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Experimental investigations of the shrinking–splitting tube collision energy absorber

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ABSTRACT

This paper researches a type of absorber of kinetic collision energy that works on the principle of shrinking and splitting a tube of circular cross section. During collision, a seamless tube is thrust through a cone bush, squeezing the tube. Energy is absorbed by the plastic deformation, and through the friction between the tube and the bush. After passing through the cone bush, the tube presses against a splitter, and further energy is lost to friction and plastic deformation during the splitting process. Grooves on the inner wall of the tube prevent uncontrolled longitudinal tearing of the wall during the splitting. This new combined method of energy absorption enables greater absorption power with compact dimensions. Scaled samples have been tested in the laboratory. The influence of geometry and manufacturing technology of the samples, as well as the benefits of using such an absorber, are presented and discussed in this paper. The results show that the combined absorber has approximately 60% higher absorption power than the shrinking absorber by itself.

1. Introduction

Energy absorption elements in the body frame of railway vehicles are critical for passive safety. The role of the absorber is to absorb as much kinetic energy as possible during collision by controlled deformation of the elements and so reduce the force which is applied to the rest of the vehicle structure. The combined absorber studied in this paper is based on the tube absorber that works by pressing a seamless tube through a cone bush, plastically deforming and shrinking the tube [1,2]. This type of absorber is characterized by a gradual increase of force, without peaks, until reaching a maximum. This maximum force is then sustained until the end of the deformation process. One of the main deficiencies of this type of absorber is the relatively large space required in the limited space available at the front of the vehicle. The extra space required in order to add a second phase to the plastic deformation and energy absorption process is not great, and indeed less space is required for the same amount of energy absorbed. It is important, however, that adding the second phase should not produce peaks in the force, or undesirable deformations of the tube.

Experimental and theoretical analyses of splitting tubes were presented in Refs. [3–5]. These investigations used samples made of aluminium and mild steel with different wall thicknesses and lengths. Different top angles of the special cone die were used to split the cone. This angle has a direct and important influence on the material flow of the splitting tube. The force vs stroke diagrams show a characteristic peak at the start of the deformation process, and after that the force decreases to approximately half the initial value and stays at that level with minimal deviation until the end of the deformation process. Theoretical investigations also showed undesirable peak in the force at the start of the deformation process [6]. These theoretical investigations were verified using quasi-static tests with axial loads on tubes with different geometries and materials. The influence of wall thickness, diameter and number of grooves, material and die angle on the force-versus-stroke characteristics was studied. Analyses of different deformation types, i.e., transverse and axial load of the tube, inversion process and splitting, are given in Ref. [7]. They noted that the high (peak) force at the start of the deformation process could damage the vehicle structure behind the absorption elements. The absorber should be designed, therefore, so that the maximum and average values of the force are as close, which is possible with pre-deformed tubes. Another way to decrease the peak force is to machine longitudinal grooves along the tube wall, creating weak paths for a controlled splitting process.

Experimental investigations of tubes of circular and square cross-sections driven by axial pressure, with parallel analyses of inversion and splitting processes, are presented in Ref. [8]. Folding of the tube is characterised by a jagged force-versus-stroke curve. Experimental investigations of the shrinking–folding combined process of a seamless tube show that folding is not an acceptable second phase to follow

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shrinking [9–11]. The results show that the combination of these two processes may increase absorption power with a compact design of absorber, but it is not possible to eliminate force peaks at the start of deformation (loss of stability) of each segments of the tube wall.

Using a larger number of folding segments in the tube wall could alleviate the jagged effect seen in the force-versus-stroke diagram, but reduction of peaks doesn't mean their elimination, so research should address other possible combinations. This paper presents detailed experimental investigations of a type of absorber which combines shrinking and splitting of a seamless tube. The splitting process is selected because it requires smaller space for assembly in comparison with the inversion process, and also because the plastic deformation during the first phase (shrinking) reduces the force required to split the tube.

