Mechanical Properties of Sintered Tungsten Cu-WC Composites by using Artificial Neural Networks

H.Sandeep[1], S. Prakash[2], R.Christu Paul[3]

[1]Associate Professor,Department of Mechanical Engineering,Satyam College of Engineering and Technology, Kanyakumari Dist,Tamil nadu

[2]Associate Professor, Department of Mechanical Engineering, Bharat Institute of Engineering and Technology, Ibrahimpatnam, Hyderabad.

[3] Professor,Department of Mechanical Engineering,Hindustan University,Chennai,Tamilnadu

Abstract: High-vitality mechanical processing was utilized to blend Cu and WC powders. Cylindrical preforms with initial preform density of 85% were prepared using a die and punch assembly. The preforms were sintered in an electric muffle furnace at 750°C, 800°C, 850°C, and subsequently furnace cooled and then the specimens are hot extruded to get 92% preform density. Scanning Electron Microscope and X-ray diffraction observations used to evaluate the characteristics. The experimental results showed that the density of the composites increase with increased WC content and agrees with the values obtained through the rule of mixtures. The hardness and ultimate tensile strength of Cu–WC composites were found to increase with increased WC content in the matrix at the cost of ductility. Neural networks are employed to study the tribological behavior of sintered Cu–WC composites. The proposed neural network model has used the measured parameters namely the weight percentage of tungsten carbide, sintering temperature, load and sliding distance to predict multiple material characteristics, hardness, specific wear rate, and coefficient of friction. The predicted values from the proposed networks coincide with the experimental values. In addition, a relative study between the regression analysis and the networks revealed that the artificial neural networks can predict the tribological characteristics of sintered Cu and WC composites better than regression polynomials within a very few percent error.

Key-words: Scanning Electron Microscope, X-ray Diffraction, Composite Material, Mechanical Properties.

1 Introduction

Composite materials are those that are formed by the combination of two or more materials to achieve properties that are superior to those of its constituents. MMC types are commonly subdivided according to whether the reinforcement is in the form of (a) particles (b) short fibres (with or without a degree of alignment) or (c) long aligned fibres [1]. The selection of the processing route depends on many factors including type and level of reinforcement loading and the degree of micro structural integrity desired [2]. The particulate MMC are extensively used for tribological applications due to excellent wear resistance during sliding as well as its ability to withstand high stress and their ability to carry heavier loads.

Metal matrix composites are designed to achieve high strength properties [3]. Metal matrix composites (MMCs) reinforced with ceramic particles is widely used because of their high specific modulus, strength and wear resistance. Many of the investigations have shown improved mechanical properties but are limited with low and poor ductility.

Though there is no clear relation between the mechanical properties of the composites, type and volume fraction of reinforcement, surface nature of reinforcement and size of the reinforcement are proved to be effective in improving the strength of the composites [4]. Composite ductility is governed by matrix processors that will be affected by the presence of the reinforcements.

The use of tungsten as a reinforcing phase for copper has been studied by several researchers. Tungsten, being a refractory metal provides some degree of wear and arcing resistance when used with copper as an electrical contact material however, higher hardness and lower density of reinforcing phase can extend the areas of application for copper based MMC's. Tungsten carbide (WC) in place of tungsten (W) has been used as the reinforcement for silver based composites for electrical contact applications. There are number of merits in using WC as reinforcement in copper based composites. It has a lower density (13.43g/cc) as compared to tungsten carbide (18.2g/cc) .WC retains its room temperature hardness up to 1300°C and its wear resistance is better than the tool steel. WC does not undergo phase changes during heating and cooling and is stable indefinitely. These advantages were the driving force behind the development of Cu-WC composites [5].

Copper–tungsten (Cu–WC) composite materials are developed for applications such as electrical contacts, resistance electrodes, and contact tips in welding guns as well as for components requiring higher wear resistance. In addition to the aspect of improved performance, it is exciting to assess the tribological behavior and therefore, the objectives of the present work include WC additions in improving the adhesive wear resistance of Cu.

