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The Effect of Sintering Temperature on Components Prepared by Cu Powder Mixed with Binder

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Abstract. Copper is one of the most widely used material for thermal conductivities, fuel cells, sensors, processor chips of high-speed computer, and applications which require miniaturization, sophisticated design, and improved thermal management/electrical conductivity. In the powder metallurgy, manufacturing of more difficult to machine parts are produced by this method. In this research article, water atomized copper powder is selected and blended with the aqua-based binder, which is placed in a die and compacted with minimal pressure. The samples were sintered in both air and nitrogen with varying three sets of 860, 980, 10000C temperatures. The fabricated components were characterized by hardness, density, porosity by various tests.

INTRODUCTION

Applications of higher thermal conductivities Copper is the most widely used material for high thermal conductivity applications. Copper is more difficult to extrude, stamp, machine, or cast than aluminum, hence it is commonly processed with powder metallurgy techniques. R. M. German et al., [1] and J.L. Johnson et al., [2]Indicated the combination with a net-shape methodologies viz. Metal Injection Molding(MIM), complex heat sink components, fuel cells, sensors, high-speed computer processor chips, and applications which require miniaturization, sophisticated design, and improved thermal management/electrical conductivity with optimized features can be manufactured. It is a predominantly appropriate material for thermal management applications due to its high thermal conductivity and relatively high sintering activity. J.L. Johnson et al., [2] have reported the feedstock created by copper powder in MIM process have appreciable development and can be done in different process. MIM is a cost-effective process in allowing necessary freedom in design and fabricating in high quantities for microelectronics requiring heat sinks. From several years the uses of copper powder (unalloyed) in electronics systems, especially in the dissipation of heat are made out of the MIM process by Chan, T Y et al., [3], and German, R. M, et. al., [4]. In commercially, copper powder is available in many types and have adequately proven in conventional molding with binder systems. Attaining high conductivities and high sintered densities are a prime challenge, which can be achieved by attaining nearly full density sintering while reducing oxygen and other impurities to a very minimum level.

METAL INJECTION MOLDING PROCESS

The metal injection molding method consists of several stages that are compounding (mixing of metal powder and binder), injection molding, debinding and sintering. A homogeneous feedstock has to be formed by thorough mixing of binder and metal powder. The more important in this process is binder because in this process the powder has to flow and maintain some adequate permeability which is the most necessary in Metal Injection Molding process expressed by Abolhasani H et al., [8] and J.L. Johnson [9]. A homogenous feedstock is injected into a mold which takes the shape of the mould that part is known as green part. The green parts have to undergo,debinding process in which the binder will be removed the parts previously molded and known as green parts. It is the essential

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step among the entire process of MIM, debinding is the process which can determine the process was success or failed. The specimen after debinding stage was called as a brown part. The brown part has to undergo sintering, in which the residual binder will be removed and the powder particles will be bonded to form a sintered part detailed by by S. Banerjee et al., [10] and Jamaludin MI et al., [11]. The gain the mechanical properties the part should undergo this process and the part is called as sintered body. As discussed earlier in this process manufacturing of complex designed parts, precision parts, could be manufactured with cost effective manner in the production of high volumes. Improvements of binders will result in faster debinding and cost effectiveness with little environmental impact expressed by K. Zhou et al., [6].

MIM is cost effective for the production of components of complex shape and size. This process is capable of producing parts of small size with complexity in shapes from different type of materials like plastics, metals, composites, inter-metallic compounds, and ceramics. The important inspiration by using different binder systems have accomplished the production rate of MIM components. The community's among the MIM analysis were trying to improve unique system of binder. Jamaludin MI et al., [11] have derived to improve process and quality control requires a wider understanding on the development of binders and the role of variables. The example of complex design component made from MIM as given in figure 1. It was designed for the application of heat sink of LED made by R. Zauner et al., [12].

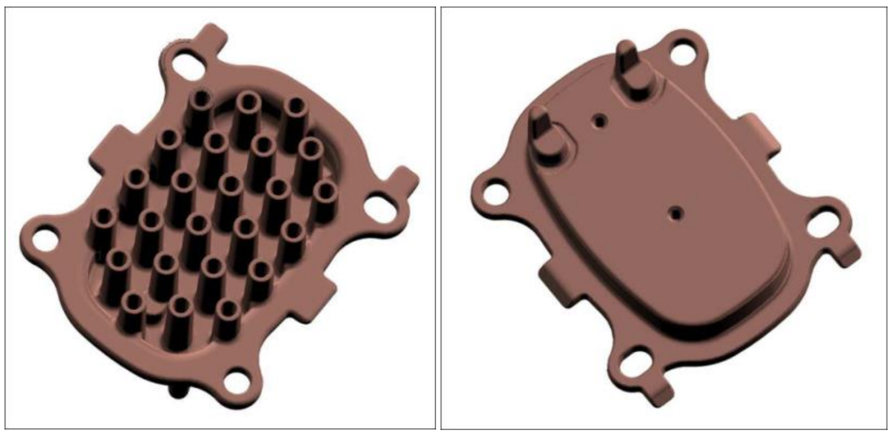

FIGURE1. LED heat sink [12]

