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Structural Aspects of Remelting of the AZ91 Magnesium Alloy Surface Layer

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Abstract

In this study, modification of the AZ91 magnesium alloy surface layer with a CO_2 continuous wave operation laser has been taken on. The extent and character of structural changes generated in the surface layer of the material was being assessed on the basis of both macro- and microscopy investigations, and the EDX analysis. Considerable changes in the structure of the AZ91 alloy surface layer and the morphology of phases have been found. The remelting processing was accompanied by a strong refinement of the structure and a more uniform distribution of individual phases. The conducted investigations showed that the remelting zone dimensions are a result of the process parameters, and that they can be controlled by an appropriate combination of basic remelting parameters, i.e. the laser power, the distance from the sample surface, and the scanning rate. The investigations and the obtained results revealed the possibility of an effective modification of the AZ91 magnesium alloy surface layer in the process of remelting carried out with a CO_2 laser beam.

Keywords: Structure, Magnesium alloy, Laser remelting

1. Introduction

The use of concentrated heat sources in the process of formation of both structure and properties of engineering materials constitutes an important branch of surface engineering. The application of a laser beam, plasma stream, or electric arc results in the operation of formation of the material surface layer being accompanied by rapid crystallization, which means that the structure of the remelted material is formed in conditions of a high temperature gradient, and a very short duration of solidification. The changes in both the structure and the morphology of phases triggered this way may lead to creating a material with a new spectrum of properties [1-11]. Modification of magnesium alloys surface layer is an interesting research issue of a high application potential [12-19]. These materials, rated as the most innovative and prospective metallic materials, are distinguished by low density and high specific strength. The specific gravity of magnesium alloys is by one third lower in relation to the specific gravity of aluminium alloys, and almost 80 % lower than the specific gravity of steel. Due to their properties, these materials have a series of applications in the automotive and aviation industry as well as in electronics and electrical engineering. What limits the application potential of magnesium alloys is, first of all, low resistance to abrasive wear, low hardness, and low resistance to corrosion [20-22]. The surface remelting processing is one of the solutions making it possible to obtain an improvement of magnesium alloys properties by triggering specific changes in the material structure. Taking this into consideration, the assessment of possible use of laser technologies in the process of the AZ91 magnesium alloy structure formation was undertaken.

2. Material and experimental procedure

The material used in this study was AZ91 magnesium alloy. The chemical composition of AZ91 alloy is presented in Table 1. The samples were polished with 500 grit SiC paper prior to remelting treatment and chemically cleaned with alcohol to eliminate surface contamination and dried in air.

Table 1.
Chemical composition of the AZ91 alloy

Alloy	Content of element, wt. %						
	Al	Zn	Mn	Si	Cu	Fe	Mg
AZ91	8.5	0.7	0.32	0.01	0.001	0.001	rest

The remelting of the AZ91 magnesium alloy surface layer was carried out with the use of a CO_2 continuous wave operation laser; the λ wave length was 10.6 µm, and the rated power was 5.5 kW. Argon was used as a shroud gas, and the intensity of blowing-in was 20 l/min. To improve the absorbing capability of the laser beam by the remelted surface, the alloy surface was etched with nital. The dimensions of the remelting zone were controlled by an appropriate selection of basic process parameters. It was operated with laser power Q (within the range of 900 – 1400 W), scanning rate V (within the range of 33.3 – 53.3 mm/s), and focal distance df from the sample surface (within the range of 20 – 30 mm). For multi-run remelting, the mutual overlapping of adjacent bands was about 30 % and about 45 % of the remelted band width.The structural research was carried out with the use of the Axiovert 25 light microscope and the JEOL JSM-6610LV scanning electron microscope. The investigations carried out using the light and scanning electron microscopy methods were conducted on the material in its initial state and after the remelting process. Transverse sections of the samples were mounted, polished and etched using nital solution. The microscopic investigations were complemented with an analysis of the alloy surface layer chemical composition, carried out using the EDX method. The measurements of remelting width and depth were carried out on etched transverse microsections. The remelting depth was determined in the central part of the remelting area. Each time, the measurements were carried out three times, and the value assumed for further analyses was averaged. As for the width of the remelted zone, the measurements were carried out directly at the material surface.

