Effect of Compaction Aspect Ratio on Wear Characteristics of Sinter Extruded Pure Copper Processed Through Powder Metallurgy Route

S. Shruthi, S. Venkatakrishnan, S. Raghuraman and R. Venkatraman

Abstract Powder metallurgy is widely used, unique manufacturing process resulting in a near-net shape. The parameters like, the compaction pressure, aspect ratio (height to diameter ratio), sintering conditions can be varied in order to achieve the required properties of the end product. In this research work, all the above parameters except the aspect ratio are fixed. Wear analysis is carried out on sinter-extruded copper samples are made for two different aspect ratios, i.e., 0.5 and 1. The experiments are conducted based on Taguchi's L18 orthogonal array by taking the aspect ratio, speed, and load as three important factors. The mass loss and COF (coefficient of friction) are the main results studied in this work and are supported by hardness and density measurements.

Keywords Powder metallurgy · Aspect ratio · L18 orthogonal array · Pin-on-disk method · Mass loss

1 Introduction

Powder metallurgy is a method of producing components of metals and composites from their powdered form. Components that are difficult to manufacture by conventional metal forming techniques due to its complex shape and geometry are manufactured in the powder metallurgy (PM) route, making the process simple, highly accurate, and facilitates for near-net shape manufacturing. Extensive studies in powder metallurgy are carried out to improve properties and behavior of metals tailor made for specific practical and industrial applications. As powder metallurgy process is a near-net shape manufacturing process it makes use of certain aspects of shake-making technology for powder compaction and it is followed by a consoli-

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dation process and further secondary processing is done on the material depending on the requirement. In this work, compacted samples are further subjected to sinter-extrusion. Size and shape of the initial compact, compaction pressure, sintering conditions, and soaking time are a few important factors that influence the properties of the end product. The factors like compaction pressure, sinter extrusion conditions, and soaking time are kept constant, while the compaction aspect ratio is varied. Compaction is done in two different aspect ratios, i.e., 0.5 and 1.

Taguchi experimental designs, often called orthogonal arrays (OAs), consist of a set of fractional factorial designs which ignore interaction and concentrate on main effect estimation. This procedure generates the most popular set of Taguchi designs. Taguchi uses the following convention for naming the orthogonal arrays: La(b^c), where a is the number of experimental runs, b is the number of levels of each factor, and c is the number of variables. Designs can have factors with several levels, although two and three level designs are the most common. The L18 design is the most popular. The L18 OA consists of one factor at 2 levels and up to seven factors at 3 levels each [1]. The first factor with 2 levels in this experiment is aspect ratio and speed and load are factors with 3 levels each.

Various experiments have been conducted by various researchers to find the effect of parameters like temperature, sliding velocity, surface finish on the wear characteristics of copper. Copper and its alloys have good wear resistance as it finds its application in construction, automobile, and aircraft industries. Copper, due to its high wear resistant, gives promising results when used as a material for bearings. Wear resistance of copper further gets enhanced when it is alloyed. The ranking of sliding wear resistance in descending order is CuBeNi > CuBe > CuCrZr ~ CuNiSiCr > CuZr ~ CuCr > Cu [2]. It is also found that the wear resistance of the copper-based alloys increases with decrease in normal load and the increase in hardness [2]. Dewan Muhammad Nuruzzaman and et al. have found that during friction process, copper or aluminum specimens takes less time to stabilize as the normal load or sliding velocity increases [3]. Recently it is found that, powdered materials impregnated with the inorganic fullerene like IF-WS2 nanoparticles allow to improve considerably the tribological behavior of powder materials. Confinement of the IF in the pores of the powder matrix and its gradual furnishing to the contact surface decreases the ploughing of the rubbed surfaces [4].

