Effect of Susceptor Heating on Joining of Metallic Pipes Using Microwave Energy

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Abstract – Joining of Metallic pipes are a prime requirement in the industries such as processing, oil and automotive etc. Many pipe joining processes were reported by the researchers but the producing sound and eco friendly joint is a concern for the industries. In pipe joining, rejection and rework of joint is a major concern this leads to consequently consumes more productive time and loss of energy. It has been reported that microwave (MW) energy can be used for joining of bulk metals. Usage of microwaves energy for joining of bulk metals have revealed that the process is capable enough to produce joints with lesser processing time, eco-friendly and energy saving process and the joints exhibit better mechanical and metallurgical properties than conventional joining processes. The attempt has been made to join MS pipes using microwave hybrid heating technique. This paper reports joining of mild steel (MS) pipes using micrometric size (40 μm) of nickel powder as an interfacing material in a multimode MW applicator at 2.45 GHz. Different susceptor such as Silicon carbide (SiC), Graphite and Charcoal have been analysed for the joining of pipes at 1400 and 900 W microwave power. In susceptor heating, charcoal shows most efficient susceptor material which helps to produce good pipes joint at 900 W. A ceramic fixture was designed for holding and processing the required joints in MW applicator. The basic principles involved in the MW pipe joining process have been discussed. Further, initial experimental observations have been analyzed and results have been discussed.

Index Terms – Pipe joining, microwave energy, susceptor, metal, hybrid heating.

1. INTRODUCTION

Metallic pipes are extensively used in the industries such as oil, chemical, sugar, paper, process, automotive to transport high pressure liquids and gases often at high temperature. This necessitates adequate strength and efficiency of pipe joints to overcome onsite failures. The joining processes such as TIG, LBW, friction welding etc. were reported with satisfactory joints in metallic pipes. However, industries are still looking for a better and rapid joint by a suitable joining process. Consequently, more productive time and energy can be saved by avoiding frequent rework in maintenance of pipe joints [1]. Some of these issues can be addressed using MW energy for joining metallic pipes due to their rapid and more uniform heating characteristics. In the year 2009, bulk metal joining was reported in the form of a patent using MHH technique [2]. Latter, It was reported by many researchers that MW energy can be used for eco-friendly joining of bulk metals to produce joints with reduced processing time, enhanced energy saving, better mechanical and metallurgical properties than conventional processes [3-21]. The joining of copper plates was reported by Srinath et al. [4] using MW energy by placing a sandwich layer (copper powder). The joint strength obtained was higher than that obtained by TIG welded joint [4]. Latter, joining of SS-316 plates using MW was reported with good joint strength and higher micro hardness with less porosity [5-7]. The joint strength and micro hardness of dissimilar metals joint (SS 316 and MS) were reported better with sandwich layer of SS 316 powder (50 μm) [9] than nickel powder (40 μm) [8]. The MS plates were joined using nickel powder (40 μm) as an interfacing material and hardness of joint was reported significantly higher than the parent material [10]. Recently, joining of Inconel-625 alloy was carried out using microwave hybrid heating (MHH) and it was reported that increase in specimen size, increases exposure time [11]. The MHH process is established as a metal joining process; however, process is yet to be industrialized. However, literature is hardly available on joining of metallic pipes using MW energy. The present paper reports on fundamental principles and effect of susceptor heating on joining of mild steel (MS) pipes using MHH in a multimode MW applicator at 2.45 GHz. The initial observations of the developed process emphasises on the fact that joint characteristics of metallic pipe depends on the selection of susceptor material, fixture design and its material. The SEM study reveals good fusion of joint with less porosity.

2. EXPERIMENTATION

A. Fixture and Susceptor

In microwave joining of metals, designing of fixture is a key element as it helps the microwave energy to concentrate at a particular area of the target material for selective heating. Fixture design includes selection of susceptor material, masking material, position of fixture in the cavity, height of susceptor material from the bottom of cavity and orientation of fixtures etc. Masking materials are low dielectric loss material which absorbs very less amount of Microwave energy and transmit negligible amount of energy to the pipes. Use of fixture is essential during microwave processing due to characteristics such as selective and uniform heating.

