Development and Characterization of Electrically Conductive Metal Matrix Composite Castings Through Microwave Processing

A dissertation report submitted
in partial fulfilment of the requirements for the
award of the degree of

Master of Engineering
in
Production & Industrial Engineering

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CERTIFICATE

I hereby declare that the report entitled **"Development and Characterization of Electrically Conductive Metal Matrix Composite Castings Through Microwave Processing"** is an authentic record of my study carried out as requirements for the award of degree of Master of Engineering in Production Engineering at Thapar University, Patiala under the supervision of Dr. Dheeraj Gupta & Dr. Vivek Jain, Assistant Professor, Thapar University, Patiala during July 2014 to June 2016. No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

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ACKNOWLEDGEMENT

Words are often less to reveals one's deep regards with an understanding that work like this can never be the outcome of a single person. I take this opportunity to express my profound sense of gratitude and respect to all those who directly or indirectly helped me through the duration of this work.

I express my deep sense of gratitude and a very sincere thanks to my guide **Dr. Dheeraj Gupta** & **Dr. Vivek Jain,** Assistant Professor, Mechanical Engineering department, Thapar University, Patiala for their indefatigable guidance, constructive suggestions and full support which helped me in the accomplishment of this study. I am highly indebted to them for their painstaking efforts and invaluable suggestions during the period of work.

I would like to thank all members and employees of Mechanical Engineering Department, Thapar University, Patiala for their everlasting support.

I am obliged to staff members of Mechanical Engineering Department for the valuable information provided by them in their respective fields. I am grateful to **Mr. Satnam Singh** and **Mr. Sarabjeet Kaushal, Mechanical Engineering Department** for their cooperation throughout the period of my assignment.

In the end, I wish to express my deep sense of gratitude to my parents and my siblings for supporting and encouraging me at every step of my work. It is the power of their blessings, which has given me the courage and confidence for hard work.

SOURABH BOHRA

ABSTRACT

The use of microwave vitality in heating of materials is not new; in any case, more current applications are rising in the field of material processing, which permitted microwave handling as novel processing strategies. The prior reported work depended on sintering of numerous ceramic materials, which are better absorbers of microwaves. The applications were further stretched out to metallic powders. As of late, scientists have created strategies to process bulk metallic materials. The advancements reported were in the field of joining of bulk metals and claddings on different steels. The melting and casting of bulk materials is a newer approach which has not been explored yet. The present work focuses on the development of metal matrix composite castings with copper as the matrix material and tungsten and molybdenum as the reinforcing materials in different weight % by melting of metallic powders through microwave processing routes. The compositions taken were pure copper, Cu-10 wt. % Mo, Cu-10 wt. % W, Cu-30 wt. % Mo, Cu-30 wt. % W, Cu-50 wt. % Mo, and Cu-50 wt. % W. The fabricated composites were then characterized by SEM, EDS, Vicker's micro-hardness, XRD, and four point probe resistivity measurement. Comparative analysis was carried out for the fabricated samples with the conventionally prepared sample. Results revealed that the matrix material and reinforcing materials were successfully fabricated as the metal matrix composite castings and the reinforcing materials were uniformly distributed all over the matrix. EDS reveals that the change in composition after the processing of metallic powders was approximately the same as the composition taken initially. Mechanical characterizations shows that the microwave processing enhances the mechanical strength due to better metallurgical bonding and diffusion, with lower processed defects. The vicker's micro-hardness reveals that as the wt. % of reinforcing material increases in matrix, the vicker's micro-hardness tends to increase. The maximum hardness achieved was 143 Hv for Cu-50 wt. % W. Electrical characterizations revealed that as the wt. % of reinforcing material increases, the electrical resistivity tends to increase and electrical conductivity tends to decrease. Further the thermal conductivity was also calculated for all the samples which reveals that it also shows the same trend as electrical conductivity.

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Chapter 1

INTRODUCTION

In the era of developing and creating innovations, the bunches of progressions are being identified inside the field of engineering. The commercial enterprises are needing forward for better than ever handle systems. The extensive variety of cutting edge materials together with metals, composites, non-metals and ceramics can be prepared just and successfully through these advances. These materials can be with the improvement of innovation, new materials appeared and to handle those materials high vitality efficient techniques were created. The issues identified with these advancements like, high vitality utilization, high manufacturing cost and so forth. The push for bringing down the higher vitality proficient preparing systems lead to scientists to concentrate on procedure techniques to think in the direction of less power, processing time. This may leads to turn out prime quality materials. The microwave vitality lead the specialists to investigate the field of microwave handling towards entirely unexpected regions of materials creating. The one of a kind attributes of microwaves drove the specialists to investigate the capability of microwave heating in various zones. As of late, part of the investigation has reportable in the field of joining, sintering, and cladding and so forth and applications are as yet expanding towards the melting of metals which may be named as casting. This part will represent the essential outline of microwave heating of materials and applications in shifted fields.

1.1 Introduction to Microwaves

The microwaves are the part of the electromagnetic (EM) range in which electric and magnetic waves proliferate opposite to each other with frequency scope of 300 MHz to 300 GHz [Keyson et al., 2007]. The wavelength of these waves shifts from 30 cm to 1 mm in air as shown in below Fig.1.1, which speaks to the EM range. This scope of frequency permits microwaves to be utilized as a part of an assortment of utilizations including correspondence frameworks, food processing's, medicinal purposes, industrialized heating, material handling and so on [Ku et al., 2001]. The basic frequency on which local microwaves in India works is 2.45 GHz, which is basically utilized for heating foodstuffs. The heaters have been produced for material handling purposes which are utilized as a part of numerous mechanical applications and they chip away at higher frequencies running from 915 MHz to 18 GH [Lauf et al., 1993, Thostenson et al., 1999].

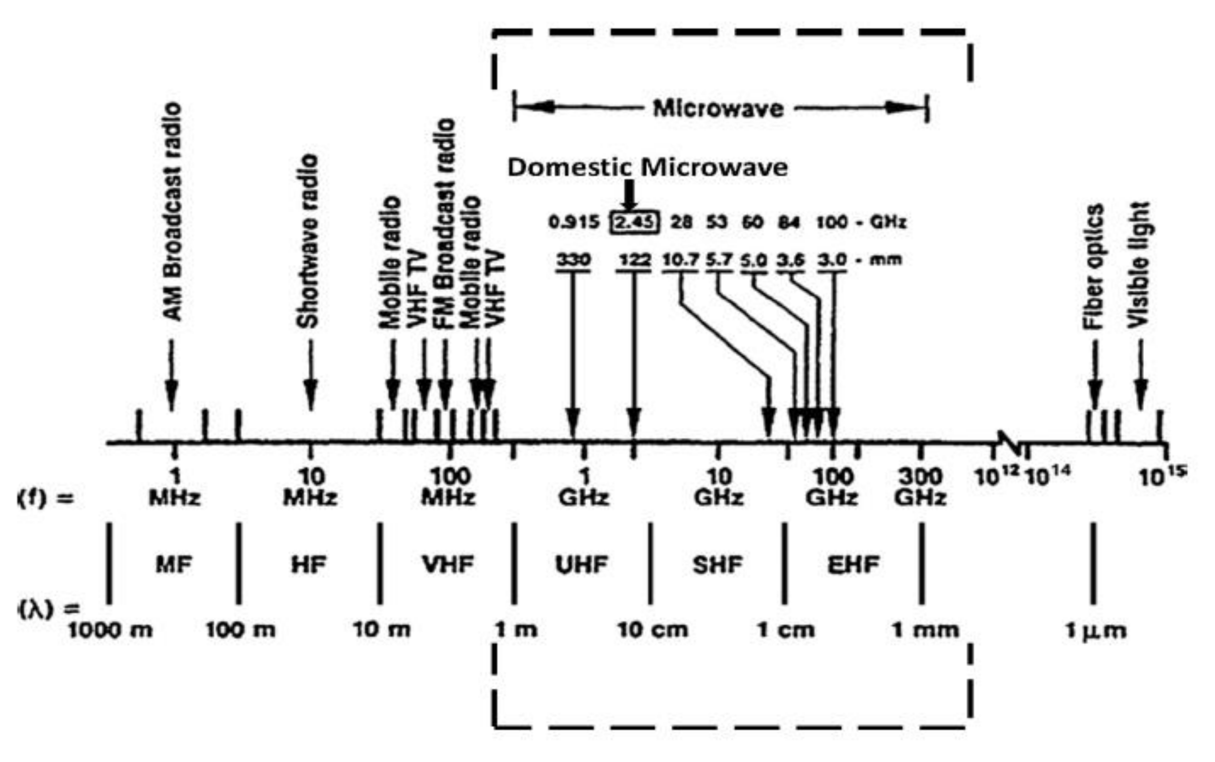


Fig 1.1 Frequency and wavelength spectrum of electromagnetic radiations [Oghbaei et al., 2010].

The essential utilizations of microwaves were included in correspondence frameworks including RADAR, satellite correspondences and television propagation. The heating impacts of microwaves were accidently found by Spencer and in the year 1945 the principal patent [Spencer et al., 1950] of microwave oven for heating intentions was filled. The microwave oven over the time gotten to be one of the mainstream household thing for doing heating of foodstuffs because of the elements of higher heating rate, low preparing time and lower vitality utilizations. These good and one of a kind attributes of microwaves pulled in numerous analysts towards the potential outcomes of handling distinctive materials utilizing microwave heating marvel.

The use of microwave energy was further developed in the field of material processing to gain the advantages of higher heating rates with having lower processing time [Thostenson et al., 1999] i.e. used tires recycling, metallic materials and ceramic processing etc.

1.2 Characteristics of Microwave Material Processing

The microwave heating has different attributes because of which it has gotten to be mainstream for heating low temperature applications and also high temperature applications. The retention of microwaves straightforwardly at the atomic level of coupled materials with the microwaves relates to volumetric heating of that material, which thusly prompts the quick heating and diminished thermal gradient inside the materials being handled. The uses of microwaves for heating of materials were further investigated by analysts [Bajpai et al., 2012, Menendez et al., 2010, and Zhou et al., 2003] in the field of material preparing so as to pick up the upsides of higher heating rates combined with lower handling time. These investigates drove the uses of microwaves in chemical reactions, vulcanization of elastic, handling of ceramics and metallic materials, steel making, elective wellsprings of vitality recuperation [Agrawal, 2010] and so forth. The volumetric heating component in microwave handling prompts high heating rate and this element beats the restriction of conventional heating and expends less preparing time, which straightforwardly brings about less vitality utilization. An exceptional component of particular heating in microwave preparing is that microwaves straightforwardly affects at the focused area, which assistants diminishes heat influenced zone up to a degree and lessens the deformities at the same time. The work completed by a few analysts in this field reported enormous measure of funds in preparing time which relates to less power utilization amid microwave handling of materials [Menendez et al., 2010].

The real qualities of microwave materials handling are represented by below Fig. 1.2, which demonstrates that microwaves can be utilized for preparing of an assortment of materials with higher heating rates and ecologically well-disposed attributes. The immediate retention of microwaves to the nuclear level of microwave coupled materials prompts volumetric heating of material from inside the materials, this prompts fast heating rates with less thermal gradient inside handled materials. The fast heating rates emerges due to volumetric heating normal for microwaves, which prompts let down the handling time and attributable to which it devours less vitality in contrast with traditional heating frameworks. The method of particular heating of material by presenting microwaves to the centered area, permits localized heating which results in lower heat affected zone (HAZ) and lower deformities amid preparing.

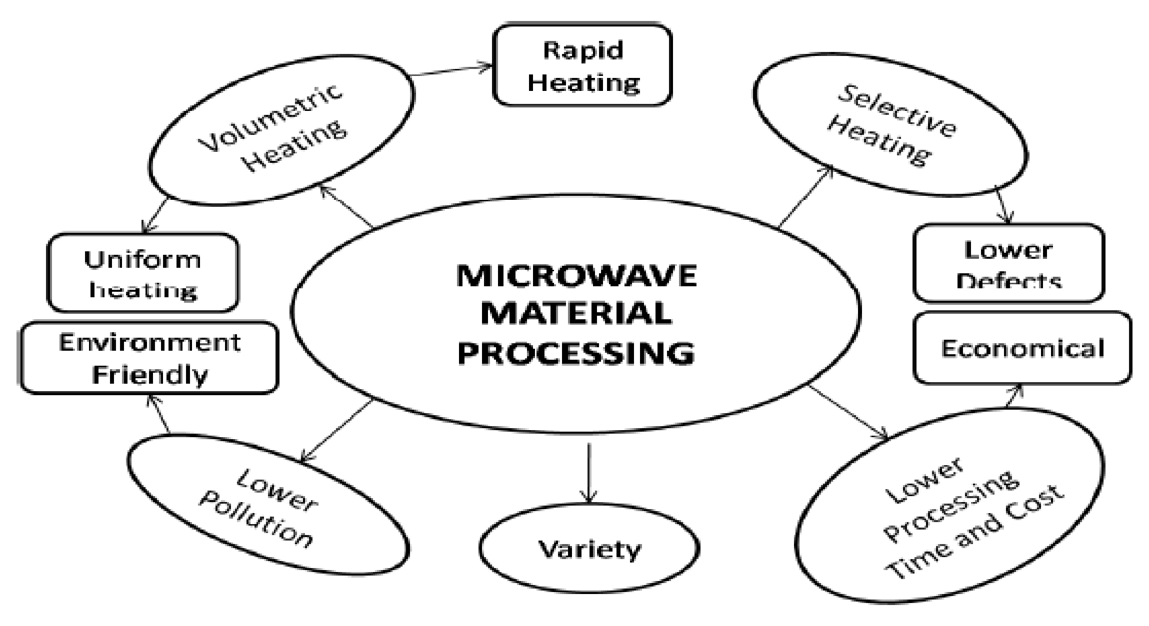


Fig. 1.2. Unique characteristics of microwave materials processing.

The work of different analysts [Ahmed et al., 2001, Bruce et al., 2010, and Giberson et al., 2009] reported colossal reserve funds in terms of handling time and power necessities amid microwave preparing. The microwave handling of numerous ceramics was accomplished effectively, with improved diffusions, densifications and enhanced properties and positive results were accounted for by numerous specialists [Fang et al., 1997, Wang et al., 2008, and Wong et al., 2007]. The sintering of the ceramic through microwave preparing course have been completed effortlessly and successfully, with upgraded dissemination rates and enhanced properties. In the wake of having an enormous accomplishments in field material handling through microwave ovens, this innovation is being executed at the mechanical level for dissolving purposes through microwave heaters.

1.3 Microwave Material Interaction

Heating/Melting is the most well-known procedure in every single manufacturing industry yet there are loads of techniques to complete these procedures. Concerning as microwave heating is concerned, it is normally utilized for heating the food items as a kitchen apparatus and with the entry of time the utilization of this innovation is being seen in various fields, for example, engineering, textile and chemical enterprises. There are heaps of electric based heating advances, which use the particular groups of electromagnetic range, for example infrared, induction, ultraviolet and microwave heating. Microwave innovation is surely understood for nourishment and elastic preparing, yet there is a developing interest towards the commercial ventures to legitimately use its potential for different assembling forms (managing metallic materials) and for the treatment of different waste-streams and so on. Microwave preparing prompts vitality sparing while it is contrasted with the customary ones. Recently, microwave handling prompts 10 – 100 times less vitality utilization and works 10-200 times quickly. The material heating happens by direct retention of microwaves all through the volume of material. This trademark (volumetric heating) of microwave heating prompts shorter preparing times, improved diffusion, superior microstructures, enhanced mechanical properties, eco-accommodating, conservative framework, higher efficiencies, energy savings and so forth over other traditional material handling innovations. The heating of materials happens by direct assimilation of microwaves all through the volume of material. In any case, the powerful and productive heating of materials through microwave radiations rely on the physical properties of the materials and these properties plays a prevailing part in choosing the processability of materials by microwaves. Different materials can associate in an alternate way with the microwaves. Three kinds of materials are presented to the microwaves and their outcomes are characterized in Fig. 1.3.

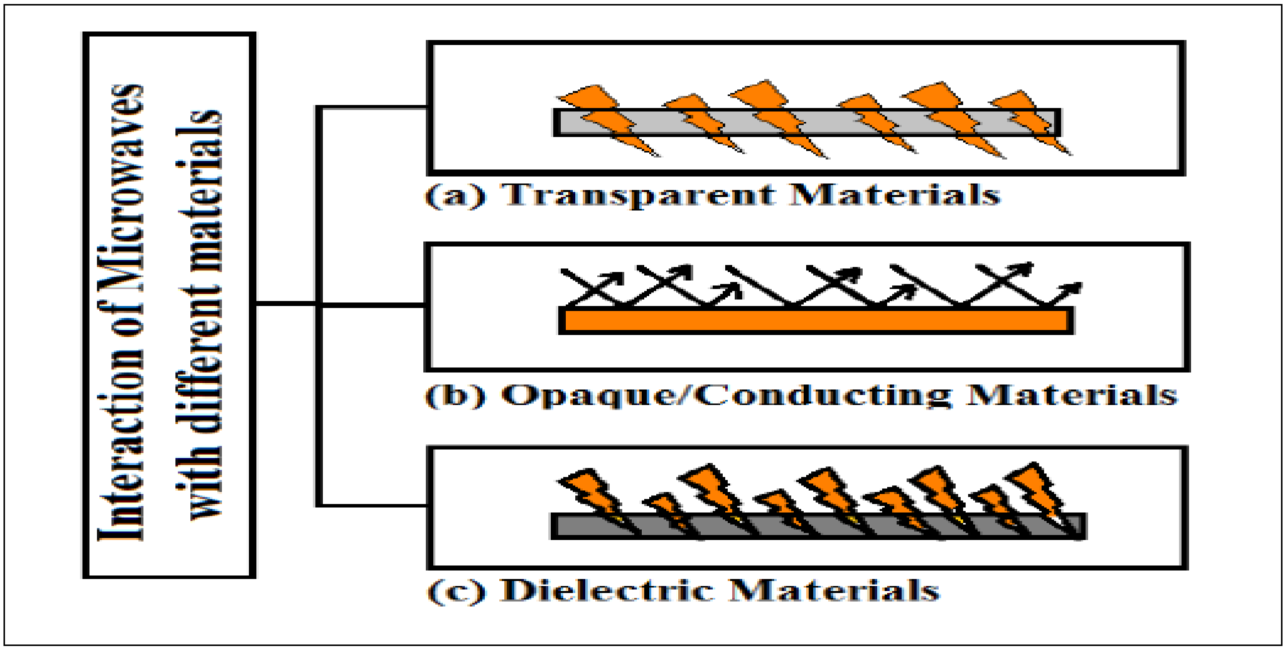


Fig. 1.3. Interaction of microwaves with (a) transparent materials, (b) conducting/opaque and (c) dielectric materials.

The transparent materials, for example, glass does not have the capacity to retain microwaves and it specifically permits them to go through without having any sort of loss and thus heating does not occur when beams are affected by it. Then again bulk metallic transmitter materials don't permit microwaves to pass and neither absorbs, however, causes reflection when these opaque surfaces are presented to microwaves. This prompts the plasma development and causes surficial heating of the body. In any case, second rate class of materials are known as dielectric materials, which has a tendency to ingest the microwaves and heating is gotten by the change of radiation into the heat and this rule of heating is known as microwave heating [Singh et al., 2015]. A detailed view of how it interacts is shown in below Fig. 1.4.

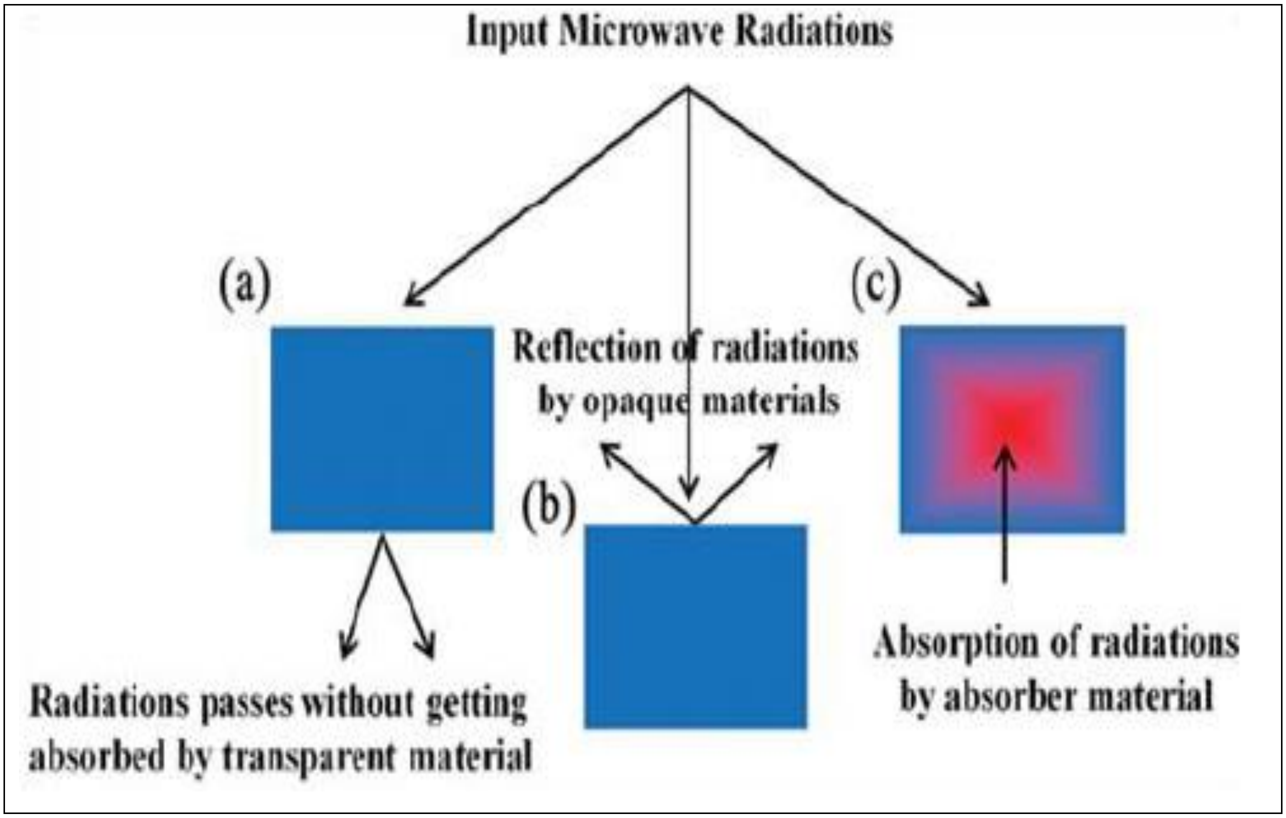


Fig. 1.4. Microwaves–materials interactions [Singh et al., 2015].

1.4 Basic Principles of Microwave Heating

International Electro-technical Commission defines, “Microwave heating of materials is carried out mainly through their molecular motion and their ionic conduction by the action of electromagnetic waves of 300 MHz to 300 GHz to heat dielectric materials". The basic principle behind the microwave heating is shown in Fig. 1.5.

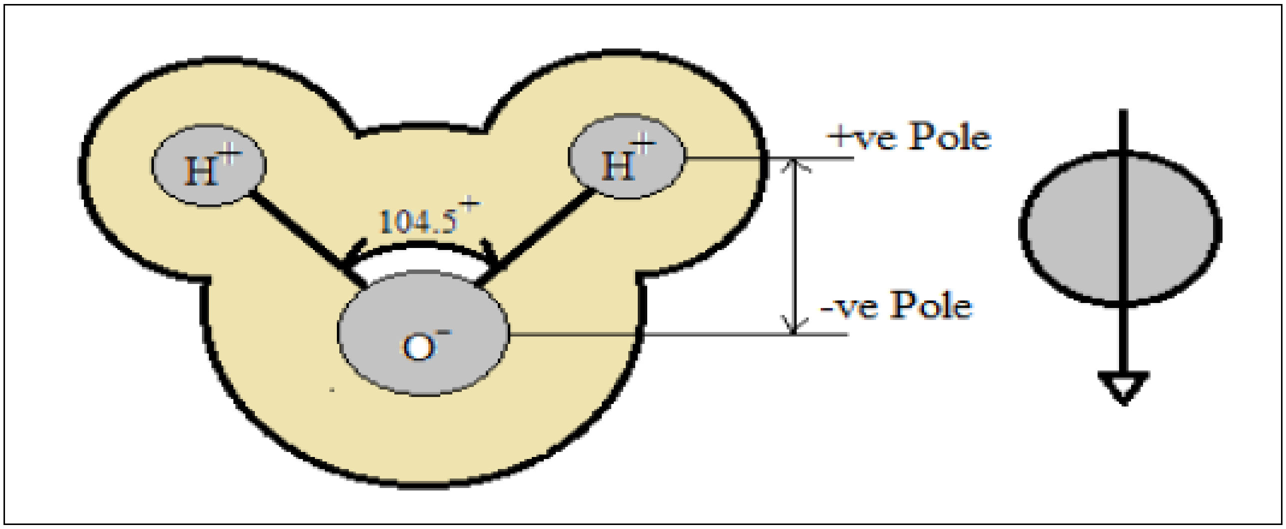
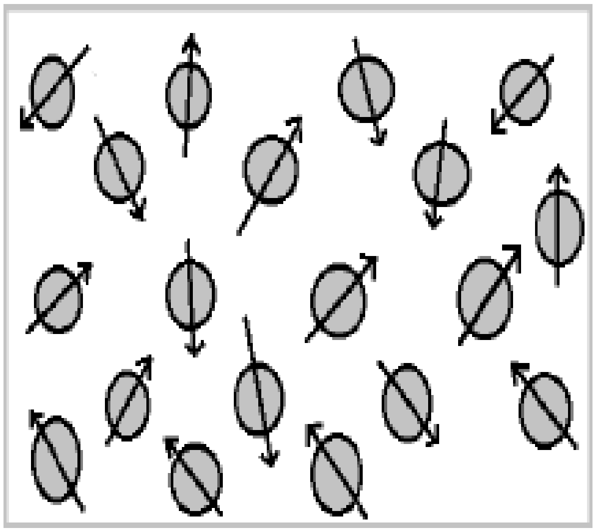


Fig. 1.5. The structure of water molecule and image of permanent dipole. [http://www.microdenshi.co.jp/en/microwave].

The structure of water atom as appeared in Fig. 1.5, which comprises of two hydrogen molecule and one oxygen molecule. It doesn't have electric charge as aggregate, an oxygen molecule is limited with two hydrogen atoms at a point of 104.5°. Those two take a little charge of each in addition to (+) and short (-) to shape a dipole.



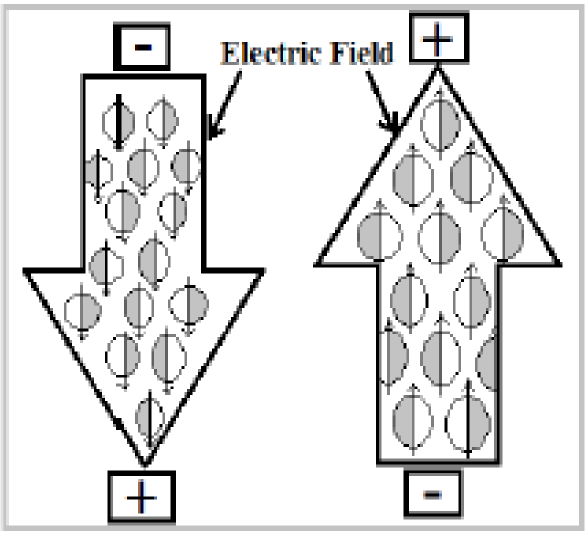


Fig. 1.6 (a). The structure of water molecule without electric field.

Fig. 1.6(b): The structure of water molecule with external electric field.

Another rule clarified that when there is no outside field it has set a parity as shown in above Fig. 1.6 (a) yet when subjected to outer electric field, dipole will swing to electric field as appeared in Fig. 1.6 (b).

1.5 Production of Microwaves in Magnetrons

In a microwave oven, microwaves are created by a gadget called magnetron. It is as an empty tube, with tube-shaped cathode going through the middle and outside of tube molded with a few holes going about as anode. In this manner, the electric fields exist in the hole inside the tube [Gallawa et al., 2008], which is shown by Fig. 1.7.

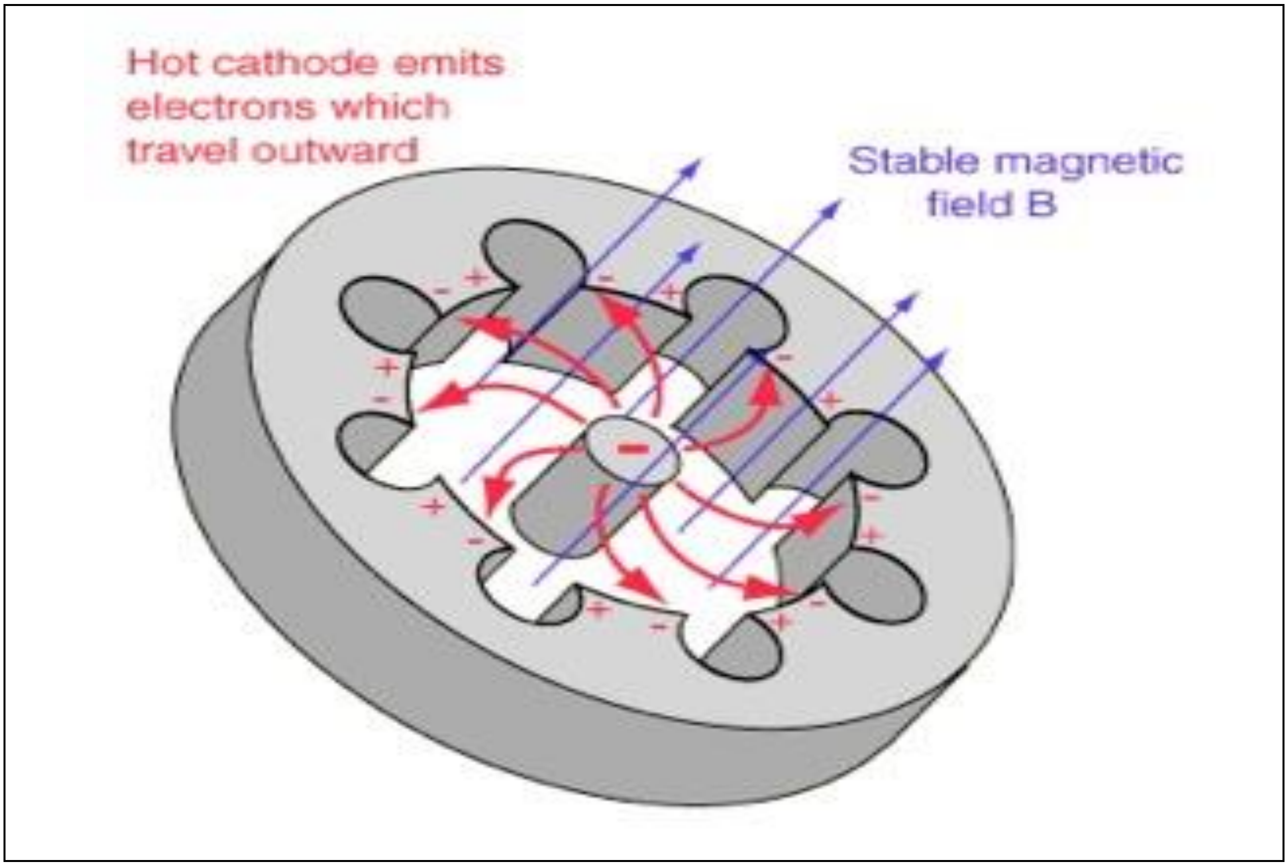


Fig. 1.7. Electrons emitted from the cathode undergo curved motion towards the anode [Nave, 2005].

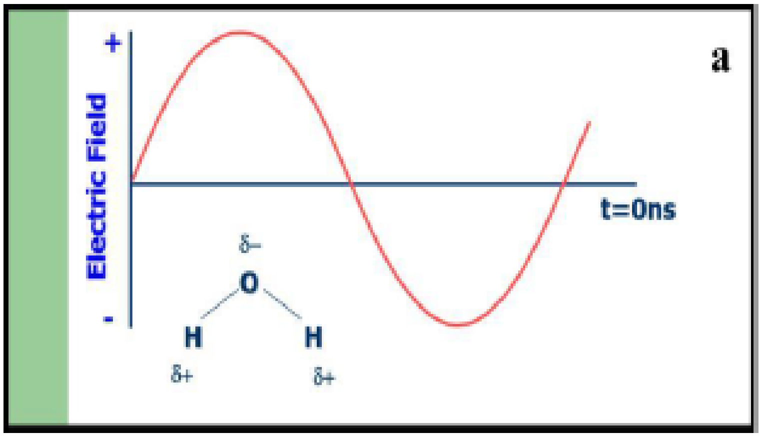
A perpetual magnetic field exists opposite to the electric field and parallel to the length of the tube. Electrons in the cathode are stripped into the electric field because of thermionic emanation (high temperature in the cathode bringing on the electrons to be energized and discharged). They quickened towards the anode, the outside of the tube, because of power connected to them by the electric field. However on their way, the magnetic field likewise connected a power to them which bends their movement. Due to their bended movement, the electrons pushed towards a zone where there is abundance negative charge anode (one side of the depression). This overabundance negative charge is pushed back around the cavity, making a swaying of electric and magnetic field because of moving charge. The frequency at which this resonance happens is predictable with that of microwaves, since electric what's more, magnetic field is transmitted oppositely to each other and opposite to the direction of travel at this frequency, while microwaves are viably emitted [Nave, 2005].

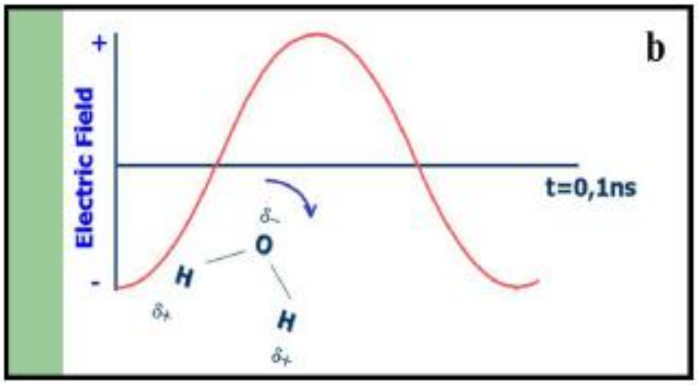
1.6 Heat Generation in Microwave Processing

(a) By dipole rotation

(b) By ionic migration

(a) Dipole rotation: Molecular rotation happens in materials containing polar atoms having electric dipole moment and they will adjust in an electromagnetic field. In the event that field is wavering, as it is an electromagnetic wave or in a quickly swaying electric field, these atoms rotates persistently adjusting to it. This rotation is called dipole rotation or dipole polarization. As the field substitutes, the particles reverse course. Rotating atoms push, pull, and crash into others particles (through electrical power), dispersing the vitality to adjoining particles and molecules in the material. Once appropriated, this vitality shows up as heat. Dipole rotation of atoms is shown in below Fig. 1.8 (a, b, c).





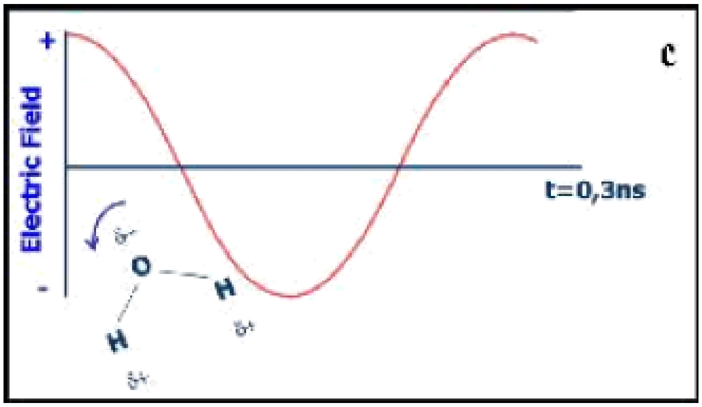
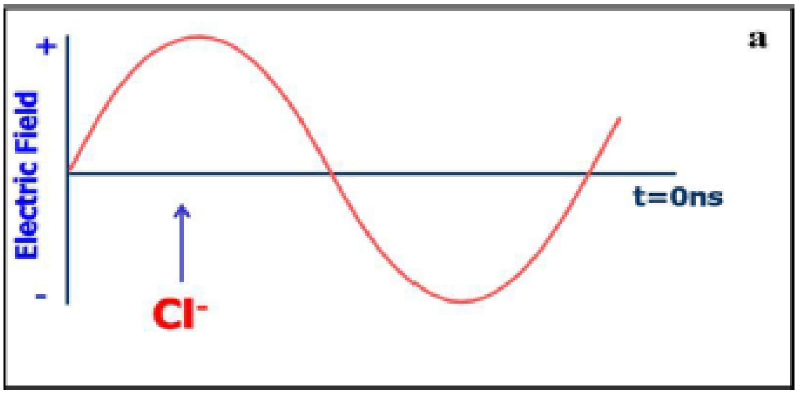


Fig. 1.8. (a, b, c) shows dipole rotation of molecules.
[http://de.cem.com/e107_files/public/pdf/525_apnote_disc_teach_gen1.pdf].

(b) Ionic migration: Ionic migration is the vehicle of the material brought about by the slow developments of particles in a conductor because of energy exchange between leading electrons and diffusing metal atoms. It is the development of broke up particles because of nearness of microwave's electric field. Ionic rotation of atoms appeared in Fig. 1.9 (a, b, c).



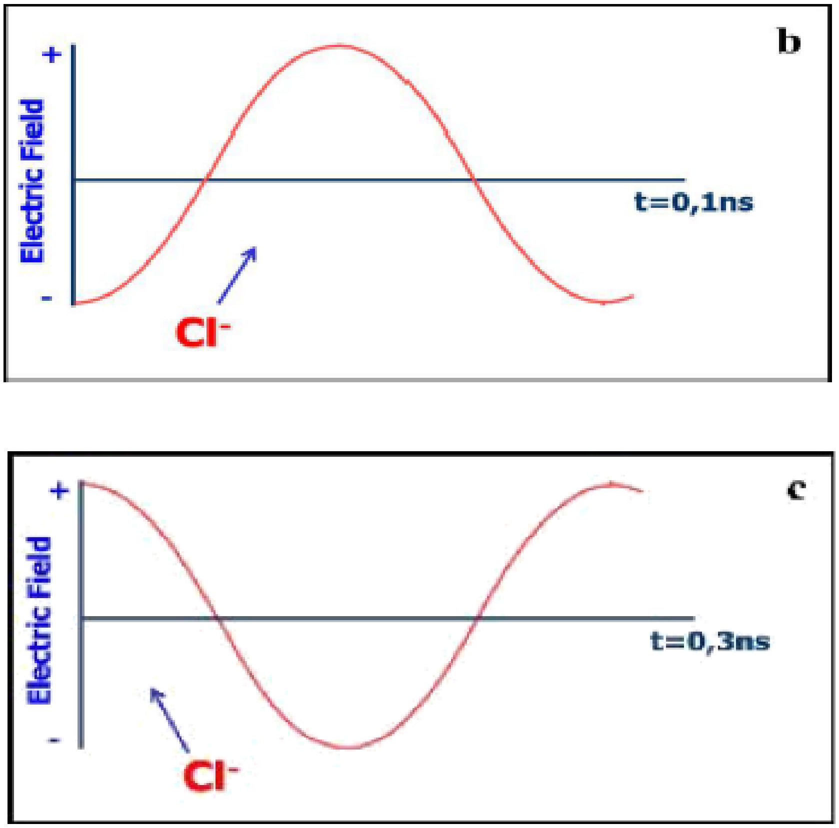


Fig. 1.9. (a, b, c) shows ionic rotation of molecules.

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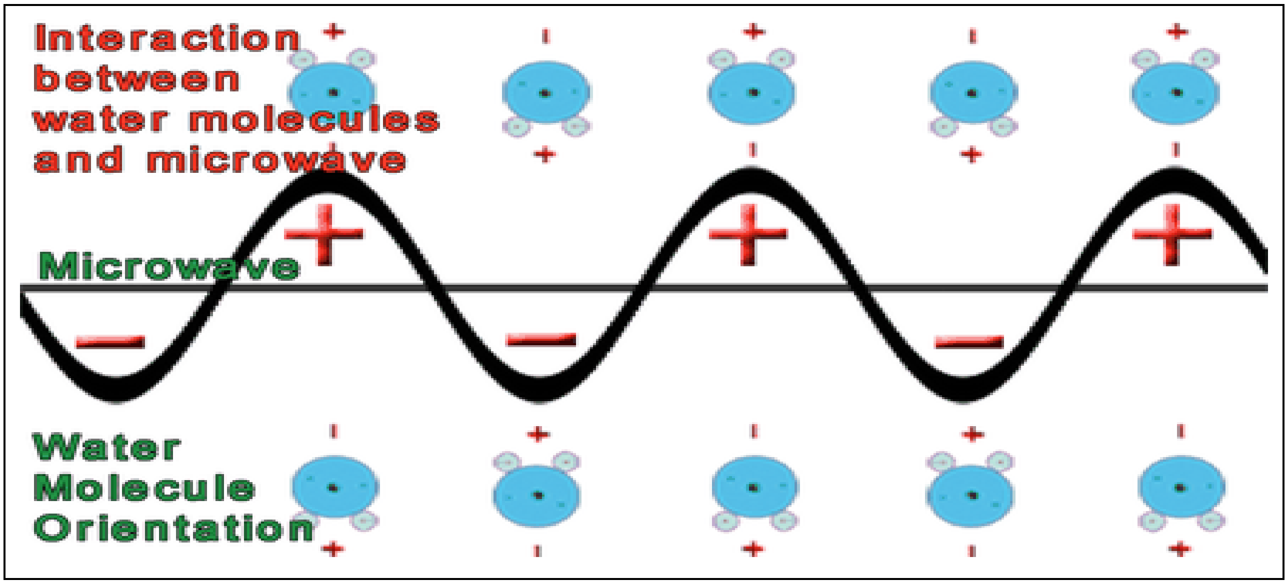


Fig. 1.10. Mechanism of dipole rotation subjected to microwaves.

[https://chanpreetvirk.wordpress.com/tag/water-molecules/].

Due to dipolar loss or reorientation mechanism, this complex phenomenon of heat generation takes place when material is subjected to microwaves then electric and magnetic fields alternates 2.45 billion times in a second and this causes rotation of dipoles as shown in Fig.1.10.

The proximity of the cohesive forces between the dipoles impedes the quick inversions and causes frictional heating. The inward resistance of material additionally causes resistance heating on utilization of rotating electric fields. This procedure happens momentarily inside the entire body and prompts the volumetric heating of entire mass subjected to microwaves

1.7 Material Parameters of Microwave Processing - Dielectric Properties of Materials

The physical properties of materials assume a noteworthy part in viable heating of materials through the microwave radiations. The managing marvel of microwaves (interaction of microwaves) with various materials relies on the properties of the materials. By and large, materials are ordered into three principle bunches as portrayed in Fig. 1.3 and microwaves bargains in an alternate way with every one of these materials. There are a few materials which are known to absorb microwaves, are known as absorbers (microwave coupled materials) and convert these radiations into heat. The properties of materials that bring about the assimilation of microwaves are the complex relative permittivity and loss tangent spoke to by the accompanying equation [Singh et al., 2015].

$$\mathbf{P = K \cdot \mathcal{E}_r \cdot \tan \delta \cdot f \cdot E^2\ [W/m^2]}$$

Where, P is the power consumed by the material.
$K = 0.056 \times 10^{-10}$ (Constant).
$\mathcal{E}r$ = Dielectric material's particular inductive capacity.
tan δ = dielectric power factor of the material.
f =frequency (Hz).
E = electric field strength (V/m).

The best essentialness of material property amid microwave preparing of a dielectric are the complex relative permittivity $\mathcal{E} = \mathcal{E}' - j\,\mathcal{E}''$ and the loss tangent $\tan\delta = \mathcal{E}''/\mathcal{E}'$, where $\mathcal{E}'$ is known as the dielectric constant generally controls that the amount of vitality enters the material interface and the amount of the amount of vitality is reflected once more from the material. The most critical property in the handling of a dielectric through microwave vitality is loss tangent tan δ or dielectric loss which tells about the ability of the material to change over the microwave vitality into heat. For best microwave vitality coupling a sensible estimation of Ɛ′ to permit sufficient infiltration and ought to be joined with high estimations of Ɛ″ and tan δ to change over microwave vitality into warm vitality. In microwave preparing, heating of material is inside and depth of infiltration fluctuates from material to material. The depth is composed of dielectric properties. Penetration depth has characterized a depth at which roughly 1/e (36.79%) of the vitality has been ingested.

1.8 Perception of Microwave Heating and Conventional Heating

The primary highlight of microwave heating is that heat is created inside the material and has rearranged profile i.e. from internal to outward surface; while in conventional heating surface (external zone, nearer to heat) is heated first and afterward heat ventures internal [Bruce et al., 2007, Zhou et al., 2003]. The distinction between the heating wonder of customary and microwave heating is shown in the accompanying Fig. 1.11.

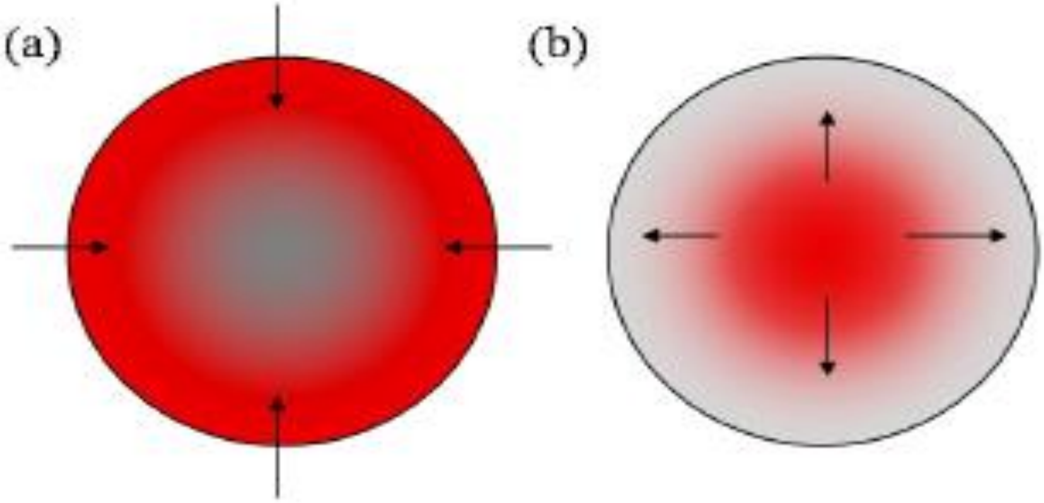


Fig. 1.11. Heating mechanism for (a) conventional heating in which heat is transferred from outer to inner surface and (b) microwave heating profile from inner to outer surface [Singh et al., 2015].

As shown in Fig. 1.11, the idea of conventional heating expresses that the heating happens from outside to inside (e.g. bubbling water on occupational oven). Essentially, in customary heating, there is a huge temperature gradient between within temperature and outside temperature of the material. This temperature distinction prompts uneven heating profile of the item. Microwave heating conquers this confinement of conventional heating, in light of the fact that the heating profile creates at the middle in this sort of heating and moves towards outside region. Microwave heating is a volumetric heating that's why in this sort of heating temperature gradient is less as relative to traditional heating [Ku et al., 2001].

1.8.1. Microwave Assisted Heating vs. Conventional Heating

Table 1.1. Comparison between conventional heating and microwave assisted heating [Savjani et al., 2010].

Sr. No.	Microwave assisted Heating	Conventional Heating
1.	The core mixture is heated directly while surface (vessel wall) is a source of loss of heat.	Transfer of energy occurs from the wall, surface of vessel, to the mixture and eventually to the reacting species.
2.	Vessel is kept in microwave cavities	The vessel should be in physical contact with surface of a higher temperature source (e.g. electric plate heater, oil bath, heating mentle, steam bath, sand bath etc.)
3.	Heating takes place by electromagnetic waves	Heating is achieved using both thermal and electric source.
4.	Heating mechanism involves dielectric polarization (dipolar polarization) and conduction.	Heating mechanism involves conduction
5.	The temperature of mixture can be raised above its boiling point.	The highest temperature (for an open vessel) that can be achieved is limited by boiling point of particular mixture or solvent.

6.	The core is 5°C hotter than the outside, because of surface cooling. Therefore in microwave heating, we can raise the boiling point of solvent by as much as 5°C, an effect known as super heating.	Heating is done from outside; therefore the core of the solvent may be as much as 5°C cooler than at the edges.
7.	A properly designed vessel allows the temperature increase to be uniform throughout the sample, leading to fewer byproducts and/or product decomposition.	There may be more by-products & more chances of decomposition of products, substrates and reagents
8.	The heating procedure is highly controlled since the energy input starts and stops immediately when the power is turned on or off, respectively.	The heating procedure is controlled to a lesser extent.
9.	Reduction in unwanted side reactions. (Reaction Quenching), so purity of the final product is high.	There may be unwanted side reactions, so final product is less pure.
10.	Environmental heat loss is saved.	Environmental heat loss is more.
11.	Heating rate is several folds high. Reactions which require many hours or even days to complete, have been accomplished in a minutes.	Heating rate is less.
12.	Average reaction time using microwave heating is 15 minutes.	Average reaction time using conventional heating is 6 hours.
13.	High efficiency of heating since specific component can be heated specifically (more selective heating).	Less efficiency of heating since all the compounds in a mixture is heated equally. (Lesser selective heating)
14.	Microwave heating is also known as "GREEN SYNTHESIS" because: (i)	Large amount of solvents are used which are hazardous and carcinogenic

	minimal amount of solvent is utilized. (ii) use of water (supercritical water) in organic reaction, instead of organic solvent, as water in microwave acts as an excellent solvent.	
15.	High investment costs.	Low investment costs.

In the wake of comprehension the idea of ordinary heating and microwave heating, the guide comes toward comprehending the idea of microwave hybrid heating (MHH).

1.8.2. Theory of Microwave Hybrid Heating

The processing of non-coupled materials through the microwave energy is really a challenging task. To deal such types of materials through the microwave energy, the research was carried out and microwave heating came out with a different form to process these materials, named microwave hybrid heating [Huang et al., 2009, Leonelli et al., 2008]. This type of heating phenomenon considers the concepts of conventional heating as well as the concept of microwave heating. The concept of microwave hybrid heating with its temperature profile is shown in Fig. 1.12.

