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EXPERIMENTAL INVESTIGATIONS ON PROPERTIES OF COPPER – SILICA FUME PARTICULATE COMPOSITES

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ABSTRACT

Copper-silica fume mixtures containing 0-15 wt% silica fume were prepared. Small cylindrical specimens of 9 mm diameter and 10.5 mm length were fabricated at 300 MPa using single acting die compaction at ambient temperature. These compacts were sintered in argon atmosphere for a period of 45 min at 850^0C. The physical and mechanical properties of green and sintered compacts were determined as a function of silica fume weight percent. It was observed that green density and strength decreased, while green porosity and hardness increased with increasing weight percent of silica fume. Sintering resulted in decrease in volume and increase in density of green compacts. It was further observed that addition of silica fume resulted in increase in porosity and hardness and decrease in density and compressive yield strength of sintered compacts under the present experimental conditions. Electrical conductivity of sintered copper-silica fume compacts was also determined as a function of silica fume content. The electrical conductivity gradually decreased with increase in silica fume content.

Keywords: Density, Porosity, Hardness, Strength and Electrical conductivity.

1. Introduction

The conventional materials do not always provide the requisite properties under all service conditions. Metal matrix composites are capable of providing higher temperature operating limits than their base metal counterparts, and can be tailored to give improved strength, stiffness, thermal conductivity, abrasion resistance, creep resistance and dimensional stability [1]. Copper matrix composites with particulate ceramic reinforcements such as SiC and Al_2O_3 are potential candidate materials for electronic applications [2-6]. These copper composites combine the superior ductility, toughness and thermal conductivity of copper and high strength and low coefficient of thermal expansion of ceramic reinforcements. However, the high cost of these ceramic reinforcements remains a major barrier in their wide spread use. Hence, there has been an increasing interest in composites containing low density and low cost reinforcements. Extensive studies have been reported on metal/polymer composites containing fly ash for wide range of applications [7-21]. Silica fume is an industrial waste by-product, composed of mostly amorphous silica produced by electric arc furnaces during the production of elemental silicon or ferro-silicon alloy. So far, silica fume particles have been used as filler in concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance [22, 23]. Silica fume, compared with other ceramic dispersoids commonly used in MMCs, such as SiC and Al_2O_3, demonstrates that many of the constituents of silica fume are much lighter and closer to ceramic dispersoids. This low cost particulate ceramic reinforcement is added to copper matrix to prepare copper-silica fume composites for possible electronic applications.

Several processing techniques are used for the production of metal matrix composites, which can be grouped into two main routes depending on the state of the matrix during the fabrication process, either liquid or solid routes. Copper-silica fume composites by casting are likely to exhibit segregation and non-uniform distribution of particles because of the differences in density between the silica fume particles and the matrix. So, powder metallurgy is used to prepare copper-silica fume composites in the present work. Hence, the present experimental investigations are carried out on properties of copper-silica fume particulate composites using powder metallurgy.

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2. Experimental Procedure

Copper powder (99.5% pure) was procured from M/s Loba Chemie Pvt. Ltd., Mumbai and the silica fume powder was obtained from Ferro Alloys Corporation, Garividi, Andhra Pradesh. The average size of copper powder is 44 μm. The chemical composition and density of silica fume used in the present study is shown in Table-1.

Table 1: Chemical composition and Density of silica fume

Chemical Constituent	Weight (%)
SiO_2	85.6
Al_2O_3	7.2
Fe_2O_3	2.4
CaO	0.38
MgO	0.12
Na_2O	0.15
K_2O	0.1
H_2O	1.72
Loss on ignition	1.98
Density	20.51 kNm^{-3}

The sieve analysis of silica fume was carried out and bulk of the particles of silica fume were in the size range of 90-600 μm with the median size around 193 μm. Copper, and silica fume powders were mechanically mixed using a rotating rectangular container. Mixtures of copper-silica fume powders containing 0-15 wt% were prepared. Cylindrical compacts were obtained by single action die compaction at ambient temperature at a pressure of 300MPa. Silicone spray was used as the die wall lubricant. The compact dimensions were 9 mm diameter and 10.5 mm length. The compacts were sealed in transparent silica tube under argon atmosphere and sintered at 850^0C in a tubular furnace for a period of 45 min. Scanning electron micrographs were used to study the structural details of the particles. Metallographic examination of green and sintered compacts was carried out using optical microscopy. The physical and mechanical properties of the green compacts, viz., green density, green porosity, green hardness and strength were evaluated as a function of silica fume weight percent. Volume change, density, porosity, hardness, compressive yield strength and electrical conductivity of the sintered compacts were also determined as a function of silica fume weight percent. Green and sintered densities were determined by physical measurements. The porosity of the green and sintered compacts was determined by taking theoretical density of the specimen into consideration.