Susceptor material plays a very important role as it acts as a source of heat during Microwave irradiation. It should be a high dielectric loss material which can directly absorb microwave energy at room temperature and gets heated up very rapidly. It is placed near the joint area where the fusion of materials required. Selection of susceptor material is depends upon the high heating rate and the generation of heat energy per unit mass. The susceptor materials also act as oxidation prevention as it covers whole area which is to be joint. Susceptors such as SiC plate, graphite plate and charcoal powder were examined for appropriate use by recording their time-temperature characteristics inside a microwave applicator at 1400 W power for 600 seconds as shown in Fig.1.

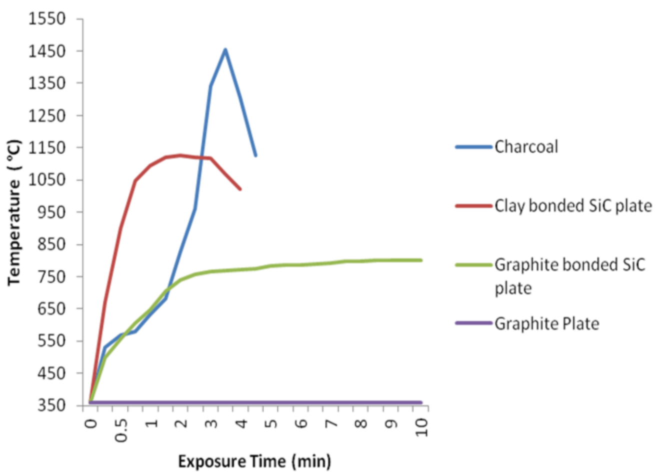


Fig.1. Comparisons of different susceptor heating by microwave energy

For better coupling of Microwave with the susceptor and alignment of pipes, the positioning of fixture play an crucial role. Fixture helps in better results due to ease of susceptor placing and proper covering of interfacing zone leading to more uniform and selecting heating of interfacing zone and better fusion of joint area. Due to the circular geometry of the substrate challenges were observed are difficulties in susceptor placing at joint zone and maintaining thickness of the susceptor around the pipe. The optimum microwave exposure time was optimized. Beyond the optimum exposure time, if substrate heated than melting and overheating of joint zone was observed.

B. Materials and Method

Trials were carried out to join commercially available Mild Steel pipes having inner diameter: 10 mm, outer diameter: 12 mm, lengths: 15 mm and 30 mm respectively in multimode microwave applicators having power capacity 900 W (Model: solar DOM, make: LG) and 1400 W (Model: MH-1514-101-V6, make: Enerzi microwave systems Pvt. Ltd.) at 2.45 GHz.. The chemical composition of the as received MS pipe is shown in Table.1. Interface slurry consisting of 10% of binder (Epoxy resin- Bisphenol-A) in nickel powder (40 μm) was used to position the mild steel samples. The slurry helps to bind the substrates and maintains their alignment.

