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Conventional sintering of copper powder with and without addition of different weight percentage of aluminium powder

Cu-Al powder for different weight percentages of 5, 10 and 15 was ball milled for 30 min. The compacts of pure Cu, Cu-5 wt.% Al, Cu-10 wt.% Al and Cu-15 wt.% Al was compacted using metallic die by applying 70 kN force. The compacts were kept in a heat treatment electrical resistance furnace at 600°C for 8hr for conventional sintering. The conventional sintered compacts were tested to measure the behaviour of the alloy. The density of the sintered compact of Cu, Cu-5 wt.% Al, Cu-10 wt.% Al and Cu-15 wt.% Al were calculated using water displacement method. The surface topography of the sintered compacts were analysed using optical metallurgical microscope for the magnifications of 100x. The microstructure of the copper is exhibited cellular structure. The quantity of the secondary phase increases with increasing Al content. The hardness values of respective compacts were measured using Wilson micro Vickers hardness testing machine. The micro Vickers hardness values of Cu, Cu-5 wt.% Al, Cu-10 wt.% Al and Cu-15 wt. % Al were measured as 38.78 ± 1.2, 21.22 ± 2.0, 24.54 ± 3.7 and 39.44 ± 3.5 HV1 respectively. The compression strength of the sintered compacts of pure copper, copper with 5, 10 and 15 wt.% Al were determined using universal testing machine. The compression strength of Cu-15 wt.% Al is higher than copper and other sintered Cu-Al compacts.

Keywords: Conventional sintering, copper, aluminum, bronze, microstructure, mechanical characterization.

1.0. Introduction

Copper based sintered materials are extensively used in various industries due to their low cost and required minimum metal working process. In general sintered materials are mainly utilized in sliding bearings and are produced unique properties than that of standard melting casting technique [1]. The main advantages of sintered materials used in bearings, structured parts, filters and electrical parts. It can also be used as self-lubricant layer on the friction surfaces and wear resistance due to its presence in the pores of the material and addition of special additives respectively [2–4]. The bearings of sintered materials are having low coefficient of friction (0.01–0.04) and operate reliably at 60-120°C temperature without lubrication for 3000-5000h of operation [2]. Copper alloys, aluminium alloys and magnesium alloys are predominantly used in MMCs. The alumina, nickel, carbides and oxides are used as reinforcement particles in metal matrix composites while manufacturing sintered MMCs [5–9].

To provide better wear resistance, high fatigue strength and compatibility of engine bearings the dispersed alumina (0.5-2 %) particles added with their base metal [10]. Adding alumina particles to copper matrix material increased the wear resistance and refractory properties compared to pure copper matrix composites. The study recorded that the wear rate of copper matrix composite increased three times with increase in Al_2O_3 in the range of 1 wt.% to 5 wt.% than that of copper matrix material without adding additives [11]. The properties of sintered bronze based compacts can be improved by adding reinforcing particulates in the bronze based metal composites. The various reinforcements like; Tic [12], Sic [13], WC [14], Al_2O_3 [15, 16], borides and metal oxides are widely used as reinforcement materials due to their high wear resistance and hardness. Tu et al. [17] investigated friction and wear properties of Cu–Fe_3Al sintered composites under dry sliding. It was recorded that the friction coefficient of Cu-Fe_3Al composites were independent of the different sliding velocity and contact pressure. The wear resistance of the composite increased with increase in Fe_3Al content at lower contact pressures. The wear rate and friction coefficient of Cu-Fe_3Al is decreased with the sliding velocity. In this study, investigated the effect of different weight percentage (0, 5, 10 and 15 wt.%) of alumina additives to sintered aluminium bronze to characterize their mechanical and tribological properties.