Brinell hardness measurements were obtained using TIME TH130 Integrated Micro Hardness Tester. Compression testing was conducted using an Electronic UTM at a crosshead speed of 0.2 mm/min. The electrical conductivity was measured in % IACS using a Digital Electrical Conductivity Meter.

3. Results and Discussion

3.1 Powder characteristics

The scanning electron micrographs of copper and silica fume particles as shown in Figs 1 & 2 indicate their size, shape, size distribution and structure. Fig.1 indicates the flaky and dendritic structure of copper powder which is partly porous in nature.

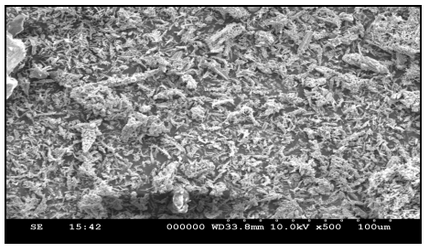

Fig.1 Scanning Electron Micrograph of Copper Powder

Copper particles have a diameter in the range of 2-3 microns while the length is around 20 microns. Figure 2 reveals the approximately spherical shape and rough surface of silica fume particles with diameter ranging from 5 to 80 microns.

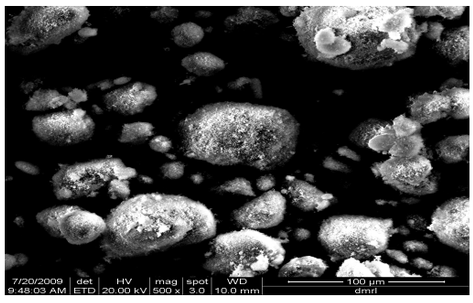

Fig. 2 Scanning Electron Micrograph of Silica Fume

3.2 Green characteristics

The effect of silica fume weight percent on green density and porosity are shown in Figs. 3 & 4.

