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An experimental and numerical crashworthiness investigation of crash columns assembled by spot-weld

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1. Introduction

The welding known as standard method of joining, has received attention in last decades [1-3]. During recent years, the car body assembly techniques were dominated by spot–welding. Resistance spot-welding is a very quick, cheap and accessible technology to join metal sheets. Also it is controllable and it can be done automatically. Resistance spot-welding does not need special preparation of the parts before joining. Peroni [4] compared experimental results on the use of structural adhesives, laser-welding and spot-welding in structures subjected to crash. The obtained results demonstrate that continuously joined structures are at least equivalent to and generally better than spot-welded structures, and have further advantages typical of these joining solutions (higher stiffness and fatigue strength, improved vibration response, especially in the case of adhesive joints).

Yujiang Xiang [5] performed crashworthiness optimization of a spot-welded thin-walled hat section. Various spot-weld models were first used in a thin-walled hat section to compare with experimental works. An appropriate spot-weld model was then used in the transient nonlinear finite element analysis (FEA), and the number of spot-welds was selected as one of the design variables in optimization. The mass of the thin-walled tubes was optimized subject to constraints on the required mean crushing force and sectional stiffness.

In this paper, the experimental and numerical quasi-static crushing responses of spot-welded structures are investigated and used for crashworthiness design. The numerical crash analysis of spot-welded columns was performed using the Abaqus finite element software. In addition, a pre-crushed trigger was introduced to decrease the initial peak force of spot-welded columns under axial loading.

2. Numerical analysis using the finite element method

The numerical simulations were carried out using the finite element software Abaqus/Explicit. In this simulation, a self-contact algorithm was used to prevent interpenetration during the folding of the columns and the spot-welds are modeled by surface-based tie constraints option in the Abaqus/Explicit. [6]. The structures considered in this study are spot-welded thin-walled hat section, as illustrated in Fig. 1.

For applying boundary conditions on the edges of the spot-welded columns, two rigid plates were used that were attached to the ends of the columns. All degrees of freedom in the lower plate and all degrees of freedom in the upper plate, except in the direction of longitudinal axis, were constrained.

For this analysis, the linear element S4R, that is a four-node element with four degrees of freedom per node, suitable for analysis of columns.

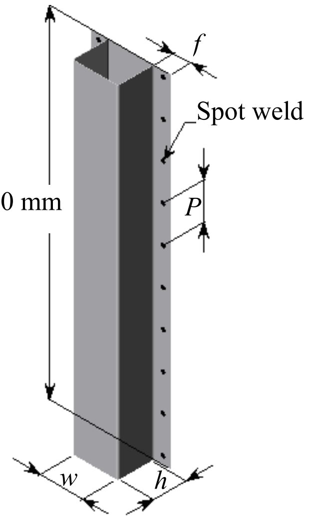


Fig. 1 Schematic drawings of the spot-welded column used in the current study

The spot-welded columns used for this study were made of mild steel alloy. The mechanical properties of this steel alloy were determined according to ASTM E8 [7] standard, using the INSTRON 8802 servo hydraulic machine. Fig. 2 shows the stress-strain curves for the mild steel with Young's modulus $E = 185$ GPa, yield stress $\sigma_y = 220$ MPa and ultimate stress $\sigma_u = 260$ MPa. Furthermore, the value of Poisson ratio was assumed to be $\nu = 0.3$.

FE models are created for spot-welded columns and they are used for the crashworthiness analyses. FEA results of SEA and the maximum crushing force P_m are acquired from the analyses. The force versus displacement responses of FE model are shown in Fig. 3.

As shown in Fig. 3, during the axial crushing of the spot-welded column (with $h = w = 55$ mm and $t = 1$ mm), the peak crushing force (43 kN) appeared right after the crushing occurred and after that the force dropped down quickly and stabilized at around 20 kN.

The crashworthiness of the spot-welded columns is expressed in terms of specific energy absorption (SEA). The SEA is defined as

$$SEA = \frac{Total\ energy\ absorotion\ E_{total}}{Total\ structural\ weight}$$

The area under the load-displacement curve gives the total energy absorption.

