Jurnal Ilmiah PPI-UKM
Scientific Journal of PPI-UKM
Persatuan Pelajar Indonesia
Universiti Kebangsaan Malaysia
Selangor, Malaysia

Scientific Journal of PPI-UKM

Sciences and Engineering

ISSN No. 2356 - 2536

Characteristics of FeCuAl Powder Compacts Sintered at Different Schedules

M. M. Rahman, H. Y. Rahman, N. H. M. Zabri*

Centre for Advanced Materials (CAM), College of Engineering, Universiti Tenaga Nasional, Putrajaya Campus, 43000 Kajang, Malaysia

Abstract

This paper presents the characteristics of FeCuAl powder compacts formed through uniaxial die compaction process and sintered at different schedules. Elemental iron, copper, and aluminum powders were blended mechanically and the blended powder mass was subsequently compacted at 30°C (cold compaction) and 150°C (warm compaction). The defect-free green compacts were then sintered at argon gas fired furnace at a heating/cooling rate of 10°C/min by varying the sintering time and temperature. The sintered samples were characterized for their physical, electrical, and mechanical properties and their microstructures were evaluated. The results revealed that higher relative density was obtained when the samples were sintered at 500ºC for 30 minutes. However, stronger products were generated by sintering the samples at 700ºC for 90 minutes.

Keywords: Sintering schedule, mechanical characteristics, microstructures, powder forming

1. Background

In order for the mixture of two or more powders to function effectively, it must be a coherent powder mass, which is termed as an alloy. Existing practice of alloy forming is either through foundry process or mechanical alloying (mixing through high energy ball milling). Alloying through foundry process requires a huge quantity of thermal energy to melt the matrix as well as the other alloying elements. Foundry process can produce only alloy billets which require a series of further metal forming steps, i.e., casting, forging, machining, surface finishing, etc. to produce an end product. On the other hand, mechanical alloying could be used to form material in a small volume in powder form which also requires a lengthy series of further processing step to produce an end product.

Iron (Fe), copper (Cu), and aluminum (Al) are the regular metals that are used in alloy industries where iron is the highest demand in the market. However, pure iron is highly corrosive, copper is ductile but too soft, and aluminum is ductile and expensive material lead to a lot of researchers to find out the solution in order to overcome the weaknesses of these three metals in full filling new metal demand for new product design [1].

Powder metallurgy (p/m) is the production of solid components from powders by compaction and sintering [2]. It is a new generation of manufacturing process with a lot of advantages, i.e., production of complex shape parts with exact dimensions in lower manufacturing cost, minimization of scrap metal losses, and shortens manufacturing steps hence lower overall production cost [3].

Powder metallurgy can be divided into isostatic pressing either in hot (HIP) or cold (CHP) condition, powder forging, injection molding (MIM, PIM), and powder compaction [4]. Powder compaction technology has advanced significantly over the past decades [5] and is considered as an alternative lower cost process to machining, casting, stamping, forging, and other similar metal working technologies [6].

In the late 90's, a breakthrough in the powder compaction study was made by the revelation of thermal load in giving significant impact on density of the green compact. The most popular method of compaction with the combination of thermal load is the warm powder compaction where the powder mass is formed in the range of 100°C to 150°C working temperature [7].

The basic principle of sintering is the achieving rate of the desired degree of bonding among the particles in powder compact [8]. The heating and cooling rate, sintering temperature, and holding time play important roles in controlling the microstructure and porosity that determine the degree of particles bonding. In solid state sintering, the bonding among particles requires material transport by volume diffusion (migration of vacancies), grain-boundary diffusion, surface diffusion, viscous or plastic flow, and evaporation/condensation of atoms on the surfaces. The densification and the strengthening of particles inside the metal powder compact reflect the properties of the sintered component. The sintered strength and hardness implies on the degree of particles bonding and

* Corresponding author. Tel.: N/A; fax:N/A.
E-mail address: Mujibur@uniten.edu.my.

particles arrangement at the surface of the compact, respectively.

It is evident from the brief explanation above that both alloying methods are time consuming, energy ineffective, hence expensive. Since the metal powders (Fe, Cu, Al) considered in this research are having different transport as well as thermo-physical properties, and sintering is one of the key steps in manufacturing a mechanical components through the powder compaction route, therefore the proper sintering schedule is an important factor in the full cycle of production process. No thorough study is found on the proper sintering schedule for the production of mechanical components from FeCuAl powder mixture through powder compaction route. Therefore, the objective of this paper is to investigate experimentally the effect of sintering schedule in manufacturing of components from FeCuAl powder mixture through powder compaction route.

