DESIGN AND CRASH ANALYSIS OF CAR BODY USING FRP MATERIALS ADOPTING FEM

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Abstract- Due to the improvement in todays world, increasing demand have been putforth regarding the safety measures in a car along its efficiency towards fuel consumption. This results in the requirement for changing the structure of the car considering its weight. Hence light weight car body design along with crashworthiness are considered as significant factors for the design of automobiles. The advent of automobiles that use fewer non-renewable energy sources, as well as sacrificing the protection of occupants due to the minimized weight of the car, is a key problem of both the vehicle sector as well as government. Henceforth, a hatch back car is designed with the utilization of Solid works 2016 software which is a tool for modeling design exploiting FRP material. The car body crash analysis is performed in ANSYS 16 deploying explicit dynamic module utilizing FEM approach. Testing is carried out with varying speeds and the analysis of stress generated by crashing, deformated car body parts as well as strain are performed.
Keywords: FRP, SEA, crashworthiness, deformation, FEM.

1 INTRODUCTION

Lightweight design is becoming highly relevant in automotive engineering as a means of progressive developing of sustainable mobility services. Although restrictive CO2-emission standards lead to effective lightweight design ideas, ever-increasing crash protection standards are pushing vehicle bodies to become highly reinforced, hence crashworthy yet heavy [1-3]. More recently, increased interest in crashworthiness and vehicle lightweight has resulted from increased crash safety and environmental legislation aimed at reducing gas emissions. These issues, along with a need to increase vehicle energy efficiency, motivate car makers to reduce vehicle weight, resulted in lighter and lighter cars. Perhaps one field in which the elements of lesser weight are particularly important is in devices which absorb vehicle energy. As a result, improving the crashworthy nature of these materials is a major priority for automakers [4].

Generally, materials are perhaps meant for decreasing the mass of vehicle's body-in-white (BIW) and also satisfying increasingly strict crash safety standards. Metals are fairly affordable and are well-understood as well as reliable energy-absorbing folded processes. Advanced composites, like fibre reinforced plastics (FRP), also have been thoroughly researched in the literature as well as reported to have weight sensitive crash safety properties which, although highly depending upon its components and the configuration, generally exceed materials [5-7]. Fiber-reinforced polymers are being used in modern commodity methods to provide optimal solutions through appropriate material technologies as well as structured material selection [8-10]. Numerous methods for incorporating fibre-reinforced plastics (FRP) into BIW survive today. FRP has excellent basic energy absorption (SEA) values in owing to increased specific stiffness and strength. For example, utilizing FRP rather than conventional steel grades resulted in a weight reduction of 50–60%. As a result, FRP is utilized as elements for crashing to absorb energy in impact [11-13]. High SEA values for FRP are typically associated with crushing behaviour, whereas absorbing of energy by metallic elements occur primarily through the deformation of plastic.

Crashing is known as a material's ability for absorbing energy continuously through fragmenting as well as destruction.As a result, the material fails due to a series of fracture processes perpetuating in the loading direction. Crashing is achieved only if a system do not collapse due to instability condition, a component's geometrical form must be suitable for crashing [14-16]. Collapse initiators are used in order to achieve and maintain a stable and sustainable crashing operation. Triggering is a mathematical gradient attribute in the component's top or upper zone that functions as a stress concentration to ensure that the component collapses [17]. Although the industry has a lot of experience with experimentally treating FRPs at conditions of crashing, the designers of vehicle are looking for precise tools to predict their behaviour in simulation analysis. As a result, FRP is to be correctly modelled and simulated using finite element method (FEM) codes.

Commercially accessible tools and research reveal shortcomings in accurately predicting FRP crashing in terms of automotive engineers' needs [18-20]. Also FRP parts, which are lighter and more durable, have drawbacks in terms of the designing car body, including catastrophic collapse as well as cost of production. The hybrid material integrate metals as well as FRP to balance the advantages and disadvantages of each material to achieve the best mechanical characteristics as well as cost. However, lightweight ability related to these elements is highly dependent with the situation of loading, geometry, and cross - sectional area [21]. Since the fibre portion is anisotropically oriented, the structural properties of injection moulded FRP materials are anisotropically localized. The fibres move with the liquid flow in the mould, which causes anisotropy. The resulting fibre orientations for complex formed parts remain unpredictable to monitor. Hence, spots which are structurally weak as well as regions emerge, potentially leading to early component failure. Components are often constructed too thick to prevent this. As a result, the purpose of using FRP to save weight is thwarted [22-24].

