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A Review on Green Technology Material Processing Through Microwave Energy

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ABSTRACT
To meet the demand of to days of industry, it has become necessary to develop the new processing and manufacturing techniques. These new techniques need to reduce the cost and enhance the properties. These new developed methods should be suited for all types of materials. Microwave processing is a new technology which can be applied to wide variety of materials. The microwave energy can be used for material joining, cladding, coatings etc. The microwave processing is economical and materials processed have better mechanical properties with lesser defects than the conventional methods. In this review paper, the recent published work on microwave joining is briefly summarized.

KEYWORDS: *Microwave, Microwave joining, Mechanical properties*

1. INTRODUCTION

The growth in the field of engineering and technologies led the industries to find new and improved methods/processes that can be used for processing of wide range of materials like metal, non-metal, ceramics composites etc. For sustainability the developed methods should have characteristics of lower energy consumptions and higher production rates. Novel microwave material processing is emerging as one of the promising sustainable process in manufacturing sectors. The unique characteristics of microwave radiations like volumetric heating, less power consumption, eco-friendly with environment, high quality products etc. are attracting numbers of researchers in this field.

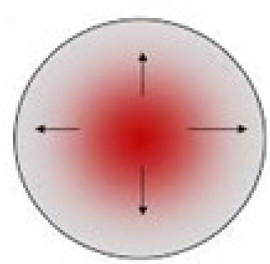
The permanent joining of materials has been one of the prime requirements in most of the manufacturing and assembling industries. The existing techniques like welding, soldering and brazing are being widely practiced in industries; however, they have their own limitations regarding processing time, materials to be joined and characteristics of the joint. Further, ease of processing and environmental hazards, are some of the issues that need to be addressed. Thus a more versatile, faster and cleaner process could have a huge impact on production. The investigations reveal that application of microwave energy as a tool in materials processing is not only a green manufacturing process, but also significantly faster at relatively low investment. Microwave materials processing can give an alternative to high energy consumption heating techniques that are commonly used in industries [1].

Microwave material processing is attracting interest as a green technology for conserving energy and improving efficiency in conventional industrial processes for mitigating CO_2 emissions. Because of various advantages over conventional methods, such as rapid and selective heating, as well its ability to provide internal heating of substances, microwave heating can reduce the time and lower the temperature necessary for material processing. [2]. Microwave is a radio wave, which is one of the electromagnetic wave. Since electromagnetic wave is spread by the interaction of electric field and magnetic field. Microwaves are electromagnetic waves with wavelengths 1mm to 1m and equivalent frequencies from 300MHz to 300GHz. For microwave heating 0.915GHz to 2.45GHz frequencies are commonly used. As per the Federal Communication Commission (FCC) reserves the use of microwaves to 915MHz and 2.45GHz for heating purposes in various fields [3].

Material joining is one of the important manufacturing processes which are used widely in industries for production of complex parts. Heating of material during joining/welding is important part of process, which is still uncontrollable. This attempts the heating of material through microwave radiation and its application in different fields of engineering and technologies.

1.1 Microwave Joining

Microwave welding is a form of electromagnetic welding, similar to radio frequency, laser, induction and IR welding, using a radiation frequency of typically 2.54 GHz. Microwave materials processing can give an alternative to high energy consumption heating techniques that are commonly used in industries. In microwave processing, energy is directly transferred to the material through interaction of electromagnetic waves with molecules leading to volumetric heating. Heat is generated internally within the material, instead of originating from the external sources, and gets transmitted outward as shown in the below figure1.2 and figure 1.3. Hence, there is an inverse heating profile, 'inside-out' unlike in a conventional heating 'outside-in' [1]



