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Energy Absorption and Response Speed of Crush Beam in Smaller Electric Cars

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***Abstract*—The use of composite materials to construct the crush beam could enhance the structure performance and provide a lightweight solution. In this paper, we studied the influence of materiel, cross-sectional shape and can structure on crush beam properties by finite element simulation analysis. Firstly, the crush beam structure in the Smartfortwo electric version was chosen to construct the model, but the parameters were changed appropriately according to BYD Qin PHEV to suit smaller electric cars. Then, by finite element simulation analysis we got the energy absorption capacity and response speed of crush beams with different variables. At last, by analysis of the simulation results, we knew the effect of variables above on crush beam properties, which can direct the design of better crush beam.**

Keywords-crush beam; materiel; cross-sectional shape; can structure; energy absorption; response speed

I. INTRODUCTION

Reducing the weight of automobiles is one of the most important goals of sustainable development and is of great significance in terms of both energy-saving and environmental purposes [1]. Currently, such lighter weight automobiles are also required to comply with harsher energy-saving and emission-reduction standards [2]. One of the most effective ways to achieve weight reduction is the use of alternative lightweight materials. Composite materials are ideal for this purpose owing to their high specific modulus and strength, as well as their good chemical stability. Therefore, the application of composite materials in the automobile industry has a long history, facilitating the production of eco-friendly and energy-saving vehicles while simultaneously achieving weight reduction [3]. The Lamborghini Murciélago, for example, has a carbon fiber monocoque vehicle body, which is cured to function as one single component. Although this car weighs only 145.5 kg, its vehicle body still has great strength. The vehicle crush beam, which is an important automotive safety component [4], absorbs collision energy through the crush cans with lower yield strength at its ends. Consequently, cans reduce the damage on impact and protect people and vehicles from danger.

The energy absorption capacity of a vehicle crush beam is mainly determined by two aspects: the first is the design of the beam structure, mainly the beam curvature, locations of crush cans, and tendon size, and the other is the material properties, such as the crystal structure and chemical bond properties [5]. The design of the crush beam mainly involves three aspects: the cross section of the beam part, the material, and the crush can [6]. Among them the design of the beam section is the most basic aspect [7]. Common cross-sectional shapes are as shown in Figure 1.

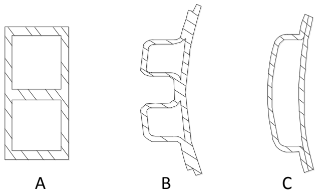


FIGURE I. THREE CROSS-SECTIONAL SHAPES

Worldwide, scholars have intensively studied various materials for application in vehicle crush beams. For example, Ye studied the ductile fracture behavior of 6xxx series aluminum alloy thin-walled parts for automobiles [8]. The fitting parameters of the constitutive model, the Johnson-Cook model, for 6061 and 6063 aluminum alloy and the Cockcroft-Latham ductile fracture were determined by experiments. In addition, a method to predict the ductile fracture behavior was proposed. Gao studied the crashworthiness behavior of an H-beam, and proposed the idea of optimizing the design of the aluminum alloy material against the collision beam based on the hybrid cellular automata method [9]. Even though there was a theoretical difference, the results were very close to each other in the specific frequency range of interest. A numerical simulation with identified model parameters was carried out to predict the damping behavior in its first two vibration modes. Experimental testing validated the numerical prediction satisfactorily.

The study presented in this paper, is based on the various crush beam cross-sectional shapes mentioned above and on the crush beam finite element model that was built to design the beam structure [10]. We chose the SMARTFORTWO electric version model to design the crush beam structure and the parameters were changed appropriately according to BYD Qin PHEV to suit smaller electric cars.

The variation of the beam curvature is an important process for studying the collision energy absorption. The beam first hit the object during the collision, which causes the shape of the beam to change. This change involves cross-sectional collapse and curvature change. The smaller the curvature of the beam part, the more energy the beam can absorb during the collision. Nevertheless, a crossbeam with a small curvature would occupy considerable space in the front of the vehicle. Thus, it is important to design the cross-sectional shape and beam curvature appropriately.

Crush cans, connected to the front crossbeam by bolts, absorb most of the crush energy during a collision. The energy absorption capacity mainly depends on the crush can thickness and tendon position. Therefore, it is important to design the form of the crush can structure such that it improves the energy absorption capacity.

This research aims to optimize the above-mentioned crush beam structure parameters achieved by finite element analysis, the result of which is expected to guide the construction of models to investigate the structure of a crush beam [11]. The study attempted to analyze and compare the effect of different materials and beam structures on the energy absorption capacity and additionally aimed to determine the rules and mechanism according to which these properties are influenced [12].

