International Journal of Advance Research in Science and Engineering
Volume No.07, Issue No.03, March 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

Current advancement and Research Development in Copper Composites fabricated by Powder Metallurgy: A Review

Jitender Sharma[1], Parveen Goyal[2], Vikas Kumar[3]

[1]*Post Graduate student, Dept. of Mechanical Eng., U.I.E.T, Panjab University, (India)*

[2]*Assistant Professor, Dept. of Mechanical Eng. U.I.E.T, Panjab University, (India)*

[3]*Research Scholar, Dept. of Mechanical Eng., U.I.E.T, Panjab University, (India)*

ABSTARCT

Present paper reviews the work of numerous authors who studied different problems and gave results which contributed in the field of Copper (Cu) metal matrix composites with particulate reinforcement fabricated through Powder Metallurgy (PM) route. Though, several method are available by which Cu metal matrix (CMM) composite can be fabricated. PM is the most preferable one as it is cost effective and its simplicity of the fabrication technique. In this review paper material properties such as hardness, strength, electrical conductivity, thermal conductivity, wear resistance, coefficient of friction etc. of various Cu composite and critical parameters such as compacting pressure, compacting temperature, reinforcement size, reinforcement volume fraction, milling time, sintering temperature, and sintering time which greatly influences the material properties of Cu composite have been studied. PM has very high potential to be used as route for fabrication CMM composite and it is yet to be explored.

Keywords: Compacting, Copper Metal matrix, Powder Metallurgy, Reinforcement, Sintering Temperature.

I.INTRODUCTION

Copper (Cu) has high thermal and electrical conductivity, easy joinable, hot and cold workable, good corrosion resistance, good tempering property and economical. It has vast application in electrical and electronic sector[1] and readily use in power transmission lines electrical cables, wiring and bus bars electrodes, heat exchangers, high conductivity wires, refrigeration tubing, spark plugs, cooking utensils etc. However, the poor wear resistance, low value of hardness and strength of Cu are the major drawbacks in use of pure Cu in certain application. These drawbacks could be overcome by reinforcing Cu matrix with reinforcement having good mechanical and metallurgical properties thus improving the properties of Copper Metal Matrix (CMM) composite.

There are various methods of fabricating Cu metal matrix composite such as reaction sintering, hot press sintering, stir casting, compo-casting, squeeze casting, liquid infiltration, spray deposition, Powder Metallurgy (PM) etc. However, PM is one of the most cost effective technique for fabricating complex shaped composite parts which reduces the need for machining.[2] It is highly reliable method for fabricating ferrous and non-ferrous parts. Various combinations of alloys and non -metal (mostly ceramics) can be easily fabricated. PM route is well known for its great advantages over other routes in certain applications. Refractory materials, special alloys, heat resistances materials and cutting tools are popularly processed by PM. It is very economical for mass production due to low setup and operating cost.[3] It is very good in material utilization that gives very less material loss during processing and also the finished part processed by PM possess good dimensional tolerance and very fine surface finish which reduces further machining action.

Due to these features, PM has wide application in industrial sector and are used to make Cutting Tools and Dies, refractory composites, high strength shock resistant filters, machinery parts (gears, bearing, rotors, brushes etc.) and permanent magnets.

In this review various CMM composite properties such as hardness, strength, electric conductivity, thermal conductivity, wear resistant, coefficient of friction and critical factors which influence these properties have been studied.

1.1 Powder Metallurgy Methodology:

The PM process generally consists of four basic phases: powder production, blending, compacting and sintering (Fig.1).

Fig.1 Various stages in fabrication of composites by PM route.

.

IJARSE
ISSN: 2319-8354

1.1.1 Powder production

There are various methods that could be used to produce metallic powders which includes mechanical method, chemical and physical methods (Fig.2).

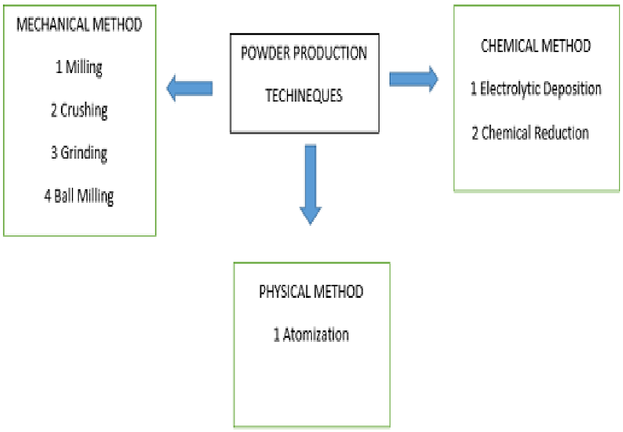

Fig.2 Various methods of powder production.