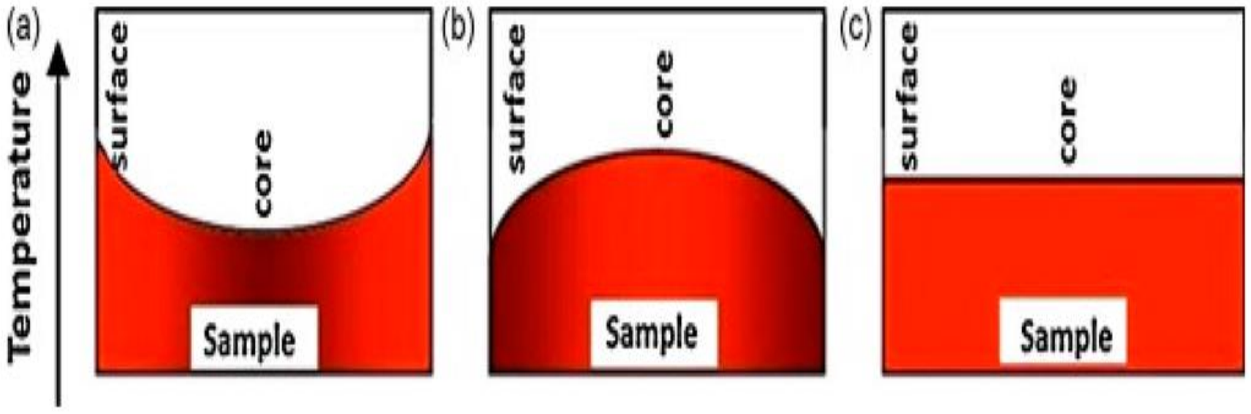


Fig. 1.12. Temperature profile within the sample in: (a) conventional heating; (b) microwave heating; and (c) microwave hybrid heating [Oghbaei et al., 2010].

In conventional heating of materials, surficial heating happens first and after that heat exchange happens all through the staying material from the external surface to the inward surface with having a differing temperature angle, which compares to the microstructures having poor surfaces and it might prompt the overheating of the surface in contact or at times the metallic powder may get intertwined. In connection with microwave heating, this sort of heating mode may prompts the poor microstructure of core in view of carbon substance at the core surface, which can bring about extreme brittleness and because of burning of core, cracks may produce. This is a direct result of heating from inside to outside of the material. To diminish the thermal gradient between the surface and core and to make the confinements of these procedures as an extra point of interest, another methodology was presented after heaps of examination in the field of material handling through microwave named it as two directional heating or Microwave Hybrid Heating, such that heating can occur from the outside towards inside and from within towards outside amid preparing. The heating wonder prompts lessened high rate of heating and temperature gradient [Singh et al., 2015].

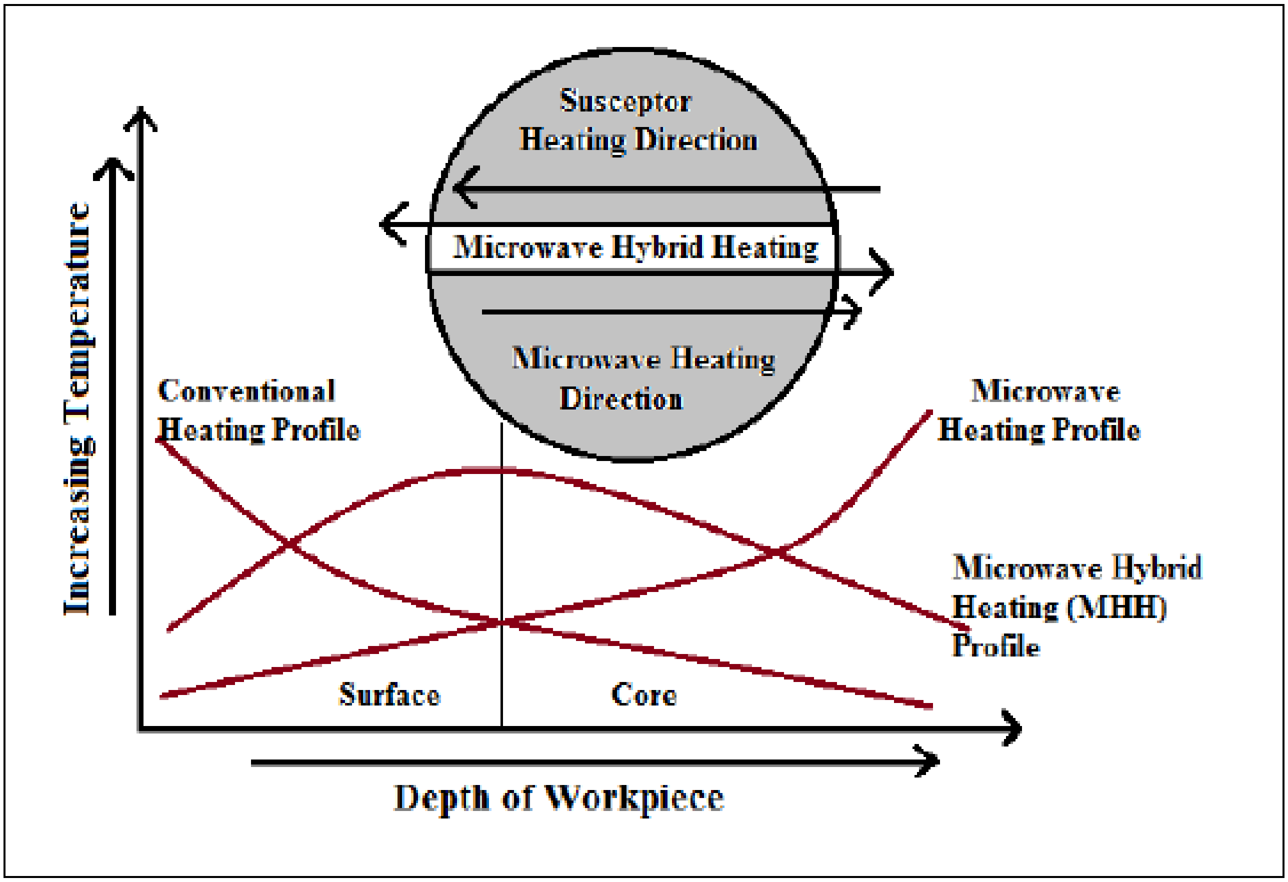


Fig. 1.13. Heating profile for conventional, microwave and microwave hybrid heating of materials [Singh et al., 2015].

The different heating phenomenon are shown in above Fig.1.13, which shows the approximate flattening of temperature profile by using MHH within the specimen. The MHH produces uniform heating throughout the materials with reduced temperature gradients and rapid heating. These characteristics are absent in conventional or microwave heating processes.

1.9 Historical Development in Material Processing Through Microwaves

Essentially the microwave innovation was firstly utilized with the end goal of telecom in the year of 1940 and it was surely understood innovation for the low temperature application and after this in 1950-65, innovation utilized for the preparing of food processing, wood curing, and rubber curing and so on. It was the time, when microwaves were utilized to treat the materials up having temperature of 450° C. After the progression of time with the ceaseless exploration, the scope of control was accomplished up to 1000° C and this innovation was actualized in earthenware handling, preparing of nitrides and glasses from the time of 1970-99.

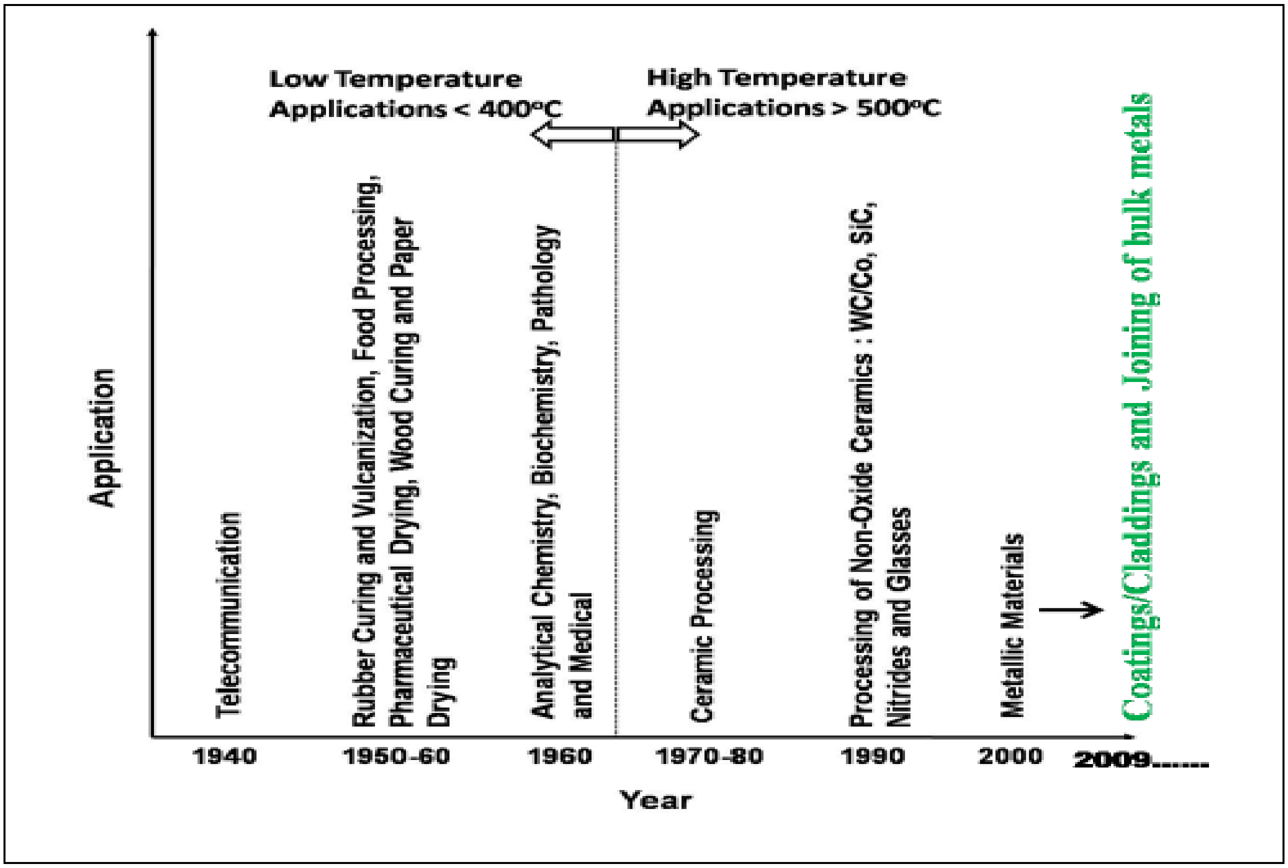


Fig. 1.14. Developments in the field of microwave materials processing in chronological order [Singh et al., 2015].

The verifiable improvements in the field of microwaves are represented in above Fig. 1.14, which appears that the prior improvements were in the field of low temperature applications. These improvements were further investigated for higher temperature applications, chiefly the preparing of ceramic materials. In the year 1999, the principal writing on fruitful sintering of metallic materials was accounted [Roy et al., 1999] and research demonstrated that metallic materials as fine powders can couple with microwaves. This extraordinary work drove specialists to concentrate on the preparing of metallic powders utilizing microwaves and a while later effective sintering takes a shot at an assortment of metallic materials have been accounted. Be that as it may, the test of preparing of bulk metallic materials utilizing microwaves was still left, which was effectively endeavored by [Sharma et al., 2009] through joining of mass metallic materials by utilizing a domestic microwave oven. This work drove the uses of microwaves for higher temperature applications. Further, [Gupta et al., 2010] in the year 2010, research was extended by using household microwave oven for delivering claddings of different materials on metallic substrates.

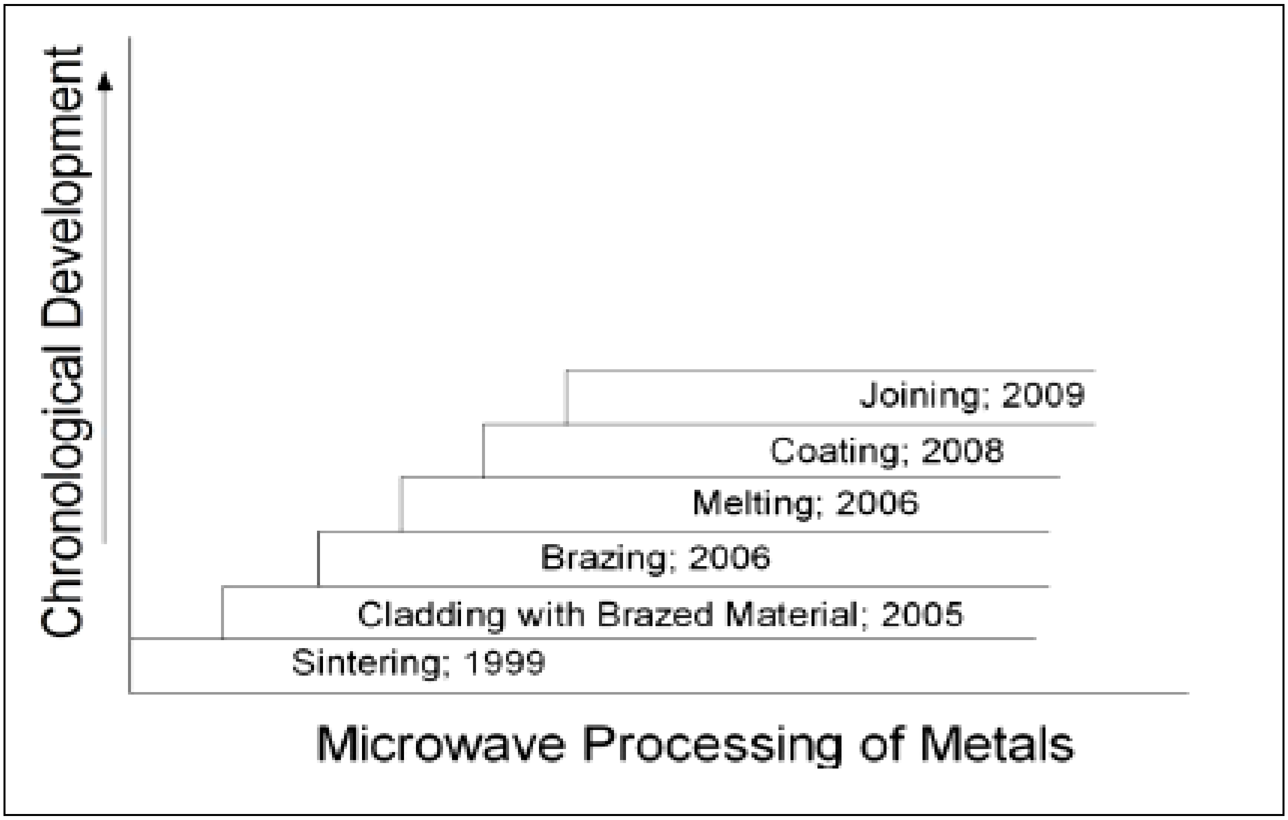


Fig. 1.15. Chronological developments in microwave processing of metallic materials [Singh et al., 2015].

These advancements further opened wide range for exploration in microwave handling of materials which requires high temperature up to the request of 1500^0C through microwave hybrid heating methods. The improvements in the field of handling of bulk metallic materials utilizing microwave radiations are represented in above Fig.1.15. In late years the uses of achieving of high temperature by microwaves were investigated also, parcel of work was done in the field of material joining, claddings and coatings utilizing microwave hybrid heating.

1.10 Microwave Furnace

It comprises of three noteworthy parts.

(a) Source: It creates electromagnetic radiations.

(b) Transmission lines: Deliver electromagnetic vitality from source to tool.

(c) Applicator: Energy ingests or reflects by material in the instrument.

Applicator might be single mode, travelling wave and multimode, for straightforward geometry single or travelling mode utilized. Multimode principally utilized as a part of commercial enterprises for vast and complex segments.

1.11 Characteristics of Microwave Heating Process

(a) Internal heating: Microwave will achieve the article to be heated at the same velocity of light, then it goes into the object as a wave and by getting retained, the item produces heat, in this manner microwave heating is internal heating. Diagrammatic view is being shown in Fig. 1.16.

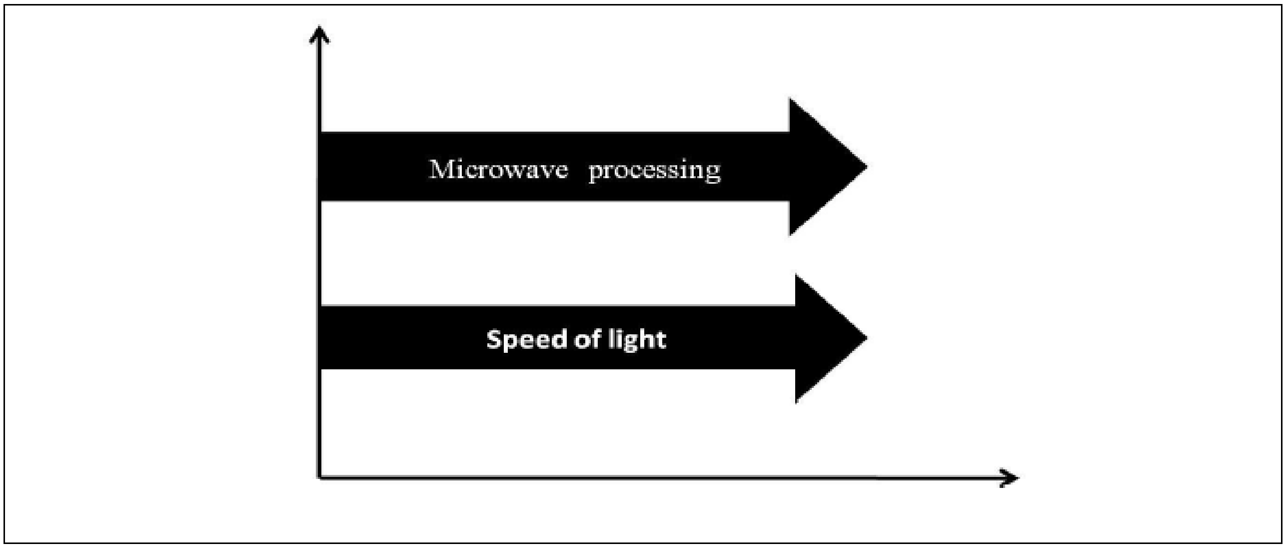


Fig. 1.16. Comparison of transmission speed of microwave as same as light.

In microwave heating, the heat will be produced in the item by assimilation of microwaves which has opposite heating profile. It heats the item inside and heat streams from internal bearing to an outward course which diminishes heat loss and rapid heating is accomplished. The heating wonder in microwave heating and customary heating appears in Fig. 1.17.

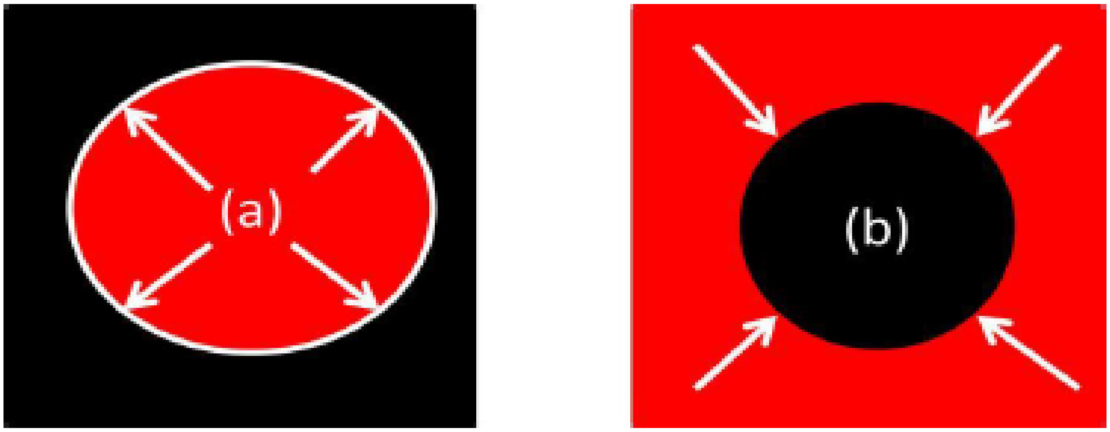


Fig. 1.17. (a) Microwave radiations heat objects internally while in (b) Conventional heating externally.

(b) Rapid heating: In microwave heating, heat is produced all alone by entrance of microwaves, not important to consider about heat conduction that is the reason why rapid heat is conceivable by microwaves, as shown in figure 1.18 underneath.

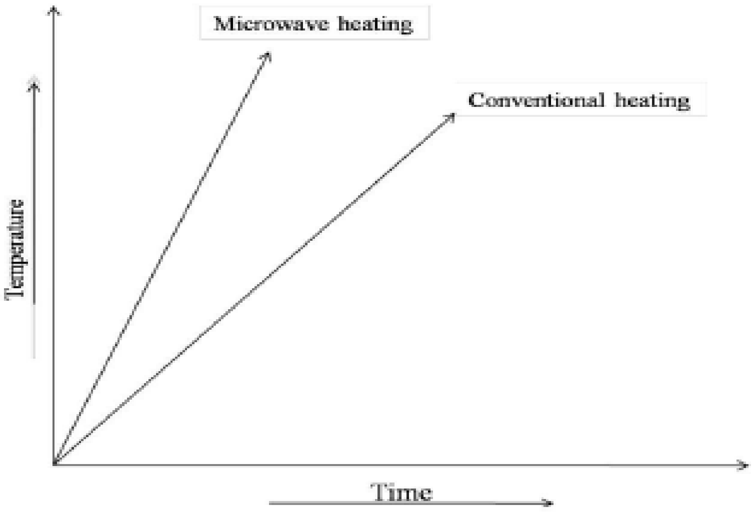


Fig. 1.18. Microwave heating vs. conventional heating.

(c) High heating effectiveness: Microwaves infiltrates into item at the rate of light and the item to be heated produces heat on their own. Microwave heating has high efficiency because of no compelling reason to consider the heating losses of air inside the heating kiln.

(d) Lower power utilization: The microwave heating of material includes direct assimilation of radiations by material, it gives a higher rate of heat transfer in the examination of customary techniques and accomplishes higher temperature in shorter time, and this diminishes overall utilization of power, as represented in below Fig. 1.19

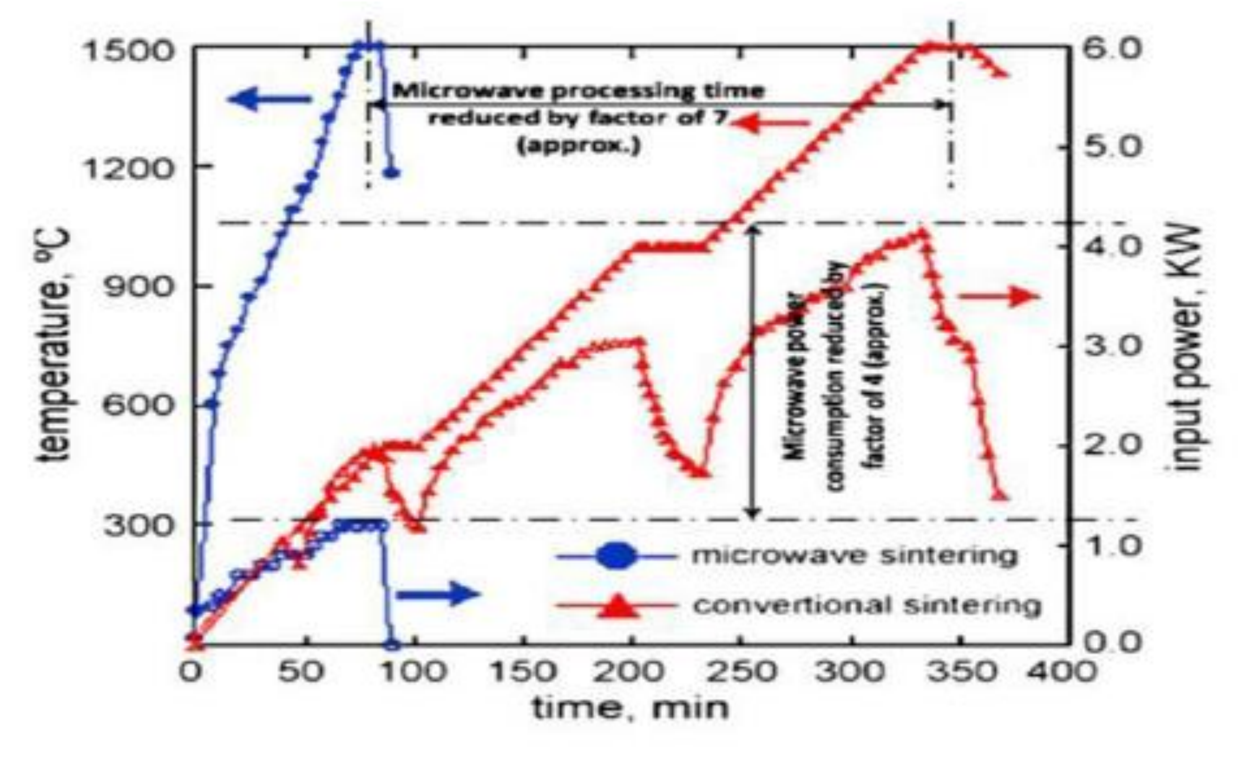


Fig. 1.19. Power and processing time comparison during microwave and conventional sintering process [Upadhayaya et al., 2007].

(e) Quick reaction: Microwaves enters into item at the same pace of light and item generates heat on their own and volumetric heating of materials takes place which permits quick reaction. Begin and quit heating in a flash if there should arise an occurrence of microwave handling.

(f) Heating consistency: Microwave heats consistently i.e. it gives volumetric heating impact. Every part of heated article produces heat, so notwithstanding for those item with convoluted shape, it can be heated generally uniform.

(g) Clean vitality: Microwaves doesn't require medium, it spreads by just changing the electric field what's more, magnetic field. It can proliferate even in a vacuum. It achieves the article and infiltrates without heating air.

(h) Good operation and working environment: Microwaves only uses electricity to generate heat, there is no hazardous effects and eco-friendly with environment.

1.12 Prospects of Microwave Material Processing

Every technology when gets invented, it’s not perfect from every aspect for which it’s made or the purpose for it is used to be. There are lots of parameters and specifications, lots of challenges have to be controlled while dealing with newer technologies. These are lots of advantages and little bit limitations, because of which this technology has been emerged in material processing.

1.12.1 Advantages of Microwave Material Processing

There are certain distinct advantages of using microwaves in heating processes. The characteristics of lower energy consumptions coupled with higher heating rates and lower processing times, led microwave heating as one of the challenging process in material processing. The main advantages of microwave material processing involves better microstructures, lower defect formation, higher efficiency with reduced energy consumptions and lower cost of heating in comparison to conventional heating. The advantages of microwave processing are as follows:

- Rapid Heating.
- Volumetric Heating.
- Variety of production.
- Environment friendly.
- Energy and Cost Effective.
- Improved Mechanical Properties.
- Improved Densification Parameter.

Rapid Heating: Microwaves achieve the article as same as the pace of light. Firstly, these voyages towards an article as waves and gets ingested after that protest creates heat. Rapid heating is conceivable in microwave heating on the grounds that in this sort of heating, the heat is produced by the article by its own particular with infiltration of microwaves by the item.

Volumetric Heating: Volumetric heating is seen amid microwave heating, so there is no temperature gradient as saw in traditional heating as the temperature differs from core to surface. In microwave material heating, the temperature stays same all through the material which prompts a superior quality item.

Variety of Production: There is an assortment of creation in microwave material handling, as a result of the scope of the temperature control and distinctive heating parameters. This prompts the microwave innovation in the field of metal preparing through microwaves and having assortment of production in various territories of generation like, cladding/Coating, sintering, joining of metallic materials.

Environment-Friendly: Microwave vitality is said to be totally environment well disposed of when contrasted with conventional vitality techniques for material preparing. Customary techniques for heating the metals as in heater, heating creates exhaust, risky gasses, smoke and so forth which prompts environment corruptions and this thing can be maintained a strategic distance from in microwave handling so its surroundings well disposed of starting here of perspective.

Energy and Cost Effective: Microwave heating prompts vitality sparing and in addition cost sparing. The vitality prerequisite to rise the temperature in heater for liquefying a material is high yet this necessity of vitality can be satisfied effortlessly and inconceivably with microwave vitality. Vitality sparing specifically or in a roundabout way prompts cost adequacy, which likewise tends to spare the time in view of its high productivity.

Improved Mechanical Properties: The run of the mill necessities for the traditional sintering process incorporates higher heating rates, high temperature and support of this temperature for a certain timeframe. Be that as it may, to keep up the uniform temperature conveyances, the examples are typically kept for higher dousing periods which prompt the over the top grain developments and abandons, for example, porosity and breaks. These issues can be removed through microwave preparing which gives relatively homogeneous microstructures with better grain development and improved properties in expansion to lower handling time. These acquired great attributes are because of the higher heating rates, uniform heating of materials (volumetric heating), and lessened the time for accomplishing higher temperatures. The examination of microstructures is represented by Fig. 1.20.

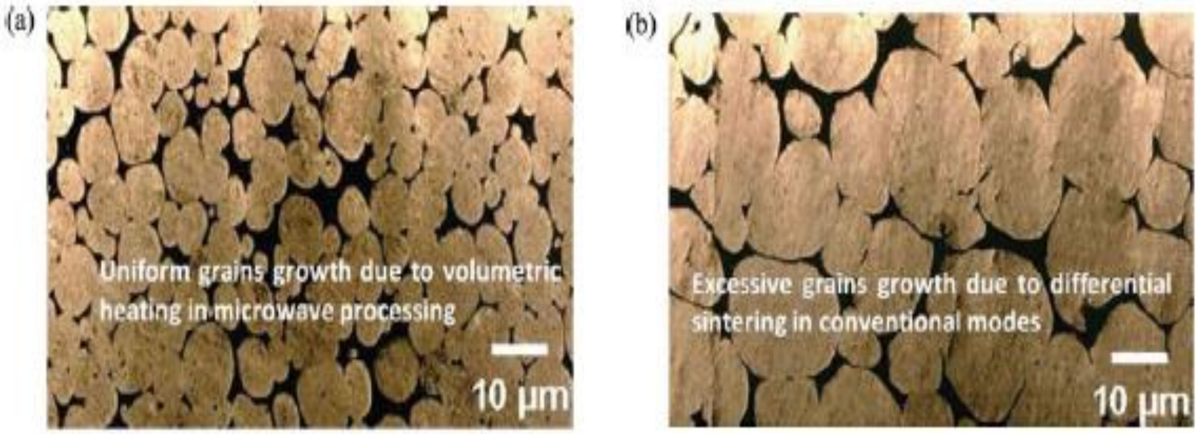


Fig. 1.20. Effect of (a) microwave processing and (b) conventional processing, on microstructure of processed material [Upadhayaya et al., 2007].

Improved Densification Parameter: The thickness of powder compaction chooses the properties of the completed product. Higher the thickness of prepared material, lower will be the deformities mostly as far as porosity. Because of uniform heating and volumetric heating of an item, the densities acquired are higher on the off chance that of microwave sintered or prepared parts. The compacts sinterability considers the effect of at first squeezed density values, which can be connected as far as standardized, dimensionless densification parameter, or consider and is represented by equation [Mondal et al., 2013].

Densification factor = $\frac{\text{Sintered Density}-\text{Green Density}}{\text{Theoritical Density}-\text{Green Density}}$

The other advantages may be explored as:

- Up to 70% less energy usage than conventional energy.
- Greatly improved throughputs resulting from deep penetration of microwave energy into particular materials, giving rapid heating throughout the bulk of the product being heated.
- Instantaneous control, a common feature of most electromagnetic technology systems.

- Reduced environmental pollution due to increased energy efficiency and clean transfer of energy to product being heated.
- Removal of gases from porous materials without cracking.
- Improvement in product quality and yield.
- Synthesis of new materials and composites.
- Economic advantage by time and energy saving.
- Greater control in possible on heating parameters than conventional methods.
- These characteristics of microwaves provided enhanced diffusion, shorter processing times, finer microstructures, better mechanical properties, eco-friendly, energy savings, compact system, higher efficiencies etc. over other conventional processing routes.

1.12.2 Limitations of Microwave Material Processing

As the coin has two flanks, having head and tails, likewise every procedure has a few upsides and downsides however how to minimize or to control these relies on upon the abilities of the administrator. The most widely recognized restrictions of microwave handling are

1. The unknown temperature inside the microwave cavity.

2. Poor coupling between metallic materials and microwaves.

3. Controlling the rate of heat exchange as for various materials.

Every one of these parameters should be get improved in light of the fact that overheating may get wire the metallic powders and radiations may hurt the wasteful laborer, so it ought to be taken care of/worked deliberately.

1.12.3 Use of Microwaves in Material Processing

Use of microwave vitality for materials handling is an inventive innovation with numerous points of interest over customary preparing, in light of the fact that it gives the lessening in process duration which relates to cost funds, giving enhanced microstructures, prompting better mechanical properties, and eco cordiality. The microwaves were usually being utilized with the end goal of nourishment preparing and for correspondence purposes. Be that as it may, its headway in artistic handling and metallic materials has grown just in the most recent two decades. Latest utilizations of microwaves are in steel making, reusing of utilized tires and option hotspots for vitality recuperation (oil shale and topped oil wells). A portion of the uncommon pottery, composites, and metal powders have been effectively handled in the microwave with better properties. The specific heating element of microwaves has additionally utilized as a part of compelling brazing and joining of metal parts. The primary concern in preparing the metals in the microwave is that the microwaves are reflected by the metals, so there is a need to discover such a powerful strategy through which the beams can be transmitted into the materials and dissolving of metal can be accomplished. The fields where microwave is already using are shown by Fig. 1.21.

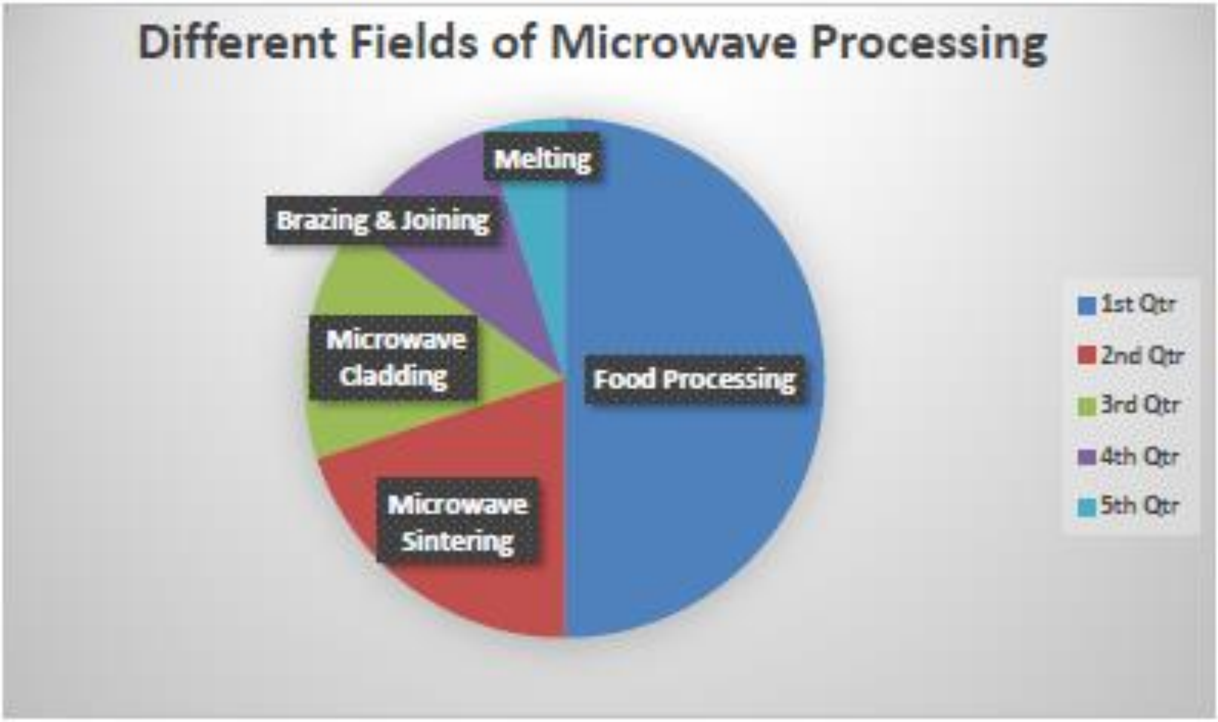


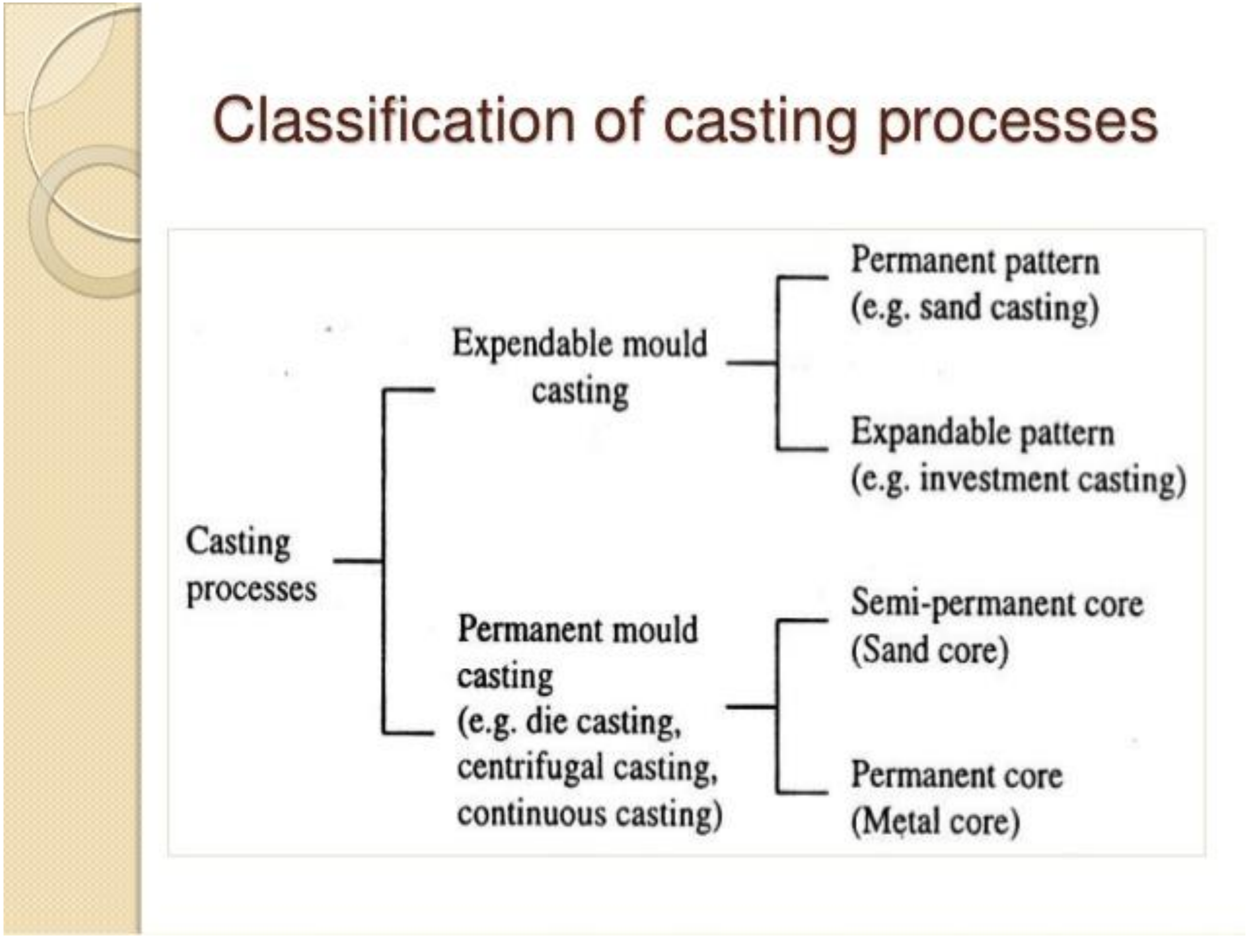
Fig. 1.21. Wheel depicting different fields of microwave processing.

1.13 Introduction to Casting

Casting is a procedure in which a fluid material has normally filled a mold, which contains an empty cavity of the fancied shape, and afterward permitted to solidify. The set part or solidified part is otherwise called a casting, which is launched out or broken out of the mold to finish the procedure. Casting materials are generally metals or different icy setting materials that cure subsequent to combining two or more parts; cases are epoxy, solid, mortar and dirt. Casting is frequently utilized for making complex shapes that would be generally troublesome or uneconomical to make by different techniques.

1.13.1 Types of Metal Casting Processes

There are diverse sorts of procedures to cast the metal matrix composites, which are represented in Fig. 1.22.



Classification of casting processes

- Casting processes
  - Expendable mould casting
    - Permanent pattern (e.g. sand casting)
    - Expandable pattern (e.g. investment casting)
  - Permanent mould casting (e.g. die casting, centrifugal casting, continuous casting)
    - Semi-permanent core (Sand core)
    - Permanent core (Metal core)

Fig. 1.22. Types of Metal Casting Processes.

With the advancement in innovation, more issues confronted by the researchers and technologists in the field of assembling and material handling for new materials and diverse metal amalgams and composites these throwing procedures appeared.

1.13.2 Composite Systems

A composite material (also called a composition material or shortened to composite) is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. Composites are made up of individual materials referred to as constituent materials. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. There are two main categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. A synergism produces material properties unavailable from the individual constituent materials, while the wide variety of matrix and strengthening materials allows the designer of the product or structure to choose an optimum combination. More recently, researchers have also begun to actively include sensing, actuation, computation and communication into composites, which are known as Robotic Materials.

Typical engineered composite materials include:

- mortars, concrete
- Reinforced plastics, such as fiber-reinforced polymer
- Metal composites
- Ceramic composites (composite ceramic and metal matrices)

Among these, metal composites are having the wide range of application in this emerging industrialization.

1.13.3 Metal Matrix Composites (MMC)

A metal matrix composite (MMC) is a composite material with no less than two constituent parts, one being a metal essentially, the other material might be an alternate metal or another material, for example, a fired or natural compound. At the point when no less than three materials are available, it is known as a hybrid composite. A MMC is reciprocal to a cermet. Metal matrix composites (MMCs) normally comprise of a low-thickness metal, for example, aluminum or magnesium, strengthened with particulate or strands of a ceramic, for example, silicon carbide or graphite. Contrasted and unreinforced metals, MMCs offer higher particular quality and solidness, higher working temperature, and more prominent wear resistance, and in addition the chance to tailor these properties for a specific application. In any case, MMCs likewise have some hindrances contrasted and metals. Boss among these are the higher expense of manufacture for superior MMCs, and lower flexibility and durability. In the blink of an eye, MMCs tend to group around two compelling sorts. One comprises of elite composites strengthened with costly persistent strands and requiring costly handling strategies. Alternate comprises of generally minimal effort also, low-execution composites reinforced with generally economical particulate or strands. The expense of the primary sort is too high for any yet military on the other hand space applications, though the cost/advantage points of interest of the second sort over unreinforced metal composites stay in uncertainty [https://www.princeton.edu/~ota/disk2/1988/8801/880107.PDF]. The particulates reinforced metal matrix composite (MMC) is another methodology in the field of casting. These are recently created basic individuals and a progressive improvement has been seen amid most recent two decades due to their extraordinary properties and is by all accounts an essential piece of future items. For quite a long while, production of metal matrix composite is the primary center of the scientists in light of the fact that neither matrix nor reinforcement alone can't satisfy every one of the necessities [Rajkumar et al., 2011]. So different materials have been blended with each other and satisfied the required properties, which are not quite the same as their base materials and turned into the inbuilt properties of the material like strength, wear resistance, stiffness, corrosion resistance, elastic modulus and so on. The fiber-reinforced metal matrix composites (MMCs) gives the accompanying favorable circumstances than contrasted with the base metal alone are high wear resistance, corrosion resistance, specific stiffness, temperature performance, elastic modulus and so on. These properties are required for every single item being made, however, the expense to make the MMCs and troubles which becomes possibly the most important factor amid creation are the principle purposes for their restricted use for the business application. In most recent quite a while, with the improvement in innovation, a few throwing procedures (die casting, investment casting, squeeze casting and so on.) appeared and MMCs now can be effortlessly produced. MMCs can likewise be made with ceramic reinforcement, usually utilized ceramics are (boron carbide, silicon carbide, alumina and so on.) which may enhance the mechanical properties of the materials up to a degree.

1.13.3.1 Properties of Metal Matrix Composites

Metal matrix composite (MMC) castings are the sorts of castings through which the consolidated points of interest of two materials can be effortlessly acquired. In MMC's, one of base metal will be metal and other being a strengthening material (clay). These focal points incorporates [Sarmadi et al., 2013]:

1. Extremely lightweight

2. Strong and consumption safe

3. Better mechanical and warm properties

MMC castings shows decreased material loss and lessened machining time and eventually bringing about an all the more effectively produced segment for complex shapes and higher volumes.

1.13.3.2 Fabrication of Metal Matrix Composites

For the fabrication of metal matrix composites two materials are required, one for the matrix (base metal) and the second one is as a reinforcement material. The matrix materials are usually metals and its amalgams (copper, aluminium, titanium, magnesium, and nickel combinations) aside from every one of these materials a few numerous more matrix materials have likewise been utilized including super alloys [Kumar et al., 2013]. The reinforcement materials might be metal and glass fibre or ceramic reinforcement. The decision of a reinforcement mostly relies on upon the end utilization of the item, for which reason it is fabricated. The primary parameters, which impact the choice of a specific manufacture procedure are:-

(i) Type of matrix and reinforcement,

(ii) The introduction and dispersion of reinforcements,

(iii) The thermal and mechanical properties of matrix and reinforcement,

(iv) Finally its end utilize and cost-viability.

Fabrication strategies to make the metal matrix composites are extremely perplexing and differing in nature. Significant issues are worried about the densification parameter, which may some of the time get impacted in light of the extreme or inappropriate chemical bonding all through the composite materials, for example, amongst matrix and reinforcements. The fabrication procedures are for the most part subdivided into two gatherings in light of its physical state i.e. solid state preparing and liquid state handling. If there should arise an occurrence of solid state handling, the matrix is as powder, sheet or thwart. To make the metal matrix composites through solid state preparing, two sorts of procedures goes under this classification are diffusion bonding and powder metallurgy. Then again side, in liquid state preparing, casting of metals comes into the part. Solid state preparing conquers the confinements becomes possibly the most important factor while completing the casting (liquid invasion forms). These can be compressed as lower handling temperatures, slower dispersion rates, and the chance of response between the matrix material and fortifications are less. The other manufacturing forms goes under the metal forming, for example, rolling, forging, extrusion and drawing are additionally essential, yet loads of consideration is expected to lessen the harm in the event of reinforcement.

Along these lines, in the present study, the work is being completed to cast the metal matrix composite castings through microwave preparing and this is the type of solid stage handling. To the extent the research is worried to manufacture the composites through microwave innovation, no work yet has been done with respect to the casting. In this way, it's an extremely difficult assignment to cast the metal matrix composites through this innovation.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

In this part, the writing on the premise of various metal handling procedures through the microwave preparing course are expounded. Literature contains different metal preparing methods, which clears up the basics with respect to the working guideline and parameters incorporates sintering, joining, melting and cladding of metals through microwave handling. This part likewise contains the literature overview in the field of casting to comprehend the idea of manufacturing, different techniques to cast the MMCs and change in their properties. Brief perceptions are highlighted from the creators work and are introduced for better understanding.

2.2 Perspectives of Microwave Processing

Clark and Sutton (1996) looked into the capacity of microwaves to process metallic materials. The material being handled through microwaves, associates for a brief span of time with the microwaves instead of radiant heat contact in customary procedures. In this innovation, the heating is volumetric and particular or quick heating can be accomplished in light of the fact that the heat is produced by the material itself. The rate of heating is corresponding to the power. These elements prompt consistency and assortment of production. The equipment requires less floor zone and quicker generation all through the procedure which compares to the legitimate usage of the facilities. Authors compressed the benefits of microwave handling over the conventional ones and diverse regions in which this innovation ought to be investigated. The microwaves at the nuclear level can be transmitted, absorbed or reflected by materials and these properties may shift from material to material. Each of the three states (liquid, gasses and solids) can communicate with microwaves and can be heated. In contrast with traditional heating procedures, microwave handled materials ordinarily shows the higher temperature at the middle than on the outside surface since heat ventures out from inside to outside. Different parts of the microwave handling have been additionally highlighted i.e. heating and drying rates, electric field dispersions, temperature profiles, power ingestion and hybrid heating.

Das et al. (**2009**) gives a brief report on prospects of microwave handling. Microwave preparing has been developing as an inventive sintering technique for many customary ceramics, progressive ceramics, specialty ceramics and ceramic composites as well as polymer and polymer composites. A few applications where microwave is by and large utilized are advancement of functionally gradient materials: joining; softening; fiber drawing; reaction synthesis of ceramics; synthesis of ceramic powder, phosphor materials, whiskers, micro-tubes, and nanotubes; sintering of zinc oxide varistors; coating of covering surface and coating development have been performed utilizing microwave heating. Microwave vitality is being investigated for the sintering of metal powders moreover. Shapeless materials (e.g. glass) is additionally been prepared by microwave heating. Heating conduct of materials in the electric and magnetic fields at microwave frequencies is being considered. Microwave heating is being looked at by conventional heating in different facilities. The thermal gradient in the microwave handled material is the converse of that in the material prepared by traditional heating. At the point when microwave vitality is in contact with materials having diverse dielectric properties, it will specifically couple with the higher loss tangent material. In this manner, microwaves can be utilized for the particular heating of the materials. Some contemporary utilizations of microwave heating to materials preparing are likewise depicted. 0.915 GHz and 2.45 GHz frequencies are generally utilized for microwave heating. These frequencies are decided for the microwave heating in view of two reasons. The first is that they are in one of the modern, experimental and restorative (ISM) radio groups put aside for non-correspondence purposes. The second is that the infiltration depth of the microwaves is more noteworthy for these low frequencies. 2.45 GHz is for the most part utilized for family unit microwave ovens and 0.915 GHz is favored for industrial/marketable microwave ovens. The connection of microwaves with a dielectric material results in translational movements of free or bound charges and turn of the dipoles. The resistance of these affected movements because of inertial, flexible, and frictional strengths causes misfortunes bringing about volumetric heating. The relative dielectric constant and the loss tangent are the parameters that depict the conduct of a dielectric material affected by the microwave field. Amid heating, the relative dielectric constant, and the loss tangent changes with temperature.