2. Experimental Procedure

The investigation consists of four consecutive steps, i.e., feedstock preparation, green sample generation, sintering at controlled environment, and sample characterization. Iron powder ASC 100.29 of 20-180 µm particle size range was used as main powder constituent. The composition of copper was 7.5 %, aluminum was 0.5%, and the balance was iron powder. The main powder constituent and alloying elements were mixed mechanically for 60 minutes. The powder mass was filled into the cylindrical shape die cavity, then all the die assembled together with the powder mass was heated up to 150ºC and kept for 30 minutes for uniform heating of the powder mass and the die assembly in the case of powder forming at elevated temperature. However, heating system was not activated in the case of powder forming at room temperature, 30°C.

The filled powder mixture inside the die cavity was formed by an axial force of 130 kN simultaneously from upper and lower punches. The defect-free green compacts were subsequently sintered using custom made argon gas fired sintering furnace (HT3-1400-SIC) at a rate of 10°C/min for 90 minutes. The sintering furnace was mounted with ceramic tube of 50 mm outer diameter, 40 mm inner diameter, and 150 mm of hot length. All the samples were sintered at 500°C, 600°C, and 700°C, respectively. The sintered samples were characterized for their physical, electrical, and mechanical properties and their microstructures were evaluated. The relative density, electrical resistivity, and hardness were measured against the sintered samples formed at room temperature, i.e., 30°C as well as elevated temperature, i.e., 150°C. However, the flexure stress measurement was conducted against all the sintered samples formed at 150°C only. The microstructures of the samples formed at 150°C and sintered for 90 minutes at 500°C, 600°C, and 700°C were evaluated.

3. Results and Discussion

Relative densities of samples formed at room temperature (30°C) and elevated temperature (150°C), sintered at 500°C - 700°C for 30 - 90 minutes, respectively are shown in Figs. 1 and 2. It is clearly evident that sintered relative density is higher when the powder mass was formed at elevated temperature. Generally, sintered relative densities were also found to be lower when the samples were sintered at high temperature for longer holding time. The highest sintered density was measured at the sample formed at 150°C, sintered at 500°C for 30 minutes only. Powder forming at elevated temperature is proved to provide higher green density. Therefore, sintering of higher density samples ended up with higher sintered density.

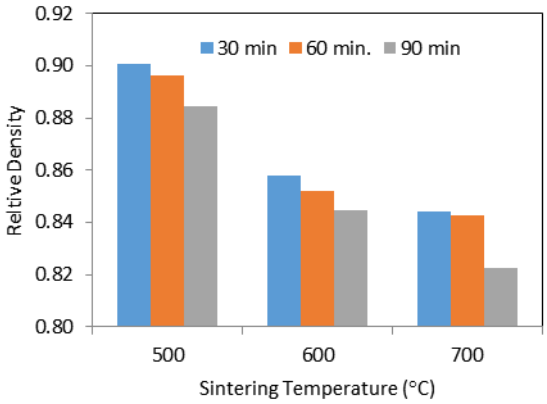

Fig. 1. Relative density of samples formed at 30°C and sintered for different holding times at different temperature

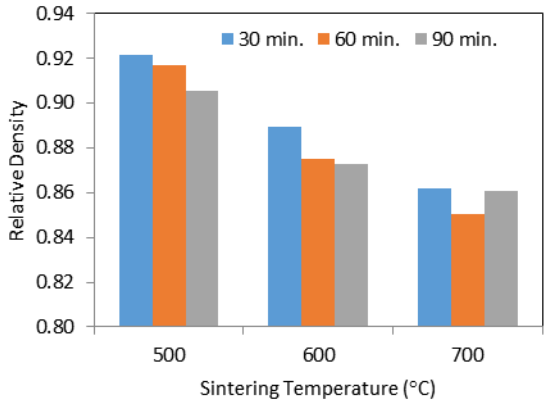

Fig. 2. Relative density of samples formed at 150°C and sintered for different holding times at different temperature

Electrical resistivity of sintered samples are depicted in Figs. 3 and 4. Overall, the resistivity data is less consistent. Generally, electrical resistivity is found to be lower when the samples were formed at room temperature regardless of sintering temperature. The lowest electrical resistivity was obtained at the sample formed at 30°C, sintered at 700°C for 60 minutes whereas the highest resistivity was obtained at the sample formed 150°C, sintered at 500°C for 30

minutes only. Higher resistivity means lower electrical conductivity hence high density sample must have lower electrical resistivity compared to low density sample. Rockwell hardness is depicted in Figs. 5 and 6. It is observed that the hardest sintered sample is formed at 150°C, sintered at 500°C for 90 minutes. However, the hardness is the indication of the bonding strength of the sample at the surface which does not really reflect the strength of the sample at a whole. Higher hardness means the presence of less pores at the surface which is a good indication of surface finish of the as pressed sample. The proper strength or ductility of a mechanical component is justified by its flexure stress or bending strength which is presented at the next paragraph.