• Mechanical method:

This method incorporate use of mechanical forces such as shear, compressive or impact forces to achieve reduction in particulate size of the bulk material. There are various milling operations such as crushers, grinders, ball mill, planetary mill, jet milling and shooting that can be used to produce different sizes of powders according to the need of end user.[4] [5]

• Physical method:

This method uses a highly pressurized fluid jet (inert gas, water or air) to break up of the liquid metal stream into fine droplets that solidifies into fine powder.[6] [7]

• Chemical method:

Powder can be either produced by Electrolytic deposition or Chemical Reduction by using chemical methods. Electrolytic deposition is used to generate metal powder from the solution containing its salts and when an electric current passed through the solution, metal deposition takes place producing fine powder with high purity. This technique is mainly used for production of powder of Cu and Fe.[8], whereas in Chemical reduction, reducing agent such as hydrogen and carbon monoxide helps in the powder production by the reduction of metal oxides. [9]

1.1.2 Blending

It is a process of mixing of metal matrix powder, reinforcement, binders and lubricants in a proper composition of weight as required in the final composite. It is done to achieve a uniform distribution of constituent particles in composites. In order to decrease porosity different sized particles are often mixed. Lubricants such as of Zn and Al used to reduce friction between particles and at the walls of the die during compaction. Binder helps in imparting sufficient mechanical strength and de-flocculants inhibit agglomeration of powders and helps in uniform distribution of particles in composites and improves flow characteristics for successive processing. Blending can be done manually or with help of blenders such as (i) rotating drum, (ii) blade mixer, (iii) screw mixer, and (iv) rotating double-cone.

1.1.3 Compacting

Metal powders are compacted in a die cavity into required shapes by applying a suitable pressure. Compacting provides sufficient mechanical strength to the green mold for further processing. With increase in compacting pressure the green density also increases, thus imparting good mechanical strength. Effect of compaction pressure on particles is shown in Fig.3.[11]

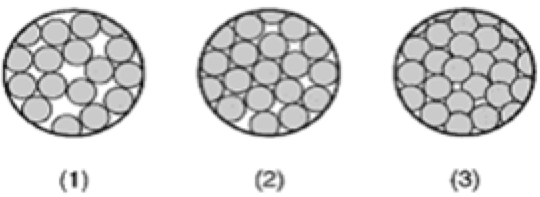

Fig.3 Effect of compaction pressure on particles: (i) moveable powders particulates before applying pressure, (ii) rearrangement of particulates with application of pressure, (iii) densification of particles due to deformation. [11]

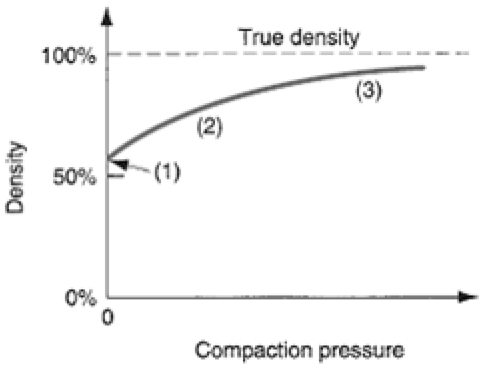

Fig.4 Density of the powders as a function of pressure [11]

IJARSE
ISSN: 2319-8354

The density of powder in compact increases with increase in applied pressure and attains a green density which is bit lower than the true density as it is clearly mentioned the Fig.4.[11]

1.1.4 Sintering

Since green compact has low strength therefore cannot be used for practical application. In order to make it useful, further sintering is needed. During sintering, the green compact is heated with or without protective atmosphere to a temperature below the metal's melting point. Sintering atmosphere can be done in ammonia, hydrogen, nitrogen or any other gas atmosphere which could be endothermic gas or exothermic gas in nature depending upon properties needed in final product. During this step metallurgical bonds are formed between the powder particles which is responsible for physical and metallurgical properties of the composites as shown in Fig.5. Sintering also help in removing the lubricants agents from the compact and also averts oxidation.[10]

