Consolidation of copper and aluminium powders by spark plasma sintering

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Abstract. Processing in the powder metallurgy route has emerged as an economical process for the production of near net shaped components with a wide range of desired mechanical properties suitable for various applications of industrial needs. This research work was conducted with an objective of studying the improvisation of density and hardness of Copper-Aluminium alloy prepared by spark plasma sintering. Cu-Al alloy with a composition of 95% copper and 5% aluminium was prepared by SPS process. SPS is a low voltage, DC pulse current activated, pressure-assisted sintering, which enables sintering at lower temperatures and shorter durations. The combination offered by Cu-Al alloy of high strength and high corrosion resistance results in their applications under a wide variety of conditions. The density and hardness of the prepared sample were measured by conducting appropriate tests. Apparently, the values of hardness and density of the specimen prepared by SPS seemed to be better than that of conventional sintering. The experimental procedure, testing methodologies and analysis are presented.

1. Introduction
Powder metallurgy process is a rapid, economical and large volume production method for making precision components from powders [1]. Copper-aluminium alloy possesses good strength and exceptional corrosion resistance, which enables its usage in components for high strength & temperature applications in automobile, aerospace and machine tool sectors [2][3]. Spark Plasma Sintering is a one-step sintering process which is very advantageous when compared to other sintering methods [4]. It is a DC pulse current activated sintering technique, which is potential to produce metals, alloys, ceramics and composite materials [5]. In SPS, pressure and temperature are applied simultaneously to the powder, thus there is no need of pre-compaction of the powder. Due to the simultaneous application of heat and pressure, the spark plasma sintered specimens achieve very high densification and superior properties which are very difficult through conventional sintering [6]. SPS utilizes uniaxial force and pulsed-DC
voltage. It allows attainment of restricted grain size during sintering, thereby enabling one to achieve better mechanical properties. This is achieved by employing a rapid heating rate and lowering the holding time and sintering temperature [7] [8]. By using SPS, specimens of higher relative density can be sintered at a lesser time when compared to other sintering methods [9-11]. Thus, this research work was conducted with an objective of studying the improvisation of density and hardness of Cu-Al alloy prepared by Spark Plasma Sintering.

2. Materials and methodology used

2.1. Materials

2.1.1. Aluminium and copper powders. Figure 1 and figure 2 shows the commercial grade aluminium and copper powders used for the preparation of the sample respectively.

![Figure 1. Aluminium powder.](image1)

![Figure 2. Copper powder.](image2)

2.2. Methodology

The methodology followed during this research work is as follows.

1. Selection of powders
2. Mixing of powders-Using Ball Mill
3. Sintering of metal powder-Using Spark Plasma Sintering
4. Measurement of density and hardness-Using Shimadzu machine & Micro Vickers hardness testing machine.

2.3. Experimental procedure

Figure 3 shows the Process flow of this research work.

![Figure 3. Process flow.](image3)

2.3.1. Composition and weighing of powder. The sample size was decided to be 60g with a composition of 95% copper and 5% aluminium. Thus the percentage in weight was calculated accordingly.
Commercial grade copper powder of 57g and aluminium powder of 3g was weighed using a Shimadzu weighing machine and taken for the experiment.

2.3.2. Mixing of powders. The two powders were mixed using a ball mill for 8 hours. The powders were taken in a glass bottle along with ceramic balls. The ceramic balls help in reduction of powder size and also in mixing of the powder particles.

2.3.3. Spark plasma sintering. Figure 4 shows the Spark Plasma Sintering machine used to sinter the Cu-Al alloy powders.

![Spark Plasma Sintering machine](image1)