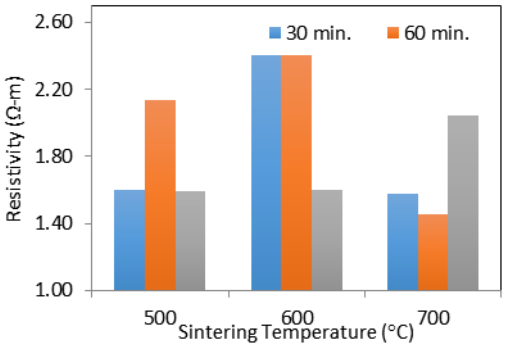

Fig. 3. Electrical resistivity of samples formed at 30°C and sintered for different holding times at different temperature

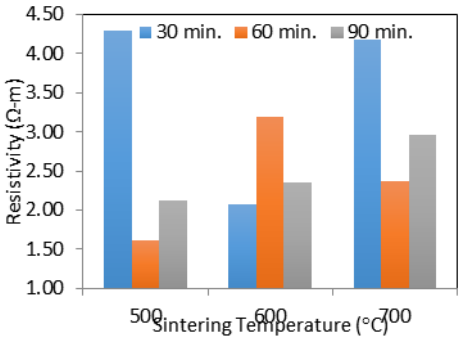

Fig. 4. Electrical resistivity of samples formed at 150°C and sintered for different holding times at different temperature

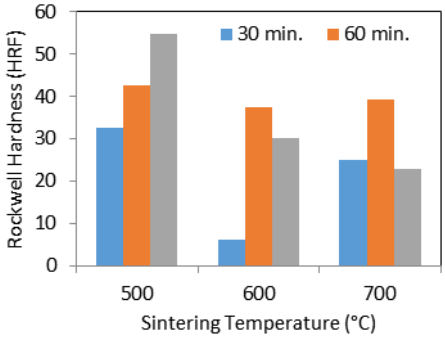

Fig. 5. Hardness samples formed at 30°C and sintered for different holding times at different temperature

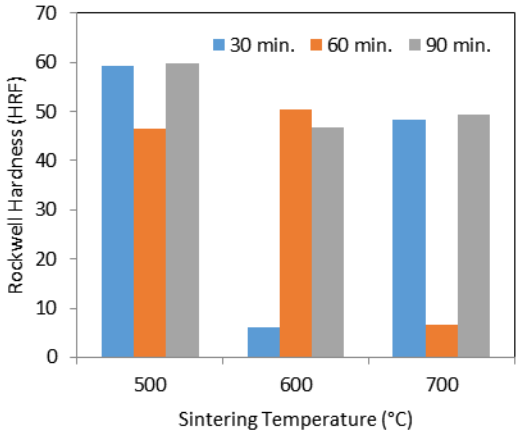

Fig. 6. Hardness samples formed at 150°C and sintered for different holding times at different temperature

The flexure stress or bending strength of the samples formed at 150°C and sintered at different temperatures for different times are shown in Fig. 7. It is evident that sample sintered at 700°C for 90 minutes is the strongest. This finding is also in line with the microstructures shown in Figs. 8 - 10. Samples sintered at 500°C and 600°C contain a lot of interconnected pores which require less transverse load to break the inter-particle bonding hence the bending strength is smaller. The microstructure of the sample sintered at 700°C shows the homogenous particle with perfect bonding among them compared to the other two samples. Melting temperature of aluminum is less than 700°C hence when the FeCuAl powder mass was sintered at above the melting temperature of aluminum, it melted and mixed sintering was taken place. The molten aluminum filled the inter-particle voids and assisted the Fe and Cu particles to bond strongly. Sintering the sample for a longer period also allowed the grain growth which could clearly be observed at the microstructure depicted in Fig. 10.

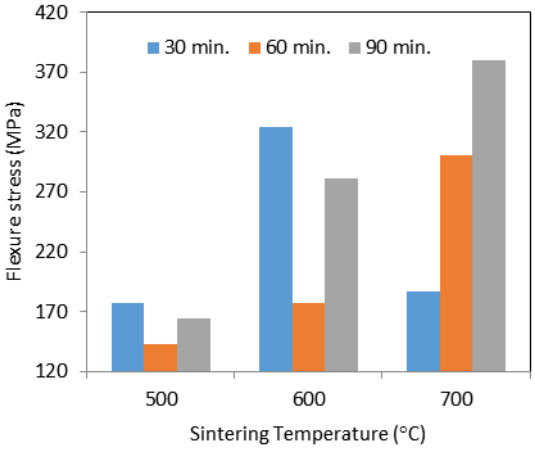

Fig. 7. Bending strength of samples formed at 150°C and sintered for different holding times at different temperature

