CRASH TEST ANALYSIS OF BUMPERS OF AUTOMOBILES USING LS-DYNA

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Abstract. This article deals with calculations of deformation and failure of the bumpers of vehicles at different speeds against different obstacles. The main aim of bumpers is to absorb the impact energy in the form of stain energy and efficiently transfer it to the chassis to avoid permanent deformation of the whole frame of any motor vehicle. Different materials have been tried out with and without supporting structures (Ribs) which are known to increase the overall strength of the bumpers while keeping the weight to a minimum. In this experiment, 3 metals namely Sheet Iron, Aluminum and Titanium of varying thickness. Using LD-DYNA 108 cases were implemented. If the component passes the test, the Factor of Safety, Max Stress and the Trends in Variation of these parameters were calculated, the Max Energy Absorbed, Transmitted, the Time required for Failure are extrapolated from the data. Comparisons are drawn between failure, with and without support structures. In the end, overall effectiveness of the support structures in enhancing the load transfer, absorbing strain energy and increasing factor of safety while keeping the mass in check. Keywords: Car Bumpers, Crash Analysis, LS-Dyna.

1. INTRODUCTION

Automotive industries have constantly focused on weight reduction to improve the mile to fuel efficiency of the vehicles. This method causes serious damage to the safety of the passengers in the events of a crash. In this study, we have considered three materials models namely Grade 5 Titanium (Ti-6Al-4V) [1], Stainless Steel (SS-304)[2],[4],[7] and Al 99.96 percentage (Pure Annealed)[11]. Using LS-Dyna, multiple simulations were done at different speeds (40, 50, 60 Km/h). Considering strength and bending stiffness, the bumper with various thickness was designed. The bumper was tested against two different obstacles (Wall and Pole). Simulation of a total of 54 cases yielded enough data to redesign the bumper and repeat the same experiment on the second iteration, the results are discussed below. In the recent years, Bumpers are being made with plastic to reduce the weight.

2. METHODOLOGY

2.1 Experiment Design

Bumpers are amongst the first components to fail in an event of a full-frontal crash. Thinner metal sheets with extra supporting structures in place, can replace plastic sheet bumpers. In this study, we have used three different materials as a replacement of the plastic bumpers. The materials used were SS-304[2],[4],[7], Al 99.96 percentage [11], Ti-6Al-4V.[6],[10]

Table 1. Properties of the materials used in Simulations

| Sr. No | Material Model         | Young’s Modul (GPa) | Density (g/cm^3) | Poisson’s | Strength Coefficient (GPa) | Hardening Exponent | Plastic Failure |
|--------|------------------------|---------------------|------------------|-----------|-----------------------------|-------------------|-----------------|
| 1      | Aluminum 99.96% Pure Annealed [11] | 68.94              | 2.685e-06        | 0.33      | 0.0974                      | 0.33587           | 0.50            |
| 2      | Titanium               | 113.8              | 4.430e-06        | 0.342     | 1.564608                    | 0.18231           | 0.14            |
The bumper is tested against a wall and a pole (both marked as completely rigid in all cases), at three different speeds (40, 50, 60 Kmph). A second iteration is based on the stress acting and the design is not considerably changed except for adding ribs at probable points of failure. After creation of 108 cases, the simulations were conducted to yield various energy plots. Stress, Strain & Deformation Contours.

### 2.2 Design

The bumper design included all the required features in a standard car. The novelty in our design that to improve the bending stiffness we have made a corrugated design. Corrugations and Ribs are the design additions that tend to improve the strength parameters. A plastic coating to hide corrugations will keep the visuals intact and reduce the weight of the bumpers; we have considered three thickness in our study (5mm, 9mm and 13mm). The Corrugations and the ribs increase the bending stiffness of the design without increasing much weight. Thus overall, the strength to weight ratio is optimised. The locations of the rib were decided on the basis of the stress concentration locations and their respective levels. Figure 1 shows the Bumper design without ribs. The main dimensions of the design are shown in the Figure 2.

| Material | Stress | Strain | Deformation | Weight |
|----------|--------|--------|-------------|--------|
| Stainless Steel (AISI-304) | 207 | 7.830e-06 | 0.3 | 1.332 | 0.395 | 0.70 |

### 2.3 Iteration 2

After careful examination of the stress distribution and stress propagation, several locations were noted down and at those places; ribs were added to the design along the direction of bending to increase the bending stiffness. Effects due to the changes in the design were studied and plotted. All the calculations were done to evaluate the Strain energy stored in the design when it crashed with the two common kinds of obstacles namely wall and pole. Figure 5 shows the modified design of the bumper along with the ribs. Figure 3 & 4 shows the locations of maximum stress.
2.4 Method of simulation

