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The microstructure of the surface layer of magnesium laser alloyed with aluminum and silicon

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ABSTRACT

The surface layer under analysis was formed as a result of diffusion bonding of a thin AlSi20 plate to a magnesium substrate followed by laser melting. Depending on the process parameters, the laser beam melted the AlSi20 plate only or the AlSi20 plate and a layer of the magnesium surface adjacent to it. Two types of microstructure of the remelted layer were thus analyzed. If the melting zone was limited to the AlSi20 plate, the microstructure of the surface layer was typical of a rapidly solidified hypereutectic Al–Si alloy. Since, however, the liquid AlSi20 reacted with the magnesium substrate, the following intermetallic phases formed: Al_3Mg_2, $Mg_{17}Al_{12}$ and Mg_2Si. The microstructure of the modified surface layer of magnesium was examined using optical, scanning electron and transmission electron microscopy. The analysis of the surface properties of the laser modified magnesium revealed that the thin layer has a microstructure of a rapidly solidified Al–Si alloy offering good protection against corrosion. By contrast, the surface layer containing particles of intermetallic phases was more resistant to abrasion but had lower corrosion resistance than the silumin type layer.

1. Introduction

Recently, increasing interest has been shown in magnesium and its alloys as low density lightweight metallic materials required by the automotive and aerospace industries. Unfortunately, the applications of magnesium and its alloys are limited because of their low resistance to wear and corrosion. It should be noted, however, that both the anti-wear and anti-corrosion properties can be improved if an appropriate surface layer is created. Numerous attempts have been made to enhance the surface quality of magnesium and magnesium alloy products subjected to severe wear and corrosion.

One of the relatively simple methods is to use a diffusion coating, which can be produced at a high temperature from metallic powders [1–6] or by treatment in a molten salt bath [7,8]. The structural changes that take place at elevated temperatures, often with the liquid phase contribution, lead to the formation of a protective surface layer rich in intermetallic phases. The literature on aluminum diffusion coatings created on magnesium and its alloys was reviewed extensively by Zhong et al. [9].

The surface properties of magnesium and magnesium alloy products can also be improved using laser melting; this method is particularly important as it is suitable for increasing hardness, corrosion resistance and wear resistance at the surface while causing no change to the composition of the bulk [10–14]. Much better results can be achieved if the surface is not only melted but also enriched with alloying elements. Laser alloying and laser cladding have already been tested to modify the surface of magnesium alloys; the powdered elements added during melting have included aluminum [15–17], nickel [18] and a mixture of Al + Cu or Al + Ni [19]. Recent investigations into laser surface treatment of magnesium alloys have also focused on laser surface cladding using Al + Si powder [20–24]. The process involves simultaneously melting the surface layer of magnesium alloy and feeding Al–Si powder (12 wt.% Si) [20,21] or depositing Al–Si powder and then laser melting it to combine with the base material [22–24]. It has been found that, depending on the laser parameters and the modification technique, the microstructure of the surface layer contains Mg_2Si, $Mg_{17}Al_{12}$ [21,23] and Al_3Mg_2 [22] intermetallic phases or a solid solution of silicon in aluminum (α dendrites) and a fine-grained α + Si eutectic matrix [24]. In the latter case, no intermetallic magnesium–aluminum phases are observed after remelting.

Complex structural changes attributable to laser surface treatment require extensive investigations. The aim of this study was to determine the effect of the laser processing parameters (laser power and scan speed) on the microstructure of the surface layer of magnesium alloyed with Al and Si. The alloying elements were deposited on the magnesium surface not in the traditional powder form (a mixture of Al and Si powders) but as a solid material (a thin AlSi20 plate), which was diffusion bonded to the magnesium bulk prior to laser melting. Accordingly, the modification processes, dependent on the laser parameters, occurred in the AlSi20 layer only or they slightly affected the magnesium bulk as well. As a result, the final surface layers differed in structure and

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properties. Moreover, this method made it possible to improve the material resistance to oxidation during the laser alloying process. It also ensured a constant ratio of Al to Si during the laser surface alloying of magnesium. The experiments were conducted on magnesium with a purity of 99.9% to simplify the interpretation of the results. This, however, does not imply that the method cannot be used for surface enrichment of Mg alloys with Al and Si. The findings of the preliminary structural analysis of the as-received surface are reported in [25].

2. Experimental procedure

The test pieces (40 mm × 20 mm × 10 mm in size), sectioned from magnesium metal ingots (99.9 wt%), were diffusion bonded with 0.5–0.3 mm thick AlSi20 plates cut from unmodified ingots. The surfaces to be joined (40 mm × 20 mm) were first ground and polished using 800 grit paper and then washed with ethanol and dried. The magnesium specimens in contact with the AlSi20 plates were annealed in a vacuum furnace at 430 °C for 30 min under a pressure of 5 MPa, which ensured good bonding of the materials. The specimens were furnace cooled. The microstructure of the AlSi20 plate bonded to the magnesium substrate is shown in Fig. 1. The lateral surface of the specimen was mechanically polished and etched using standard metallographic techniques.

The laser treatment process was carried out using a TRUMPF TLF 6000 CO_2 laser system. The values of the laser power (3 kW or 5 kW) and the scan speed (0.5–1.0 m/min) were selected on the basis of the preliminary tests [25]. The lower laser power was insufficient to melt the AlSi20 plate in that range of the scan speed; however, too high a power level resulted in the occurrence of porosity of the surface layer. A rectangular laser beam spot (20 × 1 mm) was used to melt the surface layer. The specimen was moved in the direction perpendicular to the 20 mm side of the beam spot. The laser treatment was performed under argon atmosphere.