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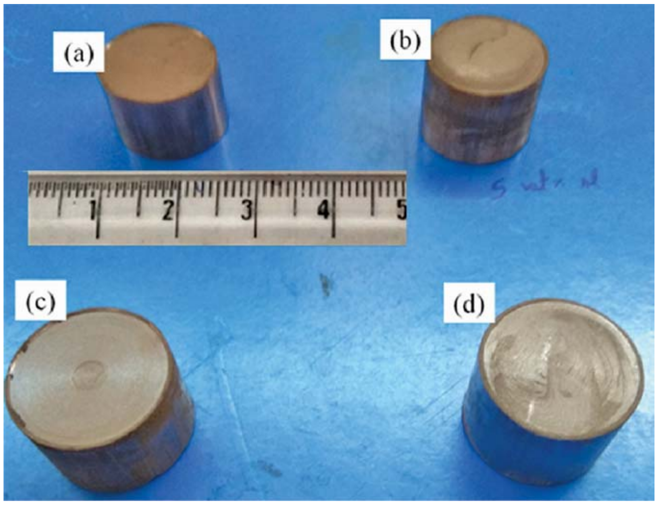

Fig.1: Photographs of conventional sintered compacts (a) pure copper, (b) Cu-5 wt.% Al, (c) Cu-10 wt.% Al and (d) Cu-15 wt.% Al

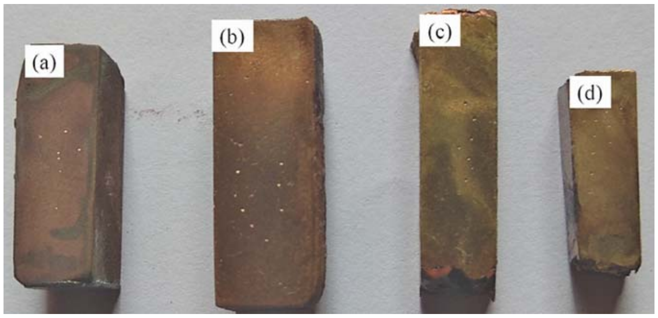

Fig.2: Samples for microstructure and hardness test (a) pure copper, (b) Cu-5 wt.% Al, (c) Cu-10 wt.% Al and (d) Cu-15 wt.% Al

2.0. Experimental procedure

2.1 Ball milling of Cu-Al powder particles

Pure copper, copper with different wt.% of Al (5, 10 and 15 wt.%) powder compositions were initially ball milled with ceramic balls (5 mm diameter). The ratio of ball to powder was equal to 1:10 and the rotating speed of the jar was 300 rpm.

2.2 Preparation of Sintered Compacts

Uniaxial die casting is used for mass production and shaping metallic powders. The powder metallic particles with different compositions are filled in a rigid metallic die under the application of axial pressure applied through punches. In this study, aluminium bronze with 0, 5, 10 and 15 wt.% of Al were prepared by using uniaxial die casting method under 70 kN pressure. After ejecting the samples from metallic die (prepared separately) were preheated using heating furnace (ASPIRE INC, having capacity of 1000ºC) at 600ºC for 8h duration. After heat treatment the samples were air cooled at room temperature shown in Fig.1. The test samples from various wt.% of Al sintered compacts are prepared as per ASTM test standards to characterize their density, compression strength, hardness and tribological properties.

2.3 Density of Sintered Compacts

Density of sintered aluminium bronze with different wt.% of Al was measured by Archimedes' principle. Initially weights of four identical samples taken from each composition were measured in air and in water using Contech weight measuring instrument. The average densities of sintered aluminum bronze compacts were shown in Fig.5.

2.4 Microstructure Examination

The microstructure of polished sintered aluminum bronze samples was examined using optical microscope (Olympus model BX53M). The test specimens (Fig.2) were prepared as per metallographic procedure and etched in a Keller's etchant (50 ml of distilled water and 50 ml HNO_3) for etching time of 1 min.

2.5 Micro Vickers Hardness test

The hardness of aluminum bronze with different loading of Al (0, 5, 10 and 15 wt.%) was measured using MicroVickers hardness tester (Wilson VH1102). The hardness value of each aluminum bronze with various wt.% of Al were taken from seven different locations within the same surface of sample and the average hardness values were calculated and shown in Fig.7.

