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Energy absorption of thin-walled profiles made of AZ31 magnesium alloy

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ABSTRACT

The paper compares the energy absorption of the AZ31 magnesium alloy with the DC04 and HC380LA steel on the example of the thin-walled model profiles made by the process of bending. Additionally, the studies involved the application of aluminium foam filling the sections in order to increase their energy absorption.

The first stage of the research included the elaboration of a technology of producing the thin-walled model profiles from a magnesium alloy by way of bending, with the use of tools heated to 270 °C and 300 °C. Next, the prepared sections halves were joined with the use of the FSW method. The static tensile tests showed that the FSW joints underwent damage in the native material or at the boundary with the heat-affected zone, which confirmed their high strength.

The main aim of the use of the magnesium alloy was to lower the mass of the bodywork. And so, in order to compare the energy absorption of the profiles made of steel with those made of magnesium alloys, the mass of the samples should be taken into consideration. To that end, in the study, the parameter of specific energy absorption was introduced, which is the absorbed energy divided by the mass of the sample. The dynamic deformation tests performed on the profiles made of the AZ31 magnesium alloy and the DC04 and HC380LA steel demonstrated that the profiles made of only the AZ31 magnesium, due to their low deformability, do not exhibit sufficient energy absorption. In order to increase it, hybrid samples should be applied. The study proposed filling the profiles made of the AZ31 alloy with aluminium foam. This caused their specific energy absorption to be higher than that of the steel profiles.

1. Introduction

Reducing the fuel absorption and improving the passive safety are the two key problems faced by the producers of car models. The process of perfecting the car in this respect is continuous in character, and recently, has become also an element of competition between producers. The most important factor influencing the mentioned aspects is the construction of the bodywork, which is built of two zones: controlled body crushing zones and safety cage. These zones must be properly distributed in the car, i.e. in such a way so that the deformation of the construction during a collision can be progressive in character. This means that in the first place, those elements should undergo deformation which are the furthest from the passenger, made of sheets of a lower rigidity, followed by those of a higher rigidity in the intermediate zone, whereas the last zone located near the passenger segment, made of very high rigidity materials, should protect the cabin by limiting the scope of deformation [1].

In respect of the human safety inside the vehicle, the very crucial aspect is the value of acceleration (deceleration) and the time of its operation, rather than the absolute value of the force operating on the body. The relation between the acceptable acceleration and the time of its operation on the human body is illustrated by the Patrik curve, from which it can be inferred that the acceleration experienced by the human during a collision should not exceed HIC = 1000 with 4 ms, which corresponds to about 90 g (The Head Injury Criterion (HIC) is a measure of the likelihood of head injury arising from an impact. The HIC can be used to assess safety related to vehicles) [2].

At present, car bodyworks are constructed from thin-walled profile sections produced by way of drawing, which are then joined through welding, seam welding, friction stir welding and spot welding [3]. Due to the costs and the properties, the end of the last century was dominated by low-carbon steels [4].

Recently, with the aim to lower the fuel absorption through a reduction of the vehicle mass, new materials, characterizing in a high strength-mass ratio, have been searched for claims that light weight materials are another important technology that can improve the passenger vehicle fuel efficiency by 6–8% for each 10% reduction in weight [5,6]. The use of light weight advanced materials in the automotive industry will make it possible to significantly lower the mass of the vehicles [7].

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Magnesium alloys are the third most commonly used materials for the construction of the structural elements, right after steel alloys and aluminium alloys. Because the density of magnesium equals about ¼ of the steel density and ⅔ of the aluminium density, it is one of the lightest metals [8]. Over the years, casting magnesium alloys have been known and widely used, but wrought alloys have higher strength parameters [9]. This allows for its use in the automotive industry, aerospace industry, power industry and other industries that put a special emphasis on the reduction of the construction weight [10].

Volkswagen was the first to introduce magnesium in the automotive industry on a global scale: the Beetle model contains 22 kg of magnesium [11].. The current examples of the use of magnesium are the Daimler-Chrysler 7G-Tronic's automatic gearbox, or the BMW's engine block, steering wheel and casing of the power transmission system. All those elements, made of magnesium alloys, are cast and they characterize in a limited strength and plasticity as well as an large porosity [12]

Unfortunately, magnesium is not currently used for the construction of bodyworks, because, on the one hand, there is a very big problem with the processes of bending and drawing, which, for magnesium alloys, must be performed at temperatures above 200 °C [13], and on the other hand, there is no information on the resistance of elements made of magnesium to the dynamic loads which are present during a collision. At present, more and more studies are being conducted on the possibility of forming magnesium alloys by way of metal forming [14,15]. A big problem during the deformation of magnesium alloys is their strong texture [16].

Lately, very intensive studies have been undertaken to introduce magnesium into the automotive industry, which is proved by the designs of large automotive companies. This is clearly demonstrated by the design of a motor car by Volkswagen, which is supposed to characterize in a fuel absorption at the level of 1 l per 100 km. This car is designed to apply metal sheets, metal formed profile sections and cast elements made from different magnesium alloys.