Agrawal et al. (**2010**) did a study to discover the most recent advancements in material preparing, in which he recognized a light on various ranges of microwave material handling. Microwave innovation is a creative innovation in light of its extra focal points over traditional preparing, which prompts diminishment in handling process duration and which in a roundabout way lessens the cost related to fabricate component. This innovation accomplishes the enhanced microstructure and no ecological issues are identified with this innovation. Latest utilization of microwave innovation was seen for steel making and reusing of tires. Selective heating element of microwave innovation was likewise used for soldering of components/metal parts and brazing. In this study, the idea of sintering and melting of ceramics was clarified and its contrast was done regarding the traditional sintering as shown in below Fig. 2.1.

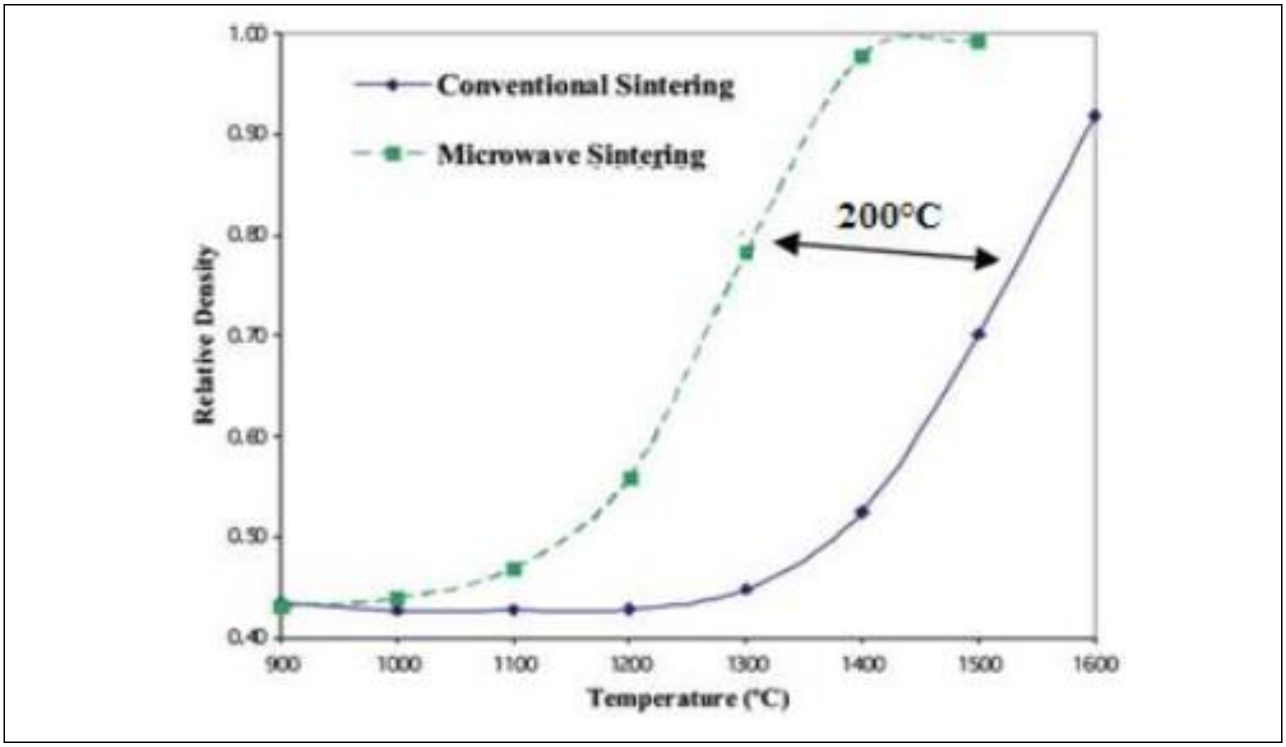


Fig. 2.1. Contrast between microwave sintering and conventional sintering [Agrawal et al., 2010].

As shown in above Fig. 2.1., microwave processing creates generally thick structures relatively to customary procedures and at lower temperatures than that of conventional procedures. The fundamental explanation for the restricted exploration if there should be an occurrence of metals preparing through this innovation, is the misguided judgment towards individuals that the vast majority of the metals replicates the microwaves. Subsequent to confronting loads of issues and research in this field, it has been demonstrated that metallic materials can assimilate the microwaves in the powder structure. Steel making adds to the arrangement of CO_2 in green-house impact on account of the exhaust created through traditional heaters, so a procedure with less CO_2 emission was required for the steel fabricating. Hwang et al., 2007 got an exceptional accomplishment by consolidating electric arc heater with the microwave handling and built up another innovation, which prompts a momentous decrease of CO_2 era up to half when contrasted with ordinary steel making innovation and 25% less vitality utilization over the fundamental heater innovation.

2.3 Microwave Joining of Metals

Joining of metal should be possible by numerous methods to make the high-quality joints yet microwave vitality assumed a crucial part in this field to join the metals with enhanced mechanical properties. There are numerous systems to join the metals like welding, soldering, brazing, laser welding and so forth, however, these all methods expands part of vitality and time. Microwave helped joints are spotless and more effective than traditional ones. Taking after writing speaks to the utilization of microwave vitality in joining of metals.

Srinath et al. (2011) clarified a methodology for joining of metallic materials through microwave handling. In this exploration, joining of copper was done utilizing local microwave having frequency 2.45 GHz and power 900 W. Copper was chosen as a material for joining through microwave heating since copper is a standout amongst the most normally utilized metal as a part of assembling of electrical gadgets and segments utilized as a part of the avionic business. The test setup for joining and pre-arrangement of joining test is shown in below Fig. 2.2.

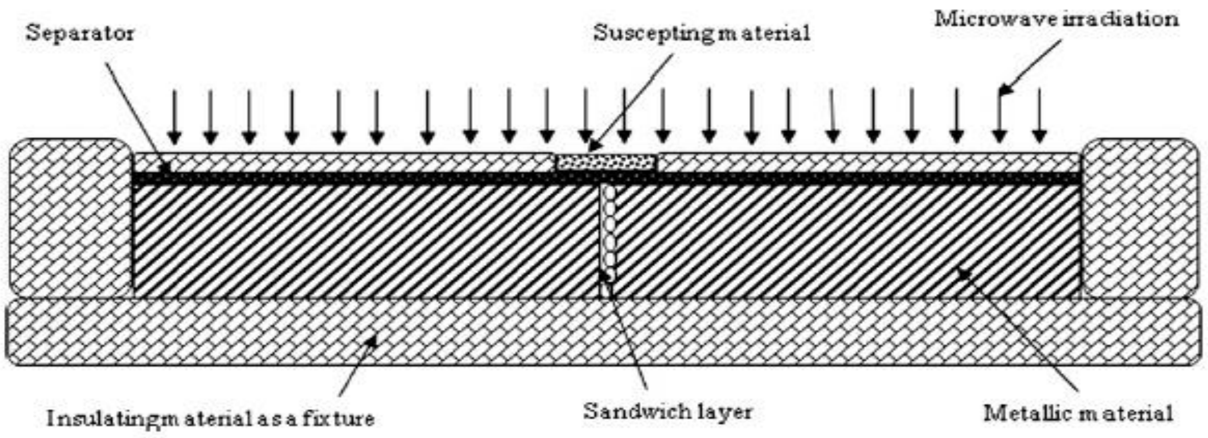


Fig. 2.2.Schematic view of the experimental process for microwave joining [Srinath et al., 2011].

As the microwaves are reflected by the metals, so susceptor was utilized to empower heating. The fine charcoal was utilized as susceptor and copper as a part of the type of plates and coins was joined effectively through microwave handling in 15 min. The copper powder was filled in a crevice between the two preplaced specimens having a gap of 0.5mm between each other. Because of the complete dissolving of metal powder at the interface because of microwave introduction lead to the metallurgical bonding of metal pieces. Characterization of the joints was completed. A uniform microstructure with better metallurgical bonds between the sandwich layer and interface was shaped. The hardness was accomplished upto 78±7 Hv and porosity was controlled upto 1.92 %. Microwave prepared copper joints had critical rigidity with high stretching.

Srinath et al. (2011) explored the mechanical and in addition microstructural properties of comparative or disparate joints manufactured through microwave preparing. The joining of SS-316 with gentle steel in bulk was done effectively utilizing microwave multimode applicator at 2.45 GHz frequency and power 900 W. Microwaves can't couple with the metals specifically at room temperature, so a susceptor medium was utilized to start the coupling of microwave with metals and joining was done by utilizing microwave hybrid heating. To shape a joint, EWAC (nickel based) powder was utilized to fill the gap between two metal pieces. The characterization of created joints was done utilizing FESEM, XRD, micro-hardness and universal testing machine. The volumetric heating nature of microwave preparing brought about the complete fusing of the interface layer, which built up a metallurgical bonding with bulk interfaces. The arrangement of metallic carbides has been seen through microwave heating. The bulk joint has a Vickers small scale hardness 133 Hv and porosity of bulk joint was seen to be0.58 %. The different joints handled through microwaves had the tensile strength upto 346.6 MPa with a stretching of 13.58 %.

Bansal et al. (2013) completed the mechanical and metallurgical portrayal of MS-MS joint created through microwave heating utilizing nickel powder as interfacing material. Joining of the bulk metallic materials is the most difficult errand with the assistance of microwave vitality, due to the poor coupling of microwaves with the metallic materials and microwaves are by and large reflected by the metals. In this study, microwave hybrid heating (MHH) procedure was utilized for joining. A nickel-based powder of particle size 40 μm was utilized as the interface layer for the creation of the joint. The bulk plates of MS were put in such a way, to the point that a butt arrangement and a gap of around 0.5 mm was kept up between both the specimens. The gap was loaded with the slurry, having the blend of EWAC (Ni-base powder) and epoxy. As a result of the microwaves reflection marvel by metallic materials, it was extremely hard to manage the microwaves at room temperature. To make it conceivable that microwaves get consumed into the material, an encasing veil of fine charcoal was conformed to the joint and thusly, metal was not specifically presented to the microwaves. Joint formed while joining MS plates through microwave hybrid heating is shown in below Fig. 2.3.

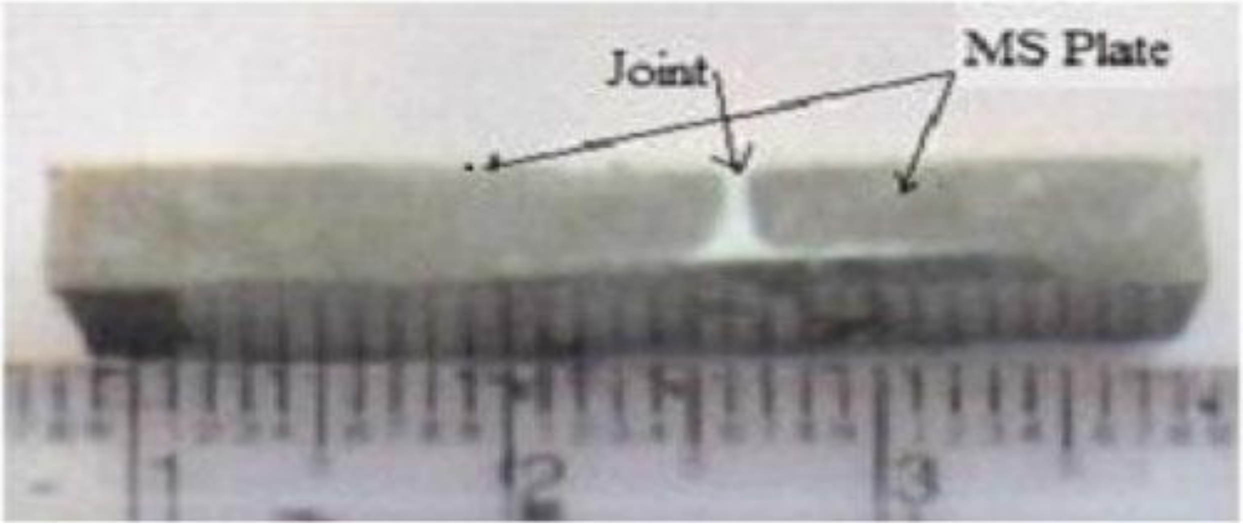


Fig. 2.3. A view of a typical joint developed by MHH [Bansal et al., 2013].

Micro-hardness of the joint and additionally base metal was measured utilizing a load of 50gm for 20sec. The extent of indentations were littler on the joint zone and bigger on the base material (gentle steel). This extent of indentations clears up that the joint formed has higher hardness when contrasted with the base metal, which is coveted for better nature of joint.

2.4 Microwaves in Surface Engineering

In the year 2010, Gupta and Sharma built up a novel preparing procedure for affidavit of metallic materials on metallic base metal by utilizing a local microwave oven of frequency 2.45 GHz to enhance its surficial properties and mechanical quality contrasted with the substrate and the procedure was guaranteed for Indian Patent [Gupta et al., 2010].

Gupta et al. (2011) did a test to examine the dry sliding wear conduct of WC10Co2Ni clads prepared through microwave radiation. Wear examination is imperative from the designing perspective, in light of the fact that a large portion of the segment gets fall flat because of wear and corrosion, it might be because of forceful working conditions. The basic fields, in which these issues by and large emerges are the parts of hydro-power plants and gas turbines. By and large, to outline these sort of material two techniques are received.

First strategy: Design a bulk material having properties of wear and corrosion resistance. ***Second strategy:*** Modification of surfaces which by and large interacts with the sliding conditions.

Planning a bulk material prompts high venture expense to make it, so for the most part adjustment of surfaces by mechanical means is by and large embraced, to give a high wear resistance and high hardness to the substrate material (Austenitic SS). In this way, the microwave cladding was completed and subsequent to delivering it, the mechanical properties of the cladding were measured. There was a gigantic distinction saw previously, then after the fact the small scale hardness of the material, the hardness was expanded upto 1064±99 HV at the highest point of the surface and at the interface it was around 800 HV, which was far-much more than the substrate alone. Microwave cladding gave a higher wear resistance, which was around 84 times higher when contrasted with the substrate material (SS-316) having speed 0.5m/s.

Sharma et al. (2012) did an examination on surface building and its impacts on the microstructure and flexural strength of cladding created through microwave handling. In this examination, metal-artistic composite cladding was produced on the substrate. As a substrate material, austenitic steel was utilized and Ni-based EWAC having 20% WC10Co2Ni as a reinforcing operator was utilized for composite cladding. Nickel was picked on account of its strength property and consumption resistance at raised temperatures and WC builds the hardness and also adds to higher wear resistance. Subsequently, a cladding delivered with this structure should have ductile and compressive anxiety bearing ability. Through microwave preparing, a deformity free cladding with 0.89 porosity was made. This strengthening creation on a substrate expanded the hardness of SS from 200HV to 416±20HV and flexural quality of clads 629±8N was accomplished.

Gupta et al. (**2012**) researched on development and characterization of microwave composite cladding. Composite cladding (EWAC (Ni-based) + 20% $Cr_{23}C_6$ powder) has been created on substrate austenitic stainless steel (SS-316). The tests were led in residential microwave oven and the clad of thickness, estimated 500 µm has been produced by the introduction of microwave radiation at frequency 2.45 GHz for the span of 360 s. Common clads cross areas of composite clads demonstrated great metallurgical bonding with the substrate by fractional dilution. The back scattered electron picture of clad cross area demonstrated the reinforced chromium carbide ($Cr_{23}C_6$) particles are consistently conveyed and all around inserted in the Ni-based matrix. The created clad is free from visible solidification cracking and has fundamentally less porosity which is of the request of 0.90%. The coating created through thermal splashing process has poor bonding with substrate and less resistance to pinpoint stacking, be that as it may, clad created through laser has fundamentally higher clad bonding quality because of metallurgical bonding. The extraordinary point heat source causes thermal distortion and high residual stresses in laser clad. The quicker cooling rate related in laser preparing causes imperfections like porosity and breaks in hardened clads. The nickel is intense and having high oxidation and corrosion resistance at room and raised the temperature. Chromium carbide has high hardness so utilized as wear resistant material. Round molded Ni-based combination powder and pyramidal formed chromium carbide having the grain size of under 40 µm was utilized for the advancement of composite clads. The estimation of skin depth for nickel which is the significant constituent (~97%) of the EWAC material is (~0.12 µm at 2.45 GHz) which is not exactly the molecule size (40 µm) utilized as a part of the present work subsequently can't specifically collaborate with microwave radiation at room temperature, rather, will have a tendency to reflect microwaves.

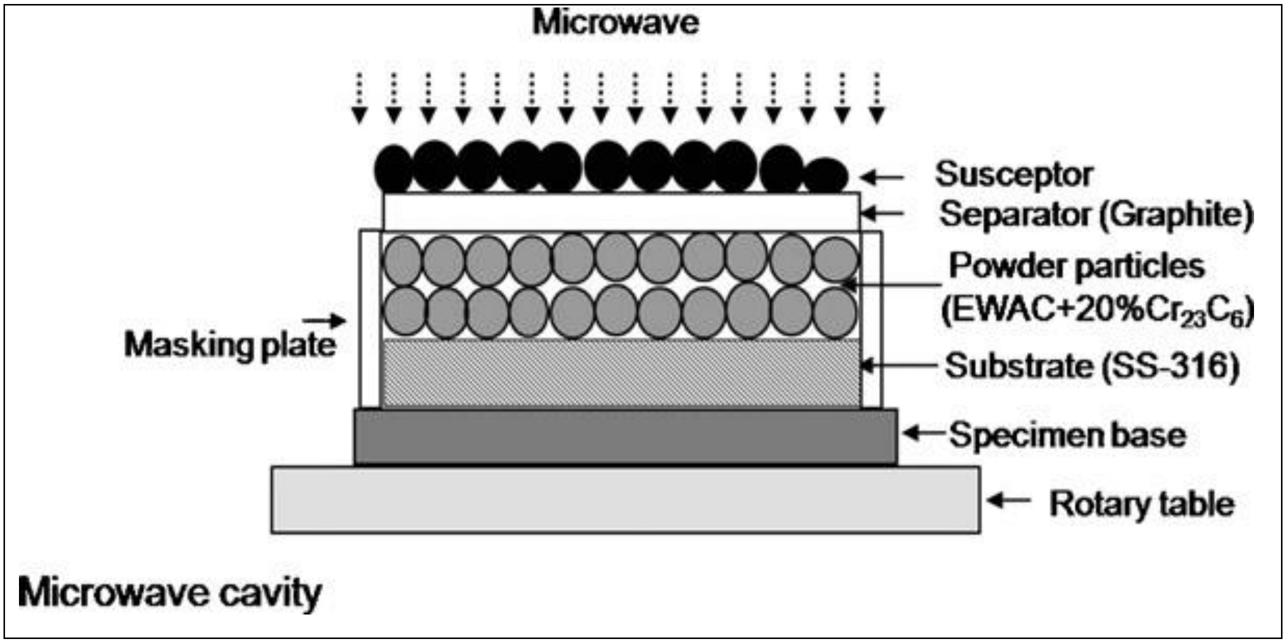


Fig. 2.4. Schematic view of the microwave hybrid heating arrangement [Gupta et al., 2012].

Keeping in mind the end goal to defeat the issue, claddings were produced by microwave hybrid heating (MHH) procedure utilizing appropriate susceptor. So as to maintain a strategic distance from conceivable pollution of clads by susceptor powder utilized as a part of the MHH, a 99% immaculate dainty graphite sheet was utilized as a separator between the susceptor and (EWAC (Ni-based) + 20% $Cr_{23}C_6$) powder. Schematic view of the whole setup used in this study is shown in above Fig. 2.4.

The clad is metallurgical reinforced with the substrate by partial mutual diffusion of components. The clad is free from visible solidification cracking and has altogether lesser porosity which is of the request of 0.90%.The $Cr_{23}C_6$ particles were reinforced in a harder and pliable metallic (mostly nickel) matrix. The normal Vicker's micro-hardness of created clad was watched 425 ± 140 Hv. The created microwave clad can be successfully utilized as a part of wear safe applications.

Prasad and Gupta (2013) did a microwave processed cladding of nickel-based lanthanum oxide composite powder molecule having molecule size of 40 µm on mellow steel. The substrates were cut into normal measurements of 10mm × 10mm × 5mm. At that point, they were cleaned with emery paper to get the simulated surface. In this study, mellow steel was utilized as substrate and composite powder was put on it. The specimen was set in microwave oven with 2.45 GHz frequency, 900 W power and uncovered for 240 sec. The roughly 500 µm clad thickness has been produced on gentle steel. The Vicker's smaller scale hardness of created clad specimen was acquired around 319 Hv and clads demonstrated a superior wear resistance and mechanical properties.

Gupta et al. (2014) spoke to another strategy of coating through microwave, it was the new approach to the surface building. In this cladding approach, they utilized WC10Co2Ni powder on SS-304 through microwave hybrid heating, the fractional weakening of the substrate (austenitic steel) with the cladding material made a metallurgical bonding between the substrate and deposits. Austenitic steels are known for their erosion resistance properties, this is the principle reason for their popularity in commercial ventures. In any case, when the point goes ahead wear, these materials show poor tribological properties. To upgrade this property surface designing as microwave handling is an entrenched innovation over the other surface building strategies like nitriding, cyaniding and carburizing and so forth. Due to its incredible feature of dilution between the clad film and substrate material and surficial completion, which prompts a superior metallurgical bonding and enhances the mechanical properties. In this study, the simplicity of handling and advantages over the laser cladding have additionally been talked about, which prompts lower setup cost, keeping up expense and also bring down working expense and higher testimony productivity. The cracking tendency, for the most part, actuates in laser cladding forms because of high cooling rate and localized thermal distortion, and residual stresses are incited on the substrate, these things can be maintained a strategic distance from upto a degree because of heater cooling. The cladding delivered through microwave handling demonstrated an incredible resistance to abrasion and erosion wear because of an arrangement of carbides of tungsten and nickel. WC enhances the hardness and wear resistance yet having a low durability, this adjusting prerequisite was satisfied by nickel content, so this mix turned into a sublime cladding material by satisfying all the required properties of the substrate material.

2.5 Microwave Sintering of Metal Powders

Sintering is the manufacturing procedure, in which item is created as solid bulk by applying pressure and heat. Sintering is the operation in which the item is not permitted to achieve a liquefying state. Sintering as a manufacturing procedure is utilized with plastics, metals, ceramics and different materials. Sintering can be completed by utilizing ordinary techniques yet the microwave helped sintered materials have had higher properties. Following literature speaks to the utilization of microwave vitality in sintering.

Agarwal (1998) built up a sintering of ceramics and W/Cu composites utilizing microwave oven. The utilization microwave vitality was logically being investigated to make better and less expensive items predominantly ceramics around then and sintering was constrained upto ceramics. Amid this research, it was demonstrated tentatively that on account of W/Cu composite, the process duration was lessened to 1/10th utilizing microwave vitality contrasted with the traditional process and brought about better properties. Sintering brought out through microwave handling prompts diminishment in sintering time, sintering temperature and aggregate process duration. The mechanical properties, for example, thickness, normal grain size, and hardness were moved forward. The microwave coupling comes about greatly quick response in the event of an imperfection and this response results in new shaped materials at much lower temperatures than that of traditional heating procedure. It has been foreseen that with aforementioned critical advances in the field of microwave preparing of earthenware production, there is an extraordinary eventual fate of microwave innovation for productive commercialization for the claim to fame ceramics.

Gupta and Wong (2005) utilized microwave hybrid heating to sinter the metallic materials and enhanced the general mechanical properties of the fabricated item. Al and Mg and lead-free solder were selected to perform sintering procedure. The sintering procedure was done by utilizing domestic microwave oven with 2.45 GHz frequency and 900 W power level. SiC was utilized as a susceptor for empowering coupling amongst microwave and the material. The sintering was brought out through microwave hybrid heating (MHH) in light of the fact that microwave heating has an element to heat the material from inside to outside and then again susceptor (SiC) bolstered the sintering from outwards to inwards. The sintering of every one of the three chose materials was effectively completed utilizing microwave heating. A superior mix of tensile properties was acquired in microwave sintering as an aftereffect of the decreased level of high-temperature thermal exposure.

Agrawal (2006) spoke to the metal handling, for example, sintering, brazing and melting of metals through microwave vitality. In this study, a significance of microwave handling over the ordinary one and the basic points of interest were highlighted, for example, short process duration (coming about into vitality reserve funds upto 90%) over customary techniques, quick heating rates, better microstructures which specifically prompts enhanced mechanical properties. In this exploration, microwave vitality was used for brazing of bulk metal pieces, super-alloy based turbine cutting edges which are extremely hard to join through routine procedures. Joining of cast iron and stainless steel was done with the assistance of braze powder. Sintering of a considerable lot of the business utilized powders have been effectively sintered utilizing microwave preparing, for example, Al, Cu, Ni, W, WC and so forth upto close full densification. The microwave sintering of different metals and metal alloys including ceramics have been sintered in the brief timeframe (75-90% less power utilization than ordinary procedures) with having high mechanical properties like modulus of rupture (MOR) and hardness accomplished was higher than that of customary ones.

Upadhyaya et al. (2006) did the sintering utilizing W–Ni–Fe amalgam through microwave preparing. In this exploration, the composite was sintered and the impact of heating mode on the microstructure and mechanical properties of composite (92.5W–6.4Ni–1.1Fe) was concentrated on and contrasted and conventional procedure. The compacts were sintered utilizing microwave oven having the frequency of 2.45 GHz and conventional heater at 1500°C and in 2.45 GHz frequency. Microwave sintered composite took around 75% less time than traditionally prepared composite, which relates to less W coarsening. The hardness of sintered composite was calculated by Vickers micro hardness tester. XRD was utilized for stage determination. From the exploratory results, it was watched that micro hardness and tensile properties of microwave sintered composite was superior to that of customary ones. The mechanical and microstructural properties of microwave sintered combinations were higher than conventional sintered composites.

Wong and Gupta (2007) did the sintering of Mg/Cu Nano-composites through microwave fast heating. In this investigation, powder metallurgy process including microwave hybrid heating was utilized to prepare magnesium composites with a differing measure of Nano estimated Cu particulates. The sintered sample was hot extruded and characterization was done as far as microstructural and also mechanical properties. The procedure was completed by utilizing microwave vitality with 2.45 GHz frequency and 900W power level. SiC was utilized a susceptor, so microwaves can couple with the material. Microstructure of arranged composite uncovered least porosity since microwave handling has an ability to make the items with high density. The Nano estimated Copper particles were consistently dispersed over the network. Cu particulates lead to an expansion in hardness, 0.2%yield quality, elastic modulus, ultimate tensile strength and work break of the matrix. Tensile properties were expanded utilizing microwave vitality.

Huang et al (2009) worked on improving the sinterability of ceramics using microwave hybrid heating. In the present study, the ceramics were sintered by using hybrid microwave sintering (HMS) which have the characteristics of both conventional heating and microwave heating. While evaluating the performance of the sintered ceramics prepared by microwave sintering and conventional sintering in respect of thermal residual stress distribution, it was found that that former can sinter a ceramic in the entire volume with enhanced mechanical properties. It was also found that pore ratio in terms of depth and radius was different for different depths and radius in conventionally sintered samples while the pore ratio for microwave sintered sample were same in all aspects. This study also reveals that micro-hardness values of microwave sintered samples were almost twice the micro-hardness values of conventionally sintered samples.

Rajkumar and Aravindan (2009) have effectively sintered copper-graphite composites through microwave preparing route. These metal matrix composites are progressively being utilized as a part of tribological applications as a result of their higher wear resistance. Microwave handling is a novel system for a combination of metals when contrasted and customary heating machines. For the experimentation, copper and graphite powders were combined altogether. A modern microwave having a frequency of 2.45 GHz was utilized for handling. SEM images for the present work are shown in below Fig. 2.5.

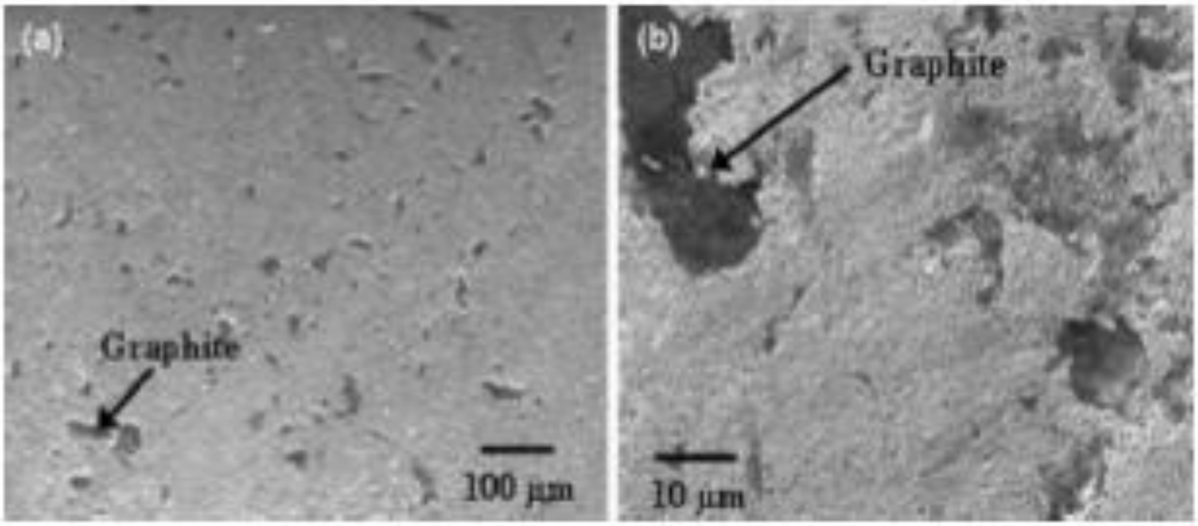


Fig. 2.5. SEM image of sintered composites through microwave processing [Rajkumar et al., 2009].

Hybrid setup was shaped in such a way, to the point that it was having two layers of components, for example, initial one was straightforward to microwave and the second one was the absorbers of the microwaves, known as the susceptor. The micro hardness and microstructure of created samples were analyzed. There was a huge change in the miniaturized scale hardness of microwave handled (sintered) copper – graphite composite in various volume divisions and the created tests were free from cracks. The better microstructure with moderate porosity level brought on because of microwave heating expands the execution of the composite.

Mondal et al. (2010) did the sintering of refractory metals/amalgams through microwave preparing. Refractory metal/alloys are understood as a result of their mechanical properties however their melting temperature is high. In light of refractoriness, it is extremely troublesome undertaking to prepare these metals/alloys, as a matter of first importance, the issue comes to accomplish the temperature in customary heaters under moderate conditions. Amid this examination, refractory materials, for example, W, Mo, W-Cu, W-Ni-Cu, W-Ni-Fe refractory materials having an extensive variety of temperature contrast between each other were taken for the investigation. Tungsten (melting temperature 3420°C) and Mo (melting temperature 2620°C) was sintered in microwaves for 30 minutes in H_2 atmosphere. The alloys W-30 Cu compounds, W-7Ni-3Cu combinations, W-Ni-Fe amalgams were sintered for 30 minutes in H_2 atmosphere. Microwave sintering of these metals conveys around 80% lessening in complete preparing time. Better grain size and better mechanical properties were likewise accomplished through microwave sintering which can be considered as an extra favorable position which expanded the execution of materials.

Rajkumar and Aravindan (2011) performed a test for copper-carbon nanotubes composite through microwave sintering and assessed the tribological conduct of alloys. Copper covered carbon nanotubes with 5-20 vol. % with copper powder were blended all together and sintering was completed utilizing microwave heating. The electrolytic copper powder was utilized as a matrix and multiwall carbon nanotubes were utilized as a reinforcement. Hybrid heating setup was to handle the material inside the microwave heater with 2.45 GHz frequency and 3.2 KW power. Created tests were described utilizing XRD, SEM, and SEM-EDS. Pin on disc setup was utilized to assess the tribological execution of the copper-carbon nanotubes alloys under dry conditions. The rate increment in volume of carbon nanotubes (CNT) lessens the coefficient of contact and wear rate of alloys. Self-oil property of carbon film was represented diminishment in coefficient of friction, which gives the property of higher wear resistance to the sintered alloys.

Rajkumar et al. (2012) spoke to the science of Cu-graphite sintered composite through microwave handling by ascertaining its wear conduct. The most well-known uses of Cu-graphite composite are found if there should arise an occurrence of those regions where the profoundly conductive material is required and additionally lubrication phenomenon. Both of these necessities can be satisfied by Cu-Graphite composite. The fundamental use of these composites are in electrical machines, for example, electrical brushes in engines and generators, where sliding contact becomes an integral factor. In view of fabulous properties of graphite to build the wear resistance and coefficient of friction because of self-grease, it's by and large utilized as a reinforced part into grids. The wear rate of the sliding part is impacted by numerous variables, for example, temperature, weight, sliding rate, and material properties. So the accelerated life testing (ALT) was done to investigate the wear properties of the material. The wear testing of the composite was completed utilizing pin-on-disc tribometer with shifting temperature and weight at various sliding speeds. In this study, copper-10 vol. % graphite composite was set up by powder metallurgy, which is a decent one mix for better sliding properties. The blending powders were mixed for 2 hours in electrical agate pestle mortar with the rate of 20 rpm. Prior to the compaction, powders were preheated at a temperature of 150^0C to dissipate the unpredictable constituents. Sintering as tube-shaped parts was done by microwave handling after compaction with water driven press and heater cooling was received. The hardness of the composites turned out to be 98 HV, which was higher than expectedly arranged composite. After wear testing, it was broke down that temperature and weight influences the wear rate of the composite upto a degree. The most remarkable component of the outcome result was that the microwave sintered composite showed 3 ½ times preferred mean life over electro-graphite sliding contact material.

Rajkumar et al. (2013) reported the work on the composites of Cu-nano graphite produced through microwave preparing. In this research, the properties of Cu-graphite composites which they conveys, the impact of particle size, loading conditions and impact of sliding rate on the wear execution were highlighted. The composites were sintered through microwave preparing. The copper-graphite composites are for the most part utilized as a part of electrical engines/generators, bush and bearings in commercial ventures. So these materials ought to have self-lubrication property so that sliding wear can be minimized upto a degree. Gibson et.al have reported that change of wear-resistance in the event of aluminum should be possible by having an expansion of 2% graphite in it, however, higher graphite content upto 8% graphite debilitates the composite by expanding its delicate quality and which relates to higher wear rate. In this study, pure copper (99.98%) was utilized as a matrix material and graphite as nano-graphite as a reinforced material was chosen. The composites were fabricated through powder metallurgy by shifting graphite content (5%, 10%, 15% and 20%) vol. of graphite. Homogeneous conveyance of nano-graphite in copper framework uncovers less porosity, high density, high hardness and high electrical conductivity Cu-nano graphite 5 vol. % composite demonstrated a high estimation of hardness and most noteworthy thermal conductivity when it was contrasted and the other fluctuating graphite extent of composites.

2.6 Microwave Melting of Metal Powders

Chandrasekaran et al. (2011) did an experimentation to melt the metals through microwave handling. It was the first run through in microwave material preparing when the melting of metals was helped out through microwave oven/heater. Melting metals through customary heaters prompts high measure of vitality and in addition time utilization. Most importantly, its exceptionally tedious procedure to accomplish the required temperature for melting metals in customary heaters, and there is a probability of material and vitality misfortunes. In ordinary heaters, some dangers are additionally connected with it. Keeping in mind the end goal to conquer the confinements connected with the conventional melting, some propelled melting advancements appeared, for example, plasma melting, electron beam melting, infra-red melting, microwave melting, solar melting and so forth are favored over the ordinary ones due to their excellent generation for some extraordinary application and necessities. Microwave heating is a tad bit more mindful on account of its significant points of interest, for example, high heating rates because of hybrid heating idea, which specifically compares to improve the handling time, less utilization of power and less environmental hazards. Microwaves can't bargain legitimately with metals and cause sparking when interacts with the metallic materials.

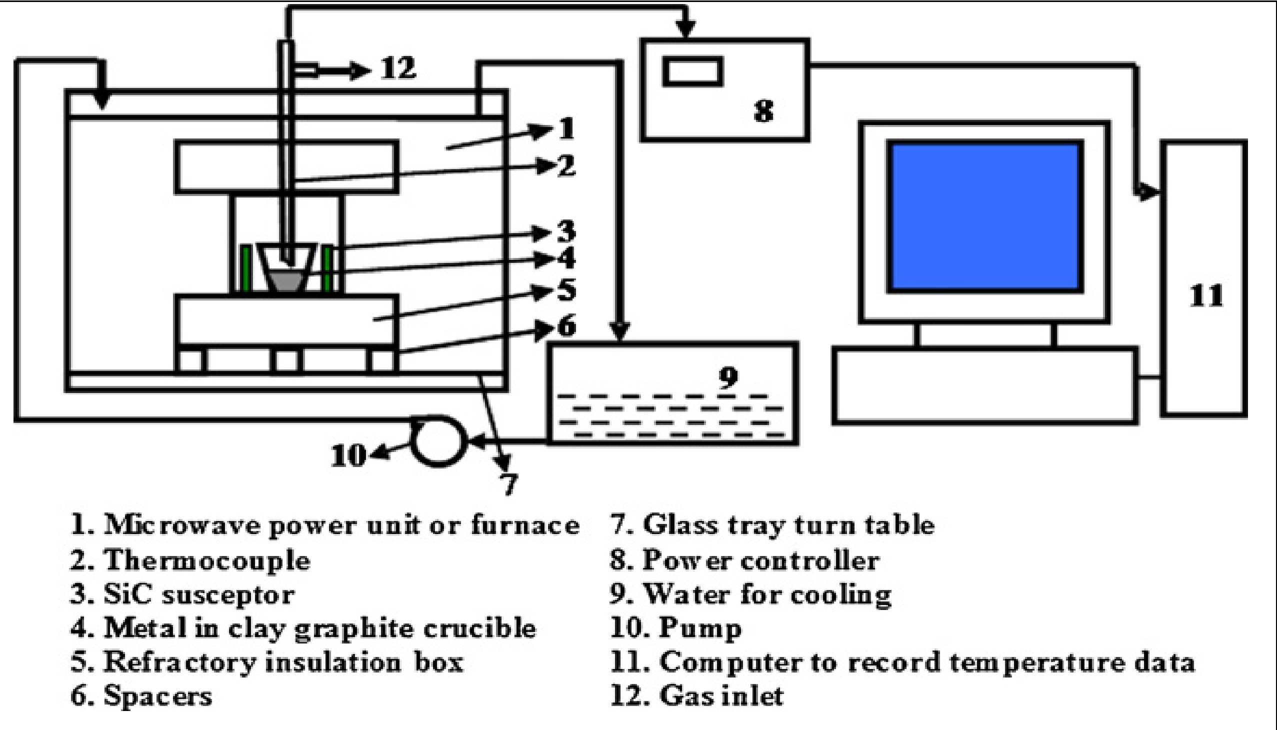


Fig. 2.6. Schematic diagram of microwave melting of metals [Chandrasekaran et al., 2011].

The microwaves are reflected by the metals, in light of the fact that their skin depth is of a couple of microns. Microwave melting of low-temperature materials, for example, lead, tin, aluminum and copper was done with the guide of susceptors. Aluminum and copper samples were melted in the climate of argon/nitrogen (idle gas) to minimize the danger of oxidation. On contrasting it and the melting through the traditional heater, microwave melting was observed to be twice quicker, which specifically prompts less vitality utilization and less time utilization. The apparatus used in this research is shown in above Fig. 2.6.

2.7 Conventional Casting Methods

Customary throwing strategies which are utilized for the creation of metal matrix composite incorporates squeeze casting, powder metallurgy, friction stir casting, die casting, centrifugal casting. Stir casting and so on. Different techniques have extra focal points and a few constraints, which are highlighted by different specialists, and are clarified underneath;

Kang et al. (1996) created the metal matrix composites through die-casting and assessed the mechanical properties of composites. A slurry was readied, which contains alumina filaments with silica binder and impeller was utilized to guarantee the correct blending of the fixings. The fundamental handling parameters of the creation were the blending time, a measure of binder and measure of water and so on ought to be dealt with while planning composites through this innovation. A customary aluminum combination was utilized as a matrix material. Infusion speeds having a range from 0.1 to 3.6 m/s were utilized to create Al_20_3-short-fiber reinforced MMCs. The preheated preform was settled in the preheated die cavity and liquid metal has filled the mold. After closing up the dies, the pressure was applied till the complete solidification took place. At last, the MMC part was shot out. To think about the metallurgical properties of the composites, the examples were cleaned through programmed polisher. The metallographic readiness of composite examples was accomplished by cleaning on a programmed polisher. Microstructural investigation of the composites was done by scanning electron microscope instrument. It was seen from the investigations that with the lessening in infusion speed, the infiltration length of the composite was expanded. The genuine pressure, when contrasted with the applied pressure, was little. From the outcome perspective, the conclusion turned out that infusion speed is the principle parameter to control the infiltration length. With expansion in fiber length, the physical and mechanical properties additionally got expanded, for example, tensile strength, hardness of the composite and elastic modulus.

Beffort et al. (2006) exemplified the microstructure and mechanical properties of SiC reinforced aluminum composites by squeeze casting process and examined its alloying impacts. In this procedures, the matrix material was utilized as Aluminum composite (99.90%) and Silicon Carbide (SiC) was utilized as reinforcement material. The steel castings were utilized to pack SiC particles, with graphite based covering and preheating was completed at 750°C and were blended with the liquefied matrix material. After expansion, the weight of 1400 bar was connected for two minutes. The microstructure was broke down by utilizing optical microscopy, SEM, EDS and so forth. The outcome demonstrated that the hardness element was expansion up to 10-20% and bending strength was accomplished upto 700 MPa alongside versatile modulus 200 GPa. Which expresses that rate of SiC substance ought to be changed according to the constituents of the alloying components and the required mechanical properties of the MMC's.

Kovacik et al. (2008) did a study to a friction coefficient of composites conveying copper as a matrix and graphite as a reinforcing specialist by changing the compositional rate of graphite. The hot-isostatic squeezing procedure was utilized to set up the composite and % age of graphite was differed from 0-50 vol. %. On the second hand, copper covered graphite having 30-50 vol. % of graphite was utilized. With expanding convergence of graphite in copper, first, wear rate of covered and uncoated specimens at first abatements and the coefficient of friction of composite gets to be autonomous on the composites, when it achieves the threshold value. Copper powder demonstrates a dendritic shape and graphite has a drop shape in SEM pictures. The outcome demonstrated the limit esteem for fine graphite powder (16μm) was 12 vol. % and for coarse powder, it was 23 vol. %.

Huang et al. (2011) directed a test to produce aluminum composite cylinders utilizing SiC as support material through centrifugal casting. An aluminum alloy was utilized as a matrix material and the reinforcement of SiC particles with the widths of 15 and 30μm. The same extent of the SiC particles having 50% each was utilized for both the distinctive sizes of particle structures. The liquefying of Al–Si compound was done in a graphite crucible. After planning of melt, a stirrer was brought into the liquid metal and afterward it was mechanically disturbed. The slurry arranged was then filled the turning mold of the vertical outward machine comprising of iron mold with two sections lastly, the Al alloy based composite cylinders were manufactured by centrifugal casting reinforced with SiC particles. These kind of cylinders conveys an enormous measure of SiC particles, where the most required properties are, for example, hardness and wear resistance and so forth. Three diverse zones exists in the cylinder from the cylinder head to the cylinder skirt. The hardness values along the hub of the cylinder bit by bit diminish from the head to the skirt, which prompts the change of structure all through the length of the cylinder. The cylinders were effectively created through centrifugal casting having a temperature of the slurry 850^0C and temperature of mold 600^0C. The rotational velocity of the mold was 800 rpm, has the most elevated hardness esteem, i.e., 93.9 HRB. The outcomes demonstrated that with the expansion in nano-CuO content, Micro-hardness of the specimens expanded. The most extreme hardness is watched for the example with 2 wt. % nano-CuO. The mechanical properties of the composites enhanced with expansion in weight% of nano-CuO particles.

Akbari et al. (2013) performed an analysis to make aluminum composite reinforced with Al_20_3 and assessed its properties. A356 amalgam was utilized as matrix material and Al_20_3 nanoparticles as reinforcement material. A resistance heater with a graphite stirrer was utilized as a part of resistance heater to blend the liquid aluminum combination with the Al_20_3 powder wrapped in aluminum foils. The readied slurry was mixed for 12 min, having temperature 850^0C at 450 rpm and afterward it was filled solid metal molds and round and hollow formed composites were completed after hardening. The scanning electron microscope instrument (SEM) was utilized to investigate the microstructural portrayal. In results, SEM micrographs indicated consistently circulated support of Al_20_3 all through the matrix. The mechanical properties, for example, hardness, tensile and compressive quality diminished with the expansion in processing time and the porosity of the composite expanded relatively.

2.8 Copper Composites Manufacturing and Their Properties

Relevant literature on copper composite manufacturing has been reviewed to determine electrical, mechanical and fracture properties with varying composition of copper and other composite materials. Determination of these important properties helps in recognizing the application of these composites in the field of electronic application, wireless telecommunication, as a heat sink, as a microwave carrier and so on.

Dusane et al. (2013) did a study on determination of electrical and mechanical property of graphite reinforced copper composites by varying the reinforced material in the form of weight%. Copper is used as the matrix material and graphite as a reinforced material. Powder metallurgy was used for preparing the copper composites. This study is mainly focused around electrical conductivity of the composite. Copper is reinforced with 2%, 5% and 10% graphite. Three samples of each varying composition were prepared and each at different compacting pressures and sintering temperatures to avail the changes in electrical conductivity, density and vicker's micro hardness. Graphite particles were evenly distributed in the composite. Electrical conductivity of the composite increases till 5% graphite by weight and then decreases due to increased resistance between material which is because of bad affinity of material towards each other and clustering effect. The study also revealed that as the graphite% by weight increases, density decreases as the wt. % of graphite increases with simultaneous decrease in wt. % of copper which eventually drop down the density**.** Vicker's micro hardness tends to decrease as the wt. % of graphite increases.

El-Hadek et al. (2012) did research on the fracture properties of SPS Tungsten Copper powder composites with various copper nano- particles volume fractions. A new technique of sintering is used i.e. Spark Plasma Sintering (SPS) in which pulsed direct current was simultaneously used with uniaxial pressure to mainly sinter the powders. The reasons behind using SPS are uniform heating energy conditions and fast heating rates. Samples of tungsten-copper composites with varying Cu composition of 20%, 25% and 30% by volume were prepared at two different sintering temperatures among which one is above the melting point of copper (1373 K)and one is below the melting point of copper (1273 K). Very fine tungsten powder of size 2µm was used whereas copper powder was taken of the size 35µm. Both the powders were milled in an agate rock mortar to obtain uniform sphere like nano-sized particle of both copper and tungsten. SEM images of the composite reveals that the small copper particles were homogeneously distributed around large tungsten particles. With the help of vicker's micro hardness tester hardness was calculated, which reveals that with the increase of copper the hardness tends to decrease but the hardness values tends to increase with increasing sintering temperatures. This study also reveals that with increase in copper volume fraction, the electrical conductivity and coefficient of thermal expansion increases. Fracture surface roughness was noticeably higher with higher copper volume fraction.

Wang et al. (1998) did a study on the effect of tungsten particle size on the processing and properties of infiltrated W-Cu compacts. W-15Cu compacts with three different tungsten particle size (8.7, 23.2 and 65.2 µm) were prepared by sintering then by infiltrating with oxygen free copper. It is found that compressibility was maximum for medium size powder, followed by coarse than fine powder. It is also achieved that for the similar desired skeleton density, higher sintering temperatures and compacting pressures were needed when the size of the tungsten particle decreases. This study also reveals that with the increase in the infiltrated density, the resistivity decreases.

Kandavel et al. (2010) investigated on the microstructure and mechanical properties of sinter-forged Cu and Mo- alloyed low alloy steel. Initially fundamental powders of graphite, copper, atomized iron and molybdenum were taken and mixed properly with the help of hydraulic press and then sintered at 1000 ± 10^0C, so that alloy compositions by weight can be prepared. Various composition includes Fe-0.5% C, Fe-0.5% C-1% Mo, Fe-0.5% C-2% Cu, Fe-0.5% C-1% Cu and Fe-0.5% C-2% Mo. The prepared samples were then hot upset forged to near about theoretical density. This study reveals that the addition of Mo or Cu to C-Fe boosts the hardness and tensile strength to adequate levels with a decrement in fatigue strength. The alloy having 2% Mo by weight possess the highest tensile strength among all the compositions. Sinter-forged alloy steels from fundamental powders with Cu or Mo added as alloying elements may achieve fairly moderate levels of hardness and strength, which may favor them to be used structural as well as automotive components applications.

Junhui et al. (2011) did a study on the fabrication, properties, and microstructures of copper matrix composites reinforced by molybdenum-coated carbon nanotubes. In this study multiwalled carbon nanotubes (CNTs) were layered by a molybdenum layer using carbonyl thermal decomposition process with a precursor of molybdenum hexacarbonyl. Copper powder was added to the Mo-coated CNT’s to prepare Mo-CNT/Cu composite by the means of mechanical milling which is then treated by spark plasma sintering. This study reveals that the hardness and tensile strength of Mo-CNT/Cu composite were 2.2 and 2 times more than those of CNT specimens respectively. This study also showed that the Mo-CNT/Cu composite exhibits an improved thermal conductivity but poorer electrical conductivity as compared with the sintered pure Cu.

2.8 Summary of the Literature

The uses of microwave vitality in different areas of engineering are expanding step by step because of noteworthy upgrades in mechanical properties, lessened processing times and cost. The idea of microwave hybrid heating has investigated its potential upto the characteristic of commercial ventures. The lower vitality utilization with a higher rate of heat generation because of volumetric heating quickened the examination in this field of preparing materials. The most critical component of specific heating is one of the primary explanation for its fundamental use for metals preparing. Most importantly, to comprehend the idea of microwave handling, different assembling procedures being done through this innovation were considered i.e. joining, sintering, cladding and melting of metal powders and so on. Microwave hybrid heating brought about enhanced properties than routine techniques were accounted for because of the arrangement of new more grounded stages and uniform grain development amid MW preparing.

The different techniques were utilized to set up the MMCs with the target to get increasingly upgrades in their mechanical properties and their correlation with different strategies for assembling the same. The impact of the strengthened materials with their changing rate were concentrated on. The adjustment in reinforcement influenced the properties as well as changed the microstructure and grain development of the composites. For the assembling of MMCs, the routine procedures, for example, friction stir casting, stir casting, die casting and normal techniques to set it up were examined. In the wake of summing up, it was inferred that every one of these properties can further be improved by manufacturing the MMCs through microwave hybrid heating.

Chapter 3

RESEARCH GAP, PROBLEM FORMULATION AND METHODOLOGY

This section represents the fundamental thought that how the idea produced to create the composite castings through microwave heating, different goals found in the field of microwave processing and its constrained use in materials development.

