Journal of Alloys and Compounds 737 (2018) 8–13

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

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

The effect of sintering temperature on microstructure and mechanical properties of alloys produced by using hot isostatic pressing method

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A R T I C L E I N F O

Article history:
Received 19 September 2017
Received in revised form
22 November 2017
Accepted 10 December 2017
Available online 11 December 2017

Keywords:
HIP (Hot Isostatic Pressing)
Powder metallurgy
Microhardness
Three-point bending
Density
CuSn
Co
Ni

A B S T R A C T

In this study, a new matrix material was produced via HIP (Hot Isostatic Pressing) method by adding Cobalt and Nikel elements to CuSn (85/15) bronze alloy at certain ratios and the effect of sintering temperature during the production was examined. One of the biggest advantages of the HIP method is that the heat and pressure are applied at the same time during sintering process. Thus, all or almost all of the gaps during the production were removed and a more dense material was obtained. During the operation, it was kept constant that the sintering pressure was 30 MPa and the sintering time was 15 min, and the sintering temperature was selected as the variable parameter between 700 °C and 800 °C. The sintering process was carried out under the vacuum condition after the moment of first combustion. The produced samples were then metallographically prepared and SEM and EDS analyses were carried out for microstructure studies. Microhardness was taken from the samples and three-point bending test was carried out in order to examine the mechanical behaviors of the samples. Finally the density test was applied to the samples and their experimental and theoretical densities were calculated. As a result, it was observed that more homogeneous samples were obtained by increasing the sintering temperature.

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1. Introduction

Powder metallurgy is a general name given to the technique of shaping pure metal and alloy metal powders in a mold and bringing the strength to them with heat treatment (sintering). In recent years, the number and variety of parts produced by powder metallurgy method have increased. Main reasons for this are affordability, their high strength as well as low densities and production for specific uses [1]. Hot Isostatic Pressing (HIP), which is one of the production methods of powder metallurgy, is a method containing high pressure gas in which pressure is applied isostatically to one or more parts in order to produce completely dense materials [2].

Co and Ni powders are used in an opposite amount to the Cu-Sn contribution as diamond-binding phase in accordance with their good wetting properties. Cu-Sn addition can be in the form of a mixture of Cu and Sn powders or in the form of pure bronze powder. The manufacturer specifies the use mode with the pressure sintering application characteristic [3]. The best result in bronze-based material production and abrasion tests performed after the production with the powder metallurgy method by adding ceramic powder in different types and rates was obtained at 350 MPa pressing pressure and at 820 °C temperature. It was found from the microstructure images that low-melting powders in the material formed liquid phase sintering and accordingly the pores shrank. It was also observed that some of the metal powders with low melting temperature evaporated during sintering [4].

Park et al. joined FeCrAl and Zr alloys with HIP method for melting energy applications. In the study, they chose the HIP temperatures between 700 °C and 1050 °C. They evaluated the mechanical properties of HIPped samples with four-point bending and tensile tests. They obtained higher strengths from the samples obtained with HIP at 700 °C. They stated that with increasing HIP temperature, the diffusion layer forming in the interface and its thickness increased and intermetallic compound and cavity were not observed at the interface up to 950 °C [5]. Tam et al. investigated the effects of temperature on production of Cr and Si by hot isostatic pressing. They examined the microstructures and porosity properties of the samples. As a result of the study, they determined the optimum temperature as 1373 K [6]. El Rakayby et al. investigated the condensation behavior of Nickel alloy powder during the

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https://doi.org/10.1016/j.jallcom.2017.12.097
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hot isostatic pressing by using the finite elements method [7]. Chang et al. examined the effect of temperature on microstructure and tensile properties by using hot isostatic pressing method in the compacting of Inconel 718 powder. They noted that the density of MC carbide particles decreased with increasing temperature and a yield resistance of 0.2% formed with increasing HIP temperature [8].

2. Experimental studies

In this study, a new matrix material was produced by adding Co and Ni elements into 85/15 Bronze alloy at certain rates. In the study, the metal powders used were obtained in the grain size specified in Table 1.