3. Results and discussion

The application of concentrated heat sources leads to changes not only in the surface layer of the material, but also to specific (and not always favourable) changes in the surface geometry, reflecting the heat source characteristics. Therefore, the macroscopic changes in the geometry of remelted surfaces were an important criterion for assessment of the correctness of the remelting process parameters selection in the first phase of the experiment. As a result of the investigations it was found that within the adopted remelting parameters, the risk of development of unfavourable changes in the surface geometry (loss of material, loss of band cohesion, etc.) is lowest for the treatment carried out with use of Q = 900 – 1200 W, in the full range of V (33.3 – 53.3 mm/s) and df (20 – 30 mm). An increase of the laser power above 1200 W led to considerable material loss in the remelted bands. Some examples of the macroscopic effects of magnesium alloy remelting with a CO_2 laser beam versus the applied parameters are presented in Fig. 1.

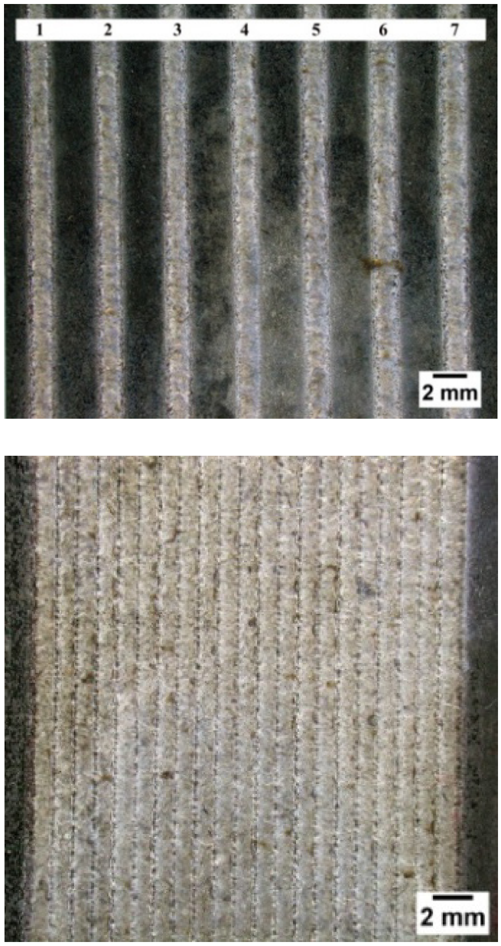
a)
b)


Fig. 1. Examples of the macroscopic effects of remelting the AZ91 alloy with a CO_2 laser beam. Remelting parameters:
a) Q=1200 W, df=20 mm, V(band 1..7)=33.3; 36.6; 40; 43.3; 46.6; 50; 53.3 mm/s;
b) Q=1200 W, df=24 mm, V=33.3 mm/s, overlap width – 30 % of the band width

Within the range of the adopted remelting parameters at which the changes in the surface geometry were acceptable, the obtained remelting depth was within the range of 0.27 – 0.4 mm. The width of the remelted bands was falling in the range of 1.12 – 1.68 mm. The analysis of the remelted zone dimensions versus the remelting process parameters allowed to distinguish a series of correlations and relations that were useful in the process of formation of the remelted zone dimensions. Namely, it was found that along with the increase of the df distance between the focus and the sample surface, the W_p band width also increases, whereas the G_p remelting depth decreases. In turn, an increase of the laser power leads to an increase of the remelting zone depth and width. To better illustrate the relations between the remelted zone dimensions and the remelting process parameters, those relations are shown in a graphical form (Fig. 2).

