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Texture characterisation of hexagonal metals: Magnesium AZ91 alloy, welded by laser processing

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Abstract

Cooled and cast magnesium AZ91 alloy was welded using a CO_2 laser. The changes in the microstructure were analysed by optical and scanning electron microscopy and X-ray diffraction. Modification of the anisotropic properties was evaluated by the characterization of the texture in the base metal, in the core of the welded zone and in the welded zone close to the surface. In the two former zones, we have not observed a texture. Laser welding only leads to a change of the grain size and a disappearance of the eutectic phase. By contrast, in the welded zone close to the surface, the laser process leads both to a finer microstructure, to a loss of the Al-content and to the presence of several texture components. In this zone, our results showed that these textures are on pyramidal $\{1\,0\,\bar{1}\,1\}$ and prismatic $\{1\,0\,\bar{1}\,0\}$ planes. Much of the explanation for such texture rests with the fact that during the laser welding, material solidifies in strong non-equilibrium conditions. The kinetics of the nucleation and the growth are partly controlled by the high-rise and high fall of the temperature and the power produced by the laser process. The nature of the texture has been explained by the presence of a columnar to equiaxed transition in the welded zone.

Keywords: Texture; Magnesium; Microstructure; Laser welding; X-ray diffraction

1. Introduction

Magnesium alloys are potentially useful as structural materials due to higher strength-to-weight ratios, heat conductivity and recyclability compared to other alloys. These alloys have attracted the interest of modern manufacturing such as the automobile, computer, communication and consumer electronic appliances industries [1]. Up until now their use has been limited due to low corrosion resistance in some conditions [2] (formation of non-protective $Mg(OH)_2$ films). However, the demand for lighter and thinner products has led magnesium alloys being machined under various conditions, especially by rapid solidification processes like welding.

Therefore, new tools have recently been developed, especially in laser welding. Laser beam welding is a well known technique, being rapid, precise and easy to operate. It is being used more and more in industry for cutting, drilling, welding and surface treatment. The use of this technique improves the corrosion properties, increases hardness and wear resistance [3]. The principal consequence of this technique, like other non-equilibrium methods, is the production by rapid solidification of a fine microstructure, an increased hardness and an extension of the solid phase (solution) of the alloying elements [1]. But in some cases, inappropriate settings can reduce the effectiveness of the use of lasers in welding applications [3,4], leading to some undesirable or uncontrollable changes. It has been reported for rapidly solidified Mg alloys, that there is a low solubility of principal elements in liquid magnesium [5], a change of the microstructure and especially a modification of the texture [6].

This latter propriety is very important in terms of mechanical behaviour and it thus interests us particularly. Indeed the texture partly controls mechanical and physical properties [7] of metals. Textures in hexagonal metals have attracted significant interest over the years because of the widespread use of some hexagonal metals and alloys, e.g. Zircaloy for nuclear reactors, Ti alloys for the aerospace and aircraft industry [6], and also Mg alloys for many applications previously described. Although to a smaller extent than in cubic materials, many studies have been done on the ultimate source of texture in hexagonal metals and in particular on the evolution of the texture and the microstructure during solidification conditions, heat treatments and deformation in magnesium alloys [6].

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The main complexity of the hexagonal structures is that their structure presents restricted slip systems and an activation of twinning [5,8]. The above mentioned studies have improved the understanding of some of the mechanisms occurring during thermomechanical treatments (growth, solidification, diffusion phenomena, texture, deformation, plasticity) [9–11]. They allowed detailed investigations into the control and optimisation of wear and fatigue properties of these metals [12–14].

The aim of this investigation is to study the changes in the microstructure of an AZ91 magnesium alloy processed by laser welding and to explore the consequences of the temperature gradient on the texture.

2. Experimental methods

The AZ91 alloy investigated was provided from Honsel Messier Foundries. This alloy has been cast and cooled in a mould. It was delivered in the form of a 3 mm thick sheet. Two plates of AZ91 alloy put edge to edge were simultaneously welded by a laser beam throughout all the thickness (Fig. 1). Experiments were conducted using a 4000 W CO_2 laser with helium as a shielding gas. The welding speed ranged from 1 to 4.25 m/min and the helium pressure was set at 2 bars. The experiments were undertaken with optimized parameters for laser welding [4].

The microsections for the structure examination were first polished with sandpaper of 450–1200 grades and then mechanically polished with 3 and 1 μm diamond oil-suspension. After polishing, the structure was revealed by 3%-nital solution, composed by 100 ml CH_3OH + 3 ml HNO_3. The microstructures and the chemical analysis in different zones of the AZ91 alloy were investigated by scanning electron microscopy (SEM) and by optical microscopy in several locations. These characterisations were completed using microanalysis (EDS analysis) for the chemical characterisation and X-ray diffraction analysis for the identification of the phases.