2 Experimental Study

The individual powders were pulverized for four hours in a high energy ball mill (Fritsch, Germany, Pulverisette-6) with tungsten carbide vials using 10 mm diameter tungsten carbide balls. The ball to charge weight ratio was 20:1. Milling was done at 500 rpm in wet medium in the presence of toluene to prevent oxidation and agglomeration of the charge. After that it was mixed on weight basis with (10–20%) tungsten carbide, 1% graphite as surfactant and rest copper powder for 4 h continuously. Mixing is the important one for preparing the P/M process, even though much other mixing procedure, mechanical alloying method is mostly suitable method for P/M process. In general, powder milling takes place in three steps. In the first step all powders slip with a little fracture and plastic deformation. During this step powder shape plays very important role. In fact, flow ability of spherical powders is much higher than that of flake powders. In other word, spherical powders can easily escape through balls unlike irregular powders, which tend to contact together due to milling. In the second step of milling, some elastic and plastic deformation occurs as well as cold weld between powders. In the third step of milling all powders work hardens and thus their breakage cannot be avoided. As a matter of fact in this step, there is a balance between cold weld and fracture of powders resulting in changing the powder shapes to uniform. Moreover, particle size and their distribution will be uniform throughout the mixer.

2.1 Selection of Powder for this Study

Cu and Cu-WC composite preforms at micron and nano levels were selected in order to provide a wide range of study namely characterization, pores, hardness and tribological of cold compacted and sintered composite. Copper and tungsten carbide powders were used in the present investigation [6].

Electrolytic copper and atomized tungsten were obtained with 100% and 96.70% purity respectively [7]. The individual powders were characterized through the test result supplied by the metal powder company. The characteristic of the copper and tungsten powder is shown in Table 1.

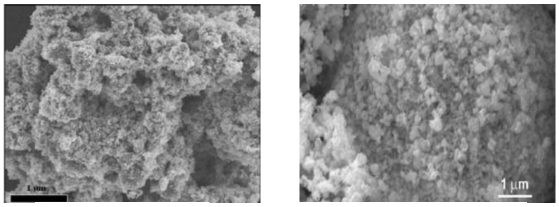
TABLE 1
EXPERIMENTAL AND PREDICTED VALUES OF HARDNESS OF CU-WC COMPOSITES

Property	**Sieve analysis, %**			**Apparent density, (kg/m^3) Flow rate Sec, (50/g) Acid Insoluble**		
	+75, µm	+45, µm	-45, µm			
EC/86 Grade	0.40	4.90	92.70	1490	Nil	Nil
Test Standard	IS 5461			ASTM B-417	ASTM B-213	ASTM B-194

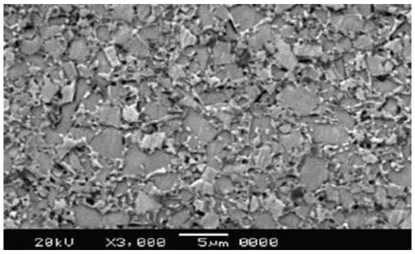
2.2 Powder Characterization

1. Scanning Electron Microscope

SEM was used for evaluation of particles after milling and is shown in Fig. 1a shows the SEM image of the Cu particle and has a structure of a cluster of tiny particles and like small flattened flake particles due to severe plastic deformation of copper; micro-welding and fracture of the large flakes due to typical mechanical milling. Fig. 1b shows the SEM image of the Cu–10WC powders, the WC particles are uniformly mixed through the Cu matrix. Fig. 1c shows the SEM image of the Cu–20W powder composite particles. Powder composite particles, which have more distribution of WC particle than in Fig. 1c.



(a) Copper (b) Tungsten carbide



(c) Particles

Figure 1: SEM micrograph after sintering at 850 C (a) pure Cu (b) Cu–10WC (c) Cu–20W

2. X-ray Diffraction Analysis

The XRD (PANalytical, Model: X'per PRO) was used for this analysis. Diffraction effects were observed when electromagnetic radiation impinges on periodic structures with geometrical variations on the length scale of the wavelength of the radiation. The inter-atomic distances in crystals and molecules amounted to 0.15–0.40nm which corresponded in the electromagnetic spectrum with the wavelength of x-rays having photon energies between 3 and 9 keV. Accordingly, phenomena like constructive and destructive interference should become observable when crystalline and molecular structures are exposed to X-rays.

