and Equivalent Stress (Von Mises), the same were added to the solution settings. The analysis was conducted.

4. Results

Maximum values of result points for three parameters were taken. Numerical values were entered in tables and comparison was presented through graphs.

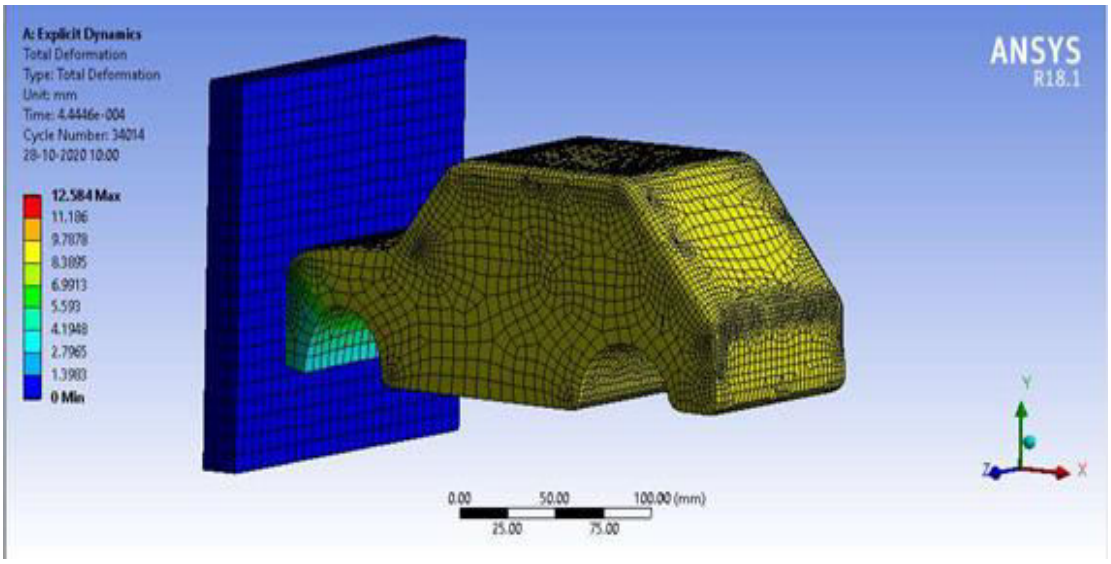

Figure 2. Total Deformation of AISI 1045 at 80 km/h

4.1. Total Deformation

Table 2. Total Deformation (mm)

Velocity	Al 6061	AMMC Al	AISI 1045 Steel
40 km/hr	5.1251	5.1392	5.9304
80 km/hr	6.9847	6.9514	12.559
120 km/hr	10.533	10.005	20.927

Deformation is an important indication of how the material reacts under a force. In this case, collision from the concrete wall causes the material in the frontal structure to deform.

Values show an increasing pattern with increasing velocity. Deformation can be attributed to higher force, as higher velocity translates to higher impact force at the time of collision.