2.6 Compression Strength test

The compression strength and modulus of pure copper and aluminum bronze with 5, 10 and 15 wt.% Al were measured using the UT-01-0025 BISS nano hydraulic system testing machine at room temperature. Average compression strength and modulus of aluminum bronze with various weight percentage of Al were calculated from four identical rectangular samples taken from each composition shown in Fig.3. The dimensions of the rectangular samples are 10 mm length, 5 mm width and 5 mm thickness were compressed with a strain rate of 0.016 mm/sec.

2.7 Dry Wear test

Wear properties of pure copper and various wt.% of Al

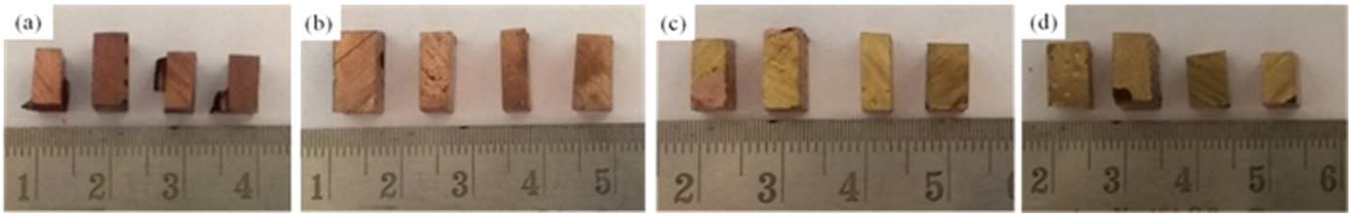

Fig.3: Compression test samples (a) pure copper, (b) Cu-5 wt.% Al, (c) Cu-10 wt.% Al and (d) Cu-15 wt.% Al

aluminum bronze were carried out using Ducom TR 20LE pin-on-disk wear testing machine. The wear and coefficient of friction of the rectangular samples having dimensions 40 mm length, 10 mm width and 10 mm thickness were taken from each compositions compact for testing as is shown in Fig.4. The counter part of wear testing machine was made of C45 steel with the hardened of 45-51 HRC. In the present study, the wear track diameter and wear sliding time for wear test was selected as 100 mm and 10 min respectively.

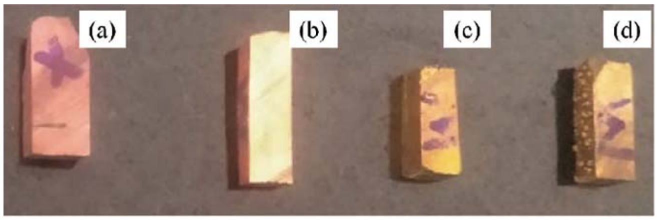

Fig.4: Photographs of the samples after wear test (a) Pure Cu, (b) Cu-5 wt.% Al, (c) Cu-10 wt.% Al and (d) Cu-15 wt.% Al

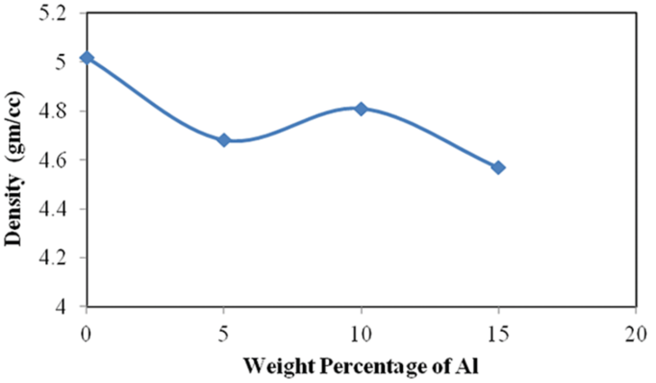

Fig.5: Density of conventional sintered aluminum bronze with 0, 5, 10 and 15 wt.% of Al