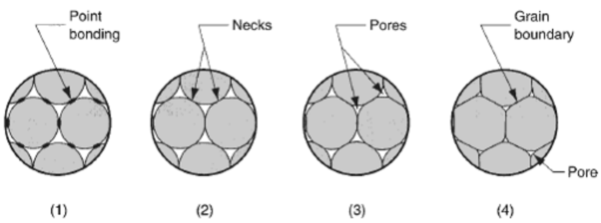

Fig.5 (i) bonding is initiated at point of contact, (ii) formation and growth of necks at point of contact, (iii) diminution of pore size (iv) formation of grain boundaries between particles substituting the necked regions. [11]

II.MATERIAL PROPERTIES:

2.1. Hardness

Hardness generally described as the ability of a material to resist plastic deformation, usually by indentation. The following research suggested that hardness of a Cu composites mainly depends upon factor like concentration of reinforcement, sintering temperature(ST), particulate size, milling time, compacting pressure(CP) and interfacial bonding between constituent particulate. Following observation were made regarding Cu composites:

A study by M.Ardestani *et al*. [12] shows that in the W/Cu composite containing 20%wt.Cu, the hardness improved upon elevating the ST up to 1200°C whereas for composite with 30%wt. and 40%wt. Cu as reinforcement had the maximum value of hardness, electrical and thermal conductivity was observed at the ST of 1150 °C [13]. A. Ghorbani *et al*.[14] has been studied Cu-Chromium-CNT based Nano composite which was hot pressed. It was found that pressing temperature had a significant influence on improvement of hardness and was observed that the hardness of composite increased by about 65%. Study of Kahtan S. Mohammed *et al*.[15] reported that after milling time of 8 hours, W-brass composites showed maximum micro-hardness of 234 Hv

IJARSE
ISSN: 2319-8354

and a relative sintered density (i.e. 98% True Density) . A study by A. Upadhyaya *et al*.[16] shows that an increase in Al_2O_3 content increases hardness in Cu/Al_2O_3 composite, but a loss in electrical conductivity was observed. Ch. Guiderdoni *et al*.[17] study revealed that Cu/CNT composite showed 50% higher value of micro-hardness as compared to that of pure copper. Ke-Chu *et al.*[18] study shows that in Cu-Cr/CNT composite, there was an increase of 128% in hardness due to improved interfacial bonding between Cu–Cr and CNT in the composites. With the increase of reinforcement content hardness first increases attains a maximum value and then further addition of reinforcement decreases hardness (Fig.6).

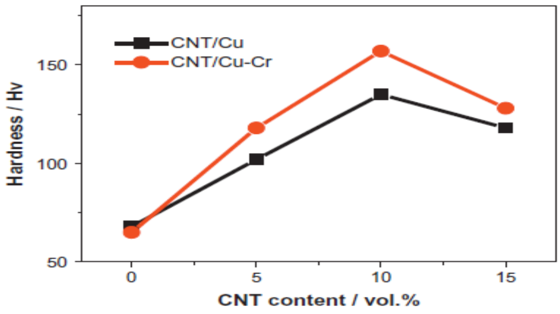

Fig.6 Hardness v/s reinforcement content (CNT) in CNT/Cu and CNT/Cu–Cr composites. [18]

A study by H. Deng *et al*.[19] showed that in Cu/CNTs composite with smaller the grain size of the matrix greater homogeneous dispersion could be achieved therefore increasing wettability which considerably improved its mechanical properties. A.S. Prosviryakov *et al*.[20] found that with increase in SiC content the hardness of the Cu/SiC composites also increases due to the refinement of reinforcing particles and homogeneous microstructure.

The general trend shows that with the increase in amount of reinforced particle, the hardness of fabricated composite also increases.[21] But, Lin C.B. *et al*.[22] who fabricated Cu/CNT composite observed that with increase in concentration of CNT particulates hardness tend to decrease and maximum value of hardness was observed at 5 vol.% CNT content.

Various studies have shown that with increase in compacting pressure there is increase in the density and hardness of the composite due to reduction in porosity as shown in Fig.7.[23] [24] [25]

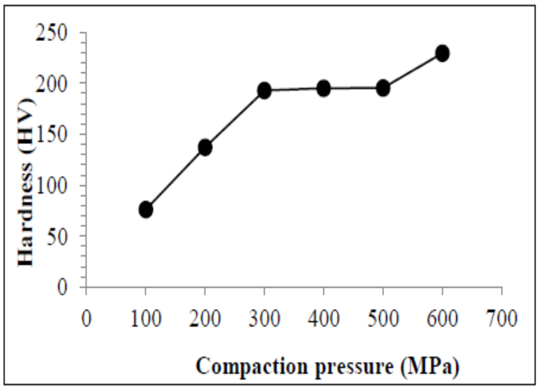

Fig.7: Change in Hardness with varying compacting pressure [23]

