Impact analysis of bumper beam to be proposed for Indian passenger cars

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Abstract. Cars equipped with modern devices like rare parking sensor, parking camera, etc. helps in avoiding low-speed impact. However, in reality, these low-speed impacts are still happening very frequently because of no of factors like slow-moving heavy traffic, the experience of the driver during parking the vehicle, etc. The bumpers, which essentially act as low-speed energy absorbers, are provided in the rear and front side of a vehicle. In the present work, three different bumper beams are fabricated based on the design parameters obtained during numerical simulation conducted as per low-speed impact guideline of standards of automotive stated in E.C.E. United Nations Agreement, Regulation no. 42 (1994). The energy absorption capacity and strength of these bumper beams are numerically investigated. The numerical simulations are obtained for low-speed pendulum impact test to prove the crashworthiness of the proposed bumper beams.

Keywords: Low-Speed Impact, Bumper Beam, Crashworthiness, Finite Element Analysis, Pendulum impact test.

1. Introduction

Today’s modern cars equipped with various safety devices like airbags, anti-collision sensors, etc. where a passenger can be saved/protected during high-speed impacts. However, the safety of the passengers during vehicle crashes, especially the low-speed velocity impact scenario can be ensured by using good bumpers. Bumpers will also contribute to the safety of various vehicle parts such as the cooling systems, radiator, exhaust system, hoods and taillights, fenders headlights that are expensive. Front and rear bumpers beams are made up of steel metal sheets. Eventually, aluminum and/or magnesium alloys are popular. Nowadays materials like Glass Mat Thermoplastic (GMT), Sheet molding compound (SMC), etc., also offer various benefits like low weight, easier to produce the complex shape, etc. along with the high impact energy absorption capacity. However, the usability of these materials over steel is still in the pre-acceptance stage.

As per as low-speed bumper impact test and its analysis is concerned, Marek et al. [1] produced the bumper crash simulation data for US, Federal regulation FMVSS 215. They used ABAQUS to analyze crash data for two bumper beams. George Jacob et al. [2] described different methodologies for crushing composite tubes. They reviewed the effect of various parameters such as specimen geometry, fiber type, fiber orientation, fiber content, etc. on the energy absorption capacity of the polymer composite. Zhang et al. [3] compare the bending behavior of the rib-reinforced beam without filler foam materials and with a thin-walled hollow tube. They used Ansys APDL for numerical analysis to check the crushworthiness of the bumper beam. Park [4, 5] studied Plackett-Burman optimized design by intermediate response surface modeling (IRSM) design technique. He conducted a test for the optimized shape of a vehicle bumper beam against front rigid-wall impact as per the regulations protecting pedestrians from lower leg injuries. He also compared compare the result with the non-
linear finite element analysis with error limiting to 3%. Belingardi et al. [6] studied impact tests of the bumper beam made up of three different materials as GMT, GMTex, and GMT-UD. The kinetic energy, Potential energy, and stiffness values are been investigated. Their experimental impact tests concluded that GMTex exhibits the highest absorption energy. Zhixiao et al. [7] used LS-DYNA to simulate a numerical FGF-filled bumper beam model such as to improve its energy absorption capacity. Sonawane et al. [8] used LS-Dyna to simulate a slow speed impact test as per IIHS regulation. They also analyzed various bumper material, bumper shapes, bumper thickness, and impact conditions to enhance crashworthiness design in a low-speed impact.

From the above papers, it can be clear that several researchers have studied and improved the bumper beam for low-speed impact test conducted as per various international regulations. However, it has been observed that many existing Indian car bumper beams fail if tested, with these existing international regulations. In this paper, slow speed impact test results for the bumper beams, fabricated based on the FEA study conducted [8], are presented. The dimensions for these bumpers are selected such that they can directly be adopted by the Indian automotive industries (like TATA, Maruti, etc.). These bumper beams are tested as per E.C.E. United Nations Agreement, Regulation no. 42 (1994). Simulation for impact test is performed using ANSYS software. The results produced are then compared and validated experimentally.

2. Bumper Beam: Model Information

Based on the designed information collected [8], where some bumpers were tested for low-speed impact as per IIHS standards, three bumper beams were fabricated. The geometrical, as well as meshing (shell mesh) details for these beams bumper, are listed in table 1. The bumper beam is mainly made up of alloys steel having two different types of material compositions (Mat-1 and Mat-2) as shown in table 2. The bumper beam is fabricated from the local bumper beam supplier. New CAD models are created and then they are imported in Hyper mesh for meshing, where shell type of mesh is created for FEA analysis.