Table.1. Chemical composition of the as received MS pipe

Element	C	Mn	Si	P	S	Fe
% Wt	0.15	0.428	0.28	0.009	0.014	Balance

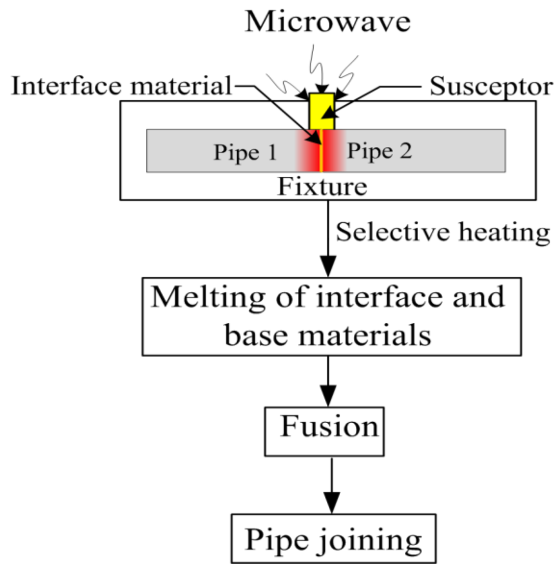


Fig.2. Principle of MW pipe joining

A susceptor (a high dielectic loss material) which absorbs Microwave energy rapidly and acts as a source of heat during microwave exposure was used for hybrid heating of area to be joined as shown in Fig. 2. Experiments were carried out using SiC, graphite and charcoal susceptors at different microwave power. A ceramic fixture was developed for selective heating of joint area. Initially, sandwich material and faying surfaces of MS pipes gets heated up due to transfer of heat from heated susceptor. The MS pipe and interface powder starts microwave absorption after reaching a critical temperature [3]. The melting of base metals and interfacing powder provide a fusion joint of MS pipes (Fig. 2). The initial observations for fusion of base metal and interfacing powder were carries out for SiC, graphite and charcoal susceptors. The developed joints were characterized by Scanning electron microscopy (SEM) study using the equipment FEI Quanta 200 FEG-SEM, Czech Republic at IIT Roorkee, India.

3. RESULTS AND DISCUSSION

Initially, the experiments were carried out for joining of mild steel pipes using SiC, graphite and charcoal as a susceptor to check the feasibility of interface powder and base metal fusion in microwave applicators at different power level with different exposure time. The summary of the experimentation and effect of susceptor heating on joining of pipes are shown in Fig.3.

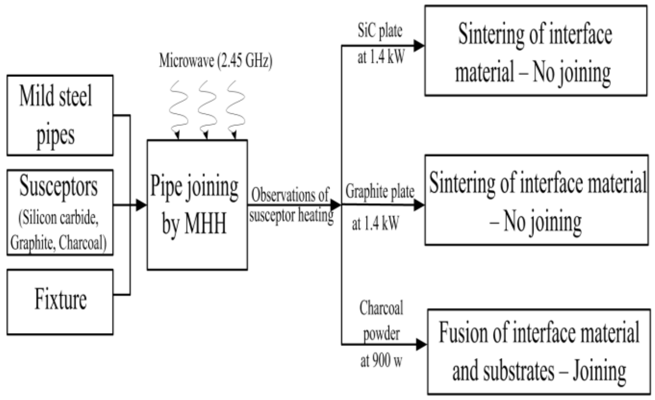


Fig.3. Summary of effect of susceptor heating on MS pipe

The initial observations of the joining of MS pipes using SiC, graphite and charcoal susceptors are shown in Table .2. In the case of MS pipe joining using microwave energy with SiC susceptor at 1400 W indicates that the increase in exposure time up to 840 s, causes sintering of nickel powder with poor bonding with base metal. Melting of interfacing powder was observed beyond 900 s exposure time; however, no melting of the base metals was obtained. The use of graphite plate, as susceptor does not affect the interface powder and base metal as no sintering of sandwich layer was observed up to 1080 s.

Table 2: Effect of susceptor materials and exposure time on joining of MS pipes

Sr No	Power (W)	Susceptor	Exposure time (s)	Results
1	1400	SiC	600	No fusion
2			720	Joining by sintering of interface material
3			840	Joining by sintering of interface material
4			900	No fusion - melting of interface materials
1	1400	Graphite	900	No fusion
2			1080	No sintering of interface material
1	900	Charcoal	300	No fusion
2			360	Joining by sintering of interface material
4			420	Fusion of faying surfaces
5			480	Proper fusion of faying surfaces
6			520	Melting of faying surfaces at weld zone
7			600 & above	Overheating and melting of joint zone

The successful joining of pipes was observed while using charcoal as susceptor at 900 W. Charcoal powder provides shielding to the joint zone and restricts formation of oxide layer resulting in rapid fusion of interface powder and base metal with reduced processing time. It was observed that at exposure time of 360 s, the pipes were joined by sintering of the interfacing powder with the candidate materials. It was not sufficient for proper heating and melting of interfacing powder and the base metals as shown in Fig.4. (a). However, proper fusion of base metal and interface powder was observed at 480 s (Fig.4.(c)). As the temperature increases and exposure time approaches to 520 s and above 600 s, melting of joint zone was observed due to overheating and the joints get distorted as shown in Fig.4. (d & e).