II. FINITE ELEMENT SIMULATION

In this project we built a geometric model by using CATIA, a computer aided three-dimensional interactive application produced by DASSAULT in France. This model was imported into HYPERMESH, a leading and powerful CAE application package produced by Altair in the United States, in the igs format. The geometry size was as indicated in table 1 [13].

TABLEⅠ. SIZE OF CRUSH BEAM

Size		
Length (mm)	***Width (mm)***	***Height (mm)***
1030	30	83

In the finite element analysis model of this project, the solid sheets, simulated as a collision wall and vehicle body, were set as rectangular elements with sides of 10 mm [14]. The crossbeam model, which was a rotational body with an irregular cross section, such as structural rounded corners, consisted of triangular and rectangular elements with maximal sides of 10 mm. Crush cans were modeled as structures consisting of triangular and rectangular element units, the maximum side of which was 8 mm. The number of triangular element units should be less than 5 percent of the number of rectangular element units to ensure the desired operational speed. The simulated condition is shown in Figure 2.

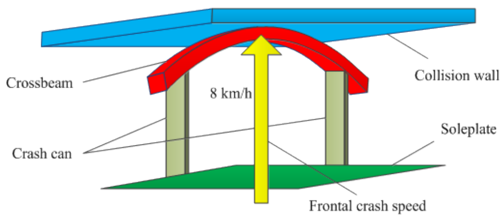


FIGURE II. THREE CROSS-SECTIONAL SHAPES

The sample material was high-strength steel DP600 and aluminum alloy 6061 [15]. The constitutive material parameters in the model of high-strength steel DP600 were as in Table 2, was and correspond to the Cowper-Symonds constitutive model in the HYPERMESH material model library. The material stress-strain curve is shown in Figure 3.

TABLEⅡ. MATERIAL PARAMETERS OF DP-600

Material	*Density (kg/mm^3)*	*Young's modulus (GPa)*	*Poisson ratio*	*Yield stress (MPa)*
DP-600	7.86E-06	200	0.3	1000

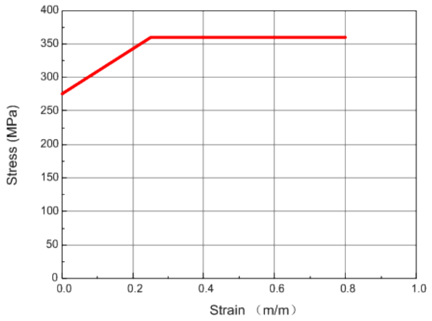


FIGURE III. THREE CROSS-SECTIONAL SHAPES

The collision wall was set to be a rigid body with steel DP600, which consumed no additional energy as a result of deformation during collisions. With regard to the setting of the connection, the crush cans and the vehicle body were arranged as a rigid body connection, and the crush cans and the cross beam were provided with a welding connection. The static and dynamic friction factors were 0.1 and 0.2, respectively [16]. The hourglass setting was chosen as selection mode 4 based on the collision structure and partial integral [17].

III. FINITE ELEMENT SIMULATION ANALYSIS

In this paper, we studied the effect of three research variables: cross-sectional shape (Shown in Figure 1), crush can structure (Integral and separated type shown in Figure 4) and material (Aluminum alloy DP600 and steel 6061). In order to study the influence, we paid attention to energy absorption and response speed to assess the crush beam performance.

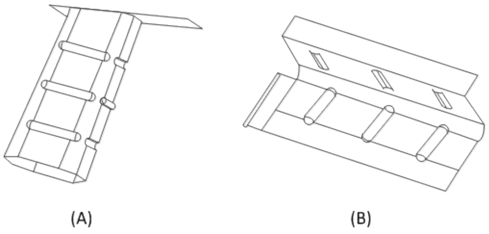
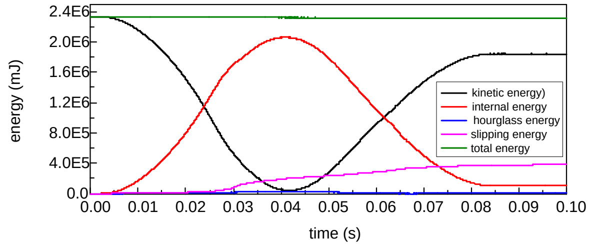


