Wear and Frictional Behaviour of Metals

J.G. Alotaibi*, B.F. Yousif, and T.F. Yusaf

School of Mechanical and Electrical Engineering,

University Southern Queensland, Toowoomba, 4350 Qld, Australia.

Jasem.Alotaibi@usq.edu.au; Jasem_alotaibi@yahoo.com; Fax +6146315331

Keywords: metal; sliding; dry adhesive wear; wear mechanism; operating parameters;

Abstract. In the current study, wear and frictional performances of different metals are investigated under different operating parameters against stainless steel counterface under dry contact conditions. The experiments performed using block on ring machine. Microscopy was used to examine the damage features on the worn surface and categorize the wear mechanism. Thermal imager was used to understand the thermal loading in the interface during the rubbing process. The results revealed that the operating parameters influence the wear and frictional behaviour of all the metals. Brass metal exhibited better wear and frictional behaviour compared to others. Three different wear mechanisms were observed, i.e. two body abrasion (Brass), three body abrasion (Aluminium) and adhesive (Mild Steel).

Introduction

There are several works have been reported in studying the frictional and wear behaviour of metals. However, there is still a demand on how the metal behaviour under different tribological applications since there are several recent publications are reported on different type of metals such as aluminium, steel, and brass. Due to the fact that metals are used in different applications under different operating conditions, the need to study their tribological performance is on-going study. Most of the work focused on specific applications in which specific sliding speed, sliding distance, environmental temperature and applied load are used in the study. However, operating parameters have significant influence on the wear and frictional behaviour of metals under either dry or wet (lubricant) contact conditions, [1-4]. In [2], friction and wear behaviour of grey cast iron has been investigated under different test parameters, i.e. applied load, sliding speed and test environment and the results revealed that the wear loss increases with the sliding velocity and/or applied load increase. Furthermore, high applied load and sliding speed introduces high frictional heating. Beside the above, the participant authors found that the reported works in the literature have been presented in different format. For example, the wear performance of a metal have been presented in wear rate [5], weight loss [6], volume loss [7], specific wear rate and/or wear resistance [8, 9]. Each form of these wear units introduces different understanding which in turn misleading the readers and establish confusing date for comparison purposes. Therefore, it is highly recommended to present the wear performance of materials in term of specific wear rate which represent the volume loss per applied load and sliding distance. This motivates the current study to study the wear and frictional behaviour of aluminium, steel and brass materials sliding against stainless steel counterface considering different operating parameters.

Methodology

Materials selection and experimental procedure

From the literature there are several materials selected for tribological applications in bearings, bushes … etc. and among the most common and recent materials used under dry and lubricant

contact conditions are mild steel, brass, and aluminium. In the current study Brass Cu64Zn36, mild steel SAE52100 steel, and aluminium (Si 0.08%, Fe 0.25%, Cu 0.01%, Al balance) was selected.
Adhesive wear tests of the composites were conducted against a stainless steel ring (AISI 304) using the block on ring technique, **Fig. 1**. Before each test, the disc was polished with abrasive SiC paper (G1500) to a surface roughness of 0.1-0.3 μm Ra. Before conducting the experiments, the metal surfaces were rubbed over an abrasive SiC paper (G1500) to ensure an intimate contact between the sliding face of the specimen and the stainless steel counterface. Sliding tests were conducted at ambient temperature and humidity conditions with varying normal loads (30 N, 40 N and 50 N), and sliding distances (0 – 10.9) km and sliding speed of 2.8 m/s. Block on Ring technique was adopted in the current study according to the ASTM G77-98 [10].

