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Experimental and numerical investigations of a splitting-bending steel plate energy absorber

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ABSTRACT

Based on the splitting and bending of a steel plate, a new type of energy absorption structure is presented in the paper. The absorber consists of a steel plate, die, and support tool. During collision, the steel plate is split and bent by the die. Using this type of absorber, energy absorption occurs through the splitting of the steel plate, elastic–plastic bending, and friction between the steel plate and the die. Two kinds of steel plates with different thicknesses are constructed and tested. The experimental results show that the deformation of the steel plates is stable. The grooves on the end of the steel plate effectively eliminate the initial peak of the force. This combined method performs energy absorption effectively. The energy absorption responses of the structure are also analysed using the finite element method. By comparison with the experimental results, the numerical results are validated.

1. Introduction

Urban mass transit is developing at a rapid speed in China. At the same time, the operating speed of vehicles is increasing. High speed systems bring new challenges to equipment design. Operating at these high speeds could increase the severity of collision conditions. Attention must be focused on the structural crashworthiness of vehicles to provide safety in a changing environment. The most popular occupant-protection approach is passive protection [1]. Deceleration and forces that impact on the occupants are limited to acceptable levels of human tolerance through a combination of structural crashworthiness measures, such as energy-absorbing components which are installed at the end of the vehicle structure.

Energy-absorbing components must dissipate the kinetic impact energy in a controllable manner while maintaining the integrity of the occupant compartment during a crash [2]. An ideal energy absorber should absorb the impact energy at a constant steady force throughout the entire plastic deformation of the structures [3]. In addition, an ideal energy absorber also has to ensure good controllability and repeatability. Depending upon the crash conditions, such as the crash speed and crash location, energy absorption devices may be required to be adaptive or controllable to the amount of energy absorbed with regard to the crash distance/time. The main mechanisms associated with energy absorption of metal structures are plastic deformation and fracture. A wide range of deformation modes exist for axially loaded tubes, such as plastic buckling, inversion [4,5], splitting and curling [6,7], cutting [8], and shrinking–splitting [9].

Due to the higher energy absorption per unit mass, the axial plastic buckling of thin-walled structures has been studied extensively. Progressive folding deformations for square tubes and circular tubes were defined by Abramowicz and Jones [10–12]. To improve the energy absorption of tubes, several methods have been proposed, such as dividing the enclosed cross-sectional area of the tube into multiple cells [13] and introducing patterns to the wall of tubes [14]. However, one disadvantage of axial plastic buckling is that its crushing load is not uniform, and in particular a high initial peak of the force exists [15]. There are basically two types of tube inversion: free inversion and inversion with a die [16]. There are two characteristic stages of the tube inversion process in the presence of a die: the first stage is the curling stage, when the tube end is forced to conform to the shape of the curved die and begins to curl up; the second involves the formation of a second wall after the curling process. The main advantage of this mode of deformation is the constant steady-state load that can be obtained for a uniform tube. However, tube inversion is limited by the die radius [17]. The splitting mode of deformation is a special case of tube inversion where the die radius is large enough to cause splitting instead of inversion [17]. It can be found from past investigations that the advantage of the splitting mode lies in having not only a long stroke but also a steady crush force. Cheng and Altenhof [18] investigated the energy absorption characteristics of square aluminium alloy under a cutting deformation mode. No initial peak of the force was observed to initiate the cutting deformation mode. Two energy dissipating mechanisms

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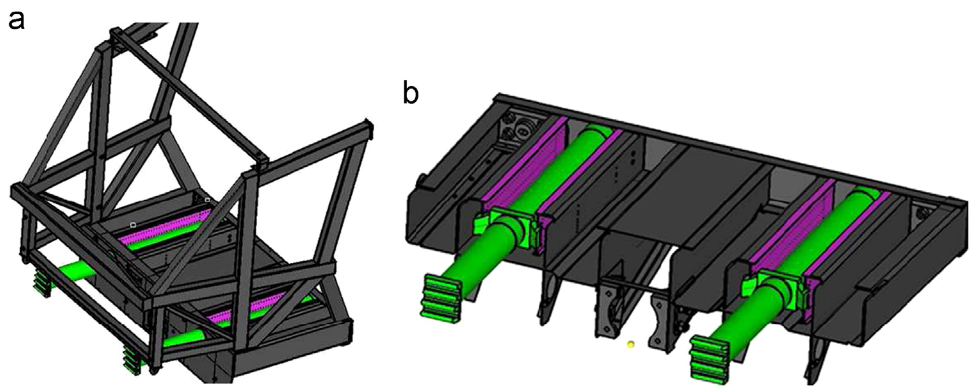

Fig. 1. (a) Absorber mounted in the front part of the wagon structure; (b) enlarged view of the absorber.

were identified, namely a cutting deformation mechanism and a petalled sidewall outward bending mechanism. The energy absorption is highly dependent on the plastic deformation mode under specific loading conditions.

