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Microstructure and mechanical properties of magnesium alloy AZ31B laser beam welds

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Abstract

Microstructure and properties of a Mg AZ31B laser beam weld without filler are studied using electron microscopy, X-ray diffraction and mechanical tests. The microstructure of the weld is characterized by a narrow heat affected zone, columnar grains and precipitate coarsening in the fusion zone. Texture in the fusion zone is significantly different from the texture of the base material. The residual stress distribution observed is similar at the top and the bottom of the weld, maximum tensile residual stress values are observed in the fusion zone. Tensile tests reveal differences in the mechanical behavior of the fusion zone and the parent material, which can be related to the differences of texture and the resulting deformation mechanisms.

Keywords: Magnesium; Microstructure; Texture; Laser welding; Mechanical properties

1. Introduction

Because of their extremely low weight in combination with their good castability, workability and damping capacity [1], the use of magnesium and its alloys in specific structural applications increases, often replacing aluminium alloys [2,3]. In order to further widen the field of application of Mg alloys, joining processes such as tungsten inert gas welding (TIG), laser beam welding (LBW), friction stir welding (FSW) and electron beam welding have been applied to weld magnesium alloys [4–7]. Among these processes LBW is particularly attractive for innovative and cost-effective applications, which require high precision, and processing speed [8,9].

Although heat input in laser welding is rather low, temperature cycles, and thus recovery and recrystallization in the melt pool and heat affected zone (HAZ) produces significant microstructure changes. Theses changes include local variations of grain size, precipitate size, shape, distribution and orientation and, thus, have a strong influence on mechanical properties.

The mechanical properties of the welded joint are determined by the properties of the joint constituents (basically parent material, HAZ and fusion zone). Further, residual stresses, due to their superposition with applied stresses may have a crucial influence primarily on the fatigue strength of welds.

In Mg-alloy welds microstructure–property relations are of particular interest. The ductility of commercially used Mg alloys, due to their hexagonal close packed (hcp) crystal lattice, is limited by the number of slip systems on both basal and non-basal planes, which are activated during deformation [10–13]. In addition to dislocation slip also twinning contributes to plastic deformation of Mg alloys. Whereas the microstructure–property relations of Mg alloy sheet material have been studied intensively [1,14–17], knowledge about microstructure–property relations of welds so far is scarce. The deformation mechanisms activated during deformation of a weld depend strongly on the microstructure and texture of the fusion zone, the HAZ and the base material and the residual stress state of the welds.

It is interesting to compare the microstructure–property relations of laser beam welded joints with these obtained in friction stir welding process, where metallic bond is achieved below the melting point of the base material and, thus, avoiding diverse problems associated with the solidification process. Friction stir welded joints of magnesium alloys have received a lot of

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interest in science and technology, and so recently have been intensively studied [18–24]. A number of investigations have shown that under the influence of the FSW tool (i.e. mechanical deformation) and processing temperatures a fine recrystallized microstructure is formed in the stir zone [25]. These fine recrystallized grains in the stir zone improve the local properties of this region. It is also reported that the high dislocation density in the weld region further contributes to a more homogeneous hardness profile for FSW Mg alloys [7]. Likewise to the LBW, the integrity and performance of FSW joints of magnesium alloys can be significantly influenced by changes in the texture during the friction stir welding process. Recently, Park et al. studied the fractured surface of a FSW AZ61 Mg alloy tensile specimen and observed a strong texture (i.e., basal plane was tilted 45° from the fracture surface normal) [25]. Other examples include: micro-texture evolutions in AZ61 [26], tensile properties of AZ31B-H24 [27], and grain size/orientation of AZ31 [28] after FSW. However, the relation between the microstructure and the mechanical properties of the FSW as well as LBW has not been fully established.

Therefore, this study is conducted to investigate and establish the relationship between microstructure and mechanical properties of the laser beam welded Mg-alloy AZ31B. In particular, the effect of the different crystallographic textures in fusion zone, HAZ and base material on the plastic deformation behavior of AZ31B LBW is investigated systematically.

