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Energy absorption performance of thin-walled metal plate due to upheaval deformation based on experiments and numerical simulation

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ABSTRACT

To explore an energy-absorbing device satisfying the crashworthy requirements of railway vehicles, a new type energy-absorbing structure (EAS) was developed according to the energy-absorbing mechanism of a thin-walled metal plate subjected to plastic upheaval deformation. Quasi-static tests were performed on rectangular and U-shaped thin-walled plates to validate the feasibility of the proposed EAS. Additionally, the numerical simulation test was conducted to investigate the influences of the spacing between pressure plates, punching parameters and the thickness of thin-walled plates on the energy-absorbing properties of the proposed structure. The results showed that the structure had favourable repeatability in compression and the deformation of thin-walled plates was shown to be regular and controllable. In the whole compression stage, the force effects exceeded 70% with no peak being found. In the first stage, the force rapidly increased with the growth of height of the upheavals on the thin-walled plates; in the second stage, the force slowly rose when the increase in the height of the upheavals was ceased in which the mean forces in two groups of tests were both about 12 kN. The energy-dissipation forms of the structure appeared as two types: energy dissipation induced by plastic deformation of thin-walled plates and that caused by friction between the thin-walled plates and the punch.

Increasing the height of the punch and the thickness of the plates cannot significantly improve the energy absorption of the structures. Additionally, decreasing the spacing between pressure plates and enlarging the width of the punch also can increase the amount of energy absorbed. After decreasing the inclination angle of the punch, there was a lag in the change of force.

1. Introduction

When subjected to a collision accident, trains with favourable energy-absorbing structure (EAS) can effectively protect passengers from injury or death and reduce property loss [1–3]. Therefore, an EAS has to be designed to absorb the kinetic energy dissipated upon collision [4,5]. Based on the changes in the force-displacement curves, EASs can be divided into two types: those subjected to axial plastic collapse (called collapsing type EASs hereinafter) and splitting-, expansion-, shrink- and cutting-type EASs. For the former structure, the force peaks and then rapidly decreases with growing displacement; while for the latter type, the force rapidly grows and then stabilizes with increasing displacement [6–8].

Collapsing type EASs have been widely used because, when they are subjected to axial loads and oblique impact, they absorb energy through the large plastic deformation of metals with different advantages, including low cost, high strength to weight ratio, and good energy absorption efficiency [9,10]. During the energy absorption of collapsing type EASs, the force increases with the change of displacement and then declines post-peak: the force change is unstable, which threatens the driving safety of trains [11,12]. Thin-walled tubular structures under axial plastic collapse are the most commonly seen collapsing type of EAS. To assess the energy absorption performance of thin-walled tubes, Alexander [13] investigated the circular cross section of thin-walled tube using a macro-element method to establish a mathematical analysis model for forecasting the collapse force on an EAS in a steady state. Afterwards, Wierzbicki and Abramowicz [14] proposed a new super-folding element and established a theoretical model for predicating the collapse load of a thin-walled tubular structure. Based on previous research, the following conclusions can be obtained: conic tubes show better resistance to oblique loads compared with thin-walled rectangular tubes [15,16]; multi-cell, multi-angular, structures

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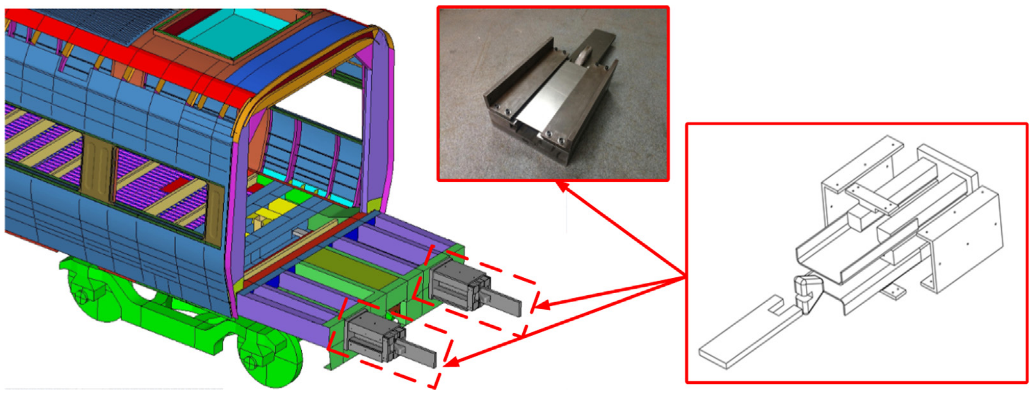

Fig. 1. Design and application of EASs.