3.1 Research Gaps in the Literature

The broad writing review on microwave material processing uncovered that microwave radiations are presently utilized for high-temperature applications as a part of the field of manufacturing. Initially, the fundamental utilization of microwave vitality was seen mainly for the communication reason. A short time later, this innovation was proposed for heating food stuff materials for low temperature applications. With the advancement of innovation, its heating ability was utilized for the processing of polymers, minerals, ceramics, inorganic materials and so forth. It has been seen that the fundamental impediment of microwave radiations at the room temperature can't collaborate with the metals, so it's extremely hard to heat metals with this innovation. Thus, look into amid most recent two decades uncovered that microwaves can couple with metal by a mediating medium called separator and susceptor. The assistance of this methodology, different manufacturing forms like joining, sintering, cladding and melting of metal powders have been done utilizing microwave innovation. Microwave materials processing uncovered surprisingly magnificent properties and wonderful lessening in preparing time yet an extremely restricted examination has been seen in the field of melting and casting of powders, so part of degree is still left in the field of melting and casting. In the other metal preparing operations helped out through this innovation, it is found that the mechanical properties, tribological properties and microstructural properties were enhanced when contrasted with the products prepared by conventional processing. Every one of these properties are wanted in metal casting likewise and to make giving the process a role as a green manufacturing framework with lessened vitality utilization, the choice was taken to cast it through microwave hybrid heating.

3.2 Limitation in the Existing Literature

The various degree of improvement have occurred in the range of manufacturing, with the advancement in innovation, however, nobody has edified on these taking after parameters while producing the MMCs, and these parameters are;

- The priority strategy to fabricate the MMCs, with keeping up its good mechanical properties, wear resistance, hardness, microstructural properties, fracture properties, electrical properties(electrical resistivity, electrical conductivity)
- Based on vitality utilization, which technique is ideal and what are the underlying prerequisites of the procedures on the premise of its basic use.
- In all the manufacturing forms, the idea of volumetric heating or melting is not presented, which is one of its primary impediments.
- Most of the metal matrix composite (MMC) casting procedures are exceptionally tedious strategies and time consuming.

  In the event of microwave processing, the various improvements in the properties have seen as reported in the literature studies. For instance, in the event of microwave joining and brazing, sintering, surface medications, microwave cladding, and so forth. Be that as it may, a very no work has been reported in the field of melting of powder and fabrication of metal matrix composite through microwave processing.

3.3 Problem Formulation

In the time of ferocious rivalries in the field of manufacturing, planning particular materials for fancied application is not a financially savvy arrangement in the present situation. Microwave processing can be a potential candidate in developing a MMC instead of traditional or conventional processes like sintering, infiltration, etc. which requires much time and high cost of production. The fundamental target of the present research is to build up another savvy and in addition green procedure for creating metal framework composite utilizing a non-conventional wellspring of vitality (microwave) which offer an assortment of points of interest when contrasted with the conventional ones. The microwave as a heating source can be a substitute for the current sources and can defeat those restrictions. Therefore, an attempt will be made to develop MMC’s casting through microwave heating and investigate the mechanical, metallurgical and electrical properties of developed casting. The fundamental qualities of microwave incorporate:

(1) Radiation depth of penetration

(2) Rapid and volumetric heating

(3) Hybrid heating

(4) Selective heating of materials.

These inalienable attributes of microwave heating gives more quick and uniform heating in a green situation and offers better product quality. The fabricated items through this innovation have novel microstructures, better mechanical properties and extra favorable circumstances from a monetary perspective, for example, a decrease in preparing times which likewise relates to lessened manufacturing cost. Be that as it may, heating metals and therefore cladding utilizing microwave is a testing errand because of poor penetration depth of the microwave at regular frequency 2.45 GHz at room temperature.

3.4 Objectives of the Research

Subsequent to experiencing the literature in different fields of microwave handling by various writers, research crevices were detailed. The principle goal of each research is to minimize the confinements of the current handling upto a degree and to improve the required properties. The audit of literature permitted the investigation of crevices in research and to satisfy the above expressed gaps taking after research objectives has been characterized: The principle objectives of the present research are;

1. To develop a metal matrix composites (MMC's) through microwave processing by using household microwave oven of 900W power at 2.45 GHz frequency.

2. To optimize processing conditions for development of electrically conductive MMC casting and to produce net shape components with homogeneous microstructure.

3. To metallurgical and mechanical characterize microwave processed composites castings by using various available methods.

4. To investigate the electrical properties of the casted samples.

5. To compare the result obtained from the samples prepared with the help of microwave casting and cast produced by traditional/conventional processes.

3.5 Methodology of the Present Work

The research gaps were shaped and objectives were produced for the present work on the premise of literature survey. To convert these objectives from initial phase to final phase following methodology was used:

- In the first phase of work, detailed literature review was conducted and on the basis of that problem was identified to be worked on.
- In the second phase of work, proper matrix material and reinforcement materials on which this research is to be carried out was selected on the basis of their properties, usage and applications.
- In the third phase of work, the cavity of required dimensions was prepared for casting of these selected materials using microwave processing’s.
- In the fourth phase of the work, the selected materials was casted to prepare a metal matrix composite in a domestic microwave oven.
- In the fifth phase of work, characterization of the prepared samples in terms of metallurgical, mechanical as well as electrical was conducted.
- In the final and sixth phase of work, comparative analysis of microwave prepared samples and traditionally/conventionally prepared samples was carried out.

The projected plan of the current research is illustrated in Fig. 3.1, which shows the flow chart showing the main phases of work.

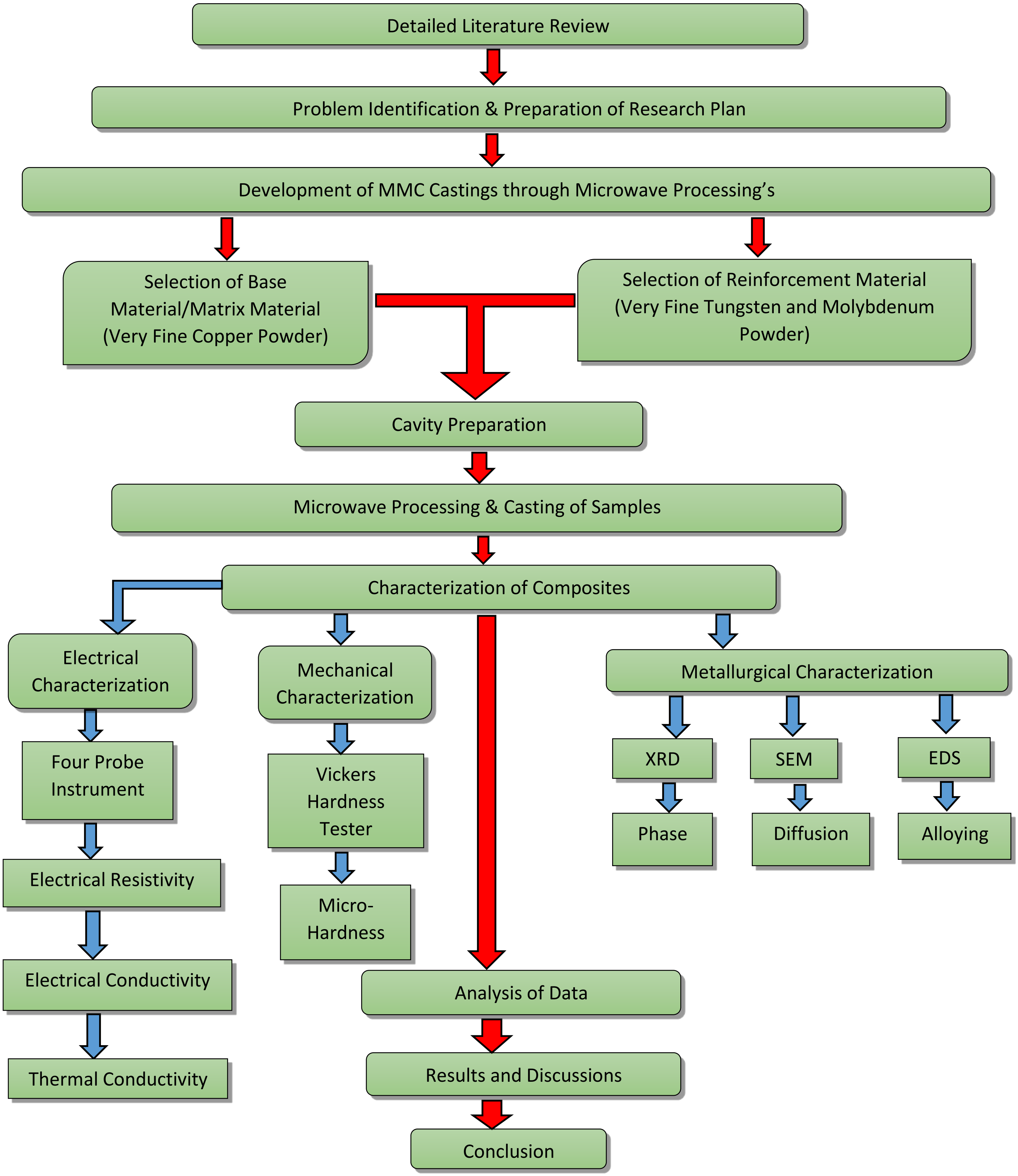


Fig. 3.1. Flow chart showing the brief methodology of the present work.

Chapter 4

EXPERIMENTAL PROCEDURE

The advancement of metal matrix composites is a difficult errand by utilizing the microwave radiations. The fundamental explanation for this task is the poor coupling amongst microwaves and metals and an exceptionally restricted measure of exploration has been completed if there should arise an occurrence of melting of metallic materials. In the present research, highly electrically conductive composite castings having copper as the matrix/base material with varying tungsten and molybdenum by weight% as a reinforced material have been fabricated by utilizing domestic microwave oven of 900W power and 2.45 GHz frequency as a heating source. The underneath sections briefly describes that why these materials have been selected and the procedure for fabrication and characterization of composites.

4.1 Material Selection and Its Application

Matrix material: To fabricate metal matrix composite, copper was chosen as the matrix or base material for the reason that it is widely used in electrical and electronics appliances due to its highly conductive nature [Dusane et al., 2013].

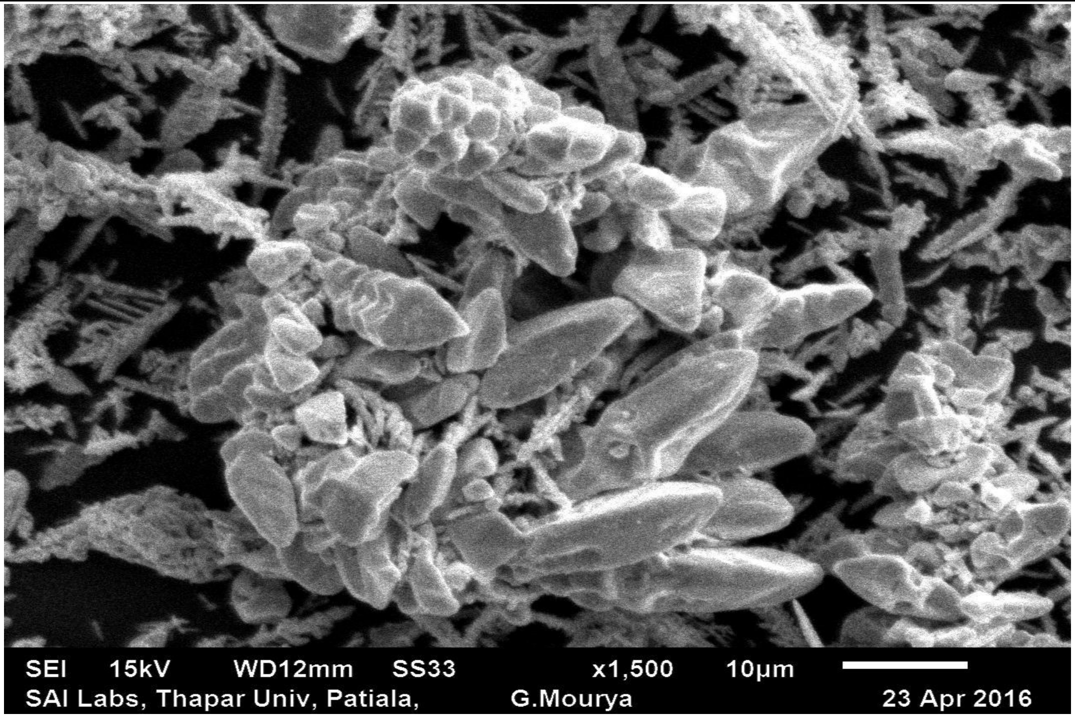
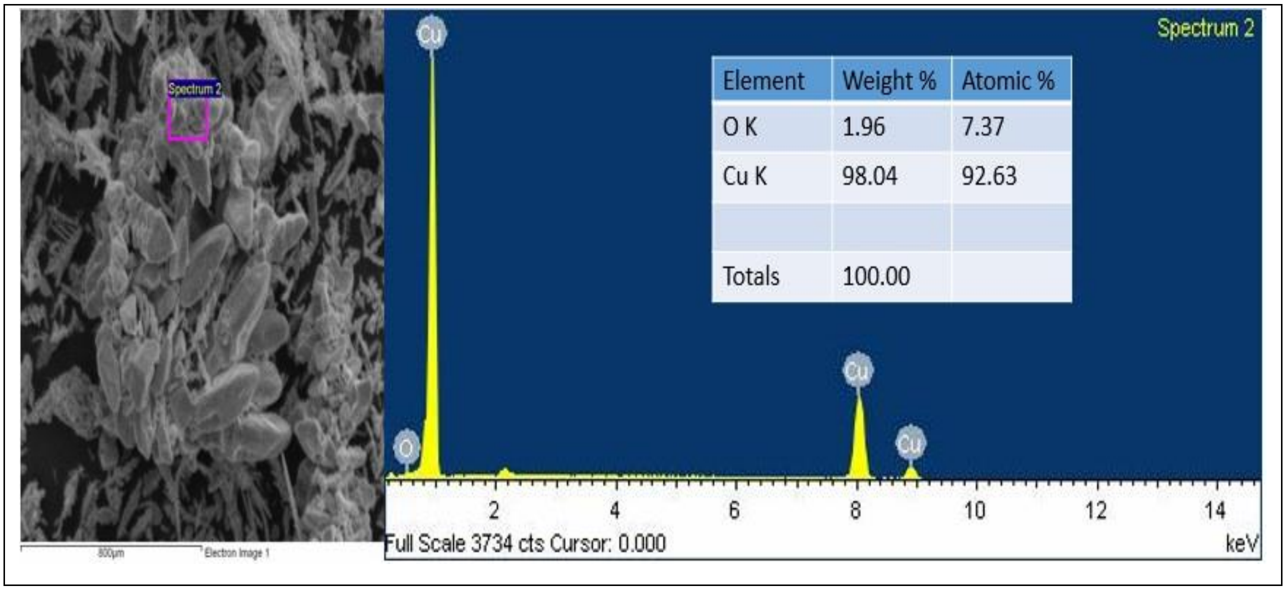


Fig. 4.1. Microstructure of the copper metal powder.



Element	Weight %	Atomic %
O K	1.96	7.37
Cu K	98.04	92.63
Totals	100.00	

Fig. 4.2. Elemental composition of copper metal powder.

The microstructure and the elemental composition of the copper powder used are shown above in Fig. 4.1 and Fig. 4.2. From the above figure, it can be clearly seen that copper powder was 98.04% pure, so the results would come accordingly after microwave processing and the oxygen content would also be reflected in the casted samples.

Reinforcing material: Tungsten and molybdenum was chosen for reinforcing material as they exhibit tremendous properties which together with copper can make a big difference. As far as tungsten is concerned, it has a high hardness value, even more than many steels. It is highly wear resistant. It is malleable so it is quiet easy to work on it. It has a higher melting point and tensile strength which makes it suitable in adverse conditions. It has low coefficient of thermal expansion which is desirable for high thermal applications. It even has a good electrical conductive value, so that it can be mixed with copper and that doesn’t makes a big difference to the copper. Molybdenum also exhibits the similar properties as tungsten but except the fact that it has a little bit high electrical conductive value than tungsten, else in all respects it shows the lesser values than tungsten [El-Hadek et al., 2012, Wang et al., 1998]. The microstructure and the elemental composition of the reinforcing materials i.e. molybdenum metal powder and tungsten metal powder are shown in below Fig. 4.3, Fig. 4.4, Fig. 4.5, and Fig.4.6.

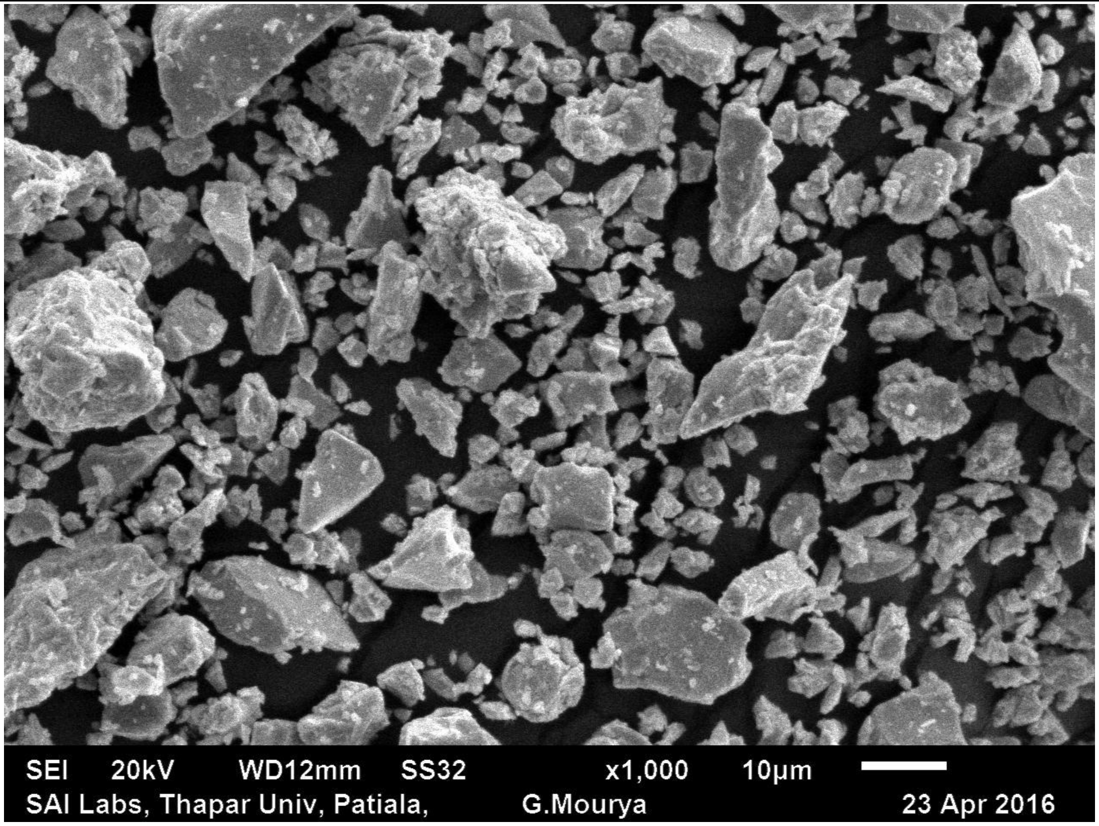
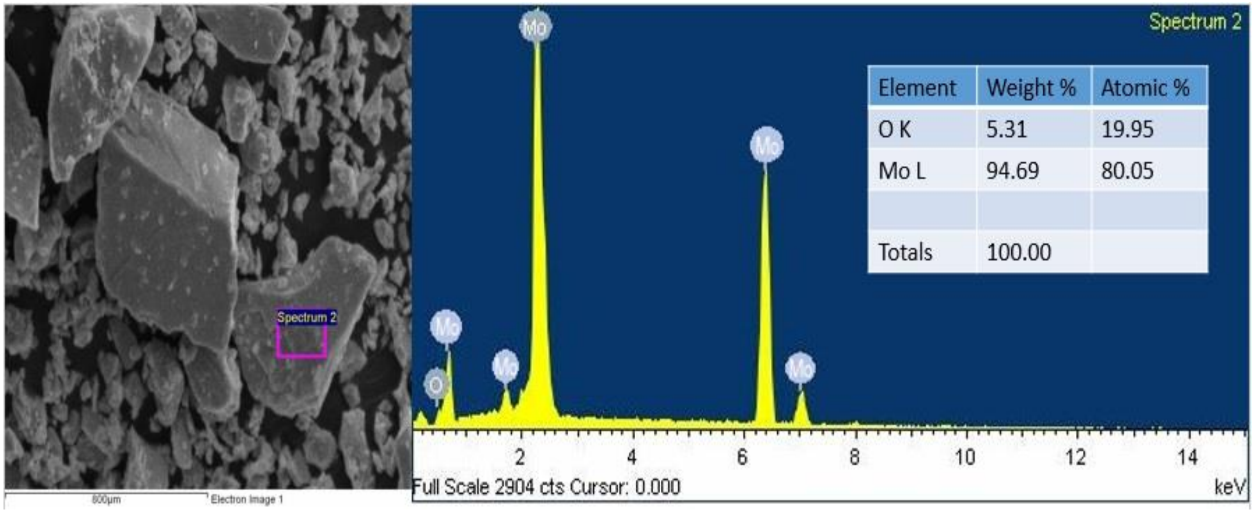


Fig. 4.3. Microstructure of the molybdenum metal powder.



Element	Weight %	Atomic %
O K	5.31	19.95
Mo L	94.69	80.05
Totals	100.00	

Fig. 4.4. Elemental composition of the molybdenum metal powder.

The molybdenum powder was 94.69% pure with high oxygen content, so there might be the chances of getting high oxygen content in molybdenum reinforced samples after microwave processing’s.

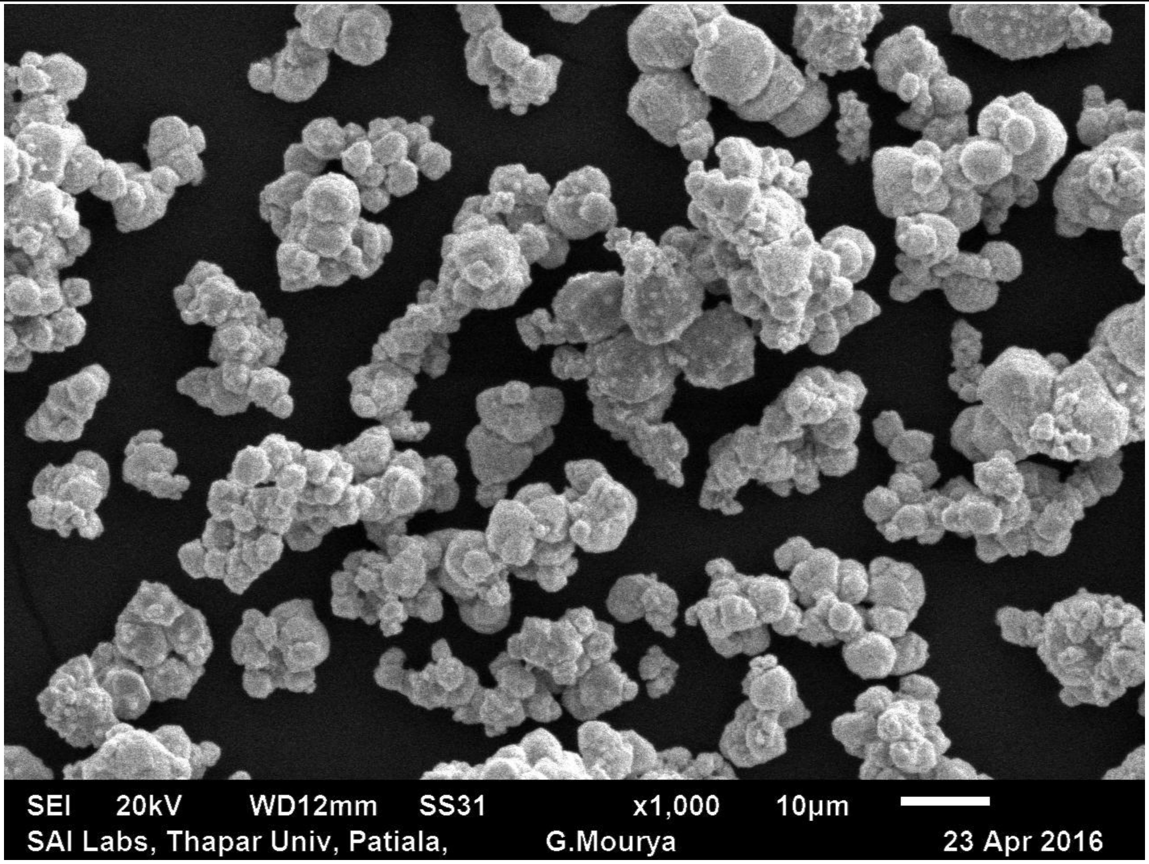
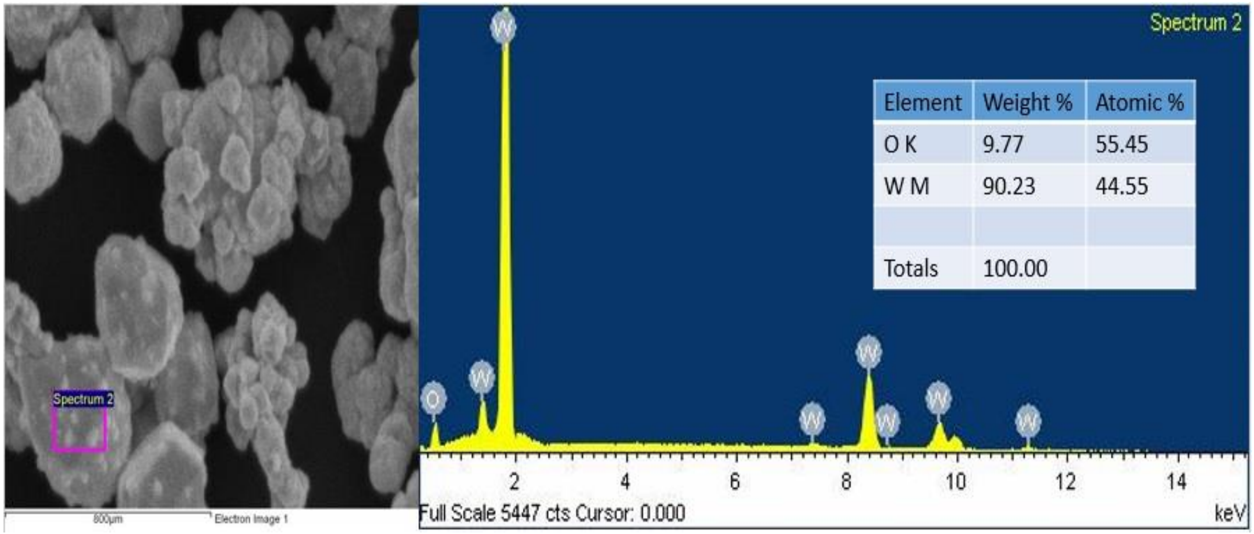


Fig. 4.5. Microstructure of the tungsten metal powder.



Element	Weight %	Atomic %
O K	9.77	55.45
W M	90.23	44.55
Totals	100.00	

Fig. 4.6. Elemental composition of the tungsten metal powder.

The tungsten powder was 90.23% pure with too high oxygen content. The tungsten powder has agglomerated structure.

4.1.1 Applications of Cu-W and Cu-Mo

The low coefficient of thermal expansion of tungsten/molybdenum and high thermal conductivity of copper makes Cu-W and Cu-Mo composites suitable for thermal management materials in microelectronic devices. Cu-W and Cu-Mo composites exhibits mutual insolubility [El-Hadek et al., 2012, Wang et al., 1998]. Furthermore on the basis of their properties these composites are used as:

1. Heat sinks in electronic packages
2. Electrical sliding contacts in high power switches & plasma facing components
3. For thermal management materials in microelectronic devices
4. Microwave carriers
5. Hermetic package bases
6. Ceramic substrate carriers
7. Laser diode mount
8. For microelectronic industries(power and radio frequency packages)
9. Wireless telecommunication

4.2 Production of Copper-Tungsten and Copper-Molybdenum Metal Matrix Composite Castings

The copper-tungsten and copper-molybdenum metal matrix composite castings were prepared by reinforcing the reinforcement material (tungsten and molybdenum) into matrix material (copper) through microwave hybrid heating. Studies were carried out to analyze the microstructural, mechanical and electrical properties of microwave processed pure copper, conventional cast copper and microwave processed tungsten and molybdenum reinforced copper composites castings.

4.2.1 Selected Parameters for Microwave Processing

Before the microwave processing, matrix material and reinforcing material was selected, According to that seven compositions were decided to fabricate through microwave processing. Pure copper, Cu-10 wt. % W, Cu-10 wt. % Mo, Cu-30 wt. % W, Cu-30 wt. % Mo, Cu-50 wt. % W, Cu-50 wt. % Mo were selected as a composition to cast metal matrix composites utilizing domestic microwave oven. Other than these, a copper was also selected for comparative analysis. The experimental setup, material requirement and other necessities required during experimentation were tabulated below in Table 4.1.

Table 4.1. Various process parameters and material requirements.

Process Parameters	Description
Microwave applicator	Domestic multimode microwave (Made: LG, Model: Charcoal)
Working frequency and microwave power	2.45 GHz and 900 watts
Cavity material	99.9 % pure thick graphite block
Susceptor material	Fine graded charcoal powder
Separator material	99.9 % pure thin graphite sheet
Processing raw material	Copper as base/matrix material Tungsten and Molybdenum as reinforcing material
Powder Particle size	Copper powder (Average particle size 325 mesh or 44µm) Tungsten powder (Average particle size 325 mesh or 44µm) Molybdenum powder (Average particle size 270 mesh or 53µm)
Optimized Exposure time	Preheating (Convection) – 360 seconds Microwave Heating 1. Pure copper- 480 seconds 2. Cu-10 wt. % Mo- 570 seconds

	3. Cu-10 wt. % W- 660 seconds 4. Cu-30 wt. % Mo- 720 seconds 5. Cu-30 wt. % W- 840 seconds 6. Cu-50 wt. % Mo- 870 seconds 7. Cu-50 wt. % W- 1020 seconds

A much detailed view of the optimized exposure time for all the composites is represented by the below Fig. 4.7 which signifies the increase in exposure time as the wt. % of reinforcement increases.

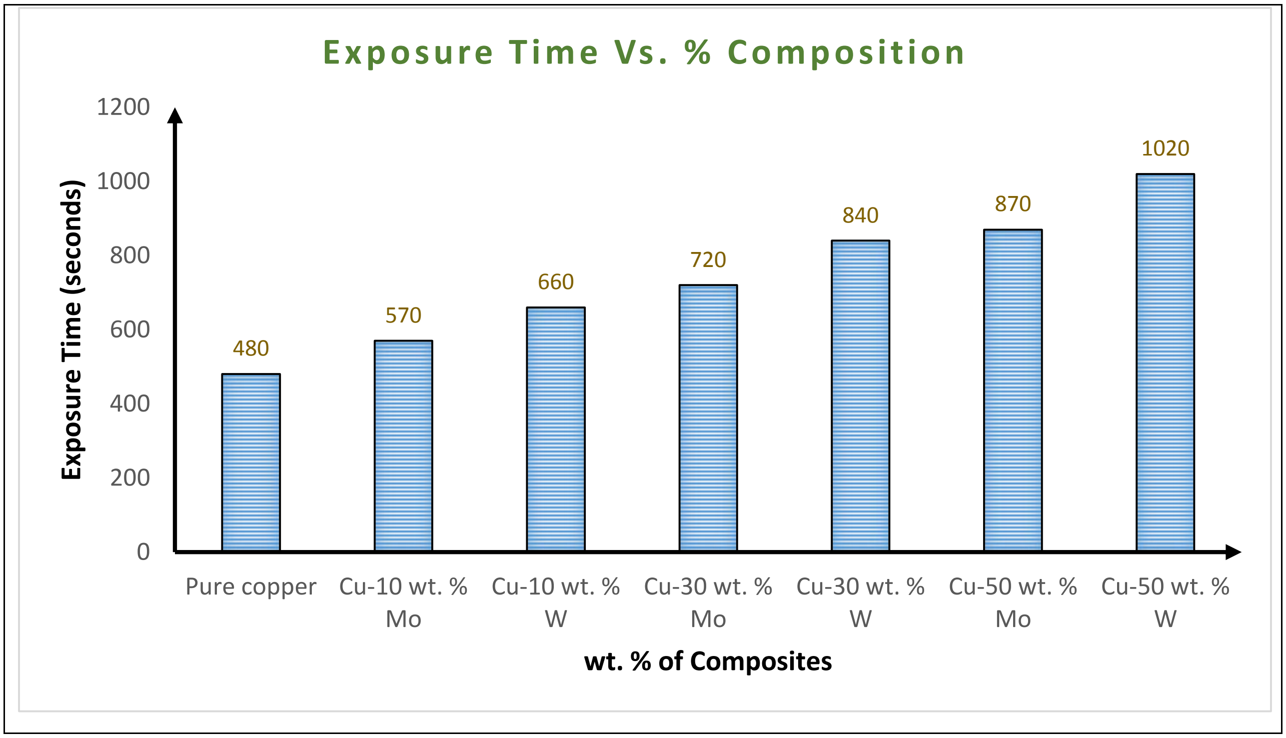


Fig. 4.7. Detailed view of change in exposure time with wt. % of reinforcement.

4.3 Preparation of Cavity

A thick graphite block was first cut into a small rectangular piece with the help of hacksaw. Then the block was machined through milling machine to obtain a desired shape of cavity. An 8mm drill bit was used for milling to prepare the cavity of approximate 15mm length, 8mm width and 5mm height. The size of the prepared sample will differ from the size of the cavity as after microwave processing, there will be little bit shrinkage. So an average of all the dimensions will be taken for all the characterization. Prepared graphite cavity is shown in the below Fig. 4.8.

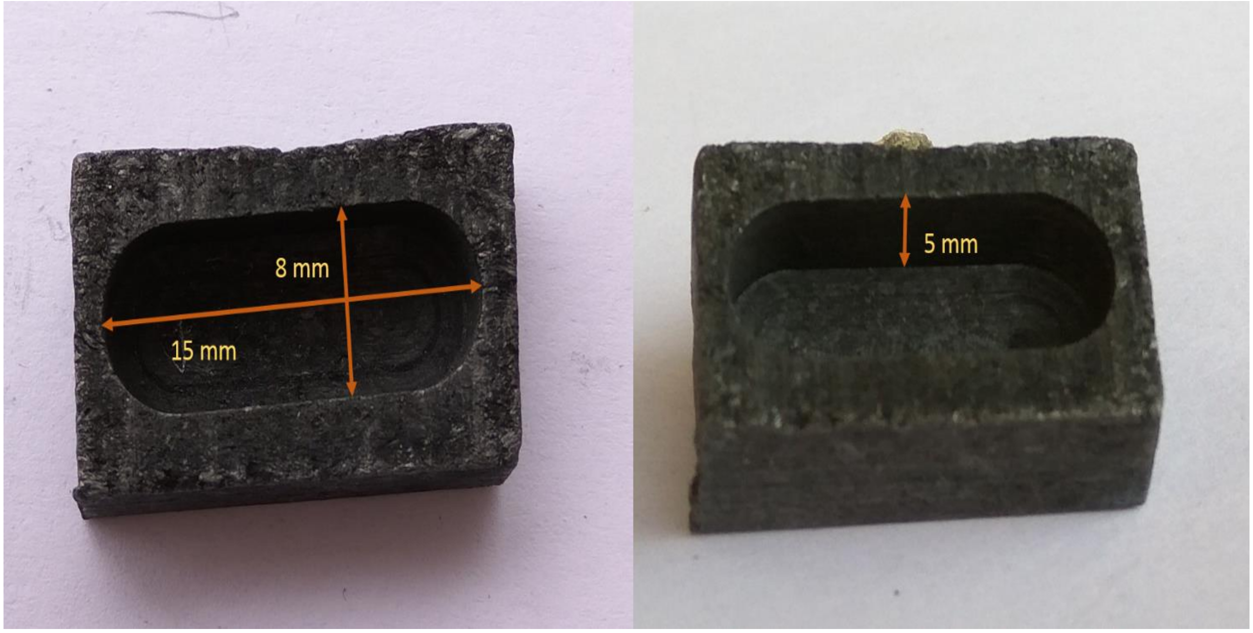


Fig. 4.8. Graphite cavity with the required dimensions.

4.4 Experimental Procedure

First of all, the powders were taken in a required quantity according to the composition as already decided and weighted with the help of weighing machine. Then to mix them thoroughly, matrix material and reinforcement material along with the very small steel balls packed in a container were rotated in a lathe machine at a very low rpm to obtain a uniformity in mixing. As the powders are of different sizes, it will help to obtain the powder of uniform size due to rolling action of steels balls. Then to remove the moisture, the mixed powder was preheated at 120°C in the graphite pot for 360 seconds through the convection method of heat exchange and afterward permitted to stay at room temperature for a predetermined timeframe. After preheating, the mixed powder was poured in a test tube from graphite crucible to ensure the proper mixing before pouring into cavity. Then the powder was poured in the graphite cavity which is to be placed on the refractory brick. The cavity was covered with the separator i.e. thin graphite sheet and then the susceptor material i.e. fine charcoal powder was poured on the cavity to fill it completely so that microwaves can penetrate through it. The charcoal powder was used here as a susceptor because of its coupling property with microwaves that allows it to get heated up quickly which turn heats the powder inside the cavity. The refractory brick is then kept in the domestic microwave oven of 2.45 GHz frequency and 900 W power rating. While keeping the brick on the rotary table of microwave oven, special attention have to be given as the rotary table may break while keeping the brick and the brick should be placed at the center. A schematic diagram of whole setup is shown below in Fig. 4.9.

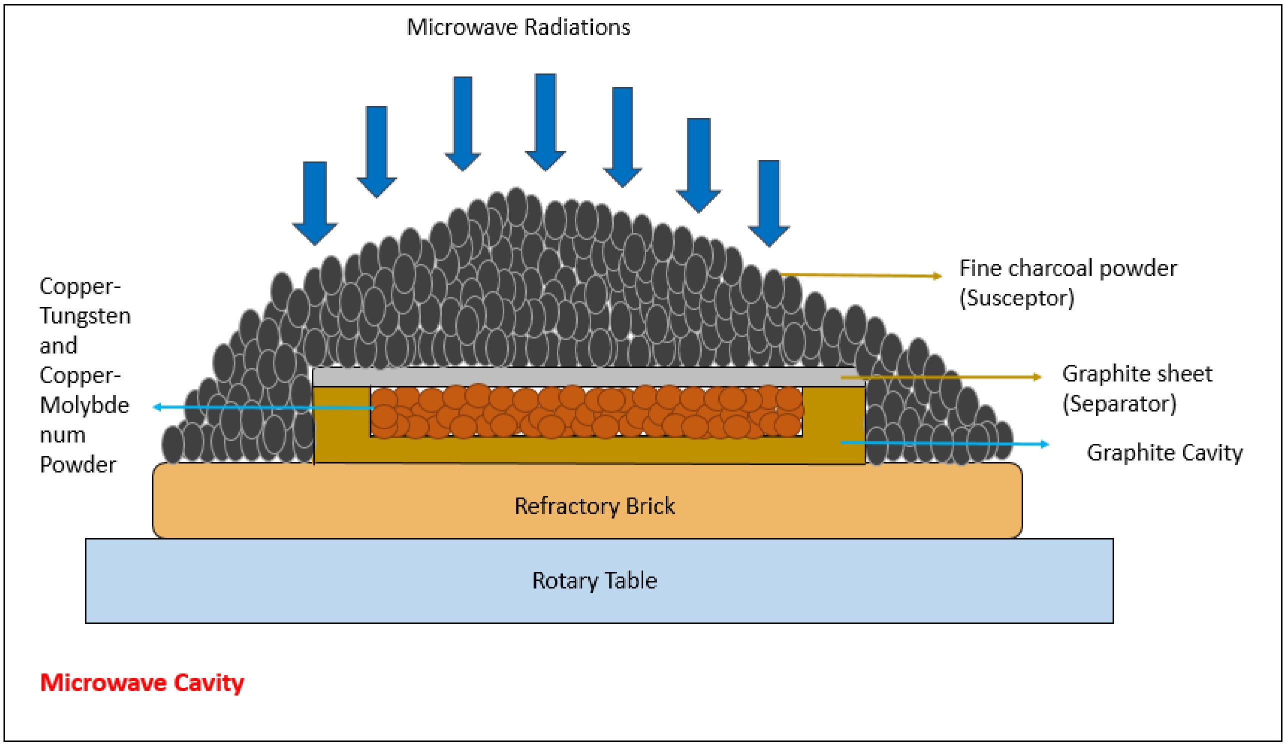


Fig. 4.9. Experimental setup for microwave processing.

The oven is set at a defined time period which is different for all compositions and then microwave processed to fabricate metal matrix composites. After completion of the process, before taking out the brick, the whole setup was allowed to cool. Then after getting cooled the cavity was taken out from the burnt charcoal and prepared sample was taken out from the cavity. The exposure time for pure copper sample was 480 seconds, for Cu-10 wt. % Mo was 570 seconds, for Cu-10 wt. % W was 660 seconds, for Cu-30 wt. % Mo was 720 seconds, for Cu-30 wt. % W was 840 seconds, for Cu-50 wt. % Mo was 870 seconds, for Cu-50 wt. % W was 1020 seconds. This difference in exposure time was due to the fact that as wt. % of reinforcement increases, the melting point of composite also increases. So to reach to that melting point, exposure time must be increased. Microwave oven used for this work and complete setup while heating and cooling are shown in below Fig. 4.10 and Fig. 4.11.

Fig. 4.10. Active microwave oven while heating the composite material at 900 W power (Courtesy: Microwave Processing Lab, Thapar University).

Fig. 4.11. After Processing microwave oven getting cooled to room temperature.

A detailed overview of whole process which was followed to fabricate metal matrix composite from initial step to final step was discussed below.

1. Firstly, the powder was poured into the graphite cavity.

2. Secondly, the cavity was covered with the separator i.e. thin graphite sheet to avoid charcoal powder to get mixed with the powder inside the cavity.

3. Thirdly, susceptor material i.e. fine charcoal powder was poured on the cavity to couple the microwaves which can then penetrate through it to carry out the microwave hybrid heating and melt the metallic powder

4. Finally, the whole setup was kept inside the domestic microwave oven for the processing. The final view of burnt charcoal was shown in Fig. 4.12. The sample was then taken out from the cavity as soon as refractory brick get cools.

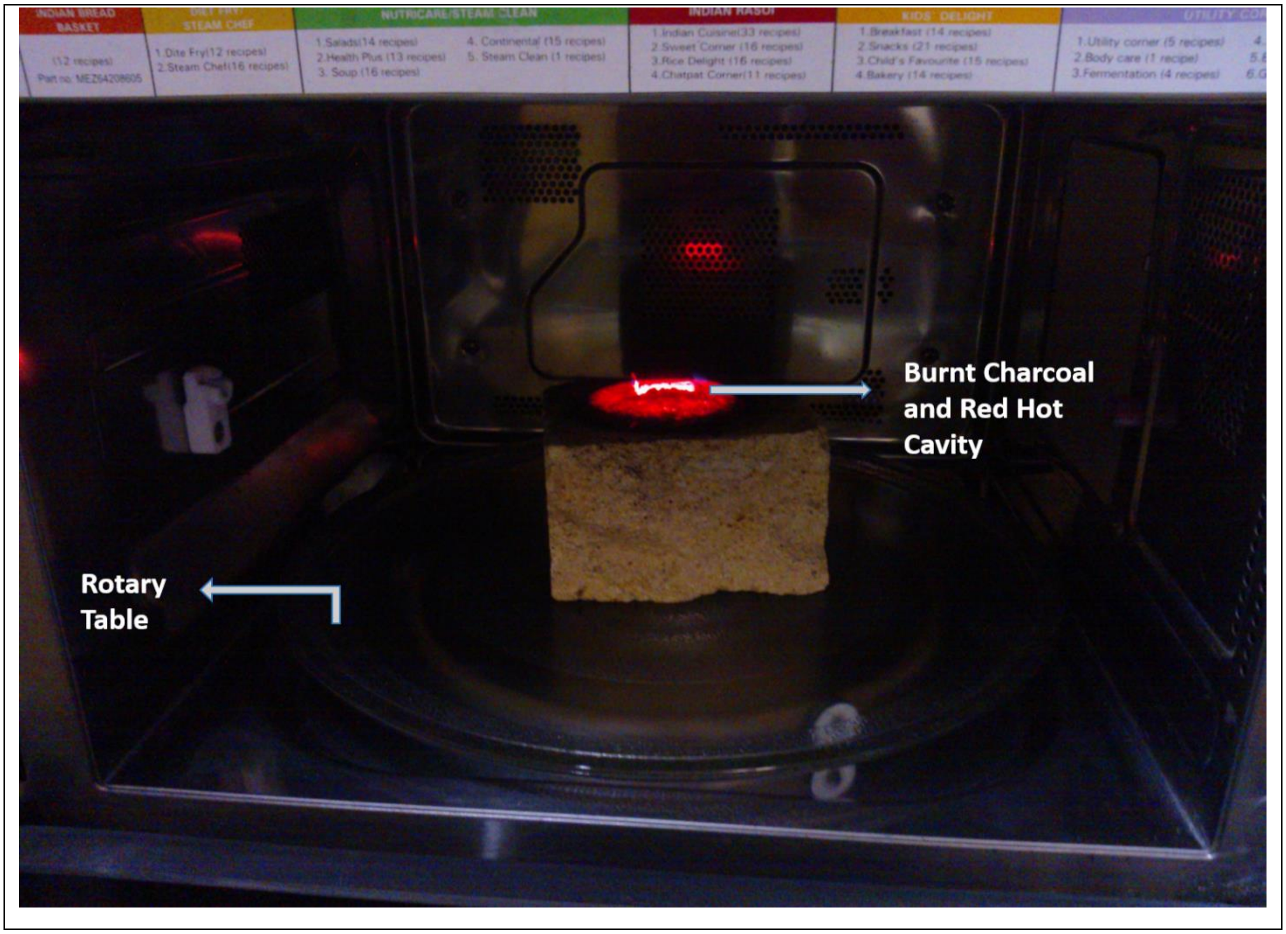


Fig. 4.12. Burnt charcoal view after microwave processing.

4.5 Characterization of Fabricated Samples

The samples were firstly rubbed on a very low grade emery paper of 50 to remove the carbon deposits which may indulge on the surfaces of the sample while microwave heating. After removing it, the samples were fully washed with acetone to carry out various characterizations. Then the low speed diamond cutter was used to cross-sectionally cut the samples according to the required dimensions. A conventional cast copper sample was also taken and cut cross-sectionally for comparative characterization. The samples were then polished by various emery papers to obtain a desired surface finish for characterization.

4.5.1 Diamond Cutter

A diamond cutter is essentially a sharp edged blade on which diamonds as abrasives are settled on the surface of the bleeding edge. It is essentially a cutting through grinding in light of the fact that a sharp edge carves the material through the abrasives mounted on the cutting outskirts. It cuts the material gradually yet the nature of the product in light of the surface finish is high.

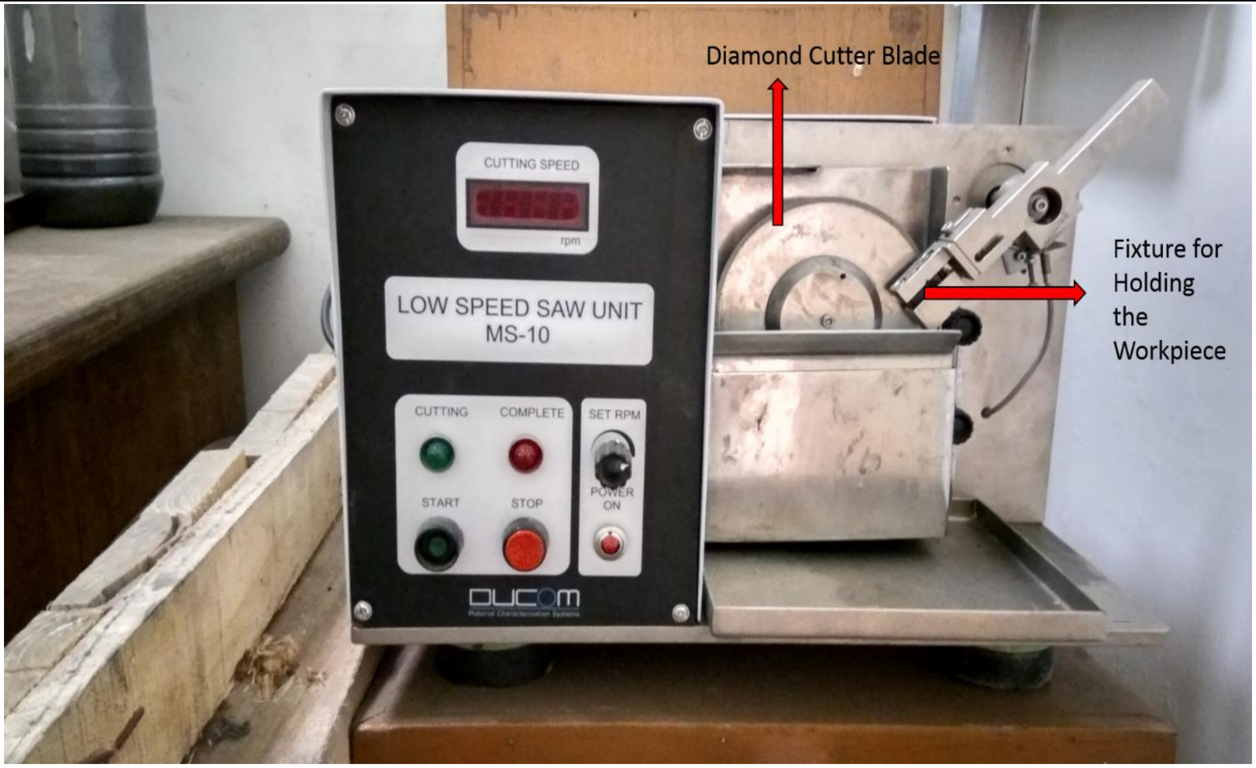


Fig. 4.13. Diamond cutter used for cutting the samples. (Courtesy: Microwave Processing Lab, Thapar University).

There are diverse sorts of diamond blades for various applications i.e. for ceramics or concrete/glasses, cutting stones at the commercial level however here it was utilized for metal cutting. The diamond cutter used for this work is manufactured by DUCOM Material Characterization System and is shown above Fig. 4.13 showing diamond cutter blade and fixture to hold the workpiece.