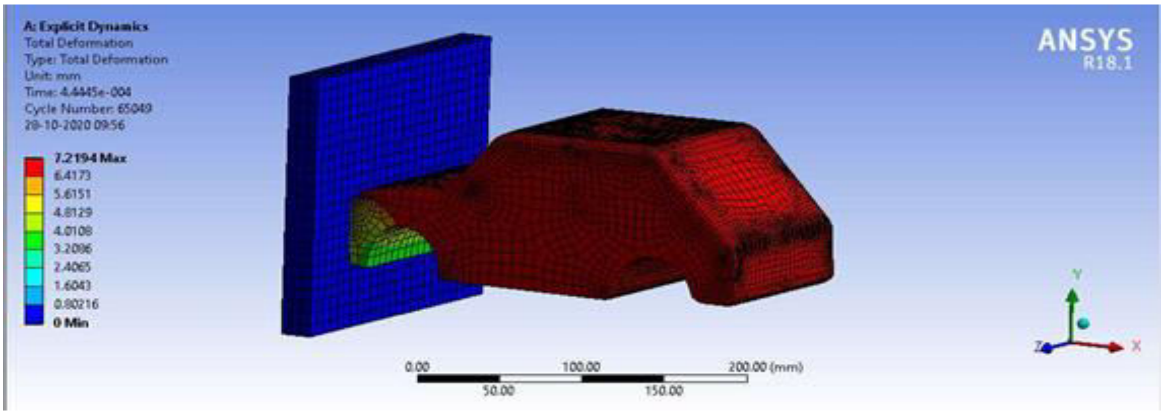

Figure 3. Total Deformation of AMMC at 80 km/h

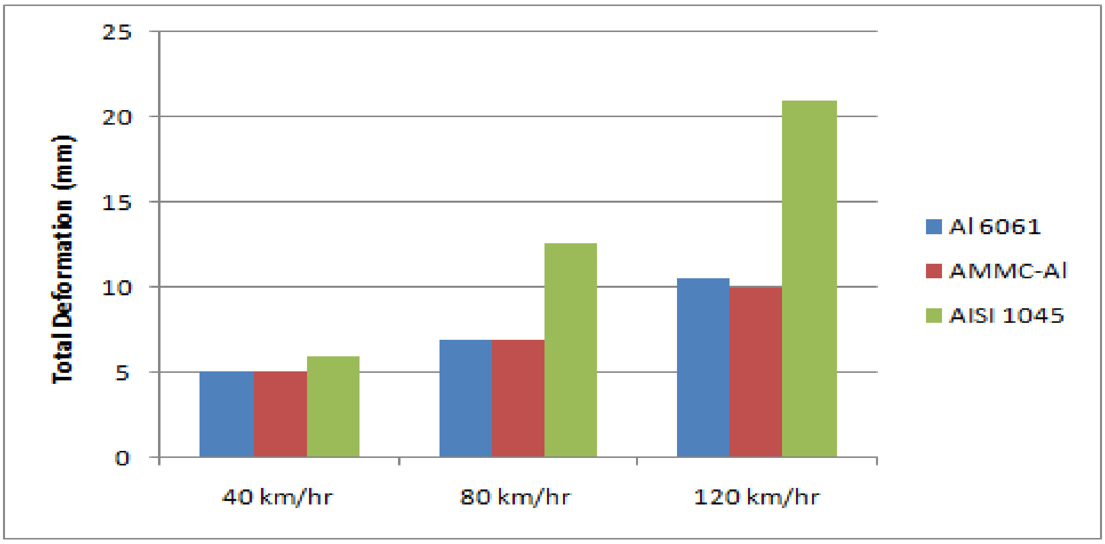

Figure 4. Total Deformation (mm)

Comparing the three materials, at 40 km/hr, Aluminium Alloy shows the least deformation of the three materials and significantly less deformation compared to AISI 1045 Steel which is a widely used material in the Automotive industry. At 80 km/hr and 120 km/hrAluminium Alloy sustains a significantly high deformation compared to AMMC. Both Aluminium Alloy and AMMC sustain considerably less deformation when compared to AISI 1045 Steel in all three cases.

