Vacuum 86 (2012) 1262–1267

Contents lists available at SciVerse ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Influence of focusing thermal effect upon AZ91D magnesium alloy weld during vacuum electron beam welding

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ARTICLE INFO

Article history:
Received 16 July 2011
Received in revised form
1 November 2011
Accepted 9 November 2011

Keywords:
Magnesium alloy
Vacuum electron beam welding
Focus state
Heat input
Alloying element

ABSTRACT

The influence of focusing thermal effect upon the weld shape, microstructure and alloying elements distribution in the welded joints during vacuum electron beam welding on AZ91D magnesium alloy was studied. The results show that the focus state affects the offset of DOF, and further significantly affects the actual welding heat input in the process of vacuum electron beam welding. The sharp focusing state is characterized with higher welding energy density, but the welding energy density of defocusing state is lower. Therefore, the welding process with sharp focusing state and smaller calculation welding heat input can obtain the same weld penetration as the welding process is the conditions of defocusing state and larger calculation welding heat input. And the welding process of sharp focusing state and smaller calculation welding heat input can induce more strongly burning loss of Mg element than the conditions of defocusing state and larger calculation welding heat input. Then, which will affect the distribution of alloy elements in weld seam.

1. Introduction

To the fusion welding taking the energy beam as welding heat source, the shape variation of energy beam can often attain the purpose of changing the energy density distribution of welding heat source, thus improve welding efficiency or the welding quality. Many studies have made deep discussions about this [1–3]. Luo et al. developed a method of loading a longitudinal magnetic field during gas tungsten-arc (GTA) welding. On the premise of the total energies of GTA welding arc are not increased, the magnetic fields are used to change the thermal distributions of GTA, so as to get a better welding results [4,5]. In vacuum electron beam welding (VEBW), on the premise of without changing the other welding parameters, adjusting the focus coil current can change the welding heat source shape of electron beam, such as the beam spot size and the DOF offset, thus change the energy density distribution of electron beam [6].

The heat source of vacuum electron beam welding is characterized with a high energy density and can get a large aspect ratio weld and narrow weld HAZ (Heat Affect Zone) [7]. But the welding process of VEBW is very complex, so that the welding quality depends strongly on the design of welding parameters. A lot of researches, such as characteristics of electron beam heat source and the influence of beam current, accelerating voltage, welding speed, heat power and other process parameters upon VEBW quality, has been carried out [8–10]. In the thermal effect study of VEBW, we often tend to focus toward the direct process parameters of thermal effect, such as beam current and accelerating voltage, and ignore the influence of other indirect factors upon the thermal effect, such as the electron beam focusing state, which can affect the characteristics and the heat efficiency of welding heat source.

In this study, the focus coil current affecting the focusing state of electron beam is discussed, actually, which has so significant impact on the welding heat input that the effectiveness of conventional method of calculating the heat input is loss, thus affects the thermal effect of welding.

2. Thermal effect of focus condition

The effective energy of electron beam heat source applied to the materials depends on the welding heat input, that is the composite effect of the electron beam power interacted with the affecting time. Heat input will alter the process of melting and the evaporation effects of the materials, which influence upon the weld shape and microstructure is very significant. Many studies have explored this problem. It is generally considered that the accelerating voltage, beam current and welding speed are the basic parameters to control welding heat input. However, the focus coil

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0042-207X/$ – see front matter
doi:10.1016/j.vacuum.2011.11.011

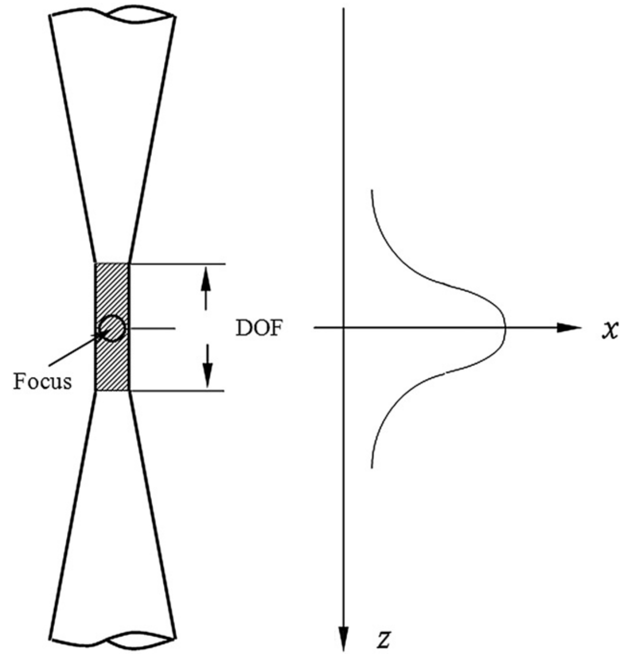

Fig. 1. Schematic diagram of the DOF of electron beam.

