Review of Microwave Brazed Joint in Industry 4.0

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Abstract— *The industry 4.0 is a significant planning of digitation of manufacturing which optimize the operations of production line quickly and efficiently. The industry 4.0 greatly influences on metal processing (joining) with digitation of new power sources that can increase metal joining efficiency and quality. The microwave brazed joining is one of the special features of joining technique (such as quick joining, saving time and low cost) in manufacturing joining system that is the most considerable technique of joining for industry 4.0 initials. The microwave brazed joining technique is a process in joining of similar and dissimilar metals (alloy-based and thermoplastic) which are jointed with filler metal or without filler metal (or powder) via microwave hybrid heating (radiation). Generally, the metal melted drops were flowed into joining (welding) area via microwave heating processing that is cools to become a strong joint in microwave applicator. In this paper, the microwave brazed joint technique is reviewed and extracted its basic function and parameters. It is a best method related to setting parameters and joining process that its results were compared with conventional brazing technique for industry 4.0 initials which can reduce processing cost and cycle time in specific metal joining process area. In addition, this paper also addressed the issue of conventional brazed processing that provided the gap of traditional brazed joint from previous research on brazing in industrial fields. In the part of the merit microwave joining, the advantages of microwave heating were illustrated through case study and research testing. Other than that, this paper also introduced industry 4.0 for microwave joining process that is focused on benefits and contributions with microwave (radiation).*

Keywords— *Microwave Heating; Conventional Brazing; Industry 4.0*

I INTRODUCTION

In the past, the microwave heating processing was used for several food producing and industrial fields, such as, baking of meat processing, preheating rubber, preheating bacon of food, and drying pasta. Nowadays, the microwave heating was applied to thermoplastic, alloy-based metal and steel metal material. The main function of microwave heating is a volumetric heating which support to convert from electromagnetic energy to thermal energy and which has instantaneous, rapid and highly efficient (Zhang & Kong, 2015). The source of microwave may deliver to a base metal (specimen) via few of applicator system such as internal system (susceptor and separator) and external system (single mode and multimode probes). The microwave heating source can weld alloyed-based metal, steel and thermoplastic materials from radiation (Wise & Froment, 2014). In microwave joining technique, it was used to bulk material (metal powder) for metal joining that the joining of process implements at frequency of 2.45Ghz in microwave (Thomas Dutta, Shrey Sanwaria, Vanesh, & Sri Dhinakaran, 2017). In the welding and joining process, the joining technique of brazing was fully implemented on metal joining with special inner gas and filler metal. The brazing technique was considered as the most useful technique for metal joining and production line because it is efficient and in average cost (Khasempong Songsorn, Keartisak Sriprateep, & Sampan Rittidech, 2016). The brazing approach is a common technique in manufacturing fields that is known for ability of joining as dissimilar metals, as well as materials with different melting point (Niwat Mookam, 2019). From the conventional brazing process, the filler metal melting point of brazing decides the lowest suitable joining temperature (Janczak-Rusch, Kaptay, & Jeurgens, 2014). In modern brazing approach, the issue of joining heat sensitive materials was generally increased during the requires of reduced temperature and cycle time in joining process (Lehmert, et al., 2015). Meanwhile, the issue of energy consumption, material cost and safety implementing were strictly considered on brazing processing (Verma , Ghunage, & Ahuja, 2014). In industrial 4.0 initials, the microwave brazed joint is the most attractive technique of metal joining process that able to reduce material cost, more efficiency to joining metal, decreasing cycle time and safety operating.

This paper aimed to review the microwave brazed joint for industrial 4.0 that the best of method in microwave process was extracted from the case study and mechanical properties was analyzed from different way in joining part, as well as this article compare with between the microwave brazed joint and conventional brazed joint and recommend to novel method about microwave brazed joining for future research.

