

Casting of commercially available bulk copper by microwave melting process and its characterization

M L Shashank¹, M S Srinath² and H J Amarendra¹

¹ Department of Mechanical Engineering, Malnad College of Engineering, Hassan- 573202, Karnataka, India

² Department of Industrial and Production Engineering, Malnad College of Engineering, Hassan- 573202, Karnataka, India

Abstract. Metallic materials are known to reflect microwaves owing to lower skin depth. The present work demonstrates melting of commercially available bulk copper using Microwave Hybrid Heating (MHH) technique. Microwaves generated from a 3.3 kW furnace operating at 2450 MHz are used as a source to heat and melt copper. Complete melting of copper is achieved in 25 minutes. As-received and as-cast copper are characterized using X-Ray Diffraction (XRD) technique to study the phases present. Microstructural study of the as-cast copper under Scanning Electron Microscope (SEM) shows closely packed grain structure with negligible porosity. Hardness of the as-received and as-cast copper are also measured.

1. Introduction

Processing of material is very important in making them suitable for required applications. Nearly all of the material processing techniques involve heat as a major source of energy. Heat energy may be generated from conventional sources like fossil fuels, bio-oils, firewood or by non-conventional sources like wind energy, solar energy, tidal energy, etc. However, non-conventional energy sources are finally converted to electrical energy, which in turn is used in electric furnaces, induction furnaces and so on. Yet, all these sources results in conventional heating of the materials. Due to the transfer of heat from outer surface to inner core in the materials, conventional heating gives rise to temperature gradients [1]. Material and energy losses are the major outcomes of this nature of conventional heating [2]. Further, non-uniform heating, time consumption and operator hazard are the additional drawbacks of conventional heating of materials. The drawbacks of conventional heating of material processing can be overcome by processing of materials using microwave energy [3,4]. Fundamental characteristic which makes microwave processing as a better method is its ability to penetrate into the material and generating heat at the molecular level [5]. This in turn gives rise to uniform volumetric heating and reduces temperature gradients. However, metals reflect microwaves at room temperature [6]. This is for the reason that good conductors possess lower depth of penetration of microwaves, which makes it difficult to process metals in microwave environment. Literature study indicates that metals will be capable of absorbing microwaves only at elevated temperature [7]. Hence, metallic materials have to be brought to certain elevated temperature to make them absorb microwaves. Microwave Hybrid Heating (MHH) technique provides a solution for processing of metallic materials through microwave energy. MHH is a technique where susceptor materials which are capable of absorbing microwaves are used to generate heat energy and transfer it to the metallic material [8,9]. Heat from susceptor increases the temperature and aids in direct absorption of microwaves by the metallic materials. In the present work, commercially available copper in bulk form is melted by MHH technique and cast. The cast copper is subjected to metallographic and mechanical characterization.



2. Experimentation

A schematic representation of the experimental setup of microwave melting of commercially available copper is shown in figure 1. A microwave furnace with 3.3 kW power which is operating at 2450 MHz is used to heat and melt bulk copper, having melting temperature of 1083 °C. Infrared Pyrometer is used to record the temperature of the target metal. Maximum temperature is set to 1100 °C. Experiment is carried in non-vacuum environment. As indicated by the literature study, lower skin depth of metallic materials causes reflection of microwaves from its surface, which makes it impossible for processing of metallic materials in microwave environment. Due to higher conductivity, electron cloud formation is caused when microwaves interact with metallic materials. Hence, Microwave Hybrid Heating (MHH) technique is used to process bulk copper in the present work. Around 250 g of bulk copper is weighed and taken in a graphite crucible and covered with refractory casket. Refractory casket acts as an insulation material. Refractory casket is covered with glass wool for further insulation. Silicon Carbide (SiC), in the form of a small brick is used as a susceptor material. Microwaves irradiated are reflected by bulk copper; however they are absorbed by the susceptor, which converts microwaves into heat energy. Developed heat energy is transferred to bulk copper. After attaining certain higher temperature, skin depth is increased and microwaves are directly absorbed by bulk copper. The temperature at which metals begins to absorb microwaves is called as 'Critical Temperature (T_c)' [10]. Once the critical temperature is reached, the target material undergoes direct volumetric heating by microwave absorption and also experiences conventional heating by the susceptor until complete melting is achieved. Molten copper is solidified by pouring it to previously prepared sand mould. As-cast copper is sectioned to prepare specimens for required characterizations accordingly.