**Figure 4.** Spark Plasma Sintering machine.

Graphite die of diameter 30mm was chosen. The mixed powder was filled in the graphite die. The punches, made of graphite were insulated with a layer of graphite sheet. It was then inserted into the die. The use of graphite sheet enables easy removal of the sintered specimen from the die. It also helps in forcing the current to pass through the powder particles. Then the set up was placed in the SPS chamber, and the process parameters were set. A temperature of 700°C, 40MPa pressure, heating rate of 100°C, and a holding time of 10 minutes were set. A vacuum was created in the SPS chamber before sintering, which avoids reaction with hydrogen, nitrogen, and oxygen, especially for metallic materials. The temperature of the walls of graphite die was measured using a thermocouple. Once the sintering got started, pressure and temperature were applied simultaneously to the powder particles. In seven minutes, the temperature reached 700°C, and the pressure reached 40MPa. The specimen was retained for 10 minutes at this temperature and pressure for achieving homogeneous structure. This stage is shown in figure 5. Then it was allowed to cool for about one hour and the sintered specimen was removed off the die. The specimen was later polished to get rid of the graphite sheet stuck to it. Figure 6 shows the measurement of the diameter of the specimen, which was equal to 30mm.

![Diameter specification of specimen](image2)

**Figure 6.** Diameter specification of specimen.
2.3.4. Measurement of Hardness. The micro hardness of the specimen prepared was measured using a micro Vickers hardness machine which is shown in figure 7. Emery sheets were used to polish the sample. A diamond with pyramid indenter was used for measuring the hardness of the specimen. The hardness values were measured at different points, and the average value was calculated.

2.3.5. Measurement of Density. The density of the prepared specimen was measured by Archimede’s principle using SH1MADZU machine. The machine has a least count of 0.001mg and an accuracy of ±0.01 mg. Density of the specimen was calculated five times, and the average value was computed.

2.3.6. Optical Microscope Image. The sintered specimen was polished using emery sheets and disc polishing machine. Nitric acid was used as etchant and then the microstructure was analyzed using an optical microscope at a magnification of 100X. Figure 8 shows the microstructure of the specimen. It shows the development of dendritic colonies of β particles in α matrix of copper [12].

![Figure 7. Micro Vickers hardness machine.](image1)

![Figure 8. Microstructure of specimen.](image2)

3. Results and comparison

3.1. Density

3.1.1. Calculation of theoretical density. Theoretical density was calculated with the below mentioned formula.

\[
\text{Theoretical Density of the alloy} = 100\left[\frac{\% \text{ of Cu}}{(\rho_{\text{Cu}})^{1} + (\% \text{ of Al}) \left(\rho_{\text{Al}}\right)^{1}}\right] = 100\left[\frac{95\left(8.96\right)^{1} + 5\left(2.699\right)^{1}}{1}\right]
\]

Hence the value of theoretical density was calculated to be 8.02876 g/cc.

3.1.2. Measurement of actual density. The density of the sintered specimen was measured using a Shimadzu machine. The procedure of finding density using a SHIMADZU machine is as follows. The mode of the machine was set to density-mode. Then the weight of the specimen was checked. Following that a float was connected to the hook below the machine, which was kept in a beaker of water. The specimen was then placed on the float and the density readings were noted down from the digital display. The density of the specimen prepared by spark plasma sintering was found to be 7.91g/cc. The same specimen was also prepared by conventional sintering techniques. The density of the conventionally sintered specimen was measured to be 6.80456g/cc. Figure 9 shows the comparison of density of the Copper-aluminium alloy prepared by conventional sintering and spark plasma sintering.
3.2. Measurement of hardness

The hardness of the sintered specimen was measured using a Vickers micro hardness tester. Hardness was checked from the periphery to the core of the specimen and the average value was noted down. The hardness of the specimen prepared by spark plasma sintering was found to be 90.3HV. Also, the same specimen prepared by conventional sintering method, and its hardness was found to be 83HV. Figure 10 pictorially compares hardness of the specimens prepared by conventional sintering technique and SPS.

4. Conclusions

Cu-Al powders were sintered using the spark plasma sintering technique. The powders were sintered at a pressure of 40 MPa and a temperature of 700°C. This technique results in higher density (7.91 g/cc) of sintered Cu-Al alloy with increase in hardness (90.3 HV). A relative density of 98.52% was achieved by using SPS technique. This unique technique helps in effective powder consolidation at relatively low operating temperature and pressure with minimal holding time facilitating for a higher rate of production.

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