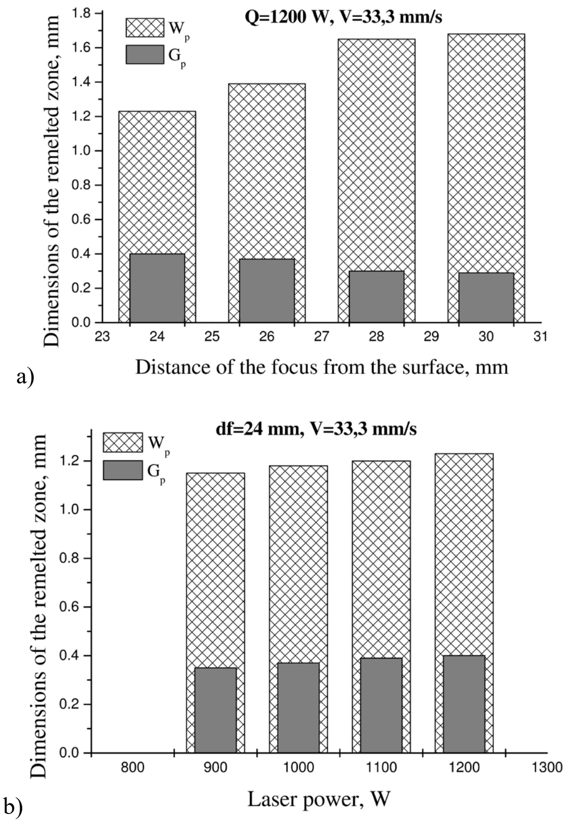


Fig. 2. Relation between the remelted zone dimensions and the distance between the focus and the sample surface (a) and the laser power (b)

The investigations of the AZ91 magnesium alloy microstructure revealed the presence of solid α-Mg solution and an α+γ eutectic mixture (γ – $Mg_{17}Al_{12}$ intermetallic compound). Also, the presence of secondary precipitations of γ phase was revealed. On the stage of microscopic investigations, the presence of a small amount of Al_xMn_y manganese phase was also found (the content of manganese phase was below the X-ray detection threshold). In Fig. 3, an example of magnesium alloy microstructure in its initial state is presented.

The next stage of the investigations was the analysis of the structure of the AZ91 magnesium alloy, which was subjected to surface treatment with a CO_2 laser beam. The observations with use of light microscopy and scanning electron microscopy revealed considerable changes in the remelted material structure when compared with the state from before treatment. In Fig. 4, examples of the remelting effect, resulting from the reaction of a CO_2 laser beam with sample surfaces, are presented. As it can be noted, the main components of those changes are: an evident refinement of the structure, and a more uniform distribution of individual phases. In the structure of the analysed samples, fine dendrites of the α phase were revealed, whereas the presence of the γ phase was found in the interdendritic spaces (Fig. 5).

