Finite Element Analysis and Shape Optimization of Automotive Crash-box Subjected to Low Velocity Impact

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Abstract—**Crash-box equipped at the front end of a car, is one of the most important automotive parts for crash energy absorption. In case of frontal crash accident, it is expected to be collapsed with absorbing crash energy prior to other body parts so that the damage of the main cabin frame is minimized and passengers may be saved. In the present work, energy absorption characters of automobile crash-box at low-velocity impact are studied by using Finite Element Method and shape optimization design for thin-walled tubes has been successfully proposed through choosing proper cross section and adopting appropriate grooves. Six types of thin-walled tubes with different cross section were studied and different grooves on the tubes were adopted and compared. Results show that the energy absorption characters improved obviously for square cross section thin-walled tube with double concave and bulgy grooves.**

Keywords- crash box; low velocity impact; finite element analysis; shape optimization

I. INTRODUCTION

The automobile impact has been an important problem in vehicle research field, since traffic accidents are one of the severest social problems around the world. As for in China, the death and injuries caused due to motor vehicle crashes increased year by year [1, 2]. It is therefore of great necessity to improve the safety performance of the automobile. Crash-box equipped at the front end of a car (see Fig. 1), is one of the most important automotive parts for crash energy absorption. In case of frontal crash accident, it is expected to be collapsed with absorbing crash energy prior to other body parts so that the damage of the main cabin frame is minimized and passengers may be saved [3]. Most of the research work focus on high velocity impact of automobile, only few on low speed impact at present in China [4]. However, the low velocity motor vehicle accident often happened for the traffic jam in most of the cities in China. It is therefore necessary to study the technical problems involve in low velocity impact.

In the present work, the energy absorption characters of automobile crash-box at low-velocity impact are studied by using Finite Element (FE) method. And shape optimization for thin-walled tubes is proposed.

II. FINITE ELEMENT MODELING

A. Model Description

Thin walled tubes, particularly those of square or circular cross-section, are a common type of automobile crash-box since they are relatively cheap, versatile and efficient for absorbing energy. This has led to them being used in a wide variety of impact loading applications [5].

In this paper, a finite element model was developed by using the software LS-DYNA. The tube was modeled using shell element of designation Belytschko-Tsay, which is interpreted as a quadrilateral element with four nodes, suitable for large strain analyses. After convergence adjustment an element size of 4 mm was adopted and found to produce suitable results.

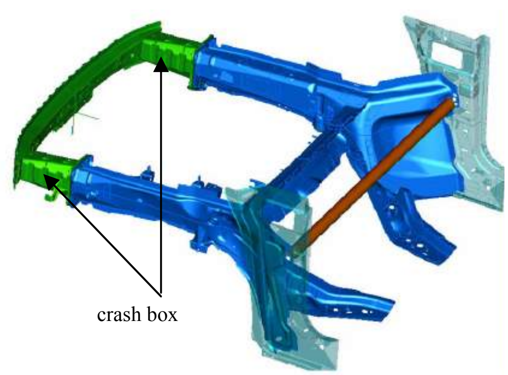

Figure 1. Crash-box in the bodywork

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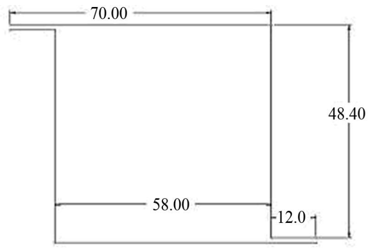
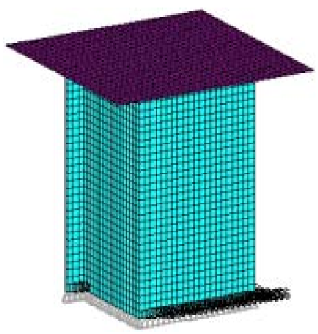


(a)



(b)

Figure 2. Geometry and mesh of the tube

The axial low velocity impact of the rectangular tube (120mm long and 1.65mm thick) was studied firstly. The tube geometry and finite element mesh is illustrated in Fig. 2 (a) and (b) respectively. The base of the tube was fully fixed. A rigid plate of 1000kg, placed on the top of the tube as shown in Fig. 2 (b), impacted the tube at the velocity of 4.44 m / h. The material used was a steel of yield strength, σ_y = 430MPa, density, ρ = 7.85 x 10^{-6}kg / mm^2, Poisson ratio, v = 0.3 and Young's modulus, E = 210GPa.