Maximum crushing force and SEA are important factors that these have to be considered during crashworthiness design. For human safety, the maximum crushing force that occurs during the crash should not exceed a certain criteria, which is an important issue in the vehicle design and manufacturing. Also high values for SEA indicate a lightweight absorber.

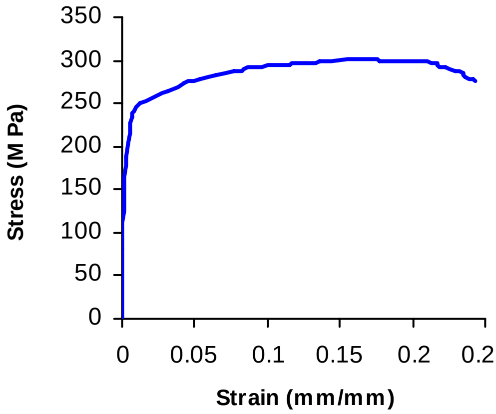
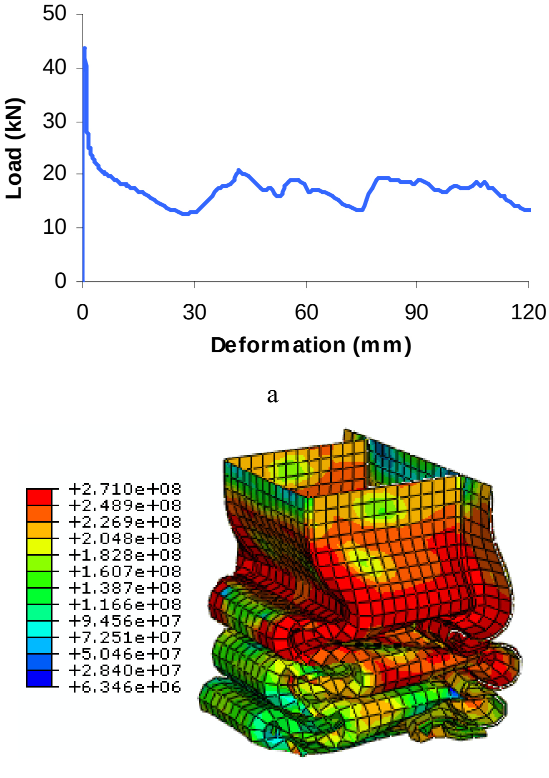


Fig. 2 Stress-strain curve for the mild steel



a

b

Fig. 3 Numerical load-deformation curves (a); Von Mises stress states (in MPa) for the spot-welded columns (b)

Figs. 4 - 7 show that with increasing side lengths *h*, *w* and flange width the absorbed energy is reduced, monotonously while the peak force increases. Figs. 8 - 9 show with increasing column height the peak crashing force is constant, approximately and SEA was reduced. Also Figs. 8 - 9 show with increasing thickness peak crushing force and SEA were increased. Comparing Figs. 4 - 9 it can be deduced that a good energy absorber has the least of side length, flange width and column height.

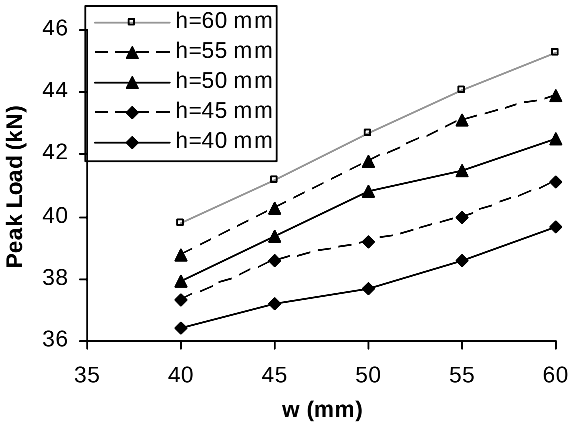


Fig. 4 Variation of peak crushing force with side lengths *h* and *w* for the spot-welded columns

