Quasi Static Compressive Behavior of Al-Si-SiC-xFe Foam Filled Crash Boxes

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1- Introduction

Safety of the passengers has become an important factor in design engineering because of the advancements in the transportation industry. Thin walled structures are widely used to absorb energy during crashes. Their uniform axial deformation in concertina mode and high ability of energy absorption make them ideal structures. However, their low mechanical characteristics in non-axial loading, limit their expanding usage as energy absorber. Numerous experimental and numerical studies have been conducted to overcome this issue. Using high strength material, bi-tubular structures and folding pattern are the main activities which have led to an increase in non-axial strength of thin walled structures.

Metallic foams as a significant class of advanced cellular materials, exhibit a distinct combination of physical and mechanical properties, such as low specific strength, high stiffness and similar efficient energy absorption in all directions. Foam filled tubes absorb much more energy than the sum of absorbed energy for individual foam and tube. This is due to the interaction between the foam and the tube. This interaction has a direct relation to the structure and density of the foam. Unfortunately, the mechanical properties of the commercially metallic foam does not meet the predicted properties by numerical modeling which is due to the structural defects such as missing or wavy cell walls, the various geometry of the cells, porosity and micro shrinkage. Some studies have been performed to diminish such defects. Although iron has a stabilizing effect during the foaming process of Al-Si-SiC composites, it does not get enough attention. The aim of this paper is to investigate the effect of iron on the microstructure and structural properties along with its energy absorption capabilities under uniaxial quasi static compression of aluminum closed cell foams.

2- Experimental procedure

Aluminum, silicon, silicon carbide, titanium dehydrate and iron powder were used to produced different alloys in accordance to Table 1. To this end, the powders were weighed and homogenized for an hour in a mixture and then further processed using both hot and cold iso-static pressing at 450 $^\circ$C. Cold press was used to produce a high-density specimen and hot press was used to eliminate the foreseeable porosity.

To evaluate the effect of the tube cross section on the energy absorption ability of the foam filled tube, brass tubes with circle and square cross sections were chosen with various diameters and a constant H/D ratio of 1.5. After hot iso-static compression, the pre-foam was placed inside the tubes and exposed to furnace heat in order to produce the final foam. After the foaming process, specimens were taken out and cooled using an air blower. The specimens were uniaxially loaded using an Instron 8502 instrument with a load capacity of 25 KN and a crosshead speed of 25 mm/min. Also, optical and electron microscopy were used in order to investigate the microstructural changes of the foams. To this end, specimens were ground, polished and etched with a 1% nital etchant.

Table. 1 Characteristics of the used powders

Compound	Purity (%)	Size (μm)
SiC	95	<25
TiH$_2$	98	<44
Si	95	<150
Fe	99	<44
Al	97	<63

3- Results and discussion

The density of the samples with 0, 1 and 3 percent iron was calculated as 2.56, 2.86 and 2.36 g/cm^3, respectively. It has been pointed out that the presence of SiC particles results in the augmentation of cells and a decrease in drainage. On the other hand, an inhomogeneous distribution of these particles in the solid-gas interface will lead to crack formation in the specimens. In the present study, as it is depicted in Fig. 1, SiC particles are distributed homogenously in the cell wall material which means they act as stabilizers.

Image analysis showed that the iron content has a direct impact on the sphericity and compactness of the cells, which results in the formation of a homogenous microstructure. Moreover, it was shown that the iron has an inverse relation to the thickness of the cell walls, which arises from the decrease in drainage (Fig. 1). On the other hand, the number of cells per square inch increases by increasing the iron content of the foams (140, 200 and 220 cells for 0, 1 and 3 percent of iron, respectively). In other words, the strength of the foam increases due to having round cells and a lower drainage.

