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Joining Of Bulk Cast Iron Through Microwave Energy

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Abstract – **The applications of microwaves are increasing rapidly in material processing due to the unique characteristics of volumetric heating, selective heating, lower energy consumptions and lower processing time. The present work focuses on the joining of bulk cast iron through the microwave hybrid heating, using domestic microwave applicator at 2.45 GHz and 900 watt power. A slurry of nickel based powder was placed at the faying surfaces for development of joint. Microstructural characterizations of joints were carried out by using SEM (scanning electron microscopy), EDS (energy dispersive X-ray spectroscopy) and XRD (X-ray diffraction). Results revealed that joints were formed by metallurgical bonding of interface powder with base metal and wavy interface was observed due to dilution of the base metal. EDS confirms the uniform distribution of elements in the joint region and SEM results revealed that little porosity was observed at the interface; however, defect free joint region was obtained.**

Keywords – Microwave Hybrid Heating, Joining, Microstructure, Porosity, EDS, XRD.

1. INTRODUCTION

The process of thermal joining is one of the vital manufacturing processes that are applied for assembling of various similar or dissimilar structural, mechanical and machinery parts to achieve shapes and sizes for their functionality [Messler, 2004]. The available joining processes include conventional welding, brazing, soldering, energy welding through LASER, electron beam welding, friction stir welding, etc. [Wit and Poulis, 2012], however, efficient joining of material is characterized by quality of joint and energy requirements [Kah and Martikainen, 2012]. Conventional welding processes have certain limitations which include unavoidable defects, higher energy requirements, higher setup costs, hazards to the environment and operator [Srinath et al., 2011]. To minimize the limitations, researchers are continuously working on development of newer technologies. Microwave material processing is one such development which eliminates some of the limitations of conventional processes. A lot of literature [Singh et al., 2014; Agrawal, 2009; Chandrasekaran et al., 2011] is available on the principle of microwave processing of material and in recent times efforts are made in the field of joining of materials through microwave hybrid heating systems. The developments in the field of microwave material processing started with sintering of ceramic materials due to their good absorption characteristics [Thostenson and Chou, 1999; Clark and Sutton, 1996]. Later on the erroneous belief that metals cannot be processed by microwaves due to reflection and plasma formation; was removed [Roy et al., 1999] and first literature on successful sintering of metals was reported. This sparked the research in microwave material processing and bulk metallic materials were successfully processed in the form of joining of metals by domestic microwave applicator [Srinath et al., 2011]. This work on high temperature application of domestic microwave was further carried out [Gupta and Sharma, 2012; Sharma and Gupta, 2012; Gupta and Sharma, 2014] in the form of metallic cladding generated on metallic steel substrates for better wear resistance, by using the applications of MHH through domestic microwave applicator.

2. LITERATURE REVIEW

The application of gray cast iron includes automobile parts, machinery parts and structural parts due to the excellent properties of high strength, good wear resistance, excellent castability and toughness as reported by Abboud, (2012). The welding of cast iron through conventional methods leads to inherent embrittlement, development of macro cracks and inferior weld quality coupled with greater heat affected zone (HAZ). These limitations suppress the effective utilization of cast iron in many precision engineering applications. The research carried by Ghaini et al., (2011) focused on cracking in HAZ of ductile cast iron in powder welding through the oxyacetylene process. It was reported that HAZ cracks with the combination of hard deposits and higher cooling rates. Graphite nodules were the potential sites for crack initiation, which further propagate to the martenistic matrix. The work of Pouranvari, (2010) studied the weldability of gray cast iron using nickel based filler using shielded metal arc welding process. It was reported that nickel inhibited the formation of hard phases in the fusion zone and post weld heat treatment reduced the hardness in the fused zone. Ebrahimnia et al., (2012) studied the effect of cooling rate and characteristics of powder on HAZ zone in powder welding of ductile cast iron. It was reported that use of higher hardness powder with higher cooling rates in welding of larger castings leads to the micro cracking in HAZ and this cracking was predominantly affected by the stress field in the toe of weld deposit due to shrinkage effect. El-Banna, (1999) reported the effect of preheating on the microstructure of HAZ of multi pass weld ductile cast iron. Further, qualities of weld joints were evaluated by using ultrasonic and mechanical tests. Further to obtain the combined properties of various materials researchers have studied the joining of cast iron with steels as reported by Hatate et al., (2004); Kurt et al., (2007). However, the problems of cracking and higher HAZ were reported with cast irons. The work of Bansal et al., (2014); Gupta et al., (2012) already stated that microwave processing leads to lower porosity and cracking which may be due to selective heating, volumetric heating and inverse heating profile in which heat is transferred from inside to outwards. To reduce these problems, the present work focuses on the development of bulk cast iron joint through microwave hybrid heating at 2.45 GHz by using domestic microwave, which involves selective heating and helps in reducing the HAZ and micro cracking of joints.