International Journal of Advance Research in Science and Engineering
Volume No.07, Issue No.03, March 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

Strength:

Strength is defined as the ability of a material to endure stress (applied load) without failure or plastic deformation. As it is evident from previous research that pure copper has low strength, hence in order to improve its strength Cu is reinforced with various types of reinforcement. The critical parameters that affect the strength of Cu metal composites are concentration of reinforcement, sintering temperature, particulate size and interfacial bonding between constituent particulate. Following researchers studied the strength of Cu metal composite and following observations were made:

K. Chu *et al.* [18] Investigated Copper chromium (Cu–Cr) matrix/CNT composite and found improved interfacial bonding due to formation of Cr_3C_2 at interface of CNT/Cu–Cr composites and showed 135% increase in Yield strength (YS). Fig. 8 shows that with increase in reinforcement content YS first increases attains a maximum value and further addition of reinforcement decreases YS.

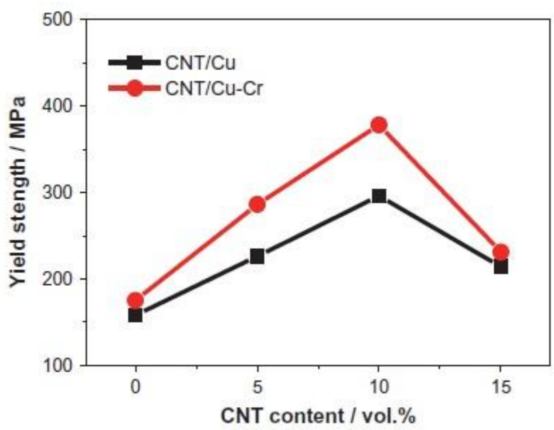

Fig. 8: Yield Strength v/s Reinforcement content (CNT) /vol.% in CNT/Cu and CNT/Cu–Cr composites. [18]

Due Z.W. *et al.*[26] added CNT as reinforcement and observed that with a slight increase in CNTs concentration in the Cu matrix, remarkable improvement in the Tensile Strength (TS) and YS of Cu matrix can be achieved, where a TS was found to be around 380 MPa. A similar trend was observed by Daoush W.M. *et al.* [27] who investigated Cu/CNT composite and result showed that with increase in CNT content in Cu matrix, YS improved considerably. Z. Wang et al. [28] studied multi-walled carbon nanotubes (MWCNTs)/Cu composites fabricated by amalgamation of electro-deposition and PM route. It was observed that there was increase in TS (451.57 MPa) due to high interfacial bonding strength between the reinforcements and Cu matrix with homogeneous distribution of MWCNTs. D. Jianhua *et al.*[29] studied Cu/n-SiO_2Cu composites (reinforced with 1.0 wt.% nano-SiO_2 particles) between the temperature range of 850 -950℃, the higher temperature does favor to the dispersion of SiO_2 nanoparticles in copper matrix, which improve the strength of Cu matrix.

1.2. Electrical Conductivity:

Electrical conductivity (EC) defined as the ability of electric current to flow though a material. EC of Cu composite generally depend upon factors such as conductive properties of reinforcement, gain refinement (size), concentration of reinforcement, sintering temperature and networked structure of constituent particles. Following research observations found:

G.C. Fee *et al.*[21] fabricated Cu/SiC composite and found that the optimum sintering temperature for the Cu–1 wt.%SiC composite was 900 °C and highest EC and relative density were obtained at this sintering temperature(ST). M. Yusoff *et al.* [30] studied the effect of sintering time (1 to 3 h) and ST (800°C to 1000°C) on the microstructural properties of Copper-Tungsten Carbide composites and found that Tungsten Carbide (WC) was formed at lower value of ST and the formation of WC facilitated in improvement of the properties like EC and hardness. It was also observed that with the rise of ST, the number of WC formed also increased therefore further enhancing these properties. Luo Laima *et.al*[25] fabricated Cu/W composite and found that 3D Cu network was formed throughout the composite's structure which improved EC considerably.[31] Similar results were observed by Z. Wang et al.[28] where increase of EC was observed with directional alignment of MWCNTs in the matrix. Uddin S.M. *et al.*[32] showed that in Copper (and cu alloys)/CNT composite, EC of bronze composite showed 20% better results as compared to pure alloy. Whereas a study by Daoush W.M. *et al.*[27] showed that in Cu/CNT composite, with increase in concentration of CNT, EC tend to decrease. Praveennath G.K *et al.*[33] studied Cu/CNT composite and found that grain refinement has negative effect on EC and EC tend to decrease with grain refinement.

