SURFACE TREATMENT INFLUENCE ON PROPERTIES OF THE HEAT TREATED LIGHT CAST ALLOYS

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Abstract

The goal of this paper is to present the results of the investigations concerning heat and surface treatment of Mg-Al-Zn magnesium alloys. Magnesium are more and more frequently applied wherever the reduction of subassembly mass is significant, desired and feasible. To improve their usable properties, laser treatment has been used, particularly laser remelting and feeding of hard ceramic particles. The surface treatment of the magnesium alloys was carried out with the use of laser surface treatment, including in particular laser feeding of hard ceramic particles into the surface of materials produced, enabling the production of a quasi-composite MMCs (Metal Matrix Composites) structure. The results of mechanical and functional properties measurements of heat treated samples confirms, that the performed heat treatment, consisting of solution heat treatment with cooling in water, as well aging with cooling in air, causes strengthening of the investigated cast magnesium alloys according to the precipitation strengthening mechanism, induced by inhibition of dislocation movement due to the influence of strain fields of the homogeny distributed precipitates. The combination of properly chosen heat treatment with the possibilities of structure- and phase composition modelling of the magnesium matrix using laser feeding provides an additive increase of mechanical and functional properties by significant grain refinement and production of micro-composite layers with homogeny distributed dispersion phases particle and characteristic zone structure.

Keywords: Manufacturing and processing; Surface treatment; Heat treatment; Laser treatment; Properties

1. INTRODUCTION

In this work there is presented in detail the research methodology, as well as technical details related to the realised technological processes of heat and laser surface treatment, as well as chemical composition data of the applied engineering materials. To meet the new requirements set by present users and in line with the current tendencies to eliminate technologies that contaminate natural environment, some universal solutions have been searched for, ones that combine inexpensive, light metal alloys and the best possible properties with appropriately selected technology of its surface processing. The appropriate interpretation of the mutual correlations between the properties and structure of the top coating and the base and its environment, enables a more extensive analysis and precise identification of the failure mechanisms that occur both on the surface and inside the material core. The gain of simultaneous development of both production technologies and processing of light materials, including in particular magnesium alloys and technologies of formation and protection of their surfaces, also seem to be the key issue here, which in consequence shall enable the maintenance of balance between the modern base material and new generation coating.

Magnesium alloys that have been used in various branches of industry for a long time are characterised with combination of low density and high strength. The above characteristics largely contributed to the application of magnesium alloys to fast moving parts, in places where rapid velocity changes occur and in products where the reduction of the final mass of the product is required. The highest demand for magnesium alloys was shown and still is by automotive industry [1-9]. In the mass production of cars the weight of elements made with magnesium alloys ranges from 7 to 21 kg. The tendency of contemporary designers to create possibly the lightest vehicles and, in consequence, with possibly the lowest fuel consumption, contributed to the use of magnesium alloys as the structural material for car wheels, engine pistons, housing of...
transmission gear and clutch, sunroofs and structures of doors, pedals, suction conduits, collectors, housings of drive shafts, differential gears, cantilevers, radiators and other [10-14]. The cast elements made with magnesium alloys find common applications in electronics as well (including without limitation housings of laptops, PDA, mobile phones, GPS, thermal imaging cameras, industrial modems, LCD screen covers, digital photo frames), in aviation, electrical engineering and for structural elements, as well as in armament, optical, sports and other industries. Currently, the global development tendencies of production of top layers of light materials mainly focus on learning and improvement of the knowledge of the scope of obtaining and depositing coatings with the use of laser beam and physical and chemical vapour deposition techniques [15-17]. The trends using multiplex techniques combining the characteristics of several methods, are also noticeable.

2. INVESTIGATION METHOD AND RESULTS

2.1 Structure of cast Mg-Al-Zn alloys in as cast state as well after heat treatment

Own investigations results concerning the structure of the cast Mg-Al-Zn alloys in as cast state as well after heat treatment are presented in references [1-12].

