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Optimized metal foam-filled Crushbox structure to improve the impact energy absorption

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Abstract. According to the transport statistics, there are many personal injury affected road fatalities on the EU's roads. The increasing urbanization results in huge daily crowded paths in the cities. Drivers try to recoup for lost time in traffic jams with increased speed and reduced tracking distance, and the inattentive behavior to using mobile phones is a common cause of rear-end collision.The most common personal injury of the rear-end collision would be decreased by an optimized crumple zone to reduce the impact load force. With mass optimization not only the operational efficiency would be improved but the impact energy can be reeducated also. To achieve this aim integrated and advanced materials must be applied. This study is focusing on the optimization of the bumper-crushbox, and apply an improved structure in which more volume of the metal foam can be utilized, than the recent solutions.

1. Introduction

Analysing the reports of the ACEA (European Automobile Manufacturers' Association) we can realize in the last decade the number of cars is in use have been increased by more the 42%. According to their published report in 2010 more than 278 million vehicles were in use in Europe, while this number in 2020 has been almost exceeding 400 million [1]. Due to the increasing urbanization, the cities and their roads have become crowded with passenger cars day by day [2]. The road infrastructure (intersections, traffic lights program) can not follow this pace of the increase of traffic. The crowded roads result in impatient and uptight behaviour in the member of the traffic. Due to this impatient and careless driver behaviour generates upgraded tendency of the rear-end collisions. Analysing the statistics about the road fatalities, the rear-end collision gives a considerable proportion of the whole crash occasions [3]. Usually, the impact energy level of a rear-end collision is lower than a head-of-collision, notwithstanding the fatality can involve serious personal injury and bodywork damage as the effect of it. Therefore this study is focusing on the improvement of the outer passive safety system of road vehicles.

2. Damaged parts of the bodywork of the rear-end collision

Figure 1. shows the most frequently damaged vehicle body parts by rear-end collision (REC). The investigation is focusing on the city-road type rear-end collision, therefore the distinction is made between three main separations. The extent of the physical injury of the vehicle and the personal injury of the driver or passenger is influenced by the difference in the kinetic energy of the participants. The kinetic energy depends on the mass of the vehicle and the velocity of the vehicle. However analyzing the effect of the collision, we have to compare the kinetic features of each vehicle simultaneously. In the first group, where the low speed or low mass caused impact energy is low, only some front and rear optical parts will be damaged or destroyed. Broken bumper shells, broken mouldings, grilles, PDC sensors are the most common damaged vehicle body parts during low impact energy. If we increase the speed or/and mass of each participant vehicle, this results in higher impact energy during the collision. Not only the optical bumper shell will be destroyed, but –being the first member of the crumple zone- the bumper beam will be also damaged. We frequently experienced the sub- or full breaking of the glass-fibre-reinforced polymer manufactured front wall-beam. Owing to the bumper beam damaging, behind the beam, the coolers (air, water, oil, air-condition) are often idamaged by this collision. In favour of the mass optimization, the support of the head and rear light, support of the coolers is made by polymer, which results in easily damaging of these components. Over about 30 km/h or with heavy massed vehicles the impact energy will be multiplicated and result in serious technical damaging in the participants' vehicles. Over the bumper beam, the front and rear rails, the rear wall is damaged by the hood and tailgate destroying. The front hood conducts the impact energy through the support to the A-pillar, where the impact force will have appeared in windshield breaking. Naturally, this type of collision involves the activation of the airbags and the seat-belt tensioners, therefore the dashboard, inner upholstery expand on the list of parts to be replaced.

Figure 1. Most common bodywork damages of the REC. [own source]

3. Description of the safety level of the vehicles

Basically, the safety system of the vehicles can be divided into passive and active safety technologies. Active technologies try to prevent collision to improve the safety of the traffic. Nevertheless, the passive safety system tries to reduce the personal injury and technical injury effect of the collision [4]. Furthermore, the distinction is made between inner and outer passive solutions. However nowadays, in the case of modern vehicles, there is no strict boundary between the passive and active safety system, since their common operation of influence the level of the vehicle's safety. Owing to this we can use the integrated safety notion to describe the safety of the vehicles. The integrated safety is in fact a description based on the Haddon matrix model expressing the complete safety of vehicles. With a systematic approach to road transport, we can divide the human-vehicle environment into three. These elements in the pre-, during-, and post-accident states continuously determine and actively influence the circumstances of the accident and its consequences. Consequently, technological developments based on traffic accident research are based on this system-based principle [5].