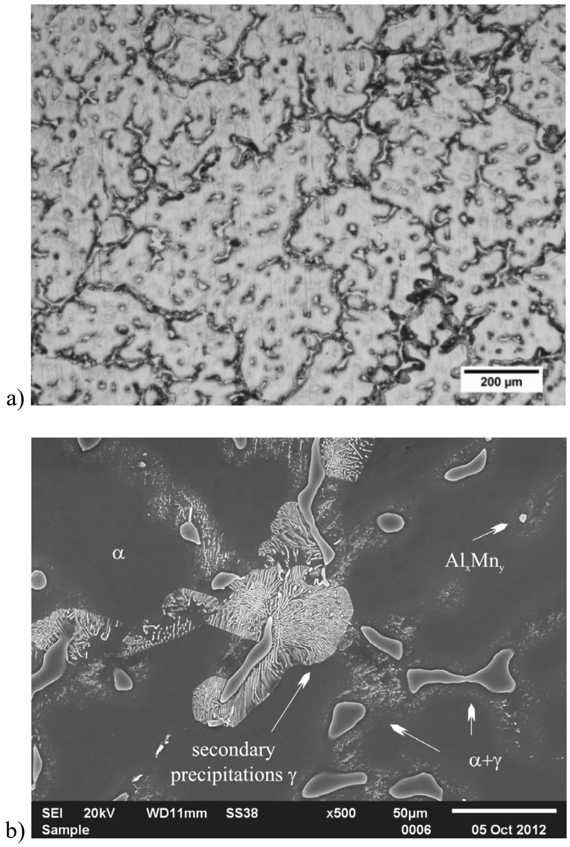


Fig. 3. The AZ91 alloy microstructure in its initial state, etched microsection; a) light microscopy, b) scanning electron microscopy

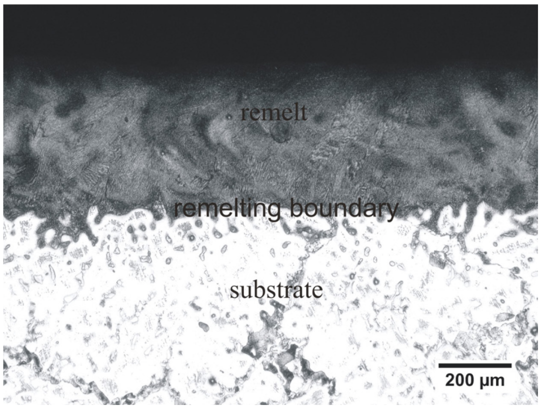


Fig. 4. The microstructure of the AZ91 magnesium alloy after remelting, etched mircosection, light microscopy

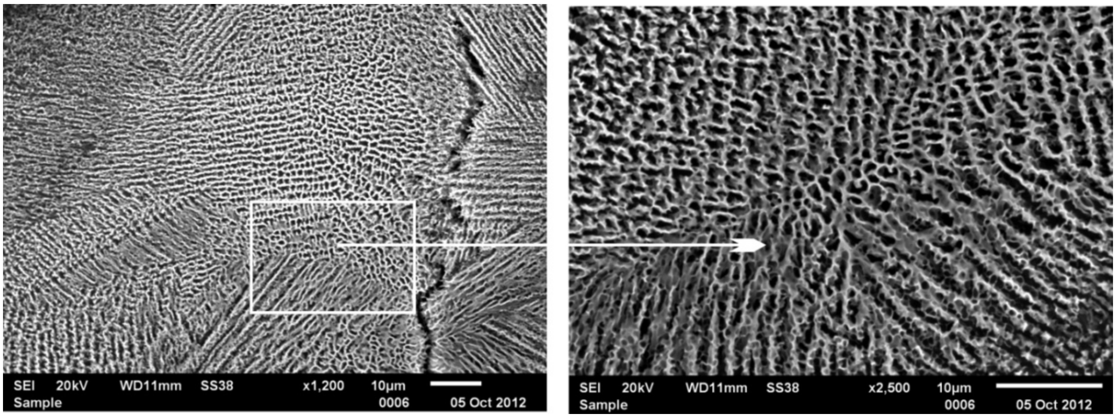


Fig. 5. Microstructures of the remelted zones at Q = 1200 W, df = 200 mm, and V = 40 mm/s; transverse etched microsections, scanning electron microscopy