3. EXPERIMENTAL DETAILS

This section provides the details on the material and method used for the development of a joint through microwave energy.

3.1 Materials

The commercially available bulk gray cast iron was cut in the rectangular specimens of dimensions 20x10x10 mm for development of joint. A nickel based powder was mixed with epoxy resin to form a thick paste and was introduced between the faying surfaces to form the powder interface of approximately 1mm between cast iron pieces. Epoxy on getting heated gets evaporated from the joint region, leaving concentrated nickel powder in the joint region. The typical SEM image of powder used is shown in Figure 1, which shows spherical morphology of nickel powder having an average size of 40 µm. For MHH, pulverized charcoal was used as susceptor material such that it initially couple with microwaves and starts conventional heating. To prevent the contamination of joint powder from charcoal, separator in the form of thin sheet of graphite was used.

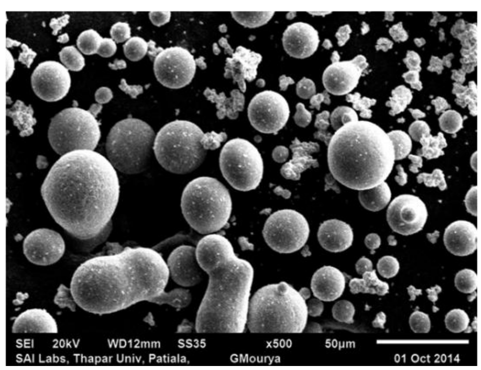

Figure 1: SEM image of nickel powder showing spherical morphology

3.2 Experimentation

The joining of cast iron was carried out in the domestic microwave applicator working at frequency of 2.45 GHz and at a power rating of 900 watts. The schematic principle of MHH is shown in Figure 2, which shows microwave cavity and other materials for carrying out experimentation.

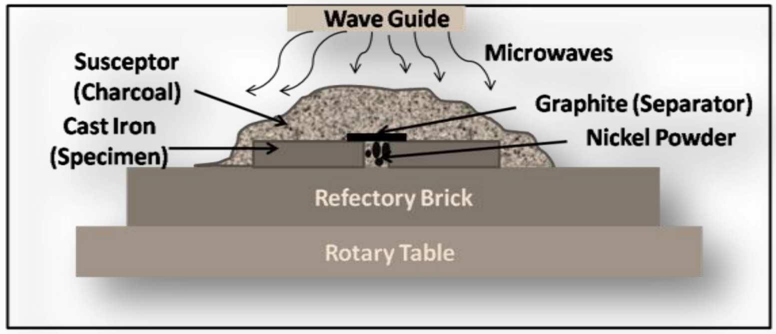

Figure 2: Schematic principle for development of joint through microwave hybrid heating

Table 1 shows the process parameters for development of joint through MHH. The experiments were carried out to obtain joints by hit and trial method to find the optimum time for joint development. It was found that overheating of material can lead to the melting and fusion of bulk material, whereas under heating leads to the non uniform joint formation. The contour of charcoal used for initial heating also plays an important role in the development of joint. If thick layer of charcoal is placed than at the center adequate heat does not reach the joint region and leads to non fusion of powder to form joint. On the contrary, if a thin layer of charcoal is used, it burns up quickly and again leads to the non uniform heating and joint.

Table 1: Process parameters for obtaining joint through microwave hybrid heating

Parameters	Description
Applicator	Multimode (LG, Model: Charcoal)
Frequency	2.45 GHz
Exposure Power	900 Watt
Exposure Time	380±20 seconds
Interfacial Powder Size	40 μm

4. RESULTS AND DISCUSSION

This section describes the microstructural analysis and elemental distribution of the joint formation by microwave hybrid heating. This section is divided into three sections i.e. XRD analysis, SEM analysis and EDS analysis.

