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Crash response of laser welded high-strength steel energy absorbers: experiment and numerical simulation

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ABSTRACT: In this paper, axial crushing an experimental design of thin-walled, laser-welded miniature energy absorbers made of two commercial steel grades, Docol 1000DP and Docol 1200M, was carried out. Two different loading conditions were investigated: quasi-static conditions at 0.5 mm/s loading speed (electromechanical machine) and impact loading at 27.0 m/s using a novel process for this application, a direct impact Hopkinson (DIH) method. The material data were determined from tensile tests of welded and non-welded specimens at three strain rates: 10^{-3}, 10^{2} and 10^{3} s^{-1}. A simple constitutive model with the Cowper-Symonds hardening rule was adopted for simulations. The experimental results were validated with numerical simulations of the crushing process. Different methods of reproducing the absorber geometry were compared: idealized and scanned with computer tomography and optical devices. Qualitative and quantitative comparisons were discussed. Crashworthiness parameters characterizing the proposed geometry, absorbed energy, mean force, and peak force, were calculated. A good correlation between the numerical and actual tests was noticed.

KEYWORDS: energy absorbtion, FEM, crashworthness, static compression, dynamic compression, high strength steel

1. Introduction

In the automotive industry, the restrictions associated with the amount of harmful substances emitted into the atmosphere are becoming challenges for vehicle design engineers [1]. One of the solutions is reduction of car mass through the use of advanced high-strength steels (AHSS), especially for structural elements that absorb mechanical energy during impact.

Energy absorbers in crashworthiness applications such as trains, cars, ships, aero-planes and other high-volume industrial products, the thin-walled structures have been widely used to ensure crash safety due to their lightweight, low cost and high energy absorption [2]. High strength parameters of AHSS, however, are associated with technological problems when joining these materials. The solution is laser welding technology, which is an increasingly used technology in the series production of thin-walled column mechanical energy absorbers.

2. Experimental and numerical analysis results

The strength tests were carried out for steel column energy absorbers with a square cross section of 23.0 × 23.0 mm, length 100.0 mm and sheet thickness 0.6 mm. They were made of three grades of AHSS, i.e. Strenx S700MC, Docol 800DP and Docol 1200M. Each absorber consists of two laser welded elements on which trigger was made. The tests were completed for two crushing speeds, 0.0005 m/s – using a testing machine and approximately 29.0 m/s – under the direct Split Hopkinson Pressure Bar (SHPB) test condition. Fig. 1 shows the crushing curves of an absorber made of Strenx S700MC steel at a speed of 0.0005 m/s compared to the results of numerical analysis (Fig. 1a) and view of the crushed absorber (Fig. 1b). In turn, Fig. 2 is shown comparison of experimental and numerical results under quasi-static test. The numerical model was prepared according to the CAD geometry of the welded absorber.

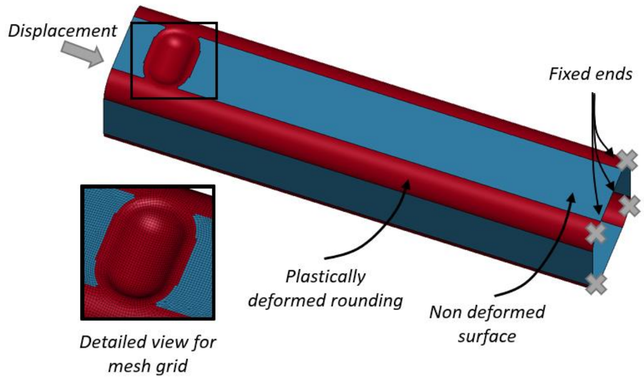

Fig. 1. Boundary conditions applied for the model

Shell elements with an edge length equal to 0.3 mm were used. Mesh sensitivity study proven, that this dimension is a compromise between accuracy and computational efficiency. Steel material data was determined from experimental tests and applied to elastoplastic model with a non-linear hardening rule. The hardening phase was defined as an effective plastic strain – true stress curve. Because the absorber and trigger were cold-formed, the plastic strain accumulated on the material had to be considered on the model. The rounding's of geometry were modeled as a separate component with higher yield strength, but with lower failure strain.

