Use of zinc foam for filling of hollow steel profiles

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Abstract

The possibility to use zinc instead of aluminium for „in-situ" foaming of steel tubes by PM route was investigated. The performance of both metallic foams was evaluated with respect to the attainable porosity (weight difference), changes in steel microstructure and mechanical properties (bending stiffness, strength and ability to absorb deformation energy).

1 Introduction

One of the attractive industrial applications of aluminium foams is the stiffening of hollow steel profiles made by hydroforming technology where partial foaming in the weakest points eliminates the peak stresses and allows the use of profiles with reduced wall thickness. This leads to the overall weight savings and permits also the exploitation of economical hydroforming technology in applications where it is recently not possible due to the insufficiently attainable wall-thickness [1]. The partial foaming of hollow components has less environmental impact and is more cost effective than the welding of various stiffeners. Moreover, the foam increases the capability of the component to absorb front and/or side crash energy and suppresses the noise and vibration of initially hollow structure. The problems still to be solved are the foaming rate, which is too slow for high production output, the impact on the properties of profile material because of high foaming temperature (removing of work hardening, oxidation of the surface) and the potential corrosion problem when aluminium foam is used in combination with steel. These problems could be significantly minimised if zinc or its alloys are used instead of aluminium because of lower melting temperature of zinc and its compatibility with steel regarding the corrosion resistance. This idea was investigated in this work.

2 Experimental

The zinc foams were prepared by powder metallurgical route [2] from extruded precursor made of plain zinc powder mixed with TiH_2 as foaming agent. For comparison aluminium foam samples based on AlSi12-alloy were also manufactured by the same way. The both types of precursor were inserted into the steel tubes with geometry ϕ 38.5/37 x 400 mm and then, together with the tube, heated to the foaming temperature. Some of the tubes were filled with foam inserts, which were prepared outside the tube. The tubes were foamed or filled either fully or partially (foam length about 100 mm) in the mid of the profile. Three point bending tests were run on INSTRON testing machine at ram speed of 10 mm/min with supports distance l = 300 mm and roller diameter 30 mm. From some of foamed samples the foam was removed and the empty tubes were tested under the same conditions as foamed ones, in order to examine the effect of heating on the properties of steel profile. Thus in a case of AlSi12-foam the tube was heated up to 800°C while in a case of Zn-foams only up to 500°C. The "as-received” empty tubes with the higher wall-thickness (adapted to the weight of foamed samples) were also tested for comparison.

3 Results and discussion

3.1 Filled profile

When the foam stiffener is inserted into the profile it does not fill the hollow space entirely because of necessary tolerances and usually has to be fastened by expandable adhesives, which increase the costs and also weight of the component. This approach is usually applied for steel or aluminium profiles of simple shape or for profiles consisting of various parts welded together. The experiments show, that the filling in the whole profile length with the foam is disadvantageous because of the excessive weight increase of the component without satisfactory improvement of mechanical properties (see Fig. 1). The full filling can improve the energy absorption capacity in axial direction, but it is unfavourable for side impacts. The property-to-weight ratio can be improved if the profile is filled partially in the weakest sections (or in the sections with maximum load). The weight increase in this case is acceptable for the achieved improvement of bending properties [1]. If the foam is inserted into the as-received profile, the aluminium foam always dominates over the zinc foam, because of considerably better properties at comparable weight [3-4].

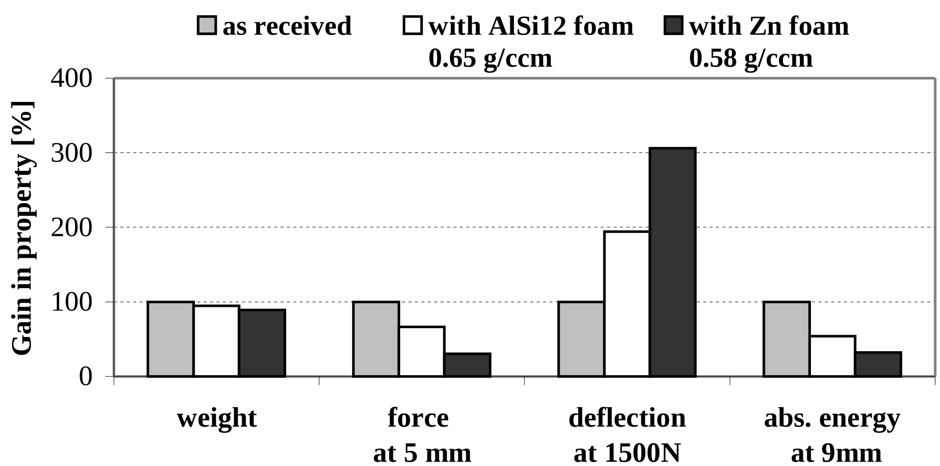

Fig. 1. Property changes of steel profile after full filling with foam inserts of comparable density (steel tubes ϕ 38.5/37 x 400 mm, as-received tube ϕ 40/37 x 400 mm)

