WELDABILITY OF POWDER METAL IRON MATERIALS BY STUD WELDING

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Abstract

In this study, Fe powders with average particle size of 60 µm and 1wt.% graphite have been blended and the samples uniaxially pressed in 25x25x5 mm dimensions at 250 MPa pressure. Compacted samples were sintered at 1000 °C, 15, 25 and 35 minutes in atmospheric environtment. Steel studs for Ø 5 mm were welded 100, 120 and 140 V. Microstructural analysis and hardness tests are performed to the welded samples and investigated the welding parametres and sintering time to the weldability.

Key Words: Powder metal iron, sintering time, stud welding, weldability.

1. Introduction

In recent years, microwave processing has been increasingly applied for synthesis of materials by sintering. The use of microwaves in ceramic sintering started in 1967, but microwave sintering of metallic powder materials has been a relatively new and surprising development in recent years .

Many research efforts were focused on microwave sintering of ceramics. Physical, mechanical, electrical, thermal properties, and microstructures of many types of microwave-sintered ceramics and hard metals were studied. In recent years, some researchers have studied microwave sintering of metal powder materials [4].

Powder metallurgy is a process whereby a material powder is compacted as a green body and sintered to a net shape at elevated temperatures about 0.6–0.8Tm. There are challenging demands from the PM industry for new and improved sintering process with finer microstructures and enhanced physical and mechanical properties. This is where the microwave technology is found to be advantageous.

Microwave energy is a form of electromagnetic energy with the frequency range of 300MHz to 300 GHz. Microwave heating is a process in which the materials couple with microwaves, absorb the electromagnetic energy volumetrically, and transform into heat. This is different from conventional methods where heat is transferred between objects by the mechanisms of conduction, radiation and convection.

The fundamental difference between microwave sintering and conventional sintering is in the heating mechanism. The temperature profile for both methods is shown in Figure 1. For conventional sintering, heat is generated by heating elements and transferred to samples via radiation, conduction, and convection. In microwave sintering, however, the materials themselves absorb microwave energy, and then transform it into heat within their bodies. The microwave heating presents a potential economical sintering. This heating mechanism is advantageous due to the following facts: enhanced diffusion processes, reduced energy consumption, very rapid heating rates and considerably reduced processing times, decreased sintering temperatures, improved physical and mechanical properties, simplicity, unique properties, and lower environmental hazards. These are features that have not been observed in conventional processes [1].

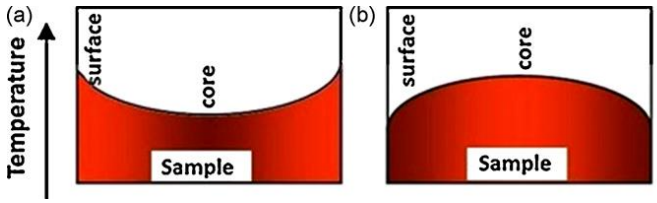


Figure 1. Temperature profile within the sample in: (a) conventional heating, (b) microwave heating [1].

High heating rates in conventional furnaces result in a thermal gradient within the compacts and lead to compact distortion and inhomogeneous microstructure. One of the techniques to achieve relatively homogeneous as well as fast sintering in compacts is through microwave heating. Microwaves directly interact with the particulates within the pressed compacts rather than being conducted into the specimen from an external heat source, thereby provide rapid volumetric heating. This reduces processing times and results in energy saving.

Microwave heating has been suggested as a means of reducing the time of preparation and the energy consumption as its effect originates from the natural ability of certain substances to efficiently absorb, and then to transform electromagnetic (radiation) energy into heat. If sufficient heat is generated at a local level, chemical reactions may be initiated at a very rapid rate. In addition, the higher sintering temperature as can be prepared by microwave sintering, can significantly shorten the sintering time leading to efficient processing.

