DYNAMIC STUDIES OF TOP-HAT THIN-WALLED ELEMENTS JOINED BY SPOT-WELDING

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Abstract

The main subject of the work was numerical and experimental dynamic studies of top-hat thin-walled elements joined by spot welding. Spot weld diameter and pitch distance were the main parameters describing geometrical shape of examined elements as well as the material they were made of. The main purpose of the carried out investigations was to determine the spot weld pitch distance and diameter influence on thin-walled elements deformation as well as energy absorption capability. The results enabled determination of high-grade spot welds execution technology and full utilization of thin-walled elements energy absorption ability. The analysis of joining technique influence the longitudinal beam deformation manner as well as dynamic energy absorption was executed. Moreover the analysis of materials energy absorption application was carried out. High strength steels, the most often used in the automotive industry, were chosen for the energy absorption elements and load-carrying structure application.

Realized experimental tests enabled the verification of elaborated top-hat profiles discrete models for various materials, spot weld diameters and pitch distances. The comparison analysis of the acquired experimental and numerical results was carried out.

The obtained outcome may be utilized during the energy absorption elements design and the elaborated discrete models building methodology can be used in preliminary project works, where one has planned numerical simulations of load-carrying structures crash loadings.

Keywords: *finite element method, energy absorption elements, crash tests*

1. Introduction

One of the main advantages of the thin-walled structures is their high rate of load capacity to the weight [1, 2]. The achievement of this effect is possible thanks to the appropriate shaping of load-carrying structure elements in such a manner to take the full advantage of the applied material strength. Thin-walled structures, when axially increasingly loaded, have a tendency to the stability loss. This phenomenon takes place the most often locally and when the suitable proportion of element dimension occurs – the obtained deformation form is characterized with high regularity and repeatability. It enables the designer, at the early planning stage, to determine such parameters as energy absorption, maximum and mean crashing force precise values. The above factors might be obtained with the use of computer simulations, based on the finite element method, or analytically, assuming the appropriate failure mechanism [3, 4]. Nevertheless, the main problem is to define geometrical parameters, which would assure regular and proper crushing. The solutions of analytical models building question as well as geometrical parameters selection for circular and rectangular cross-section specimens had been presented in the Alexander's and Wierzbicki's works, however most of the publications omit the joining technique influence the thin-walled sections deformation manner.

Loss of the structure local stability (e.g. vehicle longitudinal beams) is a required phenomenon (in case of front impact accident) – in that case a gentle exchange of kinetic energy into deformation energy takes place. The behaviour of thin-walled structures during postbuckling state is characterized by essential singularities, which do not take place in the conventional constructions and joining technique in the meaningful way influences the stability loss mode. The understanding of the phenomena taking place during and after the stability loss, until do whole construction is crushed, is required when correctly designing new and precisely establishing of existing thin-walled construction load-carrying ability. This results in necessity of joining technique influence on the thin-walled profiles local stability loss investigation.

Commonly employed in automotive vehicles thin-walled elements (longitudinal beams) joining technique is spot welding. Performed connection (spot weld), in a meaningful manner, influences the thin-walled element local stiffness, what affects the stability loss [5, 6]. One tends towards the influence of the spot welds on the deformation behaviour was the smallest (lack of the change of the loss stability character, critical force and energy absorption values). Simultaneously, economic factor must be preserved – there must be carried out so many spot welds with the determined parameters and pitch distance as many it is required. There were presented in the current work the findings of the experimental tests of the energy absorbing thin-walled elements during axial crushing and the comparison of the obtained results with the numerical ones.

2. Methodology of the experiments

Top-hat thin-walled beams (Fig. 1) were used during experimental tests. The main exchangeable parameters explored during these experiments were: material, spot weld diameter and pitch distance. In order to obtain initiation of the regular crushing manner, the triggers were introduced (Fig. 2).

Specimen dynamic crushing tests were executed on the gravity drop hammer based on the construction of the frame tower, which was equipped with specialized measuring systems. A hammer mass of m_1 = 233 kg (in case of top-hat profiles made of 1 mm sheet steel mass of the hammer was m_2 = 149.5 kg) being released in a controlled manner from a specific height of 3.2 m. The height was measured between the hammer front surface and upper surface (surface determined by the upper edges) of the crushed beams. The measured quantities were as follows: forces – measured by the three force gauges located in the anvil and accelerations – registered by the piezoelectric acceleration gauge. The measurements were carried out with the frequency of 96 kHz.

3. Numerical model

A discrete model (Fig. 3) was used during numerical analyses. Simulations were performed with the use of ABAQUS/Explicit system. Four-node reduced integration shell elements S4R with the approximate size of 1.5 mm were employed.