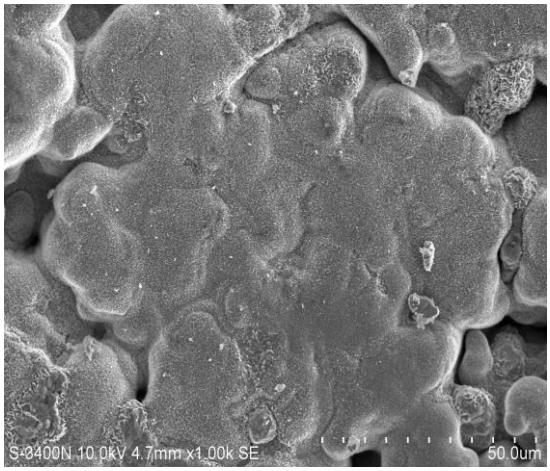

Fig. 8. Microstructures of sample formed at 150°C and sintered for 90 minutes at 500°C

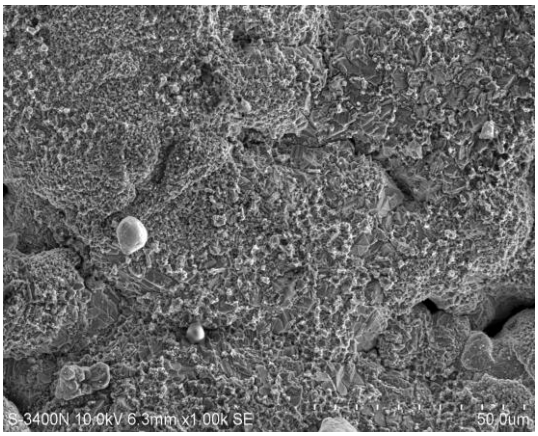

Fig. 9. Microstructures of sample formed at 150°C and sintered for 90 minutes at 600°C

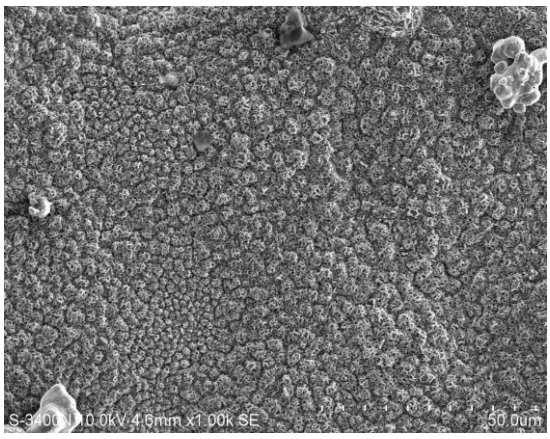

Fig. 10. Microstructures of sample formed at 150°C and sintered for 90 minutes at 700°C

4. Conclusions

Sintering schedule is found to affect the properties of final products of FeCuAl formed at room temperature as well as elevated temperature. The results also revealed that for FeCuAl powder mixture, the suitable sintering temperature is 700°C which led to better microstructure, lower sintered density means lighter end products, and higher ductility or bending strength.

Acknowledgements

This research is financially supported by Ministry of Education (MOE) Malaysia through the research project 20140117 FRGS.

References

[1] Sharma, D., K. Chandra and P.S. Misra, 2011. Design and Development of Powder Processed Fe-P Based Alloys. Materials and Design, 32: 3198-3204.
[2] Yamaguchi, K., N. Takakura and S. Imatani, 1997. Compaction and Sintering Characteristics of Composite Metal Powders. Journal of Material Processing Technology, 63: 364-369.
[3] Rahman, M.M. and S.S.M. Nor, 2009. An Experimental Investigation of Metal Powder Compaction at Elevated Temperature. Mechanics of Materials, 41: 553-560.
[4] Dowson, G., 1998. Introduction to powder metallurgy, EPMA education aid, MPR Publishing Services Ltd.
[5] Rahman, M.M. and A.M. Nor, 2014. Effect of Feedstock Preparation and Forming Temperature to the Characteristics of Green Compacts. Advanced Materials Research, 879: 245-250.
[6] Nor, S.S.M., M.M. Rahman, F. Tarlochan, B. Shahida and A.K. Ariffin, 2008. The effect of lubrication in reducing net friction in warm powder compaction process. Journal of Materials Processing Technology, 207: 118-124.
[7] Babakhani, A., A. Haerian and M. Ghambari 2006. On the Combined Effect of Lubrication and Compaction Temperature on Properties of Iron-Based P/M Parts. Materials Science and Engineering A, 437: 360-365.
[8] German, R.M.,1996. Sintering theory and practice. John Wiley & Sons, Inc.