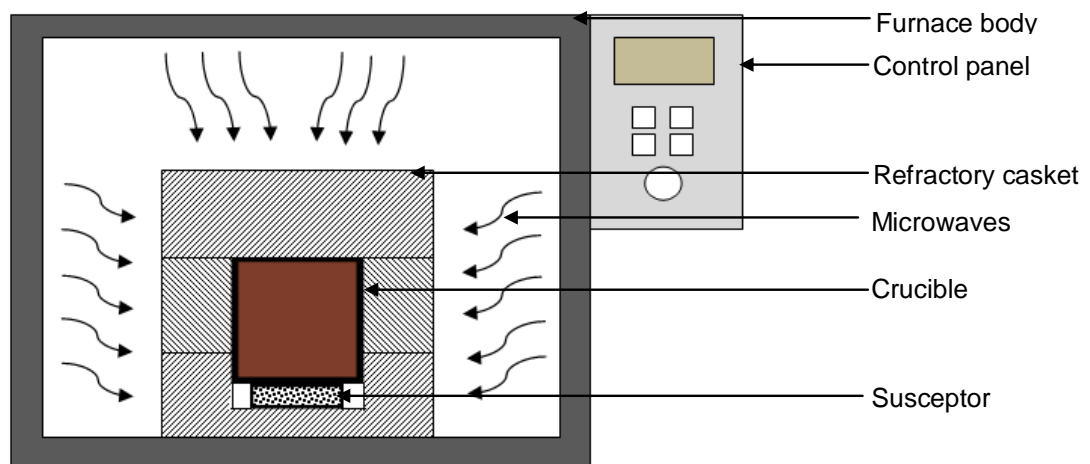


Figure 1: Schematic of microwave processing setup

3. Results and discussions

3.1. X-Ray Diffraction Study

Analysis of X-Ray Diffraction was carried out at a scanning rate of 1° / minute. Pattern obtained was analyzed to study the phases present in as-received and as-cast copper. Typical XRD patterns for as-received and as-cast copper are shown in figure 2. XRD profile of the as-received copper consists of two high intensity peaks at 63.24° and 75.04°, corresponding to Cu₂O and Cu respectively (figure 2a). XRD profile of as-cast copper is presented in figure 2b. Phases recognized in as-cast copper from XRD analysis are Cu and CuO. XRD spectrum of as-cast copper has three high intensity peaks; two at 43.79° & 50.94° which shows dominant Cu phase and one at 74.59°, showing CuO phase. The presence of oxide in as-cast copper could be attributed to conducting the experiment in non-vacuum environment.