2. Experimental details

2.1. Material

AZ31B magnesium alloy rolled plates in original dimensions of 2 mm × 1300 mm × 1000 mm size with a nominal composition of 3.34–3.63 wt% Al, 0.45–0.53 wt% Zn, 0.27–0.29 wt% Mn, balance Mg were purchased at Sinomag company, China.

2.2. Laser beam welding

Nd:YAG Laser Beam Welding was used to join 2 mm thick rolled magnesium alloy AZ31B at the GKSS Research Center Geesthacht, Germany. Butt welds were manufactured by joining plates of 200 mm × 330 mm × 2 mm (Fig. 1) without wire on a vacuum clamping table. The welding parameters chosen were: 2.2 kW laser power, 5.5 m/min welding speed, 0 mm focal point, helium shielding gas (16 l/min on the top side and 40.7 l/min on the bottom side), no post-welding heat treatment was performed. The welding direction (WD) coincides with the rolling direction (RD) of the Mg-alloy sheets.

2.3. Mechanical tests

Standard flat tensile test specimens with gauge sections of 2 mm × 12 mm × 70 mm were extracted by spark erosion cutting from the base material and the welds both in welding direction (WD) and in transversal direction (TD) of the specimens (Fig. 1). Additional tensile tests of the welded joints in TD were performed up to different deformation levels to clarify the active deformation micromechanisms; specimens were deformed up to different deformation levels of 0.35% (sample marked as D_1), 0.59% (sample marked as D_2), 0.9% (sample marked as D_3) and 4.5% strains (sample marked as D_4), respectively.

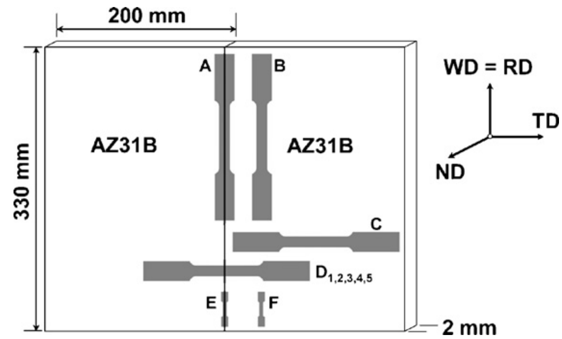

Fig. 1. Schematic overview of the configuration of the AZ31B magnesium alloy plates joined by laser beam welding in but-joint without wire. The configuration of the machined tensile samples of the welded joint and the base material is shown. WD, welding direction; TD, transversal direction; ND, normal direction.

In order to determine the mechanical properties of the fusion zone, micro-flat tensile (MFT) test samples with a gauge length of 9 mm, 1.5 mm width and 0.5 mm thickness were manufactured from the material in the fusion zone. The longitudinal direction of these MFT samples coincides with the welding direction (WD). This test technique has been specially developed at the GKSS to be able to determine the stress strain curves of narrow weld seams or regions with microstructural gradients (e.g. HAZ) [29]. Microhardness measurements were performed across the weld cross-section according to ASTM E384-99 standard at three different levels in plate thickness.

2.4. Metallography and microscopy

Microstructure characterization was carried out by optical microscopy, scanning (SEM) and transmission electron microscopy (TEM).

The specimens were sectioned, ground, polished using lubricant without water and etched using acetic–picral solution (10 ml acetic acid + 4.2g picric acid + 10 ml H_2O + 70 ml ethanol). For SEM investigations, after polishing, surface oxides on the specimens were removed in a Gatan Precision Etching Coating System (Gatan 862).

EBSD texture analyses were performed using a SEM with Shottky field-emission gun and an EDAX/TSL electron back scattering diffraction (EBSD) system equipped with a Digit view camera. The EBSD measurements in the fusion zone and the base material covered sample areas of 1500 μm × 350 μm. Several pole figures and inverse pole figures were generated from each grain map determined.

For transmission electron microscopy (TEM) samples were first mechanically ground to a thickness of 300 μm, then 3 mm diameter discs were blanked of the base material and fusion zone (disc out-of-plane direction is perpendicular to the normal direction (ND) of the AZ31B sheets). Mechan-