3.0. Results and discussion

3.1 Density and Microstructure

The average density of sintered pure copper and copper with addition of aluminum at different weight percentages are found to be 5.018 ± 0.027 g/cc for pure copper, 4.681 ± 0.043 g/cc for Cu-5 wt.% Al, 4.810 ± 0.158g/cc for Cu-10 wt.% Al and 4.568 ± 0.194 g/cc for Cu-15 wt.% Al. The density of sintered pure copper is higher in contrast to addition of low density aluminum (2.7 g/cc) to copper sintered compacts. In the present study, the density of Cu-5 wt.% Al, Cu-10 wt.% Al and Cu-15 wt.% Al are found to be 6.71%, 4.14% and 8.96% respectively lesser than that of the density of pure copper.

The microstructure of pure copper and aluminum bronze with 5, 10 and 15 wt.% Al the microstructure changes from cellulose structure to faceted microstructure by increasing Al content from 0 wt.% to 15 wt.%. The change in microstructure from cellulose to faceted is shown in Figs.6(a-d). The microstructure of pure copper shows cellular structure of copper powder particles shown in Fig.6(a). The microstructure of aluminum bronze with 5 wt. % Al and 10 wt.% Al shows increased in secondary phase and the presence of porosity (Fig.6(b)) and decrease in primary phase and increase in secondary phase (Fig.6(c)). The further increase in addition of Al content in aluminum bronze from 10 wt.% to 15 wt.% increases the size of secondary phase and produce micro pores as is shown in Fig.6(d). Due to increase in secondary phase in Cu–15wt.% Al sintered compact increases the hardness and compression strength.

3.2 Micro Vickers Hardness

Average micro Vickers hardness values of the sintered pure copper, Cu-5 wt.% Al, Cu-10 wt.% Al and Cu-15 wt.% Al for 10 N load are 38.78 ± 1.2, 21.22 ± 2.0, 24.54 ± 3.7 and 39.44 ± 3.5 HV1 respectively. The hardness of the sintered aluminum bronze with the addition of 5 and 10 wt.% Al is decreased by 45.28 % and 36.71% respectively in contrast to hardness of pure copper sintered compact. The hardness of sintered aluminum bronze compact is increased by 1.67% after adding 15 wt.% of Al to copper. Fig.7 shows the hardness values of sintered pure copper and copper with various weight percentages of Al.

3.3 Compression Strength

Fig.8 represents the compression stress-strain curve of pure copper and copper with different weight percentage of aluminum (5, 10 and 15 wt.% Al). The compression strength