Henceforth, an efficient crash analysis of car body is designed with the contributions given as,

- Design of a hatchback car considering light weight and crashworthiness.
- Crash analysis by Ansys 16 work bench software.
- Analysis of stress resulted because of crashing, deforming as well as regions of car body deformation and strain.

The arrangement of paper is: Section 2 elucidates the relevant works. Proposed framework is detailed in section 3. Results as well as discussion are explained in section 4. Finally, work summary is given in section 5.

2 RELATED WORKS

Hesse et al [25] proposed an efficient strategy for designing as well as integrating improved composite materials which were laminated for crashworthy regarding the design of automotives. A physical surrogate was developed for predicting the validity of the structure as well as filtering the dsign of the space. Further, a design parameter was derived and its robust nature was increased. The approach resulted in minimal duration for earlier development.

Martin et al [26] investigated the utilization of two-component adhesives which were modified. These adhesives were utilized to join FRP by Body in White (BIW) approach. In order to assemble the car bodies, there existed a need for specific structural adhesives which combined increased strength by the dissipation of energy during the occurrence of crashes. Various parameters influencing the characteristics of the crash optimized adhesives were investigated.

Sebastian et al [27] presented a methodology for improving multi-material equipments that revealed dependencies as well as relations in a systematic manner. The design considering the light weight parameter along with the crash analysis was performed. In addition, the boundary specifications including the manufacturing of components as well as its assembling were satisfied.

Xudong et al [28] proposed an integrated concept for the detailed designing of components which were composite in nature. The design of an SUV hatchback was performed based on the concept of FEM to generate a better effect of light weight. The stiff nature as well as the conditions for modal constraints were attained by numerically analyzing the benchmarks of the metal.

Lucaszewicz et al [29] applied FRP for crash worthiness which occured at edgewise impact utilizing the testing of impact and simulating in a numerical manner.The crash analysis was carried out with the help of FEM through which the capability of modelling was analyzed. The proposed design favoured the absorption of energy in various directions of impact.

Giovanni et al [30] proposed a numeric model utilizing the potentiality of composite material. Evaluation of crashworthiness was performed by biomechanical impact along with the comparison of traditional methods. The traditional door panels were replaced with FRP door panels ensuring a light weight design.

3 PROPOSED METHODOLOGY

Crash analysis demands the destruction of wide range of test vehicles during test courses as well as consumes more time and is not economical. Hence, the crash analysis of cars utilizing computer-aiding concepts are emerging.

3.1 Design of Car Body

The optimal parameters for the design of car body to be considered are given as,

- The driver is kept alive during the impact of front force as well as side force.
- The frame is maintained with possible minimal weight.
- All subsystems withstanding loads are provided with mounting framework.
- The centrifugal force is to be withstanded during cornering.
- The forces generated with accelerating as well as sudden brake are to be withstanded.

3.2 Material Used

In today's world, a variety of materials are used to make chassis. Owing to their various uses, different vehicles have different material requirements. The materials are selected based on the vehicle's intended use. The vehicles of heavy-duty require a material with increased potent in contrast to vehicles of light-duty. A most crucial factor is the long-term viability. During the selection of products, a few characteristics are to be considered. The selected material has to be light in weight as well as effective in terms of economy. Safety and recycling of thes elected materials is to be ensured. Hence in this approach, FRP is selected which offers improved resistance, rigidness and is stiff and flexible in nature.

3.2.1 Fibre Reinforced Plastic

Fibre reinforced plastics possess an increased ability for reducing the mass of components as well as parts on a conceptual basis. The combination of fibre orientation in the load direction and feature integration, which decreases the number of components, is an advantage that has only been used infrequently in the automotive industry. Furthermore, holistic body principles, which include sections that are engineered to fit the measured load path such that unidirectional fibres absorb the loads optimally, are still missing. Another important consideration is the incorporation of plastics into traditional production lines, specifically if incorporation into the body structure is required before painting. While there are currently plastics that withstand the high temperatures of cathodic dip-paint coating without being damaged, they are typically costly. For multi-material design systems, appropriate joining principles are created and validated.

