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Aspect of multilevel triggers in crashworthiness analysis of thin-walled energy absorber

Michał Rogala[1], Mirosław Ferdynus[1]

[1]Katedra Podstaw Konstrukcji Maszyn i Mechatroniki, Politechnika Lubelska
email: m.rogala@pollub.pl, m.ferdynus@pollub.pl

ABSTRACT: The article presents a dynamic crush analysis of thin-walled columns with a multi-level crush initiator. The columns have a constant height of 200 mm and are made of aluminum to allow better observation of the formation of plastic hinges. The analysis carried out included the crush of energy absorbers with an initiator in the form of concave-convex embossments at one, two and three levels. The initiator had fixed geometric parameters, i.e. 36 mm diameter, 4.8 mm embossing depth. In order to precisely determine the effect of the number of levels on the energy-absorbing performance of the crash-boxes, the authors assumed constant mutual positions of the initiators, i.e. 30mm from the center of the first trigger to the base and 30mm between the centers of the other triggers. On the basis of the analyses carried out, crush efficiency indices describing dynamic crush were determined.

KEYWORDS: crashworthiness, trigger, multi-level, passive energy absorber

1. Introduction

Over the years, passive safety has become a very important aspect in the design of motor vehicles. Initially, passenger cars had a rigid structure that was not significantly damaged during a collision, but it generated severe overloads that were dangerous to passengers more extensively described by the MaCaulay'a [1]. As a result of increasing performance, engineers began to design crumple zones in vehicles. The initial shape for later research was a column with a circular and square cross-section. Pioneers in the study of such structures were Pugley and Alexander [2, 3].

At the turn of the 1980s, there was interest among researchers in passive energy absorbers. The main authors analytically describing the behavior of thin-walled structures compressed statically or dynamically were Jones, Abramowicz or Wierzbicki [4-6]. As a result of their work, the crush efficiency indicators commonly used to this day were determined.

Studies of structures have shown that forming dependent plastic hinges have a certain capacity to absorb energy. According to the results of the Jones et al. study [7], the height of the plastic hinge depends on the width of the profile and the thickness of the wall. Scientists have noticed that during dynamic crushing, the most dangerous stage of crushing is the formation of the first fold. The main disadvantages of thin-walled structures are the susceptibility to global buckling of the structure and the large force peak accompanying the formation of the first plastic joint simultaneously with its low energy-absorbing capacity.

The most common shape of the crush initiator in the world literature is a drilled hole[8, 9]. Its execution is the simplest, however, the accompanying discontinuity of the material in the thin-walled structure promotes the occurrence of stress sintering and possible material cracking. A much safer way to initiate the crush is to overpress the structure at its end initiating the crush while keeping the performance of the first plastic hinge at a high level [10]. The results of Hanssen et al. show that the use of a crush initiator makes it possible to reduce the maximum force peak generated in the first stage of crushing.

With the development of technology, origami-type structures began to appear in the literature [11, 12], the shape and principle of which resemble multilevel crush initiators, however, the origami sample is very expensive to produce, hence the unprecedented topic of multilevel crush initiators in the form of spherical embossing undertaken by the authors.

2. Crashworthiness indicator

The basic quantity determined during the analysis is the amount of mechanical energy that is dissipated during the dynamic crushing process. Its measure is the area under the curve is given by the formula:

$$EA = \int_0^d F(x)dx, [J] \tag{1}$$

The value of this energy is generally related to the mass of the energy-absorber, is denoted as SEA (Specific Energy Absorption), and is given by the formula below:

$$SEA = \frac{EA}{m}, \left[\frac{J}{kg}\right] \tag{2}$$

Another indicator is the Mean Crushing Force – MCF, occurring during crushing defined as the ratio of energy absorbed to total crushing distance:

$$MCF = \frac{EA}{d_x}, [N] \qquad (3)$$

where: EA – energy absorbed, d_x – crushing distance

A very important parameter is the value of the Peak Crushing Force (PCF). The value of this force directly affects the maximum overloads that occur at the beginning, and their duration will determine the probability of severe injury and the chances of survival.

The ratio of the average crush force MCF to the maximum crush initiating force PCF is referred to as the CLE ratio and is given by the equation:

$$CLE = \frac{MCF}{PCF} [-] \qquad (4)$$

3. Subject of the study

The subject of the study is axially crushed columns with constant energy defined by the mass of the tup and its initial velocity. The analysis was carried out until the top plate, shown in Figure 1, was fully braked. The numerical analysis consisted of two steps, the first was to obtain the buckling form and implement it, the next was a dynamic analysis of the axial crushing of the columns.

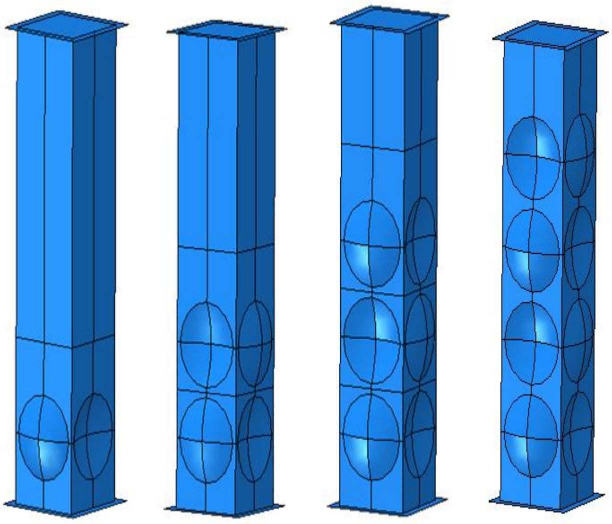

Fig. 1 Comparison of thin-walled structures with multilevel trigger mechanism

The numerical model consisted of a thin-walled profile and two plates, the boundary conditions were modeled using Tie relations between the edges of the profile and the non-deformable bottom and top plates. The surface type elements of S4R were used when modeling the energy absorber.

4. Results

Based on the determined force-shortening characteristics seen in Fig. 2, the crush efficiency indicators described in Section 2 were derived. The values are presented in tabular form (Tab. 1) to define the effect of multilevel triggers on the thin-walled structure.

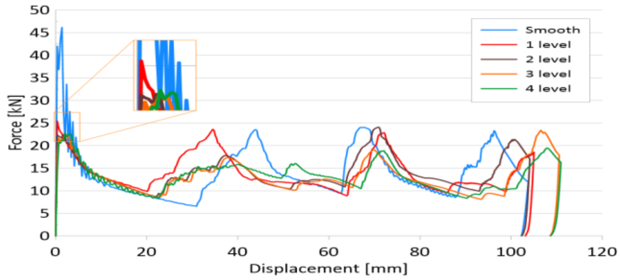

Fig. 2 Force-Shortening characteristic for multilevel triggering mechanism

Table. 1. Crashworthiness indicators for samples with multilevel triggers.

	Energy [J]	PCF [kN]	MCF [kN]	CLE [-]	STE [-]
Smooth	1474.7	46.158	14.213	0.3079	0.519
1 level	1471.9	25.442	14.018	0.5510	0.525
2 levels	1467.8	24.086	14.101	0.5854	0.520
3 levels	1469.0	23.375	13.289	0.5685	0.553
4 levels	1468.3	22.769	13.239	0.5815	0.555

The study shows a significant effect of the crush initiator on the magnitude of the peak and mean crushing force. Samples depending on the number of levels at the same energy obtained different shortening, which indicates a change in the behavior of the crush.

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