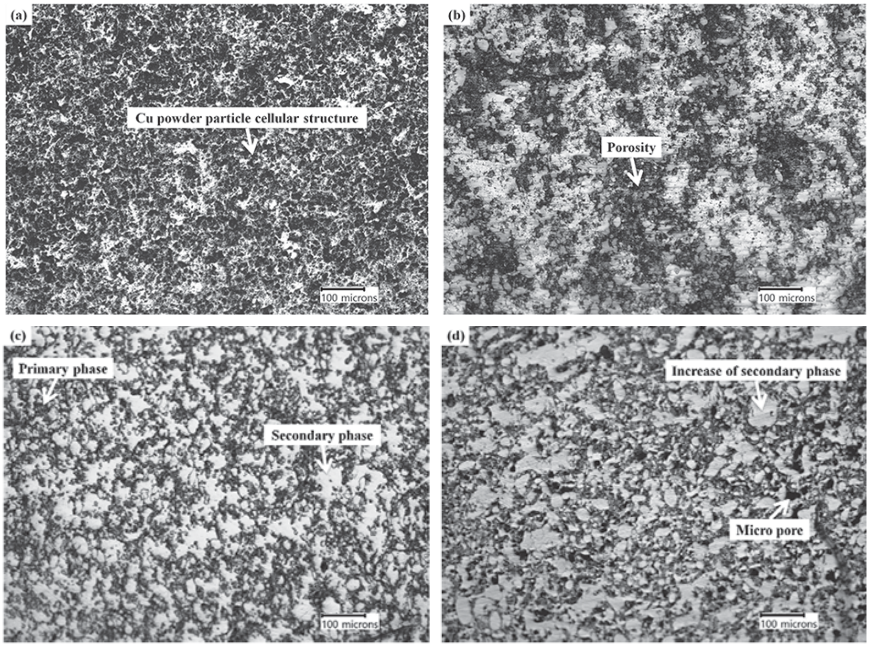

Fig.6: Optical micrographs produced by conventional sintering: (a) Pure copper (b) Cu-5 wt.% Al (c) Cu-10 wt.% Al and (d) Cu-15 wt.% Al

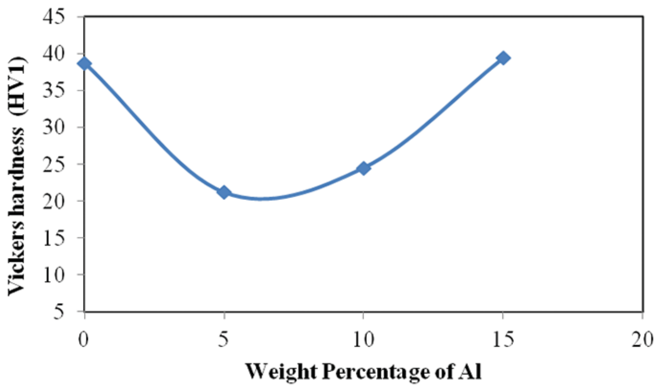

Fig.7: Micro Vickers hardness of conventional sintered aluminum bronze with 0, 5, 10 and 15 wt.% of Al

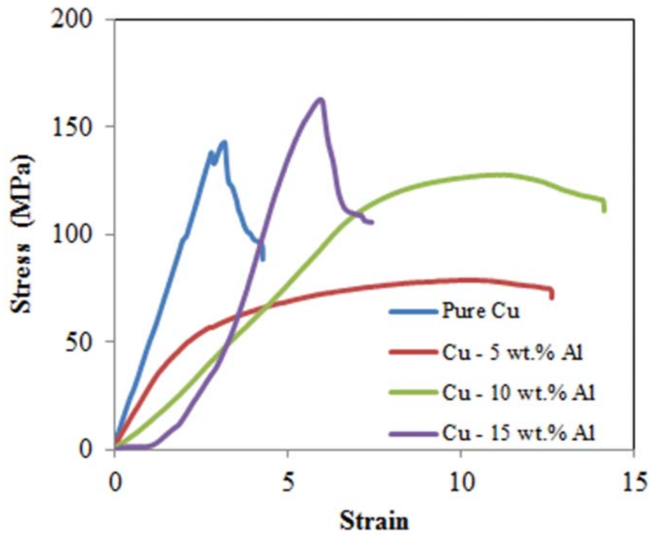

Fig.8: Compression stress-strain curve of conventional sintered aluminum bronze with different weight percentage of Al

of pure copper, copper with 5 wt.% Al, 10 wt.% Al and 15 wt.% Al are 154.97 ± 8.61 MPa, 75.36 ± 4.16 MPa, 126.08 ± 1.74 MPa and 162.84 ± 1.1 MPa respectively. Addition of 5 wt.% Al and 10 wt.% Al to copper, the compression strength is decreased by 51.37% and 18.64% respectively compared to corresponding value of pure copper. The decrease in compression strength could be the presence of porosity and decreased primary phase. Further increase in addition of aluminum (15 wt.% Al) to copper increased the compression strength of compact by 4.83%. The increase in compression strength of sintered aluminum bronze at the addition of 15 wt.% Al to copper is due to increase in size of secondary phase as is shown in Fig.6(d).