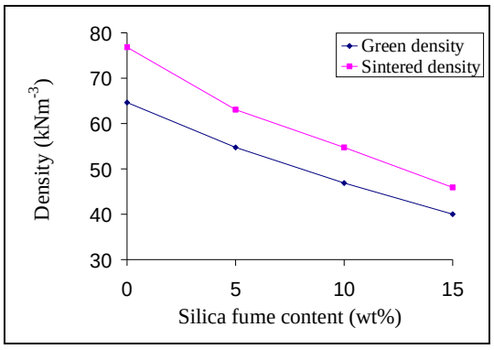

Fig. 3 Effect of Silica Fume Content on Green & Sintered Densities

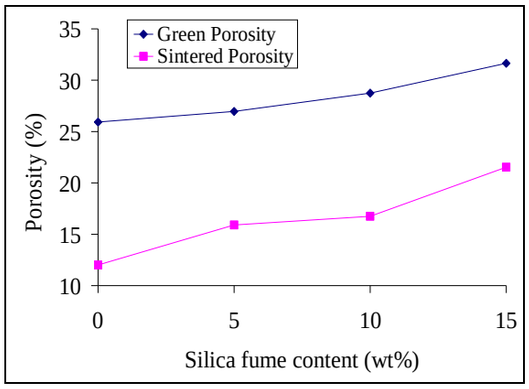

Fig. 4 Effect of Silica Fume Content on Green & Sintered Porosities

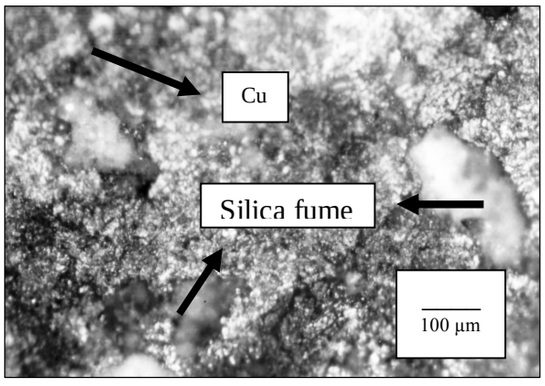

Fig. 5 Microstructure of Cu-10% Silica Fume Green Compact

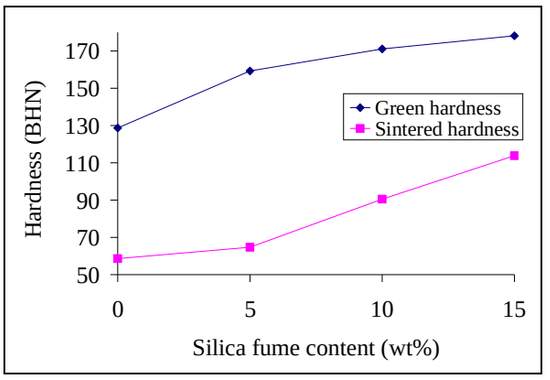

Fig.6 Effect of Silica Fume Content on Green & Sintered Hardness

These figures indicate that green density decreases, while porosity increases with increase in silica fume weight percent. The green density is reduced around 15% with the addition of 5% silica fume, where as the addition of 15% silica fume results in around 38% decrease in the green density of pure copper compacts. This is because the density of silica fume (20.51 kNm^{-3}) is less than that of copper (87.67 kNm^{-3}) and as the silica fume content increases, the compacts exhibit a reduction in green density for similar processing conditions. The porosity of green compacts gradually increased from a minimum of 4% to a maximum of 22% with increase in silica fume content. The gradual increase in porosity with increase in silica fume content may be because of the spherical shape of silica fume powder. The microstructure of copper-10% silica fume green compact is shown in Fig.5.

Figures 6 & 7 represent the effect of silica fume content on green hardness and strength.These figures show that green hardness increases, whereas green strength decreases with increasing silica fume content. The addition of 15% silica fume resulted in around 40% increase in the green hardness of pure copper compacts. The increase in green hardness with increase in silica fume content is due to the presence of hard silicates in silica fume. The addition of 15% silica fume decreases the green strength of pure copper green compacts more than 50%. The decrease in green strength with increasing silica fume content may be attributed to the poor mechanical interlocking between the silica fume and copper powder particles. This may be because of the spherical surface and lack of plasticity of silica fume as compared to that of copper.

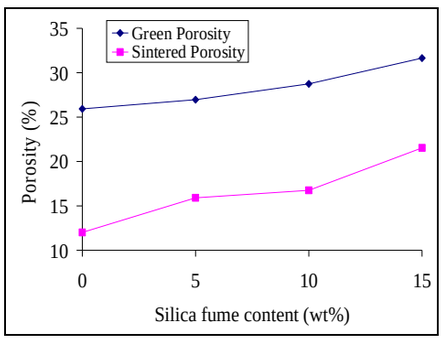

Fig.7 Effect of Silica Fume Content on Green Strength & Sintered Yield Strength

3.3 Sintered characterstics

Dimensional changes (volume changes) always occur during sintering of a green compact due to solid state diffusion processes or liquid phase sintering in a multi- component system with widely different melting points of constituents. For sintering of copper powders, the recommended range of sintering temperature and time are 840^0-900^0C and 12-45 minutes respectively [24]. In the present investigation, the copper-silica fume compacts are sintered at a temperature of 850^0C for 45 min duration.

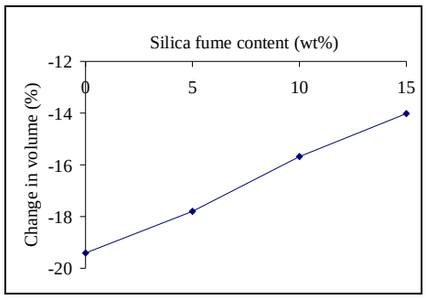

Fig. 8 Effect of Silica Fume Content on Change in Volume

Since the sintering temperature employed in the present investigation (850^0C) is less than the melting point of copper (1083^0C) and silica fume (1200^0C), the composites undergo solid state sintering. Figure 8 represents the variation of volume change as a function of silica fume weight percent. It shows that sintering results in shrinkage or negative growth in volume of the green compacts and the percentage change in volume gradually decreases with increase in silica fume content. Figures 3 & 4 also indicate the effect of silica fume on sintered density and porosity.