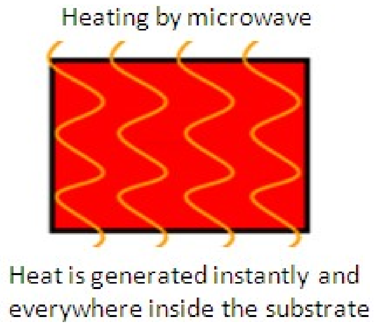


Figure 1.2: Heating Mechanism for Microwave heating from inner to outer surface

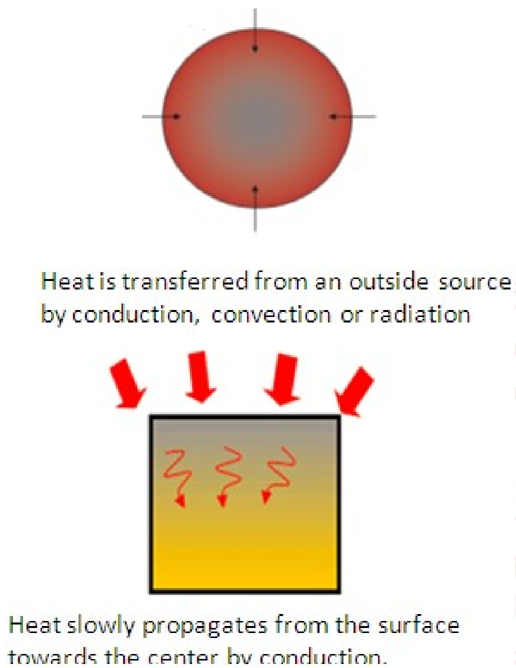


Figure 1.3: Heating Mechanism for Conventional heating from outer to inner surface

The following figure1.4 shows the joining of two similar or dissimilar materials using microwave joining technique by adding the interfacing joining powder to produce the joint.

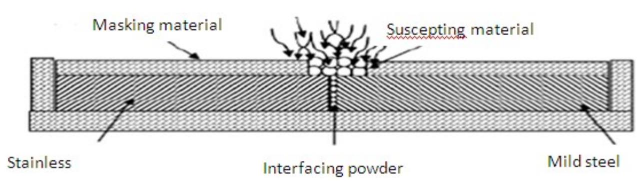


Figure 1.4: Principle of microwave joining of two materials

Figure 1.4: Principle of Microwave Joining of Two Materials

1.2 Research Developments in Microwave Joining

After reviewing literature, various developments related to microwave joining of metals and alloys have been categorized into; specimen based, susceptor based and interface powder based developments.

Specimen Based Development: Different types of specimen ranging from thin sheets to bulk metallic materials have been joined using microwave joining process. Dimensions and geometry of the cross-section are the parameters which play a significant role in joining. This is because, time required for melting and joining depends a lot upon these parameters. Joining of rectangular as well as circular cross-sections of different sizes has been investigated by many researchers.

Susceptor Based Development: Microwave joining of metallic materials is mostly performed using some form of susceptor material. However it does not mean that susceptor-less joining is not possible. MHH technique has been widely used by many researchers for joining of metallic materials. MHH can be achieved using two methods viz., use of separate heat source such as electric furnace in combination with microwaves; and; using external susceptor that efficiently couples with the microwaves. In latter method, susceptor is used as microwaves absorbing material. When microwaves incident on susceptor, its temperature increases beyond its melting temperature results in transfers of heat to metallic material in conventional mode. After gaining heat the temperature of metals increased up to some critical value. After reaching at critical temperature, they start direct coupling with microwaves. Generally charcoal powder is used as a susceptor medium and to concentrate the microwaves for localized heating. It is easily available, soft and of lesser cost. Placement of susceptor is very important to ensure selective heating in joining zone. It is a good practice to place a susceptor as near as possible to joint area.

Interface Powder Based Development: Materials with good absorbing characteristics and ability to efficiently convert microwave energy into heat can be directly heated and joined. But low dielectric loss materials such as metals require the use of an interface material during microwave joining. Most of the researchers used Nickel based powder at interface between the joints. Interfacing slurry which consists of interfacing powder and an epoxy resin (Bisphenol–A, Blumer 1450XX) is used as bonding agent. Epoxy resin helps in binding the interface powder particles together and thus helps in producing a smooth joint. Thin layer of slurry is formed at the interfacing gap. Increase in temperature of the joint zone results in evaporation of the epoxy resin and the interfacing gap is filled with molten interfacing powder particles. Various interfacing material was used during experiments by researchers. Out of all bonding material Nickel based powder has better capability of coupling with SS and has good weld ability. Researchers concluded that joining of MS and SS, SS-SS can be done using 95% Nickel based powder and 5% epoxy resin which formed good joint.

The brief observations are highlighted from the researchers work and are presented here for better understanding.

Siores and Rego [4] have discussed pioneering work and developments in the area of microwave applications into materials welding and joining. In particular, the various microwave techniques for welding metals using microwave induced plasma jet, and joining polymers and ceramics utilizing electromagnetic field focusing facilities. Their concluding remarks point to the encouragement of more efforts in this new field of materials processing using microwaves.

Ravindra et al. [5] studied the joining of bulk metals using microwave energy. The joining of Inconel-625 alloy has been effectively carried out through microwave hybrid heating. Characterization of the microwave developed joints is done through SEM, XRD, UTM and Vicker's micro hardness tester.