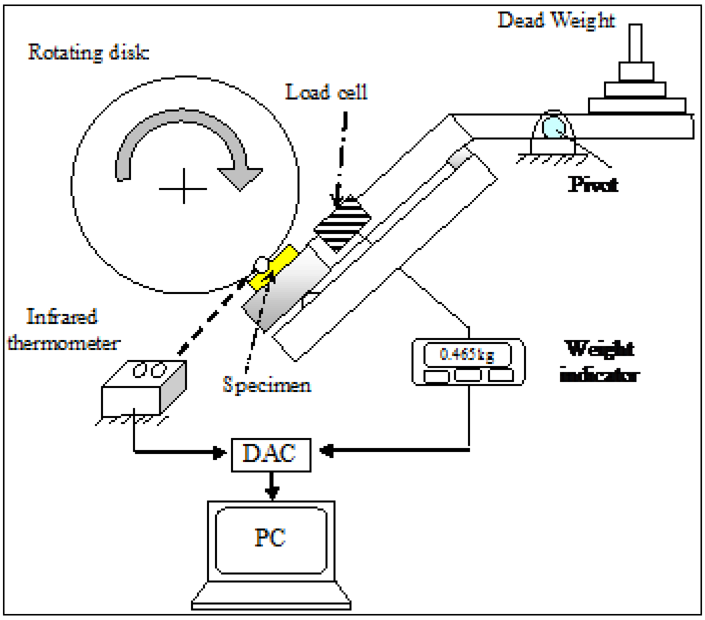


Fig.1 configuration of block on ring machine

Results and Discussion

Wear behaviour

The specific wear rate of the selected materials against sliding distance is represented in Fig. 3 showing the specific wear values of 10.9 km sliding distance for the three materials under different applied loads. To understand deeply the interaction between the stainless steel counterface and the selected rubbed materials, roughness profile of the materials and the counterface were recorded after each test associated with the optical micrographs of the worn surface after the tests. This will be explained later under surface observation section.

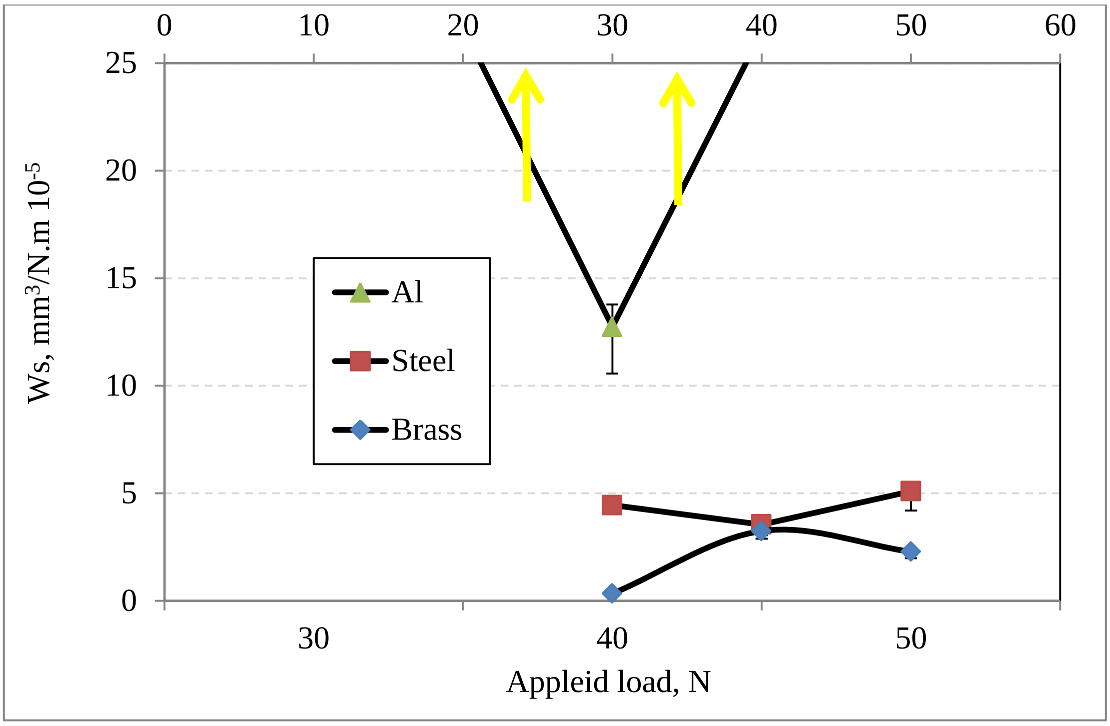


Fig. 2 Summary of specific wear rate at steady state of brass, aluminium, mild steel materials under dry contact conditions at different applied loads after 10.9 km sliding distance.