It is well known that sintering process consists of densification stage and grain growth stage. The densification rate strongly depends on the diffusion of ions between sample particles, and the grain growth rate is mostly determined by the grain boundary diffusion. Dube *et al*. have found that the intense microwave field concentrates around samples during microwave sintering. Especially, the power of microwave field between sample particles is almost 30 times larger than the external field, giving rise to ionization at the surface of sample particles. As a result, the diffusion of ions between sample particles is accelerated and the densification stage is promoted. Moreover, surrounding electromagnetic field can intensely couple with ions at grain boundaries. Under drive of microwave field, the kinetic energy of ions at grain boundaries increases, which results in decreasing the activation energy for a forward jump of ions and increasing the barrier height for a reverse jump. So the forward diffusion of intergrain ions is promoted and thus accelerates the grain growth during sintering. In many cases, the microwave

sintering has shown to produce samples with more uniform grain size distribution and higher density [1].

Reviews of microwave processing describe its use for materials ranging from wood, bacon and potato chips to rubber, ceramics and semiconductors, but make no mention of metal sintering. Walkiewicz *et al.* exposed a range of materials, including six metals (presumably partly oxidized in air) to a 2.4-GHz field, and reported modest heating (but not sintering), ranging from 120°C for Mg to 768°C for Fe. Sintering of tungsten carbide–cobalt composites has also been reported16. Nishitani reported that by adding a few per cent of electrically conducting powders such as aluminium, the heating rates of refractory ceramics was considerably enhanced; but no mention was made of the microwave sintering of pure metal powders. Whittaker and Mingos used the highly exothermic (and rapid) reactions of metal powders with sulphur for the microwave induced synthesis of metal sulphides. German discusses microwave heating of oxide and non-oxide ceramics, but does not mention sintering of metals [3].

Few materials do not absorb microwave energy at low temperatures. This problem has been overcome by using a susceptor, which absorbs microwave energy at low temperatures. Therefore, the temperature of the susceptor first increases and then the temperature of the inside sample increases, and the sample efficiently absorbs microwave energy at high temperatures (Mizuno *et al.* 2004; Breval *et al.* 2005) [2].

Capasitor Discharge (CD) stud welding, using very short weld times, permits the welding of small-diametre studs to thin, lightweight meterials. The weld cycle can be completed in 0,01 seconds on material as thin as 0,5 mm. These fast weld times minimize heat buildup, resulting in welds with very little distortion, discoloration, or burning. Therefore, CD stud welding is often used when appereance is critical product feature.

CD stud welding uses a capacitor storage system to produce a rapid electrical discharge, stud welding guns, and fasteners. No ferrules or flux are needed. The CD stud welding method, used mainly for welding mild steel, stainless steel, and aluminium studs, includes two primary techniques: Contact and Gap.

During contact stud welding, the stud is loaded into the gun and positioned in contact with the work piece. Energy is then instantaneously discharged from capacitors through the stud's projection. Since the size of ignition tip cannot handle the current density of the capacitor's stored energy, it vaporizes, creating a gap that allows an arc to be formed. As the arc begins to melt the stud and work piece, the two pieces are forced together, and a weld is produce as the metal cools(Figure 2) [5].

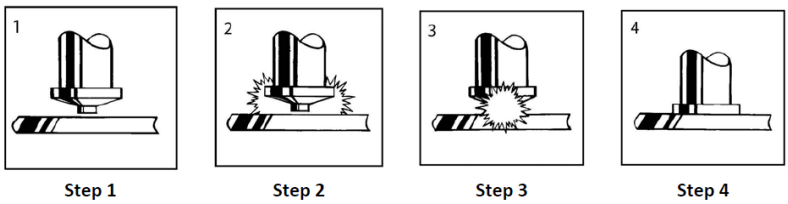


Figure 2. CD Stud welding process [6].

2. Experimental

In this study, Fe powders with average particle size of 60 μm and 1 wt.% graphite have been blended for 15 minutes. Powder metal Fe samples uniaxially cold pressed in 25x25x5 mm dimensions at 250 MPa. After pressing, green densities of the samples were measured as 77,159%. After that, samples were microwave sintered at 1000 ^{o}C; 15,25 and 35 minutes in atmospheric environment. Density changes depending on the sintering time is shown in Tab.1.

Ø 5 mm treated cylindrical steel studs were used to join with the dimension of 25x25x5 mm Fe powder as a base metal. Welding process was performed with portable capasitor discharge welding machine. The welding voltages were 100, 120 and 140 V.

