Residual Stresses in Joining Mg-alloy by Laser Beam Welding

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Magnesium and its alloys are the lightest of all structural metals available. Due to their many attractive properties, such as low density, high strength to weight ratio, good castability, hot formability, high damping capacity and recyclability, magnesium alloys have been successfully used in various structural applications [1]. Laser beam welding (LBW) is an important industrial joining process due to its high precision and processing speed, deep penetration, localized low heat input and the consequently narrow heat affected zone (HAZ) and low distortion of the welds [2, 3].

Welding is one of the most significant causes of residual stresses (RS) in industrial components due to thermal expansion mismatch, when a metal is subjected to a thermal cycle beyond its melting point. After welding the fusion zone cools down and contracts more than the neighbouring parent material, leaving RS. These thermal RS often significantly influence the mechanical performance of welded constructions, e.g. the fatigue strength. The aim of the present investigation is to correlate the residual stress state with the microstructure with respect to the mechanical properties of the LBW Mg-alloys to formulate strategies for a process optimization.

In the present work a 2.2 kW Nd:YAG LBW was applied to join thin rolled sheets and extruded L-shaped profiles of the Mg-alloys AZ31, AZ61 and AZ80 in two different configurations: similar butt-joint and single overlap (AZ31/AZ31) (Figure 1) and dissimilar single overlaps (AZ31/AZ61, AZ31/AZ80) (Figure 2). The welds were produced at GKSS Research Centre in Geesthacht, Germany.

SEM studies shows that the LBW has narrow fusion zone (0.7-1mm), narrow heat affected zone (HAZ) (20µm) and is free of cracks. Only a few small pores have been found. The quantitative analysis of the microstructure using the EBSD technique shows that, from the base material towards the fusion zone, fine and elongated grains are formed during the welding process near to the fusion line. The grain size distribution is similar for the base material and for the fusion zone (7µm ± 1µm), however, the crystallographic texture appears to be completely different (Figure 2).

Owing to the narrow fusion zone and HAZ, residual stress (RS) analysis needed to be carried out using synchrotron X-ray diffraction on the experimental station G3 at Hasylab in Hamburg, Germany using sin²ψ technique [4] with the Mg (112) reflection. The radiation energy used was 6.9keV and the beam size amounted to 1.5×1.5mm. The measurements were carried out within a sin²ψ range of 0 to 0.8 using equally spaced of 0.2. A line profile across the top side of the joints (±30mm from the weld centreline) was analyzed.
in the transversal and longitudinal direction with respect to the weld seam. The RS were also analyzed 50µm beneath the top side using the same conditions.

The measured residual stress (RS) distribution along the LBW joint is homogeneous. Two RS line profiles measured at different positions exhibit exactly the same trend for both sample directions analyzed. The RS profiles are typical for fusion welding processes (Figure 3), i.e. in the longitudinal direction (parallel to the welding direction) tensile RS arise in the fusion zone as well as in the HAZ due to the thermal contraction of the weld seam at the end of the cooling process and balancing compressive stresses are formed in the base material.

The RS are significantly higher in the longitudinal direction than in the transversal direction. A maximum tensile RS of about 40MPa is found for the weld centreline in the longitudinal direction, which corresponds to less than one third of the typical yield strength (200MPa) [1] of the alloy AZ31. The longitudinal stresses change gradually into compressive RS along the HAZ. Far away from the weld centreline, the compressive RS decrease continuously until the initial residual stress state of the rolled sheets is reached. In contrast, only low RS appear in the transversal direction and the maximum compressive RS in the welding centreline amounts to -20MPa.

On the TOP side of the single overlap joints, i.e. on the AZ31 Mg-alloy sheet, the results (Figure 4) reveal residual stress (RS) profiles, which are similar to those found for the similar AZ31 butt-joints. Thus, in the longitudinal direction (parallel to the welding direction) tensile RS arise in the fusion zone as well as in the HAZ due to the thermal contraction of the weld seam at the end of the cooling process. Consequently, balancing compressive stresses are observed in the base material. The RS profiles are, however, asymmetric with respect to the weld centerline, since the weld lines are very close to one of the edges of the Mg-sheet. This leads to a steep increase of RS from the left side (x = -4.0mm) towards the weld pool (x = 0.0mm).

Further RS analyses using neutron diffraction are required in order to assess the RS gradients towards the sheet to profile interface as well as the RS state within the Mg alloy profiles. Fatigue tests are also underway.

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