Fig. 2 shows images of the empty and foam filled crash boxes with different amounts of iron (in each picture from left to right: empty, 0, 1 and 3 percent of iron containing foam, respectively). It was shown that the mean value of energy absorption per unit volume of the square tube is less than the circular tube due to the effect of the moment of inertia. In the uniaxial quasi-static compression test, the energy absorption of the structures increase by increasing the amount of edges in the cross section. On the other

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hand, for the foam filled tubes, square tubes absorb more energy in comparison to the circular tubes.
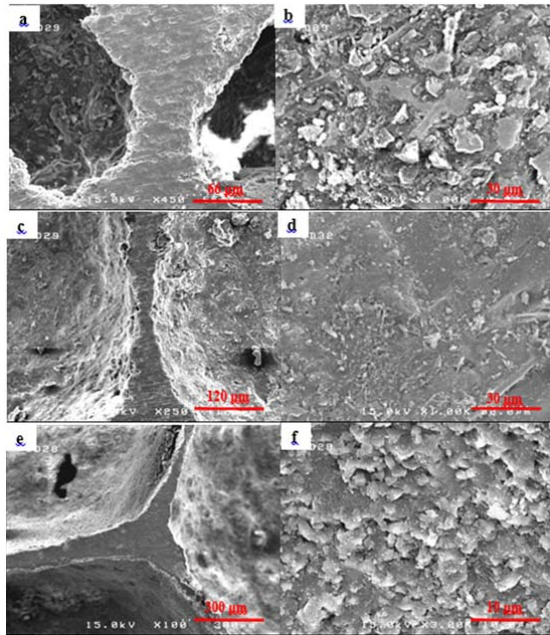

Fig. 1 SEM micrograph of the as-produced foams with (a) 0; (c) 1 and (e) 3% iron content. (b), (d) and (f) are magnified images of (a), (c) and (e), respectively.
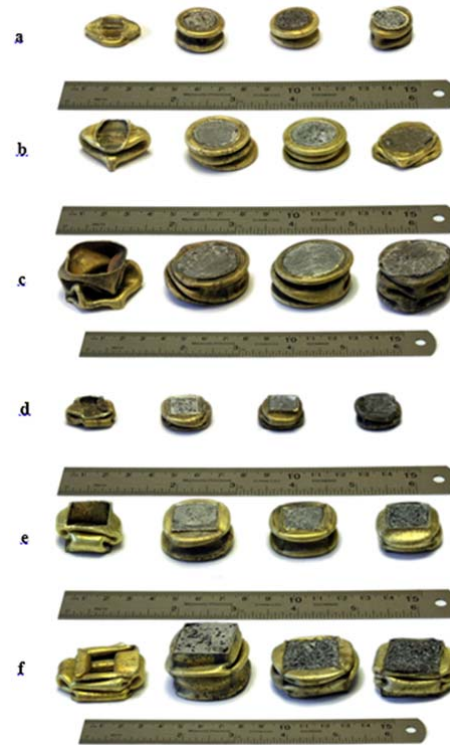

Fig. 2 Empty and foam filled tubes with different size and cross sections after compression. A (a) small; (b) medium; (c) large circular tube and a (d) small; (e) medium; (f) large square tube.

The strength and energy absorption of the foam filled tubes increases up to 40% in comparison to the empty tubes due to the interactions between the foam and the tube walls. In addition, this interaction results in a decrease in the folding length in the tubes that showed an increase in the crushing distance. So, the ability to absorb energy has increased. Quantitatively, the foam filled square tube without iron has an energy absorption of 30 MJ/m^3 which is 9 MJ/m^3 more than that of the circular tube. In other words, the square tubes absorbs 44% more energy than the circular ones. In addition, for 1 and 3 percent of iron, the square tubes absorb 4 and 3 MJ/m^3 more energy, respectively. Also, it can be concluded that with increase of iron content, the energy absorption is reduced as a result of the reduction in the density of the foam.

4- Conclusions

Closed cell aluminum foams with different amount of iron as a stabilizer were successfully produced via powder metallurgy route. The energy absorption and compressive characteristics of the foam filled tubes with different geometries showed that the addition of iron led to a uniform structure and a high sphericity factor for the foams while it resulted in a decrease in the energy absorption which arises from the formation of brittle intermetallic compounds. Moreover, the circular tube shows a better energy absorption capability than the square tube. On the other hand, the foam filled tubes with square cross-sections have a higher energy absorption. A numerical model was developed in this research to predict the energy absorption of the foam filled tubes.