current of electron beam determines the focusing state, but also determines the actual energy density distribution of the electron beam affecting on the materials, and alters the welding heat input. Shown in Fig. 1, there is a near-field zone around the focus point of electron beam focused by a high-voltage, which is called the depth of field (DOF) of electron beam. In this region, the electron beam has little change in the diameter and has a maximum energy density distribution. When the other basic parameters of electron beam are unchanged and the DOF of the electron beam affecting on materials deviates along the depth direction, the energy density of electron beam decreases and the thermal effect is greatly reduced with the increasing of electron beam radius and the strengthening of electron scattering. The DOF offset depends on the focusing state. Therefore, the electron beam focusing state is an important factor to affect the actual heat input. Fig. 2 presents the relative positions of DOF under the different focusing conditions, which are sharp focusing state and defocusing state, and the corresponding weld shape of magnesium alloy. It can be seen that, when the DOF locates on the lower surface of materials slightly, that is a sharp focusing state. The beam spot diameter acting on the surface of the materials is the smallest. So the electron beam acting on the materials gets the maximum of the energy density, the maximum of the welding thermal effect and the largest weld penetration. In addition to this, the beam spot diameter of the electron beam is larger as the DOF deviation from the surface of the materials is greater, the focus point is located either above the surface of the materials or below the surface of the materials. Therefore, the energy density of the electron beam acting on the materials is smaller. The thermal effect is weakened and a smaller weld penetration is gotten.

3. Experimental details

Test materials used are AZ91D magnesium alloy with 11 mm thick. The alloy compositions are shown in Table 1. AZ91D is a typical cast magnesium alloy. Al is the major alloying element of this magnesium alloy. Fig. 3 shows the microstructure of the base metal of AZ91D magnesium alloy. The large block of grain is the first eutectic α-Mg solid solution. A large quantity of β-$Mg_{17}Al_{12}$ eutectics produced by non-equilibrium solidification distribute around the grain boundary in the form of irregular lumps. The eutectic α-Mg attaches to the original eutectic α-Mg phase, and encircles the β-$Mg_{17}Al_{12}$ eutectic. If the cooling rate is slow enough, the over saturation region of Al composition will precipitate the

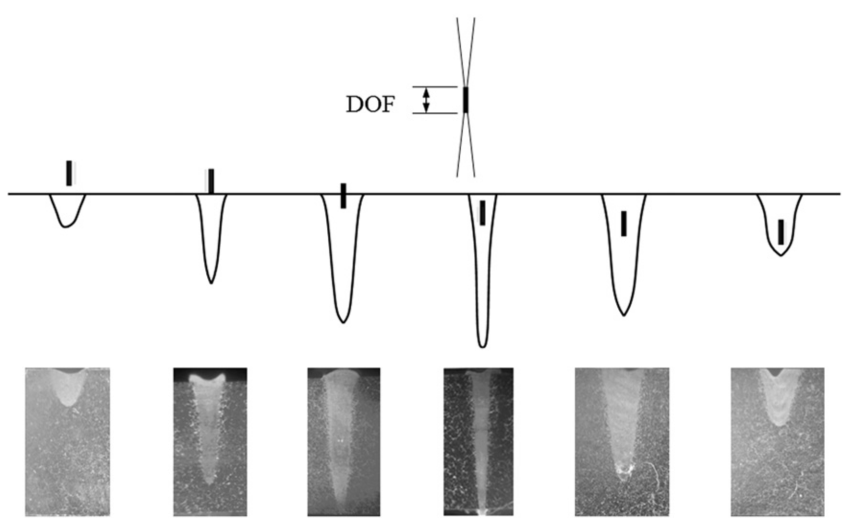

Fig. 2. Influence of DOF offset on the weld shape.

Table 1
Chemical composition for AZ91D cast alloy (wt%).

Materials	Element									
	Mg	Al	Zn	Mn	Si	Cu	Fe	P	Pb	Be
AZ91D	90.3148	8.8550	0.5474	0.2600	0.0143	0.0012	0.0041	0.0012	0.0017	0.0003