Firstly, the meshed model was created in the ‘HYPERMESH’ software, then this model was exported as a ‘.k’ file. The material model was set to MAT-018 (power law plasticity) for bumper in the LS-PrePost Software [9]. All three materials (Aluminum, Stainless Steel, Titanium) were defined under the same category along with the properties given in the Table 1. The Material model MAT-020 (Rigid) [12] was used for the obstacle, since we didn’t want to increase the simulation time for calculating the deformations in the obstacle along with same steel material. The section was defined as solid and both Bumper and Obstacle. Then the boundary conditions such velocity & fixed support were defined respectively for Bumper and the obstacle. At last the Termination time was iteratively determined to be around 4-8 milliseconds, for the wide range of simulations. The plots for Nodal Displacements and Forces under ‘ASCII-rcforc’ & D3PLOT were considered for calculating the work done and strain energy development calculations.
\[ \sigma_y = k \varepsilon^n = k(\varepsilon_y + (\varepsilon_p))^n \]

Here, \(\varepsilon_y\) - yield stress; \(\varepsilon_p\) - Elastic strain; \((\_\_\_\_)\) - effective plastic strain.

### Meshing

The meshing was done in Hyperworks with the given Specification data. The R-triad type was used for getting proper geometric Curvatures into account. It was observed that in the given size for the element the geometry was matched within limit and mesh sensitivity was conserved. Table 2 contains the parameters of the Meshing. Figure 6 & 7 shows the meshing of the bumper and the obstacles.

| Sno | Part Name | Mesh Type | 2D-Type | 3D-Type | Min Ele | Feature Angle | Max Elmen t Size | No.of Elemt | No of Nodes |
|-----|-----------|-----------|---------|---------|---------|---------------|-----------------|-------------|-------------|
| 1.  | 5mm       | V-Tetra   | R-triad | Tetras  | 6       | 30            | 10             | 134062      | 45953       |
| 2.  | 9mm       | V-Tetra   | R-triad | Tetras  | 6       | 30            | 10             | 113865      | 36724       |
| 3.  | 13mm      | V-Tetra   | R-triad | Tetras  | 6       | 30            | 10             | 133983      | 39948       |
| 4.  | Pole      | V-Tetra   | R-triad | Tetras  | 50      | 30            | 50             | 228         | 105         |
| 5.  | Wall      | V-Tetra   | R-triad | Tetras  | 100     | 30            | 100            | 1068        | 396         |

