Conventional and Microwave Metallic Joining processes - A Review

Dhirendra N Gamit
Production Engineering Department, Government Engineering College, Bhavnagar, India.

Received: June 12, 2018 Accepted: July 26, 2018

ABSTRACT *Joining of metal based materials are very essential for performing the required function in the industries because production of such material as a single unit is very difficult which results in huge production cost. This article gives a glimpse of different metal joining process and a novel route of metal joining using Microwave hybrid heating (MHH). In MHH technique, the metallic materials are joined using microwave energy which works on the principle of heating of materials from inner surface to outer surface of the materials. This heating phenomenon differentiates the microwave heating compare to conventional heating of the metallic materials.*

Keywords: *Microwave energy, Metals, Joining, susceptor, Interface.*

1. INTRODUCTION

In a currnt scenario, the worldwide development of the infrastructure, industries etc taking place due to the development in the era of modernization. The use of metal based materials in the industrial application such as automotive, structural, minerals, oil, paper and process etc needs higher strength and durability to fulfill its application [1-13]. The continuous production of such material as a single unit is not possible; hence there is a requirement of joining the metallic materials. The different metallic joining techniques are widely used by industries which facilitate the welding of faying surfaces of the metal ends by incorporating the sandwich materials in between the surfaces by the application of heat, with or without the application of pressure. Now a day, various conventional pipe joining techniques are widely used for joining the metallic materials such as stainless steel, cast iron, aluminium, etc are as shown in Fig.1. The joints developed using these welding techniques performed satisfactory function but still industries needs fast, environment friendly and economical joining process which will help to reduce the rework and save processing time and overcome onsite failures. The joining of materials using microwave energy has potential to overcome such problems and have advantage such as volumetric heating, environment friendly, lower processing time etc. [14-30].

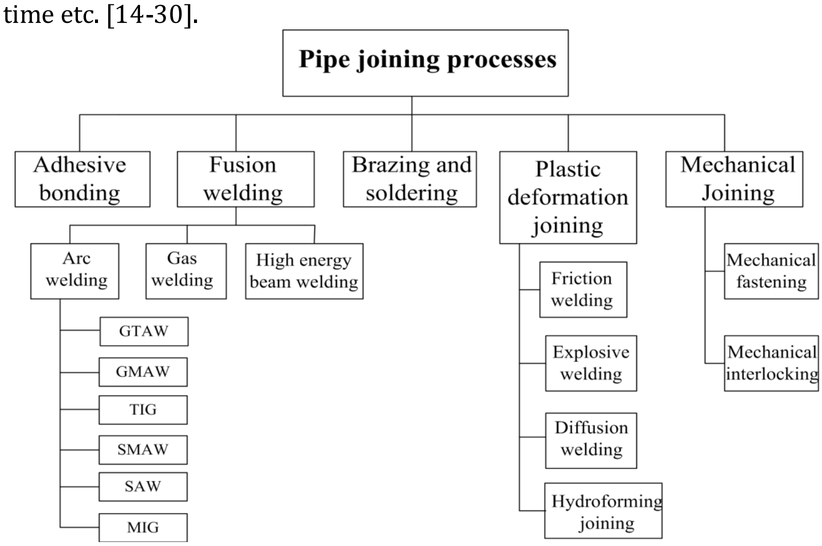

Fig.1. Classification of conventional pipe joining processes

2. LITERATURE SURVEY

Conventional Joining Processes

The various conventional joining techniques for joining of pipes including metals such as stainless steel, mild steel, aluminum, low carbon steel, cast iron etc. were used in welding industry over the years. It was reported that SUS 304 SS pipes was joined using GTAW by incorporating Y308L filler material with 1.2

