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Using Glass Mat Thermoplastic as Automotive Bumper'S Material to Enhance Pedestrian Safety

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Abstract. The usage of softer systems in automotive bumper is a growing trend currently especially to serve the pedestrians safety function. The term softer here does refer to the bumper system's dynamic behavior rather than its material's flexure or tension modules. However, the usage of such softer systems would raise issues of structural integrity of the bumper during crash. There is a strong drive currently to adopt materials such as glass mat thermoplastic (GMT), high-strength sheet molding compound (SMC) for the bumper material and plastic polypropylene (PEP) for the bumper holders [1, 2, 3] in this regard. While both the GMT and SMC do enhance the pedestrian safety condition, they both show plastic deformation at crash, even in low-speed scenarios [2, 3]. The PEP holders react only as shock absorbers and act like mechanical fuses to be destroyed in car crash, preventing the main bumper from being damaged [4].

In this paper, we propose a remedy for this problem by changing the common system that the GMT and SMC materials are usually fitted at. We propose coating the bumper beam with a Rubber padding layer that eliminates the plastic strain at low-speed crash. We also examine the behavior of the PEP during such crash scenarios. We present here the results of a low-speed head-on automotive-pedestrian crash simulation scenario for these material models, using the explicit dynamics finite element code LS-DYNA within ANSYS integration setting. A simplified parameterized finite element model of the Ford Crown Victoria car's bumper form is used in several crash simulations that are carried out to test the validity of this modified bumper system. Based on the results of these tests, we show that, applying the Rubber coating material for the GMT and SMC bumper beams eliminates the plastic stains at low-speed crash.

Introduction.

Numerous researches have been made with the aim of ensuring the safety of both pedestrians and the car passengers. Many revolve around Energy Dissipating Systems [5, 6, 16, 17], occupants safety [6, 7, 10, and 11], road safety devices such as Guardrail [8, 11, 12], bumper design investigation [9], and structure integrity [13, 14, 15, 18, 20]. A common ground in all but [9] is the energy absorption through elasto-plastic process. We consider here a visco-elastic process as an energy absorber system. In addition, we add a covering Rubber coating to the bumper beam to eliminate the plastic strain and maintain the bumper beam behavior within the visco-elastic range. we investigate using the GMT and SMC in such a system. We conduct a comparison between these two materials and another three materials, namely Commercial Steel bar, Aluminum 3105-H18, and PEP. We conduct this study at low-speeds head-on automotive-pedestrian's leg crashes which do not exceed 5 miles/hour. At these crashes, the bumper beam would retract first, towards the car structure within a safe calculated distance to dissipate the energy and then return back to its original position. This system could reduce human injury and losses of money at low speed crashes such as those happening when parking the car or moving in the parking space.

Material Models.

The commercial Steel and the Aluminum materials used for the bumper material model have the material properties shown in table 1 below. The GMT bumper material used in this research is a structure made from short glass fibers, 12–25mm long randomly mixed with thermoplastic resin. It is adopted from [2, 3]. GMT is illustrated in [21] and the SMC bumper material is described at [22]. Both materials mechanical properties are also shown in Table 1 below.

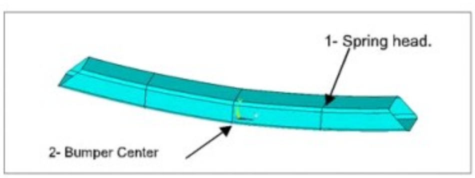
Table 1: Material properties of the bumper beam materials.

Material	E(GPa)	υ	S_y(MPa)	ρ (kg/m3)
Commercial steel bar	207	0.3	190	7860
Aluminum 3105-H18	68.9	0.33	193	2720
GMT	12	0.41	230	1280
SMC	20	0.33	309	1830
PEP	1.2	0.4	27	900
Rubber	G_{xy}=1.04			1150

The LS-DYNA material model MAT_PIECEWISE_LINEAR_PLASTICITY is used to model all the material models, except the Rubber. The Pedestrian's leg is modeled as a rigid material with the same properties as Steel above to magnify its effect at the impact investigation. The bumper beam supporting structure is composed of a spring-dashpot LS-DYAN Discrete elements with K= 60E+05 and damping parameter of C=0.015, rather than a hollow block made of PEP material [2]. Finally, the Rubber padding for the bumper beam is modeled with the MAT_BLATZ-KO_RUBBER in LS-DYNA. Table 1 above shows that, both GMT and SMC are about 85% and 77% lighter than the Steel respectively, while both are exceeding its yield stress.

Finite Element Model.