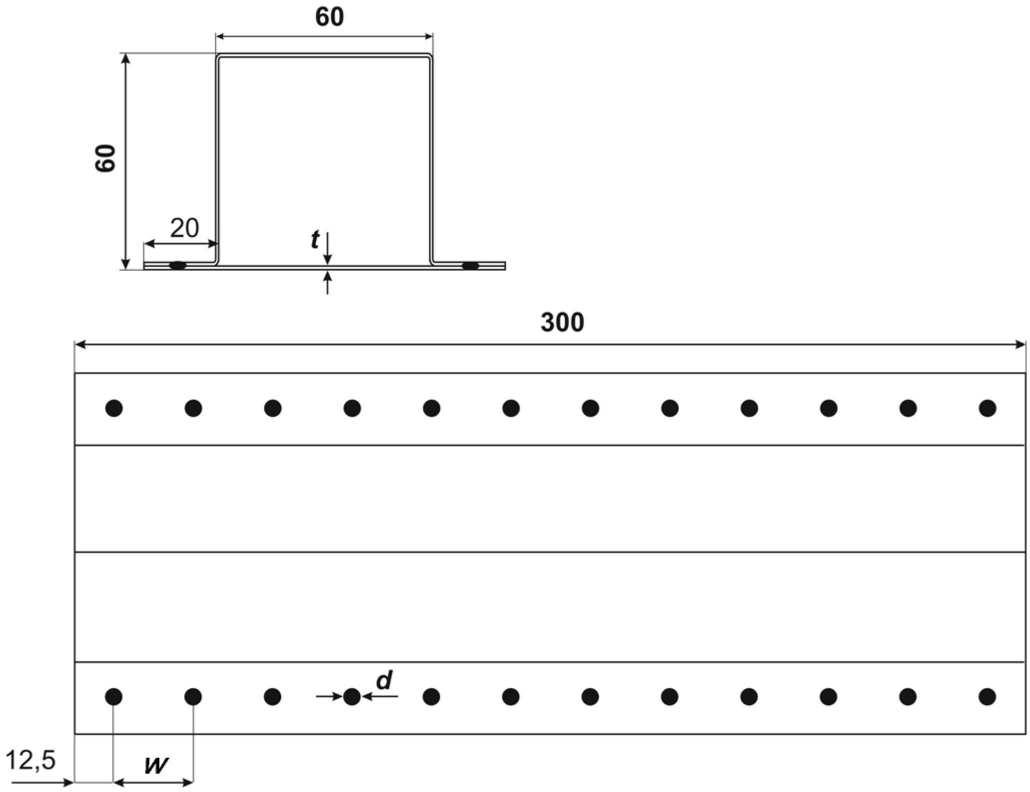

Fig. 1. The base dimensions of the top-hat profile cross sections: t - thickness, w - spot weld pitch distance, d - spot weld diameter

Fig. 2. Top-hat thin-walled beams triggered before crushing (profiles with two size of spot welds d = 4mm and d = 8mm

The base clamping was modelled with the use of rigid elements R3D4. The bottom of the profile was fixed in the base and the upper part was being struck by the rigid plate, simulating a drop hammer (elements type R3D4) with the initial velocity of V = 7.9 m/s. The weight of the drop hammer was m = 233 kg for all profiles of wall thickness t = 1.25 mm, although in case of t = 1.0 mm sections the mass of the hammer was m = 149.5 kg.

The nonlinear material characteristics (static and dynamic), obtained from experimental tensile tests, were applied during numerical simulation. Cowper-Symonds material model (Tab. 1), changing the material characteristics dependingly on the rate deformation, was applied in the numerical tests.