On comparison of sintered densities with those of corresponding green densities for respective compositions, it can be clearly noticed that the density after sintering is always more than the corresponding green density due to negative growth in volume on sintering. Sintered density decreases with increasing silica fume content. Sintered porosity increases with increasing silica fume content. The addition of silica fume to copper increases the sintered porosity of pure copper compacts around 32-79%. Since the density of silica fume is very low, for a given weight percentage, significant volume of matrix phase is replaced. With increase in silica fume content, the proportion of direct silica fume-silica fume contacts increases. The direct silica fume-silica fume contacts degrade the quality of sintering at the processing temperature, because the silica fume has a melting point (1200^0C) higher than the sintering temperature. This aids in the reduction of volume change and sintered density with a corresponding increase in sintered porosity of the composites. The microstructure of copper-10% silica fume sintered compact represented in Fig. 9 shows the dispersion of silica fume in copper matrix.

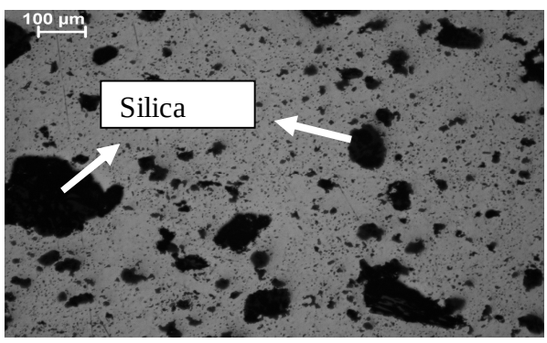

Fig. 9 Microstructure of Cu-10% Silica Fume Sintered Compact

Figs. 6 & 7 also represent the variation of sintered hardness and compressive yield strength of the copper-silica fume composites as a function of silica fume weight percent. These figures show that sintered hardness increases, while yield strength decreases with increase in silica fume content. The sintered compressive yield strength is particularly low for composites containing more than 10 wt% silica fume. It indicates that the useful range of silica fume that can be added to copper matrix lies below 15%. The decrease in strength is due to the high porosity and ineffective sintering between silica fume particles and the copper matrix in sintered silica fume composites.

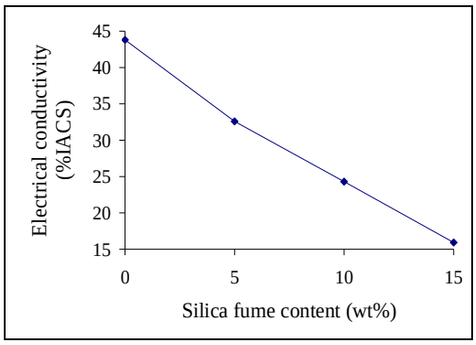

Fig. 10 Effect of Silica Fume Content on Electrical conductivity

The effect of silica fume on electrical conductivity is shown in Fig.10. Electrical conductivity gradually decreases with increase in silica fume content. This may be due to the poor conductivity of the constituents of silica fume and high porosity of the sintered compacts.

4. Conclusions

From this investigation, following conclusions are obtained.

i. The copper - silica fume composites with uniform dispersion of silica fume can be obtained by powder metallurgy processing route. Incorporation of silica fume particles modified the physical, mechanical and electrical conductivity properties of the pure copper compacts.
ii. Green density and strength decreased with increase in silica fume content. Green porosity and hardness increased with increase in silica fume content.
iii. Sintering of copper-silica fume compacts resulted in an increase in density of the green compacts and sintered density decreased with increasing silica fume content.
iv. Sintered porosity and hardness increased with increasing silica fume weight percent.
v. Compressive yield strength of copper-silica fume composites decreased with increasing silica fume weight percent. The results suggest that useful range of silica fume that can be added to copper lies below 15% and longer sintering times, higher sintering temperatures and secondary operations such as forging may be necessary to make copper-silica fume composites with improved strength properties.
vi. The electrical conductivity of the sintered copper compacts decreased with addition of silica fume.

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