The impact behavior of the crash boxes

A M Manea, D Iozsa and C Stan

Automotive Engineering Dept., Faculty of Transports, POLITEHNICA University of Bucharest, Bucuresti, ROMANIA

E-mail: mannea_annamaria@yahoo.com

Abstract. This article will study the impact behavior of the crash box structures. The crash boxes are found between the front cross member and the front side members. They play an important role in case of minor frontal impact, speeds up to 15km/h. For this study, we propose three models of crash boxes of different sections. The impact analysis will be performed using the software ANSYS, Explicit Dynamics module. The shape and dimensions of the models were obtained from repeated impact tests. Thus, the obtained results were used for the continuous improvement of the crash boxes. The proposed models are made from extruded Aluminum bars with different sections. With the help of finite element analysis (FEM) one can compare the results and what impact energy absorption characteristics each proposed model of structure presents.

1. Introduction

The strength structures of the body car are made to absorb a large part of the impact energy by deformation. It must behave in a strictly controlled manner in the event of low-speed to high-speed impact events. According to [11], the structure should fulfill a specific function in different speed regimes. At low speed impacts of up to 4 km/h, the structure of the front compartment should absorb the kinetic energy in a completely elastic way, without plastic deformation. Up to 8 km/h the system must absorb all the energy through plastic deformation limited to the front bumper beam. Up to 15 km/h all kinetic energy should be absorbed by the cross member and crash boxes. For the higher impact speed, all elements of the structure should absorb some of the impact energy, thus significantly contributing to the safety of the occupants of the vehicle [11].

In this paper it is desired to study the frontal impact behavior of crash boxes. The impact is considered to occur on 40% of the surface, at a low speed of 10 km/h [11]. Thus, numerous theoretical, numerical, and experimental studies have been carried out for the study of the impact behavior of the structures of the impact absorption blocks [3].

The impact behavior of these structures can be influenced by several factors: the cross-sectional configuration, the effective length, the wall thickness, the material properties and under different loading conditions [1] - [10]. Over time a variety of sections have been developed for impact-absorbing blocks, for example: cylindrical, square, hexagonal, conical (top-hat), convex polygon [1] - [10]. Also, the multi-cell thin-walled structure absorbs more impact energy compared to single-cell structure for the same weight [3].
2. Numerical simulation for crash boxes

2.1. Geometry of crash boxes
For the study of the behavior at the frontal impact, at low speed, up to 10 km/h, several blocks of impact absorption (crash boxes) with various sections have been proposed: rectangular (single-cell and multi-cell), hexagonal and cylindrical sections.

The dimensional parameters for the cross sections of the crash boxes structures are shown in figure 1, where in (a), (b) and (c) there are various sections with a single-cell and in (b) and (c) the rectangular multi-cell sections.

As for the thickness of the material, it was chosen differently depending on the architecture of the blocks. For single-cell sections the thickness of the material is 2 mm, and for the multi-cell sections the thickness of the material is 1.5mm and 1.2 mm, respectively. These sections are used to obtain geometric modelling of the impact absorption blocks in ANSYS software. The sections in figure 1 were extruded at the same length of L = 200 mm.

2.2. Material modeling
Modeling of the material from which crash boxes are made is necessary for performing impact resistance calculations. It is chosen from the “Engineering Data” library of the Ansys R15.0 program, the material “Aluminum Alloy Non-linear”. The properties of the material chosen are: Density = 2770 kg / m3, Poisson's ratio = 0.33, Young's Modulus = 70 GPa and Yield Strength = 210 MPa.

2.3. Element finite modelling
The discretization mode is very important, with the power of the number of finite elements grown, which can be very well analyzed [11]. To obtain a controlled deformation during the impact, a considerable number of finite elements are required. Thus, for the realization of the finite element network, the element size of 2 mm is chosen. The 2 mm dimension of the element is applicable to all the crash boxes proposed for the study, figure 2.
2.4. Initial conditions

The initial conditions imposed on each model are set by the Ansys program. For all crash boxes’ models, a fixed support is disposed on the entire lower surface of the section. The upper surface of the crash boxes section will collide with the rigid impact block, deforming.