Advances in Metal Injection Molding (MIM)

Over last few years Metal Injection Molding has gained the significant credibility and become the industrial dominating process. The process of MIM depends on shaping and later sintering of particles as of the process of powder metallurgy explained by R.M. German [5]. Higher mechanical strengths can be achieved comparing with other process and also can produce more number of components even with design complexities. The concept of MIM relies on molding of plastic to the desired shape, form feedstock prepared from powder polymer material expressed by Abolhasani H et al., [8]. Metal Injection molding is like polymer injection molding, polymer mixed with metal powder explained by R.M. German, K. Zhou et al., and Zhu B et al., [5-7]. The production of complex designs in a large-scale with metals is much easy with the MIM process, comparing with other manufacturing process. The MIM process almost does not require post processing and also produces high precision that is the reason why MIM is drawing more attention

Metal Injection Molding ProcessCommon Defects

The process of MIM consists many steps of processing and proper concern has to be taken if else many defects occur while processing. The encountered defects would be caused by mechanical factors or factors related to processing. A study by J.L. Johnson et al.,explained the defects found in conventional polymer injection molding is similar to MIM parts. Due to improper selection of process parameters a greater number of defects would occur in molding of plastics [2].

Sintering Process

MIM process consists four steps of processing, in that sintering is the most important step which affects mechanical properties and density. The parameters of sintering are heating and cooling rate, holding time, atmosphere in furnace while sintering, temperature of sintering, have an effect on the mechanical and physical properties. The incorrect sintering parameters will cause an irregular in densities, the absorption activity of some parts, deteriorated mechanical properties and reduced service time was projected by R. W. Stevenson [13]. Also, if the best parameters don't seem to be chosen, enhanced sintering prices are often expected. According to M. Khajelakzay et al., and M. Javanbakhteta et al., higher temperature sintering showed austenitic microstructure, at the same time higher densities are obtained, also a sharp increase in density and porosity level has decreased [14, 15].

EXPERIMENTAL PROCEDURE

To overcome all this defeats authors tried to make a low pressure compaction process like powder metallurgy process. In powder metallurgy it requires a huge compaction pressure to compact the powder particles, shape and size are also the major constrain. Authors attempted to make a combination of both powder metallurgy and MIM process. In this process powder material is mixed with binder and the mixture is placed in the die and compacted with a minimal pressure to form the shape, the binder material is removed by debinding process and the debinded components are further undergone sintering process.

Material

In this paper copper powder is selected, the specifications of powder are as given in the table 1. The powder supplied by Innomet Powders, Mfg by Padmasree Enterprises, Hyderabad. The technique used to manufacture powder was water atomization. Water atomizing of metals is currently a commercially necessary methodology to attain fine particle distribution fora variety of materials. The general method is effective by intruding a dropping stream of liquefied metal with water jets imping to solidify into granules or powder from metal. Compared to less modern techniques like grinding and crushing water atomization presents a value effective and economical approach to manufacture powders. The binder used in the preparation of the object is an aqua based. The main reason for selection of this binder is it leaves no or very minimal number of residues after debinding.

TABLE 1. The specification of the powder

Powder Type	Particle shape	Sieve analysis		Shape	Apparent density
Copper	- 325 # (45 microns)	>45µm: 5% max.	>25µm: 40-60 %	Irregular	3.0 - 4.0 g/cc

Debinding and Sintering.

In this project debinding is done by a thermal debinding process. The binder was evaporating at the temperatures of 380^0 C,which was leaving no or very minimal number of residues after the thermal debinding process. The spacemen's were hold in the furnace with a temperature of 380^0 C for a time period 3 hours to remove binder material, after the specimen was sintered. From the literature 20% less than that of melting temperature is sufficient for sintering the samples by the process of powder metallurgy. Based on trial and error method the remaining temperatures and time were finalized. The detailed temperatures are given in the table 2. In the sintering process, the specimen was heated to a temperature of 1000^0 C and hold it for 3 hours for sample one. Another sample was heated to the temperature of 980^0 C and hold it for a time period of 4 hours. Another sample was heated to the temperature of 860^0 C and hold it for a time period of 4 hours. For all the samples inert atmosphere was maintained ie. Nitrogen gas was introduced to the furnace with a flow rate of 1 liter per min.

Some of the samples were sintered in the atmosphere, no specific gas was flowing inside of the furnace. Temperatures maintained areas of explained above. The table 2 explains the sample in detail about the sintering temperature, time and kind of atmosphere.

TABLE 2. Sample numbering and the sintering temperature, time and kind of atmosphere.