In this paper, the splitting and bending behaviour of steel plates is investigated and presented experimentally and numerically. The working principle of the new type of energy absorber is the metal machining process. During the collision, energy absorption occurs by splitting of the steel plate, elastic–plastic bending of the steel plate, and friction between the steel plate and the die. Fig. 1 shows a way of mounting the absorber.

This paper presents a special type of energy absorber. Two steel plates of different thicknesses are designed and tested. In preparation for the quasi-static test, the deformation resistance and absorption power were analysed. Numerical simulations were performed using the ANSYS/LS-DYNA software package. Verification of the numerical model was realized using the results obtained by experimental investigations.

2. Quasi-static experiments

2.1. Quasi-static test

The purpose of the experiment was to show the shape of deformation of the steel plate under quasi-static load. In this paper, quasi-static tests of two steel plates with *different thicknesses (6 and 8 mm)* were performed.

The absorber shown in Fig. 2 consists four parts: (1) the steel plate, (2) the support tool, (3) the die, and (4) the guide bar. The die and the guide bar were connected. The steel plates were fixed by the support tool. The cross-head of the testing machine pressed the guide bar at a constant speed. The die moved forward and split and bent the steel plate. The wear resistance of the guide bar was high enough to ensure the stability of the cutting process. So in the process of squeezing the steel plates, the guide bar only produced elastic deformation. The axes of the die, guide bar, steel plate, and testing machine were carefully aligned.

The die made from cemented carbide exists on both sides of the absorber. The dimensions of the cutting tool are a width of 100 mm and rake angle of 30°. A steel plate made from Q235 steel with a length of 1000 mm and width of 280 mm was used in the test. Similarly to the cutting tool, each side of the absorber has a steel plate. In order to reduce the initial force, there is a 100 mm long groove on the end of the steel plate.

The experiments were performed in a wheelset assembly machine. The set-up used a hydraulic press with a maximum press-mounting force of 500 t and longest stroke of 500 mm. The force

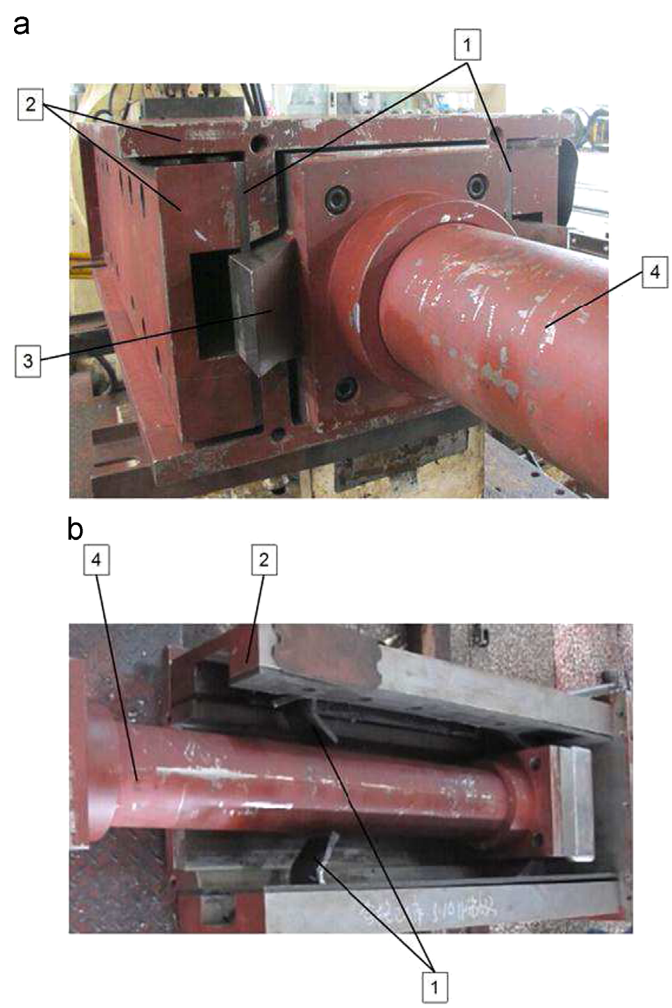

Fig. 2. (a) The appearance of the energy-absorption device; (b) internal view of the structure: (1 – steel plates; 2 – support tool; 3 – die; 4 – guide bar).

between the cutting tool and the steel plate can be measured by the following formula:

$$F = ps \tag{1}$$

where p is the pressure of the liquid which is injected into the cylinder and s is the cross-sectional area of the hydraulic piston. The hydraulic pressure can be controlled by the machine through the inputting of oil and increases gradually from zero to a constant value to ensure that the test is under the quasi-static condition. The cross-sectional area of the hydraulic piston is invariant, so the