B. Simulation Analysis

The energy absorption character of the rectangular tube on axial low velocity impact was simulated. The curve of impact load vs displacement is shown in Fig. 3. Where, the peak value of the impact load, one of the important parameter of energy absorption, is 371.45KN, much higher than the permissible value, 160KN.

It is necessary to optimum the structure of the tube to improve the energy absorption characters, especially to reduce the peak value of the impact load.

C. Model Validation

The FE model of the tube was validated by comparing both the experimental and the FE model results.

A circular cross-section tube (Φ70mm diameter, 268mm long and 1.80mm thick) was adopted for both impact test and FE simulation. Deformation results of impact test and FE model are shown in Fig. 4 (a) and (b) respectively. Table 1 provides a comparison of the main parameters obtained by the FE model and by the impact test. The curve of impact load vs. displacement for both FE model and impact test is given in Fig. 5.

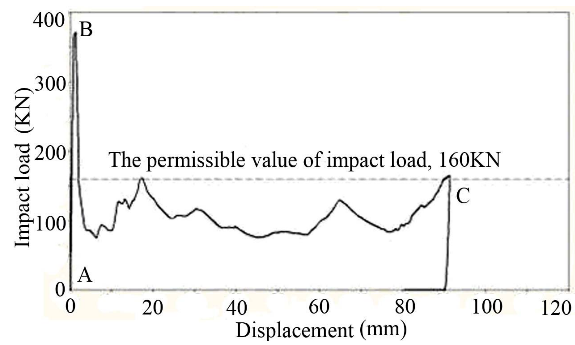
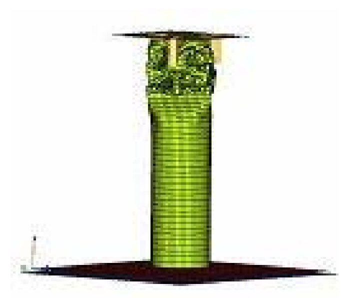


Figure 3. Impact load vs. displacement curve of the rectangular tube

(a)



(b)

Figure 4. Results of impact test (a) and FE simulation (b)

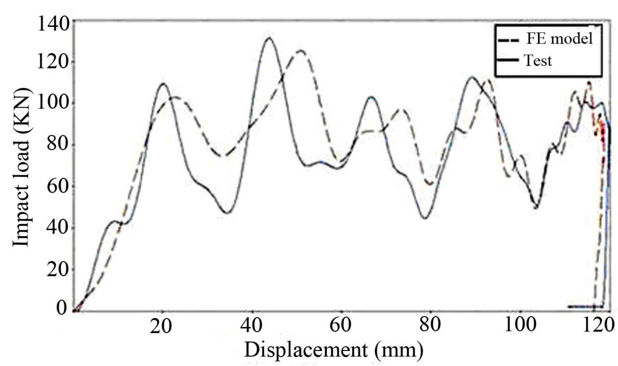


Figure 5. Impact load vs. displacement curves for impact test and FE model

TABLE I. COMPARISON OF TEST RESULTS AND FE SIMULATION

	Peak impact load (KN)	Mean load （KN）	Time for peak load （ms）
FE results	131.32	80.11	10.4
Test results	125.10	85.25	11.3

Results show that on average the difference of impact test and FE model results is within 10%. The good correlation of results obtained place the confidence in the subsequent analyses.

