EXPERIMENTAL STUDY ON IMPACT ENERGY ABSORBING ELEMENTS USING CONFIGURABLE THERMAL TRIGGERS

P. Pereira[1], N. Peixinho[1], D. M. Dimas[1], D. Soares[1], C.Vilarinho[1]

[1] Departamento de Engenharia Mecânica, Universidade do Minho





ABSTRACT

This study presents an approach for the improvement of crashworthiness properties of aluminium tubular structures using initiators introduced through localized heating. The main objective of this approach is to improve the ability to absorb impact energy in a progressive and controlled manner by local modification of material properties. Through localized heating in areas chosen for initiation and associated softening of the aluminium alloy the deformation can be introduced precisely, forcing the tubular structure to deform in a mode of high energy absorption and reducing the maximum load in a controlled manner. This study presents results of properties for an aluminium alloy 6060-T5 modified by thermal treatment and using laser beam. Experimental results of impact tests of tubular structures using the proposed approach were performed on a drop weight tower with quantitative analysis using a high speed video camera and tracking software.

1- INTRODUCTION

This study is aimed at developing an approach consisting of local heating of aluminium alloy structures with the purpose of introducing a local modification of material properties. The main objective of this approach is the management of crash-energy absorption in a cost effective manner through the introduction of triggers: by local heating in areas chosen for triggers, local softening of aluminium can be induced thus forcing the tubular structure to initiate deformation in prescribed locations and assure deformation in the mode of highest energy absorption.

Zhang and co-authors [1] proposed a new idea wherein by installing a buckling initiator near the impact end which is composed of a pre-hit column and pulling strips, the initial peak force of the square tube could be greatly reduced while the deformation mode and excellent energy absorption were retained. The investigation revealed that by using a buckling initiator, 30% reduction in the initial buckling force is achievable. It is also found that this buckling initiator can not only reduce the initial peak force, but also ensure a stable and uniform crushing mode [1].

The concept of using thermal modification of an aluminium alloy in localized areas can provide for a larger global deformation of a part and higher energy absorption before failure. Thus fracture in critical regions can be delayed and the total energy absorption can be accordingly increased. Such design features are also highly cost-effective in implementation compared to the alternative process of geometric redesign. This advantageous use of aluminium is therefore possible by applying "local material design", which in the present context is defined as controlled manipulation of material properties like strength, work hardening and ductility by means of non-homogenous heating [2].

In particular, the buckling of crash boxes during a crash situation may be controlled by deliberately imposing local soft zones (i.e. thermally induced triggers). For the impact event simulation tools can be used to assess crashworthiness performance [3] and even enable a combined simulation of the thermal processing and subsequent response in the final component subjected to dynamic loading [4].

Sunghak and co-authors [5] evaluated the energy absorption performance of extruded aluminium alloys, using numerical simulation. Different types of triggering dents were introduced in the numerical simulation in order to evaluate the results of absorbed energy. J. Marsolek [6] used non-axisymmetric folding patterns for an improved control of absorption of kinetic crash energy. The trigger geometry mechanism is optimized for different loads, and the initial peak load was significantly reduced by using these types of triggers, especially in the dynamic experiments [6].

2- MATERIAL

2.1 - Material properties

The test specimens were manufactured from an aluminium alloy AA6060-T5. The chemical composition of the alloy, determined by XRF spectrometry, is presented in Table 1.

The mechanical properties of the aluminium alloy 6060-T5 were obtained by static tensile tests, and the properties of the heating affected zone (HAZ) are about 60% less than the base material according to the Vickers micro-hardness test, as can be seen in Fig. 1.

Table 1 – Chemical composition of the AA6060-T5 alloy.

	Conc. (wt%)
Al	Rem.
Cu	0,43
Fe	0,29
Mg	0,79
Mn	0,05
Si	0,51

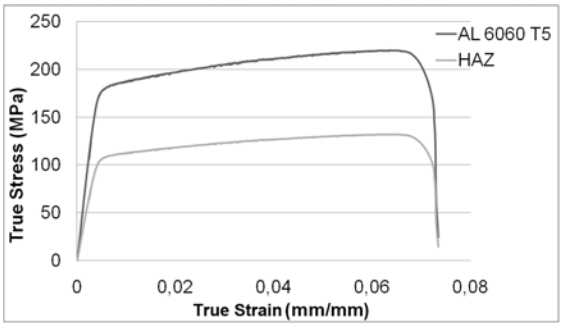

Fig. 1 - AA 6060 T5 True stress–strain curve and on the heat affected zone.