The literature gives no information on the energy absorption of elements made of magnesium alloys by means of bending and drawing methods. It only provides scarce data concerning the energy absorption of elements made of magnesium alloys by means of extrusion or casting technologies.

One of the first studies of the use of magnesium alloys for energy consuming elements was conducted by Cato Dørumet al., who proposed the construction of an energy consuming element of a magnesium alloy, which applied the mechanism of crushing the side wall of such a profile section by a mandrel fixed inside it [17]. The proposed deformation made it possible to obtain a nearly constant force during the whole process. However, the degree of complication of the process is so high that it is difficult to apply it from the practical point of view.

The most extensive studies have been performed by Beggs et al. [18]. The works concerned the drawing of profiles of a circular section made by means of the technology of extrusion from the AZ31B magnesium alloy. They demonstrated that quite different destruction mechanisms operate in these profile sections compared to steel and aluminium ones, where progressive deformation was observed. In the case of profile sections made of magnesium alloys, cracking rather than deformation of the profiles occurred. The authors showed that, in the case of minor cracking of magnesium, called “fine sharding”, the profile sections made of AZ31B could consume much more energy than the AA6061T6 aluminium alloy or the HSLA steel in respect of the unit of mass. This process is difficult to control; and so, from the practical point of view, it is hardly possible to apply.

A very comprehensive research of thin-walled energy absorbing elements made of the AZ31 and ZE10 alloy has been performed by Steglich et al. [19,20]. The profile sections were made with the use of different technologies: from rolled elements of sheets joined by way of laser welding and the extrusion technology. The profiles were examined only under static conditions. The conducted studies in the aspect of the relative energy absorption (referred to the profile's mass) of the profiles demonstrated that, for small displacements, their energy absorption is much higher than that of aluminium profiles. However, for large displacements, due to the very rapid cracking of magnesium profiles, their relative energy absorption is much lower than in the case of aluminium profiles.

In the study [21], Zhou et al. performed investigations of the energy absorption of empty and foam-filled profile sections made of the DC04 steel and the AZ31B magnesium alloy in a three point bending test. The tests showed that AZ31B significantly outperforms DC04 in terms of the energy absorption and the specific energy absorption for the foam-filled beams, when the beams are subjected to bending loads at the deflection of 250 mm. With higher deflections, unfortunately, the occurrence of magnesium cracking is observed.

The presented studies have demonstrated that magnesium possesses a good energy absorption, but it is only the case with small deflections, when the deformations are low. Magnesium alloys will find their application in bodywork elements only when their energy absorption is at least close to that of steel elements. The literature provides no such comparisons, especially for elements made of magnesium alloys by means of bending and drawing. There is only scarce information on the energy absorption of elements made by the methods of extrusion or casting. And so, this study undertakes a comparison of the energy absorption of the AZ31 magnesium alloy and that of the DC04 and HC380LA steel on the example of an energy consuming model element with the use of a fabricated by bending. Additionally, the tests involved the application of aluminium foam filling the profiles in order to increase their energy absorption.

2. Test materials

As the reference material, the HC380LA steel, thickness 1.5 mm, and the DC04 steel, thickness 1.2 mm, were selected. The first steel is microscopic steel with a ferritic-pearlitic structure, used for responsible car bodywork elements (Fig. 1), whereas the ferritic DC04 steel is usually applied for elements which do not carry high loads (Fig. 2). The AZ31 alloy, thickness 1.8 mm, was purchased at Magnesium Elektron in the annealed state. AZ31 consists of a matrix α(Mg) and precipitates of the Mg21(Al,Zn)17, Mg2Si and Al8Mn5 type (Fig. 3). The horizontal direction of the presented microstructure in the Figs. 1, 2 and 3 overlap with the axis of researched simple. The chemical compositions of the examined materials are compiled in Table 1.

The aluminium foam was purchased at ALCORAS SC (small cell), produced by Alcarbon DE. The components used in the profile were cut out of a 1000 × 500 × 200 mm block, density 0,3 g/cm3, pore size 8–10 ppi (particle per inch), pore mean diameter 2,86 mm, chemical composition Al – 96%, Ca – 3,0%, Zn – 2,8%, Si-0,2%, Fe-0,1%.

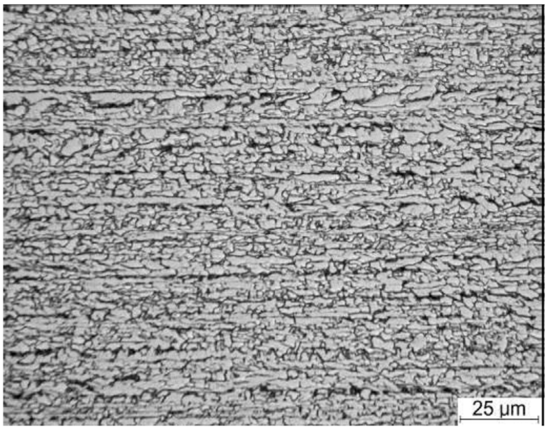

Fig. 1. Microstructure of 1.5 mm thick sheet made of HC380 steel, etched with natal; ferrite – light, pearlite - dark.