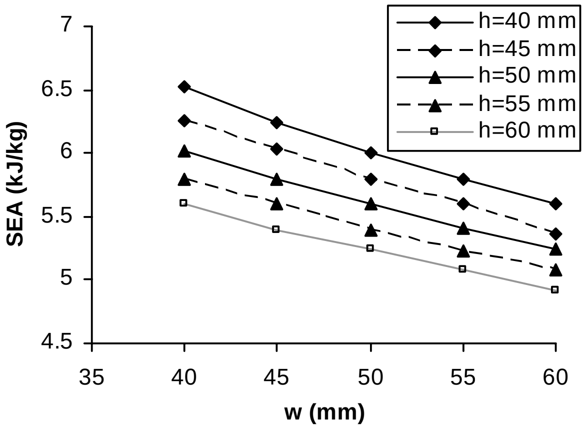


Fig. 5 Variation of SEA with side lengths *h* and *w* for the spot-welded columns

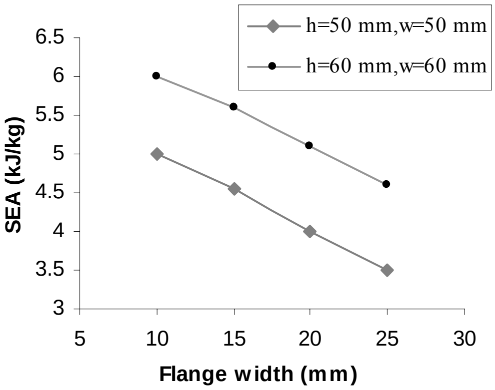


Fig. 6 Variation of SEA with flange width

The numbers of spot-weld in spot-welded columns are obtained by this method. At first, the SEA and peak crushing force is obtained based on a section with a complete weld. This obtained SEA and peak crushing force are selected constraint of SEA and peak crushing force. Then the minimum number of spot-welds is determined by satisfying this constraint.

Figs. 10 and 11 show the variation of SEA and peak crushing load with the number of spot-weld. Fig. 11 shows

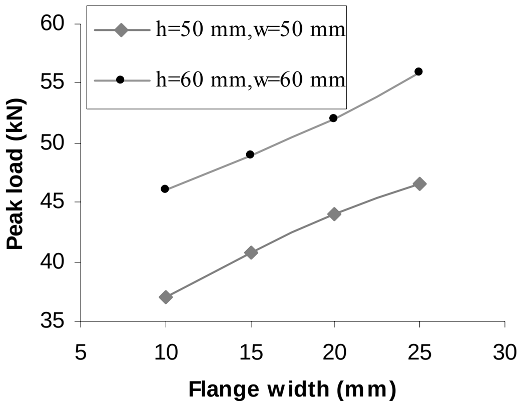


Fig. 7 Variation of peak load with flange width

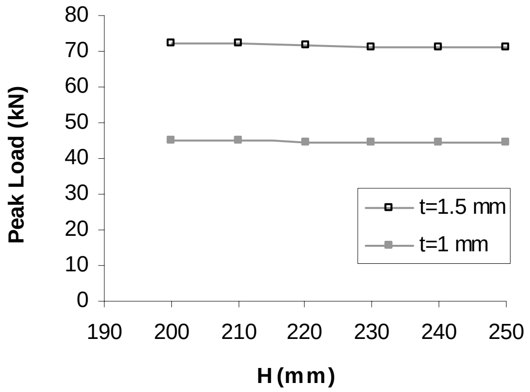


Fig. 8 Variation of peak load with column height ($h = w = 60$ mm)

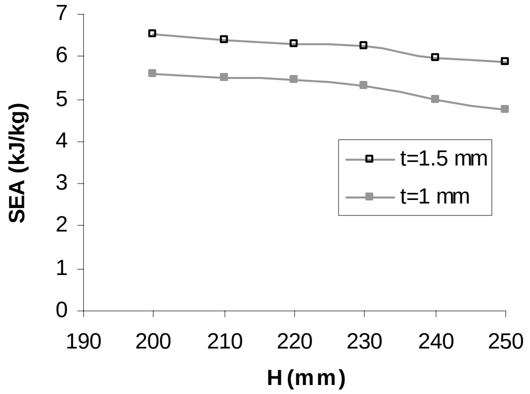


Fig. 9 Variation of SEA with column height ($h = w = 60$ mm)