In comparison to metal materials, FRP has extremely high basic stiffness as well as values for strength. The use of FRP in modern vehicle designs improves structural protection by degrading the vehicle's mass. The utilization of FRP for BIW indicates an ability to save weight up to 60% to 70% when comparing to other existing materials. This ability is utilized in motorsport for several years and is increasingly becoming a priority for traditional cars. Weight savings are directly related to increased range in future alternatively driven vehicles, bringing FRP-materials into those cars to a broader extent. In comparison to metal structures, FRP has a highly increased ratio of energy absorption per weight, in addition to the weight saving potential. As a result, it's a fascinating material for car crash structures.

3.3 FEM Based FRP Simulation

FEM is a computational method for dealing with complicated geometry, characteristics of material, restrictions of boundary as well as loading. A mathematical model of any geometric model uses differential equations and boundary conditions to explain the behaviour of geometry. It deals with partitioning of the appropriate physical object into elements which are finite in number. The system is considered as discrete as well as continuous if objects are finite in number. If infinite number of objects exist, these objects are converted to finite number. Every portion of the discrete system is termed as element, each element possess several nodes through which elements are linked together.

For an FRP material, the simulation adopting FEM comprises of three tasks as shown in figure 1.

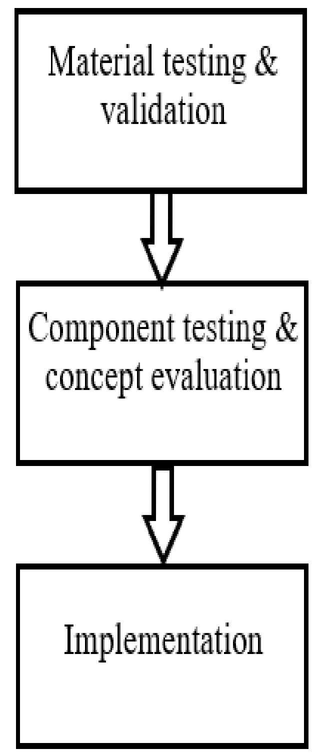

Figure 1 Process flow of FEM

Initially coupon level tests are carried out for deriving the required data in order to parametrize the choosen models of materials. To verify the test results, literature data is also utilized. During the component level testing, the extracted approaches for FRP simulation are utilized for investigating as well as evaluating the FRP structure behavior which is adaptive in nature. Hence, all the significant parameters which possess the property of influencing are investigated deeply. These parameters include utilization of various materials, thickness of wall, FRP lay-up, elastic area location, required internal pressure for the process of unfold and high burst pressure. Furthermore, the simulation by FEM is utilized for configuring the component test setup. After the completion of second validation, the adaptive structure designed is incorporated as a complete vehicle. The ability of the designed vehicle towards light weight as well as safety is analysed.

3.4 Crash- Test

It is defined as a category of damage test performed at a particular objective for providing guarantee safe design purpose measures in crashworthy nature as well as similarity of car crash and relating components. For testing the execution of security of auto within various conditions amidst lifted kinds of accidents, automobile generators perform crash testing their vehicles at specific locations, various directions as well as several articles with diverse vehicles. Generally utilized kinds of crash tests are recorded underneath.

- Front offset
- Side impact
- Roll over

Crash-testing, which necessitates the pulverisation of a few of the test car during the tests, is also time-consuming and costly. Crash-testing on a PC is a recent trend that is becoming increasingly common. Instead of using a real vehicle, a Structural analysis of the vehicle is created and used to perform the various tests that were performed before using real vehicles. Several packages for programming exist for dealing the crash testing of vehicles, but the Livermore Software Technology Corporation's LS-DYNA as well as ANSYS explicit dynamic are widely utilized. Automobile manufacturers and their suppliers may use them to test auto designs without using tooling or to reluctantly test a concept, saving time and money. Although the package continues to include an ever-increasing number of possible outcomes for determining a variety of unpredictable, real-world problems, its origins and core competency are in extremely nonlinear FEA with express coordination of time.

3.4.1 Crashworthiness Model

Crashworthiness relates to the capability of a vehicle's framework to absorb resilience while on an accident. The vehicle is to be designed so that its occupants do not experience a net decline at higher speeds.

3.4.2 Head Injury Criteria (HIC)

A biomechanical file of traveller vehicle accidents is defined as an injury indicator. As a result, many countries use head injury during a collision as a criterion for assessing the degree of HIC (Head Injury Criterion), and their outcome value is focused.