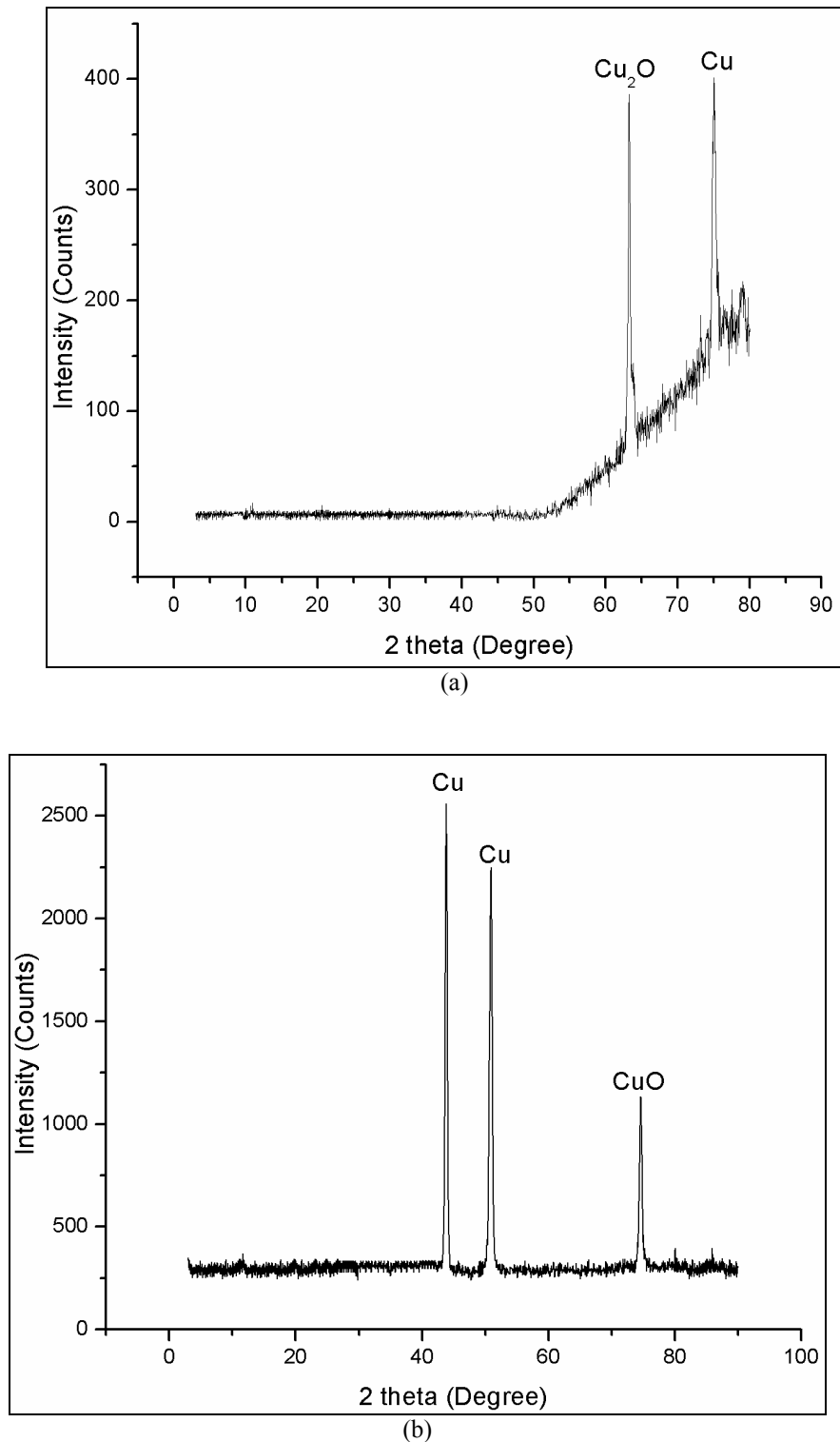


Figure 2: XRD spectrum of (a) as-received (b) as-cast copper

3.2. Microstructure study

Scanning Electron Microscope (SEM) was used to study the microstructure of as-cast copper. Figure 3 shows micrographs of as-cast copper at different magnifications. As observed from the micrographs,

grains are uniform and densely packed. Uniform and dense grain structure of as-cast copper could be due to volumetric heating by microwaves, which results in uniform grain growth. However, negligible amount of porosity in the cast copper is also observed (figure 3b). Closely packed grain structure in as-cast copper might have resulted in enhancing the hardness of the material.