From the crystallographic point of view, the results were drawn from X-ray diffraction into the base metal (BM), the welded zone in the core (CWZ) and close to the surface (SWZ). The preferred crystallographic orientation was measured using a diffractometer equipped with a four-circle goniometer (Seifert MZ VI-TS). The X-ray source has a 1 mm point collimator and the goniometer is equipped of a position sensitive detector (PSD). Cr Kα radiation was used to perform the phase and the texture analysis. Generator intensity and tension levels used were 30 mA and 40 kV.

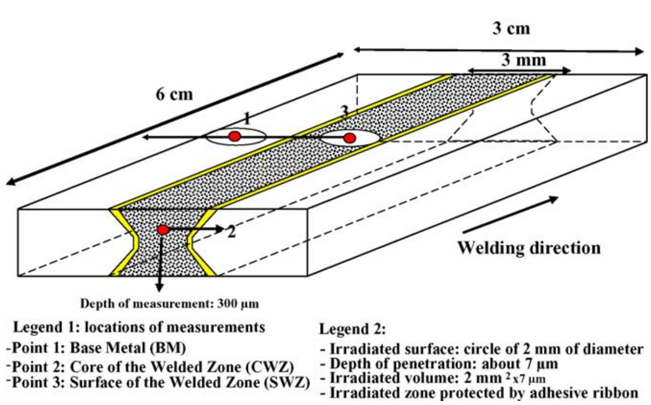

Fig. 1. Geometric parameters of the welded zone.

The texture analysis and the orientation distribution function were performed in these different zones. The surface examined by X-ray was about 2 mm^2. Geometric parameters of the sample and of the three zones analysed by X-ray are presented in the Fig. 1. The complete description of the texture in a hexagonal structure needs five pole figures. The pole figures were obtained from Bragg's peaks of the main α-magnesium phase (hexagonal structure). The pole figures corresponding to following planes were measured: $\{1 0 \bar{1} 0\}$ prismatic plane, $\{0 0 0 2\}$ basal plane, $\{1 0 \bar{1} 1\}$ pyramidal plane, $\{1 0 \bar{1} 2\}$ first order pyramidal plane, and $\{1 1 \bar{2} 0\}$ prismatic plane. The intensity is expressed as the number of counts per second (cps). Corresponding time is of 4 h by pole figure. The data was obtained as a function of the tilt Ψ angle (polar angle) ranging from 0 to 70° from the axial direction of the sample, in steps of 5° and the azimuthal angle (ϕ angle) ranging from 0 to 360° in steps of 10° from the reference direction in the plane of the sample. Poles figures were plotted using a standard stereographic projection with the welding axis (Z) and the longitudinal reference direction at the north pole as shown (Fig. 2a). The reference system selected was with the Z-axis normal to the plates (ND: normal direction). The X and Y directions were on the plane parallel to the metal and correspond respectively to the longitudinal direction (LD) and to the transverse direction (TD) (Fig. 2b).

The orientation distribution function (ODF) was calculated from five complete pole figures, using a discrete method ADC (arbitrarily defined cells method) [15–17]. The complete pole figures were calculated using Labotex software. The volume fraction of each component, g, has been calculated by integration around each orientation in the ranges given by chosen set of texture components and for each Euler angle [18]. The chosen orientations have been entered in form Euler angles: $\varphi_1 = 65.6°$, $\phi = 60.8°$, $\varphi_2 = 54.4°$ for the $\{1 0 \bar{1} 1\} \langle \bar{3} 4 \bar{1} 3 \rangle$ orientation and $\varphi_1 = 65°$, $\phi = 90°$, $\varphi_2 = 60°$ for the $\{1 0 \bar{1} 0\} \langle 0 \bar{3} 3 4 \rangle$ orientation.

3. Results

3.1. Microstructure characterisations

3.1.1. Base metal

The base metal exhibits small precipitates dispersed in the matrix but mainly located at the grain boundaries. These precipitates are β-$Mg_{17}Al_{12}$ and to a lesser degree Al_8Mn_3 (Fig. 3a). The matrix itself is heterogeneous. The mean grain sizes range from 50 to 200 μm (Fig. 3b). It is characterised by a mixture of a large primary α-Mg phase and of a (α-Mg + β-$Mg_{17}Al_{12}$) eutectic phases. This later constituent is a so-called abnormal eutectic [3] because of its lamellar shape.

The predominance of the α-Mg phase is confirmed by X-ray analysis (Fig. 4). Peaks corresponding to β-$Mg_{17}Al_{12}$ appear clearly too, but to a lesser degree (Fig. 4). Finally a third class of peaks is observed which corresponds to the superposition of the two phases, α and β (for example $2\theta = 118$ °).