4. Kinematics of the collision

The aim of this study is to reduce the effect of the collision focusing on the outer passive safety system development. However, the effect is influenced by the impact energy more exactly the impact force, which is relevant with the kinetic energy. According to the energy conversation statement, the kinetic energy must be equal to the impact energy during the collision [6].

$$E_{kinetic} = E_{impact} \tag{1}$$

The dimension of the crumple zone compression is designated as S. According to Newton's 3rd axiom in the case of two bodies interaction, they apply forces on each other that are equal in magnitude and opposite in direction. This force creates work on the S-displacement, resulting in the compression of the crumple zone.

$$E_{impact} = F \cdot S \tag{2}$$

$$F = m \cdot a \tag{3}$$

$$E_{kinetic} = \frac{1}{2} m v^2 \tag{4}$$

Take equal the (2) (3) and (4) equations:

$$\frac{1}{2} m v^2 = m \cdot a \cdot S \tag{5}$$

where the *m* is the impact mass, the *v* is the kinetic velocity and the *a* is the declaration of the vehicle.

Analysing the (5) formula, there are more options to reduce the amount of the F force, which loads the drivers and the passengers during the collision. According to the correlation, with an extended crumple zone, we can expand the compression distance results in an F force reduction. In another way, the amount of the F force that influences the collision effect can be reduced if the temporal changes of the velocity are prolonged. Furthermore, with mass optimization, not only the efficiency but safety can be improved simultaneously. Figure 2. shows the Crushbox of the bumper structure, which provides the above mentioned one of displacement of the crumple zone.

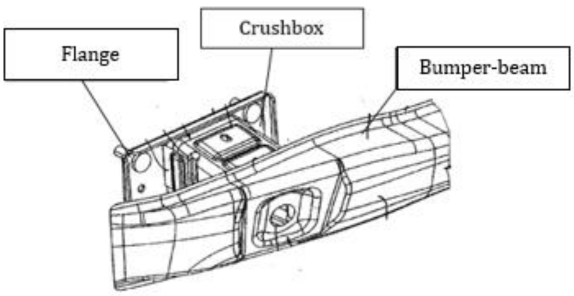

Figure 2. The parts of the bumper. [7]

5. Foam-filled crushbox to enhance the energy absorption

There are many recent investigations that confirm the statement, according to which the impact energy absorption capacity of each carrying body element can be improved with the application of the metal foam [8][9][10]. However, during the literature review, it can be experienced that the applied metal foam frequently is not utilized entirely. Figure 3. shows a foam-filled tube after impact investigation. As it can be seen the applied metal foam volume can be divided into three types of groups. Alongside the crsuhbox wall, the metal foam cells reach the maximum deformation option. Next to the extremely densified zone, in the normally densified region, the metal foam could not reach the maximum deformation state, resulting in the applied foam could suit for more energy absorption. Furthermore under there is a region, in which the foam after the collision stayed in undeformed form since it could not take part in the energy absorption. Figure 3. introduced FEM analysing also which confirms that a significant volume of the applied foam is not utilized in the absorption during the collision.

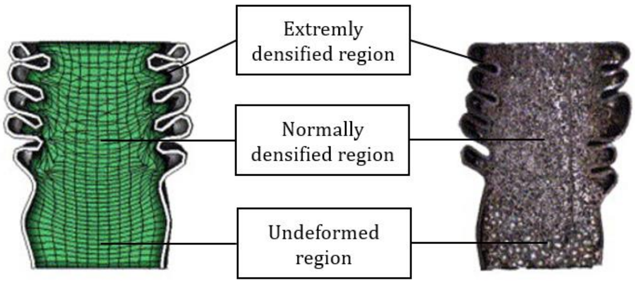

Figure 3. Impact loaded foam-filled tube. [5]

6. Utilization of the advantageous characteristics of metal foam

Before introducing the optimized Crushbox, the stress-strain characteristics of the metal foam must be discussed, since it gives the fundamental of the metal foam utilization. As it can be seen in figure 4. after the linear elasticity (cell wall bending) of the curves there is the ideal energy absorber zone. In this section the largescale strain involves almost permanent stress value, therefore one of the most proper materials for the impact absorbing. Numbers of open literature have reported the dynamic behaviours and features of the metal foams [11][12][13]. After the ideal zone, when the cells become fully deformed, there is the safety back-up zone. The aim with the application of the metal foam is to utilize the maximum horizontal characteristics (Crush Plateau) of the curves or to further extend this horizontal line.