2.2 - Heating cycles

The aluminium alloy studied, suffers modifications in microstructure for certain parameters such as, temperature and choice of the heating cycle. The significant changes in the microstructure of the alloy occur for temperatures between 250ºC and 550ºC where a decrease in hardness occurs, associated to the dissolution effect of copper rich precipitates due to the imposed thermal cycle. Appropriate choice of heating cycle parameters is also important, because the alloy may not need very long temperature cycles for full transformation, or very high temperatures, and these two factors vary depending on another, being at this moment the objective of the heat treatment the highest softening possible of the alloy.

For carrying out the heat treatment, several samples were cut from aluminium alloy sheet (average thickness 1.5mm). The cut samples were then subjected to heat treatment: each sample placed in the central zone of a furnace for prescribed temperature and time.

For the laser heat treatment a CO_2 laser welding machine was used (Trumpf – 4000W). This was found suitable for the local softening approach. The density of energy could be regulated from laser power and feed rate thus varying material parameters and the heat affected zone.

In Figs. 2 and 3 the results of Vickers micro-hardness test (with 100gf load) for the samples with furnace heat-treatment are presented. The temperature and time conditions for the furnace heat treatment are described in the figures.

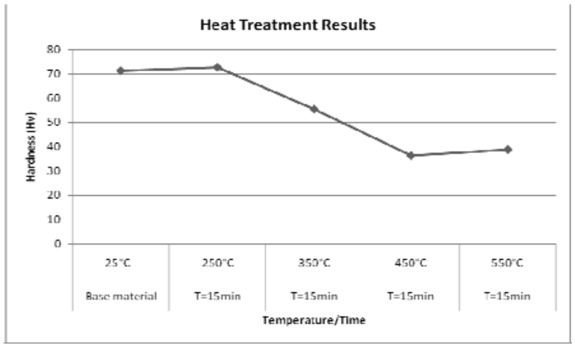

Fig. 2 -Hardness results for furnace heat treatment.

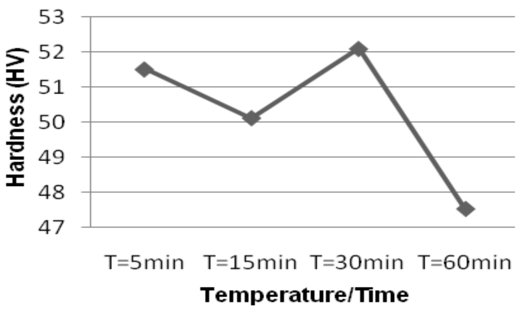

Fig. 3 - Effect of the stage time, at 400ºC, on the final sample hardness.

The laser was used with different feed rates and a power input of 1kW, 2kW, and 4 kW. The hardness results, presented on figure 4, show similar values for the HAZ (Heat Affected Zone) at 1kW and 2kW. At 4kW and feed rate of 5 m/min shows a significant increase of the HAZ with the feed rate of 5 m/min at 4kW.

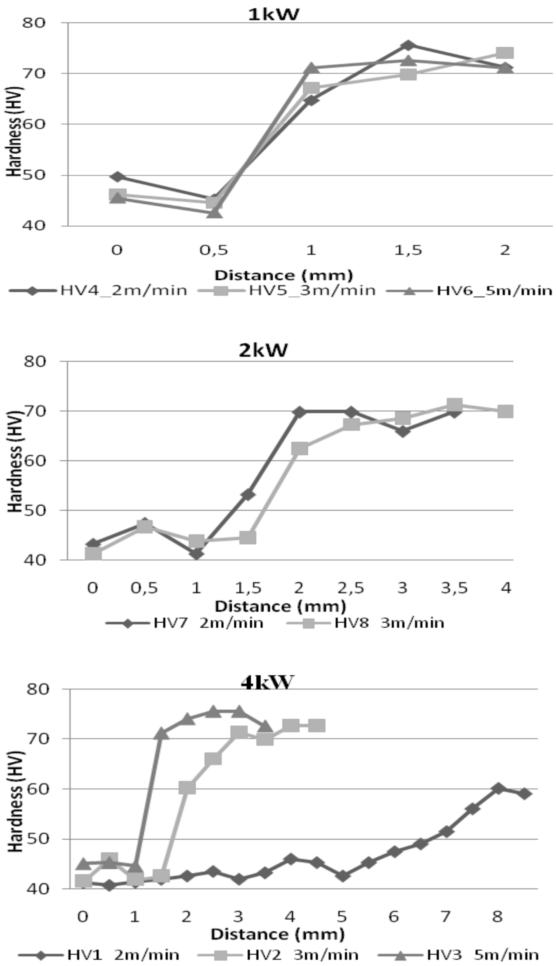

Fig. 4 – Hardness results for laser heat treatment at center of HAZ (0 mm) and distance from center of HAZ.