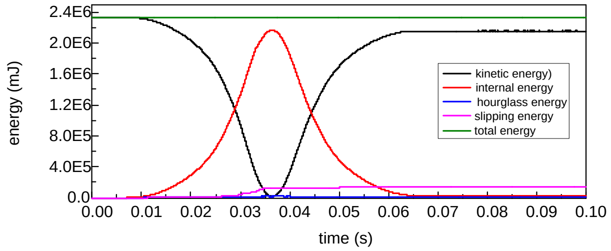
FIGURE IV. (A) INTEGRAL CRASH CAN (B) SEPARATED CRASH CAN

A. Energy Absorption Analysis

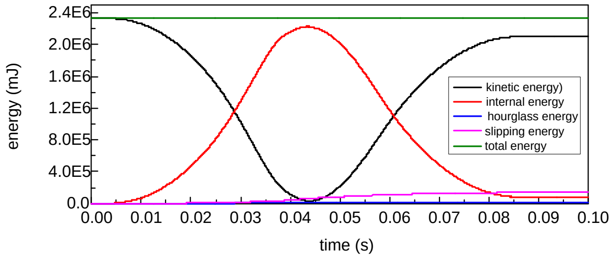
The energy profiles of crush beam with three cross-sectional shapes are shown in Figure 5. Energy distributions are shown in Figure 6. Energy absorption peak values are shown in Figure 7.



(A) A-TYPE



(B) B-TYPE



(C) C-TYPE

FIGURE V. ENERGY CHANGES OF BEAMS WITH DIFFERENT CROSS-SECTIONAL SHAPES

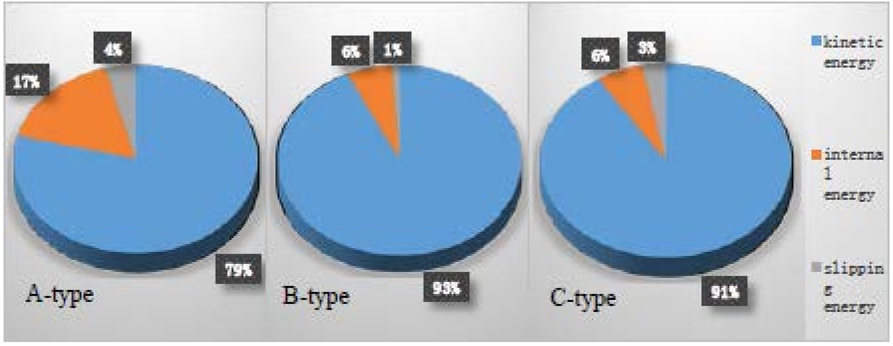


FIGURE VI. ENERGY DISTRIBUTION

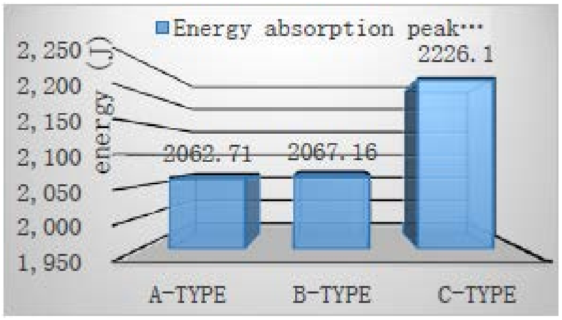
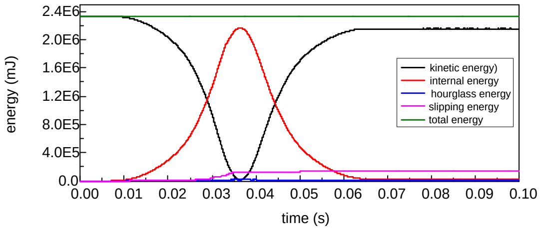
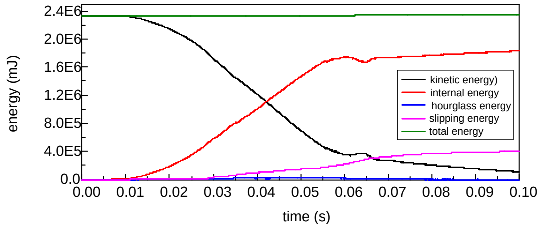


FIGURE VII. ENERGY ABSORPTION PEAK VALUE

The energy profiles of crush beam with different can structures are shown in Figure 8. Stable energy distributions are shown in Figure 9. Energy absorption peak values are shown in Figure 10.