4.1 XRD Analysis

The typical XRD spectrum of nickel based powder and joint developed through the MHH was carried on X'PERT PRO of PAN ANLYTICAL using CuKα radiations at scanning speed of 1.5 Kcps in 2θ range of 10–110˚ shown in Figure 3(a-b)

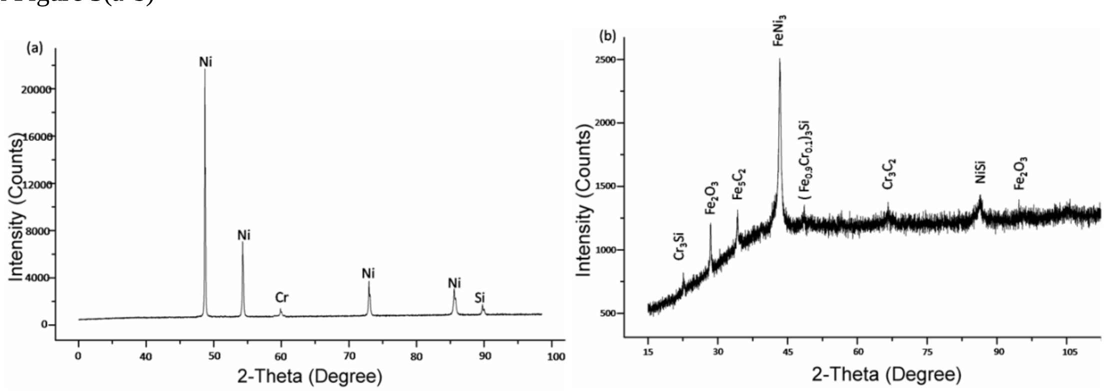

Figure 3: Typical XRD spectrum of (a) nickel based powder and (b) microwave processed joint

Presence of nickel is shown predominantly in the 2θ range of 48˚ and 55˚ and new phases were detected in the joint region, which shows the presence of nickel silicides, cementite, iron oxide, chromium carbide and iron nitride. The presence of carbides may be due to the intake of graphite from the separator, which gets mixed with the joint. The iron content in the joint region is due to the dilution of base metals from interfaces.

4.2 SEM Analysis

The joint formed between the cast iron pieces is shown in Figure 4 (a), which shows the typical SEM image. The HAZ is clearly shown by the formation of wavy interface between cast iron pieces. It is clearly seen that joint is formed by diffusion of nickel powder with the bulk metal and the presence of Eddy currents due to electric field causes an intermixing of base metal and powder particles which causes waviness.

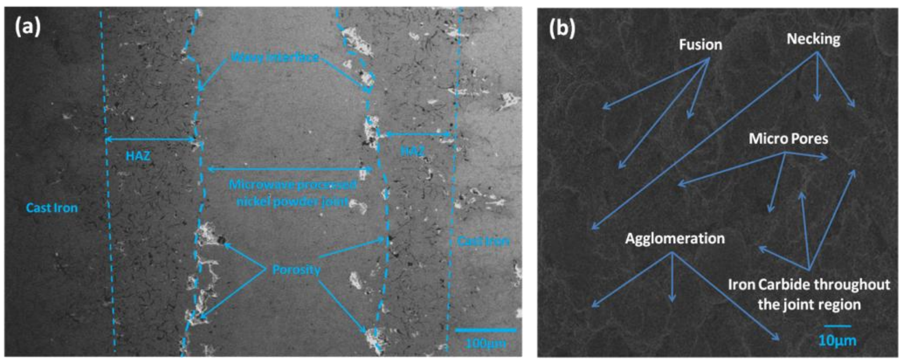

Figure 4: SEM image showing the (a) interface between cast iron and HAZ around the joint and (b) microstructure of joint

Microwave processed joint region showed lower porosity however, no cracks were detected. The selective heating leads to the lower HAZ around the joints. At higher magnification as shown in Figure 4 (b), the SEM image shows the microstructure of joint region, which is mainly composed of 3D array of chain formed by diffusion of nickel powder. At some placed agglomeration of fused particles was observed clearly and the presence of some micro-pores were observed.