Tab. 1. Cowper-Symonds material model parameters

Material	D [1/s]	p
DC01	40.4	5
DP600	1559693.678	5.3514
DP800	1694672.39	4.9753

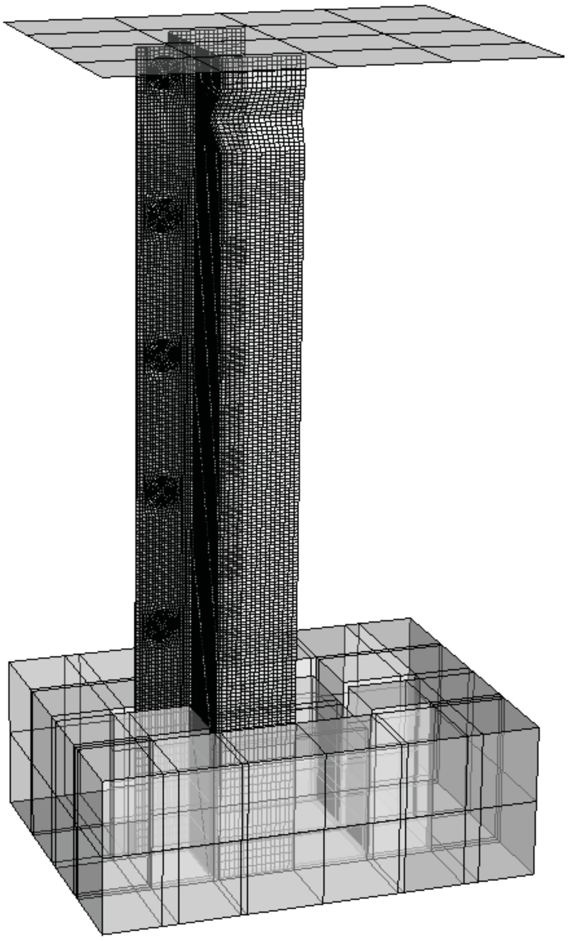

Fig. 3. Discrete model of the crushed specimen and clamping base

4. Results

The acquired form of specimens (final height and deformation) obtained from numerical studies (Fig. 4 and Fig. 5) as well as crushing force characteristics (Fig. 7) very accurately reflect the actual experimental ones.

Each combination of dimensions, material, thicknesses as well as spot weld diameters and pitch distances were investigated experimentally (3-6 trials).

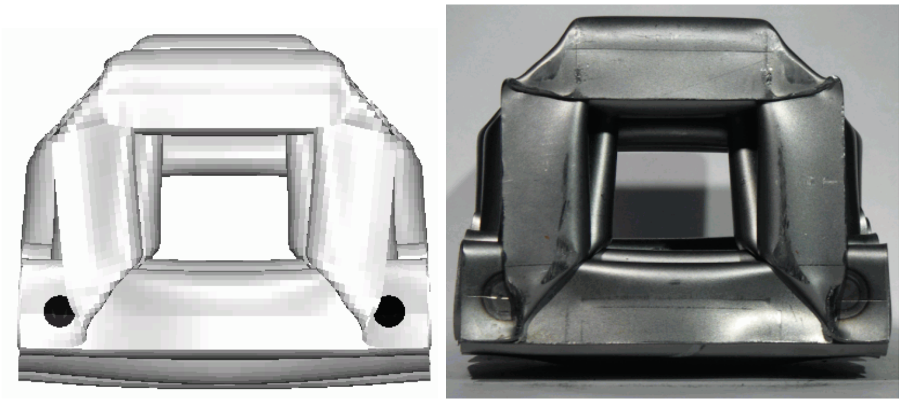

Fig. 4. Specimen TH_DP800_100_50x8 – final deformation (top view)

Fig. 5. Specimen TH_DP800_100_50x8 – final deformation (front view)

Fig. 6. Specimens TH_DP800_100_50x8 – final deformation (front view)

Experimental and numerical dynamic results for chosen specimens made of steel DP800, thickness $t = 1$ *mm*, spot weld diameter $d = 8$ *mm* and pitch distance $w = 50$ *mm* (5 specimens) were presented (Tab. 2). The realized programme enclosed the exploration of 107 top-hat section. The results obtained from numerical tests were highlighted in the table. Presented outcome confirms regularity of the material model, boundary conditions and discrete model (type and size of the finite element) selection.

Tab. 2. The outcome of the top-hat dynamic tests (t = 1 mm, w = 50 mm, d = 8 mm)

Specimen number	Name	Plastic shortening [mm]	Plastic + elastic shortening [mm]	F mean [N]	F max [N]	Energy [J]	Failure coefficient [shortening/height]	Structural effectiveness	F max /F mean
219	TH_DP800_100_50_8_nr1	136.4	136	34299	189032	4678	0.4608	0.2208	5.5112
208	TH_DP800_100_50_8_nr2	130.3	131	35897	187431	4678	0.4402	0.2311	5.2213
220	TH_DP800_100_50_8_nr3	129.9	128.5	36006	183726	4678	0.4389	0.2318	5.1026
221	TH_DP800_100_50_8_nr4	140.7	141	33240	179202	4678	0.4753	0.2140	5.3912
218	TH_DP800_100_50_8_nr5	144.3	143.5	32411	184229	4678	0.4875	0.2087	5.6841
FEM	**TH_DP800_100_50_8**	**135.5**	**136.7**	**34356**	**218670**	**4678**	**0.4516**	**0.2212**	**6.3648**