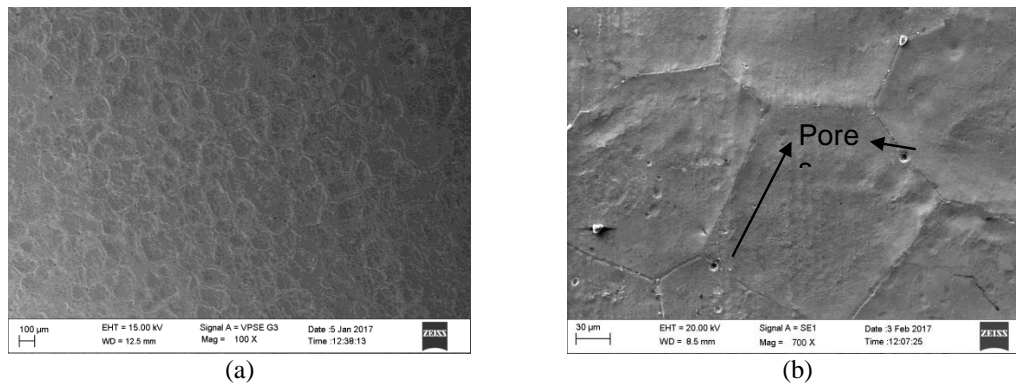


Figure 3: SEM images of as-cast copper

3.3. Microhardness study

Hardness of a material plays a very significant role in assessing the application of that particular material. Hence, microhardness study was carried out using Highwood's Vicker's Microhardness Tester. Vicker's microhardness measurement was carried out on both as-received and as-cast copper by applying a load of 1000 g for a dwell time of 30 s. Three indentations were made by maintaining a distance of 3 mm between indentations and their average microhardness value was considered. A descriptive mapping, showing the variation in microhardness value of as-received and as-cast copper can be seen in figure 4. Average hardness of the as-received copper is found to be 62 VHN, while that of as-cast copper is 78 VHN. Increase in hardness value of as-cast copper may be attributed to closely packed grain structure.

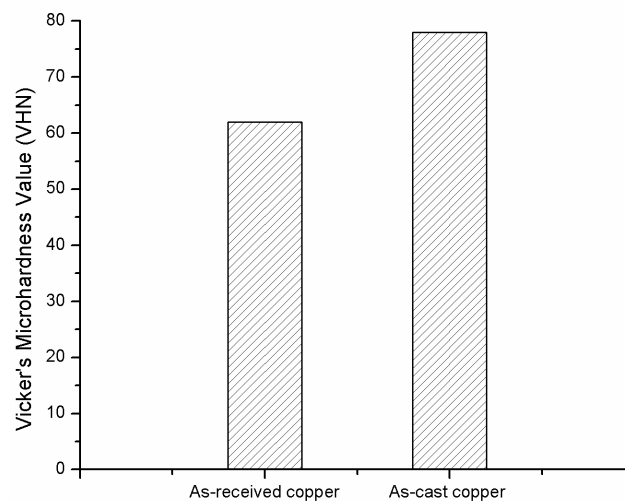


Figure 4: Column chart showing Vicker's microhardness values

4. Conclusions

Commercially available bulk copper was melted by Microwave Hybrid Heating (MHH) technique using a 3.3 kW microwave furnace and the following conclusions are drawn from the present work;

- Shift in peaks is observed in the as-cast copper, which could be due to residual stress.
- Oxide formation is confirmed from XRD analysis, which may be attributed to conducting the experiment in non-vacuum environment.

- iii. Uniform microstructure with closely packed grains is visible in as-cast copper, which might have been taken place by molecular heating by microwaves. However, negligible porosity is also visible.
- iv. As-cast copper exhibits enhanced microhardness value, which may be due to closely packed uniform grain structure.

Acknowledgments

Authors would like to acknowledge All India Council for Technical Education for providing financial support for the present work [Ref. No. : 8-201/RIFD/RPS/POLICY-1/2014-15]

References

- [1] Srinath M S, Sharma A K and Kumar P 2011 Mater. Des. **32** 2685.
- [2] Moore A F, Schechter D E and Morrow M S 2003 U.S Patent 20030089481
- [3] Metaxas A C and Meredith R J 1983 Industrial Microwave Heating, London
- [4] Gupta M, Leong E W W and Wong W L 2007 Microwaves and Metals, Singapore
- [5] Thostenson E T and Chou T 1999 Compos. Part A **30** 1055
- [6] Srinath M S, Sharma A K and Kumar P 2011 Proc. IMechE Part B: J. Eng. Manufac. **225** 1083
- [7] Mishra R R and Sharma A K 2016 Compos. Part A **81** 78
- [8] Sharma A K, Srinath M S and Kumar P 2009 Indian patent 1994/Del/2009
- [9] Badiger R I, Narendranath S and Srinath M S 2015 J. Manuf. Process. **18** 117
- [10] Mishra R R and Sharma A K 2016 Crit. Rev. Solid State Mater. Sci. **41** 217.