The XRD results for the prepared Cu & Cu-WC composite are shown in Figure 2 (a-d). The spectra of Cu and Cu-(5-20WC) are shown in Figure 2 (a-d). Peak values were collected over the 2θ range of 20-70°C with a step size of 0.01°C and step time of 4s. All the samples show wide diffraction peaks, which could be indexed to the structure of Cu (JCPDS card No. 04-3493) and WC (JCPDS card No. 07-6151).The crystalline size measurements were carried out using Debye-Scherrer equation Dh k l = 0.86 $\lambda/\beta \; Cos\theta$, where D is the crystallite size, λ is the wavelength, ù is the line width and θ is the angle of diffraction. The mean grain sizes of as-synthesized Cu and WC were found to be 5 and 16 µm respectively. The revealed characteristic peaks in the XRD pattern that was consistent with JCPDS files No. 89-2838 and 89-4900 for Cu and WC respectively. By comparing the relative intensity counts of the diffraction peaks, it can be seen that the relative intensity rate corresponding to the 2θ angle 43.49°C, 50.66°C, 74.3°C of (1 1 1) , (2 0 0) to (2 2 0) of the diffraction peaks of Cu, corresponding to the file name (JCPDS 89-2838) and WC was found to be the relative intensity rate corresponding to the 2θ angle 39.40°C, 54.24°C, 72.28°C of (1 1 0), (2 0 0) to (2 1 1) of the diffraction peaks of WC corresponding to the file name (JCPDS 89-4900) respectively.

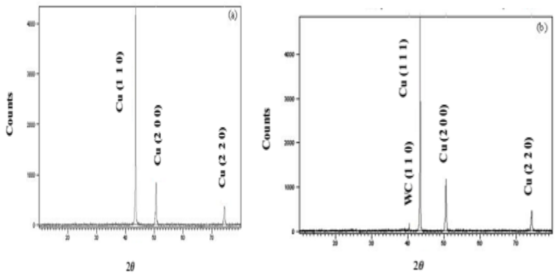


Figure 2: The XRD pattern of the different composite: (a) pure Cu (b) Cu–5WC (c) Cu–15WC and (d) Cu–20WC composite

3. Energy-Dispersive Spectroscopy Analysis

EDS (EDS, Model: 720HS) is an analytical technique used for the elemental analysis or chemical characterization of a sample. It relies on the investigation of an interaction of some source of X-ray excitation and a sample. Its characterization capabilities are due in large part to the fundamental principle that each element has a unique atomic structure allowing unique set of peaks on its X-ray spectrum. To stimulate the emission of characteristic X-rays from a specimen, a high-energy beam of charged particles such as electrons or protons or a beam of X-rays, was focused on the sample being studied. Figure 3 (a-d) shows the EDS pattern of different composite after sintering. In this present study EDS pattern was used to confirm the elements present in the particular system. Figure 3 (a-d) confirms that during the sintering and extrusion there is a formation of minimum oxide. The EDS result confirmed that the oxide weight % increased with the increase in WC content. This is mainly due to the oxidation during extrusion process in cold atmosphere.

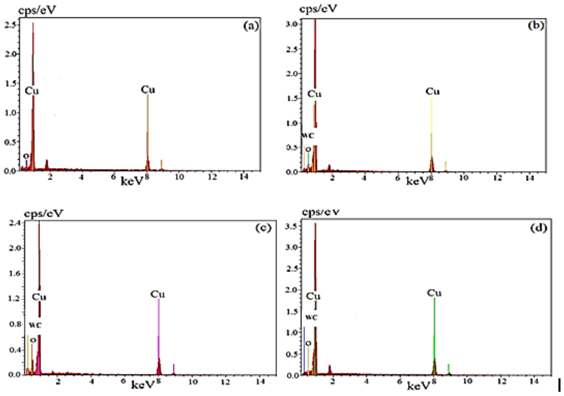


Figure 3: EDS pattern of the different composite after sintering and extrusion (a) Cu-0WC (b) Cu-5WC (c) Cu-10WC (d) Cu-15WC

3 Results and Discussion

3.1 Hardness

Hardness was measured with a Vickers hardness tester. As many as three specimens were tested, with ten different spots identified for indentation in each specimen and the results are presented in Table 2. An increase in hardness by about 21.37%% can be observed as the tungsten carbide reinforcement content is increased from 0 to 8%WC. As is known, hardness measures the resistance of a material to indentation where in there will be a localized plastic deformation under standardized conditions. The increase in hardness is quite obvious and expected since tungsten carbide particles being hard dispersions contribute positively to the hardness of the composites. The increased hardness is attributed to the hard tungsten carbide particles which act as barriers to the movement of dislocations within the matrix. This dispersion-strengthening effect is expected to be retained even at evaluated temperatures and for extended periods of time because the particles are not reactive with the matrix phase.