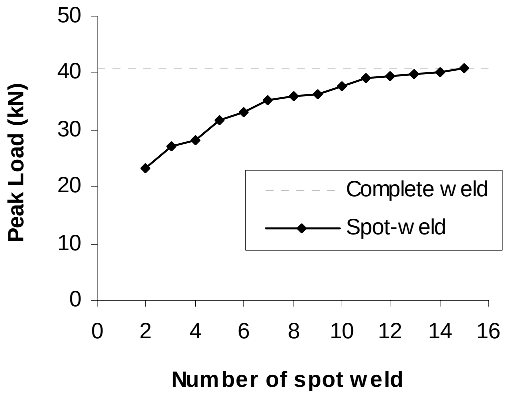


Fig. 10 Variation of SEA with the number of spot-weld

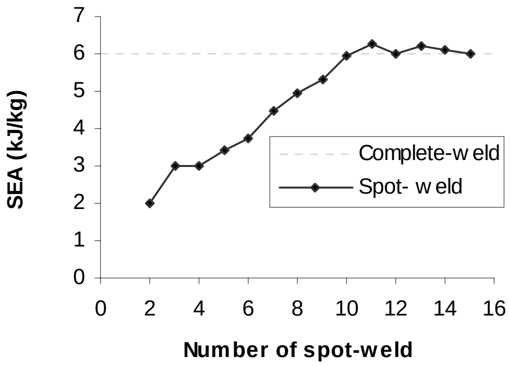


Fig. 11 Variation of peak load with the number of spot-weld

that the SEA for ($n < 10$) does not meet the constraint of ($SEA = 6$); therefore, the minimum number of spot-welds is 10. The peak crushing force corresponding to the $n = 10$ is 38 kN, which 5.5% reduction over the section with a complete weld which this reduction of peak crushing force is desirable (Fig. 10). The fluctuation of the values of SEA for ($n > 10$) is due to the highly nonlinear behaviours of crushing processes, because varying the number of spot-welds may result in different deformation modes and shapes.

3. Trigger effect analysis

Nowadays, humanity is placing increased reliance on transportation systems. Over the past several decades, there has been a sustained interest in the development of efficient energy absorbers designed to dissipate energy during a collision event and hence protect the passengers, cargo and other components of the systems. A good

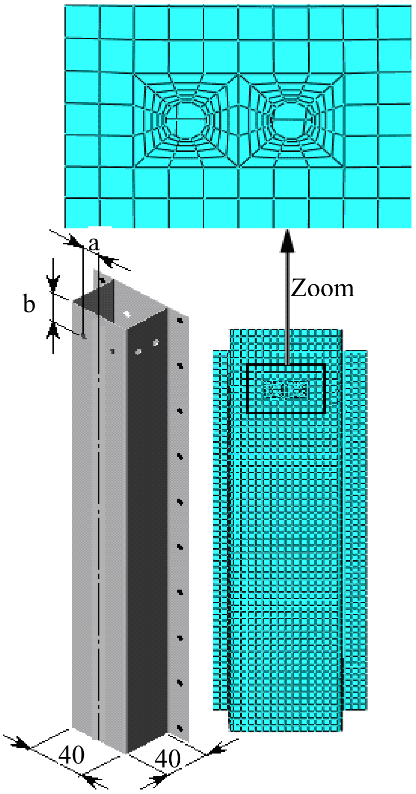


Fig. 12 Geometry and FEM model of spot-welded column with the trigger

crashworthiness design requires that the energy absorption should occur in a controlled load levels because the maximum force level was associated with safety. As usual, the high peak force was controlled by introducing a trigger. The trigger was defined by a variety of methods, indentation trigger [8-10], elastic buckling mode shapes [11], introducing a taper [12] or bump type trigger [13].