(A) INTEGRAL CRUSH CAN



(B) SEPARATED CRUSH CAN

FIGURE VIII. ENERGY CHANGES OF BEAMS WITH DIFFERENT CAN STRUCTURES

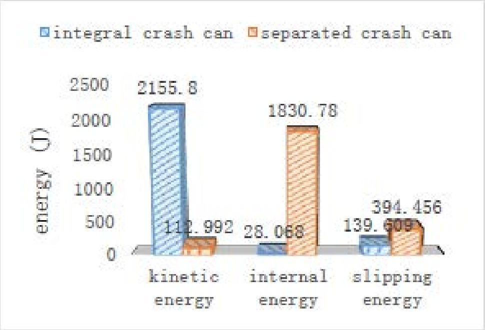


FIGURE IX. STABLE ENERGY DISTRIBUTION

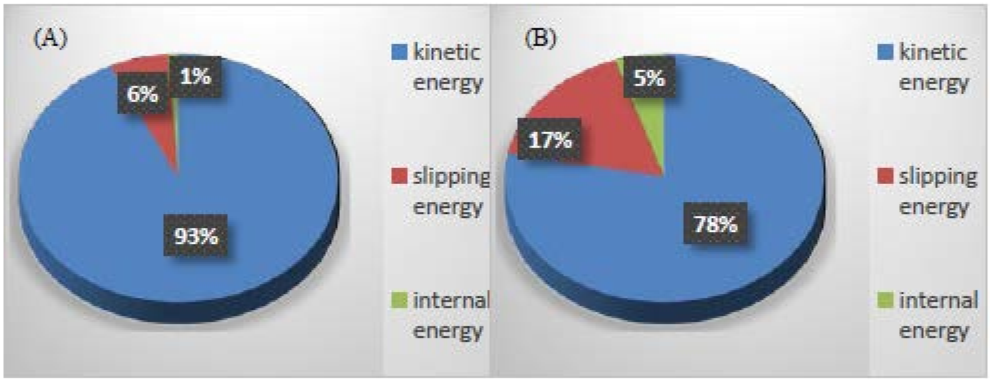
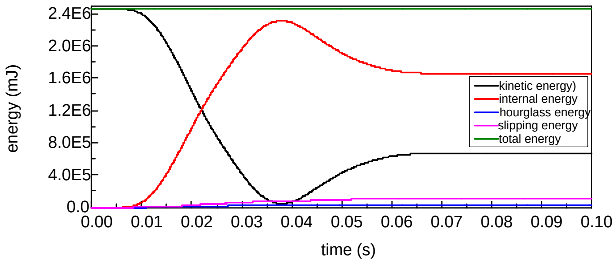
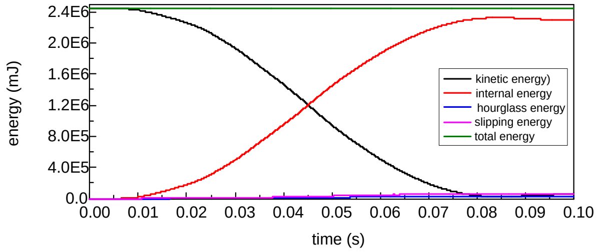


FIGURE X. ENERGY DISTRIBUTION OF (A) INTEGRAL CRASH CAN (B) SEPARATED CRASH CAN

The energy profiles of crush beam with different material are shown in Figure 11. Stable energy distributions are shown in Figure 12. Energy absorption peak values are shown in Figure 13.



(A) DP600



(B) 6061

FIGURE XI. ENERGY CHANGES OF BEAMS WITH DIFFERENT MATERIAL

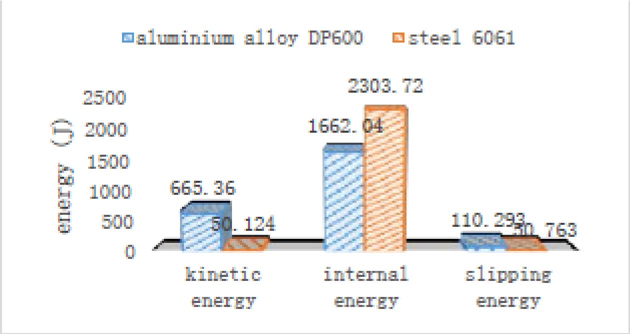


FIGURE XII. STABLE ENERGY DISTRIBUTION

B. *Response Speed Analysis*

The acceleration plots of crush beam with three cross-sectional shapes in the energy absorbing process are shown in Figure 14.