Table 1. Green and sintered densities of powder metal samples

Sintering time (min.)	Green density (%)	Sintered density (%)
15	% 77,159	%78,277
25		% 76,524
35		%74,411

Samples which were grinded 120,240,320,600,800 and 1200 meshes have been polished and etched for microstructural analysis. Microstructure investigations have been carried out with optical microscopy.

Vickers micro hardness measurements were taken for the base metal, weld metal, transition zones, steel stud by a diamond pyramid intender under 1 kg loading with the EMCOTEST DuraVision 200.

3. Results and Discussion

3.1. Characterization of Microstructure

Microstructural investigation performed after sintering process. And microstructural changes depending on the sintering time is shown in Figure 3. The sample which is shown in Figure 3.a was sintered 15 minutes, has small and spheroidal pores. And approximate grain size is seen as 50 μm. When the sintering time rise to 25 minutes, increasing the porosity rate is monitored Figure 3.b. when examining the Figure 3.c, sintering time rise to 35 minutes, big and interconnected pores are observed.

Sintering density is expected to increase with sintering time. However, increasing the sintering time tend to burn the lubricants. As a consequence porosity rate increase and sintered density decrease.

Agrawal and *et al.* are also reported that increasing the sintering time caused decreasing the sintered density [7].

Associated with increasing the sintering time, solid graphite is not observed. It is thought that a part of graphite was diffuse to Fe particle, and a part of graphite was burned and left the structure. Pearlitic zones are seen 35 minutes sintered samples.

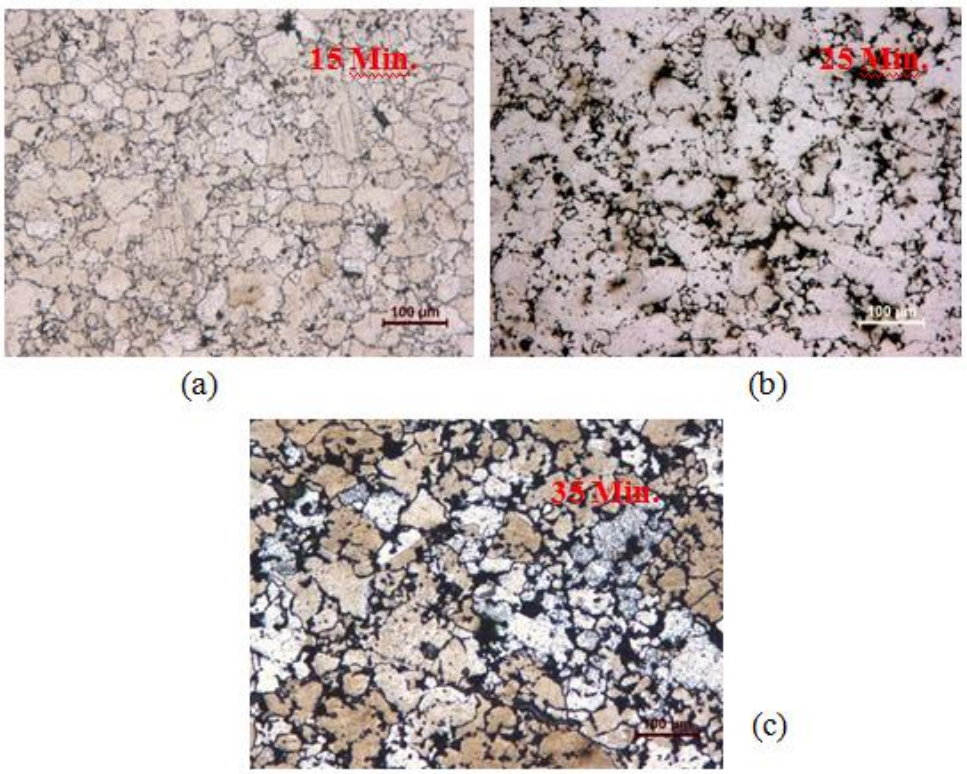


Figure 3. Relationship of the sintered densities and different sintering times

Stud welding interferences of 35 minutes sintered samples which have least densities are shown in Figure 4. Steel studs for Ø 5 mm were CD welded 100, 120 and 140V. Welding interference of 100 V is seen in Figure 4.a. Welding interference thickness decreased with increasing the welding voltage. Because of the increased welding voltage, heat input increase and melted metal expanded around the stud. And its incline the decrease of the welding interference thickness.