Frictional behaviour

The frictional force was recorded during the sliding process for all the materials. Coefficient of friction verses the sliding distances is displayed in Fig. 3 for all the materials under different applied loads. The frictional behaviour for all the materials seems to be steady especially with the brass and the mild steel. Aluminium shows a bit of fluctuation in the value which represents a modification on the surface occurring during the sliding such behaviour was noticed when the materials transfer from surface to another and detachments may occurs leading to the fluctuation in the frication coefficient. This has been reported by [11, 12] when different materials have been tested under dry adhesive wear loadings. With regards of the influence of the applied load on the frictional behaviour of the materials, increase the applied load reduces the friction coefficient especially for the brass and the aluminium materials. Mild steel shows no effect of the applied load on its frictional behaviour. Comparing the three materials, brass exhibits the lowest frication coefficient among others. This is clearly shown in the summarized frictional results in **Fig. 3**. The differences in the wear and the frictional behaviour of those materials are due to the interaction between the surfaces during the sliding. The roughness of the surfaces may assist in clarifying this.

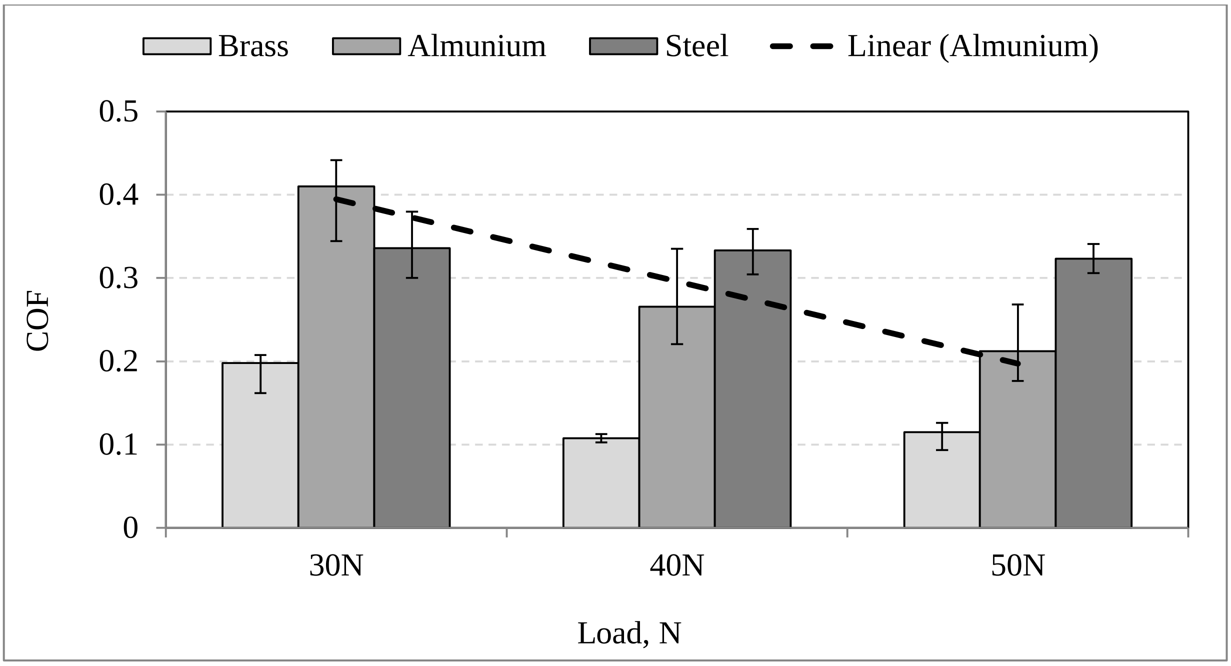


Fig. 3 Summary of friction coefficient at steady state of brass, aluminium, mild steel materials under dry contact conditions at different applied loads after 10.9 km sliding distance.

Worn Surface Observation

It was mentioned in the presentation of the results that the modification on the surface characteristics during the sliding may influence the wear behaviour of the materials. One of the characteristics which may assist in understanding the wear and frictional behaviour is the roughness of the contacted bodies. Fig. 4 displays the average roughness of the worn surface associated with the maximum and minimum values for the materials at different applied load after 10.9 km sliding distance. The roughness value was measured with the direction of the sliding. The roughness of the materials before the test was about 0.4 µm.