This work primarily concentrates on the wear analysis of sinter-extruded copper samples that are made from compacts of two different aspect ratios. Copper used in this experiment is processed through powder metallurgy route and is used for studying the effect of aspect ratio on COF and mass loss by pin-on-disk apparatus. With regard to copper it is expected to have low coefficients of friction. It must also be understood that, a greater mass loss means that a lot of debris gets collected on the bearing surface, degrading the surface properties and thereby increasing the friction between the surfaces as COF is a function of surface finish also. This shows that it is vital to study the wear characteristics of Copper with stringency. Powder metallurgy is a growing field and it is under wide research, to manufacture bearings through powder metallurgy route.

Table 1 Wear test parameter specifications

S. no	Factors	Levels		
		1	2	3
1	Speed (rpm)	300	600	900
2	Load (Kgf)	0.5	1.0	1.5
3	Aspect ratio	0.5	1.0	–

2 Experiment

The experiments are performed using 99.95 % pure copper powder with particle size 50 µm. The copper powders are compacted to a cylindrical form of diameter 25 mm and heights 12.5 and 25 mm. The amount of powder required by mass for compaction is found using the compressibility chart for copper powders from the ASM Handbook Vol. 7 [5]. The compacted copper samples are then sinter-extruded at a temperature of °C [5] to a diameter of 12 mm and then later annealed at 425 °C for 2 h [6]. The density after each stage is found by Archimedes principle, through a density measuring device, Shimadzu AUX 220. Also, the hardness of samples were tested for both 1 and 0.5 aspect ratio samples.

The wear test is conducted based on Taguchi's L18 orthogonal array, with three factors. The factors considered are aspect ratio, speed, and normal load and are shown in Table 1.

As per American Society for Testing and Materials (ASTM), G-99 is the standard test method for wear testing using Pin-on-Disk apparatus. This standard procedure is followed during this experimentation [7].

3 Result and Discussion

The extruded specimens are subjected to sliding wear test on pin-on-disk instrument. The values of coefficient of friction and mass loss for different aspect ratios, speed, and load are shown in Table 2. From the values of coefficient of friction obtained for 0.5 aspect ratio specimens, it can be inferred that, for a constant speed, coefficient of friction increases till load is 1 Kilo gram force (Kgf) and decreases when load is 1.5 Kgf; but this trend is not seen for 1 aspect ratio sample. It is found that the Vickers micro hardness value 0.5 and 1 aspect ratio specimens are 96.8 and 90.9, respectively. Figure 1 shows the line plot of coefficient of friction versus load and angular speed for (a) 0.5 aspect ratio sample (b) 1.0 aspect ratio sample.

For 60–40 brass with steel, it is found that wear rate varies independently with speed [8]. In this study, Fig. 2 shows irregular trend in variation of mass loss with respect to angular speed. It can also be inferred from the same graph that, mass loss also varies irregularly even with load. The results of this experiment are in accordance with [8]. With the experimental results, it can be concluded that wear test of pure copper processed through powder metallurgy route also exhibits the

Table 2 Values of coefficient of friction for different aspect ratio, speed and Load

	Coefficient of friction (μ)					
Aspect ratio	0.5			1		
	Speed (rpm)					
Load (kgf)	300	600	900	300	600	900
0.5	0.527835	0.700282	0.867933	0.530062	0.794674	0.985044
1	0.952104	0.923539	0.884621	0.693131	0.552685	0.448697
1.5	0.823486	0.730414	0.75434	0.735431	0.411171	0.475493
Average	0.79607			0.62515		

