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Simulation of Car Bumper Material using Finite Element Analysis

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Abstract: Bumper is one of the main parts which are used as protection for passengers from front and rear collision. The aim of this study was to analyze and study the structure and material employed for car bumper in one of the national car manufacturer. In this study, the most important variables like material, structures, shapes and impact conditions are studied for analysis of the bumper beam in order to improve the crashworthiness during collision. The simulation of a bumper is characterized by impact modelling using Abaqus 6.9 according to the speed that is 13.3 m sec^{-1} (48 km h^{-1}) given in order to analyse the results. This speed is according to regulations of Federal Motor Vehicle Safety Standards, FMVSS 208- Occupant Crash Protection whereby the purpose and scope of this standard specifies requirements to afford impact protection for passengers. In this research, the three types of material were selected that are relevant to be applied to the front bumper beam. The materials consist of Expanded Polypropylene (EPP), Glass Mat Thermoplastics (GMT) and Sheet Molding Compound (SMC). These materials were studied by impact modelling to determine the kinetic energy, potential energy and strain energy. The selected materials are compared to each other to find the best material with highest material strength and structure. Simulation using Finite Element Analysis software, which is ABAQUS was conducted. The results showed that a modified SMC bumper can reduce the impact of collision with higher performance and was suggested to replace GMT and EPP. The duration taken for SMC to deflect the impact was the shortest compared to GMT and EPP The findings also showed that EPP cannot totally absorb the energy and reduce the impact of collision.

Key words: Sheet molding compound, crash simulation, automotive, composite, simulation

INTRODUCTION

Bumper is one of the most important parts in passenger cars for which the material and structure should be considered in order to reduce the impact of collision (Fuchs *et al*., 2008). Since suitable impact strength is the main expectation for such a structure, the authors survey the variables that directly give impact characteristics and wished for easily achievable modifications resulting from impact modelling on commercial bumpers. Many researchers have studied that accident always occur in front side (Sheshadri, 2006). This impressed the authors to study and analyse the component related to frontal crash and therefore, the authors selected bumper.

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For crash simulation analysis, a marketable front bumper by Malaysian car was chosen in this study. There are many car manufacturers in Malaysia but only one car manufacturer has been chosen for this study. The details of the car manufacturer cannot be disclosed for confidential issues.

By using fiber reinforced polymer and composites type of bumper, the bumper impact of collision can be reduced by replicating the simulated bumper as similar as possible to reality into ABAQUS 6.9 and meshed in order to get a simulation results (Cheon *et al*., 1995). Study done by Ramakrishna and Hamada (1998) stated that the energy absorption capability of the composite materials offers a unique combination of reduced weight and improves crashworthiness of the vehicle structures.

A good design of car bumper must provide safety for passengers and should have low weight (Marzbanrad *et al*., 2009). Beside the role of safety, fuel efficiency and emission gas regulations are being more important which encourage manufacturer to reduce the weight of passenger cars (Hosseinzadeh *et al*., 2005).

In this project, a front bumper beam made of three materials that are expanded polypropylene (EPP), Glass Mat Thermoplastic (GMT) and high-strength Sheet Molding Compound (SMC) is studied by crash simulation analysis to determine the kinetic energy, potential energy and strain energy. The main characteristics are compared between all the materials to find best material and structure. The results show that a modified SMC bumper beam can minimize and reduce the impact of bumper collision.

Many researchers have studied the four main variables during crash simulation and analysis (Kim, 2008; Marzbanrad *et al*., 2009; Hosseinzadeh *et al*., 2005). The first variable studied is the material. It has been exposed in this research as a substitution in order to lower part weights and define whether the material can affect the impact of collision or not. In this section, the effect of modulus of elasticity and yield strength on impact behavior of bumper beam was investigated. Thickness is the second variable that has been studied in order to relate between bumper and thickness that can affect the impact of collision.

The third variable is the shape of the bumper. The shape is studied because the authors want to define even small changes and modifications that can result in easier decreasing material volume without lowering the impact strength. The last variable is the impact of condition in order to measure how much the crash simulation test will affect the condition of bumper after collision.

From the test conducted by Mazurkiewrcz and Tien (1997), steel and aluminum structures with a specified thickness did not fail during the test, howeverthey are not suitable for bumper structure due to increase in weight. In comparison with the composite bumper, steel and aluminum increased the weight of the structure by nearly 500 and 100%, respectively (Mazurkiewrcz and Tien, 1997). In summary, the authors developed and recommended a composite bumper, which could satisfy all the following requirements. First, the bumper beam must be easy to manufacture by simplifying the shape. Next, the bumper is essential for being economical by utilizing low-cost composite materials besides achieving reduced weight compared to the metallic bumpers. Lastly, the bumper should achieve improved collision compared to the current material.