4.3 EDS Analysis

The joint formed was analyzed for elemental distribution by using EDS as shown in Figure 5, which confirms the uniform distribution of elements. Further EDS analysis of joint microstructure shows the presence of iron carbide at chain boundary, which is confirmed by the presence of more carbon and iron.

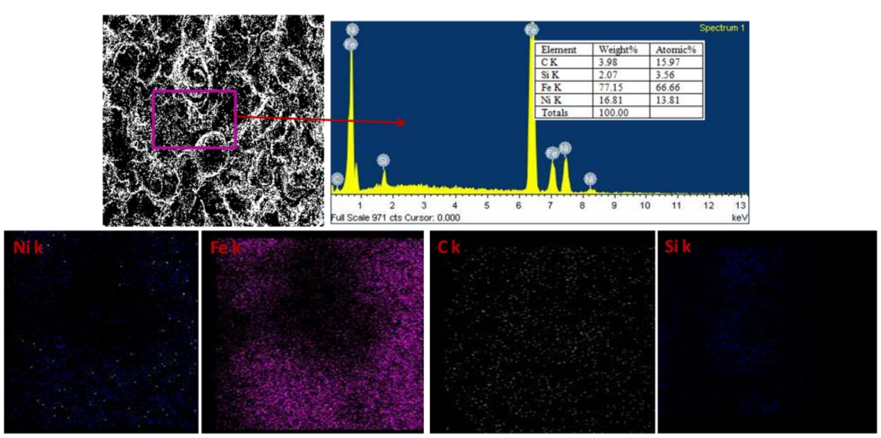

Figure 5: EDS analysis of microstructure showing the mapping of various elements

However the lower amount of carbon is present at the diffused chain links and are mainly nickel and iron rich. Figure 6 shows the comparison of elemental distributions of diffused chain and at chain boundary.

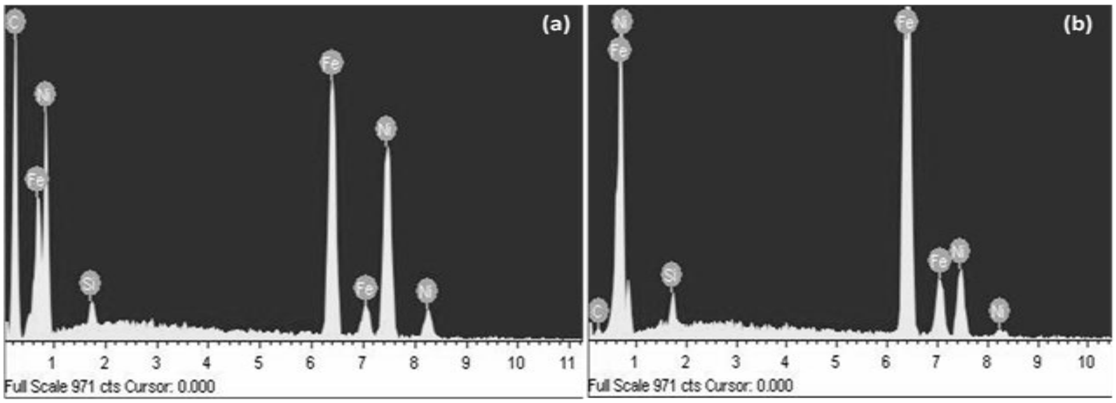

Figure 6: Typical EDS spectrum of chain boundary and fused particle

5. CONCLUSIONS

The present work on the joining of cast iron was successfully carried out using domestic microwave applicator at 2.45 GHz and 900 watts of power. Following conclusions can be drawn on the basis of the analysis carried out:

- The principles of microwave hybrid heating were successfully employed for development of a cast iron joint through domestic microwave applicator.
- The microstructural analysis of welded joint reported that joint was formed with complete melting and fusion of the interfacial powder with bulk metal pieces and due to the presence of Eddy currents wavy interface was produced, which was caused by the electrical component of microwaves.
- The presence of iron phases in the joint region as reported by XRD analysis supports the intermixing of elements and the formation of metallurgical bonding between the substrate and powder. Further new phases were detected, which mainly occurred due to microwave processing and oxidation by the atmosphere.
- The uniform distribution of elements was confirmed by EDS analysis within the joint zone and the presence of iron carbide along the boundaries of fused powder chain was observed. This higher content of carbon at the boundaries was due to the presence of free carbon content, which was absorbed from the surrounding graphite.

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