**Figure 6.** Meshing Image of the Bumper  
**Figure 7.** Meshing Image of Obst
### 2.6 Simulation Parameters

| Simulation | Material | Speed | Barrier | Thickness | With | Sim  | Without |
|------------|----------|-------|---------|-----------|------|------|---------|
| 1          | Al 99.96% | 40    | Wall    | 5         | W    | 55   | W/O     |
| 2          | SS-304   | 40    | Wall    | 5         | W    | 56   | W/O     |
| 3          | Ti6Al5V  | 40    | Wall    | 5         | W    | 57   | W/O     |
| 4          | Al 99.96% | 50    | Wall    | 5         | W    | 58   | W/O     |
| 5          | SS-304   | 50    | Wall    | 5         | W    | 59   | W/O     |
| 6          | Ti6Al5V  | 50    | Wall    | 5         | W    | 60   | W/O     |
| 7          | Al 99.96% | 60    | Wall    | 5         | W    | 61   | W/O     |
| 8          | SS-304   | 60    | Wall    | 5         | W    | 62   | W/O     |
| 9          | Ti6Al5V  | 60    | Wall    | 5         | W    | 63   | W/O     |
| 10         | Al 99.96% | 40    | Pole    | 5         | W    | 64   | W/O     |
| 11         | SS-304   | 40    | Pole    | 5         | W    | 65   | W/O     |
| 12         | Ti6Al5V  | 40    | Pole    | 5         | W    | 66   | W/O     |
| 13         | Al 99.96% | 50    | Pole    | 5         | W    | 67   | W/O     |
| 14         | SS-304   | 50    | Pole    | 5         | W    | 68   | W/O     |
| 15         | Ti6Al5V  | 50    | Pole    | 5         | W    | 69   | W/O     |
| 16         | Al 99.96% | 60    | Pole    | 5         | W    | 70   | W/O     |
| 17         | SS-304   | 60    | Pole    | 5         | W    | 71   | W/O     |
| 18         | Ti6Al5V  | 60    | Pole    | 5         | W    | 72   | W/O     |
| 19         | Al 99.96% | 40    | Wall    | 9         | W    | 73   | W/O     |
| 20         | SS-304   | 40    | Wall    | 9         | W    | 74   | W/O     |
| 21         | Ti6Al5V  | 40    | Wall    | 9         | W    | 75   | W/O     |
| 22         | Al 99.96% | 50    | Wall    | 9         | W    | 76   | W/O     |
| 23         | SS-304   | 50    | Wall    | 9         | W    | 77   | W/O     |
| 24         | Ti6Al5V  | 50    | Wall    | 9         | W    | 78   | W/O     |
| 25         | Al 99.96% | 60    | Wall    | 9         | W    | 79   | W/O     |
| 26         | SS-304   | 60    | Wall    | 9         | W    | 80   | W/O     |
| 27         | Ti6Al5V  | 60    | Wall    | 9         | W    | 81   | W/O     |
| 28         | Al 99.96% | 40    | Pole    | 9         | W    | 82   | W/O     |
| 29         | SS-304   | 40    | Pole    | 9         | W    | 83   | W/O     |
| 30         | Ti6Al5V  | 40    | Pole    | 9         | W    | 84   | W/O     |
| 31         | Al 99.96% | 50    | Pole    | 9         | W    | 85   | W/O     |
| 32         | SS-304   | 50    | Pole    | 9         | W    | 86   | W/O     |
| 33         | Ti6Al5V  | 50    | Pole    | 9         | W    | 87   | W/O     |
| 34         | Al 99.96% | 60    | Pole    | 9         | W    | 88   | W/O     |
| 35         | SS-304   | 60    | Pole    | 9         | W    | 89   | W/O     |
| 36         | Ti6Al5V  | 60    | Pole    | 9         | W    | 90   | W/O     |
| 37         | Al 99.96% | 40    | Wall    | 13        | W    | 91   | W/O     |
| 38         | SS-304   | 40    | Wall    | 13        | W    | 92   | W/O     |
| 39         | Ti6Al5V  | 40    | Wall    | 13        | W    | 93   | W/O     |
3. RESULTS AND DISCUSSION

3.1 Strain Energy

Energy absorbed by Aluminum without ribs is much less than the Ribs case. All the materials in all the cases follow this trend. The maximum energy absorbed is 16.73 KJ by a Stainless Steel Bumpers. The cumulative strain energy absorbed by bumper without ribs is 0.450 KJ while the energy absorbed by the bumper is 3.5 KJ. There is almost 600% increase in Strain energy absorbed.

![Figure 8. Strain Energy absorbed by Al Without ribs (Wall)](image1)

![Figure 9. Strain Energy absorbed by With Ribs (Wall)](image2)

Figure 8, Figure 9 represent Strain energy absorbed by Al bumper without and with ribs respectively. The maximum force exerted is almost the same in both the cases, but the displacement is higher the case of ribs, thereby increasing strain energy absorbed. The crash number can be referenced from above for particular case. It is a common observation that the common trend is as the speed increases the lesser energy is absorbed and more amount of energy is transmitted. The lower the thickness the lesser energy is absorbed.
Figures 10 and 11 represent energy absorbed by SS-304; all the trends followed by aluminum is followed by SS.

Figures 12 and 13 represent the crash by bumpers made of titanium with and without ribs. All the trends followed by Al and SS are followed by Ti only in the case Titanium without ribs. However, Titanium with ribs presents a peculiar case; the thickness does not really matter in this case. The work done is slightly increasing mostly due to the stiffness of the material.
Figures 14 to 17 represent crashes made by Aluminum and Stainless Steel. All the trends observed in wall cases all followed by the aluminum and Stainless steel.

Figures 18 and 19 represent Titanium colliding with a pole; the bumper starts to vibrate just as it collides, the loops represent vibrations on the bumper. All the other trends followed by all cases are followed by this case too.

3.2 Stress Contours

4. Future Work

The study can be expanded to plastics and composites, Composites can be used to reduce the weight, as their stiffness to mass ratio is high. Plastics are currently being used in the industry. Other factors also effect the bumpers, Cost of manufacturing and thickness of the materials should be considered in real time.
5. CONCLUSIONS

Thin Stainless Steel or Aluminum sheets can be used to make bumpers to improve the safety of the cars. Metals are stiffer than plastics and can be used as an efficient alternative to current plastics. Titanium can be used, which can reduce the weight of the bumper considerably and can easily absorb the force by vibration.

6. REFERENCES

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