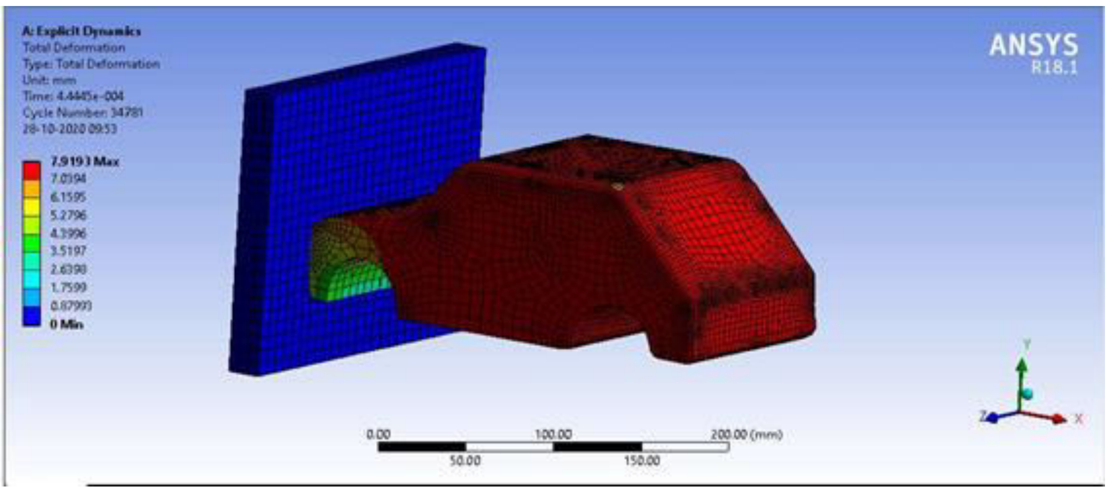

Figure 5. Total Deformation of Al 6061 at 80 km/hr

4.2. Equivalent Plastic Strain

Equivalent Strain helps characterize measurement at the moment in which the structural state of the component is formed after application of load.

Equivalent Strain shown by Aluminium alloy is considerably less compared to the other two materials at the lowest speed of 40 km/hr. This result concurs with the Total Deformation of Aluminium Alloy at the same speed. AMMC shows the second least equivalent strain and is followed by AISI 1045 Steel. The result shows a linearly increasing pattern with velocity as well. This pattern could be imparted to the total deformation result.

Table 3. Equivalent Plastic Strain (mm/mm)

Velocity	Al 6061	AMMC Al	AISI 1045 Steel
40 km/hr	0.00364	0.029166	0.10033
80 km/hr	0.22642	0.183260	0.62607
120 km/hr	0.48326	0.436580	0.74097

At 80 km/hr and 120 km/hr, Aluminium Alloy again shows a higher value of Equivalent Strain developed when compared to AMMC. Both Aluminium Alloy and AMMC show considerably less strain when compared to AISI 1045 Steel. Another observation to be made is that the increase of strain from 40 km/hr to 80 km/hr is significantly higher in every case compared to 80 km/hr to 120 km/hr.

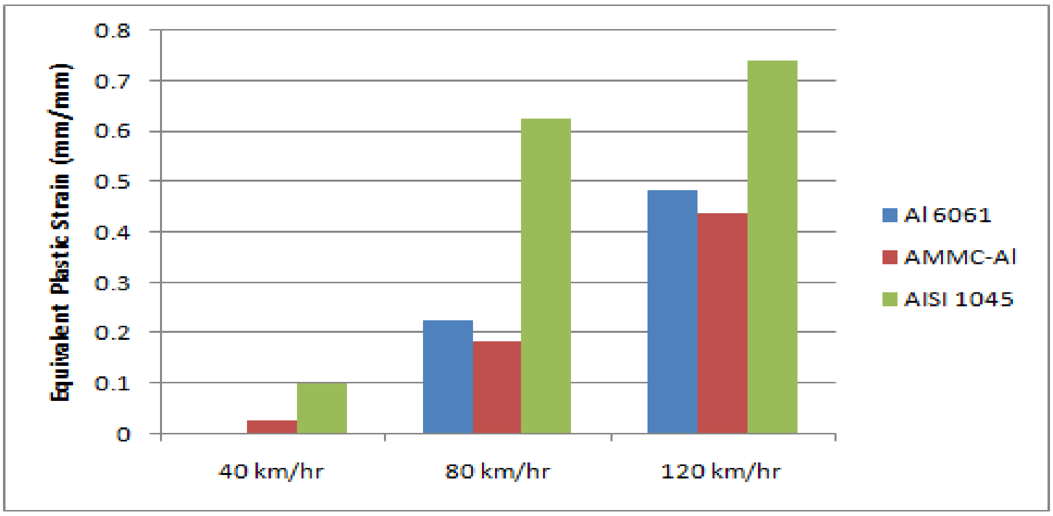

Figure 6. Equivalent Plastic Strain (mm/mm)

The Aluminium alloy at 40 km/hr in the above bar chart shows a negligible value. This is because the magnitude of the value when compared to other values in the table is extremely small (of the order 10^{-3}).