4.5.2 Disc Polisher (Polishing machine)

After cross-sectionally cutting the samples, they were subjected to disc polisher to polish them upto the desired finish. Disc polisher is a polishing machine having two rotating wheels on which emery papers are mounted having a jet for water supply and speed of rotation can be control by a knob. Samples were firstly polished by low grades (coarse) emery papers such as 180. 220, 320, 400, 600 and 800 under a jet of flowing water to remove the scratches which may come on the surface because of abrasive particles coming out after degradation.

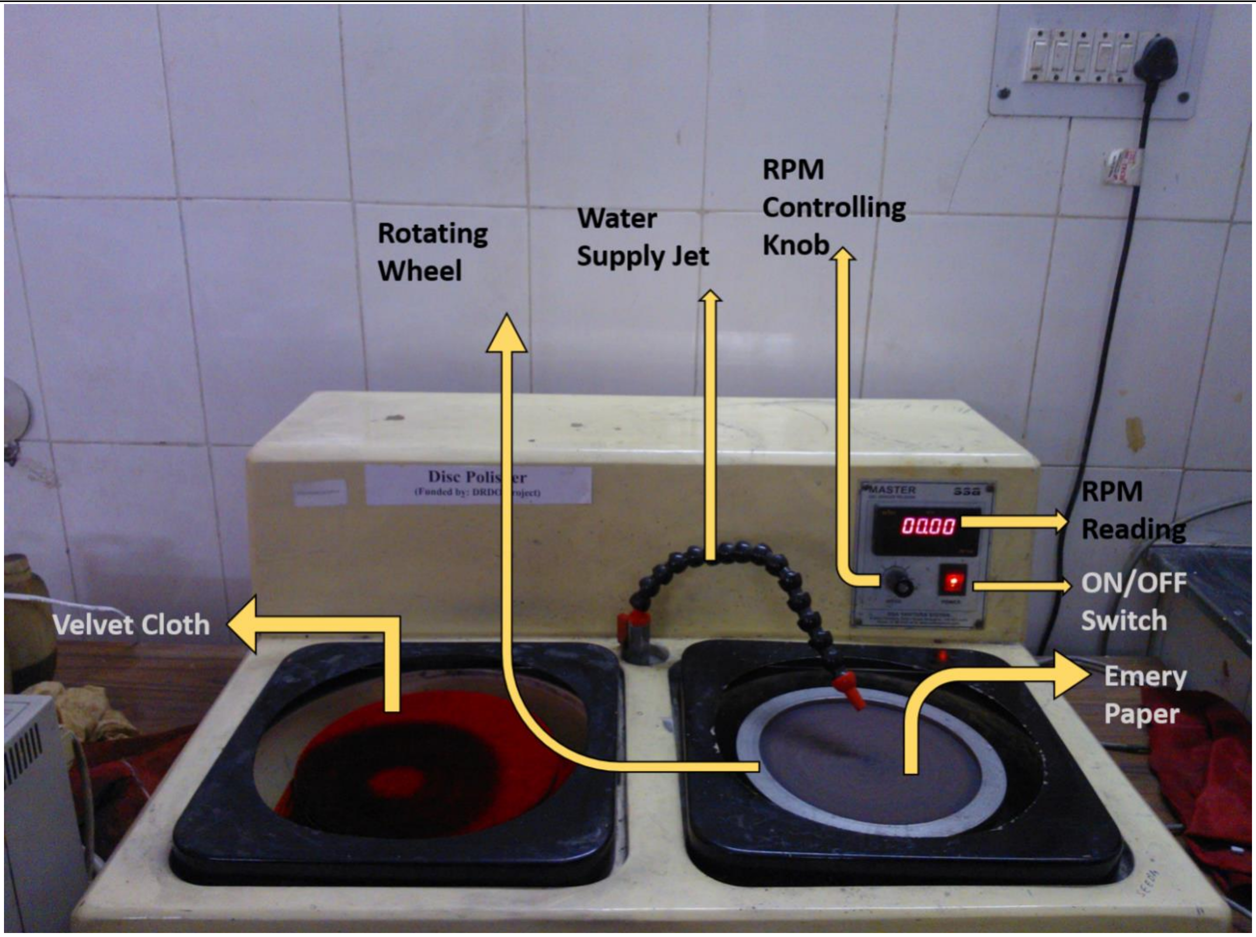


Fig. 4.14. Disc polisher (Courtesy: CNC Lab, Thapar University).

After polishing on coarse grades, they were polished on fine grades emery papers such as 1000, 1500, 2000, 2500, 3000, 4000 and 5000 to obtain a super finished surface. The soft velvet cloth was mounted on the second wheel and then the samples were polished on it by applying diamond paste of 2µm particle size on the sample along with a cutting spray to obtain a mirror like and scratch free finish. Disc polisher is shown above in Fig. 4.14.

After polishing, the samples were thoroughly washed under the jet of flowing water and then dried with the air blower to soak the water completely. The mirror finished samples and the samples before polishing of all the compositions were shown below.

Fig. 4.15. Polished view of microwave processed pure copper and conventionally prepared pure copper samples.

Fig. 4.16. Polished view of Cu-10 wt. % Mo and Cu-10 wt. % W samples.

Fig. 4.17. Polished view of Cu-30 wt. % Mo and Cu-30 wt. % W samples.

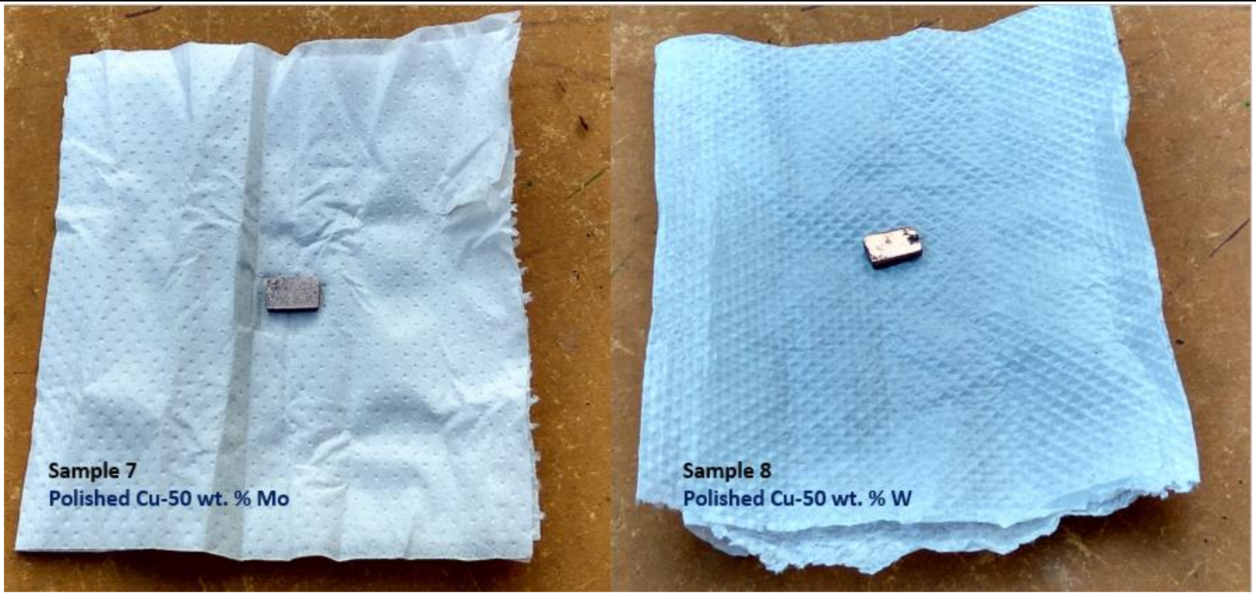


Fig. 4.18. Polished view of Cu-50 wt. % Mo and Cu-50 wt. % W samples.

From the above figures, it was clearly visible that as the amount of reinforcement increases, the metallic luster diminishes and reinforcement particles were seen on the surface which may be due to the fact that copper has red-orange metallic luster while tungsten and molybdenum have dark greyish luster and when they were combined with copper, the red-orange luster of copper started fading and then particles of reinforcement were slowly visible on the surface.

4.5.3 Scanning Electron Microscopy (SEM)

The examination of microstructures and chemical compositions are by and large completed by utilizing Scanning electron microscope and energy dispersive X-ray spectroscopy. The scanning electron microscopy (SEM) is utilized to check the surface region and is utilized to decide the microstructures of specimens at higher amplifications which utilizes an electron beam to examine the specimen surface. The electrons collaborate with the atoms of sample and produce flags that contain data about the microstructural investigation of produced pictures. It can create high-resolution pictures of the sample surface, uncovering points of interest short of what one nanometer in size. The scanning electron microscope used for this work is a product of Oxford Instruments (Model No.: JEOL JSM-6510LV) which is available at ***SAI Labs, Thapar University, Patiala*** is shown in Fig. 4.19.

Fig. 4.19. Scanning Electron Microscope (SEM) (Courtesy: SAI Labs, Thapar University, Patiala).

It is a high-performance and low vacuum SEM for quick characterization and imaging of fine structures having amplification from 5X to 300,000X. For the most part, EDS is likewise appended with SEM, in light of the fact that it tells about the elemental composition peaks for those microstructural pictures that are captured by SEM. EDS gives the quantitative examination of its basic compositional % age having a depth upto 1-2 microns and information is spoken to as crests and dispersion of reinforcement at different focuses. To carry out these characterizations, the samples were etched with an etchant (50ml HNO_3 + 50ml of distilled water) for 15 seconds after polishing. Etching is mainly used to enlighten the features of metals such as grain boundary's, microstructure, phase differences and inclusions at microscopic level.

4.5.4 X-Ray Diffraction (XRD)

X-ray diffraction procedure is a standout amongst the most capable apparatuses for subjective and quantitative investigation of materials. The investigation of this system gives the average bulk composition of materials. The fundamental guideline behind the XRD is that the monochromatic radiation is delivered by the X-rays, which are produced through a cathode tube and focused on the specimens. In the present work, XRD is utilized to decide the elemental composition of the fabricated composites, delivered through microwave processing. X-ray Diffractometer used for this work is shown in below Fig. 4.20.

Fig. 4.20. X-ray Diffractometer (XRD) (Courtesy: SAI Labs, Thapar University, Patiala).

4.5.5 Vicker’s Micro Hardness Tester

The micro-hardness of the casted composite specimens was assessed utilizing a Vicker's micro-hardness tester. The specimens subsequent to cutting and cleaning were set up for assessing the micro-hardness. In Vicker's micro-hardness test strategy, firstly with the help of the camera attached to it, the sample was fixed at the desired position. After positioning, the required load was applied through the lever. Then the machine was set for the required dwell time and loading of indenter starts. After the completion of the dwell time, the indenter unloads automatically and with the help of the camera, indentation marks were visible on the surface. By focusing the camera on the indentation mark, indentation was measured by measuring the two diagonals that were marked on the sharped ends. It must be keep in mind that whatever load was applied by the lever, the same load should also be selected while measuring the diagonal. The estimated value was based on the selected load, which may differ for different loads. After measuring the indentation, the hardness value was ascertained. The same process was repeated for 3 or 4 times to check the deviation and then an average value of all was considered as the hardness value for that particular sample. The indenter utilized for indentation can be utilized for all materials regardless of the hardness of materials. The load applied for calculating hardness of the samples in present work was 50g and for 20 seconds dwell period. The Complete setup of Vicker’s Micro-hardness tester used for this work is shown in below Fig.4.21.

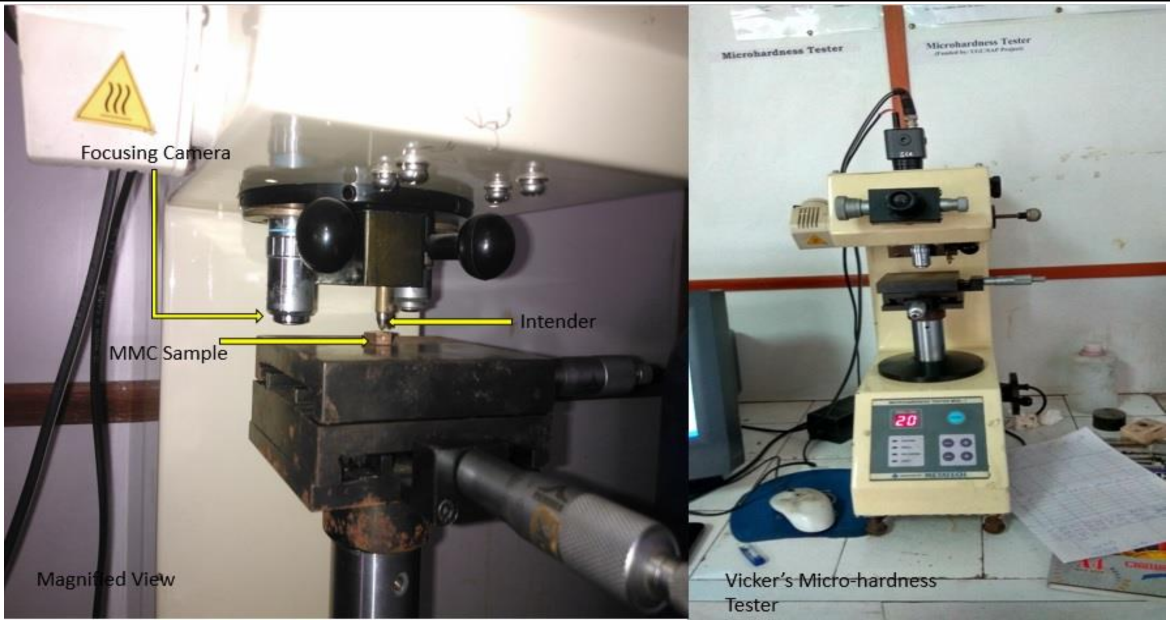


Fig. 4.21. Vicker’s Micro-hardness Tester.

4.5.6 Four Probe Resistivity Instrument

Resistivity, Rho “ρ”, is an especially critical semiconductor parameter since it can be connected specifically to the debasement substance of an example. Determination of resistivity ρ of semiconductors and insulators presents some special problems. Conventional two probe method used to determine the resistivity of material gives unsatisfactory results, which is because due to problems such as poor contact between electrode and samples and rectify nature of the metal sample contacts for non-conducting specimens. Also there is generally minority carrier injection by one of the current carrying contacts. An excess concentration of minority carrier’s will affect the potential of other contacts and maculate the resistance of the material.

To obviate these problems, four probe method is employed. This method also permits measurements of resistivity in samples having a variety of shapes. By this method, resistivity of small volumes in the bulk of material can also be determined.

A four point test is a basic device for measuring the resistivity of semiconductor tests. The resistivity of the semiconductor is frequently decided by utilizing a four-point probe method. With a four-probe, or Kelvin, strategy, by passing a current through two external probes and measuring the voltage through the internal probes permits the estimation of the substrate resistivity.

Utilizing four probe dispenses with estimation mistakes because of the probe resistance, the spreading resistance under each probe and the contact resistance between every metal probe and the semiconductor material. Since a high impedance voltmeter draws little current, the voltage drops over the probe resistance, spreading resistance, and contact resistance are little [http://www.tek.com/sites/tek.com/files/media/document/resources/FourProbe%20Resistivity%20 W4200AppNote.pdf].

4.5.6.1 The Measurement of Sheet Resistivity

The sheet resistivity of the top emitter layer is anything but difficult to quantify tentatively utilizing a "four point probe". A current is gone through the external probes and impels a voltage in the inward voltage probes. The intersection between the n and p - sort materials carries on as an insulating layer and the cell must be kept in the dark.

[http://www.pveducation.org/pvcdrom/characterisation/four-point-probe-resistivity-measurements].

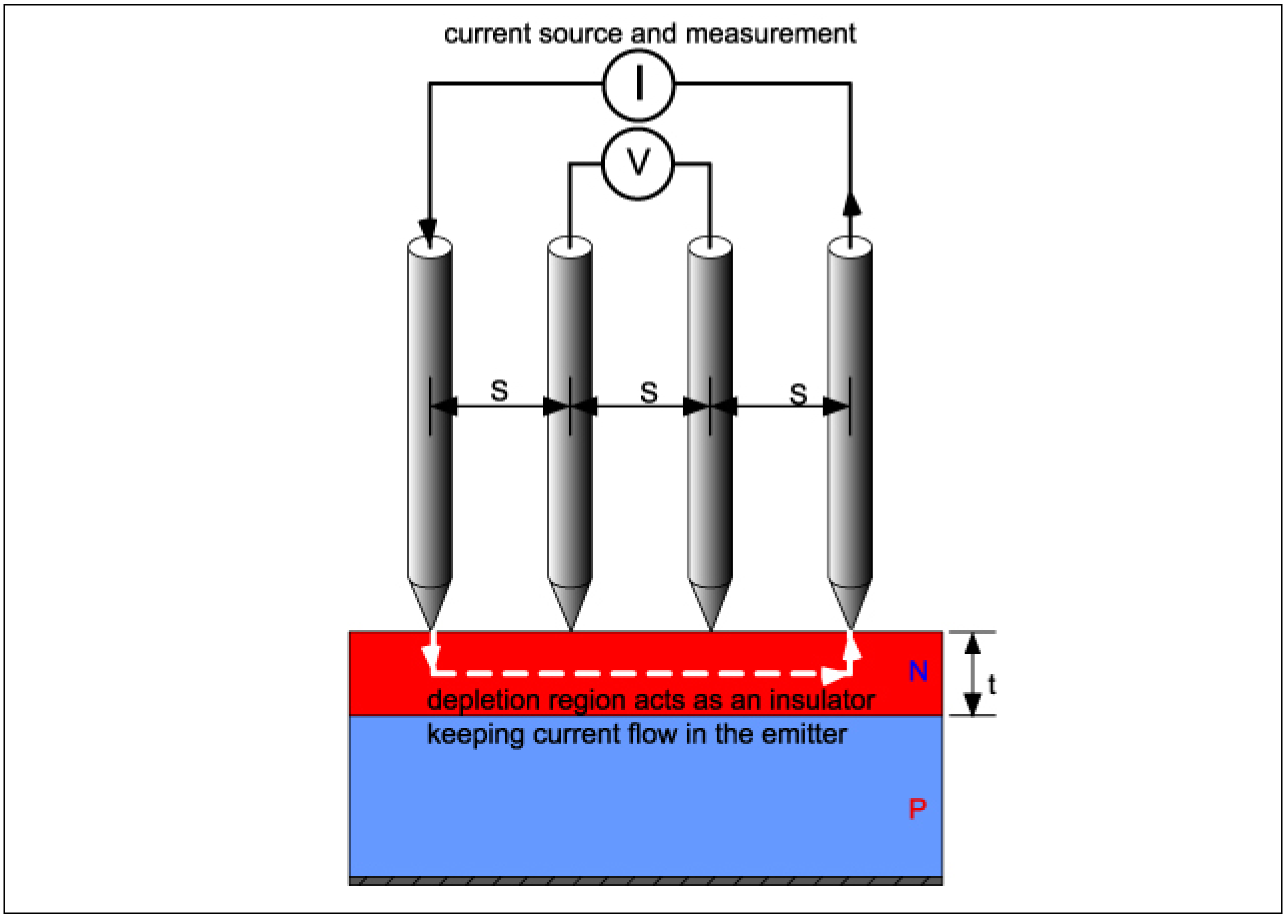
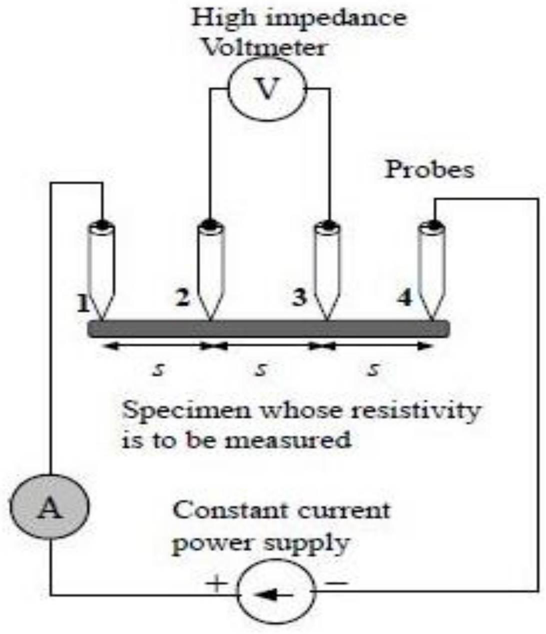


Fig. 4.22. Simplified view of four point probe resistivity measurement. [http://www.pveducation.org/pvcdrom/characterisation/four-point-probe-resistivity-measurements].

4.5.6.2 Mechanical Assembly Required For the Four Point Probe Instrument

The exploratory set up comprises of probe arrangement, specimen, oven 0-200°C, constant current generator, oven power supply and digital panel meter (measuring voltage and current). Four probe assembly (setup) is one of the standard and most broadly utilized device for the estimation of resistivity of semiconductors. This strategy is utilized when the sample is as a thin wafer, for example, a thin semiconductor material deposited on a substrate. The sample size is in millimeter and having a thickness w. It comprises of four probe organized directly in a straight line at equivalent separation s from each other. A constant current is gone through the two probes and the potential drop V over the center two probes is measured. An oven is furnished with a heater to heat the specimen so that conduct of the specimen is examined with expansion in temperature. The figure demonstrates the courses of action of four probes that quantify voltage (V) and supply current (A) to the surface of the specimen.



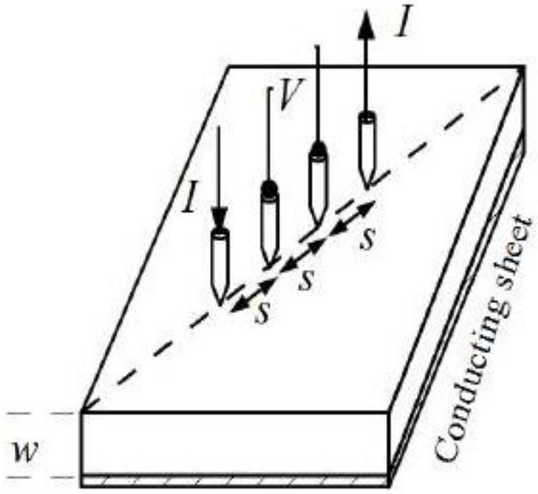


Fig. 4.23. Four probe arrangement. Fig. 4.24. Resistivity probes on a die material.
[http://vlab.amrita.edu/?sub=1&brch=282&sim=1512&cnt=1]

In the present work, metal matrix composite sample of copper, tungsten and molybdenum is provided in the form of a rectangular slab. This sample has a thickness of few millimeters. Four sharpened probes fixed to an adjustable screw head was brought in close contact of the sample. This is placed on an insulating base which can be leveled with the help of the leveling screws. The current (I) to the sample is passed through the two outer electrodes (I and IV) and floating potential difference is measured across the inner probe pairs. (II and III).

4.5.6.3 Theory of Four Point Probe Instrument

At a steady temperature, the resistance, R of a conductor is relative to its length L and inversely proportional to its area of cross section A.

$$R = \rho \frac{L}{A}$$

Where ρ is the resistivity of the conductor and its unit is ohmmeter. A semiconductor has electrical conductivity halfway in magnitude between that of an insulator and conductor. Semiconductor contrasts from metals in their characteristic property of diminishing electrical resistivity with expanding temperature. As per band theory, the vitality levels of semiconductors can be assembled into two groups, valence band, and the conduction band. Within the sight of an outside electric field, it is electrons in the valence band that can move uninhibitedly, along these lines in charge of the electrical conductivity of semiconductors. If there should arise an occurrence of inherent semiconductors, the Fermi level lies in the middle of the conduction band least and valence band greatest. Since conduction band lies over the Fermi level at 0 K, when no thermal excitations are accessible, the conduction band stays abandoned. So conduction is impractical at 0 K, and resistance is interminable. As temperature expands, the inhabitance of conduction band goes up, in this manner bringing about the diminishing of electrical resistivity of the semiconductor. Resistivity of semiconductor by four probe strategy

1. The resistivity of material is uniform in the region of estimation.

2. In the event that there is a minority carrier's injection into the semiconductor by the current-carrying electrodes, the vast majority of the carrier's recombine close electrodes, so that their impact on conductivity is insignificant.

3. The surface on which the probes rest is even with no surface spillage.

4. The four probes utilized for resistivity estimation contact surface at focuses lies in a straight line.

5. The measurement of the contact between metallic probes and the semiconductor ought to be little contrasted with the separation between the probes.

6. The boundary between the current conveying terminals and the mass material is hemispherical and little in distance across.

7. The surface of semiconductor material might be either conducting and non-conducting. A conducting boundary is one on which material of much lower resistivity than semiconductor has

been plated. A non-conducting boundary is delivered when the surface of the semiconductor is in contact with the cover.

If the materials whose dimensions are large compared with the probe spacing s, observed resistivity is computed as:

$$\rho_0 = 2\pi s \frac{V}{I}$$

s = inter probe spacing.

I = current supplied to the outer probes in ampere.

V = voltage measured across inner probes in volts.

In the event that the side boundaries are sufficiently a long way from the probes, the die may be considered to be identical to a slice or when measurements are made on thin slices or small disc of materials, then a correction factor *f* is introduced. The free resistivity ρ is related to the observed resistivity ρ_0 through a correction function *f* which corrects for the finite thickness, w, of the sample. Exact value of *f* for the given sample depends on the ratio w/s. For this instance of a cut of thickness w and the resistivity is registered as:

$$\rho = \frac{\rho_0}{f(\frac{w}{s})}$$

Where, ρ is in Ω-m.

The function, f (w/s) is a divisor for figuring resistivity which relies on upon the estimation of w and s.

A much clarified diagram of four probe setup used for this work has been shown below in Fig. 4.25.

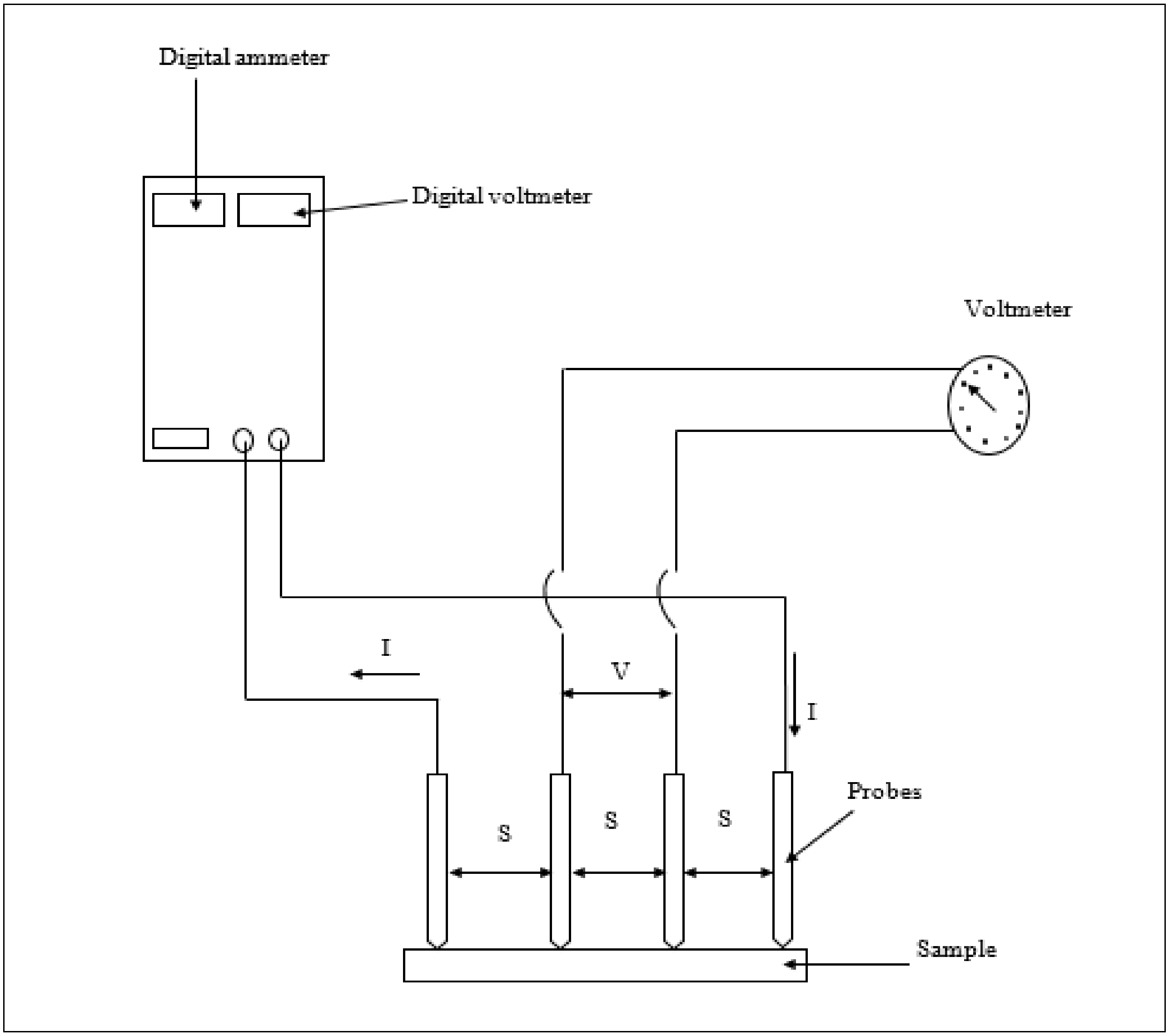


Fig. 4.25. Four probe diagram of the setup used.

The four point probe instrument used for the present work (made of Scientific Equipment, Roorkee) have probe spacing of 1.5mm and thickness of the sample is approximately 4.125 mm. Current of 1150 mA is supplied through the outer probes and voltage was measured for all the samples across inner probes. Based on the values obtained, resistivity was calculated for all the samples according to the above formulas. All the readings were taken at room temperature i.e. 298 K.

For the current setup, the value of f (w/s) is given in Table 4.2 below for the insulating base that can be employed to affect thickness correction.

Table 4.2. Showing the value of f (w/s) based on the value of w/s.

w/s	*f (w/s)*
1.0	1.094
2.0	1.015
2.5	1.009
3.0	1.000
3.5	1.000

f (w/s), approaches unity as w/s approaches 5. Thus for this setup a specimen having thickness greater than 7.5 mm requires no correction. The value of f (w/s) may differ for different setups.

For the present work, s = 1.5 mm, w = 4.125 mm, so w/s = 4.125/1.5 = 2.75 mm. So according to this setup, the value of f (w/s) lies between 1.009 and 1.000 as w/s value lies between 2.5 and 3.0, therefore the lowest value among them i.e. 1.009 was taken as the correction factor value and all the calculations were done taking this value. The actual four point probe setup used in this work is shown below in Fig. 4.26.

Fig. 4.26. Actual four point probe instrument (Courtesy: Material Science Lab (UG), Thapar University, Patiala).

The arrangement of how the sample is fixed in probes within the oven and outside the oven is shown in the below Fig. 4.27.

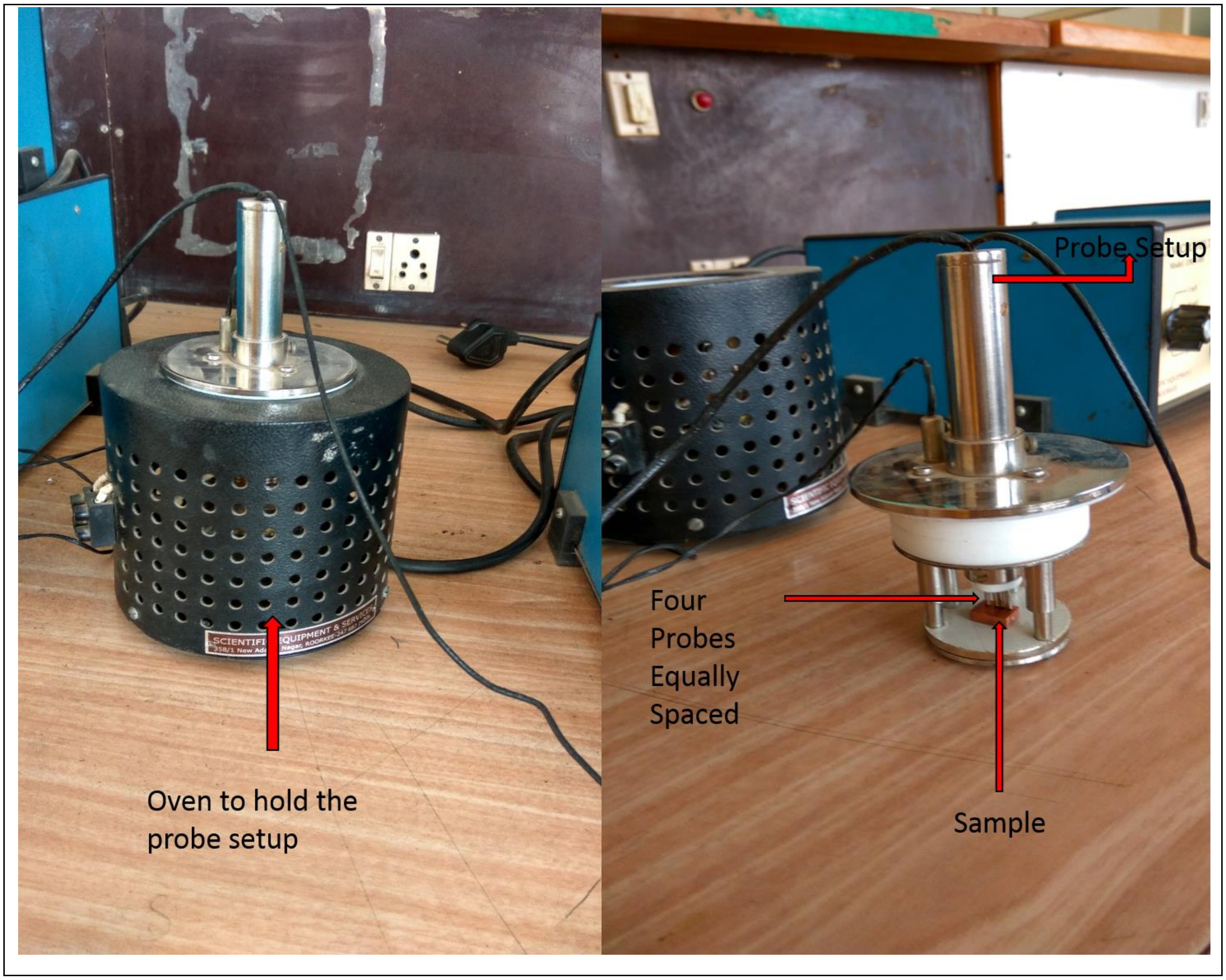


Fig. 4.27. Probe setup holding sample and oven holding probe setup.

Electrical conductivity *or* ***specific conductance*** is the reciprocal of electrical resistivity, and measures a material's ability to conduct an electric current. With the help of the resistivity calculated for each sample, electrical resistivity can also be determined for all the samples. Mathematical formula for calculating electrical conductivity is as follows:

$$\sigma = \frac{1}{\rho}$$

Where, σ is in S/m.

Thermal conductivity is a property of the material to conduct heat. With the help of the calculated electrical conductivity, thermal conductivity can also be obtained by Wiedemann-Franz law. Mathematical formula for computing thermal conductivity is as follows:

$$\frac{\kappa}{\sigma} = L * T$$

Where L – Lorenz no. = $2.443 * 10^{-8}$ $W\Omega K^{-2}$.

T – Ambient temperature, 298 K.

Where, κ is in W/m-K.

After computing electrical resistivity, electrical conductivity and thermal conductivity for all samples, a comparative analysis was carried out.

Chapter 5

RESULTS AND DISCUSSIONS

Metal Matrix Composite (MMC) castings of copper as a matrix material and tungsten and molybdenum as reinforcing materials by varying wt. % have been successfully developed by using domestic microwave oven of 2.45 GHz frequency at 900 W power. The processing has been done by the concept of microwave hybrid heating (MHH). This section briefly describes about the characterizations carried out on the developed cast samples.

5.1 Mechanical Characterization-Hardness Estimation

The hardness calculated for the different MMC casting samples were in terms of Vicker's micro-hardness. The hardness was measured at different positions and points for a particular sample at 50g load and 20 seconds dwell time, so that an average value can be taken for the analysis of data. The standard error was also calculated based on the number of readings and the deviation in the values obtained which must be consider while analyzing the final hardness value.

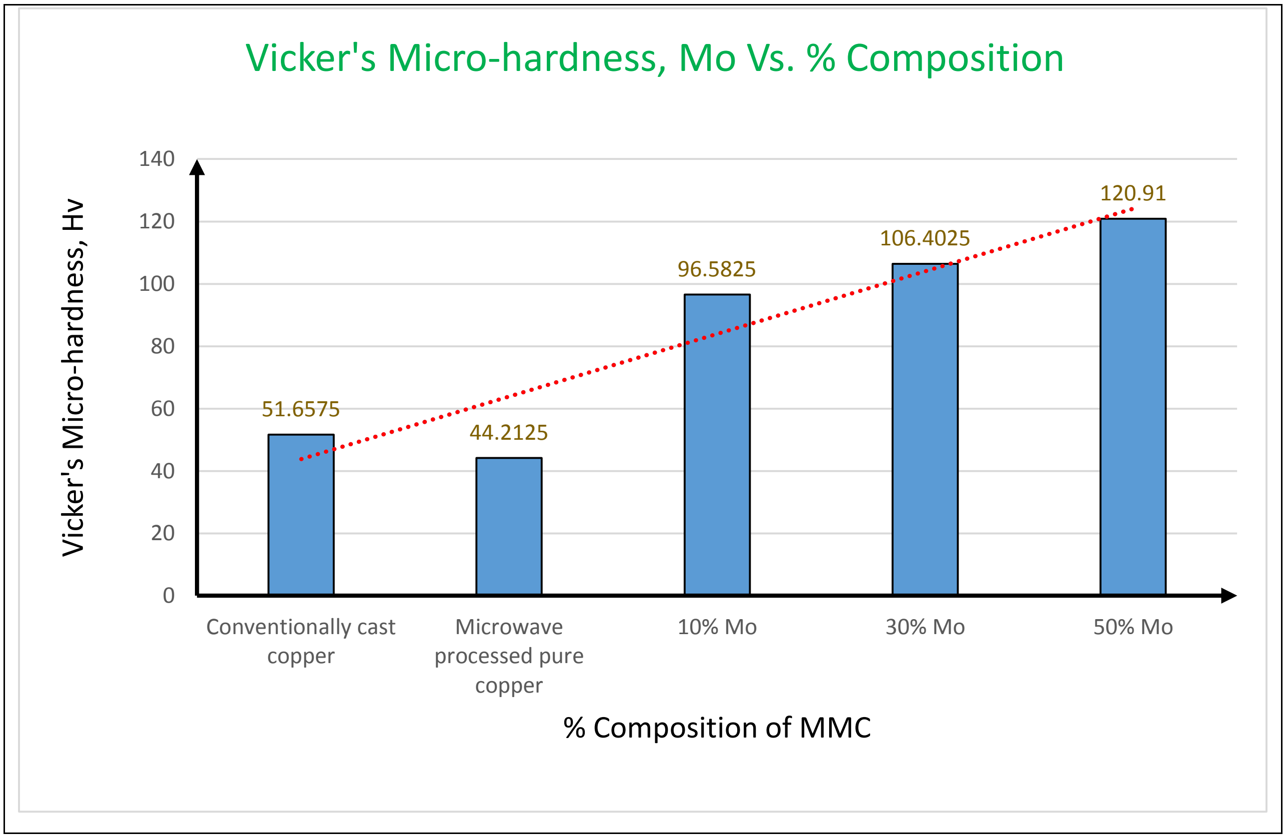


Fig. 5.1. Change in hardness value with wt. % of Mo.

Be that as it may, there were loads of varieties acquired in the information amid hardness estimations on the grounds that the hardness tackled the graphite molecule has distinctive hardness and the position where the copper was in tremendous sum, the hardness qualities were distinctive, so the information got was dispersed and patchy. Hardness was measured for all the samples with the same parameters and a comparative analysis was done. The Vicker's micro-hardness value for conventionally cast copper, microwave processed pure copper and molybdenum reinforced copper is shown in above Fig. 5.1.

The hardness value achieved for pure microwave processed copper was 44.2125 Hv which was little bit less than the hardness value of conventionally cast copper i.e. 51.6575 Hv. The reduction in hardness value of pure copper with respect to conventionally cast copper was found to be nearly 14.41%. As it can be contradict from the graph that as the wt. % of Mo increases, hardness value of the composite also increases which is obviously due to high hardness value of molybdenum than copper. The hardness values obtained for Cu-10 wt. % Mo, Cu-30 wt. % Mo and Cu-50 wt. % Mo were 96.5825 Hv, 106.4025 Hv, and 120.91 Hv respectively.

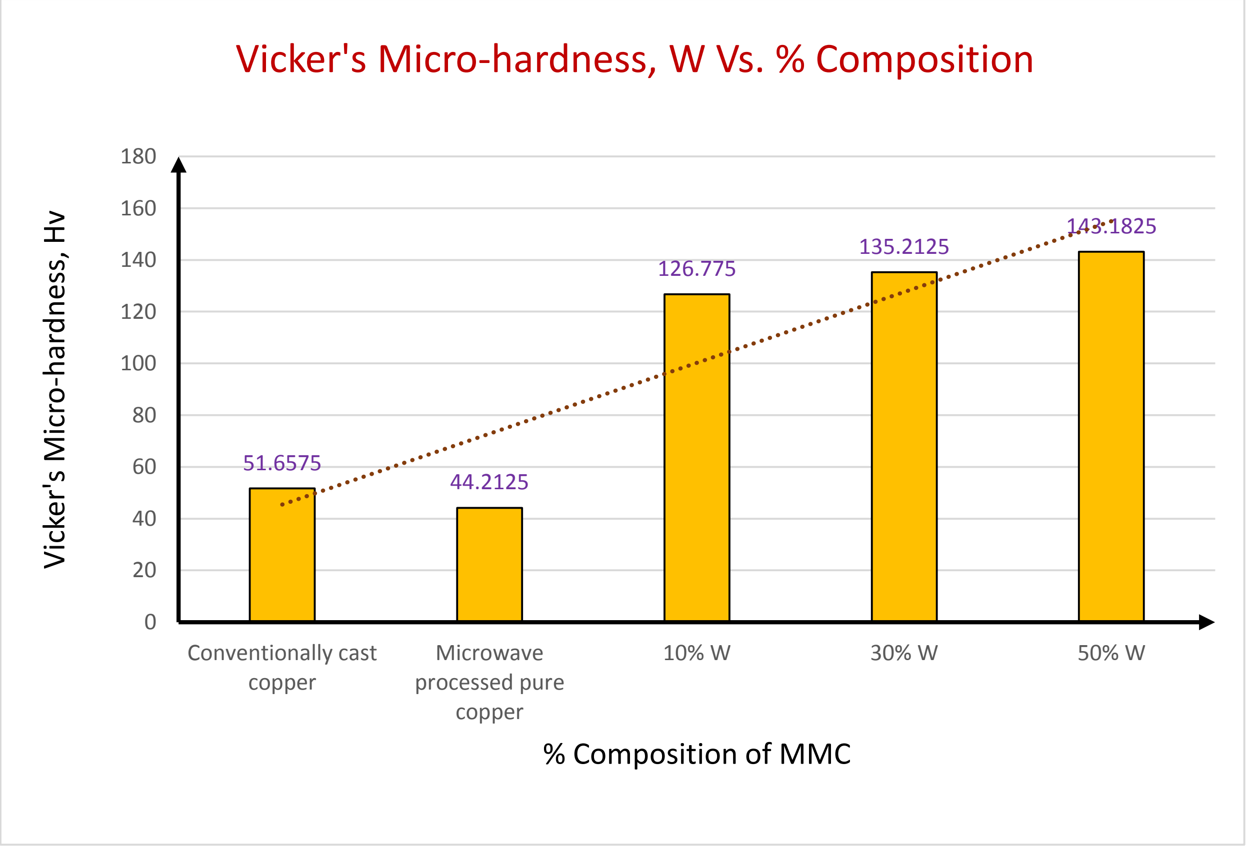


Fig. 5.2. Change in hardness value with wt. % of W.

The trend w.r.t. the conventionally cast copper was analyzed which shows that the increase in hardness value for Cu-10 wt. % Mo was much more than it should be. Rest the trend was almost correct for Cu-30 wt. % Mo and Cu-50 wt. % Mo samples. The increment in hardness value for Cu-10 wt. % Mo, Cu-30 wt. % Mo and Cu-50 wt. % Mo with respect to pure microwave processed copper was 118.45%, 140.66% and 173.47% respectively.

As the hardness values of conventionally cast copper and microwave processed copper was already discussed above, so a comparison between these two samples and tungsten reinforced copper samples was shown in above Fig. 5.2.

As it can be contradict from the graph that if tungsten is reinforced in copper, the hardness value of composite increases to a great extent and as the wt. % of W increases, the hardness value increases but gradually. The hike was much greater when initially copper was reinforced with tungsten but after that very small hike was seen even with increasing the wt. % of W to 50%. This sudden increment is because of tungsten which has very high hardness value compared to copper. The hardness values obtained for Cu-10 wt. % W, Cu-30 wt. % W and Cu-50 wt. % W were 126.775 Hv, 135.2125 Hv, and 143.1825 Hv. The trend w.r.t the conventionally cast copper was analyzed which reveals that increment was much higher for Cu-10 wt. % W, moderate for Cu-30 wt. % W and little less for Cu-50 wt. % W when contrasted with the trend line. The increment in hardness value for Cu-10 wt. % W, Cu-30 wt. % W and Cu-50 wt. % W with respect to pure microwave processed copper was 186.74%, 205.82% and 235.15% respectively.

Now after comparing the hardness values of molybdenum reinforced samples and tungsten reinforced samples with microwave processed pure copper, a combined comparison was carried out between molybdenum reinforced and tungsten reinforced samples with the estimated standard error. The Vicker’s micro-hardness value for each sample with the standard error is shown in below Fig. 5.3.

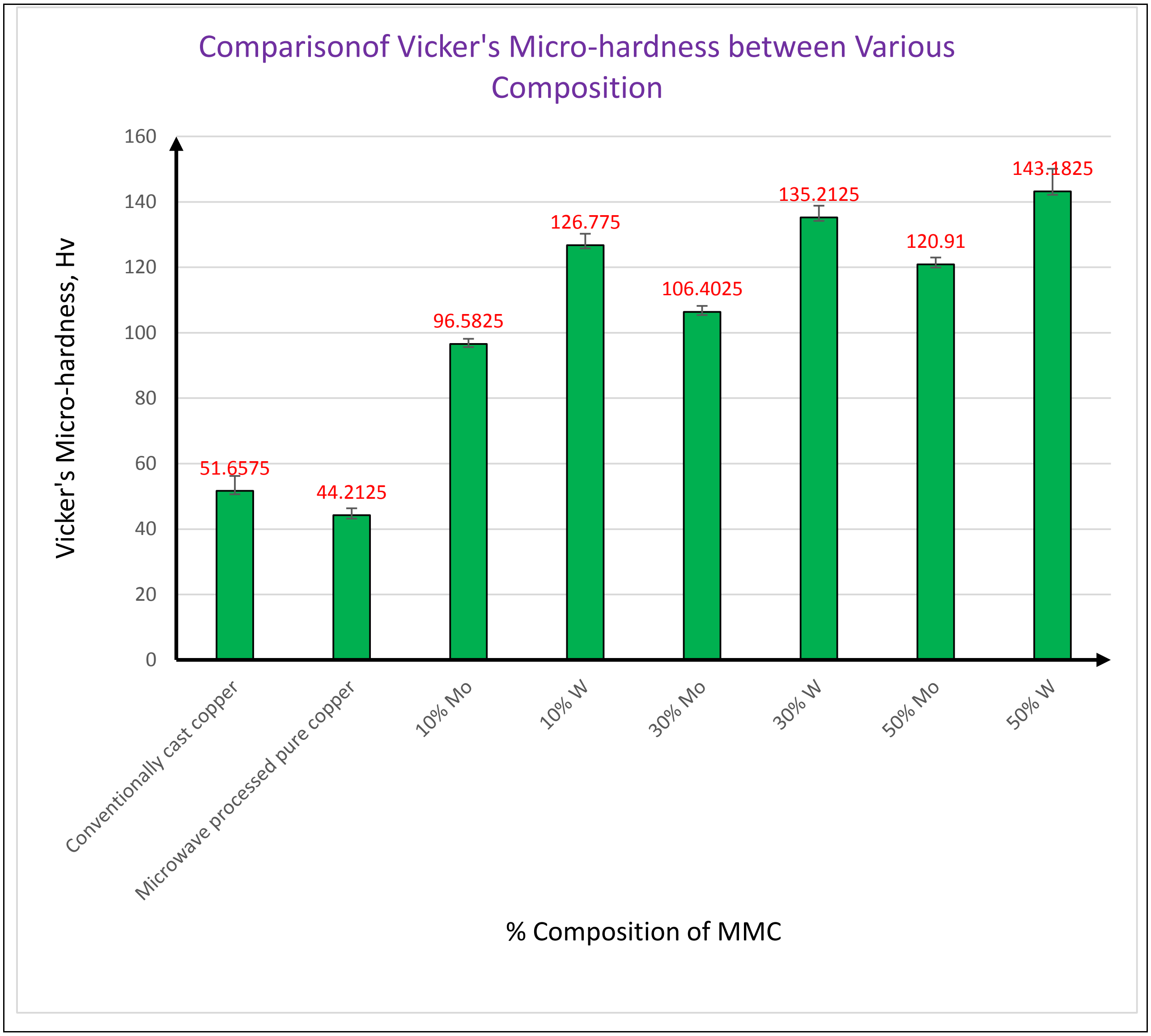


Fig. 5.3. Hardness estimations for various samples with std. error.

The standard error values for conventionally cast copper, microwave processed pure copper, Cu-10 wt. % Mo, Cu-30 wt. % Mo, Cu-50 wt. % Mo, Cu-10 wt. % W, Cu-30 wt. % W and Cu-50 wt. % W were 4.58, 2.12, 1.53, 1.81, 2.10, 3.46, 3.61 and 6.89 respectively. These values of std. error is mainly to accommodate the uncertainties in the value obtained for hardness. Comparatively it can be seen that the increment in hardness values of tungsten reinforced samples is more than the increment in hardness values of molybdenum reinforced samples. The hardness value for Cu-10 wt. % W was 1.31 times that of Cu-10 wt. % Mo, for Cu-30 wt. % W is 1.27 times that of Cu-30 wt. % Mo and for Cu-50 wt. % W is 1.18 times that of Cu-50 wt. % Mo. It is because the tungsten is harder than molybdenum.