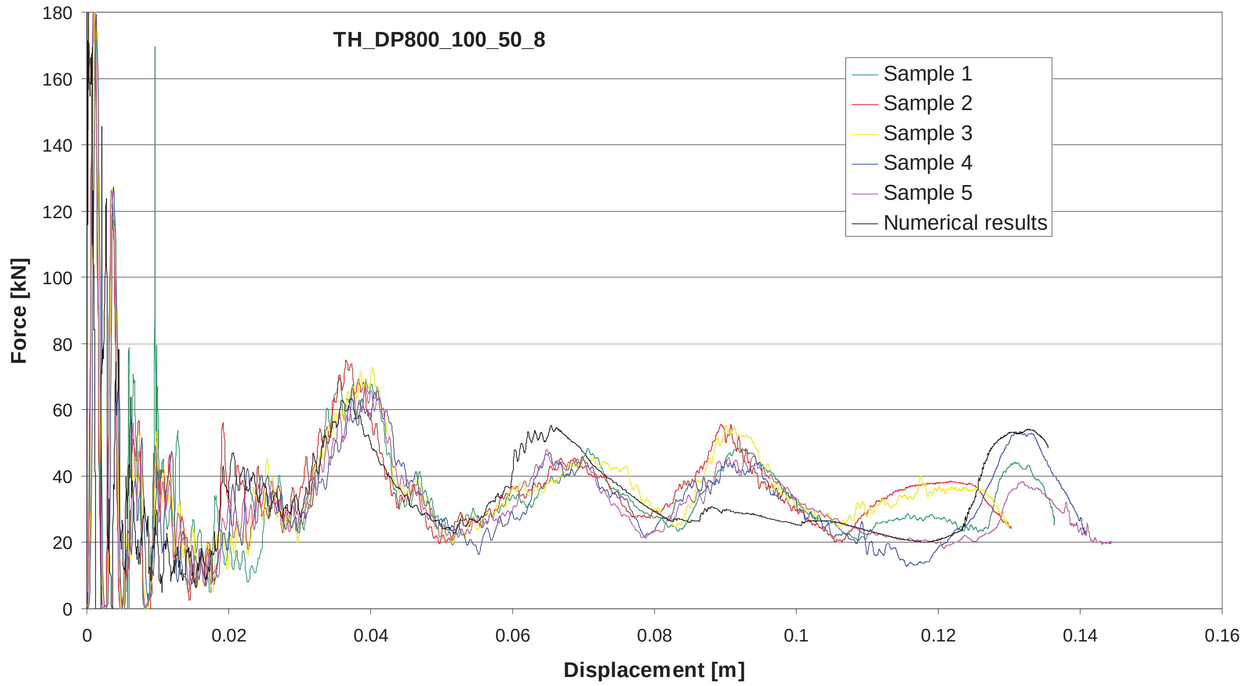

Fig. 7. Force-displacement (shortening) characteristic – top-hat specimens

5. Conclusion

The achieved outcome from the experimental investigations showed that simultaneous consideration of plastic and rheological material properties is particularly necessary when describing stress waves propagation as well as determining construction strength characteristics dynamically loaded. Making the allowance for these factors may have the crucial influence on the quantity and quality judgements of appearing phenomenon.

At the initial crushing stage sudden increase of the compressing force up to the maximum value takes place, what is caused by the plastic hinges initiation. The next phase of the process is a regular crushing of the specimen, where mean force remains at the same level. It is especially seen at the presented crushing characteristics that at the very beginning F_{max} exceeds F_{mean} value approximately three times. It might be assumed, in case of specimens without triggering, the difference would be much higher – imperfections introduction results in lowering the measured decelerations at the first crushing stage.

The simulation results are very comparable with the actual ones. Only in case of maximum force F_{max}, the numerical outcome exceeds about 15% the average value of these obtained from the experiment. The reason for this is that numerical model does not contain any physical imperfections (e.g. specimen walls deviations) as well as assumed Cowper-Symonds material model, taking into account increase of the strength parameters when dynamically loaded, is only an approximation of real one. Established strain hardening material model is especially sensitive in strain rate range 10^{-1} to 10^{-3} s^{-1}. Small strain rate differences (comparing to the real ones) result in alteration of the material characteristics and thus different value of the obtained maximum crushing force.

Performed numerical explorations are characterized by the considerable convergence with the experimental outcome therefore may be used at the very early design stage of the energy absorption elements.

Experimental and numerical testing enables plastic mechanism mode and size determination, what may be utilized in form of model imperfection introduction. Such activities enable acquiring of maximum accelerations and forces decreasing, maintaining the absorbed energy and mean crushing force.

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