mm diameter. The pipe was welded by 14 passes. The result revealed that the inhomogeneous heat affected zone (HAZ) was observed due to the multipasses which affect the yield strength of the weld zone and increase in the residual stresses [5]. Joining of 310S SS [6], Normalized steel -5LX42 [7] using friction welding was reported with low alloy steel as a filler material. It was reported that, higher friction generated at weld zone due to high rotation affects the grain size of HAZ. The joining of pipe was difficult as the wall thickness of the pipe decreases and the poor joint efficiency. The chances of high flash and buckling of pipe due to higher pressure applied. The combination of different welding processes also reported to improves the quality and properties of the weld zone of the metallic pipes. The joining of 304LN SS [8] was reported in different welding conditions. Welding of pipe with i) GTAW followed by SMAW ii) GTAW followed by GMAW iii) GTAW followed by P-GMAW in 98 to 99% argon environment. The results revealed lower level of inclusion and porosity in weld produced by P-GMAW followed by GMAW and SMAW. Higher yield strength and UTS were reported for P-GMAW followed by GMAW and SMAW. Welding of SS 316 and CS pipes using explosive welding was reported. The wavy interface (hook type locking mechanism observed) was produced with good strength due to higher explosive loading. The grains near interface were elongated due to the localized plastic deformation of pipe [9]. The problem of crack generation near the weld region was reported during welding of CS and 304 SS. The cracking was due to high hardness and brittleness of martensitic interface zone [10]. Friction welding was used to join cast iron pipe using interlayer and the joint obtained were reported with comparable tensile strength to that of the base metal.

Microwave Joining Processes

The joining of bulk metals using microwave energy was first reported in the year 2009. The researchers reported the joining of metallic plates using microwave energy with use of susceptor materials. The joint obtained were appreciably good mechanical and metallurgical properties. The joining of copper plates (15×12× 4 mm3) using MW energy was first reported by Srinath et al. [15] by incorporating micrometric size of copper powder (5 μm) as a sandwich layer in a microwave applicator. The frequency of 2.45 GHz and 900 W with charcoal as a susceptor material was used to join the plate. The researcher have successfully attempt an experiment to join copper plate using microwave hybrid heating technique. The hardness of the joint reported was 78 ± 7 Hv compared the parent material (93 ± 12 Hv). The joint strength obtained was 164.4 MPa (loss of 40% of the original strength of the Copper) compared to 159 MPa (a loss of 44% of the original strength of copper plate) in TIG welding. Latter, joining of SS 316 plates (25×12×6 mm3) using microwave energy was reported in the form of butt joint with nickel powder (40 μm) as a interfacial material and joint was obtained by using charcoal as a susceptor material in multimode microwave applicator at 900 W. The results of FE-SEM revealed that there was a good metallurgical bonding of the base material due to good fusion of faying surfaces. Vicker's micro hardness of joint zone was observed to be 290 Hv whereas in the interface zone it was found to be 420 Hv. It was attributed to the presence of metallic carbide in interfacing zone with 0.78 % of the porosity level [16]. The dissimilar joining of metallic plates (SS 316 and MS) using microwave energy was reported with nickel powder - 40 μm [17] and SS 316 powder - 50 μm [18] as a sandwich layer. The joint strength and micro hardness of dissimilar metals joint (SS 316 and MS) were reported better with lesser porosity using sandwich layer of SS 316 powder (50 μm) than nickel powder (40 μm). SEM image of the developed joint revealed good metallurgical bonding between the SS 316 and mild steel plates. The mild steel plates (30×10×5 mm3) were joined using nickel powder (40 μm) as an interfacing material. The joint hardness reported at joint zone and interface region were 420 ± 30 Hv and 350 ± 30 Hv respectively. The hardness at joint zone and interface was significantly higher than the hardness of the parent materials (230 ± 10 Hv). The ductile and brittle modes of failure were reported due to the higher hardness of the joint zone [19].

Microwave joining of SS 316 plate (25×15×4 mm3) using SiC susceptor were reported by incorporating micrometric size (50 μm) of SS 316 powder as an inserts. The harness of the inner region of grain in joint zone was reported 275 ± 20 Hv where as 650 ± 40 Hv at grain boundary. The results revealed that micro hardness of the joint zone was higher than that of the substrate. The hardness at the grain boundary of the joint zone was significantly higher compared to inside the grain due to presence of carbide particles at the peripheral area of grain [20]. Appreciably good joint strength of SS plate was obtained with very less porosity by using nickel as an interface material [22]. Recently, joining of Inconel-625 alloy was reported using microwave hybrid heating (MHH) and it was observed that increase in specimen size, increases exposure time. A specimen of size 20 × 6 × 3 mm3 was joined in 9 minutes, whereas specimen with size 102 × 12× 6 mm3 was joined in 21 minutes [23]. SEM report of joints shows complete melting and fusion of sandwich layer (nickel powder) to base Inconel. It was reported that the deposited chromium carbide along the interface of the weld zone was responsible for the increase in the hardness of the joint. The average micro hardness of the joint zone was reported as 360 ± 20 Hv. The MHH process is established as a metal joining process; however, process is yet to be industrialized. The process parameters and tools involved during the processing of microwave materials and the future scope in the area of microwave processing in the metallic pipe joining are illustrated in the Fig.2. The comparison between joining by forming, conventional welding and microwave joining is shown in Table.1.