To ensure the kinetic energy required for impact, a solid body was modelled. The impact block is made of steel and has a rigid behavior. Through the modifications made to the material of the solid body of impact it has a total mass of 636 kg. This mass represents 50% of the mass of a car. For the impact block, a single degree of freedom is established from the program, of translation along the Z axis direction, the others are constricted. Also, on the rigid body the speed of impact, \( V = 10\text{km/h} \) and the direction of its movement to the crash box are set. The static and dynamic frictional coefficients were set to be 0.3 and 0.2, respectively.

3. The results obtained at the impact of the crash boxes

Following the impact tests, performed using ANSYS software, the result obtained for each block will be presented. It is desired to study the impact absorption capacity for each proposed section of block. Figures 4, 5, 6, 7, 8 show the results obtained.

The first comparison between the obtained results will be made according to the maximum deformation of each block (figures 4.a, 5.a, 6.a, 7.a, 8.a). From the color range you can see values recorded during the simulation at impact of the blocks. Also, it was observed that all the proposed blocks have a controlled behavior and the deformation is progressive during the tests. In Figures 4.b, 5.b, 6.b, 7.b, 8.b the top views of the block deformations are shown. It is observed that the deformation is controlled. The folds are deformed on top of each other.

![Figure 2. Finite element network of the crash boxes models](image)

![Figure 3. The initial conditions: a). fixed support and remote displacement; b). velocity](image)
Figure 4. a) The total deformation; b). The top section view at total deformation; c). Equivalent plastic strain; d). Equivalent stress.

Figure 5. a) The total deformation; b). The top section view at total deformation; c). Equivalent plastic strain; d). Equivalent stress.

Figure 6. a) The total deformation; b). The top section view at total deformation; c). Equivalent plastic strain; d). Equivalent stress.

Figure 7. a) The total deformation; b). The top section view at total deformation; c). Equivalent plastic strain; d). Equivalent stress.
Figure 8. a) The total deformation; b). The top section view at total deformation; c). Equivalent plastic strain; d). Equivalent stress.

Table 1 summarizes the results obtained from the impact simulations, at low speed, of the blocks. The evaluation of the obtained results is made by the parameters: Total deformation [mm], Equivalent Plastic Strain [mm/mm] and Equivalent Stress [MPa].

| Model 3D         | Total Deformation [mm] | Equivalent Plastic Strain [mm/mm] | Equivalent Stress [MPa] |
|------------------|------------------------|-----------------------------------|-------------------------|
| Single-cell rectangular | 76,333                 | 0,941                             | 449,86                  |
| Two-cell rectangular | 80,579                 | 0,946                             | 483,82                  |
| Three-cell rectangular | 27,069                 | 0,459                             | 8508,8                  |
| Hexagonal         | 54,447                 | 0,882                             | 665,07                  |
| Cylindrical      | 45,544                 | 0,669                             | 390,85                  |

According to the data in the table and the previous figures, it is observed that the block with rectangular section with three-cell, has a deformation value of approximately 27 mm. Then it is followed by the cylindrical section block, which has a deformation of approximately 45.5 mm. The hexagonal section also performs well during the impact, recording a deformation of approximately 54.4 mm. As far as the rectangular sections are concerned, the smallest deformation is recorded among the three-cell section, followed by the single-cell section and finally the two-cell section. These differences in values among the rectangular sections are also recorded due to the thickness of the material. The single-cell model has a thickness of 2 mm, and the multi-cell ones, two and three respectively, have a material thickness of 1.5 mm and 1.2 mm respectively. The differences between the blocks arise because of the different sections used, the use of different material thicknesses of the section of the blocks, and thus, the masses of the blocks are not equal.

As for the values recorded for the Equivalent Plastic Strain, they can be read from the color grid in Figures c.