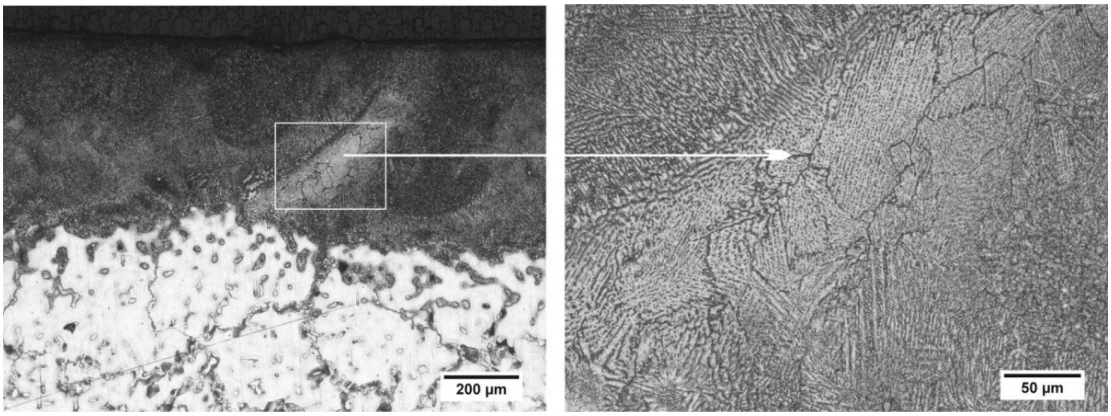


Fig. 6. The character of the microcracks in multi-band remeltings, transverse etched microsections, light microscopy

The investigations conducted within this study showed that the extent of material refinement in the remelted zone is differentiated and it varies versus the distance from the sample surface. Along with the increase of the distance from the remelting surface, the extent of the structure refinement was decreasing.

The very high speeds of heating and cooling of the material, accompanying the process of remelting with a laser beam, may lead to formation of microcracks in the zones affected by the heat source. Local presence of such material discontinuities was also found in the analysed bands. The revealed microcracks were always perpendicular to the remelting surface, and most often present in near-surface areas. The reasons of microcracks formation should be sought in the specificity of concentrated heat sources treatment. Remelting with laser beams leads to creation of a considerable temperature gradient, and the processes accompanying the treatment occur with high dynamics. Therefore, the presence of microcracks in the remelting zone is not a rare phenomenon. The occurrence of microcracks was also revealed in multi-band samples, in the areas where adjacent remeltings overlap. A characteristic network of microcracks was observed in these areas (Fig. 6). Its presence shall be explained by local concentrations of intrinsic stresses caused by repeat remelting of the material.

The main goal of the EDX investigations was to track possible changes in the chemical composition of magnesium alloy caused by the remelting process. Linear distributions of chemical elements are presented graphically in Fig. 7. The investigations focused mainly on the analysis of layout of the main alloy components, i.e. magnesium, aluminium, and zinc. Due to the tendency of magnesium and its alloys to oxidation, possible oxygen presence in the analysed areas was also taken into account in the EDX investigations. The conducted investigations showed a slight decrease of magnesium content in the remelted zone, and an increased content of aluminium at the same time. The fact of enriching the remelted zone with aluminium shall be explained mainly by more intense evaporation of magnesium than that of aluminium from the remelting area during the process. A similar effect was noted among others in studies [16, 17]. This regularity took place regardless of the adopted remelting parameters. However, the investigations did not reveal any vital differences in zinc concentrations between the remelted part and the non-remelted core. Zinc is an element which, if the ratio of Al to Zn is greater than 3:1, does not cause the formation of new phases, while it replaces part of the aluminium atoms in the phase γ [23]. Differences in zinc concentrations between the remelted part and the non-remelted core were found by the authors of study [17], who interpreted a higher loss of zinc than magnesium in the remelted zone by higher partial pressure of zinc vapours in relation to partial pressure of magnesium vapours.