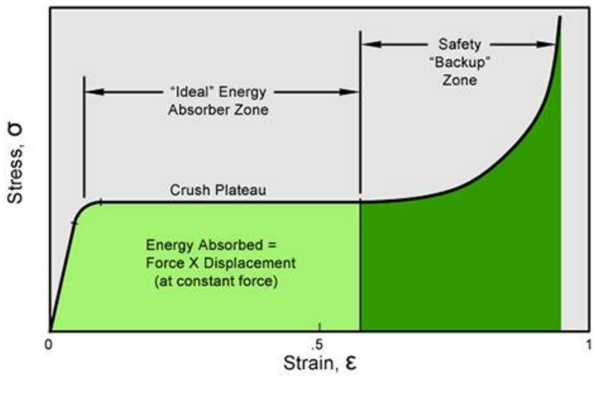

Figure 4. Stress-strain characteristic of the aluminium foam. [14]

7. Optimized Crushbox

For us, the optimized crusbox is based on the structure of the telescopic cylinder. As in figure 5. can be seen contrast with the standard one-element Crushbox, we separated it into more sections. Each section is separated by a metal foam plate. When the collision acts force on the top of the Crushbox, the first upper member slips down into the below part meanwhile it compressed the metal foam and the cells begin to densify thereby absorbing the impact energy. Since the actuating load distributes on the entire surface of the metal foam, the efficiency could be more favourable. During the operation, we try to avoid or postpone the negative vertical line of the stress-strain characteristics, therefore before the cell

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achieves the overloaded state the flange of the first upper element lays on the upper flange of the second element which begins to shink into the lower element. In the second section, the metal foam is also loaded on the entire surface by the compressing force. Moreover owing to the separated sections we can apply different characterized metal foam, or different material foams can be applied simultaneously that can result in new stress-strain characteristics due to their serial arrangement. The sliding components are mounted with a certain amount of clearance to provide the displacement, with a proper clearance the energy absorption can be improved since more energy will be dissipated to overcome the friction between the components. With a different variety of clearance and with different features metal foams applying we can create modulated Crushbox.

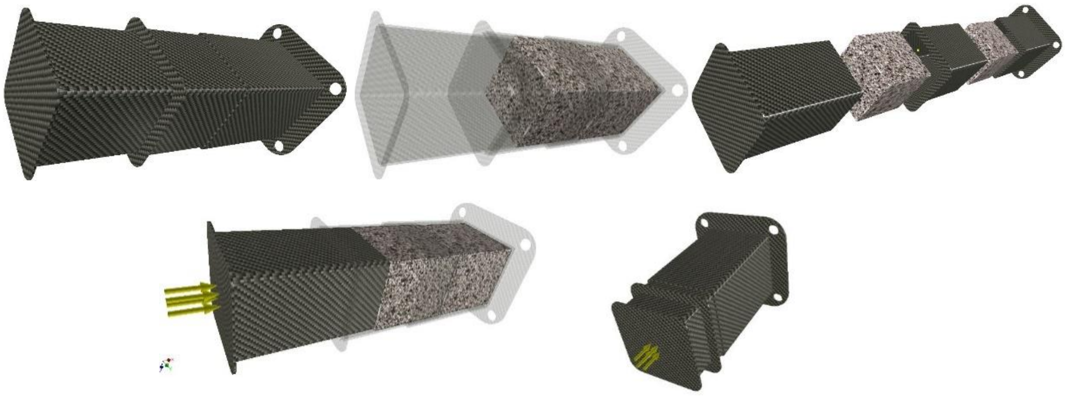

Figure 5. Structure of the developed telescopic based crsuhbox. [own source]

8. Conclusions

The significant growth of the road vehicles in use results in frequently crowded paths on the city roads. In order to retrieve the wasted time in traffic jams, drivers often neglect the following distance and the speed limits during the transport which results in the increment of the number of rear-end collisions occasions. To prevent the serious personal injury effect of this type of facility the impact energy must be reduced during the collision involving the improvement of the outer passive safety system of the vehicles. Recent investigations verify that the foam-filled Crushbox of the bumper-beam results in enhanced energy absorption efficiency. However, the amount of absorbed energy would be increased by our developed optimized structure, which involves lower impact forces on the drivers and passengers. In contrast with the standard Crushbox, the telescopic structure provides the possibility to apply different featured foam simultaneously thereby creating a modulable structure. Owing to the enhanced absorption capacity, conventional metals (steel, aluminium) can be replaced by lighter but advanced materials, for example, CFRP(Carbon Fiber Reinforced Polymer).

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