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Weldability of iron-based powder metal materials using pulsed plasma arc welding process

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ABSTRACT

The objective of this study was to investigate the weldability of three different iron-based powder metal alloys (pure Fe, Fe–Ni and Fe–P–Ni alloys) using the keyhole pulsed plasma arc process (PAW). The work undertaken included the effect of pulsed welding parameters on the microstructure and mechanical characteristics of the welded joints. Microstructural examination results revealed that for the pure Fe and Fe–Ni alloys, the fusion-welded zone was free of porosity and cracks. However, the Fe–P–Ni powder metal alloy with a high level of phosphorus content (0.25 wt%) and 7 mm thickness specimen presented solidification cracks and tunneling failure as a result of high shrinking stress due to the higher volume of molten metal and faster cooling rates. This problem was overcome by reducing the thickness of the specimen to 4 mm. No significant differences were noted in the hardness profile of the welded specimens, which warranted a heating affected zone with no excessive hardness. Furthermore, tensile tests showed that the failures of the specimen occurred always in the base metal with tensile strength slightly superior to the value of unwelded samples. Therefore, this study indicates that iron-based powder metal alloys can be successfully joined by keyhole pulsed PAW process without filler metal.

1. Introduction

Powder metal (P/M) iron-based alloys have been extensively used as structural parts in mechanical components due to their good balance between ductility and tensile strength, good magnetic properties and corrosion resistance. Such P/M components have emerged as attractive candidates for replacing wrought alloys in many applications due to their low cost and high performance (Chawla and Deng, 2005; Sudhakar et al., 2000). However, continued efforts are demanded for obtaining optimum combination of properties to withstand various service conditions. Joining is one of the important mechanical requisites expected of P/M parts in actual service conditions like in structural and automobile parts and many of these parts need to be joined to one similar part or dissimilar materials as integrated components (Hamill, 1993; Jayabharat et al., 2007). The joining of dissimilar metal is generally more challenging than that of similar metals because of difference in the physical, thermal, electrical, mechanical and metallurgical properties of the parts to be joined. In order to take full advantage of the dissimilar metals involved, it is necessary to produce high quality joints between them (Jayabharat et al., 2007).

The welding of powder metal parts is different from the welding of rolled or cast parts due to the presence of porosities in their microstructure. The nature of the porosity is controlled by several processing variables such as green density, sintering temperature and time, alloying additions, and particle size of the initial powders. In particular, the fraction, size, distribution and morphology of the porosity have a profound impact on mechanical behavior, especially in components

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under welding conditions (Chawla and Deng, 2005). Porosity volume changes the properties of thermal conductivity, thermal expansion and hardenability of the powder metal material which may result excessive shrinkage and subsequent cracking in the base material, due to changes in both the heat transfer mechanism and thermal conductivity. As a result of the influence of the porosity volume, the welding process characteristics are significantly affected (Hamill, 1993; Kurt et al., 2004; Thümmler and Oberacker, 1993).

Fusion and solid-state welding methods are used successfully to join powder metal parts. According to (Hamill, 1993; Jayabharat et al., 2007; Kurt et al., 2004) low-density powder metals (<6.5 g/cm^3) have to be joined by solid-state welding processes like diffusion bonding, sinter bonding, friction welding, adhesive bonding and brazing. Recent studies have demonstrated also the feasibility of welding low density sintered steel P/M using gas tungsten arc welding (Jayabharat et al., 2007). Fusion-welding methods are preferred in the welding of medium and high-density (>7.0 g/cm^3) powder metals. Welding processes such as gas tungsten arc welding and shielded metal arc welding has been cited as feasible possibilities to join P/M structural parts (Jayabharat et al., 2007; Kurt et al., 2004). Plasma arc welding (PAW) process has also the possibilities to be used in this field, however literature related to this is sparse.

Plasma arc welding (PAW) is very similar to conventional gas tungsten arc welding in the sense that the plasma jet is used as a source of intense heat to melt the material to be welded. When the tungsten electrode locates within the torch nozzle and the orifice, the arc is restricted and the highly constrained plasma jet can displace the molten metal in the weld pool to form a keyhole completely through the base metal (Raymond and Slatter, 1998; Martikainen and Moisio, 1993; Zhang and Liu, 2007). The keyhole processing mode applied in plasma welding is generally used in single-pass welds requiring increased and full penetration, narrower weld beads, a minimized heat-affected zone (HAZ) and minimal distortion. Additionally, an increased possibility of using a square groove, reduced need for filler material resulting in a substantial increasing in productivity and final quality of the welding can be obtained. PAW is conventionally carried out using one of two different current modes, namely a continuous current mode or a pulsed current mode. Despite the advantages mentioned above, the conventional keyhole PAW (continuous current) process can be detrimental to joining powder metal alloys due to its high arc power density. Through the use of pulsed parameters, it is possible working with high current peaks without increasing the average heat input (energy) to the base material which enables itself as a good choice for welding powder metal alloys. Authors have related that the use of pulsed current on conventional mode has been associated with a finer structure due to an increase of the melt pool agitation and greater strength weldments under impact loading (D'Oliveira et al., 2006; Lee et al., 2007).

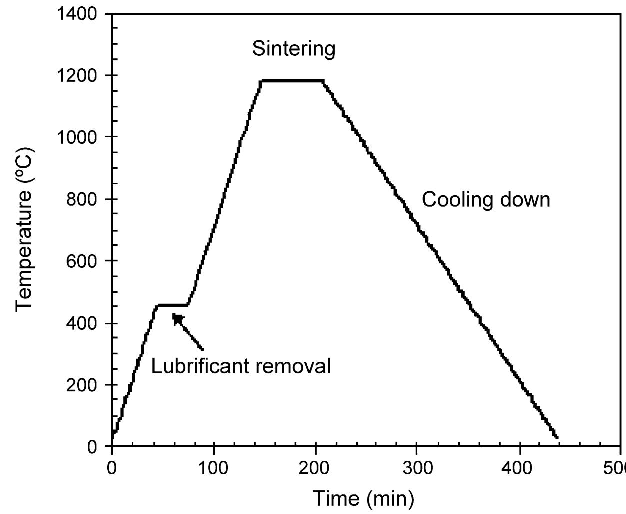

Fig. 1 – Thermal cycle of sintering.

The present work was formulated in order to investigate the feasibility of joining powder metal parts. This study examined the use of a pulsed plasma arc welding process through the use of keyhole processing mode in the weldability of powder metal iron-based alloys (pure Fe, Fe–Ni and Fe–P–Ni) and its effect in the microstructural and mechanical characteristics of the welded joint.

2. Materials and experimental procedure

The materials involved in the present study were three different sintered powder metal alloys which compositions and features are given in Table 1.

The powder metals were first mixed with lubricant (zinc stearate) according to the chemical composition of the alloys given in Table 1 to produce a homogeneous mixture of ingredients. After that, the mixed powder of each alloy was compacted to about 90% relative density in a press (green compact) and then sintered in a pure hydrogen atmosphere according to the thermal cycle shown in

Table 1 – Specification of the powder metal alloys

P/M alloys	Chemical composition (wt%)			Raw material		
	Fe	Ni	P	Powder	Particle size range (μm)	Apparent density (g/cm^3)
Pure Fe	99.90	–	–	Sponge iron	60–150	2.8–3.1
Fe–Ni	96.00	4.00	–			
Fe–Ni–P	95.75	4.00	0.25	Carbonyl nickel	3	–
				Pre-alloyed Fe–P (20 wt% P)	<44	–