Table.1. Comparison between joining by forming, welding and microwave joining [3-34]

Basis	Joining by forming	Joining by conventional welding	Microwave joining
Mechanism	Plastic deformation	Melting with addition of filler metals	Melting with addition of filler metals
Operating temp.	Ambient	Melting point	Melting point
HAZ	No	Yes	Very less
Shielding gases	No	Yes	No
Materials	Metals and polymers	Metals	Metals, polymers, ceramics
Energy consumption	Less	More	Very less
Productivity	More	Less	TBE
Cost	Less	More	TBE
Environmental friendliness	More	Less	More

TBE – To be explored

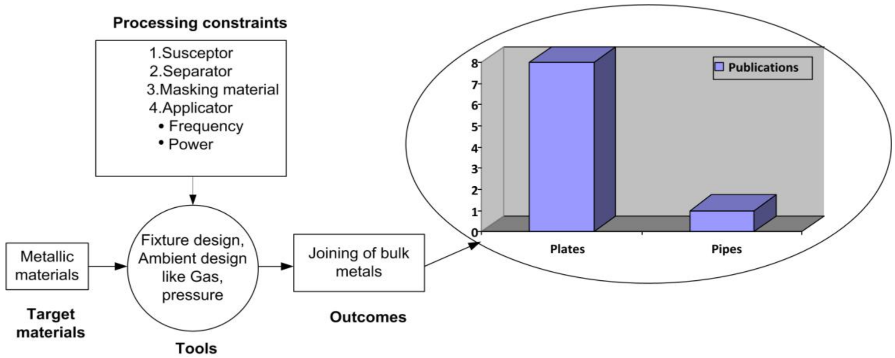

Fig.2 Process parameters and scopes in metallic pipe joining

3. CONCLUSIONS

The present work demonstrated development in joining of metallic materials using microwave irradiation at 2.45 GHz and at 900W and 1400 W. Major conclusions drawn from articles are as follows:

- Microwave hybrid heating technique can be used to join metallic material by processing it above its critical temperature so that it can starts microwaves absorption.
- Susceptor plays an important role in heating of area to be joint. Charcoal seems good susceptor material compared to SiC and graphite at 900W power.
- Low porosity attributed to the improved joint homogeneity due to the unique heating characteristic of MHH techniques.
- In microwave joining, it was reported that use of nano size sandwich materials reduces porosity and increase tensile strength and micro hardness of the developed joint compare to conventional joining processes.

REFERENCES

1. Sattari-Far I, Javadi Y. Influence of welding sequence on welding distortions in pipes. International Journal of Pressure Vessel Piping, 2008;85:pp,265–74.
2. Bae KY, Lee TH, Ahn KC. An optical sensing system for seam tracking and weld pool control in gas metal arc welding of steel pipe. Journal of Material Processing Technology, 2002;120:pp,458–65
3. Groche P, Wohletz S, Brenneis M, et al. Joining by forming—A review on joint mechanisms, applications and future trends. Journal of Material Processing Technology, 2014; 214: pp, 1972-1994.
4. Silva CMA, Nielsen CV, Alves LM, et.al. Environmentally friendly joining of tubes by their ends. Journal of Cleaner Production 2015; 87: pp,777-786.