4.2. Equivalent Stress (Von Mises)

Von Mises stress is an important factor for determining whether or not a given material will yield or fracture. This parameter is used mainly for ductile materials such as metals. It is an important indicator of how much a given material is going to yield.

Stress developed is also a linear function of velocity in all three cases. At lower speeds like 40 km/hrAluminium Alloy shows the least stress developed among the three materials. AISI 1045 Steel shows the second lowest and AMMC shows the highest stress developed at 40 km/hr.

Table 4. Equivalent Stress (MPa)

Velocity	Al 6061	AMMC Al	AISI 1045 Steel
40 km/hr	283.76	348.84	313.75
80 km/hr	263.23	372.90	308.74

120 km/hr	359.21	482.30	484.62

At 80 km/hr, Aluminium and Steel show a decrease in stress developed at 80 km/hr. AMMC follows the usual pattern. At 120 km/hrAluminium Alloy takes a surge in terms of sustaining damage, similar to AISI Steel and AMMC which tells us about the fracture. Over varying speeds AMMC takes a linear amount of damage while Aluminium Alloy and AISI 1045 steel are induced with a very high stress.

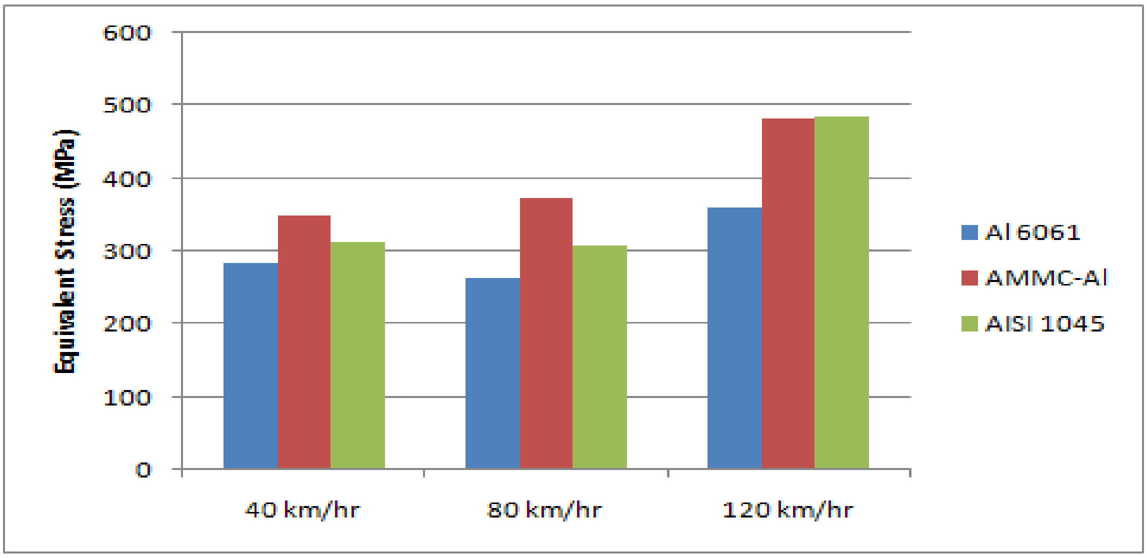

Figure 7. Equivalent Stress (MPa)

The values obtained from the analysis suggest that Aluminium Alloy and AMMC are considerably better materials in terms of damage control and impact resistance than AISI 1045 Steel as per the factors considered in this study.

With increasing concern for the environment, the weight reduction of components has become a priority. Composites (such as AMMC) have shown that they possess higher structural strength at a considerably lower weight. Since values of Total Deformation, Equivalent Plastic Strain and Equivalent Stress (Von Mises) of AMMC are comparable to those of the Aluminium Alloy, AMMC proves to be the better material, being lighter and having equivalent strength.

5. Conclusion

The results of this analysis prove why Composites are a better choice when it comes to selection of low weight and high strength materials. The comparison between the three materials taken in this study- AMMC, Aluminium Alloy 6061and AISI 1045, shows that Al Alloy and AMMC are superior to AISI 1045 in terms of their structural strength and deformation resistance. AMMC supersedes Aluminium Alloy owing to the fact that it is more lightweight, and it can thus be inferred that AMMC is the most suitable material for the frontal structure of a car for the protection of the vehicle itself and its internal components, passengers inside and pedestrians.