Both the performed investigations as well literature study confirm, that the structure of the investigated alloys, and the mechanical properties obtained, resistance to wear and resistance to the corrosion factor impact are diversified, depending on the alloy component concentration, particularly aluminium changing within the range from 3 to 12%, and on the applied heat and surface treatment of the material (Figs. 1-2). The heat treatment carried out, composed of super saturation with cooling in water and ageing with cooling in air causes reinforcement of the MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1 cast magnesium alloys, according to the mechanism of precipitation hardening reinforcement caused by stopping dislocation slip due to interaction of the stress fields of evenly located precipitations of \( \gamma \) \( \text{M}_{17} \text{Al}_{12} \) phase, which, according to the expectations [1-10], causes additional growth of strength properties, wear resistance and resistance to the corrosion factor impact. The \( \text{M}_{17} \text{Al}_{12} \) phase precipitations can also be identified as pseudo-eutectic areas (\( \gamma \) phase precipitation from the solid solution during aging, showing morphology similar to the eutectic forming from liquid phase).

Dispersion precipitations present in the solid solution in aged magnesium alloys are in most cases of privileged crystallographic orientation. Some of them (Fig. 3) present the relationships:

\[
(1\overline{1} 0 1)_{\text{a}} - \text{M}_{\gamma} (0\overline{1} 0)_{\text{M}_{17} \text{Al}_{12}} \\
[1 \overline{1} 3 0]_{\text{a}} - \text{M}_{\gamma} [1 1 1]_{\text{M}_{17} \text{Al}_{12}}
\]

compliant with those provide by S. Guldberg and N. Ryum for Mg alloys occurring without limitation in the eutectic structure of Mg alloys, containing 33% Al. In the solid solution as the matrix of cast magnesium alloys after aging there are present also clusters of dislocations in form of dislocation networks with a density much higher compared to the supersaturated state of the material. Formation of these dislocations is associated with stain generated in the matrix by precipitation of the \( \gamma \) phase particles.
Fig 1. Structure alloy MCMgAl9Zn1 after aging treatment in the temperature of 190°C for 15 hours.

Fig 2. Structure alloy MCMgAl9Zn1 after aging treatment in the temperature of 190°C for 15 hours.

Fig 3. a) bright field, b) dark field (from reflex (311) image of the MCMgAl9Zn1 alloy after aging treatment at the temperature of 190°C for 15 hours with solid solution α-Mg (matrix) and an intermetallic secondary phase γ-Mg_{17}Al_{12} in the form of needle precipitations, c) diffraction pattern of area shown in a), d) solution of diffraction pattern shown in c.
2.2 Influence of laser feeding with carbides and oxides on surface layer structure of the Mg-Al-Zn alloys

In the works [9-15] there are presented investigation result concerning structure of surface layers of the Mg-Al-Zn alloys after laser treatment. An additional improvement of the mechanical and functional properties may also be obtained as a result of reinforcement of the solid solution with dispersion phase particles of controlled amount of the analysed alloys introduced in the surface layer in the process of laser feeding and through refinement of the grains of the surface area of the material processed [9-15]. Obtaining the effect of significant refinement of the grains is possible only thanks to fast heat transport from the remelting lake through magnesium substrate of high thermal capacity and very good thermal conductivity, which, in turn, results with the increase of grain boundaries amount representing a solid obstacle for the dislocations movement and therefore reinforcement of the material.

The structure of the solidified material after laser treatment is characterised with a zone construction with diversified morphology related to the crystallisation of magnesium alloys (Fig. 4). Multiple change of crystal growth direction has been observed for these areas. In the area located on the boundary between the solid and liquid phase, minor dendrites occur the main axes thereof oriented along with the heat disposal directions (Fig. 4).