5. Deng D, Murakawa H and Liang W. Numerical and experimental investigations on welding residual stress in multi-pass butt-welded austenitic stainless steel pipe. Computational Material Science, 2008; 42:pp, 234–244.
6. Kimura M, Ichihara A, Kusaka M, et.al. Joint properties and their improvement of AISI 310S austenitic stainless steel thin walled circular pipe friction welded joint. Materials and Design, 2012; 38:pp, 38–46.
7. Koen Faes , Dhooge A, Baets PD, et.al. Parameter optimisation for automatic pipeline girth welding using a new friction welding method. Materials and Design, 2009; 30: pp,581–589.
8. Kulkarni S, Ghose PK and Ray S. Improvement of Weld Characteristics by Variation in Welding Processes and Parameters in Joining of Thick Wall 304LN Stainless Steel Pipe.ISIJ International, 2008; 48: 11,pp,1560–1569.
9. Anwar UH, Hani M T, and Abbas N. Failure of weld joints between carbon steel pipe and 304 stainless steel elbows. Engineering Failure Analysis, 2005; 12: pp,181–191.
10. Zamani E and Liaghat GH. Explosive welding of stainless steel–carbon steel coaxial pipes. Journal of Material Science, 2012; 47: pp, 685–695.
11. Atkinson K, Whiter JT, Smith PA, et.al. Failure of small diameter cast iron pipes. Urban Water, 2002; 4:pp, 263–271.
12. Moglia M, Davis P and Burn S. Strong exploration of a cast iron pipe failure model. Reliable Energy System,2008; 93:pp, 863 – 874.
13. Makar JM. A preliminary analysis of failures in grey cast iron water pipes. Engineering Failure Analysis 2000; 7: pp, 43-53.
14. Sharma AK, Srinath MS and Kumar P. Microwave joining of metallic materials. Patent application 1994/Del/2009, India, 2009.
15. Srinath MS, Sharma AK and Kumar P. A new approach to joining of bulk copper using microwave energy. Materials and Design 2011; 32: pp. 2685–2694.
16. Srinath MS, Sharma AK and Kumar P. A novel route for joining of austenitic stainless steel (SS-316) using microwave energy. Proc Inst Mechanical Engineering, part-B Journal of Engineering Manufacturer 2010; 9: pp. 1083-1091.
17. Srinath MS, Sharma AK and Kumar P. Investigation on micro structural and mechanical properties of microwave processed dissimilar joints. Journal of Manufacturing Processes, 2011; 13: pp, 141–146.
18. Bansal A , Sharma AK , Kumar P and Das S. Investigation on microstructure and mechanical properties of the dissimilar weld between mild steel and stainless steel-316 formed using microwave energy. Journal of Engineering Manufacturer, 2014;1:pp, 1-10.
19. Bansal A, Sharma AK, Kumar P and Das S. Joining of mild steel plates using microwave energy. Advance Material Res 2012; 585:pp, 465-469.
20. Bansal A, Sharma AK, Kumar P and Das S. Characterization of bulk stainless steel joints developed through microwave hybrid heating. Material Characterization, 2014; 91: pp, 34 – 41.
21. Srinath MS. Joining and characterisation of metallic materials using microwave hybrid heating. PhD Thesis, IIT Roorkee, India, 2011.
22. Gupta P and Kumar S. Investigation of stainless steel joint fabricated through microwave energy. Material and Manufacturing Processes, 2014; 29: pp, 910–915.
23. Badiger RI, Narendranath S and Srinath MS. Joining of Inconel-625 alloy through microwave hybrid heating and its characterization. Journal of Manufacturing Processes, 2015; 18:pp, 117–123.
24. Kondo N, Hyuga H, Kita H and Hirao K. Joining of silicon nitride by microwave local heating. Journal of Ceramic Society Jpn 2010; 118 (10):pp, 959-962.
25. Aravindan S, Krishnamurthy R. Joining of ceramic composites by microwave heating. Material Letters, 1999; 38: pp, 245–249.
26. Amed A, Siores E. Microwave joining of 48% alumina-32% zirconia-20% silica ceramic. Journal of Material Processing and Technology, 2001; 118:pp, 88-95.
27. Singh I, Bajpai PK, Malik D, et al. Feasibility study on microwave joining of ‘green’ composites. Akademeia 2011; 1:pp, 1923- 1504.
28. Bajpai PK, Singh I and Madaan J. Joining of natural fiber reinforced composites using microwave energy: Experimental and finite element study. Materials and Design, 2012; 35:pp, 596–602
29. Prasad KDV, Yarlagadda and Chai TC. An investigation into welding of engineering thermoplastics using focused microwave energy. J Mater Process Technol 1998; 74: 199-212.
30. Mishra RR and Sharma AK. Microwave-material interaction phenomena: heating mechanisms, challenges and opportunities in material processing. Compos Part A 2016; 81: 78-97.
31. Thostenson ET and Chou TW. Microwave processing: fundamentals and application. Composite Part A 1999; 30: 1055–1071.
32. Clark DK, Folz DC and Jon K. Processing materials with microwave energy. Materials Science and Engineering, A 2000; 287: pp, 153–158.
33. Winiczenko R and Kaczorowski M. Friction welding of ductile cast iron using interlayers. Materials and Design, 2012; 34: pp, 444–451.
34. Mori K, Bay N, Fratini L, et al. Joining by plastic deformation. CIRP Annals – Manufacturing Technology, 2013;62: pp, 673–694.