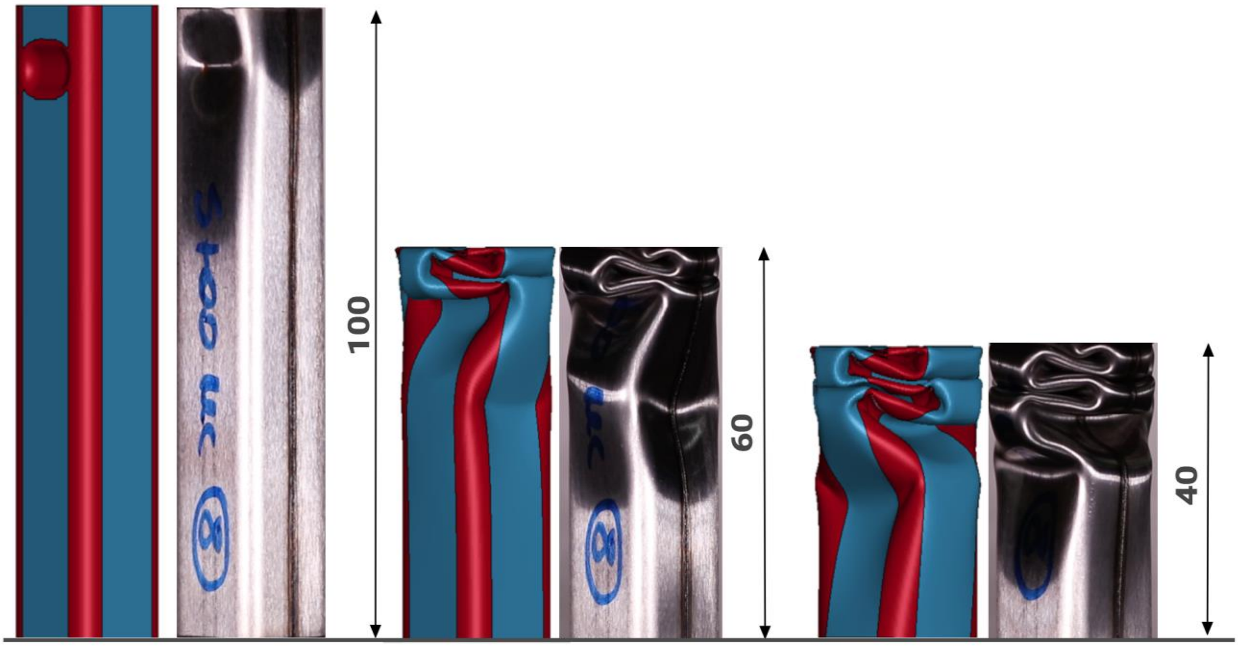

Fig. 2. Comparison of experimental and numerical results under quasi-static test

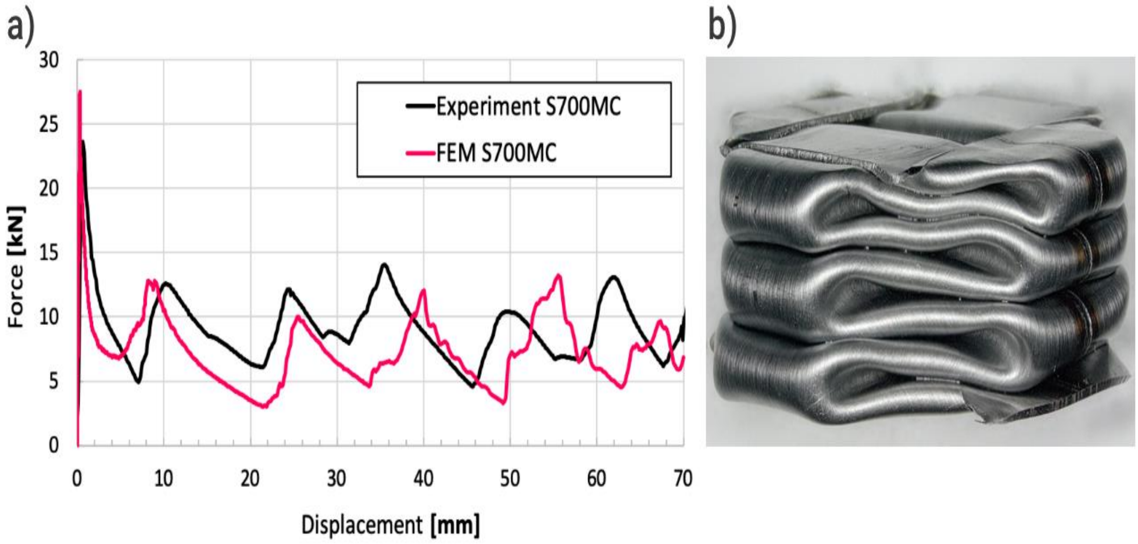

Fig. 3. Comparison of crushing curves obtained from quasi-static experiment and numerical simulation (a) and view of crushed absorber (b)

3. Conclusions

Strength tests of laser-welded absorbers made of Strenx S700MC steel, as well as the other tested steels, showed high quality of the obtained joints, none of the welded butt joints cracked during the tests, both under quasistatic test and direct SHPB test conditions. The results of numerical analysis were compared qualitatively and quantitively. A good correlation of force – displacement curve is observed. First peak of load for Strenx S700MC steel is 15% higher in simulation than in actual experiment. Probably this difference is a result of idealization of trigger shape, that delays the buckling of tube walls. This phenomenon has an impact on the "plateau" phase of the curve and determines a small offset in folding of tube geometry.

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