The reason which may also be included while concluding about the increase in hardness is fine grain size of matrix material. The better rate of tungsten and molybdenum scattering over the lattice and grain size refinement are the principle reasons which are in-charge of expansion in hardness of Cu-W and Cu-Mo composites. Indentation marks for each sample while estimating micro-hardness are shown in below Fig. 5.4 – Fig. 5.7.

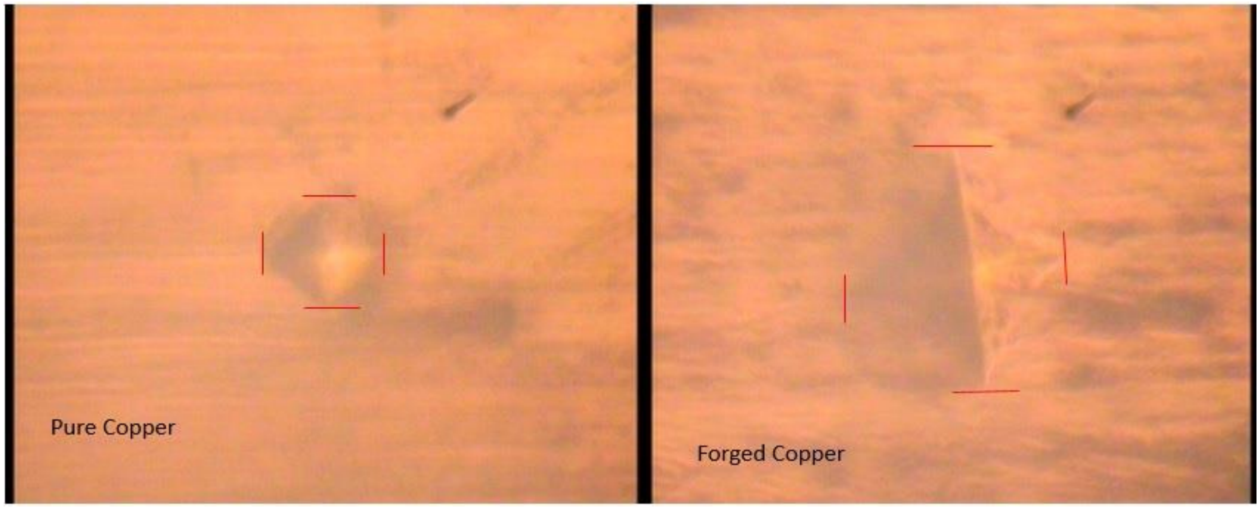


Fig. 5.4. Indentation marks for purer copper samples.

As it can be seen that indentation mark is large for conventionally cast copper than microwave processed pure copper which simply contradict that hardness value of conventionally cast copper is more than microwave processed pure copper.

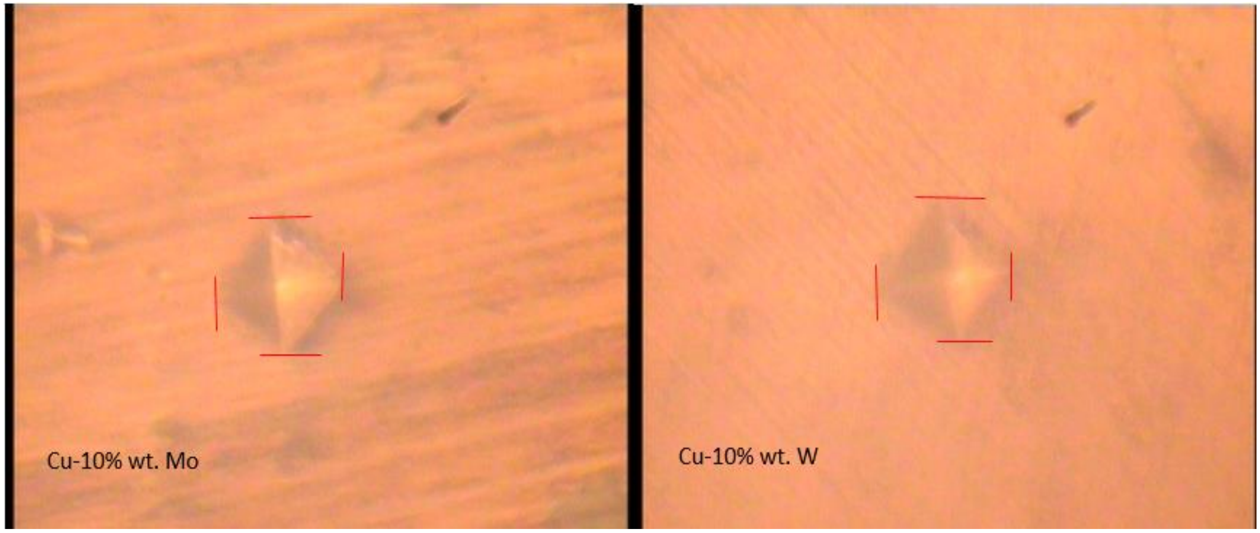


Fig. 5.5. Indentation marks for 10 wt. % composition of reinforcement.

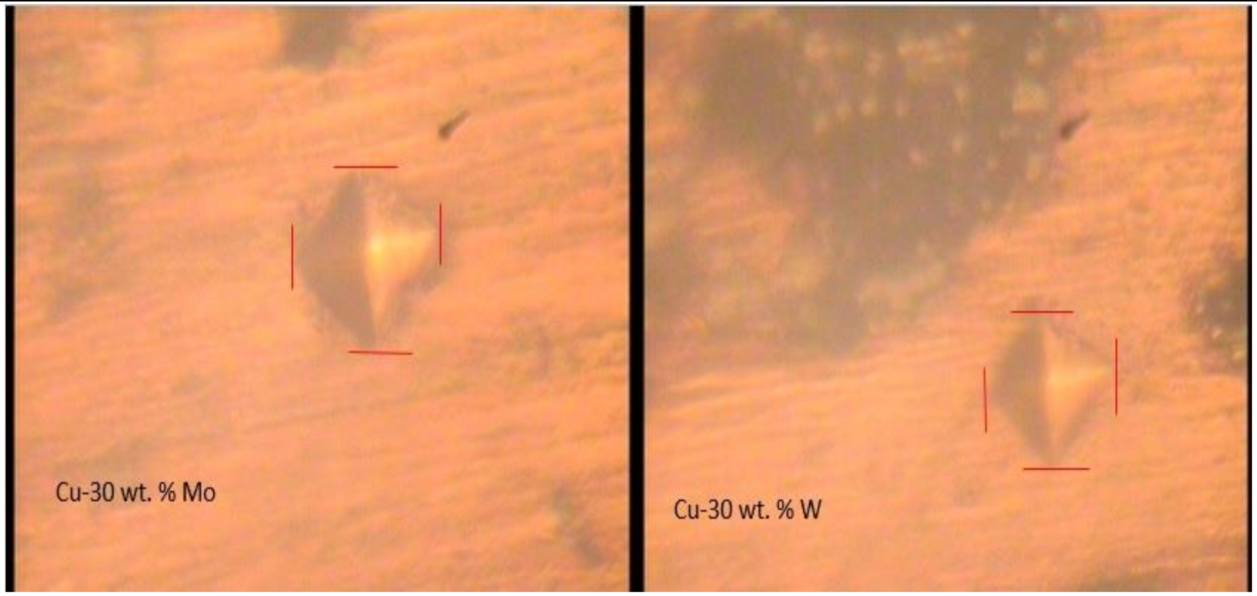


Fig. 5.6. Indentation marks for 30 wt. % composition of reinforcement.

From the above Fig. 5.5 and Fig. 5.6, reinforcement can also be seen which means hardness values for these compositions are more.

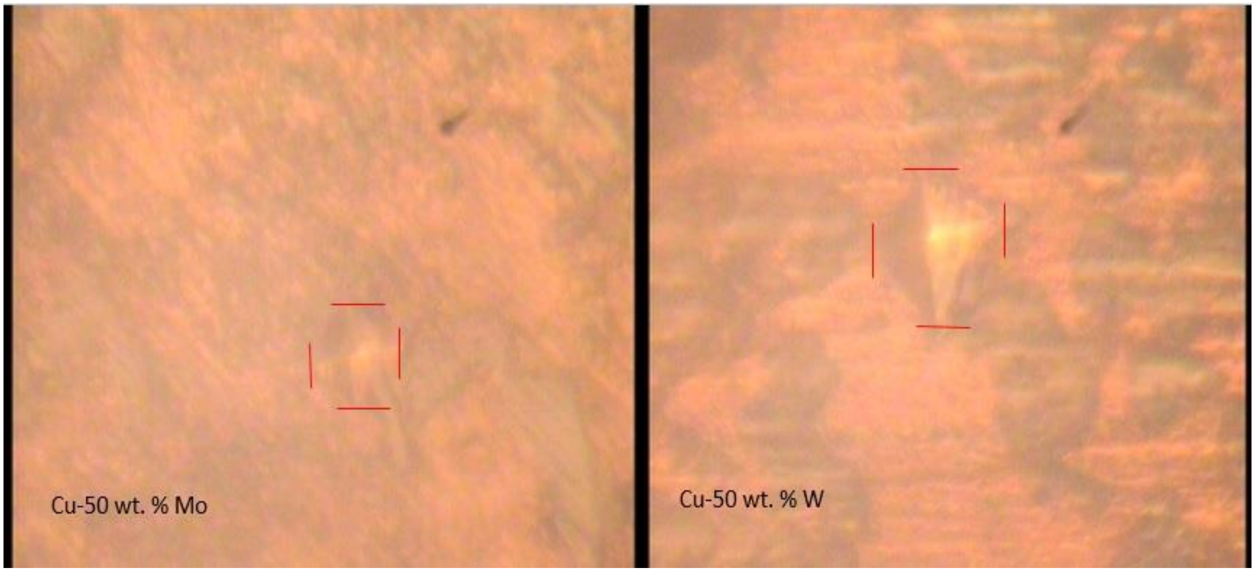


Fig. 5.7. Indentation marks for 50 wt. % composition of reinforcement.

As the amount of reinforcement was too high, that’s why the indentation marks were not visible properly.

5.2 Metallurgical Characterization

5.2.1 Microstructural Annotations of Composites

The microstructures of all the casted samples were observed and the diffusion between matrix material and reinforcing material was studied. The microstructure of the conventionally cast copper sample was also studied to have a comparative analysis. The back-scattered images of all the samples were taken. The SEM images of all the samples are shown in below figures.

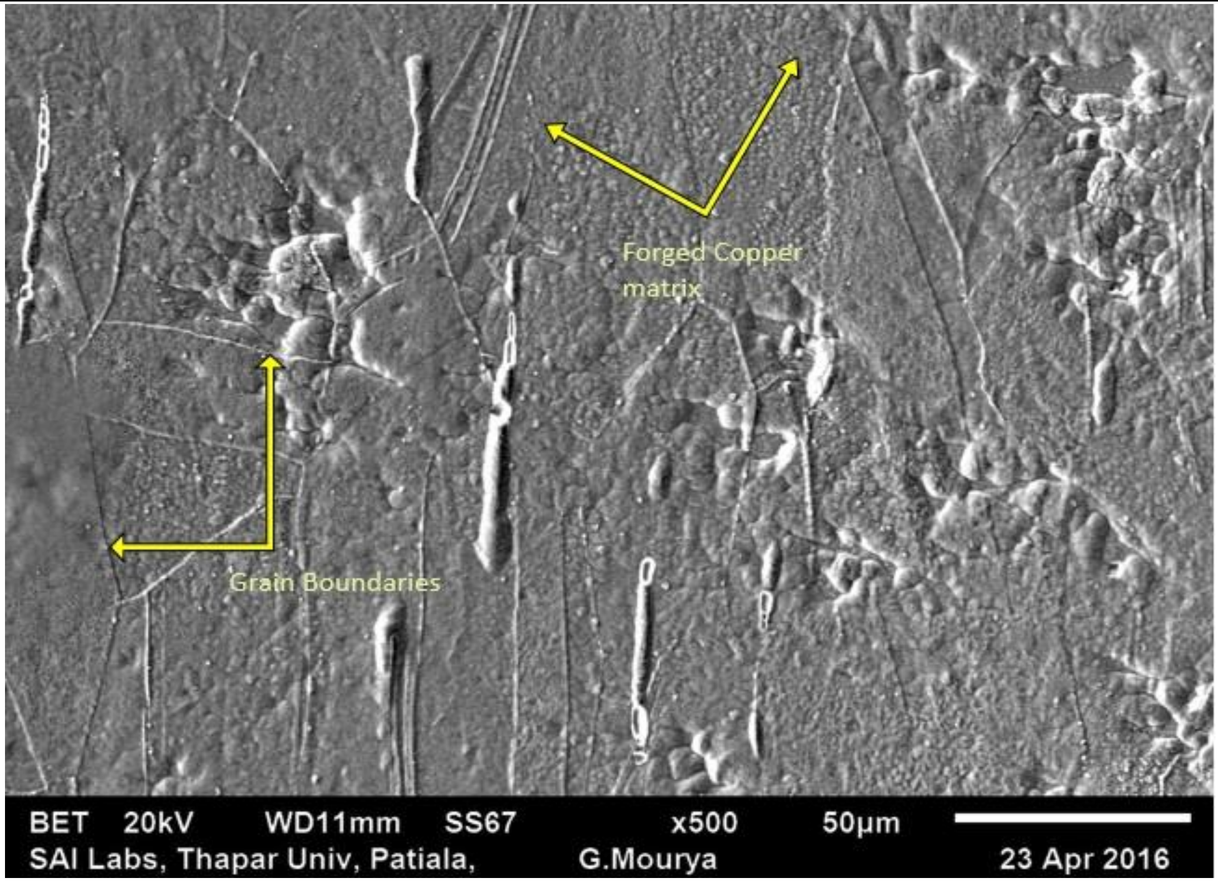


Fig. 5.8. SEM image of conventionally cast copper sample.

From the SEM images of conventionally cast copper and microwave processed copper, it can be concluded that grain structure enhanced after microwave processing. The grain structure was uniform as shown in below Fig. 5.9, while grain structure was not uniform and having complex shapes in above Fig. 5.8. The grain growth for microwave processed pure copper was also uniform. The grain boundaries were also visible clearly. It can also be seen that proper fusion and melting of copper particles was achieved throughout the cast.

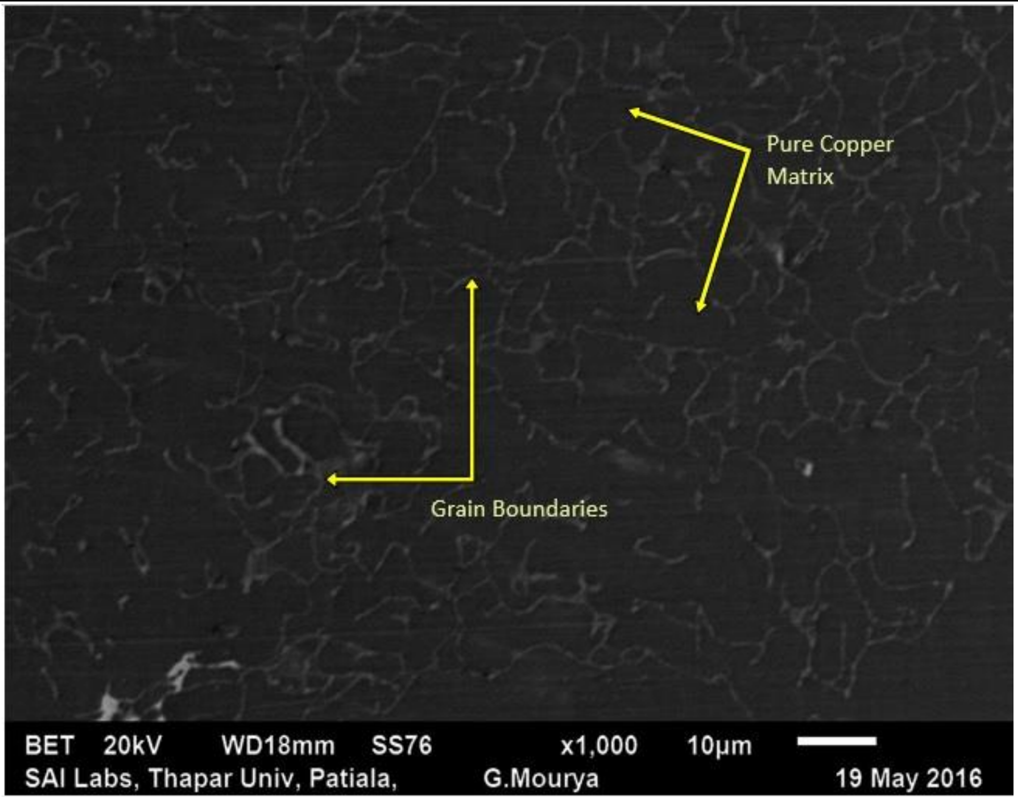


Fig. 5.9. SEM image of microwave processed pure copper.

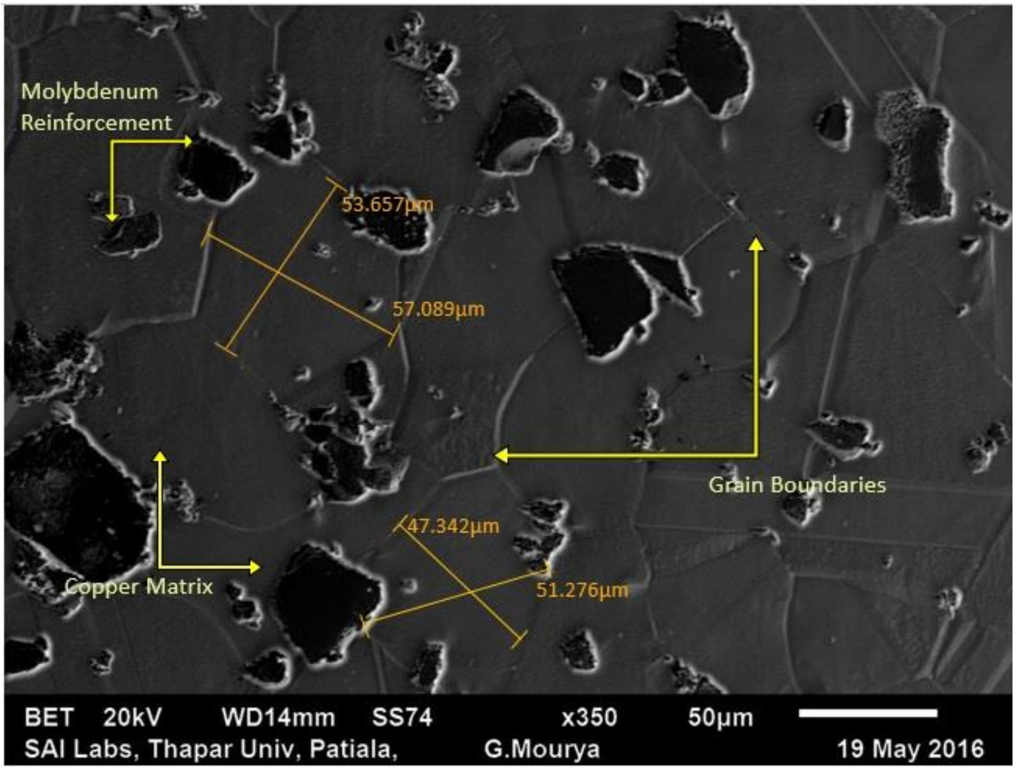


Fig. 5.10. SEM image of Cu-10 wt. % Mo composite casting.

The above SEM image of Cu-10 wt. % Mo clearly signifies that even after having mutual insolubility between reinforcing material molybdenum and matrix material copper, the reinforcing material was properly mixed and dispersed throughout the matrix. It can also be concluded that the reinforcing material being less in amount, hence could be seen dispersed only at a few places. The grain growth was also uniform. Initially the size of the particle was 50µm and after microwave processing the size was almost about 50µm which can be seen in above Fig. 5.10. Grain boundaries can also be seen clearly. Copper matrix and reinforcing molybdenum were was separately indicated.

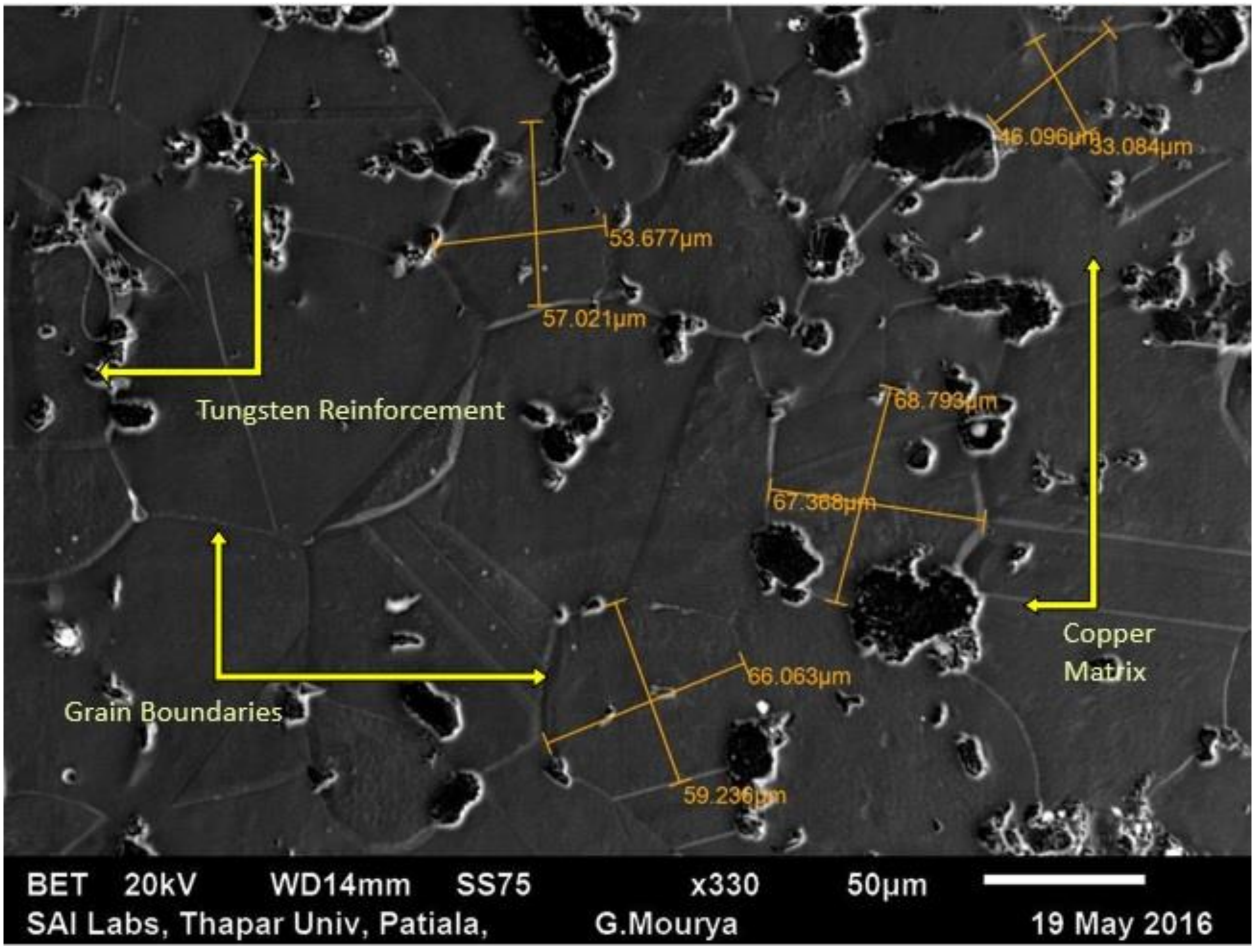


Fig. 5.11. SEM image of Cu-10 wt. % W composite casting.

As it can be seen from the above SEM image of Cu-10 wt. % W that tungsten particles were uniformly dispersed throughout the matrix and could be seen only at a few places as the amount of reinforcement was limited only to 10% of the composition. Grain growth was uniform and particle size was also found to be around 50μm which was almost same as the particle size taken initially. Grain boundaries were clearly visible in above Fig. 5.11

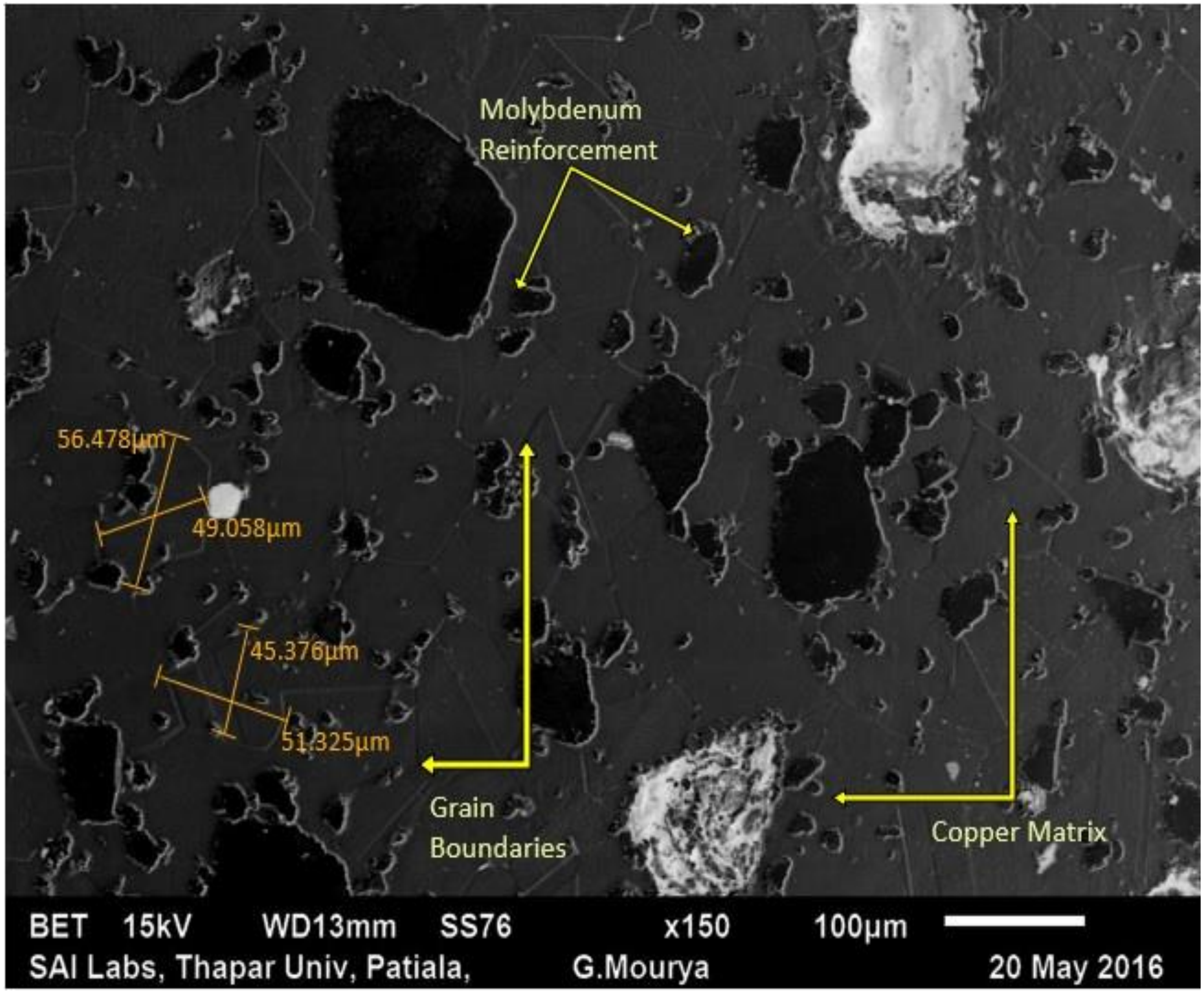


Fig. 5.12. SEM image of Cu-30 wt. % Mo composite casting.

Proper dispersion of molybdenum in copper matrix can be seen from above SEM micrograph shown in Fig. 5.12. It can also be concluded that the reinforcing material being little more in amount than the previously discussed samples of 10 wt. % of composition, hence could be seen dispersed at various places. A uniform grain growth and grain structure was seen having the particle size nearly equivalent to the initially taken particle size, i.e. 50μm. little bit voids can also be seen which was possibly due to removal of particles while polishing on coarse size emery papers. Grain boundaries were also visible in above Fig. 5.12.

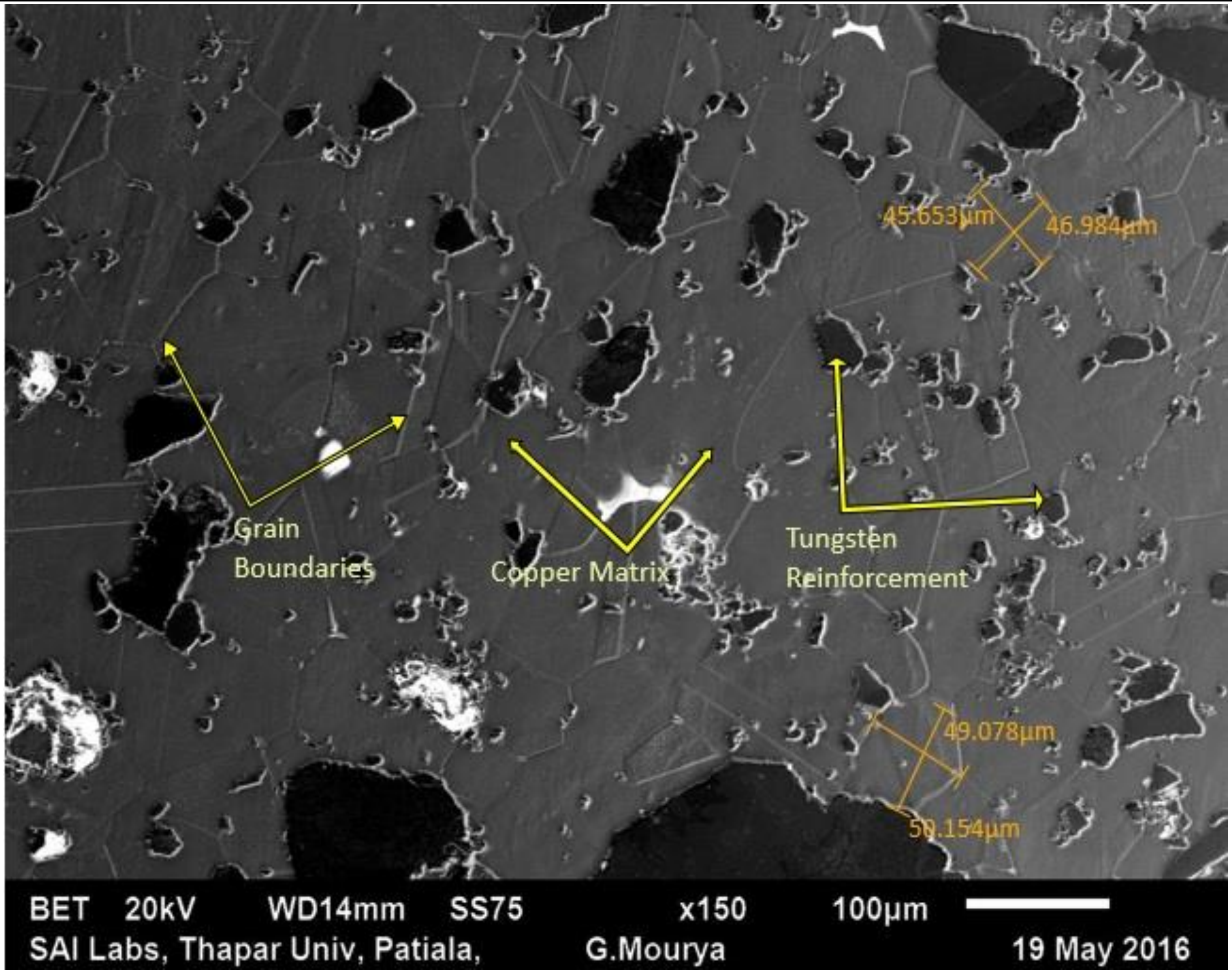


Fig. 5.13. SEM image of Cu-30 wt. % W composite casting.

Tungsten particles were seen dispersing throughout the matrix evenly and could be seen at various places as the amount of reinforcement was increased from 10 wt. % to 30 wt. % of the composition as shown in above SEM micrograph in above Fig. 5. 13. Little bit voids can also be seen due to removal of some particles. The particle size as shown resembles with the initially taken particle size of 50µm. Grain growth was uniform and grain boundaries could also be seen.

The uniform dispersion of reinforcing material, molybdenum throughout the matrix can be clearly seen from the SEM micrograph as shown in below Fig. 5.14. The amount of dispersion was high as the wt. % of reinforcing material was increased to 50% and could be seen at equally spaced places. Grain growth was uniform but the grain boundaries were not seen which may be due to high amount of reinforcement. But after zooming upto 1500x, few grain boundaries could be seen as shown in below Fig. 5.15.

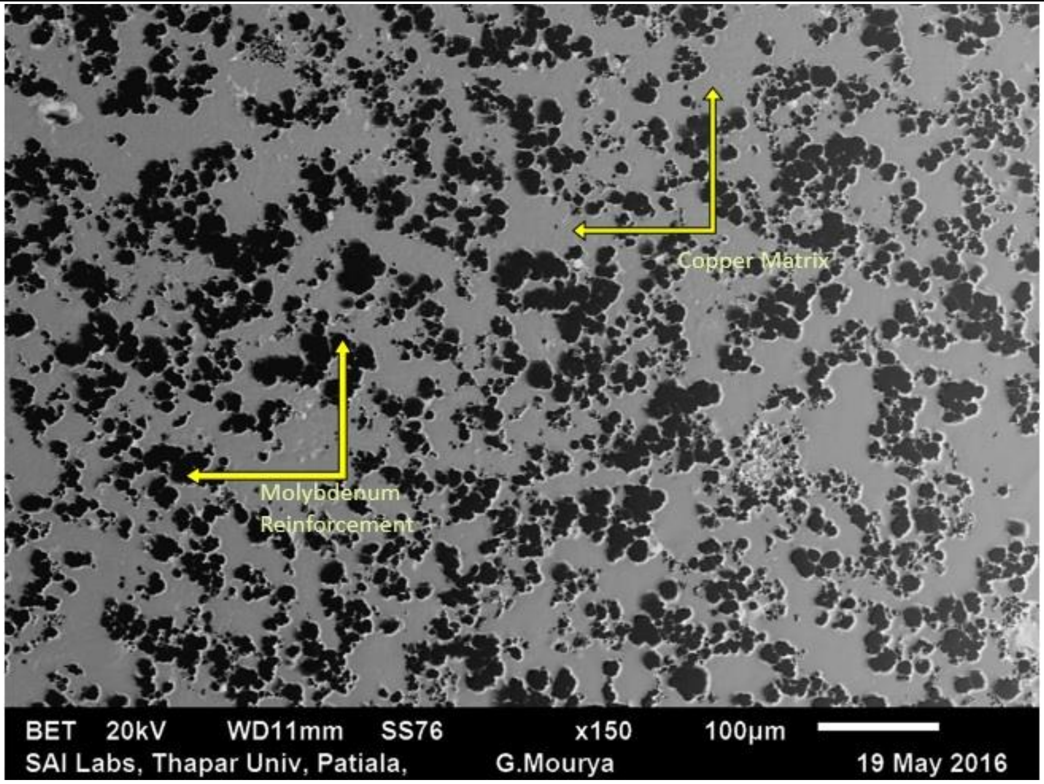


Fig. 5.14. SEM image of Cu-50 wt. % Mo composite casting.

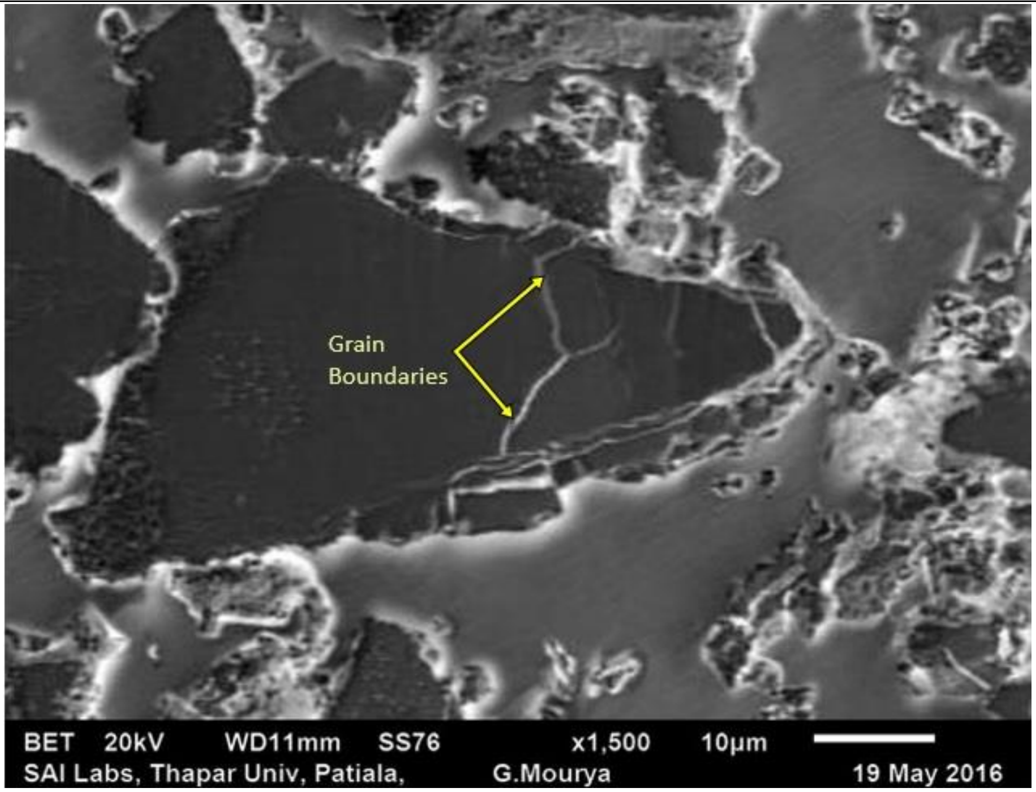


Fig. 5.15. Highly magnified view depicting the grain boundaries.

From the above SEM micrograph, it may be considered that the grain boundaries would be seen at higher magnification if the amount of reinforcement would have been high.

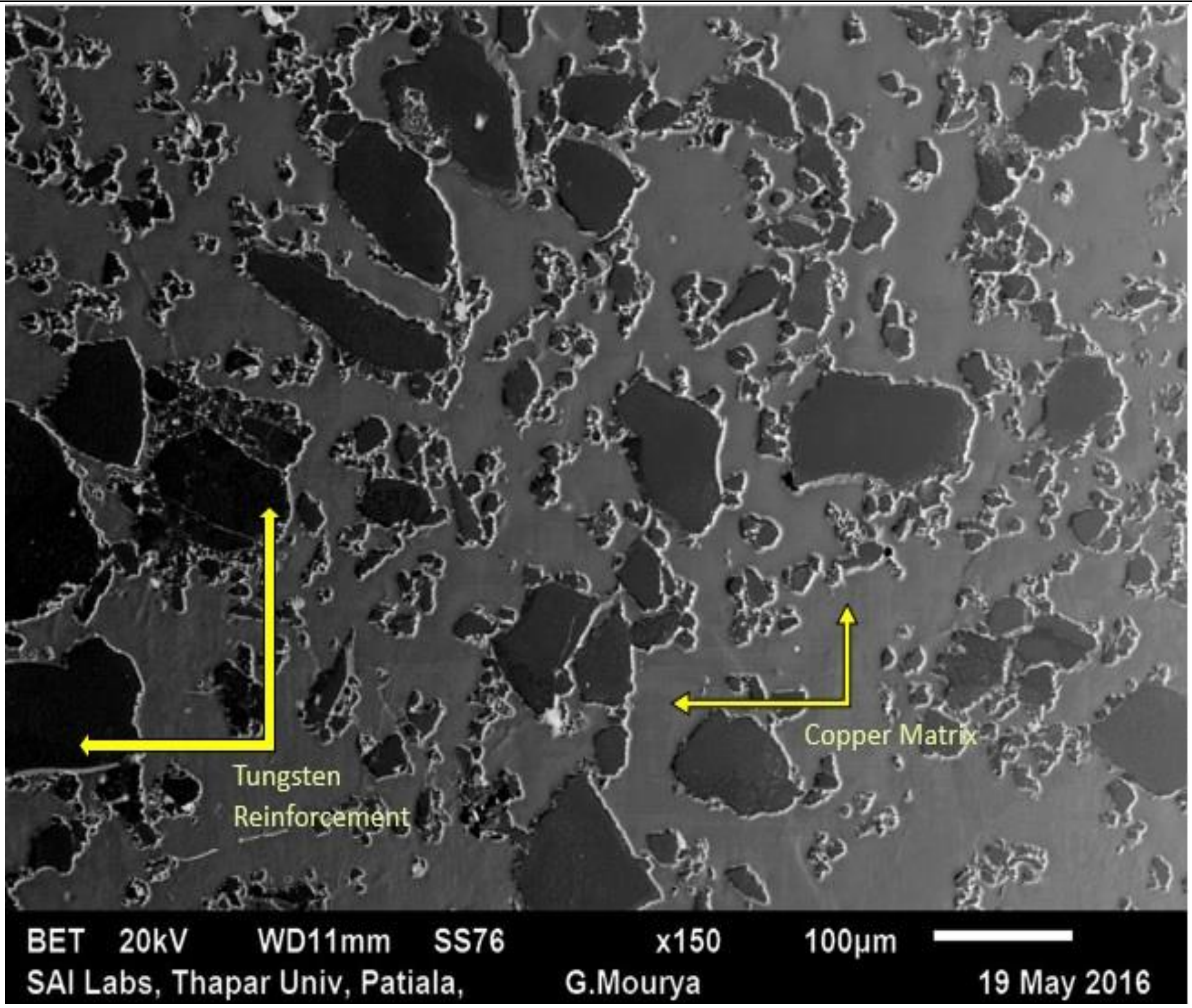


Fig. 5.16.SEM image of Cu-50 wt. % W composite casting.

Tungsten particles were properly dispersed throughout the matrix and could be seen at almost half of the places as the amount of reinforcement increased from 30 wt. % to 50 wt. % of the composition as shown in above SEM micrograph in above Fig. 5. 16. Grain growth was uniform but grain boundaries were not seen till a very higher magnification. A small part of the above captured SEM image was magnified upto 1500x and a reasonable SEM micrograph was found depicting the grain boundaries. Highly magnified view of a small section is shown in below Fig. 5.17.

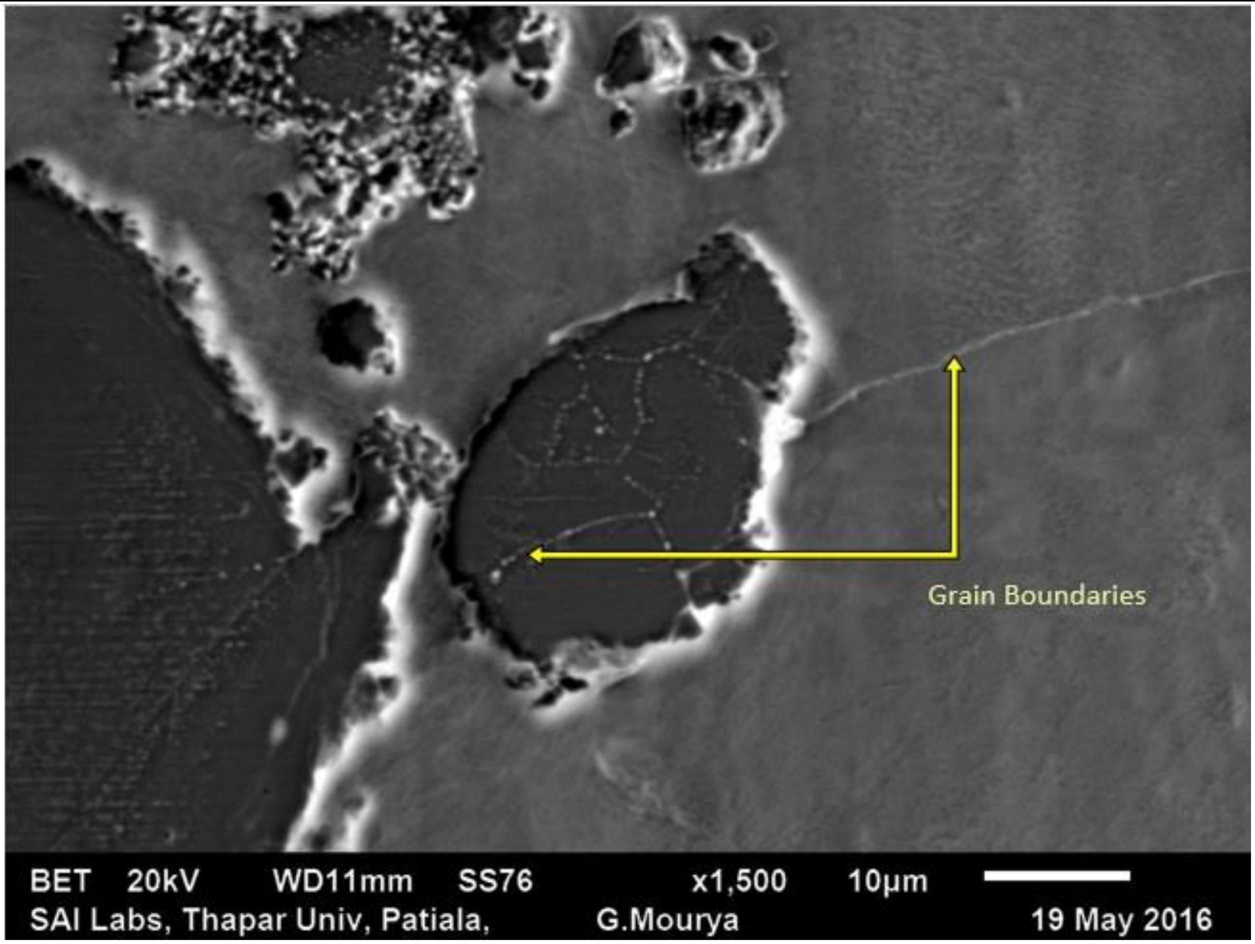
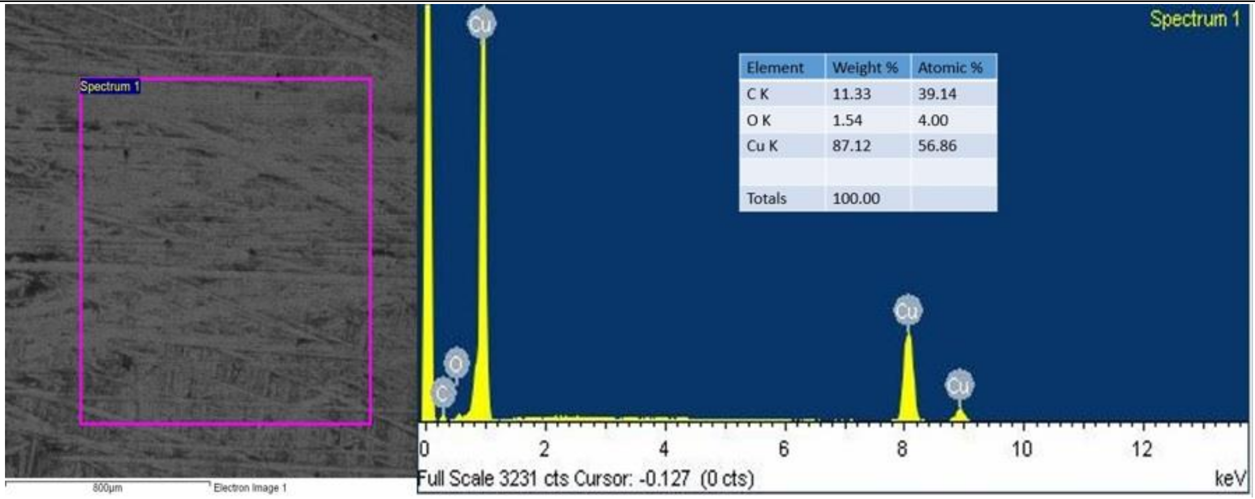


Fig. 5.17. Highly magnified view of small section showing the grain boundaries.

5.2.2 Elemental Study of Metal Matrix Composites (MMC's) Casting

The elemental study was carried out by Energy Dispersive X-ray Spectroscopy (EDS). The SEM image of cast samples were obtained and afterwards EDS for further analysis. The composition and distribution of the elements have been analyzed by selecting small area from the image. Before carrying out the fundamental studies of the prepared samples, the microstructure and composition of the matrix material and reinforcing material in powder form were studied, so that a conclusion can be drawn about the changes occurred after microwave processing and alloying.

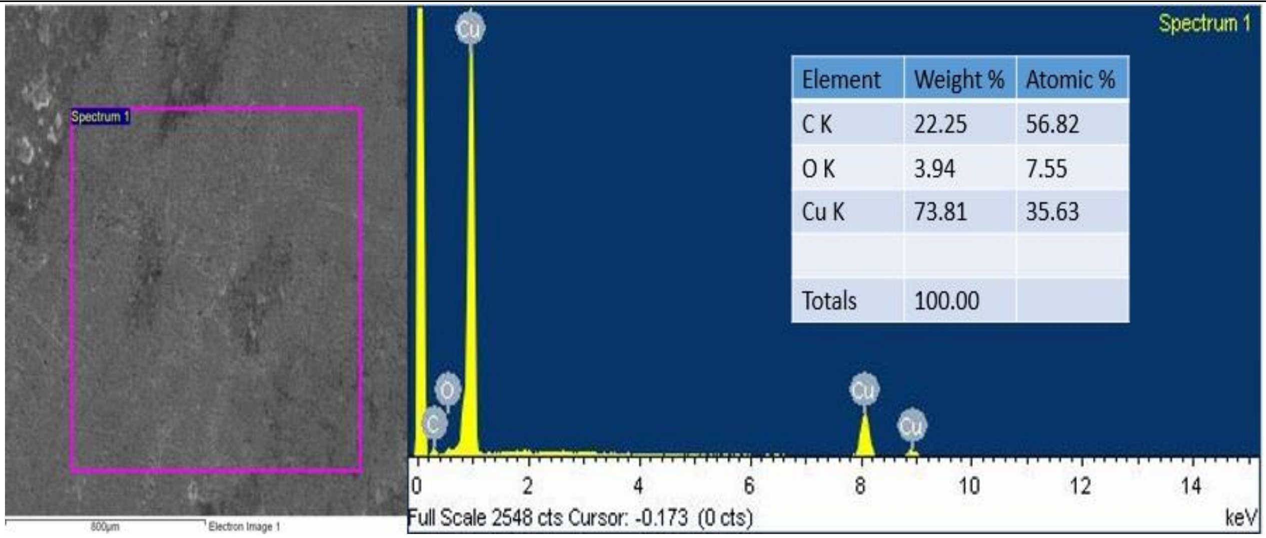
As the microstructure and elemental composition of all the three powders have already discussed earlier in section 4.1, now the microstructure and composition after alloying were studied and a conclusion was drawn after examining the EDS spectra which shows the peaks of copper, molybdenum and tungsten and their collaborations with atmospheric impurities. The below Fig. 5.18 shows the EDS spectra of microwave processed pure copper.