Stud grains are getting taper in stud – welding transition zone. By the effect of arc pressure grains are oriented to liquid metal jet line.

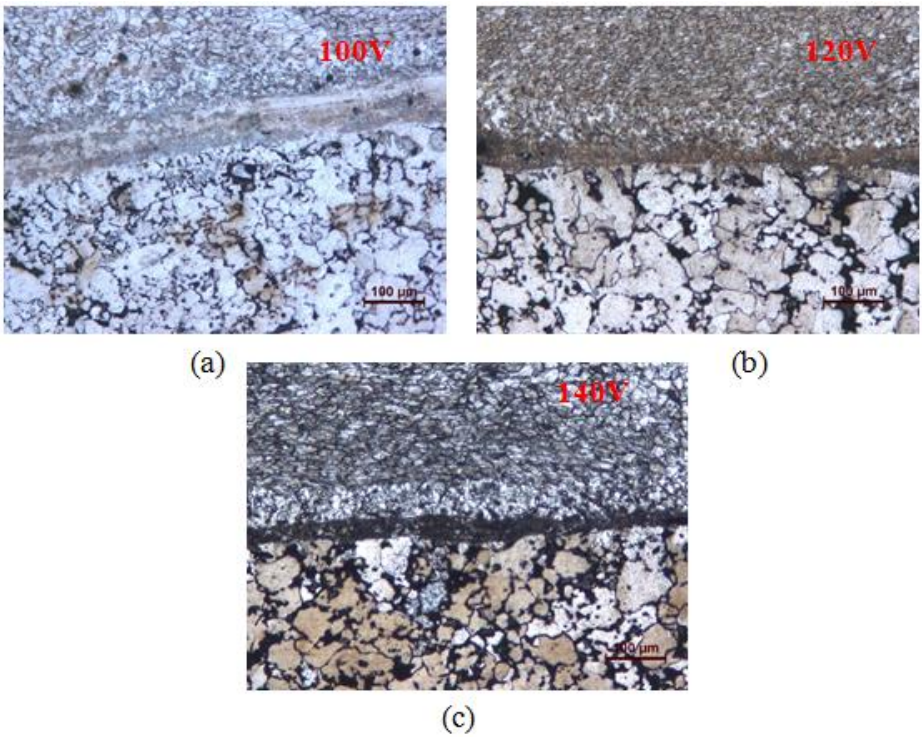


Figure 4. Welding interface of the specimen sintered at 35 minutes and welded. (a) 100 V, (b) 120 V, (c) 140V

Depending the increased welding voltage and sintering time, increasing the width of HAZ is monitored (Figure 5.). Increasing the voltage value increase the heat input. During the long sintering times porosity rate increase and sintered densities decrease. Heat transfer is reduced because of the increased porosity rate. The heat in the welding interference is effective to grow width of HAZ in stud.

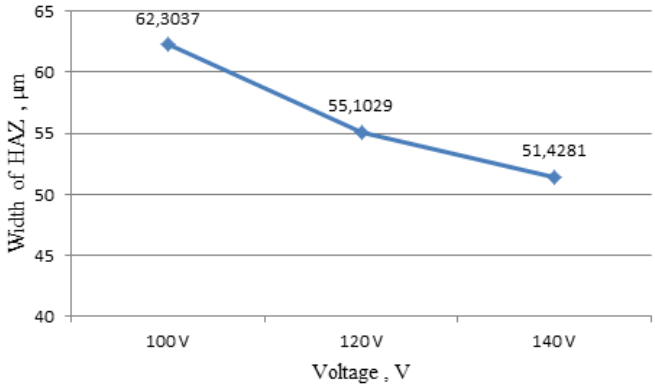


Figure 5. The relationship between welding voltage and width of HAZ

The relationship width of welding zone and welding voltage are shown in Figure 6. As shown in Figure 6 when increase welding voltage, decreased width of weld zone. Because of increased welding voltage, increase heat input and liquid metal jet and decreased width of weld zone.

