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ScienceDirect
Trans. Nonferrous Met. Soc. China 21(2011) 1917−1924
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Effects of laser beam welding parameters on mechanical properties and microstructure of AZ31B magnesium alloy

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Received 18 October 2010; accepted 31 December 2010

Abstract: The effects of laser beam welding process parameters such as laser power, welding speed and focal position on mechanical properties and microstructure of AZ31B magnesium alloy were studied. Nine joints were fabricated using different levels of laser power, welding speed and focal position. Tensile properties of the welded joints were evaluated and correlated with the weld zone microstructure and hardness. It is found that the joints fabricated using a laser power of 2 500 W, welding speed of 5.5 m/min and focal position of −1.5 mm yield superior tensile properties compared with the other joints. The formation of very fine grains in weld region, higher fusion zone hardness and uniformly distributed finer precipitates are the main reasons for superior tensile properties of these joints.

Key words: laser beam welding; magnesium alloy; tensile properties; laser power; welding speed; focal position

1 Introduction

Greater demand for reduced emissions and better fuel economy in passenger vehicles are the driving forces behind expanding the use of magnesium alloys. Environmental conservation is one of the principal reasons for the focus of attention on magnesium to provide vehicle mass reduction, CO_2 emission and fuel economy. Mass reduction through magnesium applications in the automotive industry is the effective option for decreasing fuel consumption and CO_2 emissions. The components that are made of magnesium alloys have better strength-to-density ratio, ductility and energy absorbing characteristics. Wrought alloys are currently used to a very limited extent, due to lack of suitable alloys and some technological restrictions imposed by the hexagonal crystal structure of magnesium. With the development of new grades of alloys, manufacturing techniques such as welding play an important role in exploiting the new fields of applications [1].

Gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) processes are the two important conventional fusion welding methods applied for joining magnesium alloys, especially for the removal and repair of casting defects. However, low welding speeds, large heat affected zone (HAZ) and fusion zone (FZ), high shrinkages, variations in microstructures and properties, evaporative loss of alloying elements, high residual stress and distortion of arc-welded joints have caused attention to be drawn towards laser beam welding (LBW). The advantages such as the low and precise heat input, small HAZ, deep and narrow FZ, low residual stress and weldment distortion, and high welding speed due to high power density, make the laser beam welding one of the best welding process to join magnesium alloys [2−6]. Crack-free laser welded joints with low porosity and good surface quality can be obtained for some magnesium alloys, in particular wrought material, using appropriate laser processing parameters [7].

Recently, some studies were carried out to evaluate the bead geometry and mechanical properties of laser beam welded magnesium alloys. MARYA et al [8] examined the weld morphology of laser beam welded AZ91 and AM50 magnesium alloy joints. For both alloys, important characteristics of the weld beads such as depth, width, crown height (hump), and surface ripples were analyzed as a function of the welding parameters, most particularly the heat input. ZHU et al [9] examined the defects formation during the diode and CO_2 laser beam welding of AZ31 magnesium alloy. They concluded that

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DOI: 10.1016/S1003-6326(11)60950-3

diode laser welding produced significantly less porosity than the CO_2 laser welding. Microstructure and mechanical properties of laser beam welded AZ31B magnesium alloy were studied by COELHO et al [10]. They identified that the heat affected zone was very narrow, no grain coarsening was observed adjacent to the fusion line and microhardness values were almost uniform across base material HAZ and FZ. The effect of process parameters on the weld appearance and joint properties of laser beam welded AZ61 magnesium alloy was investigated by WANG et al [11]. They concluded that the refined grain structure was expected to contribute to the excellent mechanical properties of AZ61 weld beads. Most of the published papers have focused on analysing the weld bead formation in laser beam welding of magnesium alloy. Hence in this investigation, a systematic study was planned to evaluate the influence of welding parameters on mechanical and metallurgical properties of laser beam welded AZ31B magnesium alloy.

2 Experimental

The rolled plates of AZ31B magnesium alloy with 6 mm in thickness were cut into the required size (300 mm×150 mm) by machining process. Square butt joint configuration, as shown in Fig. 1, was prepared to fabricate the joints. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the joints with the CO_2 laser welding machine (Make: Rofin slab; capacity: 6 kW). Argon gas was used as shielding gas with constant flow rate of 20 L/min. The chemical composition and mechanical properties of the base metal are presented in Tables 1 and 2, respectively. LBW process parameters used to fabricate the joints are presented in Table 3. The butt joints with high-quality can be obtained by the optimized processing. They are full penetration and lack of evident macroscopic porosities and inclusions in the fusion zone. The spot size and power density for various focal positions are presented in Table 4.

Figure 2 shows the optical microscope (OM) and scanning electron microscope (SEM) images of base metal. It basically contains coarse grains along with appreciable amount of sub-grains (Fig. 2(a)). From Fig. 2(b), grains with $Al_{12}Mg_{17}$ intermetallic compounds can be found. The $Al_{12}Mg_{17}$ intermetallic compounds are quite coarse and the distribution is non-uniform in the base metal.

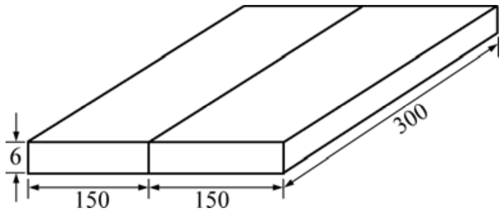

Fig. 1 Square butt joint configuration (Unit: mm)

Table 1 Chemical composition of base metal AZ31B magnesium alloy (mass fraction, %)

Al	Mn	Zn	Mg
3.0	0.20	1.0	Bal.

Table 2 Mechanical properties of base metal AZ31B magnesium alloy

Yield strength/MPa	Ultimate tensile strength/MPa	Elongation in gauge length of 50 mm/%	
171	215	14.7	
Reduction in cross-sectional area/%	Notch tensile strength/MPa	Notch strength ratio (NSR)	$HV_{0.49}$
14.3	192	0.89	69

Table 3 LBW process parameters used to fabricate joints

Joint number	Laser power/W	Welding speed/ $(m\cdot min^{-1})$	Focal position/ mm	Heat input/ $(J\cdot mm^{-1})$
1	2 500	5.0	−1.5	30
2	3 000	5.0	−1.5	36
3	3 500	5.0	−1.5	42
4	2 500	4.5	−1.5	33
5	2 500	5.0	−1.5	30
6	2 500	5.5	−1.5	27
7	2 500	5.0	0	30
8	2 500	5.0	−1.5	30
9	2 500	5.0	−3.0	30

Table 4 Spot size and power density for various focal positions

Joint number	Focal position/mm	Power/W	Spot size at work piece/mm	Power density/$(W\cdot mm^{-2})$	Spot size at exit of laser/mm	Focal length of lens/mm
1	0	2 500	0.180	98 244	24	300
2	−1.5	2 500	0.299	35 605	24	300
3	−3.0	2 500	0.418	18 218	24	300