III. OPTIMIZATION DESIGN

A. *Optimum Cross-section Shape*

In order to improve the energy absorption character of the crash-box, it is necessary to optimum the structure of the tube. Attention was firstly focused upon finding an optimum cross- section shape of the tube. Six types of thin-walled tubes were studied and compared. The tube cross-section geometries are illustrated in Fig. 6, where, (a) square section with diagonal welding line,(b) square section with middle welding line, (c) rectangle section, (d) hexagon section, (e) circular section, and (f) octagon section.

All the tubes are of 120mm long and 1.65mm thick and same material was used (yield strength, σ_y = 430MPa, density, ρ = 7.85 x 10^{-6}kg / mm^2, Poisson ratio, ν = 0.3 and Young's modulus, E = 210GPa). The base of the tube was fully fixed and a rigid plate of 1000kg, placed on the top of the tube, impacted the tube at the velocity of 4.44 m / h.

Comparing the simulation results (the variation of inner energy and kinetic energy with time, and the impact load vs. displacement) as shown in Fig. 7, we may conclude that the best cross-section is the shape (a), i.e. the square section with diagonal welding line. The peak value of the impact load for different shape tube is (a) 371.45KN, (b) 372.68KN, (c) 375.96KN, (d) 372.11KN, (e) 372.79KN, and (f) 379.87KN respectively. All are much higher than the permissible value, 160KN. Among them, the least one is shape (a). We therefore take the thin-walled tube of square cross section with diagonal welding line for further optimization design.

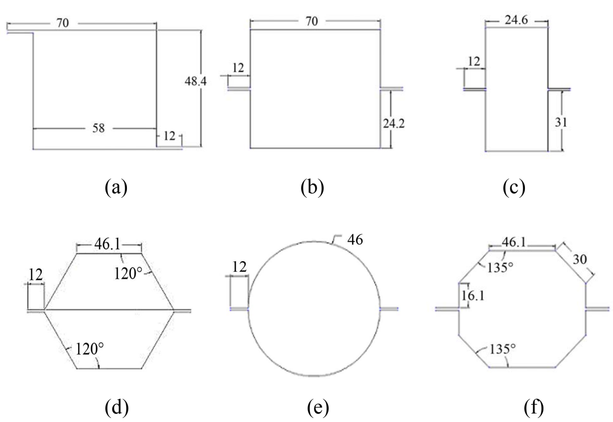
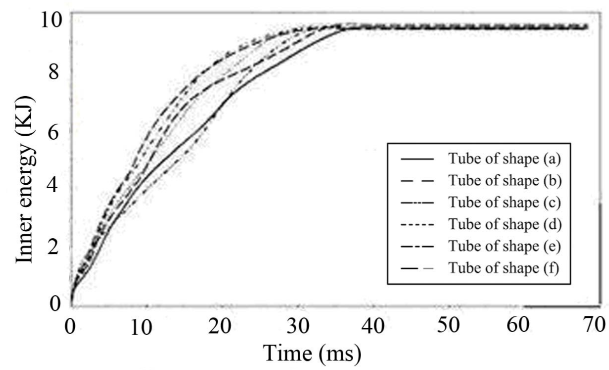


Figure 6. Geometries of different tubes

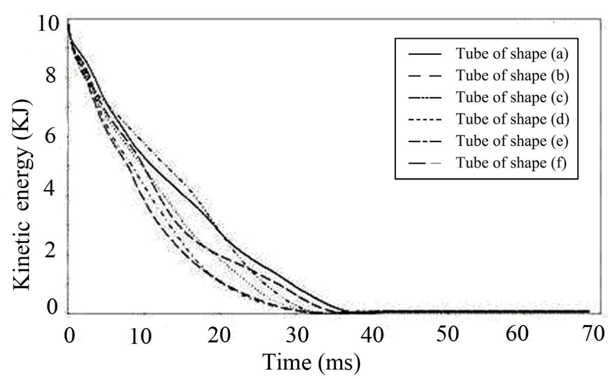
B. *Optimum Groove*

Different grooves on the square cross section tubes were adopted as shown in Fig. 8 (1), where (a) concave grooves adopted, (b) both concave and bulgy grooves adopted, (c) double concave and bulgy grooves adopted. The energy absorption character was compared. Collapse of tubes under impact load after 20 ms was shown in Fig. 8 (2).