Element	Weight %	Atomic %
C K	11.33	39.14
O K	1.54	4.00
Cu K	87.12	56.86
Totals	100.00	

Fig. 5.18. Microstructure and composition of microwave processed pure copper.

Copper was the principle constituent, so the crests of copper were seen. Carbon was seen around 11% and it was on the grounds that the melting and casting of copper powder was done in the graphite cavity and there was a collaboration between the separator material i.e. thin graphite sheet and the powder that is to be processed, so, the carbon crests additionally became possibly the most important factor. Copper oxide was also formed, which is by and large considered as contamination in light of the fact that at high temperature when copper interacts with the atmospheric oxygen, it's extremely inclined to make copper oxide ($Cu_{64}O$).

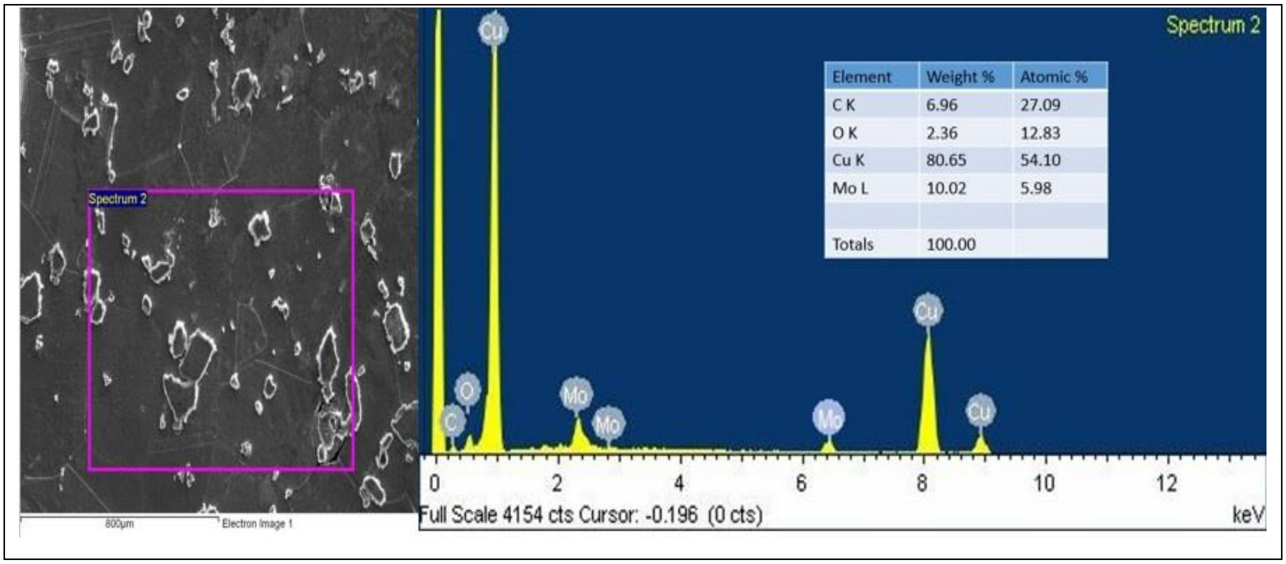


Element	Weight %	Atomic %
C K	22.25	56.82
O K	3.94	7.55
Cu K	73.81	35.63
Totals	100.00	

Fig. 5.19. Microstructure and composition of conventionally cast copper sample.

Be that as it may, once in a while the development of oxides is ideal since it gives slight increment in the hardness of the product which is by and large required when ductile materials/soft materials have to withstand the forces and when there is sliding contact with a material harder than them.

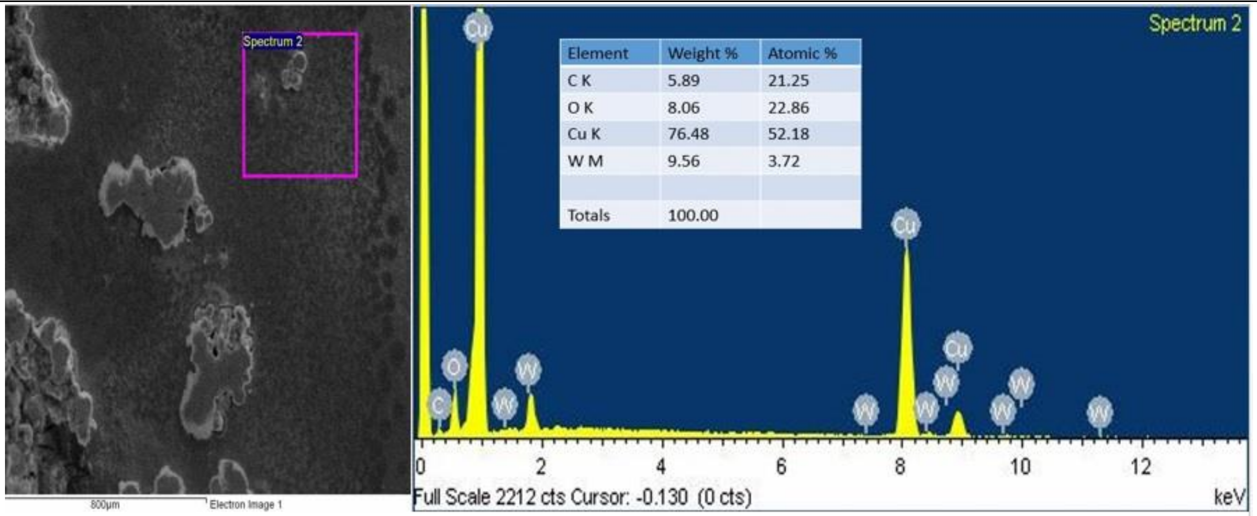
The above Fig. 5.19 shows the EDS spectra of conventionally cast copper sample. Peaks of carbon were seen in the matrix which simply implies that there were little bit impurities while preparing the sample through forging process and was achieved upto 22.25% of the composition. As it was the pure copper sample, copper peaks were also seen and was achieved upto 73.81% of the composition. Oxygen content was also present but at a very small quantity of 4% of the composition. The hardness value obtained was nearly around 51 Hv which was greater than hardness value of pure microwave processed copper i.e. 44 Hv. This was due to the fact that carbon % was more in conventionally cast copper than in microwave processed pure copper and copper plays an important role in increasing the hardness value. The below Fig. 5.20 shows the EDS spectra of Cu-10 wt. % Mo.



Element	Weight %	Atomic %
C K	6.96	27.09
O K	2.36	12.83
Cu K	80.65	54.10
Mo L	10.02	5.98
Totals	100.00	

Fig 5.20. Microstructure and composition of Cu-10 wt. % Mo.

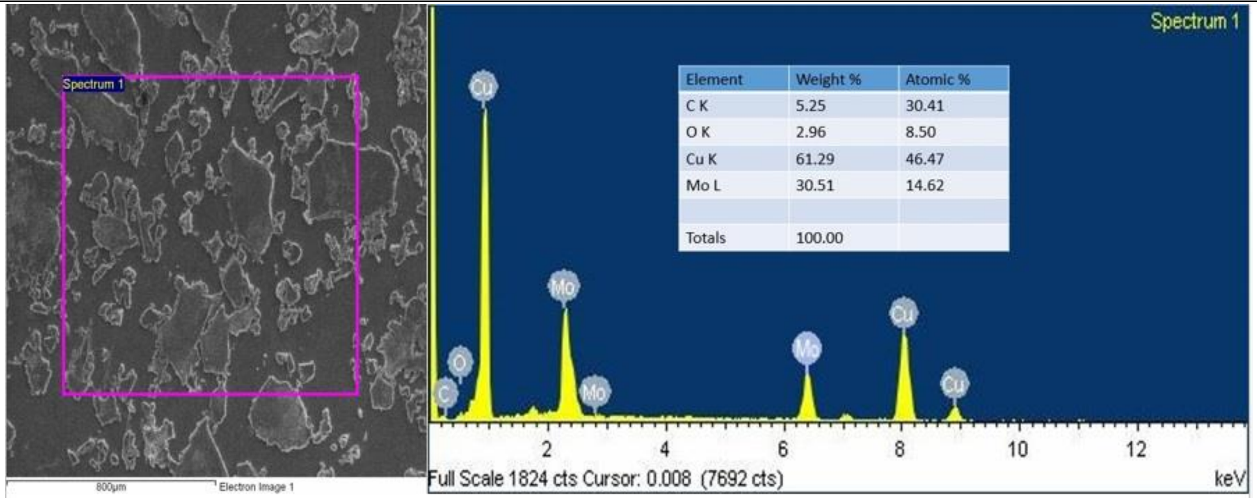
The microstructure was clearly visible showing the dispersion of molybdenum reinforced particles at few places as it can be clearly seen from the EDS spectra that weight % of Mo was 10.02% which was exactly equal to the wt. % of Mo initially taken for preparing this sample. Weight % of copper in composition was decreased as carbon peak was also seen with a small peak of oxygen when compared with the initially taken wt. % of Cu. Copper was found around 80% rather than 90%. Because of reinforcing molybdenum, the hardness of the composite was also seen to be increased from the hardness of pure copper sample of around 44 Hv to 96 Hv. The below Fig. 5.21 shows EDS spectra of Cu-10 wt. % W.



Element	Weight %	Atomic %
C K	5.89	21.25
O K	8.06	22.86
Cu K	76.48	52.18
W M	9.56	3.72
Totals	100.00	

Fig. 5.21. Microstructure and composition of Cu-10 wt. % W composite casting.

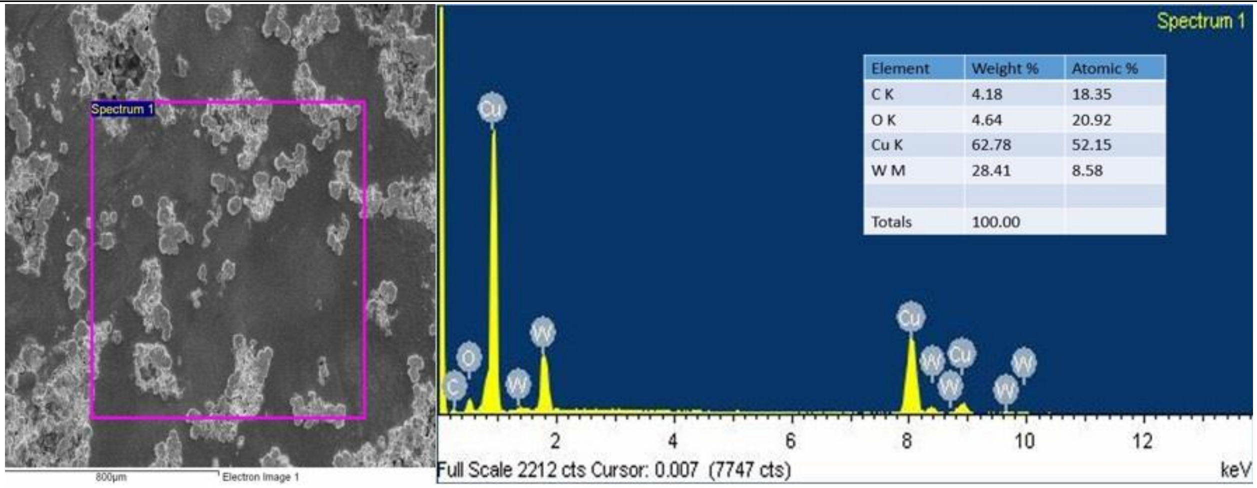
The wt. % of tungsten achieved was 9.56% which was nearly about the initially taken wt. % of composition for tungsten and the particles of tungsten were properly dispersed accordingly. Copper was found around 76% rather than 90% as it should be which is possibly because the carbon peaks were also seen and achieved upto 6%. The oxygen peak was higher than the carbon, as the oxygen content was found to be high in the tungsten powder as already seen above. Due to reinforcing of tungsten, the hardness value achieved was around 127 Hv, which was higher than both pure copper and molybdenum reinforced copper



Element	Weight %	Atomic %
C K	5.25	30.41
O K	2.96	8.50
Cu K	61.29	46.47
Mo L	30.51	14.62
Totals	100.00	

Fig. 5.22. Microstructure and composition of Cu-30 wt. % Mo composite casting.

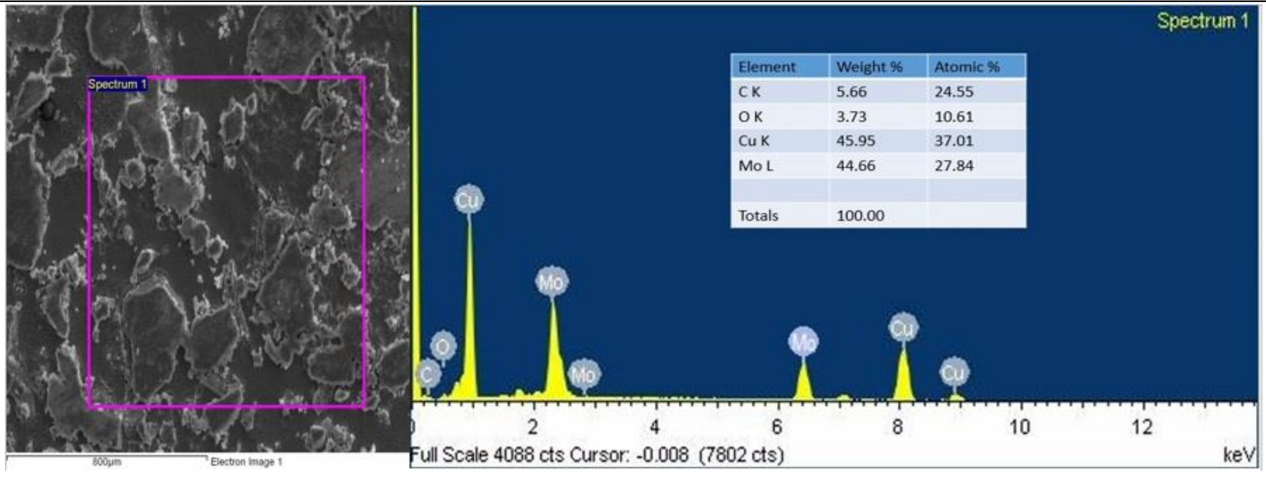
The above Fig. 5.22 shows the EDS spectra of Cu-30 wt. % Mo. As the EDS spectra was showing the wt. % of Mo around 30%, the molybdenum particles were also dispersed according to that i.e. at various places. Copper was found to be around 61% rather than 70% which was possibly because of the carbon peaks that were achieved about 5% of the composition. The hardness value achieved was about 106 Hv which was because of increase in wt. % of Mo in composition upto 30%.



Element	Weight %	Atomic %
C K	4.18	18.35
O K	4.64	20.92
Cu K	62.78	52.15
W M	28.41	8.58
Totals	100.00	

Fig. 5.23. Microstructure and composition of Cu-30 wt. % W composite casting.

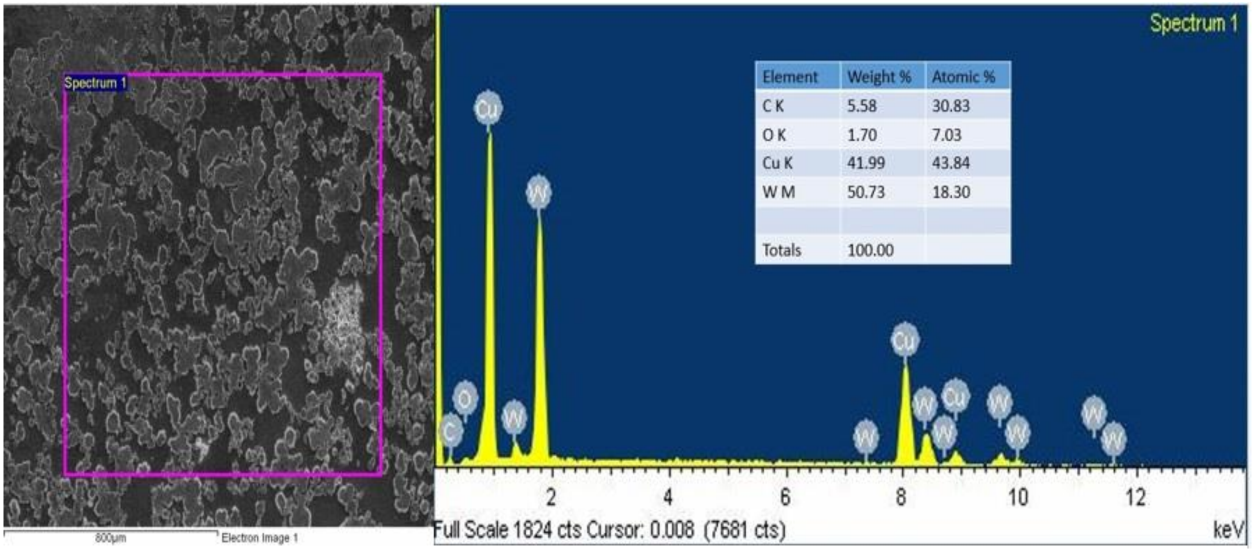
The above Fig. 5.23 shows the EDS spectra of Cu-30 wt. % W. Weight % of tungsten achieved was 28.41% which was close enough to the initially taken wt. % of W and the tungsten particles were dispersed accordingly at various places. Copper was found around 63% and carbon and oxygen peaks were also seen at an equal amount. The hardness value achieved was around 135 Hv which is because of 30 wt. % of W in the composition.



Element	Weight %	Atomic %
C K	5.66	24.55
O K	3.73	10.61
Cu K	45.95	37.01
Mo L	44.66	27.84
Totals	100.00	

Fig. 5.24. Microstructure and composition of Cu-50 wt. % Mo composite casting.

The above Fig. 5.24 shows the EDS spectra of Cu-50 wt. % Mo. Now as the wt. % of copper and molybdenum were taken at an equal amount, the EDS spectra was also showing the peaks having nearly 45% of composition for both the materials. Weight % of molybdenum achieved was 44.66% and that of copper was 45.95%. Peaks of carbon and oxygen were also seen. The harness value achieved was around 120 Hv which was less than the hardness value achieved for Cu-30 wt. % W. The molybdenum particles were equally dispersed in the whole matrix.



Element	Weight %	Atomic %
C K	5.58	30.83
O K	1.70	7.03
Cu K	41.99	43.84
W M	50.73	18.30
Totals	100.00	

Fig. 5.25. Microstructure and composition of Cu-50 wt. % W composite casting.

The above Fig. 5.25 shows the EDS spectra of Cu-50 wt. % W. Weight % of tungsten achieved was 50.73%, exactly equivalent to the initially taken amount of 50 wt. % of composition. Copper wt. % was found to be decrease and achieved around 42%. Tungsten particles were perfectly dispersed at all the places in the whole matrix and the hardness value achieved was maximum for this i.e. 143 Hv which is obviously because of high wt. % of W. It can be depicted that copper with 50 wt. % of tungsten as a reinforcement has witnessed the finest value among all but increasing the wt. % of reinforcement beyond this may have adverse effects on the matrix.

From the above EDS spectra’s, it can be concluded that there was only a little change in the composition after microwave processing’s and the compositions taken initially were correct as far as measurement was concerned.

5.2.3 X-Ray Diffraction Studies

A typical XRD spectrum of the pure copper developed through microwave hybrid heating is presented in below Fig. 5.26.

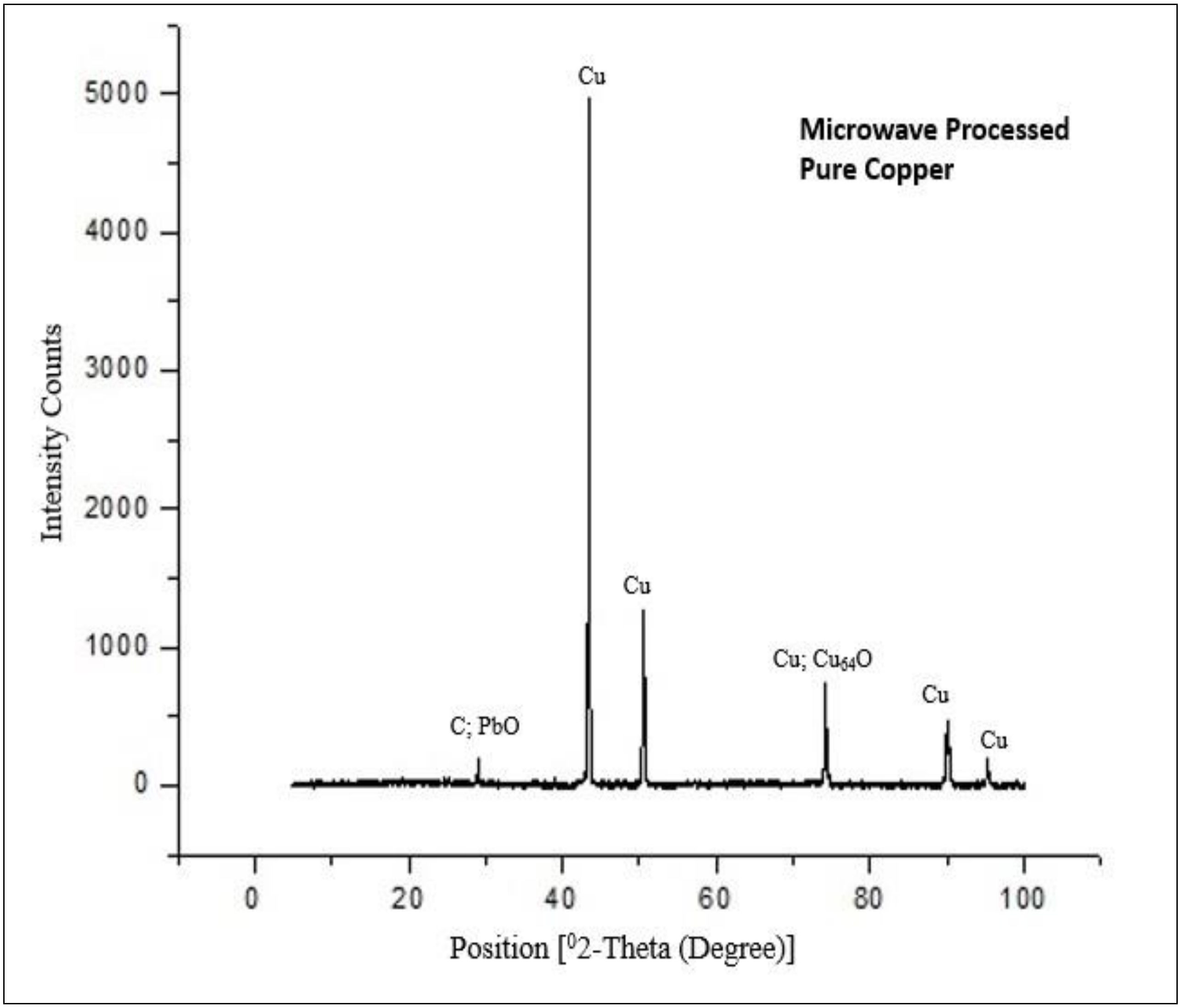


Fig. 5.26. Typical XRD Spectrum for microwave processed pure copper casting.

Presence of copper is clearly identified as a major constituent and formation of oxides are seen in the XRD pattern as shown in Fig. It is attributed to possible decomposition at higher temperature during MHH from Cu powder to $Cu_{64}O$. Carbon peaks are also seen which may be due to deposition of carbon while using graphite cavity and graphite sheet used as a separator. Little peaks of lead oxide is also seen which may be due to little impurities in copper powder.

A typical XRD spectrum of the conventionally casted pure copper is presented in below Fig. 5.27.

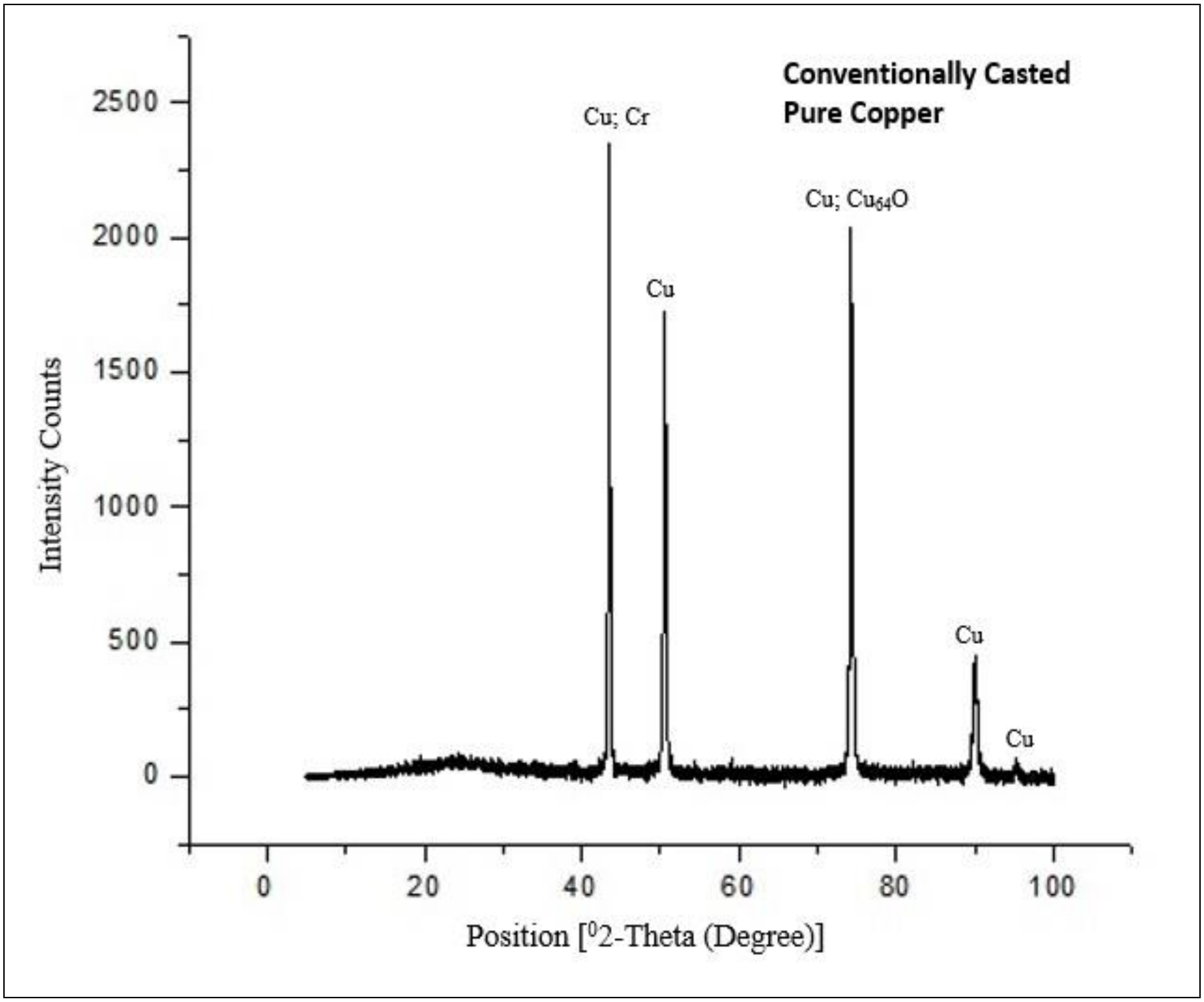


Fig. 5.27. Typical XRD Spectrum for conventionally casted pure copper.

Cu as a major constituent can be seen all over the XRD pattern. Formation of $Cu_{64}O$ is also visible which is due to the decomposition at higher temperature. The intensities of peaks obtained in conventionally casted samples are almost same as of microwave processed pure copper but the peak pattern is quite different from microwave processed pure copper. The peak at 43^0 angle in microwave processed pure copper have higher intensity than the peak at 43^0 angle in conventionally casted sample. Few chromium peaks are also seen which may be due to the impurity of chromium in liquefied copper metal while casting.

A typical XRD spectrum of the copper-10 wt. % molybdenum by same methodology is presented in below Fig. 5.28.

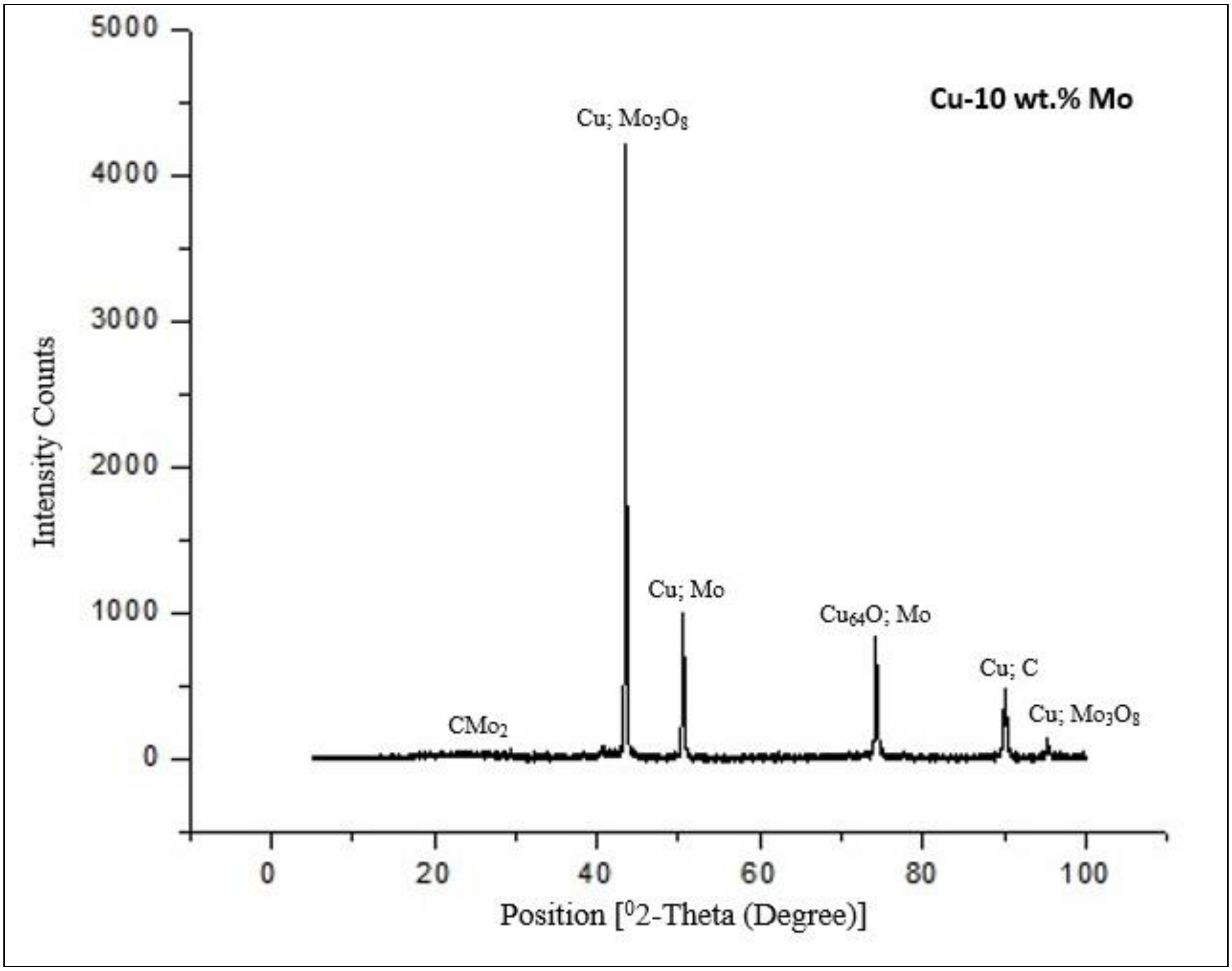


Fig. 5.28. Typical XRD Spectrum for Cu-10 wt. % Mo.

Presence of graphite due to graphite cavity and graphite separator, act as one of the main carbon constituent with diamond leads to a little carbon percentage which in turn forms the di-molybdenum carbide (CMo_2) at various peaks when carbon reacts with molybdenum, who is also even responsible as the promising candidate for increase in vicker’s micro-hardness. Formation of Copper oxides is also identified as carbon reacts with atmospheric oxygen results into the formation of $Cu_{64}O$ which during solidification (slow cooling rate) escapes subsequently leading to crack free composite and less porosity. The XRD spectrum clearly shows that there is no interaction between the copper and molybdenum during the fabrication of metal matrix composites, because it has not made any compound with the molybdenum. Molybdenum oxide is also seen at various peaks as molybdenum reacts with atmospheric oxygen results in the formation Mo_3O_8 during solidification.

A typical XRD spectrum of the copper-30 wt. % molybdenum by same methodology is presented in below Fig. 5.29.

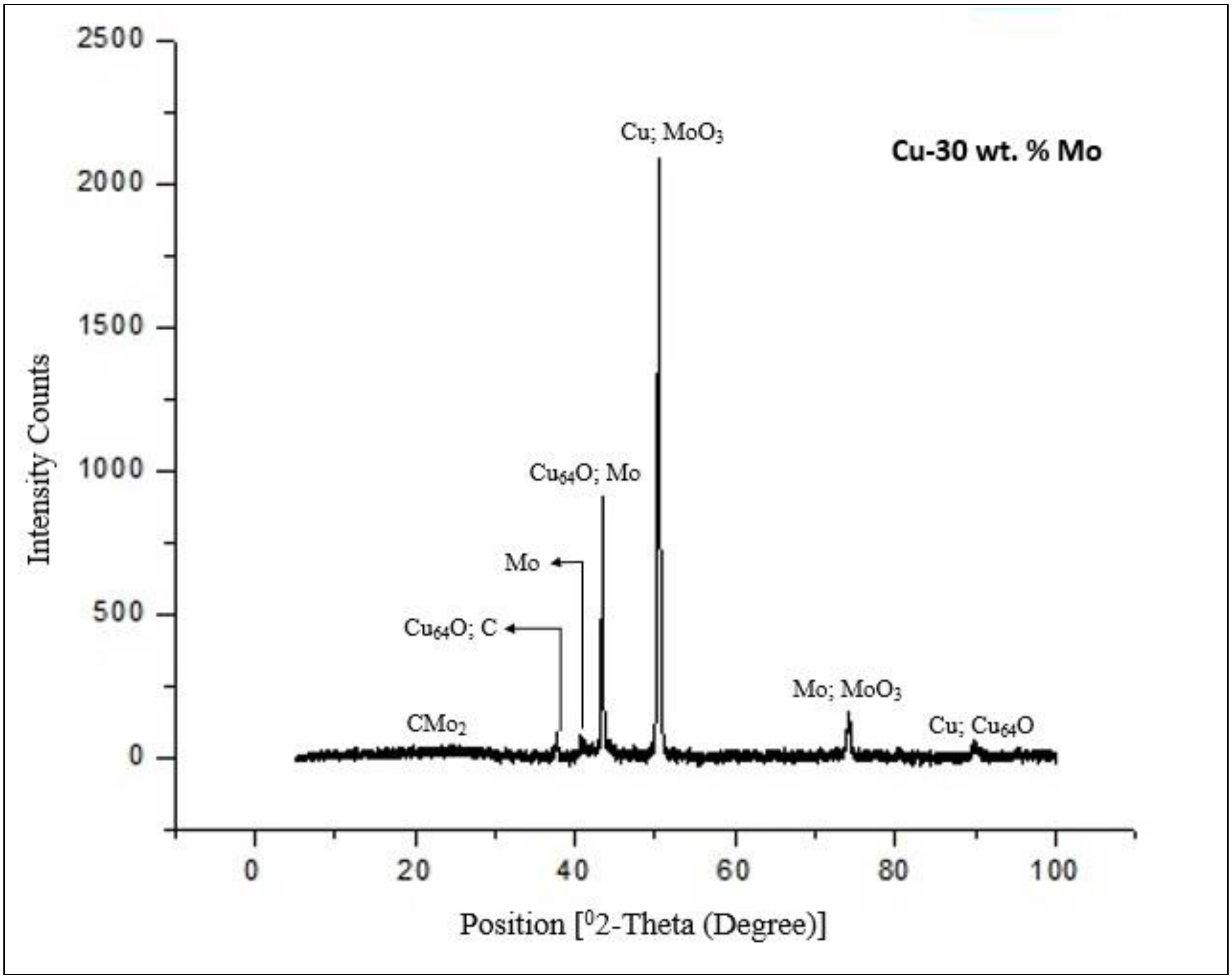


Fig. 5.29. Typical XRD Spectrum for Cu-30 wt. % Mo.

Presence of graphite due to graphite cavity and graphite separator, act as one of the main carbon constituent with diamond leads to a little carbon percentage which in turn forms the di-molybdenum carbide (CMo_2) at various peaks when carbon reacts with molybdenum, who is also even responsible as the promising candidate for increase in vicker's micro-hardness. In this XRD spectrum, smaller peaks are also available containing molybdenum. These uniform peaks of molybdenum and copper signifies that molybdenum is uniformly dispersed throughout the matrix.

The formation of copper oxides $Cu_{64}O$ is also seen which is due to the contact of atmospheric gases with the copper at high temperature. Molybdenum oxide is also seen at various peaks as molybdenum reacts with atmospheric oxygen results in the formation MoO_3 during solidification. As molybdenum peaks are seen at many peaks, it confirms that the hardness value for Cu-30 wt. % Mo is more than Cu-10 wt. % Mo.

A typical XRD spectrum of the copper-50 wt. % molybdenum by same methodology is presented in below Fig. 5.30.

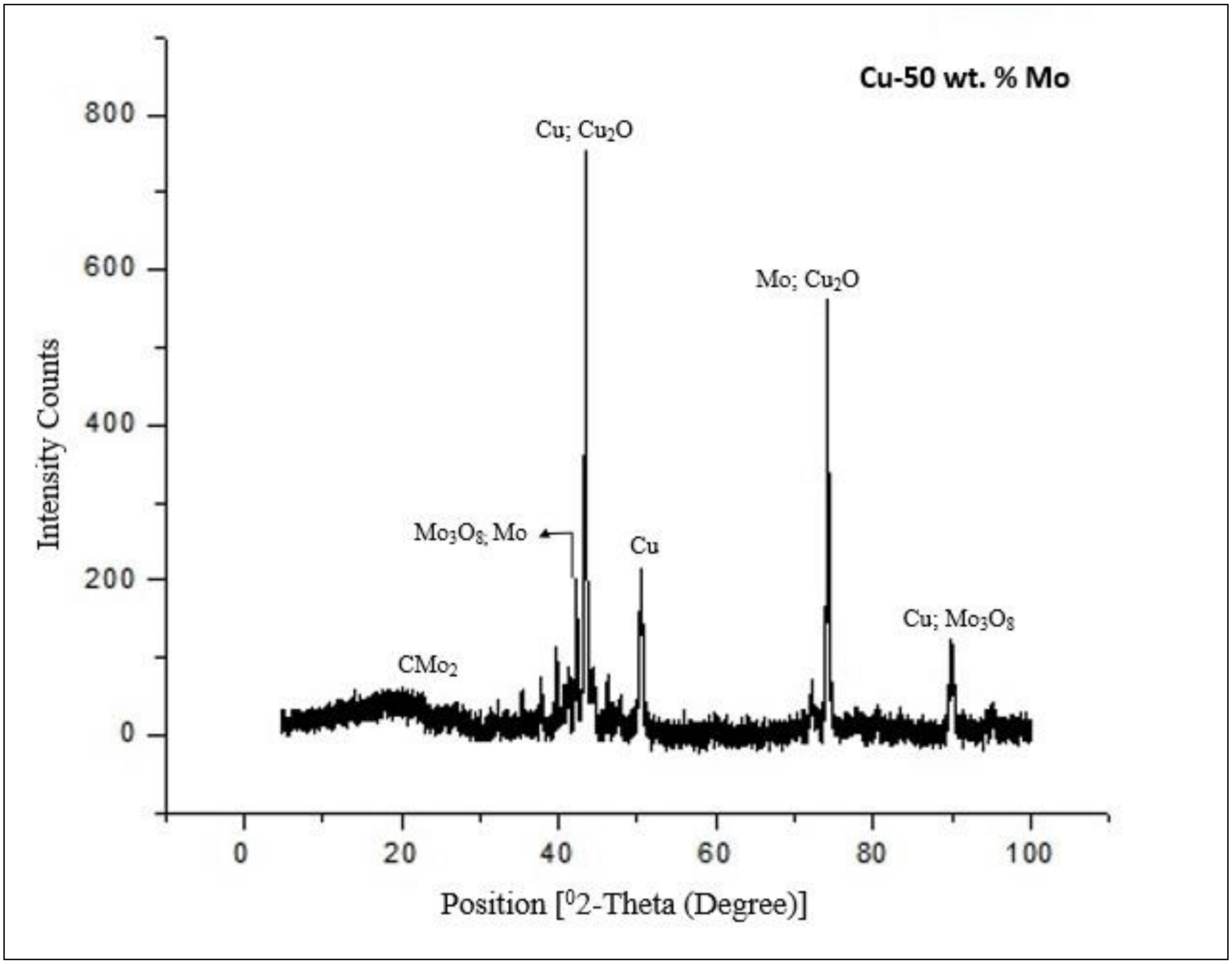


Fig. 5.30. Typical XRD Spectrum for Cu-50 wt. % Mo.

Molybdenum being the major component in this sample, molybdenum peaks are visible at various places. It simply reveals that the reinforcement material i.e. molybdenum is uniformly dispersed in the whole matrix. Other than molybdenum, the next major component is copper, so as various peaks can be easily seen. The formation of di-copper oxide (Cu_2O) is also seen which is due to the contact of atmospheric gases with the copper at high temperature. Molybdenum oxide is also seen at various peaks as molybdenum reacts with atmospheric oxygen results in the formation Mo_3O_8 during solidification. As molybdenum peaks are seen at many places, it confirms that the hardness value for Cu-50 wt. % Mo is the highest among Cu-10 wt. % Mo and Cu-30 wt. % Mo. Presence of graphite due to graphite cavity and graphite separator, act as one of the main carbon constituent with diamond leads to a little carbon percentage which in turn forms the di-molybdenum carbide (CMo_2) at various peaks when molybdenum reacts with carbon, who is also even responsible as the promising candidate for increase in vicker's micro-hardness.

A typical XRD spectrum of the copper-10 wt. % tungsten by same methodology is presented in below Fig. 5.31.

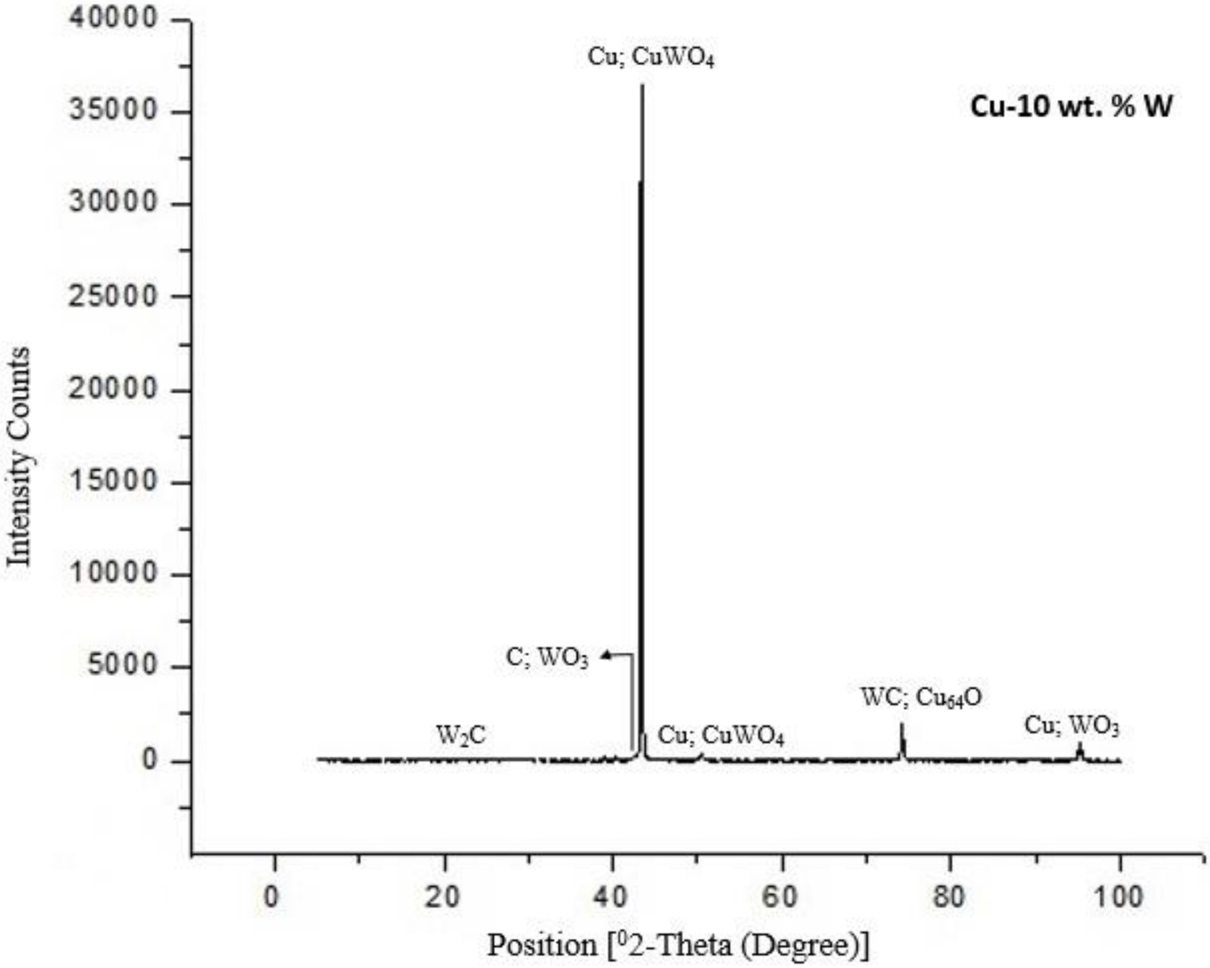


Fig. 5.31. Typical XRD Spectrum for Cu-10 wt. % W.

Presence of graphite due to graphite cavity and graphite separator, act as one of the main carbon constituent with diamond leads to a little carbon percentage which in turn forms the tungsten carbide (W_2C and WC) at various peaks when carbon reacts with tungsten, who are also even responsible as the promising candidate for increase in vicker's micro-hardness. Copper being the major component is seen at various peaks. Formation of Copper oxides is also identified as carbon reacts with atmospheric oxygen results into the formation of $Cu_{64}O$ which during solidification (slow cooling rate) escapes subsequently leading to crack free composite and less porosity. The XRD spectrum clearly shows that there is an interaction between the copper and tungsten during the fabrication of metal matrix composites, because it has made copper tungstate ($CuWO_4$). Tungsten oxide is also seen at various peaks as tungsten reacts with atmospheric oxygen results in the formation WO_3 during solidification.

A typical XRD spectrum of the copper-30 wt. % tungsten by same methodology is presented in below Fig. 5.32.

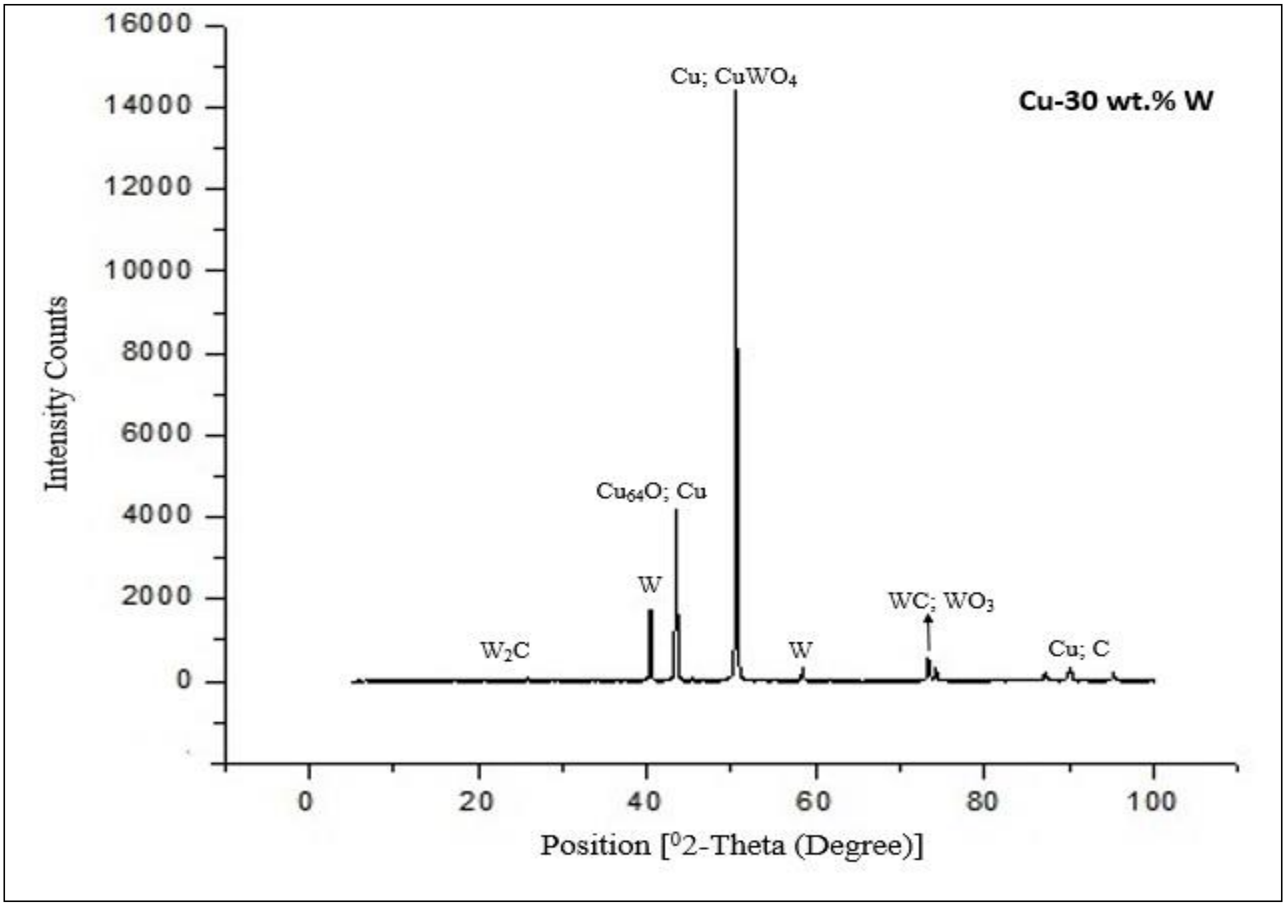


Fig. 5.32. Typical XRD Spectrum for Cu-30 wt. % W.