II STRUCTURE OF MICROWAVE BRAZED APPLICATION

In case of microwave heating from Arpita Roychoudhury and Vinay Sharma (2014), the property of electromagnetic interaction occurs between the microwave radiation (heating) and the object of metal. The electromagnetic interaction is fully controlled through the material dielectric properties (Arpita Roychoudhury & Vinay Sharma , 2014). The metal joining of microwave was divided into two parts that it included using with filler metal (or powder) and without filler metal (powder). Microwave joining (welding) without filler metal (direct heating) is only to joint from surface part of specimen with heating in microwave application and the microwave joining with filler metal (indirect heating) is the base metal to joint with filler metal or powder via heating in microwave application (microwave oven) that is given in Figure 1 (Potente, 2015). In this process, a filler metal (or metal powder) is added between the surface of parts in base metal, and the metal powder to be joined from heating factor under the radiation of microwave, and then it can pass with heating on target of parts being joined via thermal (heating) conduction.

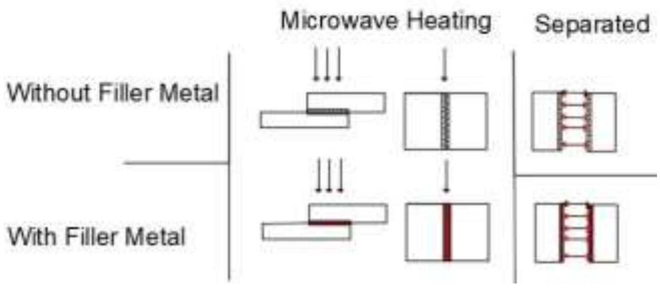

Fig.1. Microwave joining technique

From the microwave joining process, design of structure of microwave heating is a vital procedure which determined the metal joining with interface filler metal (or powder) from the microwave heating or radiation. Gupta and Kumar (2014) has investigated on microwave heating with stainless steel that they set to several mechanisms using novel method in microwave system as shown in Figure 2. For instance, refractory brick with cavity that it used to hold the specimen, charcoal powder is used to susceptor that it performed to concentrated of microwave heating (or radiations) in the joining surface, the sheet of graphite is used to separator which set between the interface filler metal (or powder) and charcoal powder for separated (Gupta & Kumar, 2014). These features can influence on metal joining quality and efficiency, as well as these components are control the quality of fusion zone of jointed metal (Pal & Samantaray, 2015). Calame, et al (2016) reported that microwave heating process is a complex joining technique that the electromagnetic waves support the heating in metal thermoplastic materials (Calame, et al., 2016). Aravindan and Krishnamurthy (2013) analyzed that the microwave heating was successfully applied to join the composites element of aluminum (30%) and zirconia ceramic that these specimens jointed with glass powder of sodium silicate (Aravindan & Krishnamurthy, 2013). The parameters of microwave also are the most important part in which lead to join of interface powder or metal in base metal. The common of microwave parameters are exposure time, interfacing material, susceptor and substrates (base metal) (Prateek Gupta, Sudhir Kumar, & Ajay Kumar, 2014).

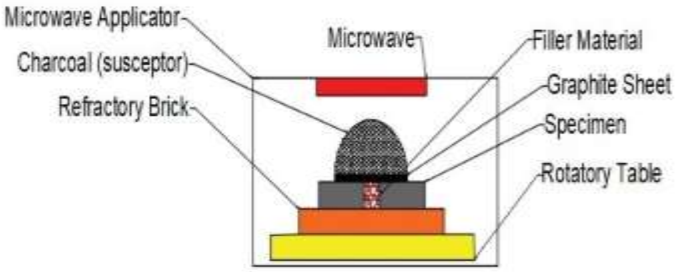

Fig.2. **Structure of microwave processing**

III ISSUES OF CONVENTIONAL BRAZING TECHNIQUE

The brazing joining process was started with similar or dissimilar metal to be joined. The conventional brazing is heated from heating source such as furnace, and the temperature is to reach suitable melting point for filler metal, then the metal drops flow into the gap. Subsequently, the welded bead is cooled from air and become to formation of brazed structure as shown in Figure 3 (Cadden, 2016). The conventional brazing process is to support the high temperature melting point and power resource for substrate (base metal). However, the brazing joining is conditional process that the melting point must be considered for metal joining application and some alloy-based base metals and filler metal need to lower melting point which lower point not easy to joint and control in conventional brazing process (Khoruno & Maksymov, 2014).