MATERIALS AND METHODS

The sample of car bumper was given by one of the car manufacturer in Malaysia to be studied by a group of researchers. The research started in September 2009 and finished on April 2010. The study was carried out in the Mechanical and Manufacturing Engineering

Department Lab where the sample and computer facilities were located. Reverse engineering was carried out to design the part using CAD software. The impact assessment of car bumper was analyzed numerically using FEA software that is ABAQUS 6.9. The model being used was the same for all analysis. The input variable is material which is thermoset polymer or engineering polymer. The materials being assessed were expanded polypropylene (EPP), Glass Mat Thermoplastic (GMT) and high-strength Sheet Molding Compound (SMC). The requested field output and history output are Von Misses stress, kinetic energy, frictional dissipation, internal energy, strain energy and total energy. The highest stress value resulting from impact was obtained from Von Misses stress and compared with yield stress of the respected material. From this comparison, the authors can conclude whether or not the material fails during the collision sustained by bumper. From the result, the authors wold suggest the most optimum solution which satisfied impact condition.

Simulation

EPP material which exhibits a low yield stress, with a high Young's modulus and a large plastic strain to failure (highly ductile) should be considered for replacement. The energy plot of the structure during the event should be monitored carefully. Any sudden changes in the plot trend/form the ALLKE, ALLIE, ALLSE, ALLFD and ETOTAL will be analyzed to determine the possible cause. Theoretically, the ALLKE plot will decrease in quadratic manner as soon as the bumper contact with impactor. Based on the result, The ETOTAL should be maintained as a constant theoretically for any event. Variation in ETOTAL is less than 10% during the whole event means that the results are quite reasonable for SMC (Yuxuan, 2003).

RESULTS AND DISCUSSION

Kinetic Energy

Kinetic energy is the energy of motion whether it is vertical or horizontal. Kinetic energy is absorbed by the bumper plastic deformation and the other energy is dissipated by other forms of deformation. If collision continues, the end of the car bumper will still bend continuously. From the Fig. 1 the maximum value of collision force incurred at the beginning and decrease slowly until it turns to zero energy. At the end, the whole structure become unstable and a large displacement incurred due to the bending of the end part. So, at this time the collision force decrease rapidly.

Kinetic energy graph of SMC in Fig. 1 showed that minor plastic deformation will occur to the bumper during the collision. Figure 2 of kinetic energy graph for GMT also showed the same result. This is because both materials have the lowest value of Young Modulus compared to EPP. For Fig. 3, the bumper showed major plastic deformation because it needs a long period in order to reduce the impact of collision. Next, the physical properties of the material will change according to the arrangement of atoms and molecules after the impact of collisions. So, the authors would choose either SMC or GMT material as substitution for car bumper material.

Linear momentum is conserved and since the impact phenomena always with losing energy, kinetic energy is not conserved. The section of kinetic energy system converts to strain energy due to elastic and plastic deformations that occur in bumper.

Strain Energy

Strain energy is studied in this research because the authors desires to determine the maximum plastic deflection after the impact decrease with increasing the material strength.

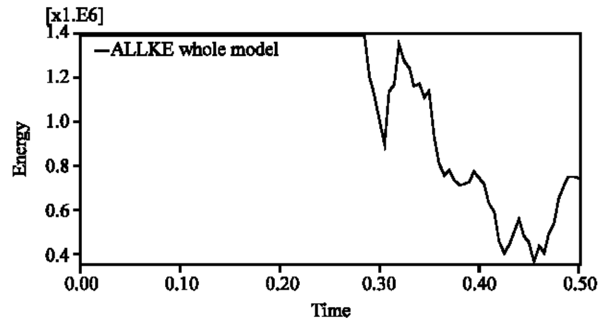

Fig. 1: Kinetic energy graph of sheet molding compound (J sec^{-1})

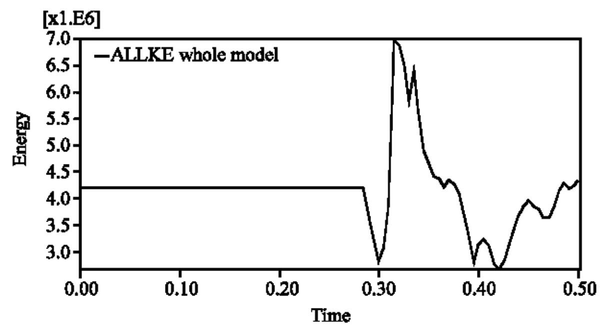

Fig. 2: Kinetic energy graph of glass mat thermoplastic (J sec^{-1})