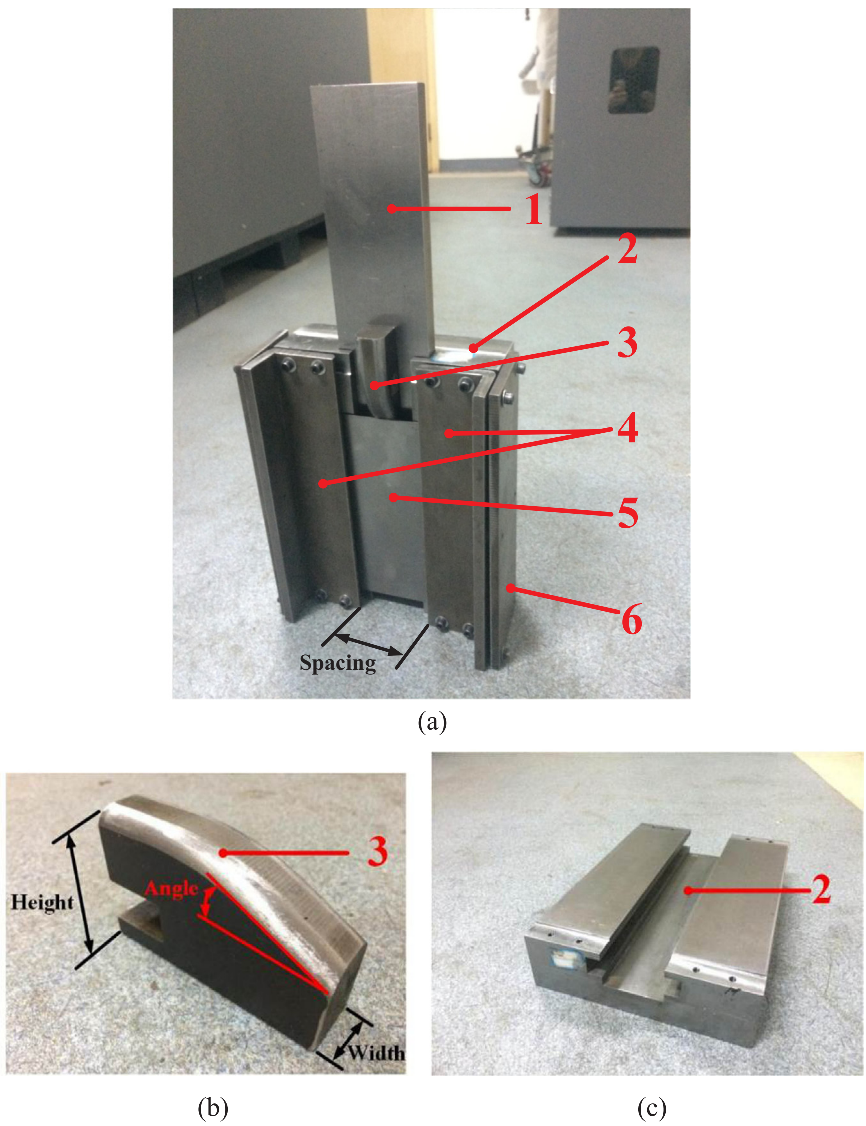

Fig. 2. Structures of the experimental devices: (a) Overall pattern; (b) Punch; (c) Guide base: (1. guide plate, 2. guide base, 3. wedged punch, 4. pressure plate, 5. thin-walled plate, 6. lateral pressure plate).

can improve the energy absorption performance of structures [17–22]; increasing the structurally-induced deformation in the front of such structures can control the deformation and decrease the peak crushing force; adding diaphragm plates in structures can control the deformation and enhance the energy absorption capacity [23]. Compared with a rectangular tube, a corrugated tube exhibits favourable stationarity in energy absorption and controllability in deformation [24–26].