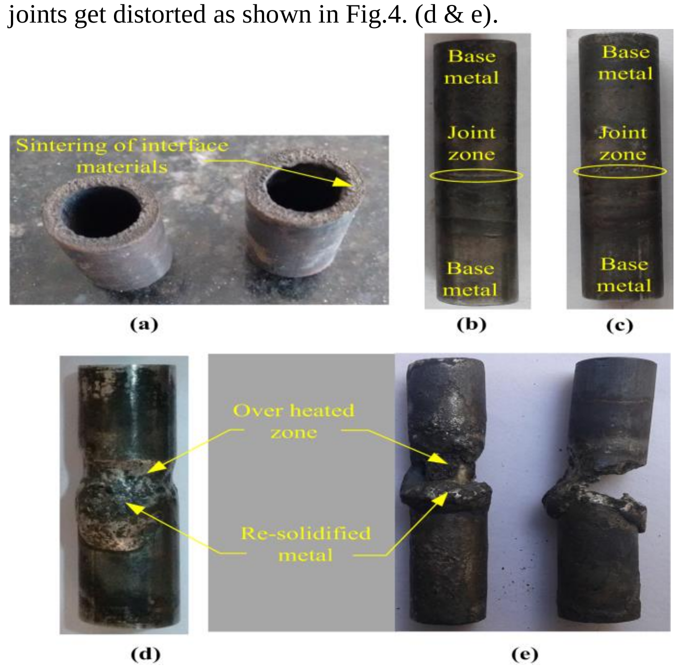
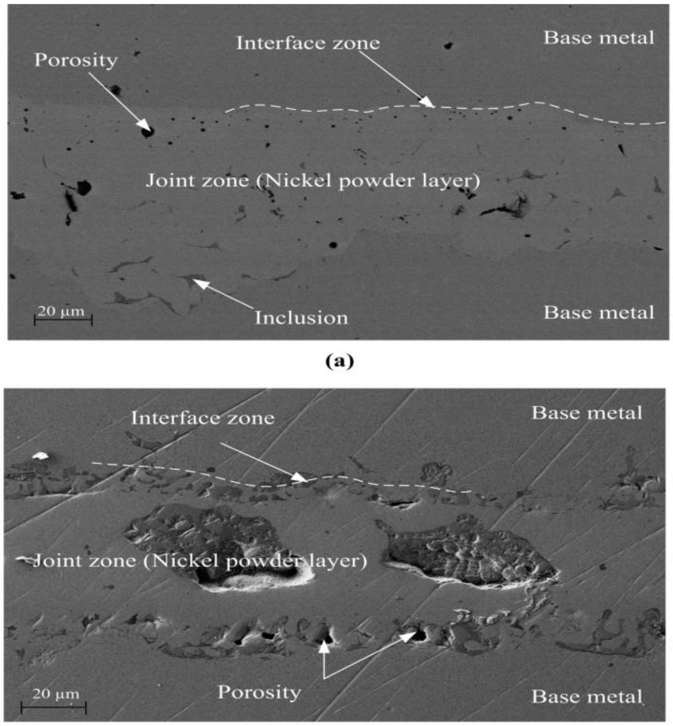


Fig.4. Effect of exposure time on MS pipe joint at a) 360 s b) 420 s c) 480 s d) 520 s e) 600 s & above using charcoal as susceptor



(a)

(b)

Fig.5. Typical SEM images of MS pipe joint: (a) Top surface weld zone (b) Bottom surface weld zone

4. CONCLUSIONS

A new joining method of metallic pipes has been demonstrated using microwave radiations at 2.45 GHz. The Microwave Hybrid Heating (MHH) was used to join Mild steel pipes by incorporating micrometric size of nickel powder. The initial observations show that charcoal provides better fusion than SiC and graphite plate. Good metallurgical bonding of the pipes was obtained at 480 s exposure time at 900 W. The presence of inclusions and porosity are some of the issues to be addressed in further studies.

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