Presence of graphite due to graphite cavity and graphite separator, act as one of the main carbon constituent with diamond leads to a little carbon percentage which in turn forms the tungsten carbide (W_2C and WC) at various peaks when carbon reacts with tungsten, who are also even responsible as the promising candidate for increase in vicker's micro-hardness. Copper being the major component is seen at various peaks. Cu-30 wt. % W being the more in weight % of tungsten, many peaks are seen of W. Formation of Copper oxides is also identified as carbon reacts with atmospheric oxygen results into the formation of $Cu_{64}O$ which during solidification (slow cooling rate) escapes subsequently leading to crack free composite and less porosity. The XRD spectrum clearly shows that there is an interaction between the copper and tungsten during the fabrication of metal matrix composites, because it has made copper tungstate ($CuWO_4$). Tungsten oxide is also seen at various peaks as tungsten reacts with atmospheric oxygen results in the formation WO_3 during solidification.

A typical XRD spectrum of the copper-50 wt. % tungsten by same methodology is presented in below Fig. 5.33

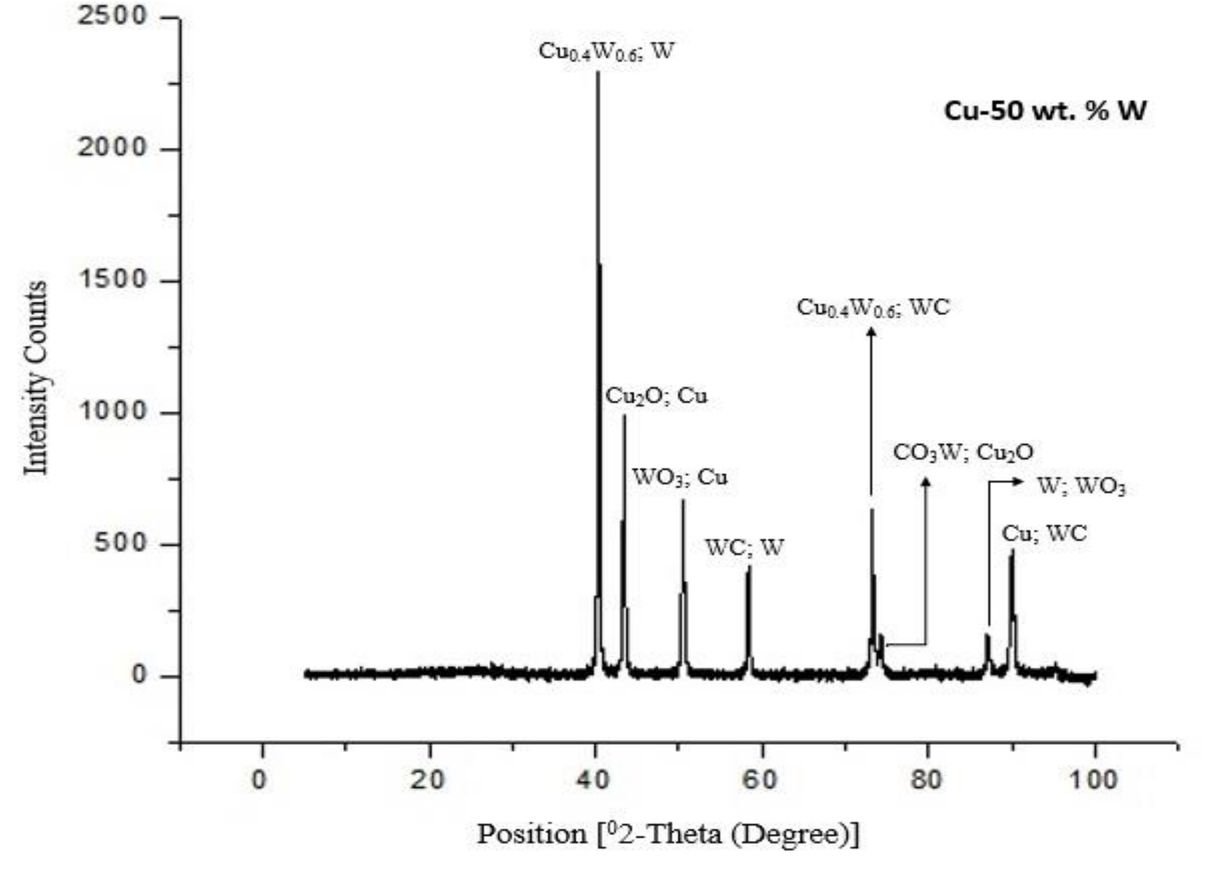


Fig. 5.33. Typical XRD Spectrum for Cu-10 wt. % W.

Tungsten being the major component in this sample, tungsten peaks are visible at various places. It simply reveals that the reinforcement material i.e. tungsten is uniformly dispersed in the whole matrix. Other than molybdenum, the next major component is copper, so as various peaks can be easily seen. The formation of di-copper oxide (Cu_2O) is also seen which is due to the contact of atmospheric gases with the copper at high temperature. Tungsten oxide is also seen at various peaks as molybdenum reacts with atmospheric oxygen results in the formation WO_3 during solidification. The XRD spectrum clearly shows that there is an interaction between the copper and tungsten during the fabrication of metal matrix composites, because it has made copper tungsten ($Cu_{0.4}W_{0.6}$). As tungsten peaks are seen at many places, it confirms that the hardness value for Cu-50 wt. % W is the highest among Cu-10 wt. % W and Cu-30 wt. % W. Presence of graphite due to graphite cavity and graphite separator, act as one of the main carbon constituent with diamond leads to a little carbon percentage which in turn forms the tungsten carbide (W_2C and WC) at various peaks when carbon reacts with tungsten, who are also even responsible as the promising candidate for increase in vicker's micro-hardness. Even the hardness value for Cu-50 wt. % W is the highest among all the fabricated samples.

5.3 Electrical Characterization

As electrical characterization being one of the important aspect of the develop castings for this research work. In this study the Metal Matrix Composite (MMC) casting samples analyzed by electrical resistivity measurement, electrical conductivity measurement, and thermal conductivity measurement. The instrument used for measuring these properties was four point probe resistivity measuring instrument. The four point probe method has been used as it possess several advantages such as variety of samples with different shapes can be processed for electrical resistivity measurements, the resistivity measured by four point probe method is uniform in the region estimated for experimentation, and so on.

The four probe instrument used for the measuring the above mentioned properties has been explained in section 4.5.6. There were 8 distinct samples prepared during casting were up for the experimentation process. Distinct experiments were performed for distinct samples and there comparative analysis was also done. During the first step, a constant current was supplied for each samples and the voltage was measured against those samples. The applied current was 1150 mA and the voltage measured is tabulated below for each sample.

Table 5.1. Measured voltage for different samples.

Sr. No.	Prepared Samples	Measured Voltage (mV)
1.	Conventionally cast copper	0.002
2.	Microwave processed pure copper	0.003
3.	Cu-10 wt. % Mo	0.004
4.	Cu-30 wt. % Mo	0.005
5.	Cu-50 wt. % Mo	0.007
6.	Cu-10 wt. % W	0.006
7.	Cu-30 wt. % W	0.009
8.	Cu-50 wt. % W	0.011

Based on these values of current and voltage, electrical resistivity was calculated for all the samples according to the process described in section 4.5.6.3.

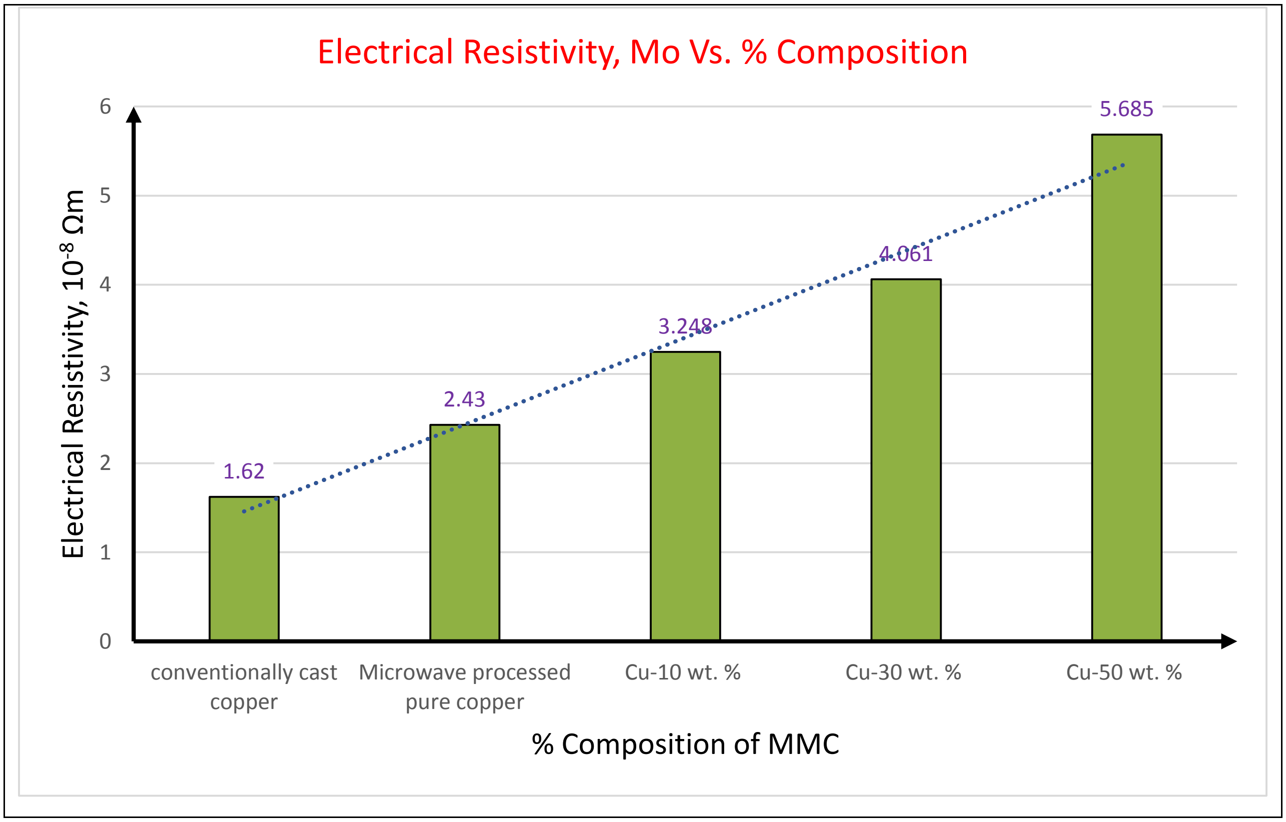


Fig. 5.34. Electrical resistivity of Mo reinforced samples versus % of composition.

Electrical resistivity of conventionally cast copper, microwave processed pure copper and molybdenum reinforced copper samples were first calculated and comparative analysis was done. The variation in electrical resistivity with increase in reinforcement is shown in above Fig. 5.34.

The electrical resistivity measured was 1.62 x 10^{-8} Ω-m and 2.43 x 10^{-8} Ω-m for conventionally cast copper sample and microwave processed pure copper respectively. It was seen that after microwave processing, the resistivity was increased by almost 50% from the conventionally cast copper sample. The resistivities measured for Cu-10 wt. % Mo, Cu-30 wt. % Mo and Cu-50 wt. % Mo were 3.248 x 10^{-8} Ω-m, 4.061 x 10^{-8} Ω-m and 5.685 x 10^{-8} Ω-m respectively. It was clearly visible from the graph, that as the wt. % of molybdenum increases, the electrical resistivity also increases but from the trend line w.r.t. the conventionally cast copper. It can be concluded that the amount of increment of electrical resistivity for Cu-10 wt. % Mo was little less than the trend or desired value, perfect for pure copper, more lessened for Cu-30 wt. % Mo and little high for Cu-50 wt. % Mo than the trend value. The increment in electrical resisitivities for Cu-10 wt. % Mo, Cu-30 wt. % Mo and Cu-50 wt. % Mo with respect to pure microwave processed copper were 33.66%, 67.11% and 133.95% respectively.

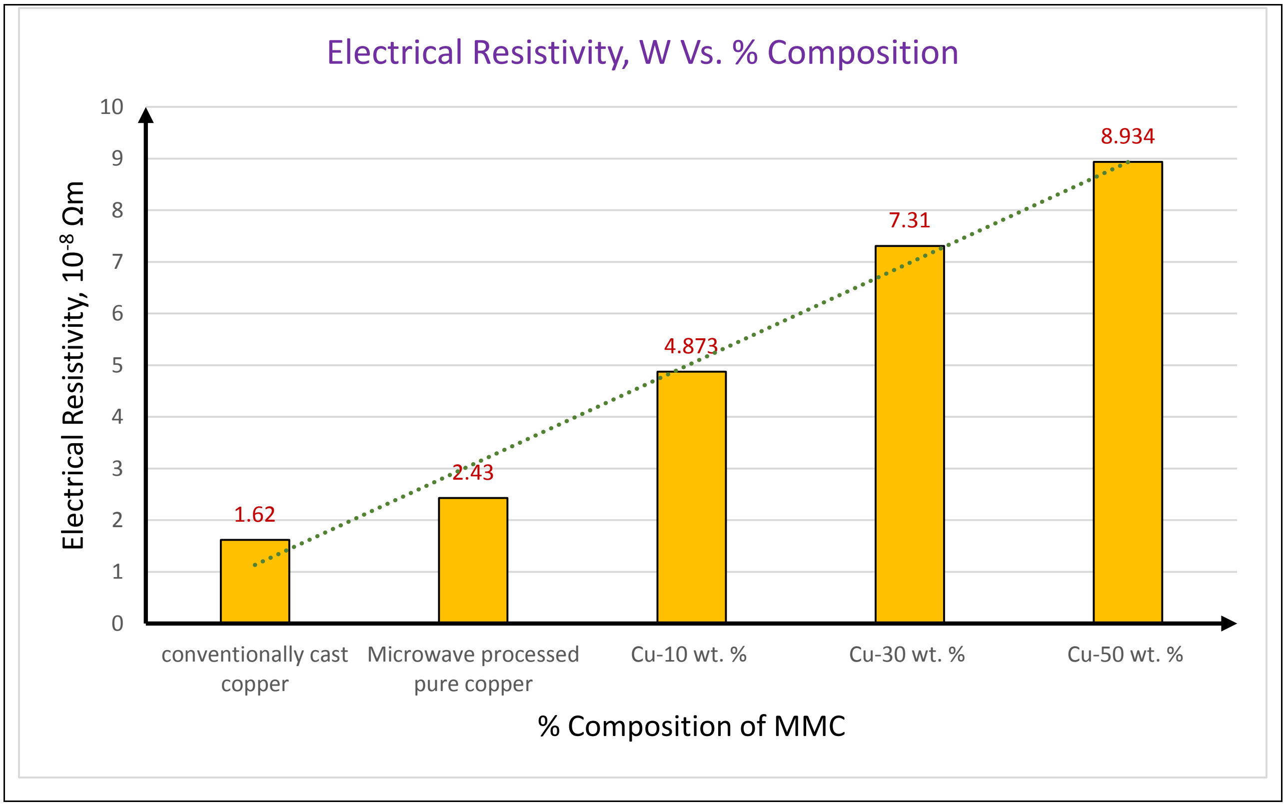


Fig. 5.35. Electrical resistivity of W reinforced samples versus % of composition.

Secondly, electrical resistivities of copper reinforced tungsten samples were measured and compared with the obtained results of conventionally cast copper and microwave processed pure copper. The variation in electrical resistivity of reinforced samples with increase in wt. % composition is shown in above Fig. 5.35.

As the electrical resistivity value of conventionally cast copper and microwave pure copper was already discussed above, the same values were taken for this comparative analysis. The resistivities measured for Cu-10 wt. % W, Cu-30 wt. % W and Cu-50 wt. % W were 4.873 x 10^{-8} Ω-m, 7.31 x 10^{-8} Ω-m and 8.934 x 10^{-8} Ω-m respectively. It was clearly visible from the graph, that as the wt. % of tungsten increases, the electrical resistivity also increases but from the trend line w.r.t. the conventionally cast copper, it can be concluded that the amount of increment of electrical resistivity for Cu-10 wt. % W was little less than the trend or desired value, much lessened for pure copper, little more for Cu-30 wt. % W and perfect for Cu-50 wt. % W than the trend value. The increment in electrical resistivities for Cu-10 wt. % W, Cu-30 wt. % W and Cu-50 wt. % W with respect to pure microwave processed copper were 100.53%, 200.82% and 267.65% respectively.

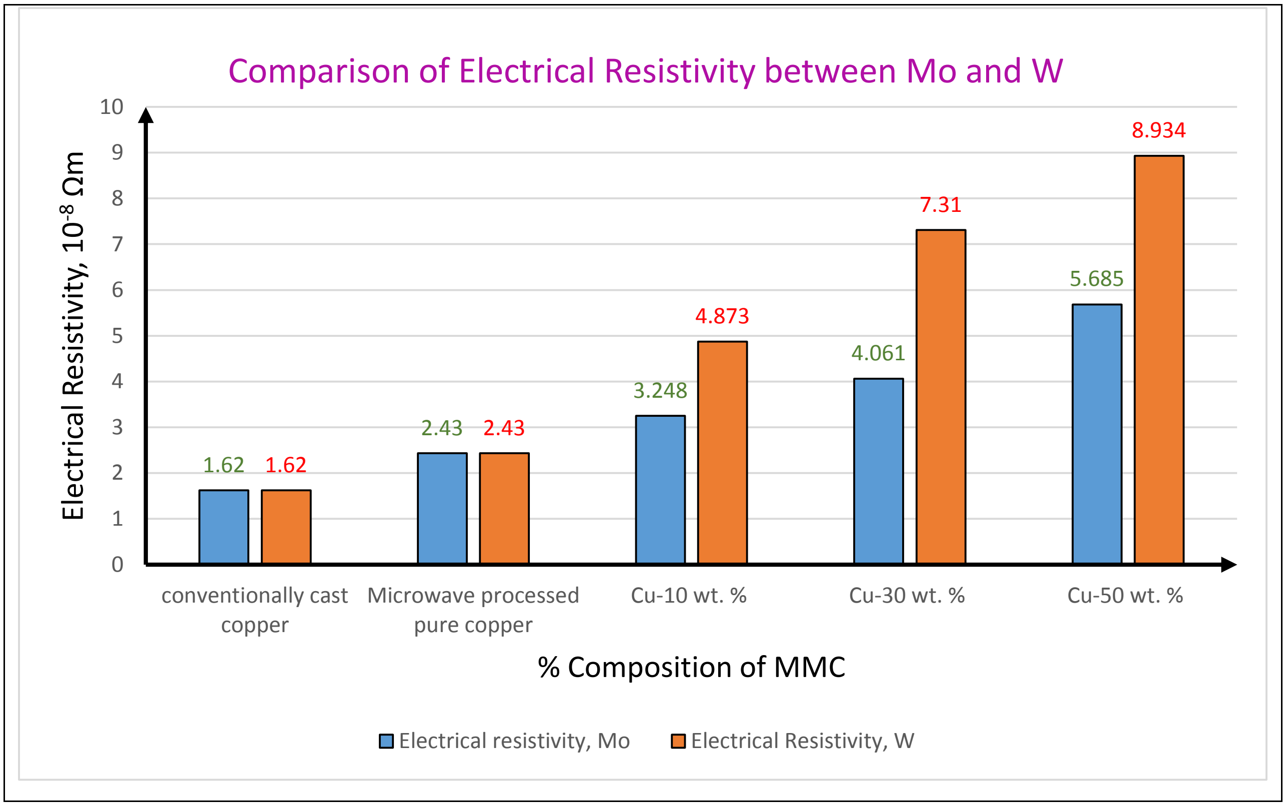


Fig. 5.36. A detailed comparison of electrical resistivity between Mo and W reinforced samples.

Despite of comparing the obtained results of electrical resistivity for molybdenum reinforced samples and tungsten reinforced samples alone with the pure copper samples, a combined comparison was also presented between molybdenum reinforced samples and tungsten reinforced samples from the above obtained results. A comparative analysis between them is shown above in Fig. 5.36.

From the above graph, it can be clearly concluded that the amount of increment in electrical resistivities for molybdenum reinforced samples were less than the amount of increment in tungsten reinforced samples or the rate of increment in molybdenum reinforced samples was less than the rate of increment in tungsten reinforced samples. The electrical resistivity for Cu-10 wt. % W is 1.5 times that of Cu-10 wt. % Mo, for Cu-30 wt. % W is 1.8 times that of Cu-30 wt. % Mo and for Cu-50 wt. % W is 1.57 times that of Cu-50 wt. % Mo. It is possibly because tungsten is more resistive than molybdenum. The trend that was seen is better for tungsten reinforced samples than molybdenum reinforced samples.

Based on the electrical resistivities values obtained from the above calculations, electrical conductivity values of all the samples were evaluated.

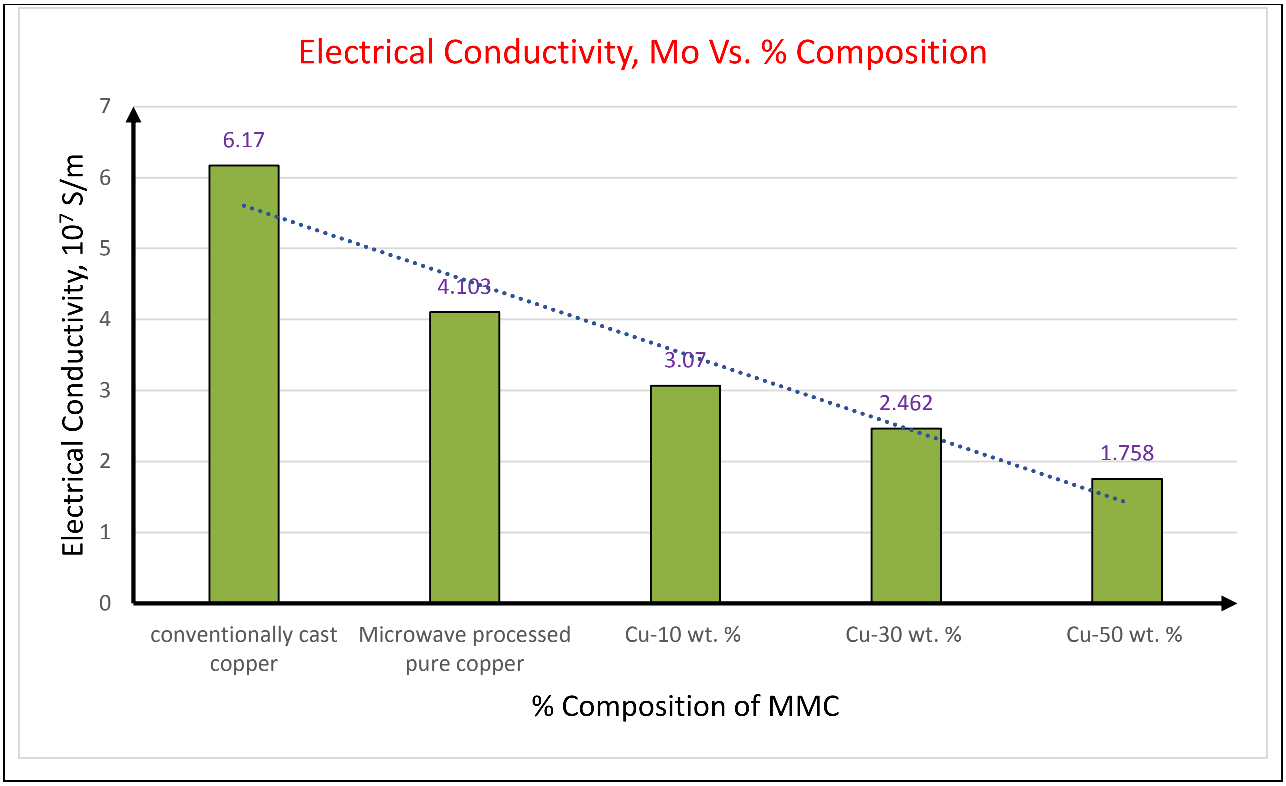


Fig. 5.37. Electrical conductivity of Mo reinforced samples versus % of composition.

Electrical conductivity of conventionally cast copper, microwave processed pure copper and molybdenum reinforced copper samples were first calculated and comparative analysis was done. The variation in electrical conductivity with increase in reinforcement is shown in above Fig. 5.37.

The electrical conductivities measured was 6.17 x 10^7 S/m and 4.103 x 10^7 S/m for conventionally cast copper sample and microwave processed pure copper respectively. It was seen that after microwave processing, the conductivity was decreased by almost 33.41% from the conventionally cast copper sample, which may be due to the change in grain structure and how the current is flowing across those grains. The conductivities measured for Cu-10 wt. % Mo, Cu-30 wt. % Mo and Cu-50 wt. % Mo were 3.07 x 10^7 S/m, 2.462 x 10^7 S/m and 1.758 x 10^7 S/m respectively. It was clearly visible from the graph, that as the wt. % of molybdenum increases, the electrical conductivity decreases, which is because of the fact that copper is more conductive than molybdenum and as the wt. % of copper decreases in the composite, the value of electrical conductivity of that composite also decreases but from the trend line w.r.t. the conventionally cast copper, it can be concluded that the amount of reduction of electrical conductivity for Cu-10 wt. % Mo and pure copper was more than the trend or desired value, perfect for Cu-30 wt. % Mo and little less for Cu-50 wt. % Mo than the trend value. The reduction in electrical conductivities for Cu-10 wt. % Mo, Cu-30 wt. % Mo and Cu-50 wt. % Mo with respect to pure microwave processed copper were 25.26%, 40.06% and 57.2% respectively.

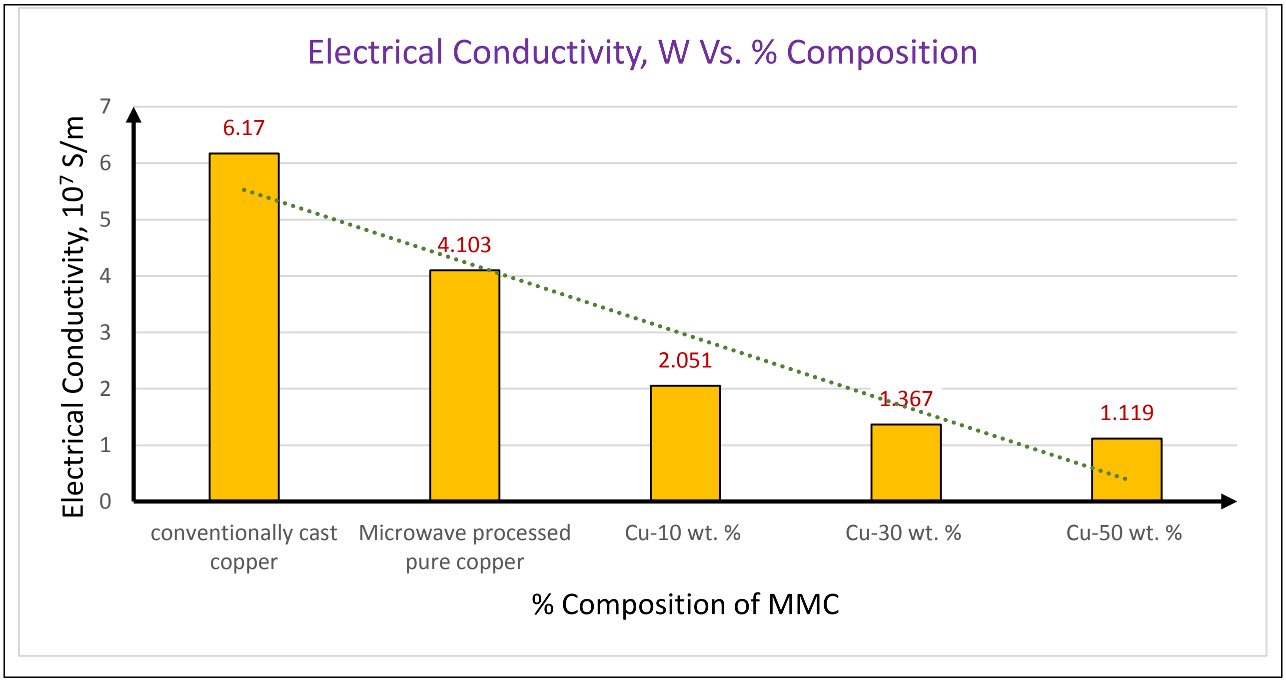


Fig. 5.38. Electrical conductivity of W reinforced samples versus % of composition.

Then electrical conductivities of copper reinforced tungsten samples were measured and compared with the obtained results of conventionally cast copper and microwave processed pure copper. The variation in electrical conductivity of reinforced samples with increase in wt. % composition is shown in above Fig. 5.38.

As the electrical conductivities of conventionally cast copper and microwave pure copper was already discussed above, the same values were taken for comparative analysis. The conductivities measured for Cu-10 wt. % W, Cu-30 wt. % W and Cu-50 wt. % W were 2.051 x 10^7 S/m, 1.367 x 10^7 S/m, and 1.119 x 10^7 S/m respectively. It was clearly visible from the graph, that as the wt. % of tungsten increases, the electrical conductivity decreases which is due to the fact that copper is much conductive than tungsten, so as the amount of copper in composite decreases with increases in amount of tungsten in composite, the overall electrical conductivity decreases but from the trend line w.r.t. the conventionally cast copper, it can be concluded that the amount of reduction of electrical conductivity for Cu-10 wt. % W was much more than the trend or desired value, reasonable for pure copper, little more for Cu-30 wt. % W and little less for Cu-50 wt. % W than the trend value. The reduction in electrical conductivities for Cu-10 wt. % W, Cu-30 wt. % W and Cu-50 wt. % W with respect to pure microwave processed copper were 50.01%, 66.68% and 72.72% respectively.

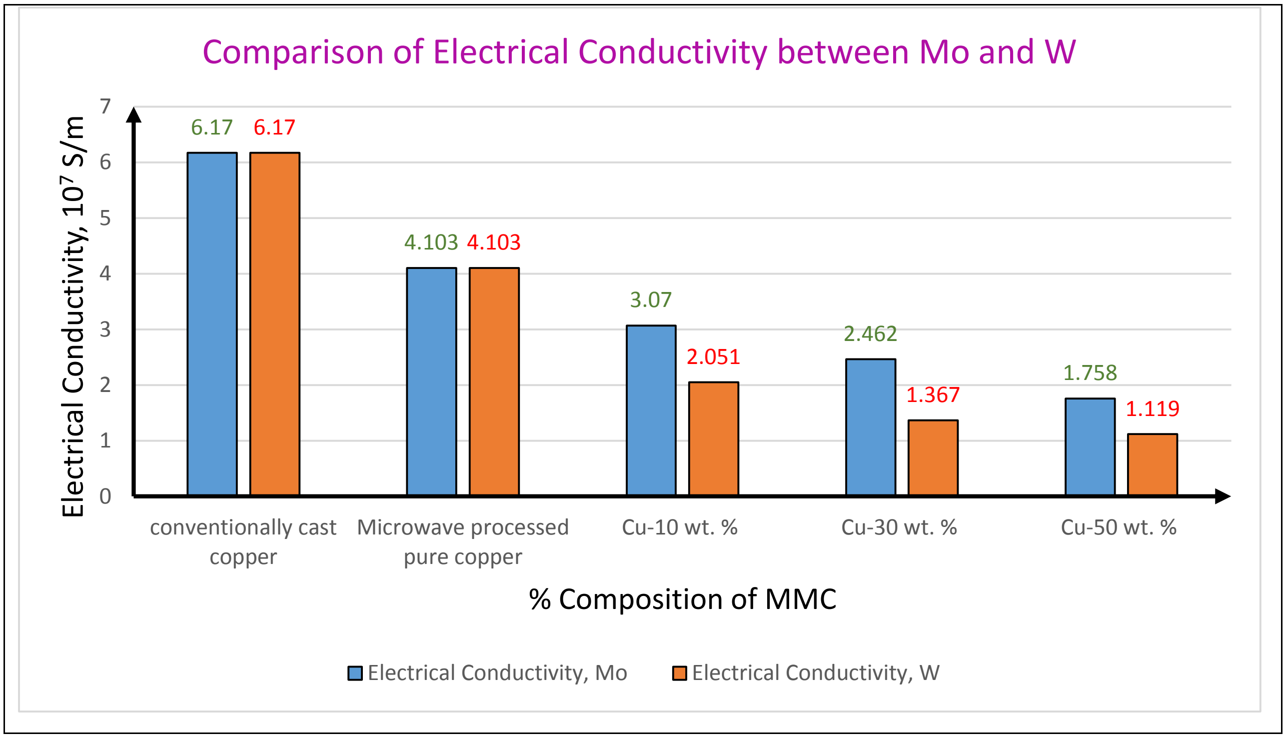


Fig. 5.39. A detailed comparison of electrical conductivity between Mo and W reinforced samples.

Despite of comparing the obtained results of electrical conductivity for molybdenum reinforced samples and tungsten reinforced samples alone with the pure copper samples, a combined comparison was also conducted between molybdenum reinforced samples and tungsten reinforced samples from the above obtained results. A comparative analysis between them is shown above in Fig. 5.39.

From the above graph, it can be clearly concluded that the amount of reduction in electrical conductivities for molybdenum reinforced samples were less than the amount of reduction in tungsten reinforced samples or the rate of reduction in molybdenum reinforced samples was less than the rate of reduction in tungsten reinforced samples. The electrical conductivity for Cu-10 wt. % Mo is 1.49 times that of Cu-10 wt. % W, for Cu-30 wt. % Mo is 1.8 times that of Cu-30 wt. % W and for Cu-50 wt. % Mo is 1.57 times that of Cu-50 wt. % W. It is possibly because tungsten has less conductivity than molybdenum. The trend that was seen is better for molybdenum reinforced samples than tungsten reinforced samples.

Based on the results obtained for electrical conductivities of all the samples, the thermal conductivity was calculated from Wiedemann-Franz law.

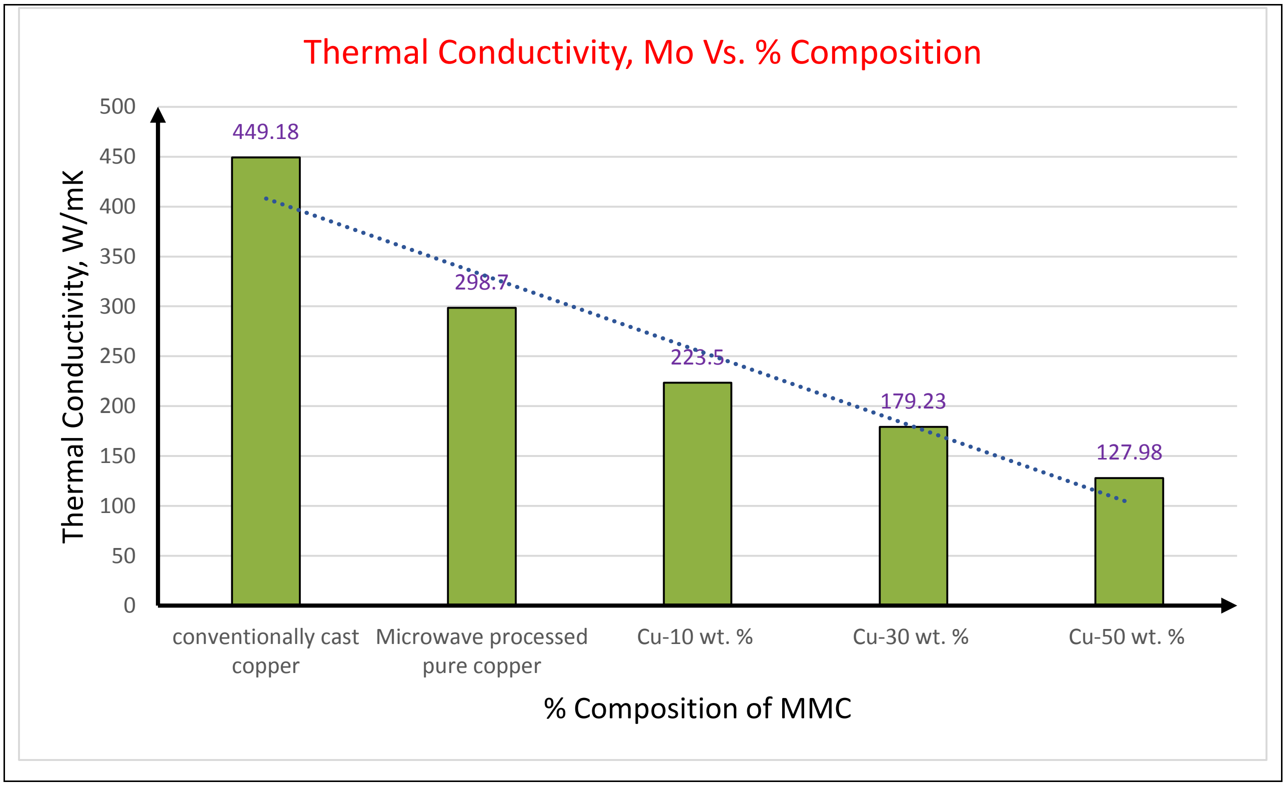


Fig. 5.40. Thermal conductivity of Mo reinforced samples versus % of composition.

Thermal conductivity of conventionally cast copper, pure copper and molybdenum reinforced copper samples were first calculated and comparative analysis was done. The variation in thermal conductivity with increase in reinforcement is shown in above Fig. 5.40.

The thermal conductivities measured was 449.18 W/m-K and 298.7 W/m-K for conventionally cast copper sample and microwave processed pure copper respectively. It was seen that after microwave processing, the thermal conductivity was decreased by almost 33.5% from the conventionally cast copper sample. The thermal conductivities measured for Cu-10 wt. % Mo, Cu-30 wt. % Mo and Cu-50 wt. % Mo were 223.5 W/m-K, 179.23 W/m-K, and 127.98 W/m-K respectively. It was clearly visible from the graph, that as the wt. % of molybdenum increases, the thermal conductivity decreases, but from the trend line w.r.t. the conventionally cast copper, it can be concluded that the amount of reduction of thermal conductivity for Cu-10 wt. % Mo and pure copper was more than the trend or desired value, reasonable for Cu-30 wt. % Mo and little less for Cu-50 wt. % Mo than the trend value. The reduction in thermal conductivities for Cu-10 wt. % Mo, Cu-30 wt. % Mo and Cu-50 wt. % Mo with respect to pure microwave processed copper were 25.17%, 39.99% and 57.15% respectively.

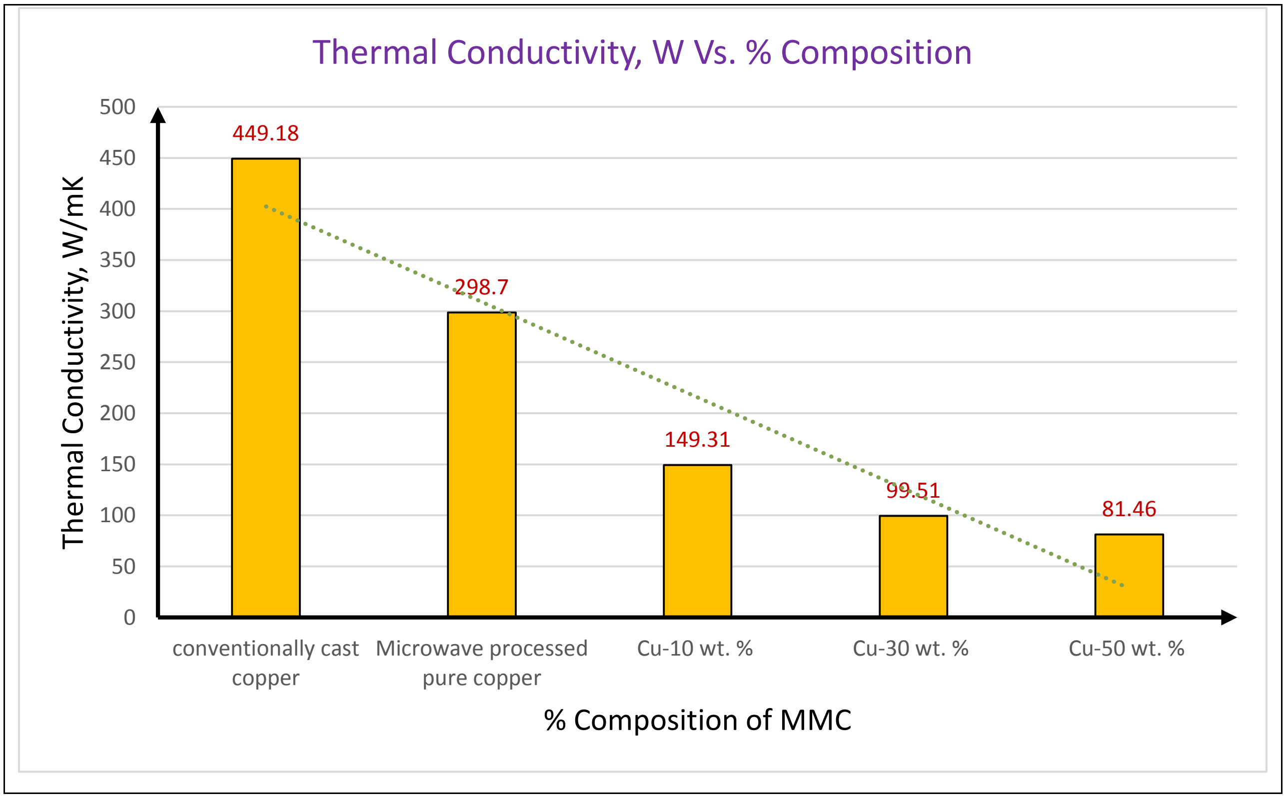


Fig. 5.41. Thermal conductivity of W reinforced samples versus % of composition.

Then thermal conductivities of copper reinforced tungsten samples were measured and compared with the obtained results of conventionally cast copper and microwave processed pure copper. The variation in thermal conductivity of reinforced samples with increase in wt. % composition is shown in above Fig. 5.41.

As the thermal conductivities of conventionally cast copper and microwave pure copper was already discussed above, the same values were taken for comparative analysis. The thermal conductivities measured for Cu-10 wt. % W, Cu-30 wt. % W and Cu-50 wt. % W were 149.31 W/m-K, 99.51 W/m-K, and 81.46 W/m-K respectively. It was clearly visible from the graph, that as the wt. % of tungsten increases, the thermal conductivity decreases but from the trend line w.r.t. the conventionally cast copper, it can be concluded that the amount of reduction of thermal conductivity for Cu-10 wt. % W was much more than the trend or desired value, reasonable for pure copper, little more for Cu-30 wt. % W and little less for Cu-50 wt. % W than the trend value. The reduction in thermal conductivities for Cu-10 wt. % W, Cu-30 wt. % W and Cu-50 wt. % W with respect to pure microwave processed copper were 50.01%, 66.68% and 72.72% respectively.

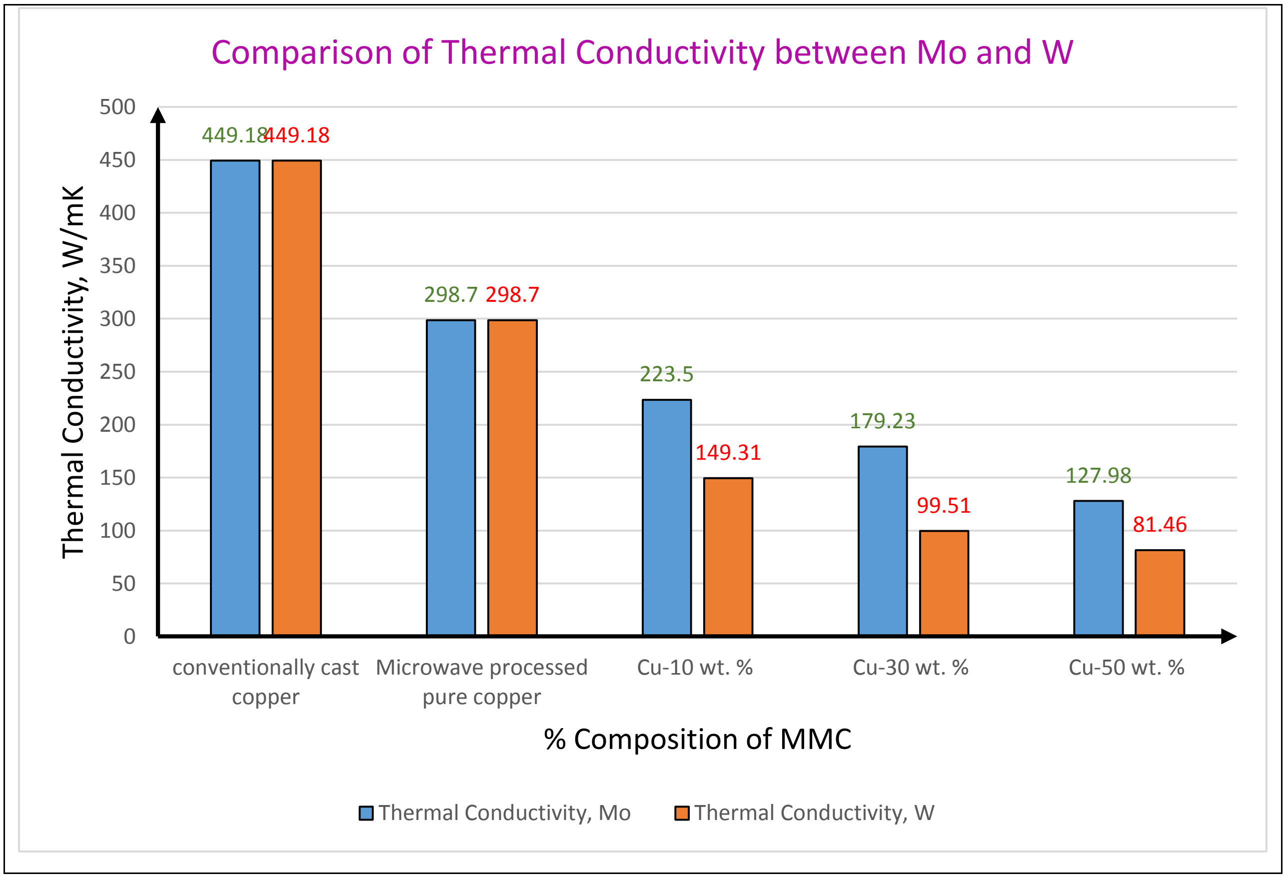


Fig. 5.42. A detailed comparison of thermal conductivity between Mo and W reinforced samples.

Despite of comparing the obtained results of thermal conductivity for molybdenum reinforced samples and tungsten reinforced samples alone with the pure copper samples, a combined comparison was also conducted between molybdenum reinforced samples and tungsten reinforced samples from the above obtained results. A comparative analysis between them is shown above in Fig. 5.42.

From the above graph, it can be clearly concluded that the amount of reduction in thermal conductivities for molybdenum reinforced samples were less than the amount of reduction in tungsten reinforced samples or the rate of reduction in molybdenum reinforced samples was less than the rate of reduction in tungsten reinforced samples. The thermal conductivity for Cu-10 wt. % Mo is 1.49 times that of Cu-10 wt. % W, for Cu-30 wt. % Mo is 1.8 times that of Cu-30 wt. % W and for Cu-50 wt. % Mo is 1.57 times that of Cu-50 wt. % W. It is possibly because tungsten has less conductivity than molybdenum. The trend that was seen is better for molybdenum reinforced samples than tungsten reinforced samples.

The results obtained for electrical conductivity and thermal conductivity were almost same and shown a similar characteristic as thermal conductivity is directly proportional to electrical conductivity.

Chapter 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

The preparing of materials through microwave vitality has risen as a novel material handling strategy, which has augmented its space from sintering of ceramics to metallic materials. Further, high-temperature applications utilizing microwaves were completed, for example, joining of bilk metals and claddings on the bulk metallic substrate. The present work was to fabricate the metal matrix composite through microwave hybrid heating in a domestic microwave oven of 2.45 GHz frequency and 900 W power by using copper as the matrix material and tungsten and molybdenum as the reinforcing material with varying weight %. Taking after significant conclusions are drawn from the work:

1. The advancement of metal matrix composite was effectively endeavored by utilizing distinctive compositions of the reinforcement through microwaves in domestic multimode microwave oven.

2. The characterizations of the fabricated composites were done and it was observed that microwave processed composites have lower noticeable defects and despite the fact that a poor bonding amongst copper and tungsten, copper and molybdenum due to mutual insolubility, a dense product was obtained.

3. SEM investigation uncovered the great bonding between copper matrix and tungsten and molybdenum reinforcement and tungsten and molybdenum were uniformly distributed over the matrix in all the reinforcement composites.

4. XRD investigations revealed that after microwave processing, some carbides were formed which were also responsible for the higher hardness. It also revealed about the formation of oxides which were because of contact with atmospheric air while cooling.

5. Higher hardness was obtained for conventionally casted pure copper sample than microwave processed pure copper but with the little addition of the reinforcement, the hardness obtained was higher than conventionally casted pure copper due to the absorption of carbon from graphite sheet as well as graphite cavity and due to reinforced material itself. The hardness values tends to increase with increase in the weight % of reinforcement.

6. Electrical characterizations were carried out which reveals that copper being the conductive material have high electrical conductivity and with the addition of the reinforcing material, the electrical conductivity tends to decrease. The electrical conductivity of the conventionally casted pure copper sample was found to be the highest among all the fabricated samples which may be due to the change in form of the copper metal used i.e. powder form in microwave processing and liquid form in conventional casting.

6.2 Scope of Future Work

A great deal of degree is still left to enhance the exploration in this specific range of microwave material preparing. Taking after work can be done in future:

- To study the effect of load, coefficient of friction, wear volume, wears mechanisms, etc. on MMC developed through microwave energy.
- The electrical conductivity of Cu-W and Cu-Mo composites can likewise be measured but with change in temperature and impact of reinforcement can be examined on conductivity.
- To contemplate the mechanical characterizations regarding tensile testing of the composites.
- Porosity level and surface harshness of microwave processed MMC's can be concentrated on.
- Cu-W and Cu-Mo composites created through microwave hybrid heating can likewise be created through microwave sintering and other propelled methods for assembling MMC's and a similar study can likewise be done.

Chapter 7

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