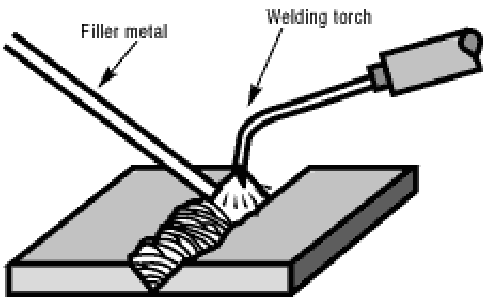

Fig. 3. **Process of conventional brazing**

Although the conventional brazing method is strong joint compares with others joining technique. However, the brazing processing is consumed of many of gas energy resource, while it increases the cost of material and resources (Hausner, Weis, Wielage, & Wagner, 2016). The issue of distortion also considered on traditional brazing process that it frequently occurs when processing in brazing such as deformation as shown in **Figure 4** (Diran Apelian, Bruce Boardman, & Roger Fabian, 2016).

Fig.4. Issue of distortion in brazing

III.I. Advantages of Microwave Brazed Joint

In the microwave joining process, Ziegler demonstrated to merit of microwave processing comparing with conventional brazing process. The microwave processing is able to non-contact heating that it is suitable for filled gap in high melting point of thermoplastics as a low thickness of molten state (Ziegler, 2016). Microwave radiation is high efficiency for generation and conduction. The microwave heating is only produced through the heating phase when the energy is using. The microwave radiation also known as cold heating equipment that can implement heating process with safety system (Santos, Valente, Monteiro, Sousa, & Costa, 2015).

IV INDUSTRY 4.0 FOR MICROWAVE BRAZED JOINING PROCESS

In the initials of industry 4.0, the new lightweight materials push into modern industrial market through efficient and sustainable uses of resources. For the materials, the polymer composites have replaced to conventional metal alloy composites for good mechanical properties and efficient joining processing. In the laboratory of Cambridge university, the researchers classified product quality by high-frequency technology, which the method increases the energy efficiency and productivity, especially, it decreases the material cost when the microwave is fully automation. The researchers also used the HEPHAISTOS-cavity which is a novel interior geometry for fast of heating that the interior process with arbitrary 3D contours is shown in Figure 4 (laboratory TWI of cambridge, 2019).

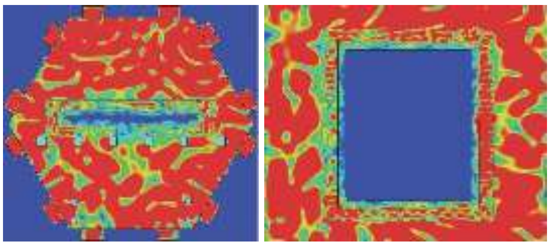

Fig.4. Microwave field distribution in HEPHAISTOS-cavity (TWI tools in Cambridge laboratory)

V SUMMARY

A review of basic function and structure of microwave brazed joint has been reviewed in this paper that are drawn through the following summary:

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In the structure of microwave brazed section, this paper begins by examining microwave structure, for instance, susceptor, separator, rotatory table, filler metal or powder, base metal and heating system. The set up of microwave system is important part of microwave research which can control quality of joining part with less energy consumption.

In the issue of conventional brazing part, this paper introduced to some problems of traditional brazing method in metal joining that it can implement to joint limitation of materials type and conditions of weather, as well as it used to common material with high energy consumption.

In the advantages of microwave brazed joining , this paper demonstrated several advantages of microwave comparing with brazing technique that the microwave heating process will replace to convention brazing process through low material cost, less energy cost and good joining.

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