1.3. Thermal Conductivity:

Thermal Conductivity (TC) is generally defined as the rate at which a material could transfer heat. For Cu composite, TC generally is dependent on factors like concentration of reinforcement, TC of reinforcement, compacting pressure, distribution pattern of reinforcement in metal matrix and sintering temperature. Following observations have been made regarding Cu composite:

G.M Vallet *et al.*[34] studied Cu/CNT composite and found that 1 vol. % of CNTs in Cu matrix improved the TC by 7%. Ke Chu *et al.*[35] fabricated Cu/CNT composites and maximum TC was observed at ST of 600 ^{0}C, sintered for 5 min. under 50 MPa. compacting pressure. Izabela Firkowska *et al.*[36] showed that in Cu/CNT Nano hybrids composite, TC was found to be increase four folds as compared to pure CNTs as sturdy coupling amongst the nanotube–matrix interface was observed. Ke Chu *et al.*[37] fabricated Cu/CNT composites which was densified by spark plasma sintering (SPS) technique. It was noticed that addition of CNT showed no positive effect on TC. The main reason for shocking low TC was the sintering condition and existence of interfacial thermal resistance between the Cu matrix and CNT due to random oriented CNT particle with low phase contact ratio to Cu particles.

1.4. Frictional Coefficient :

In general term Frictional Coefficient (FC) could be defined as the minimum force needed to allow the surfaces to start sliding, divided by the force pressing acting on the contact surfaces. In material science FC plays a vital role as it one of the most important factor determining wear resistance and therefore the life of a material. In accordance to the Cu composites FC is generally dependent on factors like concentration of reinforcement, FC of reinforcement, sliding velocity, presence of lubricants, sintering temperature.

Research analysis done by various authors made following observation regarding FC of Cu metal composite:

S.F. Moustafa *et al*.[38] fabricated Cu–graphite composites and studied tribological properties and found that composites made by uncoated graphite and Cu-coated have lower wear rates and frictional coefficients as compared to pure copper. A similar study was made by Hirotaka Kato *et al*.[24], which showed that addition of lubricants like graphite aids in reducing frictional coefficient. X. Jincheng et al. [39] studied tribological properties of the Cu matrix composite reinforced with short carbon fibres and reported that with increase in carbon fiber concentration in the composite, the frictional coefficient tend to decrease. D. Jianhua et al.[29] studied Cu/n-SiO2Cu composites (reinforced with 1.0 wt.% nano-SiO2 particles). It has been observed that with the increase in sintering temperature (between 800 and 950 ℃), the dynamic FC and wear rate of the composites also increases gradually. A.Ghorbani et al.[14] studied mechanical and microstructural properties of Cu-Chromium-CNT nanocomposite. The result indicated that with presence of CNTs, the FC decreased by 82%; whereas wear resistance decreased by 72% as compared to Cu-1wt.%Cr without CNT. LinlinSu et al.[40] studied the tribological property of Cu-based friction materials taking Cu powder as exogenous third body and the results indicated that the FC was increased by 0.03 in presence of exogenous Cu particulates as compared to non-exogenous Cu particulates, this is because exogenous Cu particulates acts as third body which further increases the contact area and thus increasing FC.

1.5. Wear Resistance:

Wear Resistance (WR) is defined as the ability of a material to resist wear. WR is generally dependent on factors like sintering temperature, compacting pressure, concentration of reinforcement and presence of lubricant, compacting time, sintering time and frictional coefficient. Various research analysis shows following observation:

P. Balamurugan *et al*.[41] fabricated CU/Fly Ash composite at sintering temperature of 900°C and found that with increase in sintering temperature there is increase in density of the composite and considerable decrease in wear rate and maximum WR was observed at the processing condition of compacting pressure of 450 MPa, sintering temperature of 900^0 C, and sintering time of 90 min. As Fig.9 shows that with increase in sintering there is considerable drop in wear rate. Lin C.B. *et al*.[22] *studied* Cu/CNT composite and result presented that minimum wear rate was observed at concentration 10–15vol.% CNT.