A. Sonnad et al. [6] have joined Graphite to 304-Stainless Steel (SS) and Copper (Cu) by actual metal brazing technique. They have joined the substrate materials under varying load and brazing temperatures and have through examined the interface characteristics of both brazed joints by SEM, EDAX, EPMA and XARD analysis. They also correlated their findings with mechanical property evaluation i.e. shear test and micro hardness test.

Amit Bansal et al. [7]have reported the joining of stainless steel-316 to stainless steel-316 in the bulk form, carried out by placing stainless steel-316 powder at the interface and through targeted heating using microwave hybrid heating. The trials were carried out in a multimode microwave applicator at a frequency of 2.45 GHz and power 900 W. The developed joints were characterized using X-ray diffraction, field emission SEM equipped with energy dispersive X-ray spectroscope and measurement of Vicker's micro hardness, porosity and tensile strength.

Srinath et al. [8] have investigated micro structural and mechanical properties of microwave processed dissimilar joints. Microwave joining of SS-316 to mild steel in bulk has been carried out successfully in microwave multimode applicator at 2.45 GHz and 900 W. Bulk joint has a Vickers micro hardness 133 Hv and porosity of bulk joint has been observed to be 0.58 %. The microwave processed dissimilar joints paraded tensile strength of 346.6 MPa with an elongation of 13.58 %.

Gupta and Kumar [9] have discussed the joining of stainless steel 316 by microwave energy using Nickel based powder as a sandwich layer and domestic microwave oven. The developed joints were crack free however small porosity is observed during micro structural investigation n and observed that with increase in Nickel content and exposure time, the joint tensile strength increase significantly.

Prakash et al., [10] discussed on tensile strength of mild steel 1018 plates joined by microwave processing at three different power (800W, 850W and 900W) with same frequency 2.45GHz. Nickel based metallic powder with mesh size 50 micrometer used as a interfacing material and observed as increase in power, the tensile strength decreases while welding time increases, tensile strength increases.

Rajkuma and Aravindan [11] have studied the effects of graphite particle size, spatial distribution, normal load and sliding speed on the friction and wear performance of microwave sintered copper metal matrix composites and reported that the Copper–nanographite composites show higher wear resistance and low coefficient of friction compared to copper–graphite composites.

Srinath et al. [12]have explained a novel method for joining of copper in bulk using microwave energy in a multimode applicator at 2.45 GHz and 900 W. Microwave processed copper joints possessed significant tensile strength with significantly high elongation.

Rajkumar and Aravindan [13] have successfully sintered a MMC (copper and graphite) using microwave. Copper-graphite composite was prepared through powder metallurgy route. Both copper and graphite mixed together in which electrolytic copper powder having average grain size of 12µm & graphite having an average grain size of 50µm.

Agarwal [14] did a sintering, brazing and joining of metallic material using microwave energy In this research author has taken iron and steel, aluminum, copper, nickel, Mo, Co, Ti, W, Sn, etc. and their alloys have been sintered in microwave oven. Further these elements have been brazed and joined with microwave energy. Various metallic materials have been microwave processed in microwave cavity with 2.45 GHz frequency. It has been found that microwave sintered powders produces superior product.

Ammar Ahmed. [15] Investigated the characterization of Alumina (48%) and Zirconia (32%) and Silica (20%) at high temperature at different power through microwave processing and observed that strength of joint is greater than the base metal.

Chandrashekaran et al [16] did an experimentation to melt the metals through microwave processing. It was the first time in microwave material processing, when the melting of metals was carried out through microwave oven. Microwave melting of low temperature materials such as lead, tin, aluminum and copper was carried out with aid of susceptors. The microwave melting was found to be twice faster, less energy consumption and less time than the conventional melting.

CONCLUSIONS

The concept of microwave heating has explored its potential up to the mark of industries. The lower energy consumption with higher rate of heat generation due to volumetric heating accelerated the research in this field of processing materials. The most significant feature of selective heating is one of the main reasons behind its main use for metals joining. The joining of metals can be done by many techniques to make the high strength joints but microwave energy played a vital role in this field to join the metals with improved mechanical properties. There are many techniques to join the metals like welding, brazing, soldering, laser welding etc, but these all techniques consumes lot of energy and time. From the above literature review, it can be summed that the microwave assisted similar and dissimilar metal joints are found to be increased mechanical strength, clean and efficient than conventional ones.

The processing of materials through microwave energy has emerged as novel material processing technique for joining of materials. It is distinct to the researchers that there is a huge scope for innovative research works using microwave technology in future. The ability to process metals with microwave could assist in the manufacturing of high performance metal parts desired in many industries, for example in automotive and aeronautical industries.

Microwave material processing is comparatively new technology and alternative that provides new approaches for enhancement in materials properties with economic advantages through energy savings and accelerated product developments.

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