![Image](image)

**Fig 4.** Central zone of the MCMgAl3Zn1 alloy surface layer after laser treatment with TiC particles, scan rate: 0.75 m/min, laser power: 1.2 kW

The alloys with laser fed particles of vanadium carbide, their share in the remelting zone being slight, are the exception from the rule. During laser feeding, a strong circulation of the liquid metal takes place and after the laser bundle remelting – its rapid solidification. The thickness of the laser formed surface layer is of vital importance in determination of the properties, period of use and final application of the material obtained.

Three zones occur in the surface layer of the cast magnesium alloys: a zone rich with unsolved particles fed in the surface layers on the surface of magnesium alloys, remelting zone (RZ) and heat affected zone (HAZ). Both RZ and HAZ zones, depending on the concentration of aluminium in magnesium matrix, laser power applied and ceramic powder, are of different thickness and shape.

It was proven that along with the growth of the power applied, the area of occurrence of both remelting zone and heat affected zone increases, and the face of weld changes, which is also confirmed by the reference studies. The MCMgA112Zn1 alloys are characterised with the largest thickness of the surface layer, 3.59 mm, processed with laser power of 2.0 kW, with silicon carbide fed into their surface.

The power of the laser within the range 1.2-2.0 kW provides the possibility to obtain flat regular remelting welds with highly smooth surface (Fig. 5, 6).
The uneven areas and hollows in the surface layer of the Mg-Al-Zn alloys with laser fed carbide particles are produced as a result of intensive heating of the surface. Depending on the type of substrate, laser power, feeding rate and the powder applied, the surface on which high gradient of surface tension is produced, is unevenly heated, which has a direct influence on the formation of the melted material in the remelting lake. Some of the alloy and ceramic parts embedded in the remelting zone is evaporated under high temperature occurring during laser treatment, therefore the characteristic hollows appear on the remelting surface. It was also found that, disregarding the ceramic powder used, in the laser bundle power range from 1.2 to 2.0 kW the porosity of the composite layers obtained increases, in comparison to that of the raw cast surfaces of magnesium alloys.

3. CONCLUSION

Structure and properties of the investigated cast Mg-Al-Zn alloys, are varied depending on the feeding elements concentration in the material, especially aluminium ranging from 3 to 12% mass, as well as the treatment, for example in as cast state before heat treatment, after aging or surface treatment. The aging process, which was confirmed on the basis of thin foils investigations, causes clear change in the structure resulting from the uniform precipitation process of dispersed phase particles in a needle form, forming large agglomerates inside the grains, which are also present in the form of pseudoeutectic areas. The results of mechanical- and functional properties measurements of heat-treated samples confirms, that the heat performed treatment, consisting of solution treatment with cooling in water, as well aging with cooling in air, causes strengthening of the MCMgAl12Zn1, MCMgAl9Zn1 and MCMgAl6Zn1 cast magnesium alloys according to the precipitation strengthening mechanism, induced by inhibition of dislocation movement due to the influence of strain fields of the homogeneity distributed Mg17Al12 phase precipitates. Whereas the alloys with a lower aluminium content in the matrix of > 6% (MCMgAl3Zn1), where hardness measurements were also performed, are characterised by a lack of occurrence of precipitation strengthening after aging. In such a case, due to the low content of the solution compound in the matrix - in this case aluminium - causes a softening effect by precipitation of the Mg17Al12 phase in the MCMgAl3Zn1 alloy matrix after aging, what in consequence results with decrease of the aluminium atoms amount in the alloy, responsible for additional solutions strengthening.

The combination of properly chosen heat treatment with the possibilities of structure- and phase composition modelling of the metal matrix magnesium alloys using laser feeding provides an additive increase of mechanical and functional properties by significant grain refinement and production of micro-composite layers with homogeneity distributed dispersion phases particle and characteristic zone structure. Beginning from the top of the surface layer there occurs a zone rich in non-dissolved particles located on the surface of magnesium alloys, the next zone is the remelting zone (RZ), with thickness and shape closely depend on the
applied laser power as well the heat affected zone (HAZ). These zones, depending on the applied laser power and the used ceramic powder have different thickness and shape.

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LITERATURE

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