3- EXPERIMENTAL IMPACT TESTS

3.1 - Procedure

The structure considered in this study is a tubular column with square cross-section of aluminium alloy 6060-T5. The dimension of the cross-section is 75x75 mm with 1.5 mm wall thickness, and the length of the column is 300 mm.

These experimental tests were performed in the Materials Testing Laboratory of the Mechanical Engineering Department at the University of Minho, with a drop weight tower (figure 5), with the following characteristics: mass, 76 kg; height, 6 m.

The acquisition of quantitative information was performed with a high speed camera Photron Ultima APX-RS, at 5000 fps and 512x1024 pixel resolution.

The steps for the different tests were the same, the aluminium column was positioned in the square platform, the drop weight and the camera were activated close to the impact event.

Fig. 5 – Drop weight tower.

3.2 - Software

The information acquired in the tests was processed by TEMA Motion software, with the digital images sequence obtained by the high speed camera, Fig.6. This software can track an object in the image and make analyses of movement presenting the results of, displacement, velocity and acceleration, in graphs and tables that can be exported to Excel for an improved analyses.

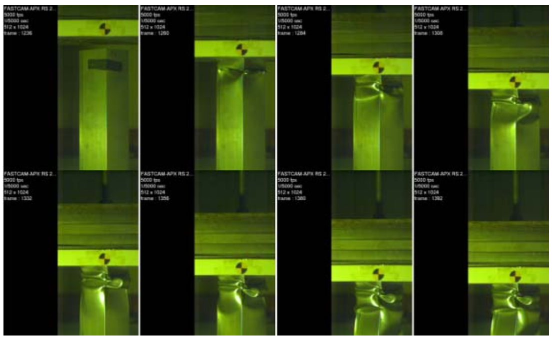

Fig. 6 – Example of sequential digital images.

In TEMA MOTION the following parameters are defined: number of frames per second used in camera at the capture; the scaling, p/pixel; the point to track; and the tracking algorithms.

The tracking algorithm is important to have a secure follow of the point by the software. In this case we use the correlation algorithm (Fig. 7), which looks in each successive image for the area that correlates best with the pattern defined in the first image.

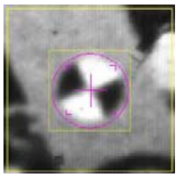

Fig. 7 – Correlation Algorithm

For an improvement of the results obtained, we used one of the filters on the software, FIR (Finite Impulse Response) and CFC (Channel Frequency Class) filters. The filter used was the CFC that applies a fourth order phaseless Butterworth filter. This filter is a non-causal IIR (Infinite Impulse response) filter, i.e. a change in any input sample affects the entire output. Invalid input samples are interpolated and the corresponding output samples are marked as invalid. Input data is re-sampled to an equidistant timebase. The value used for this filter was CFC 500, according to the values used in crash analyses for sampling frequency of 5000 fps [7].

After obtaining the results of TEMA Motion analyses, those are exported to a spreadsheet (MS Excel) where the values of position, velocity and acceleration were analyzed to obtain: total energy absorbed, medium load, maximum load, kinetic energy and total displacement.

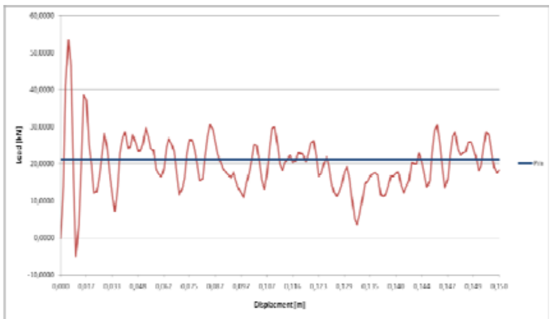

Fig. 8 – Load-Displacement curve obtain in Excel.