Table 3 shows results of different model analysis values with experimental values of hardness for 0-8%WC, it was observed that obtained experimental values are very near with Paul model, when compared with other two models.

TABLE 2
EXPERIMENTAL AND PREDICTED VALUES OF HARDNESS OF Cu-WC COMPOSITES

Reinforcement %WC	**Experimental values**	**ROM- Rule of Mixture (Voigt Model)**	**IMR- Inverse Mixture Rule (Reuss model)**	**Paul Model**
0	188	214.00	214.00	215.00
2	214	227.77	216.28	229.00
4	224	253.64	218.60	227.15
6	257	277.13	221.09	240.09
8	267	304.45	224.55	267.20

TABLE 3
EXPERIMENTAL AND PREDICTED VALUES OF ULTIMATE TENSILE STRENGTH OF Cu-WC COMPOSITES

Reinforcement %WC	**Experimental values**	**ROM- Rule of Mixture (Voigt Model)**	**IMR- Inverse Mixture Rule (Reuss model)**	**Paul Model**
0	188	186.21	185.61	194.23
2	195	202.55	188.23	203.76
4	212	214.64	192.60	208.56
6	216	230.43	195.43	214.04
8	221	242.67	200.18	223.40

3.2 Tensile Strength

The tensile test was conducted in accordance with ASTM E8-82 standards. It follows from the Table 3 shows that the Cu-WC composites shows an increase in UTS by about 20.17 % as the content of the tungsten carbide is increased from 0 to 8% by weight. The increase in UTS of the composite specimens is obviously due to the presence of hard tungsten carbide particles which impart adequate strength to the matrix there by increasing the resistance of the composite to the applied tensile stresses. The structure and properties of the reinforcements control the mechanical properties of the composites that are reasoned to the strong interface that transfers and distributes the load from the matrix to the reinforcement exhibiting increased elastic modulus and strength. The strength of ceramic particulate reinforced copper-composites is found to increase by increased volume fraction of ceramic phase and by decreasing the size of the reinforcement in the composite. In comparison with the experimental values, the results of approximate mechanics of materials prediction Paul model was closer to the experimental results, which lies between Voigt and Ruess model.

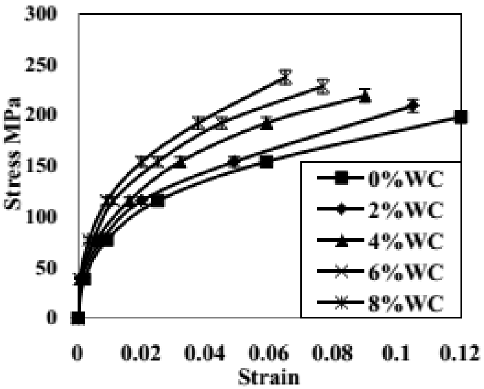


Figure 4: Showing the variation of tensile strength (stress) and strain for different %WC

4 Conclusion

The SEM image is used for characterization, also used to find out the pore area, pore diameter and pore perimeter measurement after sintering and after extrusion. Due to the effect of this extrusion process the preform density has been improved from 85% to 92%. XRD Pattern is used to identify the functional elements present in the Cu–W composite and also with the help of the peak intensity; the size of the particle has been measured. The UTS of the composites increased by about 19.67% as the content of the tungsten carbide was increased from 0 to 8% by weight. The increase in UTS of the composite specimens is obviously due to the presence of hard tungsten carbide particles which impart adequate strength to the matrix there by increasing the resistance of the composite to the applied tensile stresses. The density of the composites was found to be higher than the matrix which increased with the increase in content of the reinforcement. Similarly the hardness of the composites was found to increase with increased reinforcement content. The increase in hardness was by about 24.77% the tungsten carbide reinforcement content is increased from 0 to 8%WC. The results obtained from the Paul model are in agreement with the experimental data both for hardness as well as ultimate tensile strength. The trained networks for the Cu–W composites were developed with minimum mean square error. Fine agreement between the experimental and predicted results from using the neural networks. The prediction accuracy was good as compared to the regression polynomial curve fitting method. The second order polynomial equation has been developed for all responses with respect to the sintering temperature.

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