Modeling and Simulation of Microwave Metallic Pipe joining process

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ABSTRACT *The welding of metallic pipe is very essential as production of continuous seamless pipe is not cost effective. The discrete form of metallic pipe can be joined with different available conventional joining processes. However, industries still focused on environment friendly processes. The microwave joining process has potential to overcome some of the issues related with conventional joining processes. Hence, attempt has been made to join mild steel pipe. The modeling and simulation of the present work indicate higher temperature formation in the microwave applicator which is sufficient for the joining of MS pipe in lesser processing time.*

Keywords: *MS pipe, Microwave, COMSOL, Simulation, Joining.*

1. INTRODUCTION

Microwave joining of metallic pipes is a novel technique recently developed at IIT Roorkee. This joining technique offers characteristics such as eco-friendly, lesser processing time, volumetric and uniform heating [1-11]. It was reported that the place of material inside a microwave applicator cavity changes the distribution and orientation of field distribution, hence, heating of material. Moreover, placing of the multi-material system at high intensity field points ensure rapid and fast processing. Modeling of multi-material systems is carried out to explore the heating behavior of the multi-material system inside the MW cavity. Modeling of the MS pipe joining was carried out using COMSOL multiphysics 5.2 software tool. The positioning of the substrate (MS pipe) was in the vertical direction and the nickel powder was incorporated between interfaces of the pipes which was similar to the experimental process. The charcoal was used as a susceptor material and incorporated at the joint interface [2-4]. The alumina pipe was inserted inside the metallic pipe to insure the dimensional stability of the developed joint. A 3 dimensioning model was developed to simulate the pipe joining process by specifying the magnetic and electric properties of the MS pipe, nickel powder and charcoal. The simulation of pipe joining was carried out inside the microwave applicator at a frequency of 2.45 GHz and 900 W power levels. The details of developed model have been discussed in the following sections.

2. MODEL DEVELOPMENT

The experimental and simulation results have differences to some extends due to differences in properties of the elements used, environmental conditions etc. The limitations of the experimental assessment of microwave processing are solely based on the restriction of study of electrical, magnetic and thermal behavior inside the applicator cavity. The COMSOL software helps to understand the electrical, magnetic and thermal behavior and its interaction with the materials inside the cavity; however, the actual designing of the model introduced the complexity and create the problem. Hence, it is necessary to simplify the model by some assumptions which are as follows:

- Homogeneous substrate properties are used.
- Dielectric properties of fixtures are constant.
- Initial temperature of the system is considered to be 27^0C.
- No rotation of the centre disk is considered.
- No chemical changes at elevated temperature of target metals are incorporated.

2.1. Model geometry and parameters

A 3D model was developed COMSOL multiphysics 5.2 software tool by incorporating similar experimental conditions and material properties. The cavity wall inside the microwave oven and wave guide are considered to be copper. The developed model for microwave pipe joining process is shown in Fig.1. The microwave energy was introduced inside the microwave applicator through rectangular port known as waveguide as shown in Fig.1 (b). The half part of the setup was analysed due to symmetry of setup. In this model, base plate is considered stationary whereas, experimental trials were carried out at rotary base plate. Meshing of setup was done for the finite element analysis. The electromagnetic and heat transfer module were integrated with each other as facilitated by the software tool to simulate the modeling results. The impedance boundary condition was defined for the walls of microwave applicator cavity and waveguide which define the minimum penetration of microwaves energy. The magnetic boundary was defined to the centre of the setup and applicator due to consideration of half portion of the applicator. The fixtures (Top, middle, bottom), metallic pipes, nickel layer were considered for the heat transfer in solid module to study the thermal analysis. The diffuse surface counts for radiative heat loss from the surfaces and the diffuse surface thermal boundary conditions were applied on the outer surfaces of fixtures and susceptor.