3.3 - Results

The results obtained on the experimental test are presented, namely load-displacement curves and values of maximum load, mean crushing load and total energy absorbed, for each of the triggered tubular geometries and one without triggers for comparison.

The type of triggers used are, a) complex trigger in two sides (c1), b) four triggers in two sides (4laser), c) one triggers in two sides (2l), d) one trigger in four sides (4l), shown in the Fig. 9. The Load-Displacement curves obtained are presented in Figs.10-14.

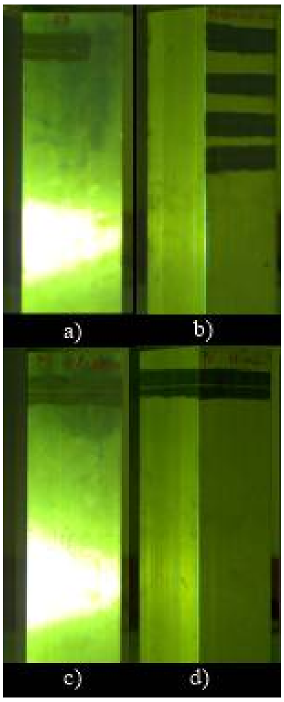

Fig. 9 – Triggers used.

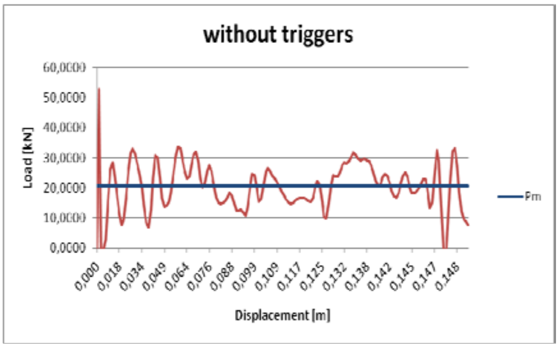

Fig. 10 – Load-Displacement curve of structure without triggers.

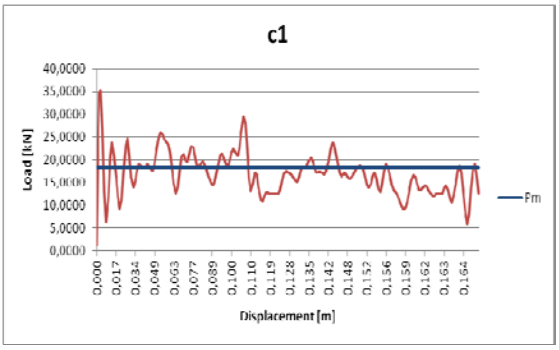

Fig. 11 – Load-Displacement curve of structure with complex trigger.

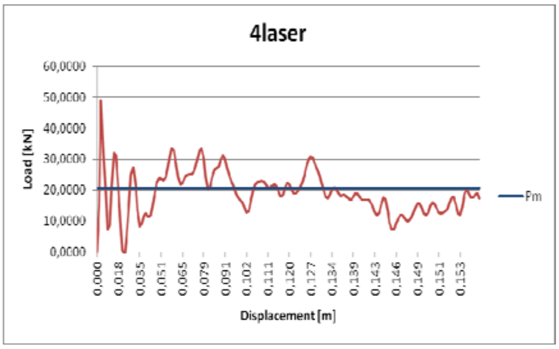

Fig. 12 – Load-Displacement curve of structure with four triggers in two sides.

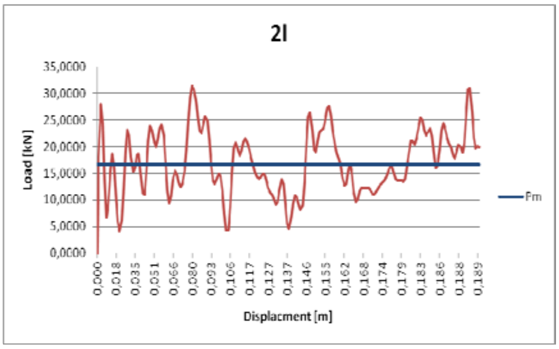

Fig. 13 – Load-Displacement curve of structure with one trigger in two sides.