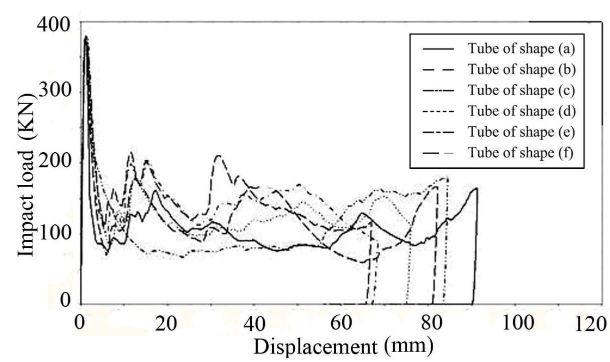
The peak values of impact load for tubes with different grooves are shown in Table 2. From the results, we see that the peak impact loads of tubes decreased at different degree when different grooves adopted. Among them the best one is case (c), i.e. double concave and bulgy grooves.



(a) Inner energy vs. time

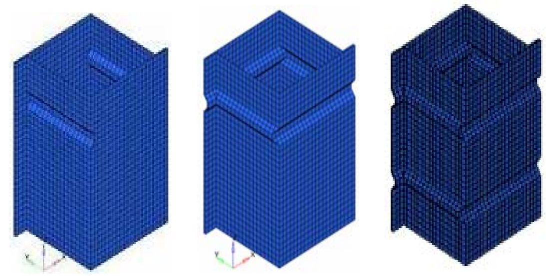


(b) Kinetic energy vs. time



(c) Impact load vs. displacement

Figure 7. Simulation results for different tubes



(a) (b) (c)

(1) Different grooves on the tube

(a) (b) (c)

(2) Collapse of tubes under impact load after 20 ms

Figure 8. Tubes with different grooves

TABLE II. PEAK VALUES OF IMPACT LOAD FOR TUBES WITH DIFFERENT GROOVES

	Peak impact load (KN)	Peak load reduction
Without groove	371.45 KN	
Case (a)	267.59 KN	28%
Case (b)	199.35 KN	46%
Case (c)	154.67 KN	58%

Comparison for tubes without groove and with double concave and bulgy grooves is given in Fig. 9. Results show that the energy absorption characters of thin-walled tube of square cross section with diagonal welding line improved obviously when double concave and bulgy grooves adopted. Where the peak value of impact load is 154.67 KN, decreased about 58% compare with the one without groove. Besides, the compression displacement also decreased. It is 81.4 mm, improved about 11% compare with the one without groove which is 91.54 mm.

We therefore conclude that the shape optimization for a thin-walled tube has been successfully proposed through choosing proper cross section and adopting appropriate grooves.

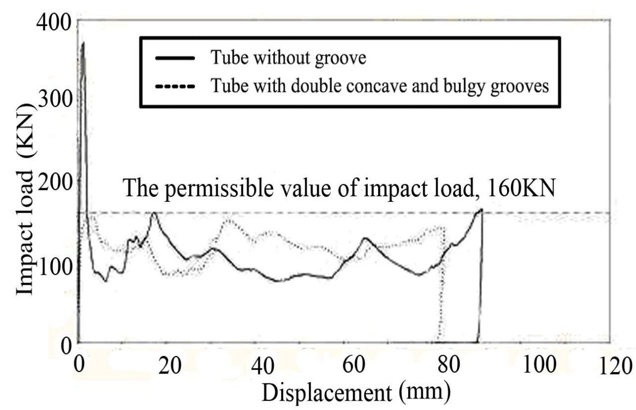


Figure 9. Impact load vs. displacement curves for different tubes

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