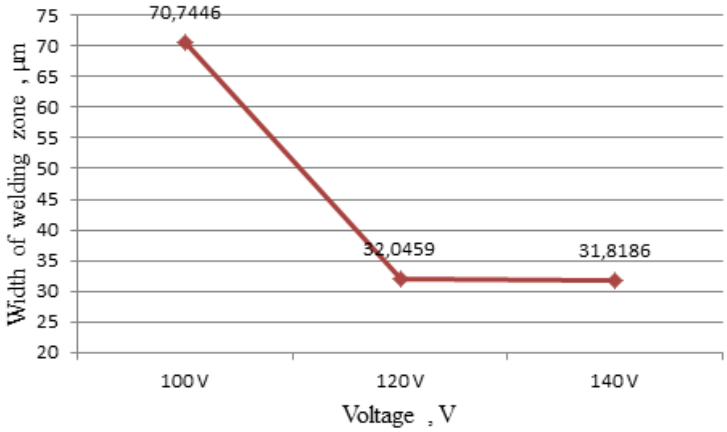


Figure 6. The relationship between welding voltage and width of welding zone

3.2. Hardness Test

Studs which were joined to the P/M Fe samples hardness values are measured with HV 1. Hardness alteration based on the welding voltage is shown in Figure7.

As it seen from the Figure 7 increasing the welding voltage cause the decreasing the hardness values. When the welding voltage increase, heat input also increase and it cause to decrease the rate of cooling. Decreasing the hardness value based on this lower rate of cooling.

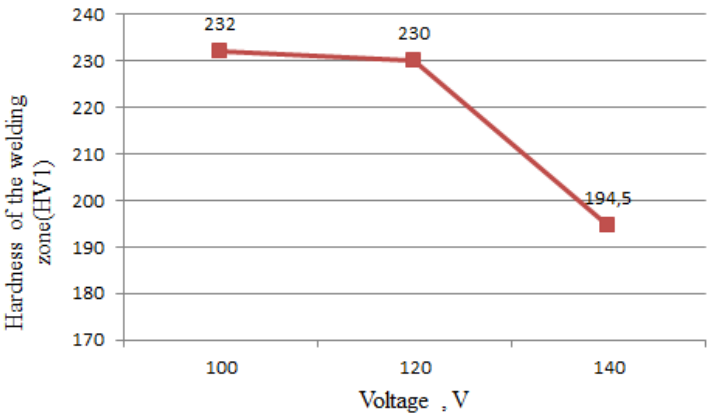


Figure 7. Hardness values of the welding zone

4. Conclusion

This investigation is done to examine the CD stud weldability of P/M Fe materials. Its occurred that all studs were joined to the P/M materials with selected welding voltage. Increased sintering time cause to sintered density decreasing in the P/M samples. The reason for this, increasing the sintering time tend to burn the lubricants. In this way porosity rate is increasing, and the theoretical density is decreasing. HAZ width is increased with higher welding voltage. In addition to that the width of welding metal transition zone is decreased with higher welding voltage.

5. References

[1] M. Oghbaei, O. Mirzaee: Microwave versus conventional sintering: A Review Of Fundamentals, Advantages And Applications, 494 (2010), pp.175–189.
[2] R. Annamalaı, A. Upadhyaya, D.Agrawal: An Investigation On Microwave Sintering Of Fe, Fe–Cu And Fe–Cu–C Alloys, Bull. Mater. Sci., Vol. 36, No. 3, June 2013, pp. 447–456.
[3] R. Roy, D. Agrawal, J. Cheng, S.Gedevanishvili : Full Sintering Of Powdered-Metal Bodies In A Microwave Field, Nature, Vol. 399, 17 June 1999,pp. 668-670.
[4] A. Nadjafi Maryam Negari, R. S. Mamoory, A. Simchi, N. Ehsani : Determination Of The Physical And Mechanical Properties Of Iron-Based Powder Materials Produced By Microwave Sintering, Powder Metallurgy and Metal Ceramics, Vol. 46, Nos. 9-10, 2007, pp. 423-428.
[5] www.imageindustries.com
[6] www.truweldstudwelding.com
[7] A. Badev, S. Marinel, R. Heuguet, E. Savary,D. Agrawal : Sintering Behavior And Non-linear Properties Of ZnO Varistors Processed In Microwave Electric And Magnetic Fields At 2.45 GHz, Acta Materialia 61 (2013) pp.7849–7858