3.2 Foamed profile

It is usually impossible to insert the foamed part into the complex shaped profile. In this case the foam must be prepared by heating of precursor “in-situ” in the profile. The advantage is that the profile is filled entirely without gaps between foam and outer shell. Even metallurgical bonding can be realised and therefore no additional fasteners are needed. Beside local stiffening and strengthening, the contact damping appears, which results in interesting attenuation of noise and vibration [5-6]. However, in-situ foaming requires the heating of profile above the melting temperature of foamed metal. In a case of aluminium foams it is usually above 700°C. This temperature leads to the significant changes in the structure of the profile material (increase of grain size, change of grain shape and removing of cold working – see Fig. 2) with dramatic consequences to the mechanical properties – the properties of the foamed profile are sometimes worse than before foaming (Fig. 3). Zinc or its alloys have significantly lower foaming temperature (below 500°C) and thus less influence on the steel microstructure. For this reason, the foaming with zinc foam seems to be more reasonable than foaming with aluminium foams.

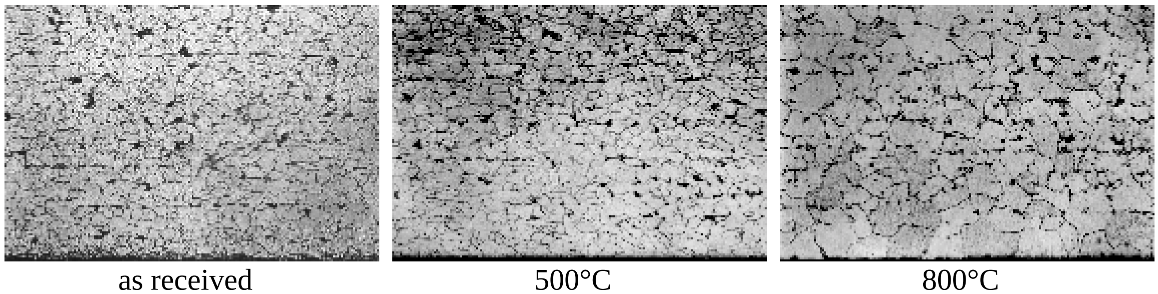

Fig. 2. Structural changes in the steel after foaming at 500°C and 800°C (zoom 200x)

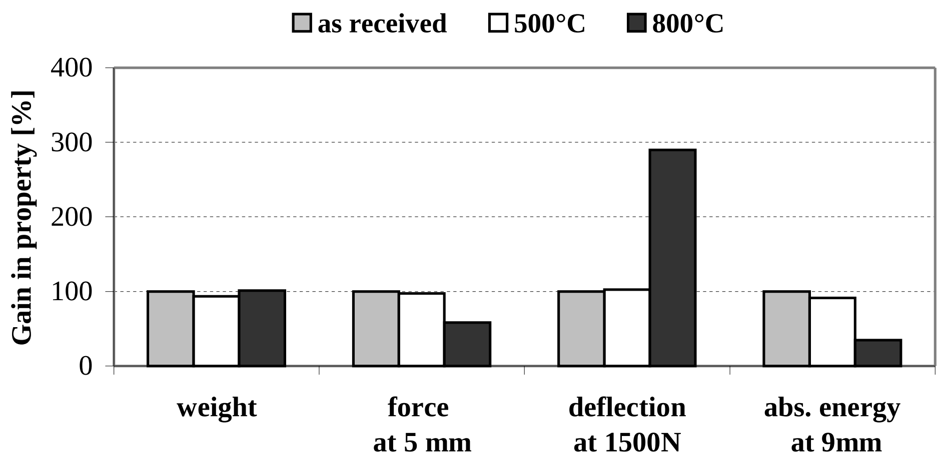

Fig. 3. Property changes of steel profile after foaming with Zn at 500°C and with AlSi12 at 800°C (steel tubes ϕ 38.5/37 x 400 mm, foam was removed from the profile before testing)

Also in this case the full foaming of the profile does not bring any advantage (Fig. 4). However, it is clearly visible, that the detrimental effect of heating diminishes the difference between properties of profiles foamed with aluminium and zinc at comparable foam density. (compare Figs. 1 and 4). Partial foaming with zinc results in the improvement of the property-to-weight ratio of initial profile and evidently dominates over partial foaming with aluminium (Fig. 5). The reason is that the lower melting temperature of zinc allows foaming of steel profile without detrimental reduction of its initial mechanical properties.