3.4.3 Investigation of FE

Ansys explicit dynamic analysis is a finite element processor of non-linear type that handles any kind of articulate problem. In most frontal impact, the vehicle suffered numerous disturbances against the front, while the focal as well as back segments are barely affected. As these designs are equipped for frontal impact, the vehicle's front casing is finely fitted, while the middle and back edges are roughly fitted. The type of test used FMVSS 208 Occupant Crash Protection over non-inflexible divider 30mph (48.3km /h) in conflict with the speed limit. The study of full frontal rigid barrier is performed in Explicit dynamic for 120 milliseconds, with geometric interfaces defining the contacts.

3.5 Deformation in Crash Analysis

Various tests have been carried out for the analysis of the crash absorber's deformation. A crash tube along with a shape memory alloy (SMA) wire is utilized for deformation analysis as shown in figure 2. Carbon as well as aramid fibers are utilized for constructing the crash tube with the diameter of 52 mm, thickness of wall as 1.2 mm as well as 98 mm in length. During the initial test, estimation of thickness is performed. For amplifying the deformation in the impact edge, holes are drilled uder the impact edge. Two clamps along with a wire is attached with the tube in which the current is applied for heating the wire.

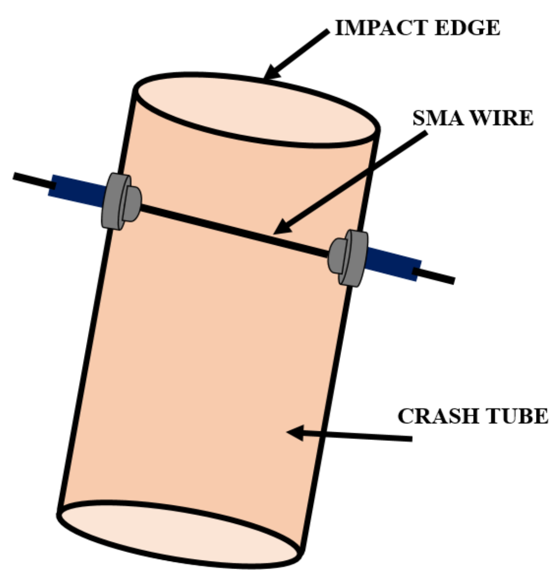

Figure 2 Crash tube with SMA wire

The estimate of deformation energy is derived for the analysis of crash methodology. Consider the velocity v is equal regarding the legform as well as safeguard system for car. The kinetic energy prior to the crash and when the crash occurs is given by,

$$K_B = w\frac{v_0^2}{2}\ , K_D = (W + w)\frac{v^2}{2} \quad (1)$$

In which W and w denote the weights of the car safeguard system as well as the legform respectively. The deformation energy when the crash occurs is given by,

$$D_E = K_B - K_D \quad (2)$$

Integration of the reaction force F is utilized for the computation of deformation energy and is given by,

$$D_E = \int Fds \text{ or } \quad D_E = \int Fdt \quad (3)$$

From these equations, the deformation energy during crash occurrence is estimated and the relation between velocity as well as F is determined.

3.6 Car Structure Modeling

Utilizing solid works, a new model of a car body is created as well as a 2D sketch is developed. Solid Works refers to an automation software for mechanical design considering the merits of the known Microsoft Windows graphical user interface. It's a simple-to-use programme that allows mechanical designers to easily sketch designs, play around with functionality as well as proportions, and create models with drawings in a detailed manner.

3.7 Car Body Crash Analysis

The analysis of crashing is performed in explicit dynamic mode considering diverse velocities of 120 km/hr as well as 150 km/hr. The explicit dynamics analysis is utilized for determining the dynamic response of the model because of the propagation of stress wave, influence or quickly varying timedependent loads. The exchange of momentum within movable bodies as well as inertia effects are generally significant factors of the analysis category that occurs. This similar analysis is utilized for modeling mechanical factors which are increasingly not linear.

4 RESULTS AND DISCUSSION

The analysis of crash in car body is simulated utilizing the ANSYS software. ANSYS is finite element analysis software package utilized for general-purpose. It performs implementation of equations which control the behavior of finite elements as well as tackles those elements; generating a description about the functioning of the system. The outputs are obtained in tabulation, or graph representations. This analysis is generally utilized for designing as well as optimizing the system to minimize the complexity thus making the analysis simple. ANSYS offers a cost-effecient manner for exploring the functioning of materials or elements during their utilization. This results in the minimization of the risk level, as well as avoids the designing of model in ineffective nature. The property of multifacet in ANSYS also offers a way for assuring the users to observe the design effects on the complete operating nature of the product, including thermal, electromagnetic as well as mechanical.