Ch. Guiderdoni *et al.*[17] *studied* Cu/CNT composite and found a reduction in value of wear rate by a factor of 10 to 20 due to the presence of CNT as reinforcement.

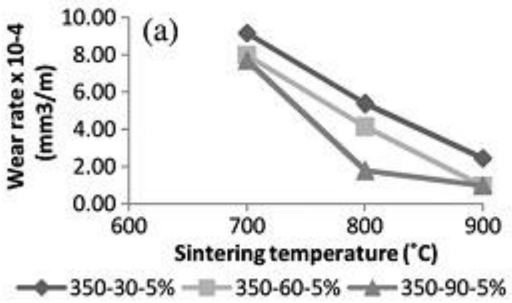

Fig.9: Wear Rate versus Sintering Temperature of different compositional CU/Fly Ash composite. [41]

Hirotaka Kato *et al*.[24] study shows that addition of graphite aids in reducing friction and wear in Cu/Sn alloys but addition of lubricants such as molybdenum disulfide (MoS_2) or graphite has an opposing effect on the mechanical properties of the composites which could be overcome by the use of Cu-coated lubricant powders which improves the bending strength. Xu Wei *et al.*[42] studied the tribological properties of Cu/CNT and it was found that with increasing the electrical current, FC and wear rate also increases. It was also observed that the wear rate and anti-friction properties of CNTs/Cu composite are far superior to those of pure Cu bulk fabricated by the same route. X. Jincheng *et al*.[39] studied tribological properties of the Cu matrix composite reinforced with short carbon fibres and their study shows that the WR of the composite can be improved by the addition of alloying elements like Al and Tin.

2.7. Metallurgical Analysis:

Metallurgical properties of the composites are mainly dependent upon the compacting pressure and sintering temperature. During compacting due to high pressure the constituent particles come very close to each other and often form bonds causing mechanical alloying of the particles, therefore increasing compact green density. While during sintering the elevated temperature helps in formation of interfacial bonds among the constituent particles which is mainly helps in improving mechanical properties such as strength, hardness, wear resistance etc.[15][25-26]

III.CONCLUSION

- Hardness increases with increase in the number of reinforcement particulate which generally have high hardness value than the matrix material thus imparting hardness to the composite and interfacial bonding also helps in increasing hardness which is dependent on sintering temperature.
- Strength of Cu metal composite increases with increase in concentration of reinforcement, interfacial bonding and increase in sintering temperature.

- With increase in sintering temperature there was an increase in EC and most of the Cu composite showed greater EC around 900-1000 °C. It was also observed that networked structure and increase in ST helped in enhancing the EC of the composites whereas grain refinement has negative effect on EC.
- With increase in concentration of reinforcement like CNT the FC tend to decrease. The using Cu coated reinforcement and fibrous reinforcement lead to decrease in FC. With increase in sintering temperature FC also increases. The presence of exogenous Cu particulates tend to increase FC.
- It is evident that for Cu matrix composite with increase in sintering temperature, WR increases and maximum WR is observed around 900°C and increase in WR is observed with increase in concentration of reinforcement but 10-15vol.% CNT concentration of reinforcement showed best results. Short Fibrous reinforcement, addition of alloying elements like Al and Tin improves WR properties

REFRENCES

[1] Y. Tang, H. Liu, H. Zhao, L. Liu, and Y. Wu, Friction and wear properties of copper matrix composites reinforced with short carbon fibers, *Material & Design*, *29*(1), 2008, 257–261.

[2] W. B. James, Powder Metallurgy Methods and Applications, *ASM Handb.*, *7*, 2015, 922.

[3] G. R.M., Powder metallurgy and particulate materials processing, *Met. powder Ind. Fed.*, 2005, 522.

[4] J. Kano, H. Mio, F. Saito, and M. Miyazaki, Correlation of grinding rate of gibbsite with impact energy in tumbling mill with mono-size balls,*Miner. Eng.*, *14(10)*,2001, 1213–1223.

[5] M. ahsanzadeh-Vadeqani, R. S. Razavi, M. Barekat, G. H. Borhani, and A. K. Mishra, Preparation of yttria nanopowders for use in transparent ceramics by dry ball-milling technique, *J. Eur. Ceram. Soc.*, *37(5)*, 2017,2169–2177.

[6] L. P. Zhang and Y. Y. Zhao, Particle size distribution of tin powder produced by centrifugal atomisation using rotating cups, *Powder Technol.*, 318,2017, 62–67.