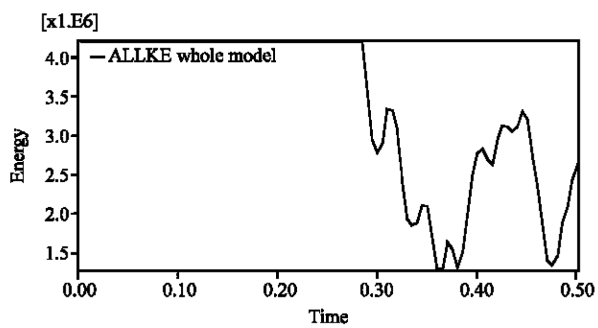

Fig. 3: Kinetic energy graph of expanded polypropylene (J sec^{-1})

According to the principle, kinetic energy must be equal to the strain energy. This means that when forces act on elastic systems subject to small displacements, the displacement is equal of the partial derivative to the total strain energy with respect to that force.

Figure 4-6 represent strain energy graph of SMC, GMT and EPP, respectively. All the three graphs showed that the elongation of the bumper occurred at the highest peak. The bumper will stretch and deform until maximum if the collision still occurs. If the energy turns to zero energy, it will become elastic collision because the atom or molecules in the bumper absorb the energy. SMC exhibit the minor deflection because the energy turn to zero and the atom absorb the energy completely. For GMT and EPP, both need a long period in order to

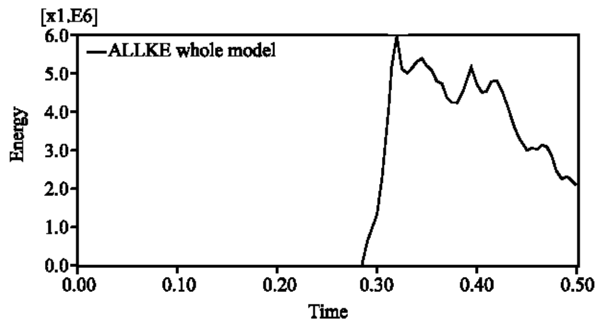

Fig. 4: Strain energy graph of sheet molding compound (J sec^{-1})

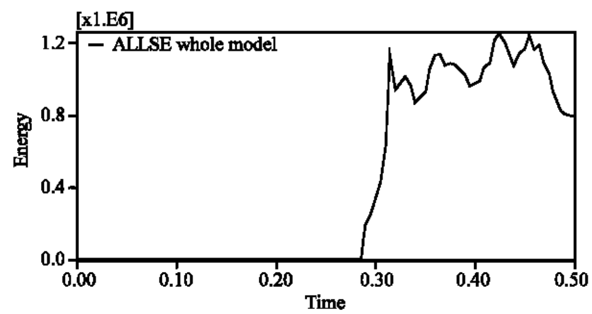

Fig. 5: Strain energy graph of glass mat thermoplastic (J sec^{-1})

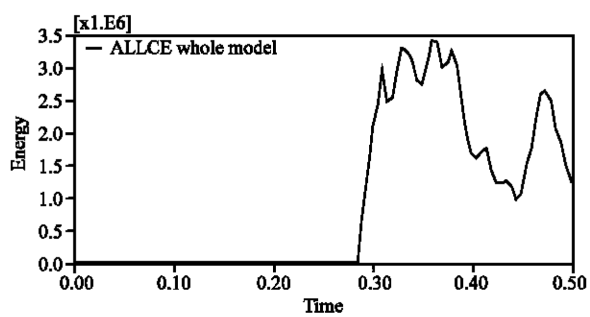

Fig. 6: Strain energy graph of expanded polypropylene (J sec^{-1})

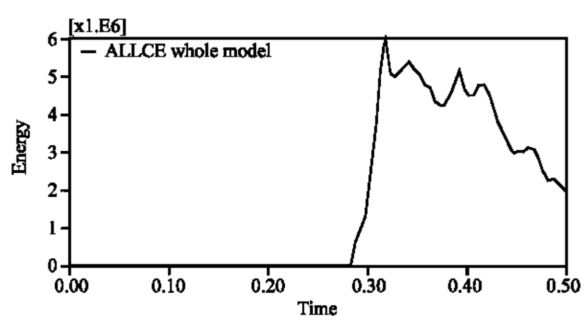

Fig. 7: Internal energy graph of sheet molding compound (J sec^{-1})