The bumper beam is approximated by a model that is shown in Fig. 1 left below. The beam is slightly curves in its lengthwise direction (designated x-axis). Its finite element model is composed of 2600 Belytschko-Tsay shell elements used by LS-DYNA as shown in Fig. 1 right below. The shell thickness is taken 4.0 mm [9]. The supporting system is 4 spring-dashpot elements with viscous damping connecting the back of the bumper beam with the car structure. The bumper model is free to move in any direction while the connecting elements are restricted to move only in their longitudinal direction (the car longitudinal axis, designated y-axis). They are fixed at the car side and free to move at the bumper beam side. The Pedestrian's leg is modeled as a cylindrical rigid body. This rigid body is impacting the center of the bumper beam perpendicularly with a 5 miles/hour speed. It is restricted also to move only in the y-axis in the car direction and is shown in Fig. 1 below. The bumper beam response will be presented at selected two points. These points are the center point of the beam (horizontally and vertically), and the spring head point of attachment to the beam. These points are shown as points 1, and 2 in Fig. 1 left below. The response of the impactor is taken at center point (horizontally and vertically), point 3 in Fig. 1 below. The contact type we used here is the Automatic General type. The model is stabilized with hourglass control.



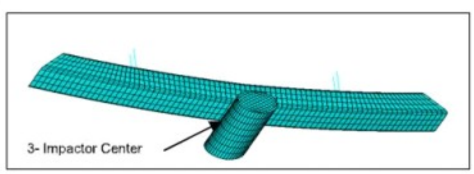


Fig. 1 Finite element model and mesh of the bumper beam, Pedestrian's leg, and supporting system.

Material Models Performance Comparison.

We study first the effect of the bumper beam material on both the elastic and plastic strain in it and the rebound displacement of the impactor. Each figure below shows the Y displacement response (on the graph Y-axis, measured from the bumper center towards the car body) for each of the materials in Table 1, against the time increment (on the graph X-axis, 50 increments each of 12 x 10^{-3} sec.). While PEP is not commonly used as a structural material, we included it in our testing for model evaluation purposes. Fig. 2 shows the response of the spring head, point 1 in Fig. 1 for the all material models. The St. and Al. are close together and the GMT and SMC are close together. All materials responses show that, the spring vibration oscillates elastically around zero until it reaches steady state condition. The spring system is pushed back further in case of GMT as SMC than in case of St. and Al. at early time of the crash (around 6.0 x 10^{-2} sec.)

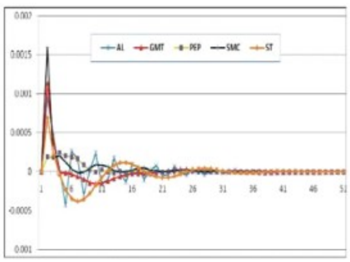


Fig. 2 Displ. Response at point 1.

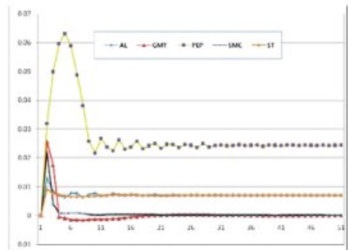


Fig. 3 Displ. Response at point 2.

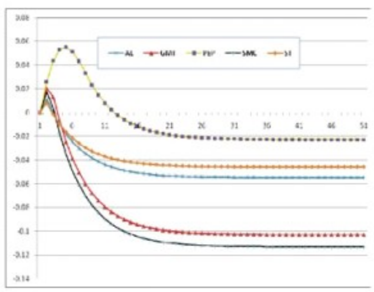


Fig. 4 Displ. Response at point 3

Fig. 3 shows the displacement response at the center point of the bumper beam, point 2 in Fig.1 for all material models. The shooting one at the top is the PEP as it almost crashed at contact with the impactor. The responses of the St. and Al. are higher and banded together and those of GMT and SMC are lower and banded together as well. GMT and SMT returned near zero (with little residual plastic strain as shown in Figs. 5 and 6 below for GMT.) while St. and Al. kept higher plastic strains. As mentioned before, this is the reason why GMT and SMC models was reported in [2, 3] as failed as they show plastic strains even at low-speed head-on crash. In the following sections we propose a remedy to this problem by cover coating the bumper beam model with Rubber. Fig. 4 shows the response of the impactor. In case of PEP, it absorbed the impact energy almost through plastic process, thus giving the impactor little energy to rebound back. Other material models pushed back the impactor significantly. The GMT and SMC pushed the impactor back further than the St. and Al. Curves of each group are close together.