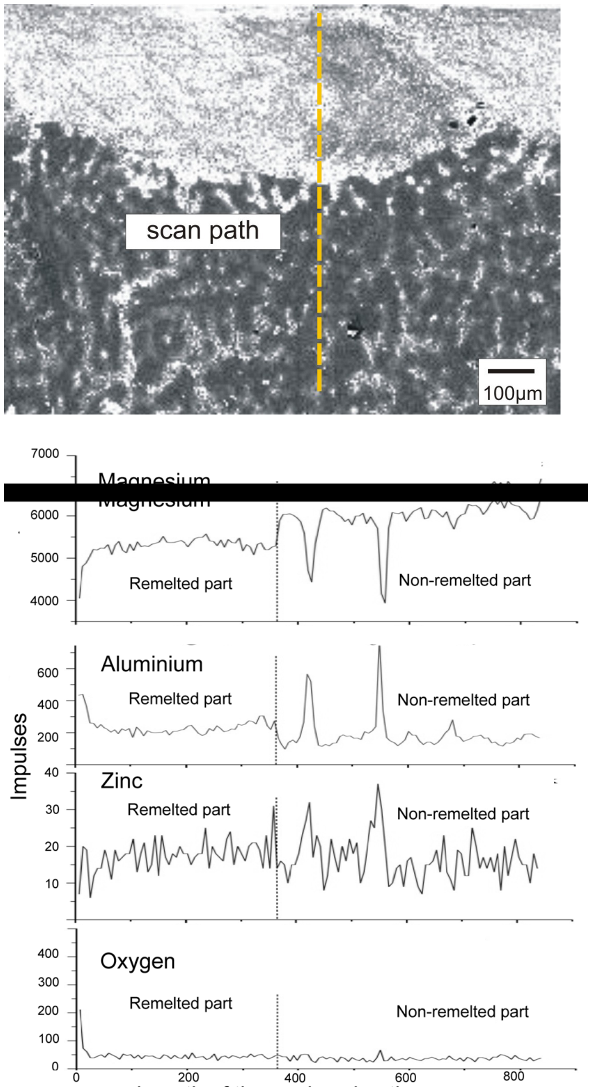


Fig. 7. Distribution of the chemical elements concentration in the layer remelted with a CO_2 laser

The EDX investigations revealed the presence of spots with increased peaks originated from aluminium and zinc, and evidently lowered magnesium content in the non-remelted material, proving the occurrence of the γ-$Mg_{17}Al_{12}$ phase in these spots. This was not observed in the remelted zone, which proves that the remelting process caused a more uniform distribution of alloy components with reference to the non-remelted material. Analogous observations were made by the authors of study [18]. Besides, the EDX investigations showed a lack of essential changes in the concentration of oxygen in the remelting area when compared with the material of the core.

4. Summary

Observations with the use of both light and scanning electron microscopy revealed considerable structural changes in the surface layer of the remelted magnesium alloy, the rate and character of which resulted from the applied treatment parameters. Therefore, the combinations of basic remelting process parameters, i.e. laser power, the distance between the focus and the sample surface, as well as the scanning rate provide the possibility to form the remelting zone dimensions and the extent of structural changes. Strong refinement of the structure and a more uniform distribution of individual phases constituted the main components of the changes triggered by the laser treatment. Regardless of the adopted remelting parameters, the presence of fine dendrites of the α-Mg phase was found in the structure of the surface layer, and the presence of the γ-$Mg_{17}Al_{12}$ phase in the interdendritic spaces was observed. The structural and morphological changes found in the analysed alloy are a consequence of rapid crystallization caused by a high temperature gradient and a very short time of the heat source influence. The EDX investigations, covering the remelting zone and the material of the core revealed an evident regularity. Regardless of the applied remelting parameters, an increase of aluminium content parallel to a decrease of the magnesium content was observed on the linear layouts of the main alloy components, i.e. magnesium and aluminium in the remelted area. It should be thought that this regularity might be caused by a more intense evaporation of magnesium than that of aluminium from the remelting zone during the processing. For zinc and oxygen, no differences in the concentration of those elements were found between the remelted and non-remelted areas. The linear distributions of magnesium, aluminium, and zinc are evidence of a more uniform distribution of the components of the structure after remelting. The conducted investigations and the obtained results showed the possibility of an effective modification of the AZ91 magnesium alloy surface layer in a remelting process carried out with the use of a CO_2 laser beam.

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