3.4 Wear performance

Wear performances for pure copper, 5 wt.%, 10 wt.% and 15 wt.% aluminum bronzes are carried out for different speed and loads. The wear of the pure copper and aluminum bronzes with 5 wt.%, 10 wt.% and 15 wt.% Al as a function of different speeds for a constant load of 40 N is indicated. The wear of pure copper, copper with 5, 10 and 15 wt.% Al are increased from 33.51 µm to 185.42 µm, 27.12 µm to 63.56 µm, 19.89 µm to 50.13 µm and 255.88 µm to 516.77 µm respectively as the sliding speed increases from 200 rpm to 600 rpm (Fig.9). The loss of material during wear test of pure copper, Cu-5 wt.% Al, Cu-10 wt.% Al and Cu–15 wt.% Al are 151.91 µm, 36.44 µm, 30.24 µm and 260.89 µm respectively as the speed increases from 200 rpm to 600 rpm. There is a significant decrease in wear as the weight percentage of aluminum increases up to 10 wt.% for various speeds. The wear and tear of aluminum bronze with 5 and 10 wt.% of Al is significantly decreased. Whereas in Cu-15 wt.% Al is increased by 41.77% compared to wear of pure copper.

The wear test of pure copper, copper with various weight percentage of Al (5, 10 and 15 wt.%) is carried out for different loads at a constant speed of 500 rpm with actual surface

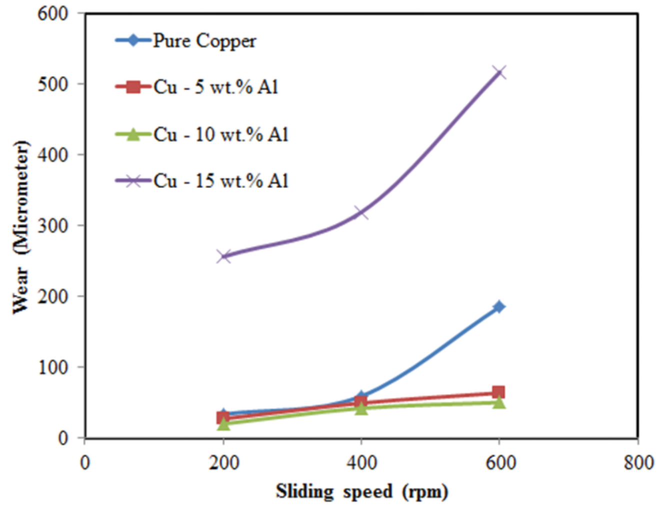

Fig.9: Wear of the pure copper and copper with 5 wt.% Al, 10 wt.% Al and 15 wt.% Al as a function of sliding speeds for a constant load of 40 N

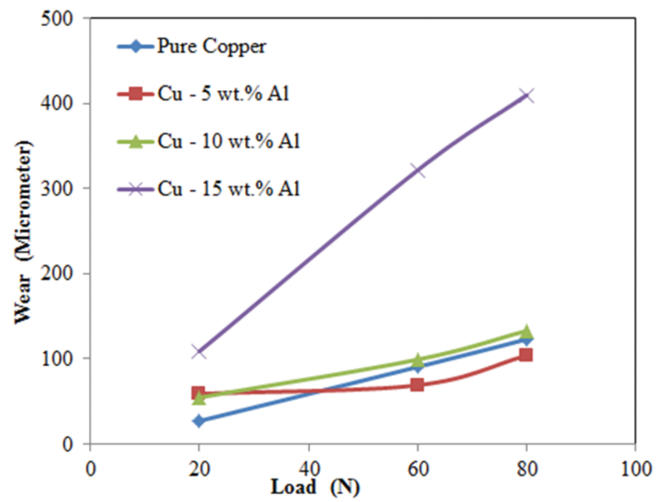

Fig.10: Wear of the pure copper and copper with 5 wt.% Al, 10 wt.% Al and 15 wt.% Al as a function of loads for a constant sliding speed of 500 rpm