In order to investigate the effect of the trigger location on crush response different simulations were carried out by using different models having a trigger placed at different locations. For this study, circular holes with the diameter of 2 mm were analyzed. Details of the specimen dimensions are given in Fig. 12. According to this figure, the distance between the center of the trigger to the upper edge of the column and mid-line of tube's wall are designated by *a, b*, respectively. Fig. 13 shows the combined effect of *a, b* on the peak force and SEA. In general, it can be seen that peak crash force and SEA decrease with increasing *a* and *b*. This behaviour can be attributed to the fact that as *a* and *b* increase the bending moment increases, too.

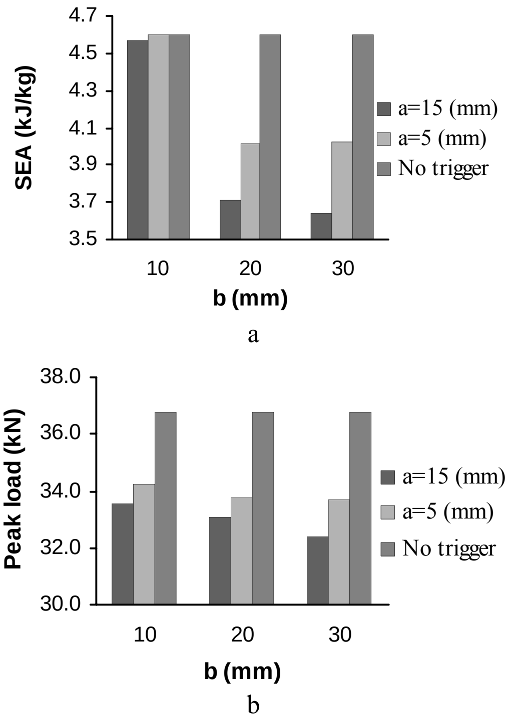


Fig. 13 Variations of: a - SEA and b - peak load with the location of the trigger

4. Experimental investigations and comparison of the experimental and numerical results

Experimental tests were performed on some specimens in order to confirm the numerical results. For these tests, servo hydraulic, INSTRON 8802 machine was used. The quasi-static tests were terminated after reaching a quasi-static tests were terminated after reaching a prescribed crushing distance, which was approximately 120 mm. Spot-welded columns, were joined by means of 6 mm diameter spots, positioned at the middle of the flanges width. The spot pitch was 20 mm. In addition, the comparison of the experimental and numerical results is shown in Figs. 14 -16. A very good correlation between experiments and numerical simulations was observed.

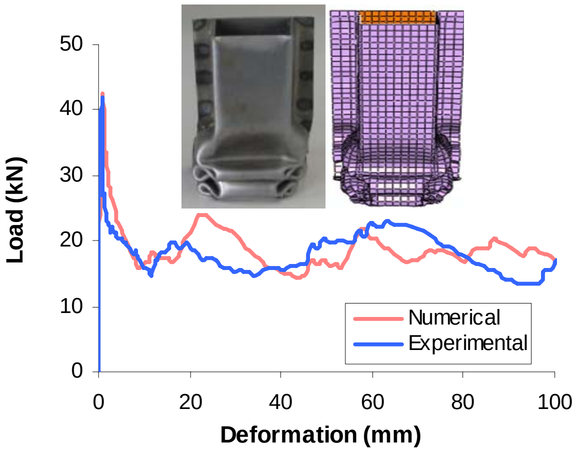


Fig. 14 Comparison of the experimental and numerical results for the specimen with $h = 50$ and $w = 50$mm

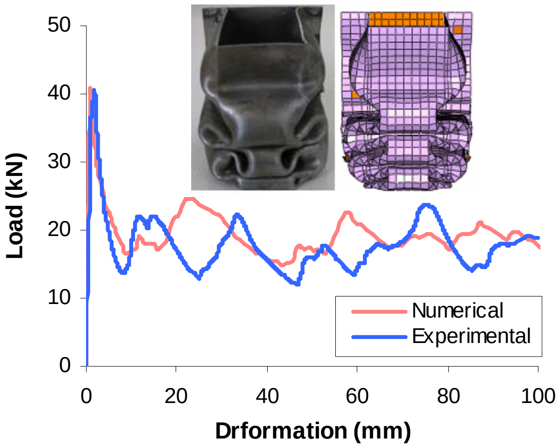


Fig. 15 Comparison of the experimental and numerical results for the specimen with $h = 40$ and $w = 60$ mm