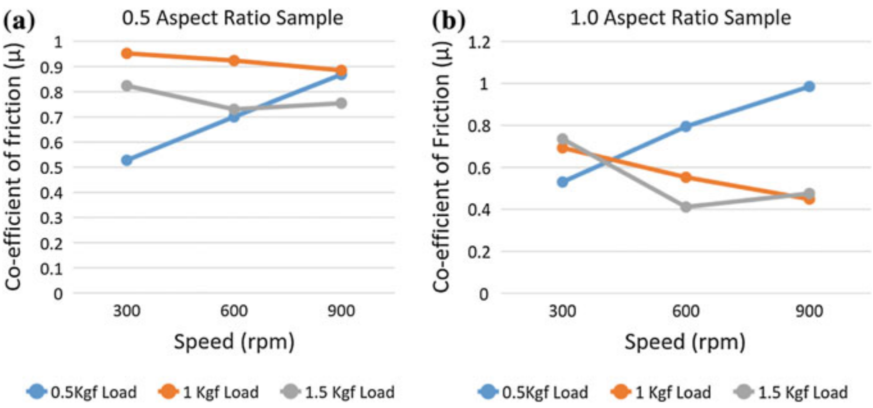

Fig. 1 Coefficient of friction versus load and angular speed for **a** 0.5 aspect ratio sample **b** 1.0 aspect ratio sample

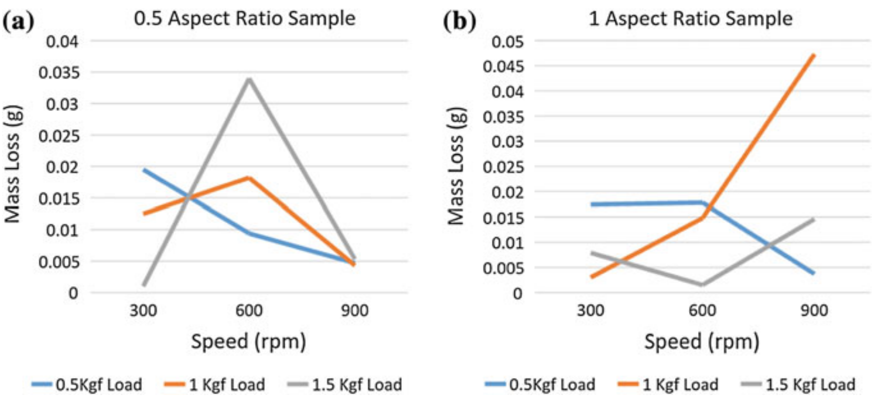

Fig. 2 Mass loss versus load and angular speed for **a** 0.5 aspect ratio sample **b** 1.0 aspect ratio sample

Table 3 Values of mass loss for different aspect ratio, speed, and load

	Mass loss (g)					
Aspect ratio	0.5			1		
	Speed (rpm)					
Load (kgf)	300	600	900	300	600	900
0.5	0.0195	0.0094	0.0047	0.0174	0.0178	0.0037
1	0.0125	0.0182	0.0043	0.003	0.0148	0.0473
1.5	0.001	0.034	0.0053	0.0079	0.0015	0.0146
Average	0.00870			0.01422		

Table 4 Vickers hardness and density values for different aspect ratio

Aspect ratio	Vickers hardness (HV)	Density (g/cc)	Relative density in % (with respect to solid copper density)
0.5	96.8	8.8446	98.71
1.0	90.9	8.5011	94.88

same trend. Table 3 shows the values of mass loss for different combinations of aspect ratio, speed and load parameters.

Densification achieved by 0.5 aspect ratio sample is greater than 1.0 aspect ratio sample which is evident from the form the density values shown in Table 4. In unidirectional compaction, powders close to the punch and die walls experience much more force than those at center and hence the lower half. The pressure difference increases with length of the specimen and there is no uniformity in the green density of the specimen [9]. In other words, 1.0 aspect ratio specimens have higher porosity content than 0.5 aspect ratio sample. Due to the reasons: high porosity content, lesser densification, and low hardness values, mass loss in wear test is higher for 1.0 aspect ratio than 0.5 aspect ratio specimens. Thus, for manufacture of powder metallurgical components for lower wear rate and higher densification, lesser aspect ratio can be preferred.

4 Conclusion

- Coefficient of friction and mass loss due to wear varies irregularly with variation in load and speed conditions.
- For pure copper specimens processed through powder metallurgy route, higher densification is achieved for lower aspect ratio.
- Porosity content in powder metallurgical specimens increases with aspect ratio.
- Density and hardness values are higher for samples of lower aspect ratios.
- Specimens of higher aspect ratios exhibit higher values of mass loss during wear test.

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