Figure 1 shows cad modeled along with meshing developed for respective bumper beams. From this figure, it can be observed that all three bumper beams have a "C" profile as a basic cross-section. The bumper beam BB-1 is sort of more open type and looks very similar to the truss structure. Whereas for BB-2, the middle portion along the length of the bumper is not having any materials and for the bumper beam, BB-3 has the least holes.

| Bumper Beam Type | Length Mm | Width Mm | Thickness mm | weight of a car, Kg | Proposed for car | No. of elements | No. of nodes |
|------------------|-----------|----------|--------------|-------------------|-----------------|-----------------|--------------|
| BB-1             | 1015.55   | 95.91    | 1.00         | 1595              | Ciaz            | 1158           | 1338         |
| BB-2             | 1032.23   | 130.0    | 1.00         | 1505              | Swift           | 1825           | 1967         |
| BB-3             | 1037.17   | 108.89   | 1.00         | 1030              | Tiago           | 3541           | 1790         |

| Material | C     | Mn    | Si    | S     | P     |
|----------|-------|-------|-------|-------|-------|
| Mat-1    | 0.077 | 0.495 | 0.049 | 0.007 | 0.016 |
| Mat-2    | 0.087 | 1.329 | 0.149 | 0.010 | 0.016 |
Impact Test

The Front low-velocity impact test for all three bumper beam BB-1, BB-2, and BB-3 were simulated as per the standards of automotive stated in the E.C.E. United Nations Agreement, Regulation no. 42 (1994). The ECE-42 test Regulation applies to certain parts of the front and rear structure of passenger cars when involved in a collision at low speed. The test performed as per ECE-42 will verify whether the protective devices of the vehicle meet the requirements. The test recommends that the vehicle shall be kept at rest. The impactor shall be rigid and made up of steel. The impactor speed should be as designated by ECE-42. The impact reference height (from the ground) should be 445 mm whereas impactor speed 4 Km/hr is maintained. Also, care should be taken for the test area which shall be large enough to accommodate the striker propulsion system.

Figure 2 (a), (b), and (c) shows the FEA simulated impact test result for bumper beam BB-1, BB-2, and BB-3 respectively. The maximum stress is found to be produced not only at the middle portion of the bumper beam but also at the various stress concentrating locations like at turning curvature of bumper beam, at locations having holes, etc. The value of maximum Von Misses Stress is 576.5 N/mm², 461.1 N/mm², and 473.3 N/mm² for bumper beam BB-1, BB-2, and BB-3 respectively.
During the impact test, it is most desirable to not only check the level of maximum stress reached but also look into the energy absorbed by the bumper beam. The energy can be classified into various components as kinetic energy, internal energy, hourglass energy, damping energy, and sliding energy.

Figure 2: Von Misses Stress obtained during the Impact test.
Figure 3: (a) Plot of Energies V/s Time and for Bumper beam BB-1

Figure 3: (b) Plot of Internal Energy V/s Time for Bumper beam BB-1

Figure 4: (a) Plot of Energies V/s Time and for Bumper beam BB-2
Figure 4: (b) Plot of Internal Energy V/s Time for Bumper beam BB-2

Figure 5: (a) Plot of Energies V/s Time and for Bumper beam BB

Figure 5: (b) Plot of Internal Energy V/s Time for Bumper beam BB-3

All these components are shown in figure 3 for bumper beam BB-1. It can be observed that at the start, kinetic energy is maximum as time passes kinetic energy decreases at that time internal energy increases while total energy remains constant. Hourglass energy is due to mass scaling and is almost zero. No friction, so sliding energy is zero. The total energy observed is 900 J out of which energy 268 J is absorbed by the bumper beam BB-1. Figures 4 and 5 show the energy plots for bumper beam BB-2 and BB-3 respectively. It is observed that bumper beam BB-2 absorb 264 J of energy out of the total
energy of 900 J, whereas bumper beam BB-3 absorbs 235 J of energy 220 out of 900 J of total energy. From table 3 it can be observed that energy absorbed during the impact of bumper beam BB-1 is maximum compared to other BB-2 and BB-3. Hence bumper BB-1 is recommended based on the impact energy absorbed. Note that bumper BB-1 has a truss-like structure, which is an ultimate reason to absorb more kinetic energy during impact conditions.

| Bumper Beam Type | Total Energy (10^2 J) | Energy Absorbed(10^2 J) | Energy absorbed in % |
|------------------|-----------------------|------------------------|----------------------|
| BB-1             | 9                     | 2.68                   | 29.8                 |
| BB-2             | 9                     | 2.35                   | 26.1                 |
| BB-3             | 15.7                  | 2.64                   | 16.8                 |

4. Conclusion
In this paper, we have investigated the three types of the bumper beam with two different materials for their crashworthiness to be proposed for Indian automotive cars. The impact test conducted on all three bumper beams concludes that bumper beam BB-1 performance better than BB-2 and BB-3 by absorbing almost 30% of total energy. It should be noted that there is still much energy (70%) that is not getting absorbed and will directly transfer to the interior parts. The impact test performed on bumper beam BB-1 also reveals that the thickness of a bumper beam does contribute, however, the value should be chosen such that the increase in energy absorbing capacity concerning the increased thickness, which ultimately contributes to the weight. Also, out of two materials, Mat-1 is performing better than Mat-2. However, as per as only material is concerned, there is a desperate need for high energy absorbing material for bumper beams

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