4 Conclusions

The effect of zinc foam on the performance of foamed steel tube was investigated and compared with performance of the same tube foamed with aluminium. If the foams are simply inserted into the profile, aluminium foam dominates because of better mechanical properties at the same weight as zinc foam. However, when the foams are prepared by foaming in the profile directly, better performance was achieved with zinc foams, because of negligible impact on the steel properties due to a lower foaming temperature. Foaming of aluminium in steel tube leads to significant changes in structure of profile material with negative consequences to its mechanical properties. It has been shown, that the use of foamed stiffeners is effective only when the profiles are foamed partially, in the weakest sections, or in the parts with highest loading, otherwise the property-to-weight ratio is reduced.

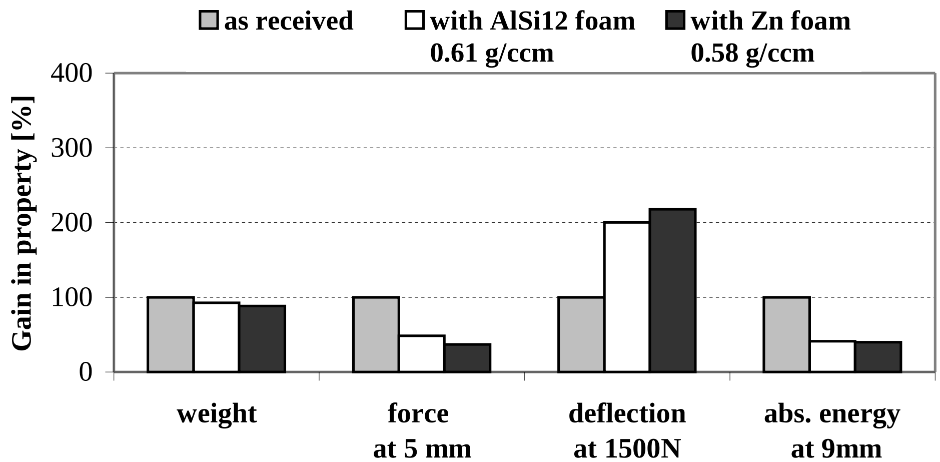

Fig. 4. Property changes of steel profile after full foaming with the foams of comparable density (steel tubes ϕ 38.5/37 x 400 mm, as-received tube ϕ 40/37 x 400 mm)

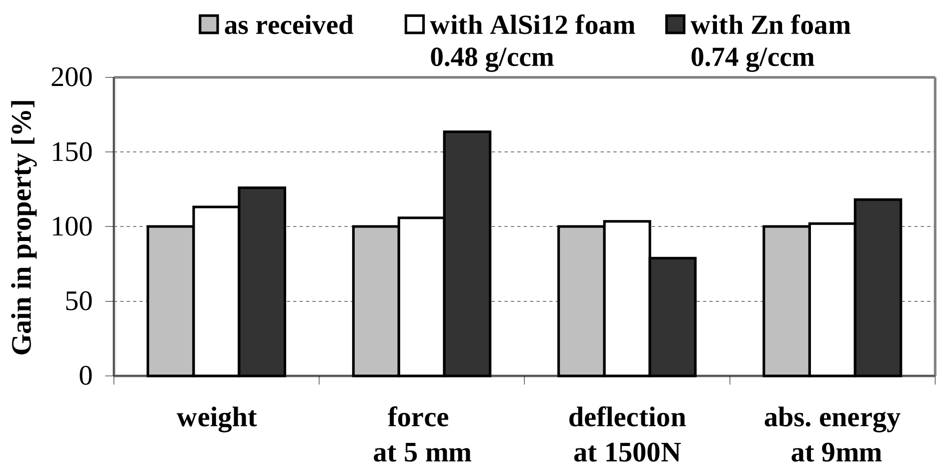

Fig. 5. Property changes after partial foaming in the mid of the steel profile (steel tubes ϕ 38.5/37 x 400 mm, foam length 100 mm)

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