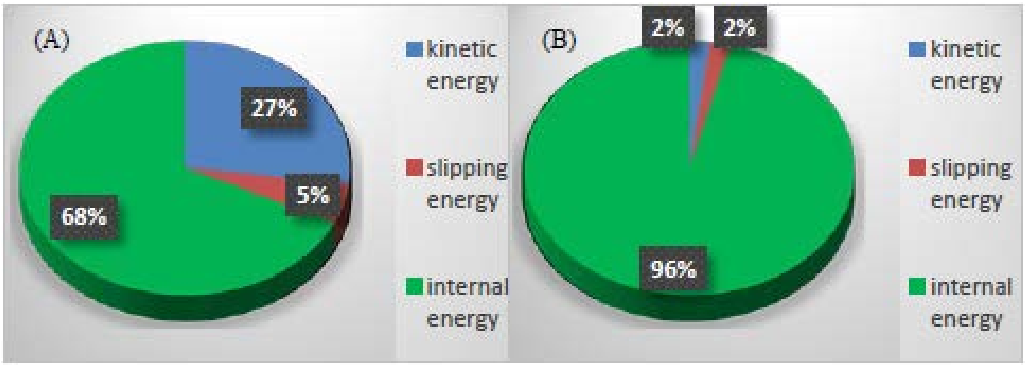


FIGURE XIII. ENERGY DISTRIBUTION (A) STEEL DP600 (B) ALUMINUM ALLOY 6061

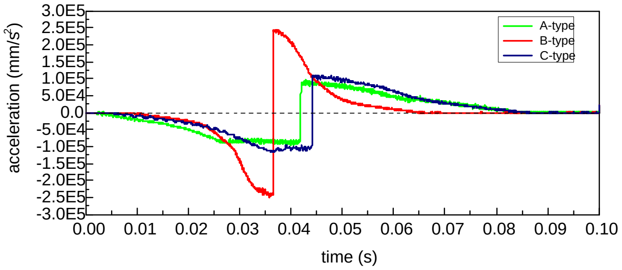


FIGURE XIV. ACCELERATION CHANGE

The acceleration plots of crush beam with different can structures in the energy absorbing process are shown in Figure 15.

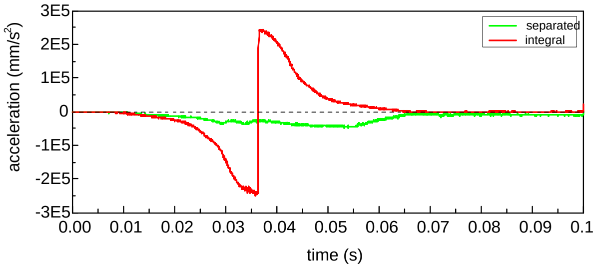


FIGURE XV. ACCELERATION CHANGE

The acceleration plots of crush beam with different material in the energy absorbing process are shown in Figure 16.

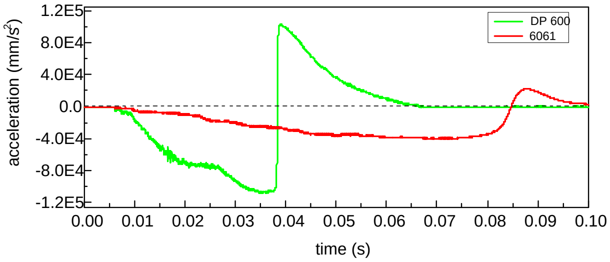


FIGURE XVI. ACCELERATION CHANGE

IV. CONCLUSION

A. Effect of the cross-sectional shape

From the point of view of energy absorption, crush beams with an A-type cross-sectional shape generated the most energy as a result of deformation and friction. Thus, crush beams with an A-type cross-sectional shape exhibited the best energy-absorbing capacity of the three types, followed by the B-type and lastly the C-type cross-sectional shape.

In terms of the response speed, crush beams with a B-type cross-sectional shape were relatively fast in response to the impact, and the response speed of A-type or C-type beams was slow in comparison.

B. Effect of the can structure

The energy-absorbing capacity of separated crush cans was superior to that of integral crush cans.

From the point of view of the response speed, the crush beam with integral crush cans experienced a large amount of acceleration vibration, whereas that of separated crush cans changed gently. The crush beam with integral crush cans required more time to reach 0 than that with separated crush cans. Although the response of integral crush cans was faster, a portion of the collision energy was transferred to the rear structure behind the crush beam.

C. Effect of the Material

The energy-absorbing capacity of aluminum alloy 6061 was superior to that of steel DP600.

In respect of the response speed, the acceleration vibration of aluminum alloy 6061 samples was huge, whereas that of steel DP600 changed gently. The acceleration vibration of the steel DP600 sample, of which the response speed was faster than the aluminum alloy 6061 sample, reached zero first. However, the steel structure transferred a greater amount of the collision energy to the rear structure behind the crush beam.

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