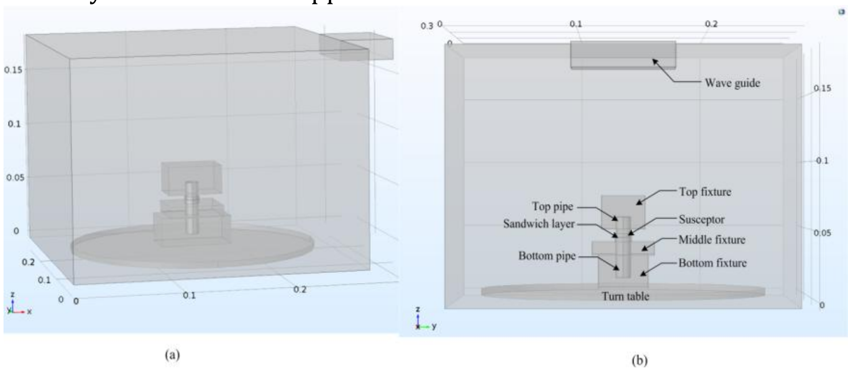

Fig.1. (a) 3-D model of setup (b) side view of model setup

2.2. Mesh quality

The meshing of the 3D model developed for pipe joining was carried out using physics controlled mesh and tetrahedral elements through COMSOL multiphysics software tool. The extra fine element size was found to be suitable with maximum element quality. The mesh generated as shown in Fig.2.with extra fine elements was found more effective with optimum characteristics.

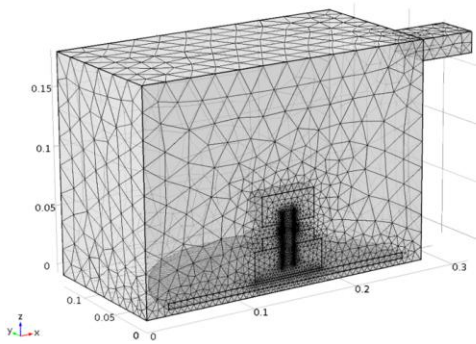

Fig.2. Typical view of the meshed model for microwave joining of metallic pipe

3. MODELING AND SIMULATION

The metallic pipe was simulated for the 600 s to identify the temperature distribution inside the specimen in microwave applicator at 2.45 GHz and 900 W. Microwaves energy interacts with materials through mutually perpendicular electric field (E-field) and magnetic field (H-field) components of the electromagnetic radiation. The temperature distribution and electric field distribution in the microwave applicator are shown in the Fig.3.

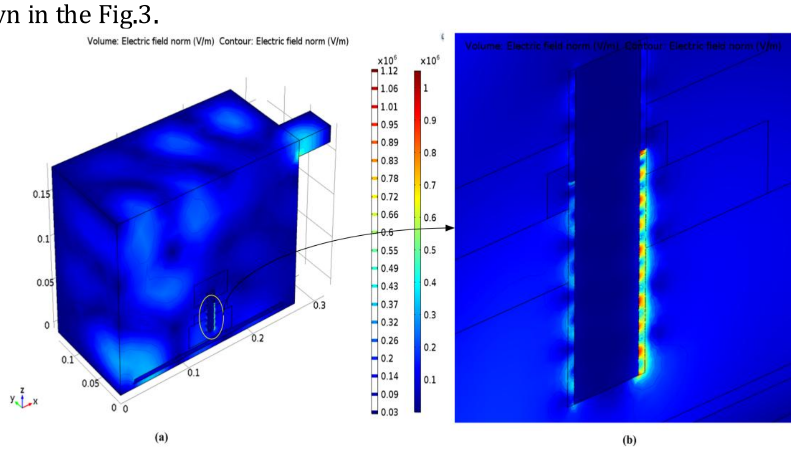

Fig.3. Electric field distribution (a) inside the applicator (b) at the metallic pipe.

The distribution of the electric field inside the applicator shows higher and lower intensity spots as shown in Fig.3 (a). The metallic pipe was interacting with electric field generated near the pipe joint as shown in the Fig.3(b). Due to this interactions, the thermal (heat) energy was generated which was responsible for the heating of the metallic pipe. The thermal energy was generated in the form of heat due to susceptor heating which was transferred to metallic pipe at the joint zone. As the heating time increases, the distribution of the thermal energy inside the metallic pipe increases resulting in increase in the temperature of the specimen. The experimental results were analysed at 360s, 480s and 540s and the fusion of joint was achieved at 480s. In simulation results, at 360s, the temperature at left and right side of the joint zone observed to be 1450^{0}C and 1650^{0}C respectively. The temperature obtained at left side was not sufficient to melt the interface and base metal at joint zone because of higher melting point of the interface material (Nickel powder – 1455^{0}C) and base metal (MS – 1482^{0}C). However, 1450^{0}C temperature at left side of pipe was sintered the interface material and 16500C was responsible for the melting of the interface material. Some melting of the interface material at 360s, was also observed during experimentation, hence no joining of the pipe was done. At 480s, the temperature of the joint was obtained as 1500^{0}C and 1700^{0}C which was sufficient to melt the interface of the pipe and sandwich layer, hence fusion of the faying surfaces with interface material was observed. At 540s, the temperature was observed to be 1525^{0}C and 1710^{0}C which was overheated the joint zone of the pipes. The melting and distorted joint was produced. Thus the simulated results are in good agreement with the experimental results.