Sample no.	Temperature (^{0} C)	Time of Sintering (Hours)	Atmosphere
Sample 1	860	4	Nitrogen
Sample 2	980	4	Nitrogen
Sample 3	1000	3	Nitrogen
Sample 4	860	4	Air
Sample 5	980	4	Air
Sample 6	1000	3	Air

RESULTS AND DISCUSSION

Hardness

The measurement of hardness is to resist localized plastic deformation applied either by mechanical indentation or abrasion. The hardness of samples sintered in the inert atmosphere and samples sintered in the air atmosphere is shown in the figure 2. The hardness was measured on the micro hardness testing machine. The harness possessed by the samples sintered in air atmosphere was very high because of carbon formation. And the samples after sintering became brittle in nature. The reason is copper powder had reacted with atmosphere and carbon formation taken place and bonding between the grains was not formed. The bonding between the grains was containing carbon. The hardness possessed was high, but have very less strength comparing with copper material. The samples sintered in anitrogen atmosphere were given the hardness as of like the copper material. As the sintering temperature increases the hardness was also increased with respectively. It is observed with both the conditions, i.e., with inert atmosphere and air atmosphere.

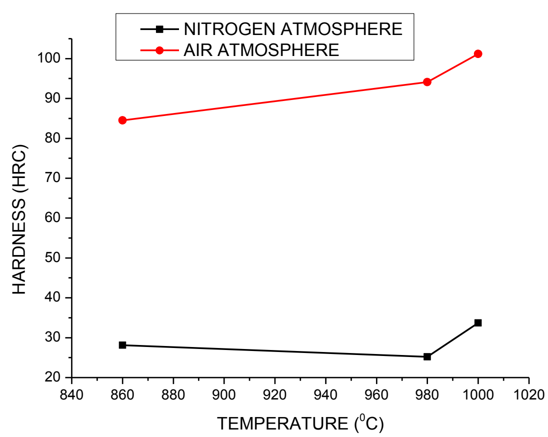

FIGURE2. Graph showing the effect of sintering temperature on Hardness.

Density

The density is defined as the volumetric mass density, of a metal is its mass per unit volume. Density is defined mathematically as mass divided by volume. Figure 3 expresses the density of samples sintered as explained in table 2. The porosity of the samples is high since the samples are mixed with a binder and not compacted to high pressure, this is the reason for obtaining low density. Density was increased with the increase in temperature and also found that the atmosphere in the furnace had also affected the density. While the increase in temperature the powder particle had liquefied, that is the reason for an increase in density. Inert atmosphere sintered samples were having comparatively good densities, with an air atmosphere sintered samples.

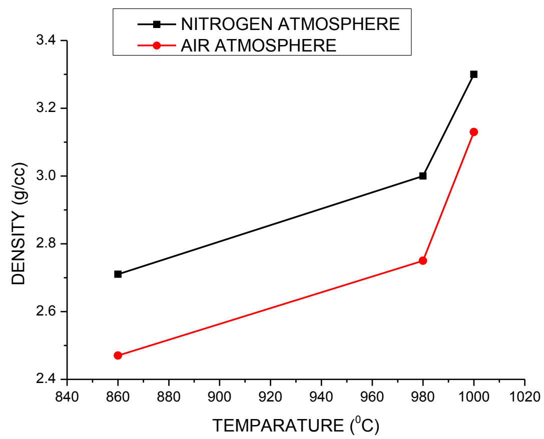

FIGURE3. Graph showing the effect of density of samples after sintering.

Porosity

Definition of porosity is the ratio of pore volume to the whole nominal volume of a body of porous, and is usually expressed as a percentage or a decimal. From the figure 4 that can be observed that the specimen prepared in this are having porosity. With increase in temperature we observe a decrease in porosity.

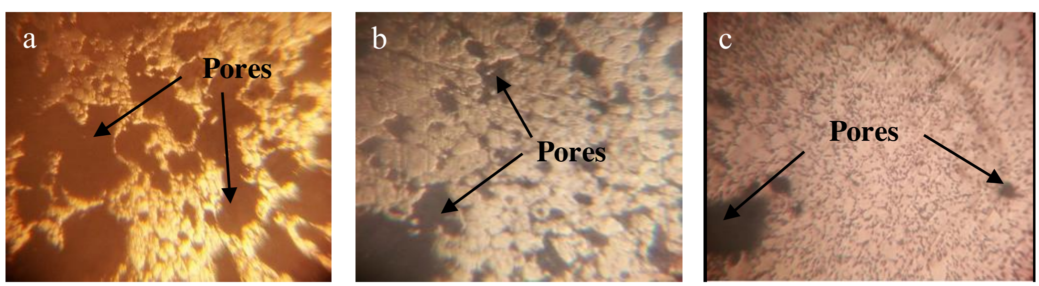

FIGURE 4. Optical Microscope images of sintered samples. (a) Sintered at a temperature of 860 ^{0} C. (b) Sintered at a temperature of 980 ^{0} C. (c) Sintered at a temperature of 1000 ^{0} C.

CONCLUSIONS

The results show that the sintering temperature plays a vital role as the atmosphere is also having an effect on the results. The majority of results depends on the variation of the temperature as the samples sintered in air atmosphere had obtained higher hardness values compared with sintered in a nitrogen atmosphere. The samples were sintered in the nitrogen atmosphere were possessing near the value of hardness of pure copper, but samples sintered in the atmosphere were possessing higher values of hardness, the material had reacted with air and carbon formation was formed the material is also converted to a brittle material. It's also observed that the density has also increased with increase in temperature. The samples sintered in nitrogen atmosphere were having higher density compared with samples sintered with air atmosphere and the porosity also decreased with increase in temperature.

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