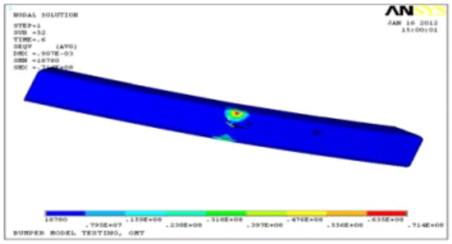


Fig. 5 Von Mises Stresses for the GMT Bumper.

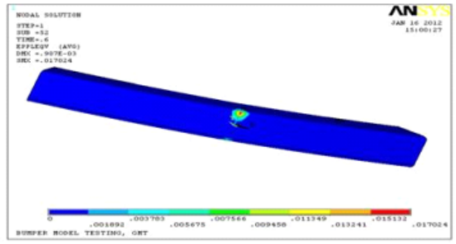


Fig. 6 EQV Plastic strain for the GMT Bumper.

Modified System.

We study here the effect of varying the Rubber coating thickness of the bumper beam cover to reach the most appropriate thickness that eliminates the plastic strain form the bumper beam while maintaining its low weight. We applied the cover layers for the finite element model with the condition that the Rubber is tied at every node to the face of the bumper beam. We selected to study its effect on St. Material model to magnify its effect where we changed the Rubber thickness from 1 cm to 5 cm gradually, with adding 1 cm increment at each step.

Modified system testing. Each figure below shows the response of the St. Bumper beam, and that of it with Rubber cover of thicknesses 1 cm to 5 cm respectively. Fig. 7 shows the response of the spring head. Better push back of the spring system is noticed with Rubber thicknesses between 1 cm and 3 cm. With higher thicknesses, the response returns closer to that of the St. with no Rubber. Fig. 8 shows the response of the center point of the bumper beam. The single higher curve is the St. alone and all curves of Rubber coating show clear improvement as they come much lower. Fig. 9 shows the response of the impactor. It indicates that the response gains from the Rubber cover with thickness 1, 2, and 3 cm's most. With thickness 4 cm and 5 cm the response comes close to that of the St. alone.

We observe from Table 2 below that there is a time shift in the response when the Rubber is applied with thicknesses up to 3 cm. The peak value happens at the second time increment for St. with no Rubber coating and also for St. with Rubber coating of 3, 4, and 5 cm. The time shift only appears when the thickness is 1 cm or 2 cm. This study suggests that, using a Rubber cover coating should not exceed 3 cm thickness to help the material model of the bumper beam most.

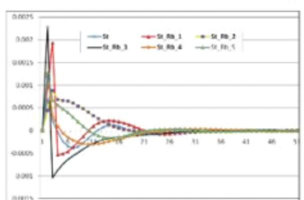


Fig. 7 St. Displ. Response at point 1.

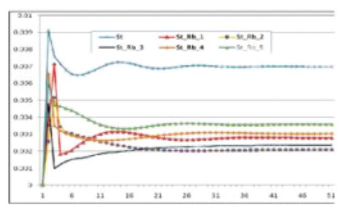


Fig. 8 St. Displ. Response at point 2.

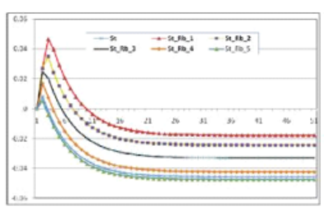


Fig. 9 St. Displ. Response at point 3

Table 2: Response time shift with St. when Rubber is applied.

Time	St.	St.+RB_1	St.+RB_2	St.+RB_3	St.+RB_4	St.+RB_5
0	0	0	0	0	0	0
1.20E-02	8.17E-03	2.72E-02	2.72E-02	2.47E-02	1.70E-02	5.18E-03
2.40E-02	-1.55E-03	4.66E-02	3.48E-02	2.05E-02	7.42E-03	-4.08E-03
3.60E-02	-9.61E-03	3.97E-02	2.40E-02	1.07E-02	-1.65E-03	-1.20E-02
4.80E-02	-1.62E-02	2.92E-02	1.52E-02	2.79E-03	-9.06E-03	-1.85E-02

Modified system application. We conducted FE simulations on both GMT and SMC with a Rubber coating of 3 cm thickness and the results are shown below in the figures. Each figure shows the comparison between the responses of the bumper beam with material model alone against that of the covered material with Rubber. Figures 10, 12, and 14 show the result for GMT at points 1, 2, and 3 respectively while figures 11, 13, and 15 show the correspondent results for SMC.

Figs. 10 and 11 show that, the spring response at point 1 for the Rubber covered beam, is less than that for the beam without Rubber coating, especially for the SMC. This is because; the Rubber cover acts as a frontal spring system to absorb some of the impact energy. Figs. 12 and 13 show that, the response at the center point on the face of the Rubber covered bumper beam is almost half that of the beam without Rubber for both of the material models. This is the desired result to eliminate the plastic strain in the bumper beam. Figs. 14 and 15 show that, the back retraction response of the impactor hitting the Rubber covered beam is almost half that when the beam is having no Rubber cover. Implying that the Rubber has absorbed a significant part of the impact energy.