From this figure, it can be seen that the roughness of the mild steel is highly increased after the test followed by the aluminium an then the brass. It seems the lowest roughness value of the brass is the main reason of the high wear performance of this material compare to others. For the mild steel, the high increase in the roughness seems not related to the wear and frictional behaviour of this material. On the other hand, there is debris was collected after each test. The lowest amount of debris collected was with the case of the mild steel. Meanwhile, aluminium introduces too much of debris associated with high interface temperature which reached to about 90 ^{o}C. Further study is required to study the reason of the high roughness value of the mild steel. Micrographs of the worn surface of the materials are presented in **Fig. 5**. For the brass material, the micrographs clearly show abrasive nature on the surface. However, the aluminium surface seems to be rougher than the brass. There is no clear plastic deformation in the case of the brass and aluminium. For the mild steel, plastic deformation is very obvious and this is the main reason of the high roughness value of the mild steel.

From all the collected information, there are three different wear mechanism can be found. These are:

1. Two body abrasive nature in the case of the bras, since it has better wear performance compared to other but it shows rough surface with less debris,

2. Three body abrasion nature in the case of aluminium, since there is too much of debris associated with very rough surface,
3. Pure adhesive in the case of the mild steel since it has the lowest amount of debris and the micrographs of the worn surface showed clear plastic deformation .

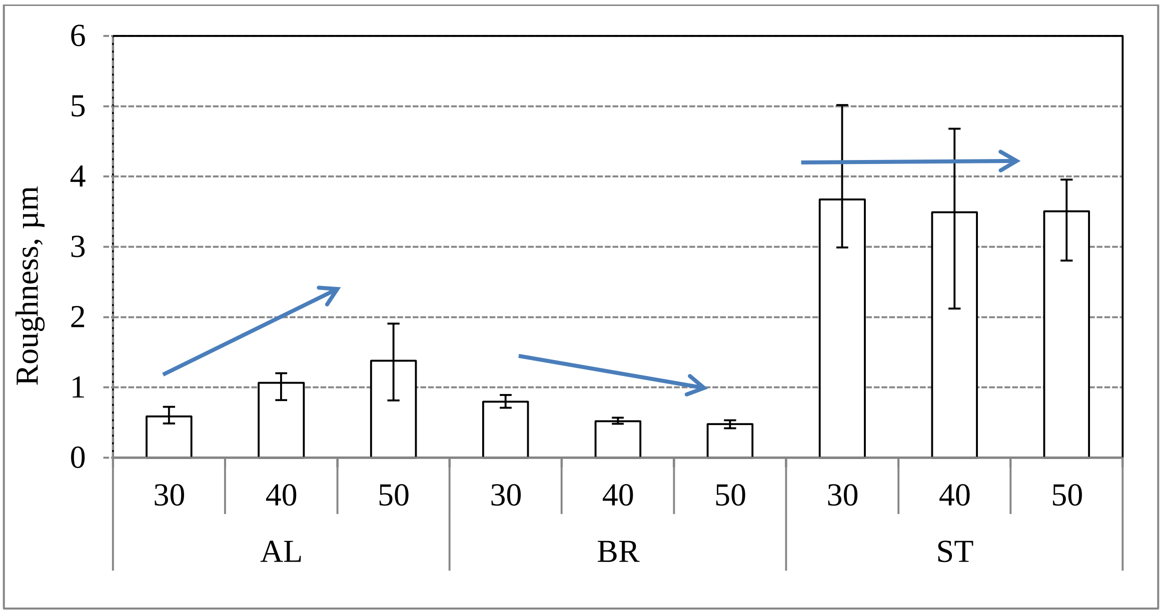


Fig. 4 Average of worn surface roughness after the test at different applied loads after 10.9 km sliding distance.