[7] K. L. Alvarez, J. M. Martín, M. Ipatov, and J. Gonzalez, Soft magnetic amorphous alloys (Fe-rich) obtained by gas atomisation technique, *J. Alloys Compd.*, *735*, 2018, 2646–2652.

[8] S. Wang, F. Xie, and X. Wu, "Mechanism of Al 2 O 3 coating by cathodic plasma electrolytic deposition on TiAl alloy in Al(NO 3) 3 ethanol-water electrolytes, *Mater. Chem. Phys.*, *202*, 2017,114–119.

[9] Y. Wang *et al.*, Synthesis of SnAgCu nanoparticles with low melting point by the chemical reduction method, *Microelectron. Reliab.*, *78*, 2017,17–24.

[10] S. Y. Gómez and D. Hotza, Predicting powder densification during sintering, *J. Eur. Ceram. Soc.*, *October*,2017. 28–33.

[11] M. P. Groover, *Fundamentals Of Modern Manufacturing: Materials Processes, And Systems*, 2nd ed. U.S.A: Prentice Hall, 2007.

[12] M. Ardestani, H. R. Rezaie, H. Arabi, and H. Razavizadeh, The effect of sintering temperature on densification of nanoscale dispersed W-20-40%wt Cu composite powders, *International Journal of Refractory Metals and Hard Materials*, *27(5)*,2009 862–867.

[13] C. Li, Y. Zhou, Y. Xie, D. Zhou, and D. Zhang, Effects of milling time and sintering temperature on structural evolution, densification behavior and properties of a W-20wt.%Cu alloy, *Journal of Alloys and Compounds*, *731*, 2018, 537–545.

[14] A. Ghorbani, S. Sheibani, and A. Ataie, Microstructure and mechanical properties of consolidated Cu-Cr-CNT nanocomposite prepared via powder metallurgy, *Journal of Alloys and Compounds*, *732*, 2018, 818–827.

[15] K. S. Mohammed, B. Gowon, S. Baharin, B. Jamaluddin, Z. Hussain, and P. Evarastics, Synthesis and Densification of Tungsten-Brass Composite by Mechanical Alloying, *Open Journal of Metal,* 5, 2015, 27–36.

[16] A. Upadhyaya and G. S. Upadhyaya, "Sintering of copper-alumina composites through blending and mechanical alloying powder metallurgy routes," *Mater. Des.*, vol. 16(1), 1995, 41–45.

[17] C. Guiderdoni *et al.*, The preparation of carbon nanotube (CNT)/copper composites and the effect of the number of CNT walls on their hardness, friction and wear properties, *Carbon N. Y.*, *58*, 2013 185–197.

[18] K. Chu, C. Jia, L. Jiang, and W. Li, Improvement of interface and mechanical properties in carbon nanotube reinforced Cu–Cr matrix composites, *Material & Design*, *45*, 2013, 407–411.

[19] H. Deng, J. Yi, C. Xia, and Y. Yi, Improving the mechanical properties of carbon nanotube-reinforced pure copper matrix composites by spark plasma sintering and hot rolling, *Materials Letters.*, *210*, 2018, 177–181.

[20] A. S. Prosviryakov, SiC content effect on the properties of Cu–SiC composites produced by mechanical alloying, *Journal of Alloys & Compounds*, *632(25)*, 2015, 707–710.

[21] G. Celebi Efe, T. Yener, I. Altinsoy, M. Ipek, S. Zeytin, and C. Bindal, The effect of sintering temperature on some properties of Cu-SiC composite, *Journal of Alloys & Compounds*, *509(20)*, 2011, 6036–6042.

[22] C. B. Lin, Z. C. Chang, Y. H. Tung, and Y. Y. Ko, Manufacturing and tribological properties of copper matrix/carbon nanotubes composites, *Wear*, *270 (5–6)*, 2011, 382–394.

[23] Y. Mahani and H. Zuhailawati, Effect of Compaction Pressure on Microstructure and Properties of Copper-Based Composite Prepared by Mechanical Alloying and Powder Metallurgy, *Advanced*

Materials Research, *795(March)*, 2013, 343–346.

[24] H. Kato, M. Takama, Y. Iwai, K. Washida, and Y. Sasaki, Wear and mechanical properties of sintered copper-tin composites containing graphite or molybdenum disulfide, *Wear*, *255(1–6)*, 2003, 573–578.

[25] L. Laima, T. Xiaoyue, and L. Zelong, Preparation and Properties of W-15Cu Composite by Electroless Plating and Powder Metallurgy, *Rare Metal Materials and Engineering*, 44(12), 2015, 3005–3008.