The increasing trend of incorporating Composites and alloys for weight reduction and higher strength has invited multiple studies over the years. The materials selected in this study were exemplary in depiction of why Composites and Alloys are materials for the future. Explicit Dynamics on Ansys proves to be a powerful tool for simulation of real time parameters. The advent of simulating software has not only decreased the cost of testing but also provided us with valuable data.

References

AbolfaziMasoumi, Mohammad Hasan Shojaeefard,Amir Najeebi. (2011). Comparison of steel, aluminum and composite bonnet in terms of pedestrian head impact,*Safety Science, Vol. 49,* 1371-1380.

N. Bhaskar, P. Rayudu.(2015). Design and Analysis of a Car Bonnet, *International Journal of Current Engineering and Technology*, *Vol. 5*, 3105-3109.

Vulavapoodi Narayana, L. Ramesh, K. Veeranjaneyulu.(2016). Design and Analysis of Car Bonnet by Using PRO-E Abs Ansys with FRP, *International Journal & Magazine of Engineering, Technology, Management And Research, Vol. 3*,811-821.

Martin Mohlin and Mikael Hanneberg**.** (2016)**.** *Chassis Component Made of Composite Material, M.S. Thesis, KTH Royal Institute of Tech., Stockholm, Sweden,* 78.

Johan Karlsson. (2016). Composite Material in Car Hood, *M.S. Thesis, Dept. Health Science and Technology*.

L.Kiran, ShrishailKakkeri, Shridhar Deshpande.(2018). Proposal of Hybrid Composite Material for Light Commercial Vehicle Chassis, *Materials Today, Vol. 5, Issue 11*, *Part 3*,24258-24267.

R. Balamurugan, Dr. M. Sekar.(2017). Design of Shock Absorber for Car Front Bumper, *International Journal of Science Technology & Engineering, Vol. 3, Issue 9*, 166-169.

Alen John, Sanu Alex. (2014). A Review on the Composite Materials used for Automotive Bumper in Passenger Vehicles*, International Journal of Engineering and Management Research, Vol. 4, Issue 4,* 98-101.

C. C. Ma, F. C. Lan, J. Q. Chen, J. Liu, F. B. Zeng. (2015). Automobile crashworthiness improvement by energy-absorbing characterisation of aluminium foam porosity, *Materials Research Innovations, Vol. 19 Supply 1*.

Shalabh Yadav, S. K. Pradhan. (2014). Investigations into Dynamic Response of Automobile Components during Crash Simulation, *12th Global Congress on Manufacturing and Management,*1254-1264.

DiogoMontalvão and Magnus Moorea. (2014). Computational Analysis of a Car Chassis Frame under a Frontal Collision, *International Journal of Engineering Research and Technology, Vol. 3, Issue 2*.

G. D. Lohith Kumar, H. S. Manjunath, N. Shashikanth, Venkatesh Reddy. (2018). Crash Analysis of four wheel vehicles for different velocity, *International Research Journal of Engineering and Technology, Vol. 5, Issue8,*1530-1538.

S.T. Mavhungu, E. T. Akinlabi, M. A. Onitiri, F. M. Varachia. (2017). Aluminum Matrix Composites for Industrial Use: Advances and Trends*, Procedia Manufacturing, Vol. 7*, 178-182.

RajanVerma, Saurabh Sharma, Dinesh Kumar. (2017). Analysis of Mechanical Properties of Aluminium Based Metal Matrix Composites Reinforced with Alumina and Sic, *International Journal of Innovative Science and Research Technology, Volume 2, Issue 6*.

David R. Cramer, David F. Taggart, (2002). Hypercar Inc. Design and Manufacture of an Affordable Advanced-Composite Automotive Body Structure,*19th International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium & Exhibition*.

J. Schulz, H. Kalay. (2016). Introducing composite material in car bonnet, *Diploma Work174/2016, Dept. Materials and Manufacturing Tech., Chalmers Univ. of Tech., Gothenburg, Sweden*.