Before the sintering process, the powders were prepared in groups at the rates indicated in Table 2 in a powder weighing device with sensitivity of 1/1000 (Fig. 1a). The proportionally prepared sample compositions were stirred for 20 min in the mixing unit (Fig. 1b). In order for the powders to be processed at a certain size and shape before sintering, the polyethylene glycol binder of 1% was added to the mixture. In order to make the mixing process more homogeneous, iron beads and chains at different diameters were left in the mixing cap. The samples were then subjected to pre-pressing process in the dimensions of 10 × 20 × 40 mm in the cold pressing machine. The pre-pressed samples were taken into pre-prepared graphite molds and made ready for sintering (Fig. 3a). In order to make the sintering process better, graphite mold was lubricated with a lubricant.

The matrix samples were produced in Çel-mak company. During the production of the samples, constant sintering pressure of 30 MPa, constant sintering time of 15 min and two sintering temperatures of 700 and 800 °C were used. While the sintering temperature is determined by taking 2/3 or 4/5 of the melting temperature of metal in single component systems, the sintering temperature in the systems with more than one component is selected below the melting temperature of the component with high melting temperature and above the melting temperature of the component with low melting temperature (Cu melting temperature was 1085 °C and Sn melting temperature was 231.9 °C). The sintering temperature in the study was determined by considering the Cu-Sn dual balance diagram given in Fig. 2. The samples were produced in the sintering machine shown in Fig. 3b with Hot Isostatic Pressing (HIP) method, a powder metallurgy production method. The sintering process was carried out under vacuum after the first combustion. The samples were produced in dimensions of 10 × 10 × 40 mm. Table 3 shows the amounts and the production parameters of the metal powders used during the production.

For the metallographic analysis of the produced samples, the surfaces of the samples were cleaned with 200, 320, 500, 800, 1000 and 1200 mesh sandpaper, respectively, and then polished with 3 μm diamond paste. Polished samples were subjected to etching process with pre-prepared etchant and EDS analyses were carried out to investigate the matrix material and to determine the compound of the compositions in the produced samples.

Microhardness measurements were made at 1-mm distances at 500 gr load and 10 s waiting time in order to determine the hardness of the samples produced by using the HIP method. Three-point bending test was then carried out to determine the bending strength of the samples. The bending tests were carried out according to the ASTM B 528-83a standard with the SHIMADZU universal test device shown the bending strengths of the samples were measured using the TRAPEZIUMX software with the aid of a special apparatus shown in Fig. 4. The measurements were carried out for the samples in the dimensions of 10 × 10 × 40 mm in a

Table 1
Grain sizes of the metal powders used in the experiments.

Powder	Bronze (85/15)	Cobalt	Nickel
Size (μm)	70	35	5

Table 2
Weight distribution of sample groups.

Group	Bronze (g)	Cobalt (g)	Nickel (g)	Binder (g)	Total (g)
S1-S2	205	0	6	4	215
S3-S4	193	12	6	4	215
S5-S6	180	25	6	4	215
S7-S8	168	37	6	4	215

Fig. 1. a) Proportionally preparation of powders b) Mixing unit.

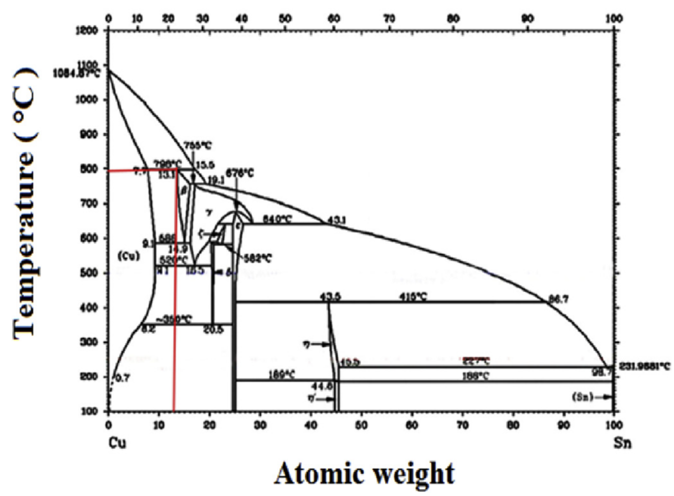

Fig. 2. Cu-Sn Dual Phase Diagram [9].

Fig. 3. a) Taking the samples into the sintering mold b) Sintering machine.

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