Analysis is carried out on two diverse speed 120 km/hr as well as 150 km /hr, with the utilization of three diverse magnesium alloy material , kevlar-49 as well as carbon fibre of improved strength. In crash test of 120km/hr speed, regarding material magnesium alloy, a max stress of 1097.30 mpa ,max strain 0.21292,and max deformation 166.62mm is obtained, and for same speed kevlar-49 achieved max stress 6183.80 mpa , max strain 0.041553 ,max deformation 142.32mm , as well as for same speed improved strength carbon fibre attained max stress 8044.30mpa , max strain 0.041238,max deformation 128.63mm. In crash test of 150km/hr speed, for material magnesium alloy, a max stress of 1.2513e+09 mpa ,max strain 0.21292,and max deformation 241.98mm is attained, and for similar speed kevlar-49 achieved max stress 7.7575e+09 mpa , max strain 0.052187,max deformation 179.82mm, and for similar speed improved strength carbon fibre attained max stress 1.0804e+10 mpa,max strain 0.050352,max deformation 166.74mm. Base over the material mass of Magnesium alloy , Kevlar49 , High Strength Carbon Fibre are 776.0kg , 642.68kg , and 784.73kg respectively.

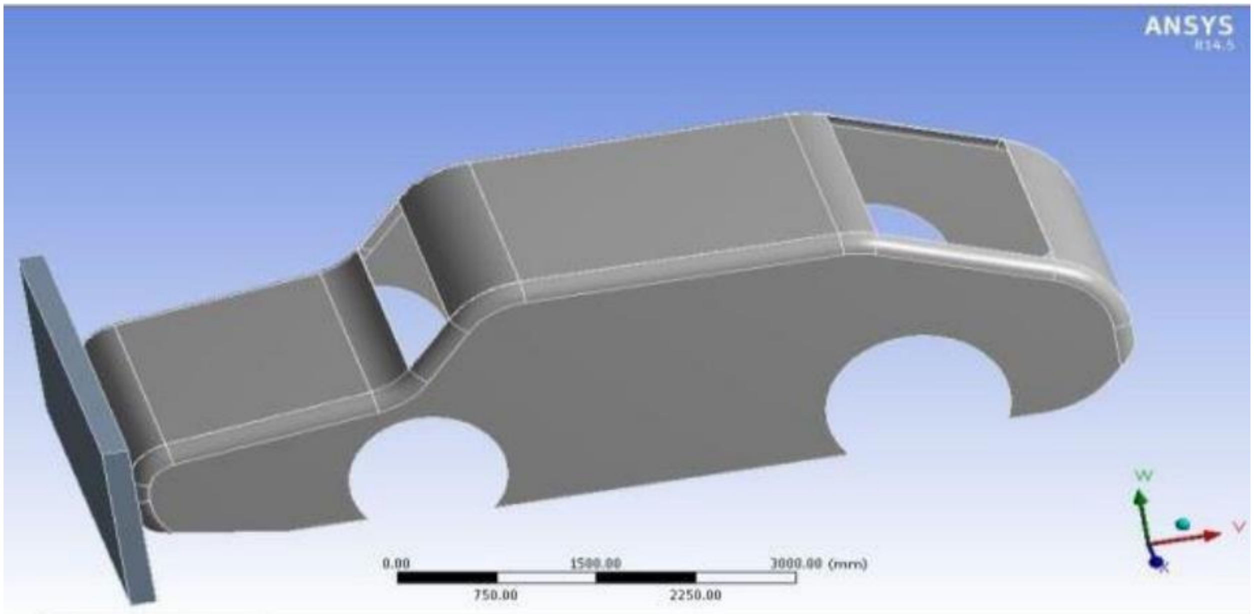

Figure 3 Model

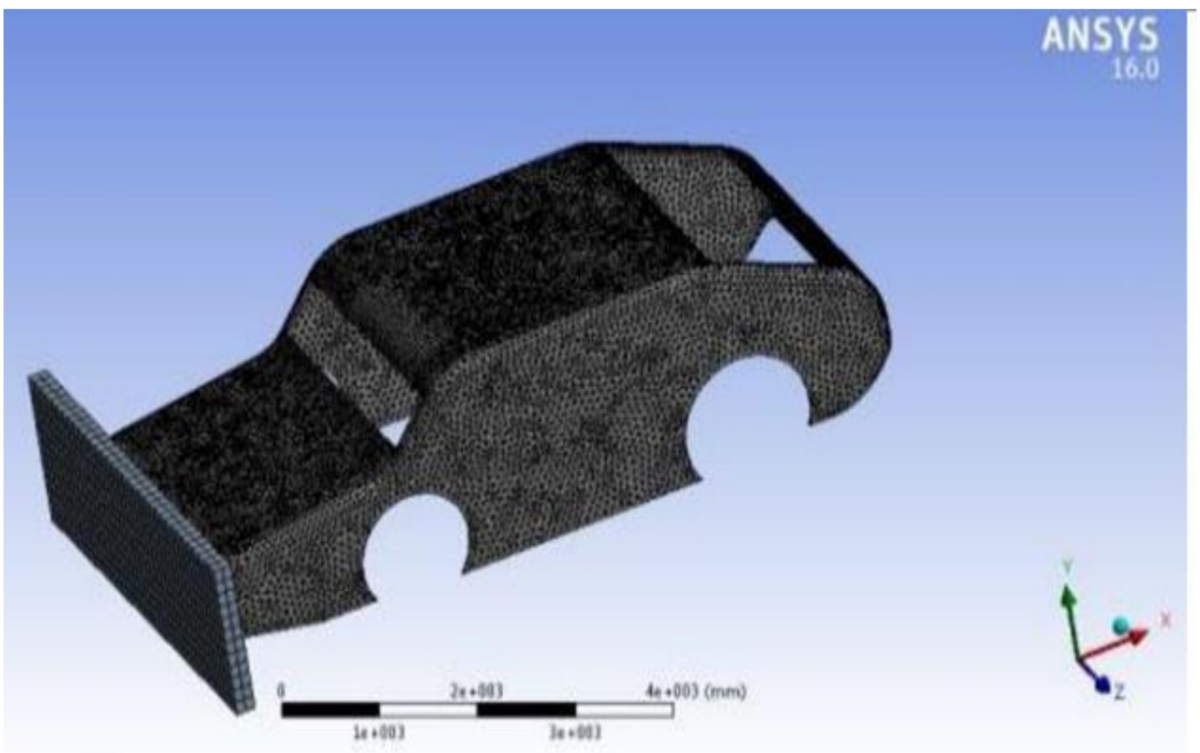

Figure 4 Meshing

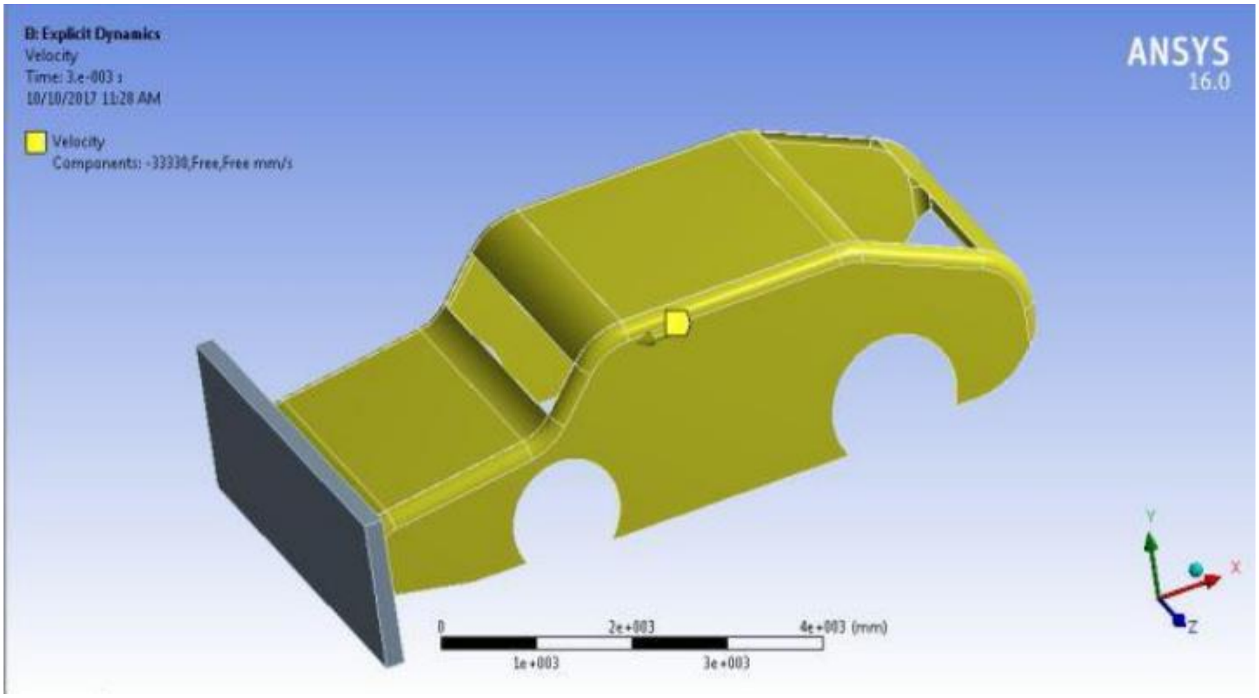

Figure 5 Velocity

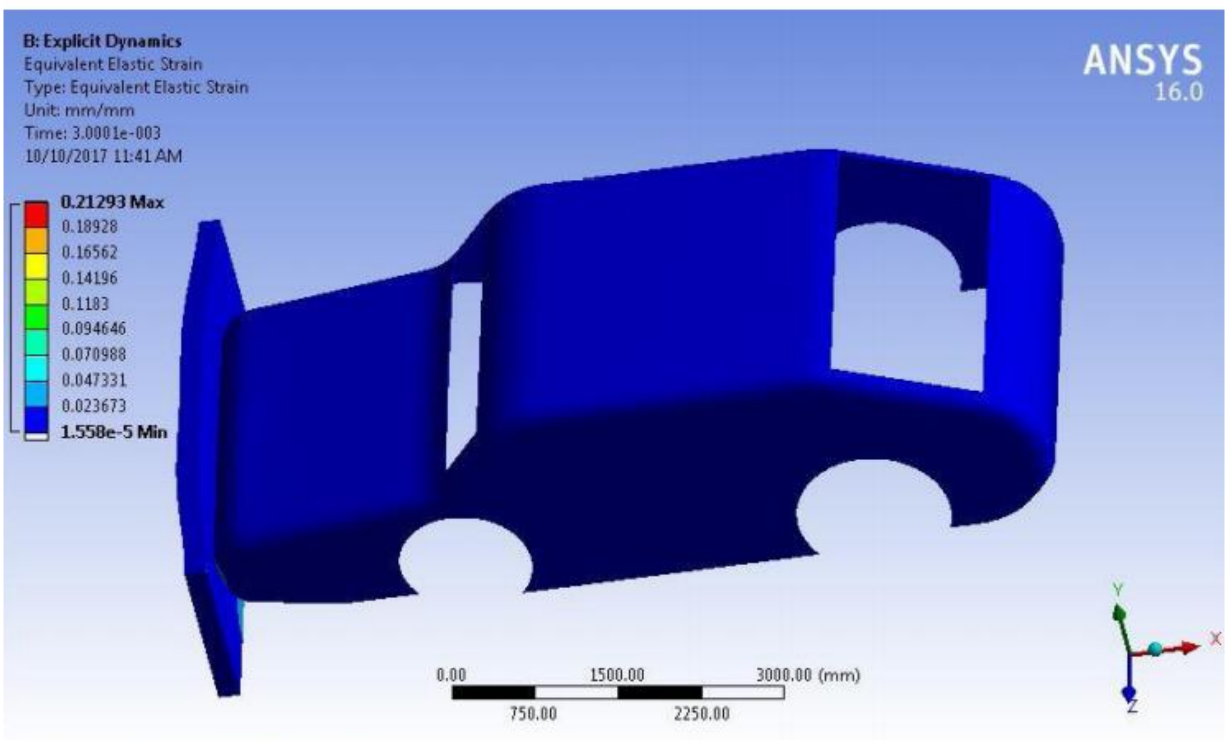

Figure 6 Equivalent elastic strain

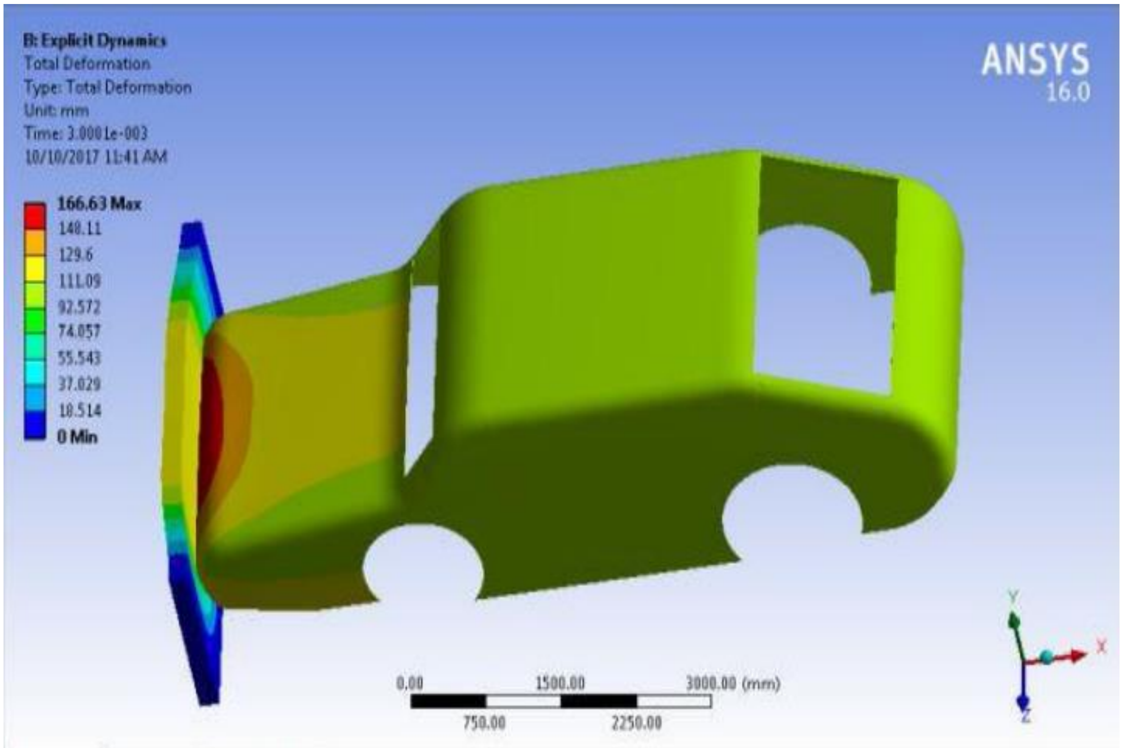

Figure 7 Total deformation

Figure 3 indicates the model of the car body utilized in this approach.

Figure 4 indicates the task of meshing utilized in the crash analysis of car body. Meshing is defined as the process of partitioning the complete car framework into elements which are smaller portions.