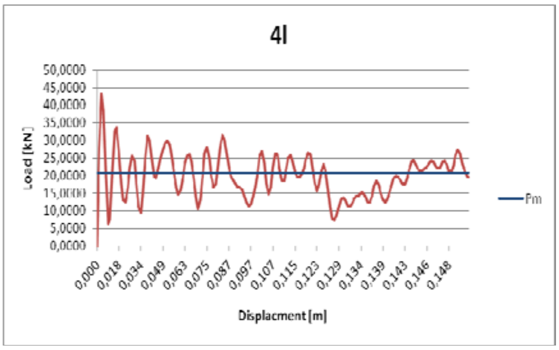

Fig. 14 – Load-Displacement curve of structure with one trigger in four sides.

Following is presented in Table 2 the exact values of maximum load (P_{max}), total absorbed energy (E_a), and medium load (P_m) for each one of the tests.

4- DISCUSSION

The observation of video recording and force-displacement curves allows the characterization of different features of the crushing process. Plastic folds are initially formed in the upper part of the test specimens and continue to develop gradually down

Table 2 –Characteristic values.

without triggers	
P_{max}	52,7 kN
E_a	3,1 kJ
P_m	20,7 kN
c1	
P_{max}	35,2 kN
E_a	3,0 kJ
P_m	18,3 kN
4laser	
P_{max}	49,1 kN
E_a	3,2 kJ
P_m	20,6 kN
2l	
P_{max}	31,4 kN
E_a	3,1 kJ
P_m	16,6 kN
4l	
P_{max}	43,3 kN
E_a	3,09 kJ
P_m	20,8 kN

into the lower parts. Besides, as soon as the folds consist in a side of the model, they develop in the side opposed in turns. These folds are a facilitating mechanism to absorb the energy on the compressive deformation. So, the tendency of formation of folds fulfils an important paper in the absorption of energy.

When the first fold is forming, the model reaches the maximum force capacity, which represents the first peak and is referred to as the maximum peak force [8]. The load decrease as the first fold is being developed where the folding outward is started. After the completion of the first fold, the force reduces to the first lowest point where the contact outward happened. The further deformation causes the load to increase until the next peak is formed with the formation of the second fold.

In the case of the tubular geometry without trigger, the maximum force exerted on the models goes through a sharp maximum significantly higher than most of the other models, as seen in figures 11-14. This maximum force is effectively reduced, particularly for geometries *c1* and *2l* for almost all models by the imposed HAZ triggers. This reduction presents a benefit for crashworthiness purposes since it helps to reduce the peak acceleration for occupants. However, this benefit must be weighted against a reduction in average mean crushing force that also occurred for the referred tests.

The objective of providing consistent triggering and therefore ability tailor the deformation process can be observed in Fig.15, where it can be seen that the folding process initiates at the thermal trigger location.

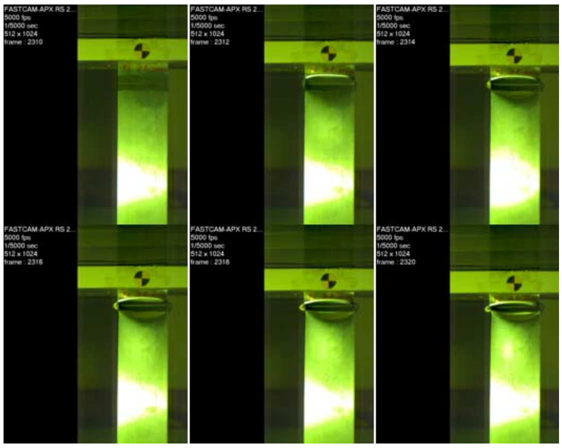

Fig. 15 – Folding process.

5- CONCLUSIONS

This paper presented experimental results of heat-treatment of aluminum alloys with the purpose of inducing local modification of material properties. This was achieved using laser heat-treatment and in furnace preliminary tests. It was verified that it is possible to change the local hardness in a controlled way, i.e. by the copper rich precipitates dissolution effect in the sample, and with a laser treatment, by changing the feed rate.

The research reveals that by using a thermal trigger a reduction in the initial crushing force is achievable. It is also found that this thermal trigger can not only reduce the initial maximum force but also ensure stable and uniform absorbed energy at most smart models.

The concept of using thermal modification of an aluminium alloy in localized areas for providing a larger global deformation of a part and higher energy absorption before failure appears as possible and effective in the experimental work presented.

6- ACKNOWLEDGEMENT

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