4. RESULTS AND DISCUSSION

The higher amount of heat transfer in the middle fixture was observed due to direct contact of the susceptor heating. More transfer of heat energy in the bottom section was observed through conduction losses. Whereas, the heating pattern changes in top fixture was due to radiative loss from the susceptor and conduction loss through metallic pipe. Due to larger area of the fixture and metallic pipe at bottom side, the thermal energy was distributed uniformly resulting in the reduction of the temperature of bottom pipe. The maximum temperature was observed at the susceptor followed by joint zone of the pipe. Fig.4. shows the temperature of setup at different point with respect to time. The temperature behaviour at the inner and outer side of the joint zone, susceptor, top and bottom end of the pipes was analysed. The variations in the temperature were observed along the periphery with higher temperature at the joint zone of the right side of the pipe compared to left side. The 1500^{0}C temperature of the left side of the joint zone was achieved in 480s, whereas at same time the temperature at the top and bottom end of the same side of pipes were observed to be 1200^{0}C and 900^{0}C. Similarly, at 480s, the temperature of the right side of the joint zone was observed to be 1700^{0}C, whereas the temperature at the top and bottom end of the right side pipes were observed to be 1200^{0}C and 900^{0}C respectively. The increase in the temperature of the joint zone on right side was due to the generation of the hot spot at the right side of the susceptor resulting in the increase in the temperature at that particular area.

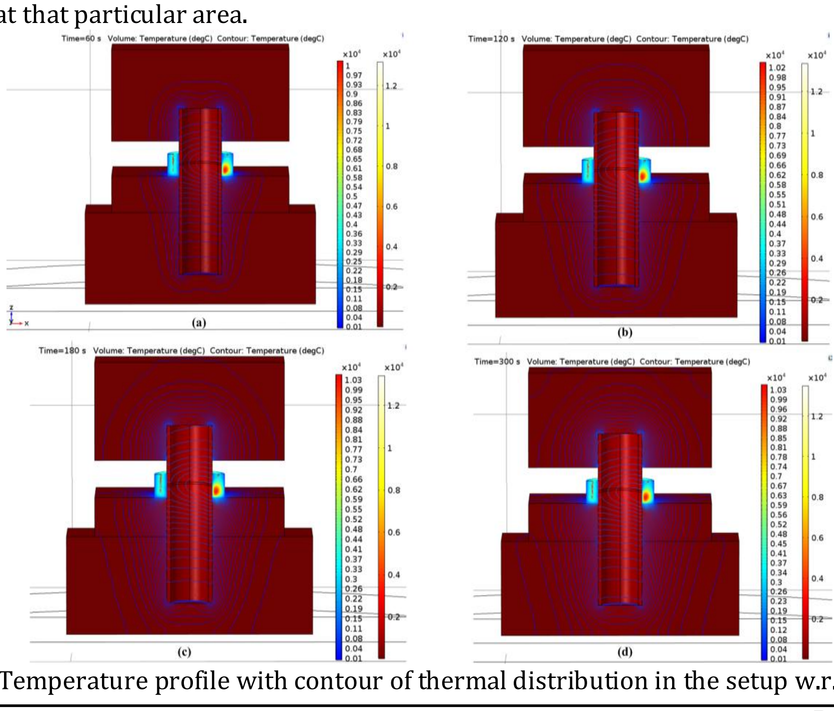

Fig.4. Temperature profile with contour of thermal distribution in the setup w.r.t time

5. CONCLUSION

The sufficient temperature was observed at the joint zone which melts the interface material and faying surfaces of the metallic pipe. Due to melting of both the surfaces a good metallurgical fusion of the joint zone was predicted. From above results, the fusion of the metallic pipe was observed in 480s at 900 w, whereas at 540s, the interface of the joint zone was melted and distorted joint was produced. The sufficient energy was produced by the susceptor which increases the temperature of the joint zone, whereas, lower temperature at the end of pipes were due to transfer of heat. The lower temperature profiles were observed in bottom pipe compared to top pipe due to larger height. Due to smaller height of the top pipe, the thermal energy was not dissipated uniformly in the fixture resulting in increase in the temperature of the pipe.

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