Standard metallographic techniques were employed to prepare the specimens for optical and scanning electron microscopy. The optical microscopic (OM) observations were carried out with a Nikon Eclipse MA200, while the scanning electron microscopic (SEM) analysis was performed using a JEOL JSM-5400 equipped with an Oxford Instruments ISIS 300 energy dispersive X-ray analysis system. Slices containing the surface layer and the adjoining Mg substrate were cut from the specimens near-parallel to the bonding surface of the Mg/AlSi layer and prepared for TEM. Each slice was placed in a holder at a 1–2 degree tilt and the Mg layer was carefully ground to obtain a specimen with a thickness of 0.05–0.8 mm to retain both the Mg substrate and the laser remelted surface layer. Then, a circular piece, 3 mm in diameter, was punched out of the transition region containing both Mg and the alloyed layer. The final thinning of the specimen required for TEM/STEM was performed with a Gatan model 691 precision ion polishing system (PIPS) using the ion thinning method. The structural analysis of the thin foils was conducted by means of a JEOL 2010 transmission electron microscope (TEM) equipped with a scanning transmission electron microscopy (STEM) system and an Oxford Instruments Pentafet X-ray detector controlled with INCA software. The XRD measurements were performed using a Seifert 3003 T/T X-ray diffractometer with radiation originating from a cobalt anode X-ray tube.

The microhardness tests were conducted at a load of 100 G using a Matsuzawa MMT Vickers hardness tester. The values of microhardness provided here are the arithmetic mean of the results from several (generally three) measurements.

The wear tests were carried out under dry sliding conditions by means of a block-on-ring configuration. The blocks with dimensions of 15.75 mm × 6.35 mm × 10 mm were cut from pure and laser alloyed Mg specimens. The ring (35 mm in diameter and 9 mm in width) was made of 100Cr6 bearing steel (65HRC). The blocks were prepared by grinding the surface in contact (6.35 mm × 15.75 mm) with progressively finer SiC papers to achieve a 1000 grit finish. The wear tests were conducted for surfaces in linear contact. The block specimens were pressed against the rotating ring. The testing parameters were as follows: load — 5 N, sliding speed — 0.055 m/s and total wear sliding distance — 660 m. The specimens were weighed before the test. Changes in the weight were recorded every 66 m. Each time, loose debris was removed to determine the weight loss per unit sliding distance. All the wear tests were repeated three times to ensure reproducibility of the results.

The corrosion properties of the specimens were investigated using a CHI 1130A computer-controlled electrochemical workstation. The electrochemical polarization measurements were conducted in a 3.5% NaCl solution at room temperature in a typical three-electrode cell, where the AgCl/Ag electrode was used as the reference electrode, the platinum wire acted as the counter electrode and the specimen constituted the working electrode. The specimens, which were in the form of disks and had a working surface area of 0.25 cm^2, rotated with a speed of 12 rev/s. The scanning rate was 1 mV/s. Before each polarization measurement, the working electrode was immersed into the test solution and kept for 1 h to attain the open circuit potential.

3. Results and discussion

The structure of the laser treated surface layer of magnesium is shown in Fig. 2 (OM micrographs). It is possible to obtain two types of structure of the surface layer. The processing parameters, i.e. the beam energy and the scan speed, can be selected taking into account the AlSi20 plate thickness so that only the plate will be melted with the

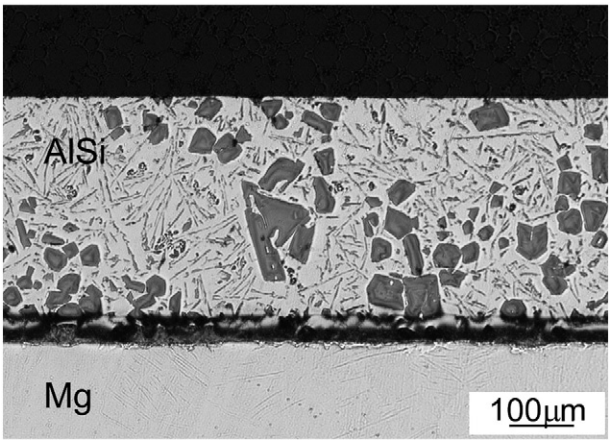

Fig. 1. Cross-sectional structure of an Mg/AlSi20 specimen annealed at 430 °C/30 min at a load of 5 MPa (OM micrograph).

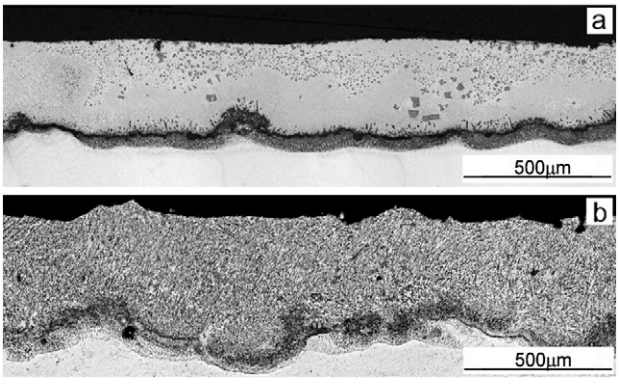

Fig. 2. Cross-sectional structure of the laser treated surface layer (OM micrograph): a) a 0.3 mm thick AlSi20 plate melted with a laser power of 3 kW and a scan speed of 0.75 m/min, and b) a 0.3 mm thick AlSi20 plate melted with a laser power of 3 kW, and a scan speed of 0.5 m/min.