Figure 5 indicates the velocity analysis of the crash approach which includes the impacts of increased as well as decreased velocity. The range of energy as well as the drop height for upper bound as well as lower bound are analyzed.

Figure 6 indicates the equivalent elastic strain for the car crash analysis through explicit dynamic analysis. It considers stress wave propagation, impact or rapidly changing time dependent loads.

Figure 7 indicates the total deformation output by which the deformation energy occurring in the crsh analysis of car is estimated.

5 CONCLUSION

An efficent design and analysis of car crashing is investigated and a hatch back car is designed utilizing solid works 2016 software. A portion of the structure of hatch back car against the wall is kept as IGES file, further transferred to ansys workbench 16. The analysis of crashing is carried out utilizing explicit dynamic module in ansys workbench considering diverse speed of car equal to 120km/hr as well as 150km/hr. Stress, strain, total deformation are analyzed prior to explicit dynamic analysis over car structure following the crashing of car against a concrete wall. Compared to mass of the structure, Kevlar-49 exhibited minimal weight ratio along with carbon fibre of improved strength. Prior crashing, magnesium alloy showes minimal stress, meanwhile improved strength carbon fibre resulted in minimal deformation as well as strain prior the crashing process. Stress as well as deformation of car structure shows increase with the increase in car speed. Therefore, with the minimal weight ratio as well as improved strength regarding crash deformation as well as strain, FRP is regarded as appropriate material fo car body.

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