For Equivalent Stress, the highest value is recorded in the three-room block. Tensions only occur in the deformation area of the block. In the case of the other blocks, tensions appear throughout the blocks.
4. Numerical simulation for the front compartment structure

4.1. Geometry of the front compartment structure and finite element network

Further, the impact behavior of the front compartment will be studied. A simplified 3D model is proposed, with the main elements of the front compartment structure, according to figure 9 [13]. The unicellular rectangular section presented in figure 2.a) will be used. From the ANSYS program library, the type of material, the properties of the material and the thickness of the section of the material will be determined. The “Non-linear Aluminum Alloy” material is preserved, with the properties: Density = 2770 kg / m³, Poisson's ratio = 0.33, Young's Modulus = 70 GPa and Yield Strength = 210 MPa and section thickness of the material of 2 mm. The connection between the two ends of the two crash boxes will be made through bumper front of varied rectangular section, with three cell. The same material used for the blocks is chosen for the cross beam. The cross member thickness is 1.5 mm.

![Figure 9. 3D model geometry and finite element network](image)

The finite element model is obtained by meshing the geometric model of the structure made from surfaces. The main parameters used for the structure, thickness and material were determined after several attempts. Table 2 lists the parameters from the last test.

| Parameter          | automobile frame rails | crash box | bumper front | the other elements | rigid barrier |
|--------------------|------------------------|-----------|--------------|--------------------|---------------|
| Thickness [mm]     | rigid 2.8              | 2         | 1.5          | 1.5                | rigid 1,5     |
| Material           | Steel Steel NL3        | Aluminum Alloy NL 10 | Aluminum Alloy NL 10 | Steel NL2 | Steel |
| Mesh size [mm]     | 150                    | 30        | 10           | 30-100             | 150           |

4.2. Test protocol and initial conditions

The geometric model used to analyze a front impact on 40% of the car body structure, attempts to simulate the impact test at low speeds according to the Research Council for Automobile Repairs protocol, (Figure 10). The purpose of the RCAR protocol is to reduce the loss of human lives and to reduce as far as possible the cost of repair [12].

The initial conditions imposed on the model are set out in the Ansys program for the entire structure, (figure 11). To provide the required kinetic energy, the body car was molded by a solid body so that the total weight of the structure was equal to the mass of the vehicle (approximately 1400 kg). The impact velocity and the direction are imposed on all the structure and the impact barrier is a rigid body, \( V = 10 \text{km/h} \).
The impact block is made of steel and has a rigid behavior. The solid body stores the mass of the car. For the structure of the front compartment and the solid body a single degree of freedom, of translation along the Z axis direction is established from the program, the others are constricted.

5. The results obtained at the impact of the front compartment structure
This chapter will present the results obtained from the frontal impact of the front compartment structure. In this test it is desired to present the impact behavior of the rectangular crash box studied in the previous chapter.

Figure 12 shows the maximum deformation suffered by the elements of the front compartment structure during the impact. It can be seen, from figure 12, the elements that deformed during the test are the front cross and the block. From the color range we can observe the values recorded during the impact simulation of the impact absorption block. It is also noted that the proposed block has a controlled behavior and the deformation is progressive during the test.

Figure 10. Test protocol
Figure 11. Initial conditions

Figure 12. a). The total deformation on the front structure; b). Equivalent plastic strain on the front structure; c). Equivalent stress on the front structure.
6. Conclusion

The sections proposed for studying the behavior at low speed impact behaved according to the imposed requirements.

The shape and dimensions of the models were obtained from repeated impact tests. Thus, the obtained results were used for the continuous improvement of the crash boxes. With the help of finite element analysis (FEM) one can compare the results and what impact energy absorption characteristics each proposed model of structure presents.

It should be mentioned that by progressive deformation the blocks have a controlled and stable behavior during the impact period. The deformations occur progressively. The folds of the deformed material are approximately uniform, coming over each other. It can be seen in chapter 3 that the deformations of the blocks are controlled. Also, the impact energy is consumed entirely by the progressive deformation of the blocks.

It should be noted that the thickness of the material is of particular importance in the behavior of the impact block and its deformation mode (collapse process).

7. References

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