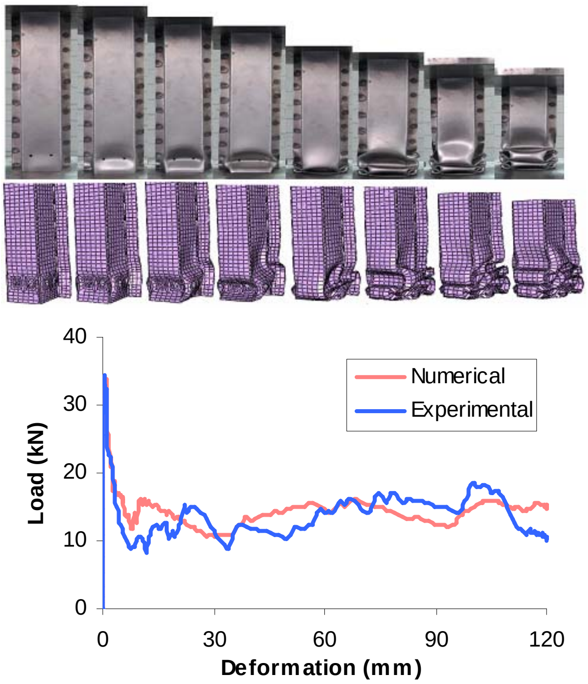


Fig. 16 Comparison of the experimental and numerical results for the column with trigger (a10-b20)

5. Conclusions

In this paper, crashworthiness of spot-welded columns was studied when no spot-weld failure occurred. And also the least number of spot-weld was obtained. Also the influence of location and size of hole trigger on the energy absorption capacity of tubes subject to quasi-static loading conditions, was investigated, both numerically and experimentally. Very good agreements were observed between numerical and experimental results. The specific conclusions reached in this study are stated below:

With increasing h and w and flange width, the SEA decreases while peak force increases. Triggers can be used to decrease the peak crushing load. The combinations of the size and location of triggers are important to have a controllable and predictable crash response.

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EKSPERIMENTINIS IR SKAITINIS SAUGIŲ TAŠKINIU BŪDU SUVIRINTŲ DETALIŲ TYRIMAS

Reziumė

Šiame straipsnyje pristatytas taškiniu būdu iš minkšto plieno suvirintų saugių detalių projektavimas. Atliktos sisteminės geometrinių parametrų studijos. Parodyta, kad atsparumą suirimui galima kontroliuoti keičiant saugiklių padėtį ir geometriją. Skaitinė analizė atlikta naudojant Abaqus programą. Taškiniu būdu suvirintos konstrukcijos suirimo pobūdis ištirtas eksperimentiškai.

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AN EXPERIMENTAL AND NUMERICAL CRASHWORTHINESS INVESTIGATION

Summary

This paper presents a crashworthiness design of thin walled spot-welded columns made from mild steels. Systematic parametric studies are carried out to study the effect of geometrical parameters. It is also shown that the crash response could be controlled by varying the location and the geometry of the trigger. The numerical analysis was carried out by Abaqus software. Subsequently, the collapse behavior of spot-weld structures was experimentally characterized

М. Схариати, Х.Р. Аллахбакхсх, Яфар Саеми

ЭКСПЕРИМЕНТАЛЬНОЕ И ЧИСЛЕННОЕ ИССЛЕДОВАНИЕ БЕЗОПАСНЫХ ТОЧЕЧНОЙ СВАРКОЙ СВАРЕННЫХ ДЕТАЛЕЙ

Резюме

В настоящей статъе представлено проектирование точечной сваркой сваренных из мягкой стали безопасных деталей. Проведено систематическое исследование их геометрических параметров. Показано, что сопротивление разрушению можно контролировать изменяя положение и геометрию предохранителей. Численный анализ проведен с использованием Abaqus программы. Тип разрушения точечной сваркой сваренной конструкции исследован экспериментально.

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