ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 18 (2018) 1013–1023

Available online at www.sciencedirect.com

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journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Synthesis, microstructure and mechanical properties of bronze–molybdenum composites processed via LPS and SPS methods

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ARTICLE INFO

Article history:
Received 22 October 2017
Accepted 22 February 2018
Available online

Keywords:
Composite
Spark plasma sintering
Liquid phase sintering

ABSTRACT

In this work, synthesis, densification and properties of bronze–70 wt% Mo and bronze–30 wt % Mo composite powders were investigated. The composite powders were prepared by mechanical milling of bronze–Mo powder mixtures for 16 h. The results of cold compressibility investigations showed that Heckel and Ge equations provided the best fit scenario for bronze–70 wt% Mo and bronze–30 wt% Mo, respectively. The composite powders were consolidated via pressureless and spark plasma sintering processes. The relative densities of spark plasma sintered samples with 30 and 70 wt% molybdenum were about 98%. However, the relative density of bronze–70 wt% Mo and bronze–30 wt% Mo pressureless sintered samples were 97.1 and 94.3%, respectively. The scanning electron microscopy observations revealed that the size and dispersion of Mo particles within the bronze matrix in the pressureless sintered samples was completely different from that of the spark plasma sintered ones. Furthermore, it was found that in spite of nearly close relative densities, the hardness and flexural strength of the spark plasma sintered samples were higher than that of the pressureless sintered ones which was due to different shape, size and dispersion of the Mo particles within the matrix phase in the different samples. According to the results, the preferred densification process was SPS method.

1. Introduction

Copper matrix composites are widely used in different electrical components like vacuum switches and interrupters, oil circuit breakers, arcing tips and wiping shoes in power transformers [1]. In this group of metal matrix composites (MMCs), various metallic elements and ceramic compounds like tungsten, molybdenum, chromium, tungsten carbide, zinc oxide and alumina have been used as reinforcement. The effect of reinforcement morphology and the interface features on the properties of copper based composites has been investigated by numerous researchers. Zhang et al. showed that the core shell structure of the reinforcement was led to

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https://doi.org/10.1016/j.acme.2018.02.009

improved arc dispersion effect and wear resistance of the composite [2]. Also, it has been shown that the phase boundaries and the features related to them have a significant effect on the properties of the copper based composites like Cu–Cr [3]. Furthermore, the result of another investigation on Cu/ZnO copper based composites confirmed that by increasing the mass fraction of the reinforcement, the relative density and electrical conductivity was decreased while the hardness of the composite was increased [4]. However, it has been shown that by using a mixture of ceramic reinforcement including ZnO, Al_2O_3 and Y_2O_3, the performance of the copper based electrical contact was enhanced [5].

Generally, powder metallurgy and casting are the two applied processes for production of copper based matrix composites [6,7]. Squeeze casting in air is one of the casting processes which have been applied for producing copper matrix composites. Formation of fragile phases at the matrix/reinforcement interface has been reported in the composites which were processed via squeeze casting method [8]. Also, irregular phases were detected at the interface of the composites which were processed via powder metallurgy routes. Grzonka et al. detected a thin layer of graphite at the interface region of a copper/diamond composite [9]. These fragile and irregular phases affect the properties of the synthesized composites. However, the conventional powder metallurgy method which includes mixing and sintering the starting powder mixtures is one of the manufacturing processes for production of copper/refractory metals composites like W/Cu and Mo/Cu. The sintering process might be below or above melting point of copper which is depend on the volume fraction of copper. In order to have a nearly dense microstructure with low volume percent of porosities, the sintered samples may be densified by a second densification process like extrusion or repressing. Many investigations have been done about sinterability and densification of W/Cu and Mo/Cu powder mixtures. It has been shown that fine dispersion of the constituents improves the sinterability of the powder mixtures [10]. Mechanical milling [10], mechanochemical [11], thermomechanical [12] and co-precipitation [13] methods are some of the applied methods for synthesis of fine dispersed W/Cu and Mo/Cu powders. The fine dispersion of the constituents within the microstructure of the synthesized powders by the mentioned processes was led to dense microstructures at relatively low sintering temperatures.

Other than the two step densification processes, one stage densification methods like spark plasma sintering (SPS) has been investigated for production of copper/refractory metals MMCs. SPS is a short time consolidation process which offers the possibility of producing bulk materials with high relative density in relatively low processing temperatures. SPS has been widely used for densification of metallic [14] and ceramic [15] based composite powders. Nearly dense structures with various weight percent of reinforcement have been made by SPS method [14]. Bulk materials with nanoscale grain sizes have been synthesized by this method [15]. Micro-arc welding, electric resistance welding and diffusion welding are some of the mechanisms which have been proposed for joining the powder particles during SPS [16].

Many investigations were conducted on the synthesis, sintering and characterization of W/Cu and Mo/Cu composites. However, few researches have been focused on synthesis and densification of copper alloys/refractory metals MMCs [17,18]. Replacing copper by copper based alloys like bronze or brass is led to decreasing the sintering temperature of the powder mixture which is due to lower melting temperature of the alloys. Also, the mechanical properties of the sintered sample would be enhanced due to using an alloy instead of a pure metal (i.e. copper) as the matrix phase.

In this research, sinterability and densification of leaded bronze/Mo composite powders were investigated. Also, the mechanical properties of the sintered compacts such as hardness and flexural strength were studied.

2. Materials and methods

High purity molybdenum and bronze powders were used as starting materials in this work. The Mo and bronze powders with >99.0% purities were supplied by Merck and Tabriz Powder Metallurgy Co., respectively. The chemical composition of the bronze powder was 88 wt% Cu, 8 wt% Sn and 4 wt% Pb. Fig. 1 shows the morphology of the powders. As it is observed, the bronze particles do not have a regular shape and their size is mainly below 200 μm. On the other hand, the Mo particles are spherical and their size is below 5 μm. Two different Mo/bronze powder mixtures with 30 and 70 wt% Mo were prepared in a tubular powder mixer. The mixed powders were milled in a planetary ball mill in a dry media. The milling

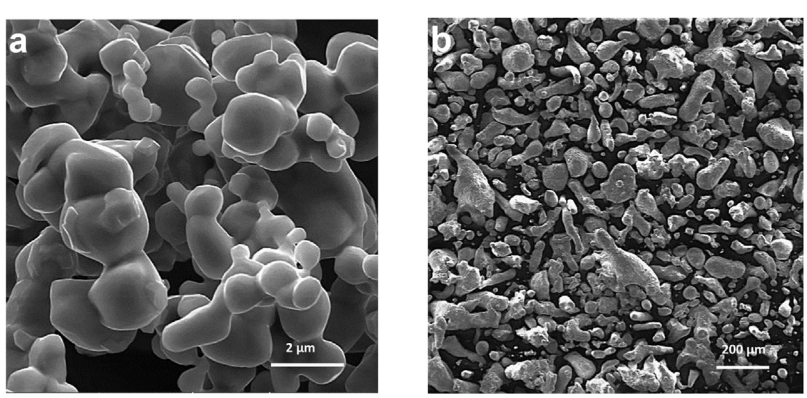

Fig. 1 – FESEM image of (a) Mo and (b) bronze powders.