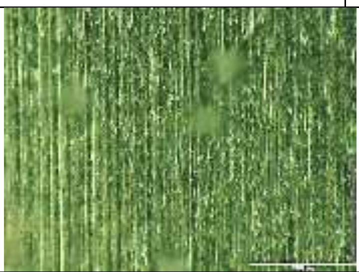
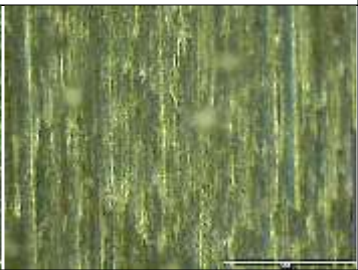
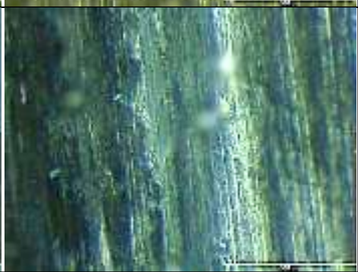
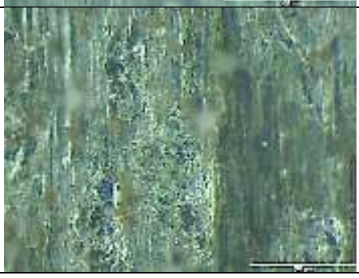
	30 N	40 N	50 N
Brass			
Aluminium			
Mild Steel			

Fig. 5 Micrographs of worn surface Roughness after the test at different applied loads after 10.9 km sliding distance.

Conclusion

The experiments of the current study were on the adhesive wear performance of the common metals against stainless steel counterface under different operating parameters. The results revealed some critical findings which can be concluded as

1. The operating parameters significantly influence the wear and frictional performance of all the metals. However, steady states of the septic wear rate and friction coefficient were achieved after about 5 km sliding distance for all the applied loads. The materials exhibited high specific wear at the lower and higher range of applied load which intermediate value of 40 N introduced the best wear performance.
2. Frictional behaviour of the metals are controlled by the applied load since the friction coefficient reduced with the increase of the applied load.
3. Different wear mechanism were observed. Brass exhibited two body abrasion due to eh change in the roughness of the wear track. Mild steel showed plastic deformation due to the high resistance to the shear in the interface. Aluminium exhibited very massive mass removal from its surface since has very low resistance to the shear.

References

1. Kumar, M. and J. Bijwe, *Composite friction materials based on metallic fillers: Sensitivity of μ to operating variables.* Tribology International, 2011. **44**(2): p. 106-113.
2. Prasad, B.K., *Sliding wear response of a grey cast iron: Effects of some experimental parameters.* Tribology International, 2011. **44**(5): p. 660-667.
3. Tewari, A., *Load dependence of oxidative wear in metal/ceramic tribocouples in fretting environment.* Wear, 2012. **289**(0): p. 95-103.
4. Yousif, B.F., *Editorial for SI: Materials, design and tribology.* Materials & Design, 2013. **48**(0): p. 1.
5. Slavkovic, R., et al., *An application of learning machine methods in prediction of wear rate of wear resistant casting parts.* Computers & Industrial Engineering, 2013. **64**(3): p. 850-857.
6. Forati Rad, H., A. Amadeh, and H. Moradi, *Wear assessment of plasma nitrided AISI H11 steel.* Materials & Design, 2011. **32**(5): p. 2635-2643.
7. Morris, B., et al., *Quantifying the wear of acetabular cups using coordinate metrology.* Wear, 2011. **271**(7–8): p. 1086-1092.
8. Cassar, G., et al., *Micro-abrasion wear testing of triode plasma diffusion and duplex treated Ti–6Al–4V alloy.* Wear, 2012. **274–275**(0): p. 377-387.
9. Jahangiri, M., et al., *Application and conceptual explanation of an energy-based approach for the modelling and prediction of sliding wear.* Wear, 2012. **274–275**(0): p. 168-174.
10. ASTM G77-98 Standard Test Method for Ranking Resistance of Materials to Sliding Wear Using Block-on-Ring Wear Test, W.C.
11. Sahin, M., C.S. Çetinarslan, and H.E. Akata, *Effect of surface roughness on friction coefficients during upsetting processes for different materials.* Materials & design, 2007. **28**(2): p. 633-640.
12. Behnagh, R.A., M. Besharati Givi, and M. Akbari, *Mechanical properties, corrosion resistance, and microstructural changes during friction stir processing of 5083 aluminum rolled plates.* Materials and Manufacturing Processes, 2012. **27**(6): p. 636-640.