sliding velocity of 2.6 m/s (Fig.10). The wear and tear of copper and copper with various weight percentage of aluminum is instantly increased with increase in applied load on the test specimen from 20N to 80N as is shown in Fig.8. The loss of material during wear test of pure copper, Cu-5 wt.% Al, Cu-10 wt.% Al and Cu-15 wt.% Al are 95.86 µm, 45.14 µm, 78.28 µm and 301.01 µm respectively as the load increases from 20N to 80N (at a constant surface sliding velocity of 2.6m/s). The loss of material during wear test of Cu-5 wt.% Al and Cu-10 wt.% Al are decreased by 52.91% and 18.33% respectively compared to wear of pure copper. Further increase in aluminum content from 10 wt.% to 15 wt.% in aluminum bronze the loss of the material is increased by 68.15% in contrast to pure copper.

3.5 Wear friction coefficient

Fig.11 represents the coefficient of friction v/s different weight percentage of aluminum for various loads of 20, 60 and 80 N for a constant sliding velocity of 2.6 m/s. The coefficient of friction of pure copper is decreased by 51.22 % and 42.91% as the load is increased from 20 N to 60 N and from 60N to 80N respectively. Friction coefficients of Cu-5 wt.% Al and Cu-10 wt.% Al are significantly decreased from 1.656 to 0.195 and from 1.363 to 0.151 respectively. The coefficient of friction of Cu-15 wt.% Al is decreased by 54.43 % and 40.99 % as the load is increased from 20N to 60N and from 60N to 80N respectively. By adding 15 wt.% Al to Cu, the friction coefficient were found to be decreased by 38.35%, 42.40% and 36.27% in contrast to pure copper as the applied load increased from 20N to 80N as shown in Fig.9. The decrease in friction coefficient of Cu–15 wt.% Al compared to corresponding value of pure copper due to increase in hardness as is shown in Fig.5. The decrease in coefficient of friction due to high resistance to wear resulting in less wear of the sample since the hardness of counter surface is higher than the sample [18].

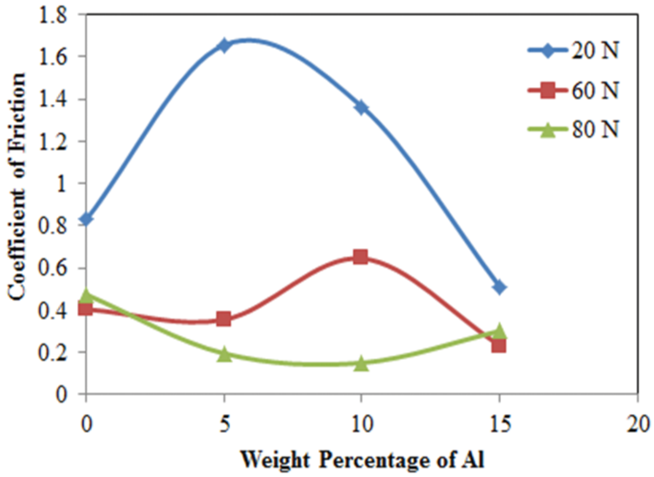

Fig.11: Coefficient of friction of pure copper and copper with 5 wt.% Al, 10 wt.% Al and 15 wt.% Al at 500 rpm for different loads

4.0. Conclusions

In the present investigation, pure copper, Cu-5 wt.% Al, Cu-10 wt.% Al and Cu-15 wt.% Al powder compacts were successfully fabricated using conventional sintering process at room temperature. The density of aluminum bronze with 5, 10 and 15 wt.% Al were instantly decreased due to increase in aluminum content. The morphology of the Cu-Al sintered compacts was changed from cellular structure to faceted structure by increasing Al content from 0 wt.% to 15 wt.%. The Micro Vickers hardness and compression strength of aluminum bronze with 15 wt.% Al increased by 1.67% and 4.83% respectively are in contrast with corresponding values of pure copper. The aluminum bronze with 15 wt.% Al exhibited both excellent wear resistance and coefficient of friction due to increase in size of secondary phase for all applied loads and speed.

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