[26] Z. W. Xue, L. D. Wang, P. T. Zhao, S. C. Xu, J. L. Qi, and W. D. Fei, Microstructures and tensile behavior of carbon nanotubes reinforced Cu matrix composites with molecular-level dispersion, *Materials and Design*, *34*, 2012 , 298–301.

[27] W. M. Daoush, B. K. Lim, C. B. Mo, D. H. Nam, and S. H. Hong, Electrical and mechanical properties of carbon nanotube reinforced copper nanocomposites fabricated by electroless deposition process, *Materials Science and Engineering A*, *513–514(C)*, 2009, 247–253.

[28] Z. Wang, X. Cai, C. Yang, and L. Zhou, Improving strength and high electrical conductivity of multi-walled carbon nanotubes/copper composites fabricated by electrodeposition and powder metallurgy, *Journal of Alloys and Compounds*, *735*, 2018, 905–913.

[29] D. U. Jianhua, L. I. Yuanyuan, and L. I. U. Yanwei, Effect of Sintering Temperature on Friction Performance of Cu-based Nanometer Composites Reinforced by Nano SiO 2 Particles, *2nd Int. Conf. Electron. Mech. Eng. Inf. Technol.*, 2012, 1158–1161.

[30] M. Yusoff and Z. Hussain, Effect of Sintering Parameters on Microstructure and Properties of Mechanically Alloyed Copper-Tungsten Carbide Composite, *International Journal of Materials, Mechanics and Manufacturing*, *1(3)*, 2013, 283–286.

[31] L. Luo *et al.*, Preparation and properties of W-15Cu composite by electroless plating and powder metallurgy, *Xiyou Jinshu Cailiao Yu Gongcheng/ Rare Metal Materials and Engineering*, *44(12)*, 2015, 3005–3008.

[32] S. M. Uddin *et al.*, Effect of size and shape of metal particles to improve hardness and electrical properties of carbon nanotube reinforced copper and copper alloy composites, *Composites Science and Technology*, *70(16)*, 2010, 2253–2257.

[33] P. G. Koppad, H. R. A. Rama, C. S. Ramesh, K. T. Kashyap, and R. G. Koppad, On thermal and electrical properties of multiwalled carbon nanotubes/copper matrix nanocomposites, *Journal of Alloys and Compounds*, *580*, 2013, 527–532.

[34] G.-M. Vallet, M. Dunand, and J.-F. Silvain, Influence of Carbon Nanotubes Dispersion on Thermal Properties of Copper-Carbon Nanotubes (CNTs) Composite Materials, *Universal Journal of Materials Science*, 3(4),2015, 55–61.

[35] K. Chu *et al.*, Fabrication and effective thermal conductivity of multi-walled carbon nanotubes reinforced Cu matrix composites for heat sink applications, *Composites Science and Technology*, *70(2)*, 2010, 298–304.

[36] I. Firkowska, A. Boden, A. Vogt, and S. Reich, Effect of carbon nanotube surface modification on thermal properties of copper–CNT composites, *Journal of Material and Chemical*, *21(43)*, 2011, 17541.

[37] K. Chu *et al.*, Thermal properties of carbon nanotube-copper composites for thermal management applications, *Nanoscale Research Letter*, *5(5)*, 2010, 868–874.

[38] S. F. Moustafa, S. A. El-Badry, A. M. Sanad, and B. Kieback, Friction and wear of copper-graphite composites made with Cu-coated and uncoated graphite powders, *Wear*, *253(7–8)*, 2002, 699–710.

[39] X. Jincheng, Y. Hui, L. Xiaolong, and Y. Hua, Materials & Design Effects of some factors on the tribological properties of the short carbon fiber-reinforced copper composite, *Material Design.*, *25*, 2004, 489–493.

[40] L. Su, F. Gao, X. Han, and J. Chen, Effect of copper powder third body on tribological property of copper-based friction materials, *Tribology International*, *90*, 2015, 420–425.

[41] P. Balamurugan and M. Uthayakumar, Influence of process parameters on Cu-fly ash composite by powder metallurgy technique, *Material and Manufacturing Process*, *30(3)*, 2015, 313–319.

[42] W. XU, R. HU, J. LI, and H. FU, Effect of electrical current on tribological property of Cu matrix composite reinforced by carbon nanotubes, *Transactions of Nonferrous Metals Society of China*, 21(10), 2011, 2237–2241.