Fig. 1 shows the working principle of the combined absorber. During the shrinking–splitting process, energy absorption starts with pressing the tube (Item 1) through the cone bush (Item 2). After a defined stroke, the energy absorption continues with splitting using a splitting tool (Item 3). Thereafter shrinking and splitting continue together until the complete use of the tube material. Energy absorption using this type of absorber occurs both by elastic–plastic deformation of the tube and by friction between the tube and the cone bush in the first phase, and friction between the tube and the splitting tool in the second phase of the combined deformation process.

The higher absorption power and compact dimensions of the combined absorber are analysed in relation to results obtained using only shrinking process. This type of absorber may be used as a separate element mounted in a vehicle body structure or in a line with a standard buffer, and so can be built in at end of the vehicle structure during refurbishment of old wagons without requiring large modifications. For the same geometry and mass of the absorber, it can be clearly seen that the absorbed energy of the combined absorber is higher than the separate absorbed energies obtained by only shrinking and only splitting processes. Tests were performed on scaled samples in order to assess their absorption power and the benefits of using the combined process of energy absorption. The new combined absorber is discussed, based on results of the experimental investigation, and potential design improvements suggested.

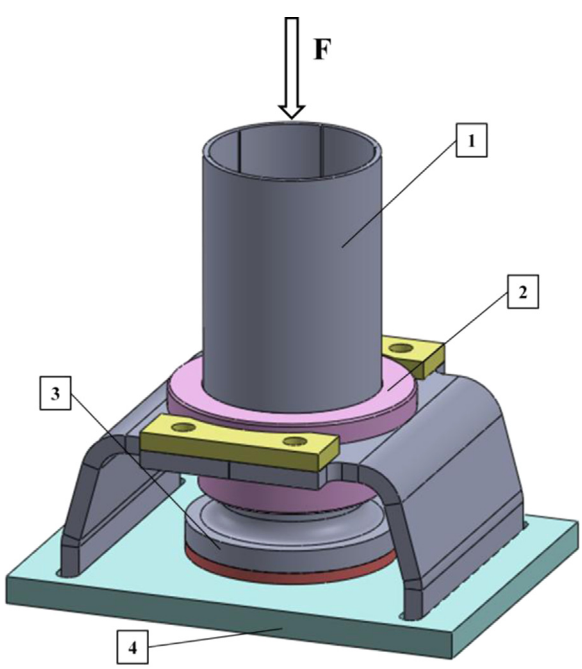

Fig. 1. 3D model of combined absorber: (1-seamless tube, 2-cone bush, 3-splitting tool and 4-special support tool).

2. Experimental investigations

Quasi-static tests were performed using a ZWICK ROELL HB250 servo-hydraulic machine at the University of Belgrade (see Fig. 2). The measurement and control systems are integral parts of the machine, and the acquisition system can record up to eight measurement channels with a sampling frequency up to 10 kHz. The maximum load which can be applied with this machine is 250 kN.

Tests were performed with a piston speed of 1 mm/s. During the tests, the stroke was pre-set and deformation resistance (reaction force) measured during the stroke. The investigations presented in this paper are the product of long-term research into energy absorption elements that were presented in the papers [1,2,10,12]. Experimental and numerical results of these researches make possible initial investigations of absorption power and shape of deformations of elements in scale models in the field with a low strain rate of deformation (quasi-static tests), and after that to continue to investigations with a full-scale model (proper dimensioning takes into account strain rate dependent options) via collision of wagons.

2.1. Working principles

The combined absorber is shown in Fig. 1 and the test machine in Fig. 2. During collision, the tube (Item 1) is pushed through cone bush (Item 2) for a stroke of approximately 50 mm. Energy is absorbed at this point as the tube is plastically deformed and shrink. After the 50 mm stroke, the second phase of energy absorption, i.e., splitting of the tube, starts with contact between the shrink-deformed tube and the splitting tool (Item 3). From that moment, energy absorption continues in parallel working mode, shrinking and splitting the tube for a stroke of approximately 40 mm (i.e., total stroke length is 90 mm). The absorber was installed in a special support tool (Item 4) which was used as a support during the testing. This special support tool represents the part of the vehicle body frame where the absorber should be installed.

Fig. 2. Servo-hydraulic machine ZWICK ROELL HB250.