Table 3: Response time shift with GMT and SMC when Rubber is applied.

Time	GMT	GMT+RB	SMC	SMC+RB
0	0	0	0	0
1.20E-02	0.01328	5.52E-03	0.011681	5.58E-03
2.40E-02	0.006842	1.25E-02	0.001577	7.64E-03
3.60E-02	-0.0002	-6.01E-04	0.001074	-3.13E-03
4.80E-02	-0.00068	1.82E-03	0.000908	-1.50E-03

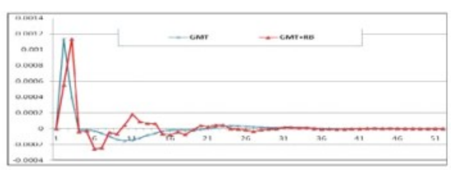


Fig. 10 GMT Displacement response at point 1.

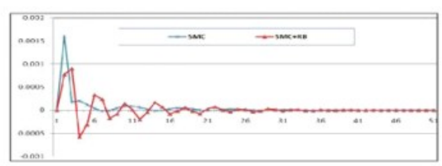


Fig. 11 SMC Displacement response at point 1.

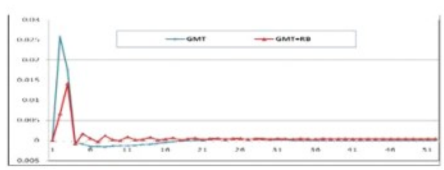


Fig. 12 GMT Displacement response at point 2.

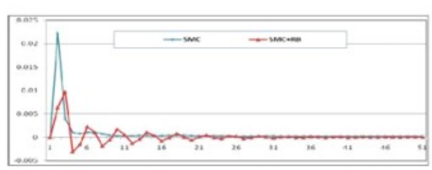


Fig. 13 SMC Displacement response at point 2.

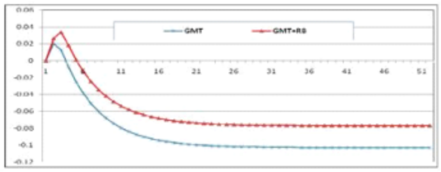


Fig. 14 GMT Displacement response at point 3.

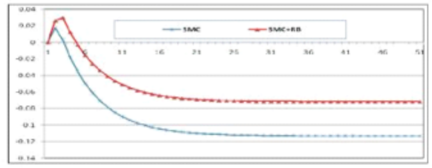


Fig. 15 SMC Displacement response at point 3.

Fig. 18 below shows that, the Von Mises stresses are way below the yield stress for the GMT at the end time of the simulation and Fig. 19 shows that, there is no plastic strain at the center of the bumper beam. In these figures, Rubber layers are removed at the bumper beam center for clarity of Figures.

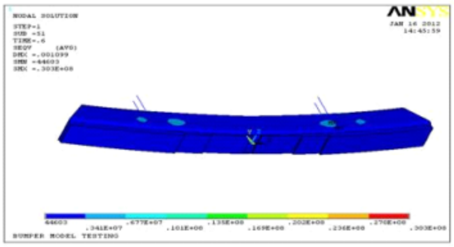


Fig. 16 GMT Von Mises with Rubber coating.

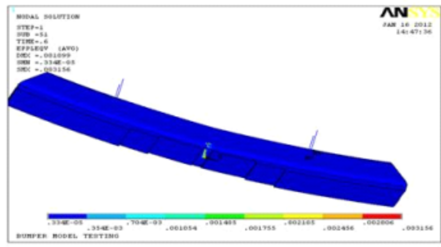


Fig. 17 GMT EQV plastic strain with Rubber coating.

Conclusion.

We presented an investigation of the behavior of automotive bumper beam that is modeled after the Ford Crown Victoria's model, with explicit dynamics for several material models. It aims at absorbing the low speed head-on crash energy, through elastic retraction of the bumper beam under viscous damping to enhance Pedestrian's safety. The usage of GMT and SMC material models as in the literature [2, 3] is examined and then modified by adding a Rubber coating cover to the bumper beam to eliminate plastic strain and allow for using these material in a visco-elastic responsive system.

A study of the effect of varying the bumper beam Rubber thickness is presented, to search for a section that is rigid enough to maintain the elastic response and light enough to serve in bumper weight reduction. A continuing effort in this direction is undergoing with considering a crash dummy to replace the impactor with a material model simulating human tissues.

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