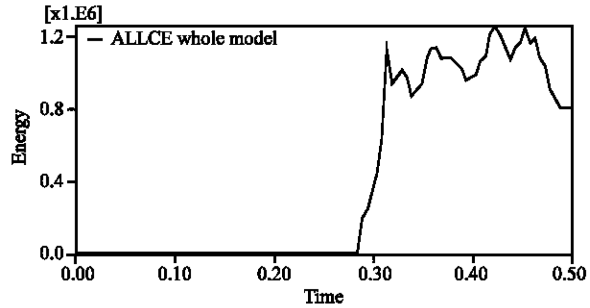

Fig. 8: Internal energy graph of glass mat thermoplastic (J sec^{-1})

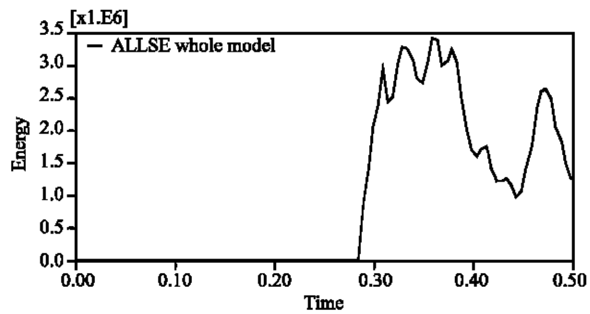

Fig. 9: Internal energy graph of expanded polypropylene (J sec^{-1})

absorb the energy because the atoms in the bumper is still moving and produce major deformation.

As the conclusion, SMC will give more benefit in order to improve bumper based on this material selection.

Internal Energy

Internal energy is the total kinetic and strain energy associated with the motions and relative positions of the molecules of an object. An increase in internal energy results in a rise in temperature or a change in phase. The internal energy also can be obtained if the value of Von Mises Stress is more than or equal to yield stress. This means that the material failed and does not satisfy to be the authors's option. This also shows that the material is ductile and spongy.

When collision occurs, the atom in the bumper will vibrate and move to the wall in the bumper. The movement of the atom will produce work done and heat and then transfer to internal energy. The physical properties of the bumper also change because it deflects and deforms during the collision.

Referring to Fig. 7, SMC exhibit the best option because it can absorb the energy in a short time and exhibit minor deformation compare to GMT and EPP. Figure 8 shows an internal energy graph of GMT has a long impulse time during impact. Figure 9 represents an internal energy graph of EPP. It was also has longer impulse time. In conclusion, SMC gave more benefit in order to improve bumper based on this material selection.

It is found that the findings for this work were aligned with studies conducted by many researchers. Based on the tested material, SMC was found as the best material to be used for car bumper. This is supported with findings from Hosseinzadeh *et al.* (2005), where they concluded that SMC in the best material for bumper beam compared to another seven materials. Many other researchers agreed to use SMC as the best material to replace GMT (Busch, 2000; Sujit, 2001; ACA, 2000).

CONCLUSIONS

Bumper as the main component in reducing the impact of collision from front view was characterized by Abaqus 6.9 so as to get the best material and also to strengthen the structure. A commercial fiber glass (composite) model made of GMT and SMC was selected and the standard variables were investigated such as material, structure and impact condition. Besides, steel and aluminium also were assigned to the model and showed inappropriate characteristics such as structural failure and weight increase (Hosseinzadeh *et al*., 2005). Expanded Polypropylene (EPP) as the first selection material was studied and the result showed that this material cannot totally absorb energy and reduce the impact of collision. However, EPP was selected by several car manufacturer because of low cost and easier manufacturing part (Sujit, 2001).

High strength (SMC) composite was proposed to replace GMT and EPP because it offers better performance in energy absorption and reduce the impact of collision. The structure of SMC showed very good impact compared to other structure which is low in energy absorption and less impact of collision. The time taken for SMC to deflect the impact also shorter compared to other materials which take more than 0.5 seconds. This can cause passenger injury and bad accident. Finally, the authors's objectives to verify new material for car bumper by simulation software and to reduce the impact of collision that are involved in front bumper are accomplished. So, the authors can conclude that SMC is the best material for bumper in reducing the impact of collision. However, the authors strongly believe rigorous investigation should be carried out to monitor the consistency and benefit of the proposed structure.

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