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Wear behaviour of cast aluminium silicon (Al-Si) alloy in Dot 4 brake fluid

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Abstract. The frictional sliding behaviour of cast Al-Si alloy was investigated with and without DOT 4 hydraulic brake fluid lubrication/environments. Cast Al-Si specimen was produced from wrought alloy and the specimen surface was metallurgically prepared. The as-cast product was characterized with aid of micro-hardness tester, the chemical composition was analysed by X-ray fluorescence (XRF), while X-ray diffraction (XRD) was used to identify phases present, microstructures and surface examinations were done on a high resolution metallurgical Optical Microscope. The properties of the polished and worn sample surfaces were examined by Scanning electron microscope (SEM) equipped with Energy dispersive X-ray (EDS) facilities. A 6mm diameter alumina ball under varying normal loads (3-10 N) was rubbed against the surface of the cast Al-Si coupon specimen. The dry and wet sliding wear behaviour was assessed based on the CoF-sliding time behaviour. From the results, the average CoF values of 0.9064 for dry and 0.2038 for wet contacts were obtained. Comparatively, 1.03E-06 and 4.21E-07 minimum wear intensities; and 467290 and 132170 wear resistances were obtained for dry and wet contacts respectively. Behaviour of cast Al-Si in DOT4 were compared with its performance in DOT3 regarding the hydraulic brake system application.

1. Introduction

Apart from steel, Al-Si cast alloys have been widely employed to produce automotive components working at ambient and fairly high temperature (up to 200 ℃) due to excellent characteristics such as low-cost manufacturing, excellent castability, high specific strength and recyclability [1, 2]. Al-Si alloys have a wide range of applications in the automotive and aerospace industries due to an excellent combination of castability and mechanical properties, as well as good corrosion resistance and wear resistivity. Si is the main and most important alloying element of Al-Si cast alloy. Cu and Mg are commonly added to improve the strength at room and elevated temperatures and enable the possibility of heat treatment [3]. The size, morphology and distribution of microstructures control the mechanical and tribological properties of Al-Si alloys [4-6].

In previous reports, the authors focused on the characterisation, usage, wear and corrosion of A6061 aluminium alloys in the DOT3 fluid; to explore and report research findings on the automobile engines study area as applicable to the automobile hydraulic brake cylinder system. The present work is motivated as part of reported large project [7-13] on the study of aluminium alloy in fluid and compared with other materials already reported [14-17]. The present work compares the Al-Si behaviours in the DOT4 with the A6061 alloy in DOT3 previously reported [7-11] whereas, in some previously reported cases, test sample materials were produced from scrap sources [8-9].

2. Experimental procedures

2.1 Materials, characterization and sample preparation

The starting material for the study is wrought aluminium-silicon alloy, received in the form of cylindrical billet (Table 1). The selection of sand-casting variables and adapted procedures complies with the best practices and has been discussed elsewhere [11-13]. The alloy specimen was shaped and cut to 25 mm diameter by 10 mm thickness cylinder size specimen and their surfaces were grinded and polished with 0.2 μm fumed silica suspension to get uniform and smooth mirror-like finishing surface. Five-point micro-indentations were made on the surface of the sample at regular intervals of 2 mm distance apart with the dwell time of 10 s on Vicker's scale HV/1 with a load of 1kgf using the InnovaTest - Falcon 500 model hardness tester.

2.2 Tribological tests

The standard tribometer (Anton Paar, TRB model) was used for the experiments. A 6mm diameter alumina ball was rubbed against the surface of the coupon specimens under varying normal loads. The tribometer was run at sequence count of 10 in a single-way (rotational) mode and at radius also varying from 2.00 to 12.00 mm, and acquisition rate of 10.0 Hz with stop condition of 4.00 m. To assess the behaviour by the sliding frictional/wear (CoFs) method, the normal load was varied from 3, 4, 6, 8 to 10N. The CoF sliding time curves were plotted. The experiments were prepared, performed, analysed and reported considering the ASTM G 115-04, G 40-02; G 99 and G 133, DIN 50324, and ASTM G 99 -95a.

2.3 Microstructural analysis

The chemical composition was analysed by X-Ray Fluorescence (XRF) using the Rigaku ZSX Primus II model. The microstructures and surface examinations were performed by using a high resolution metallurgical optical microscope (Zeiss, MTB 2011 model). The morphologies of the as received and worn sample surfaces were then examined by scanning electron microscope (Tescan Vega 3) equipped with energy dispersive X-ray spectrometer (EDS) facilities. The X-ray diffraction was done to examine phases of the Al-Si alloy material using X-Ray Rigaku Ultima IV.

3. Results and discussion

The combination of the XRF, XRD with the SEM and EDS results (Table 1, and Figure 1) validates the chemical composition, phases and microstructures present in the Al-Si sample as compared with results reported in the previous findings [10,13].

The tensile strength of a material is a function of the hardness of the material [13]. The wear resistance of a material is also a function of the hardness of the material. The harder a material is, the larger its resistance to wear. The present result shows that cast Al-Si test sample has a higher hardness (95.42) value as compared with the 65.7 obtained from the cast A6061 alloy previously reported; it signifies the impact of increased Si content on the higher hardness values in the Al-Si alloy [2] than the A6061 samples reported. Thus, it signifies higher wear resistance potential than the cast A6061 alloy earlier tested in DOT3 [7-8, 10-11].

Table 1. Composition of Al-Si alloy by XRF analysis.

Elements	Al	Cu	Si	Zn	Mn	Fe	Mg	Co	Ti	Sn	Cr	Others
Mass%	74.02	2.01	19.35	1.79	0.36	2.12	0.02	0.01	0.045	0.032	0.042	Bal

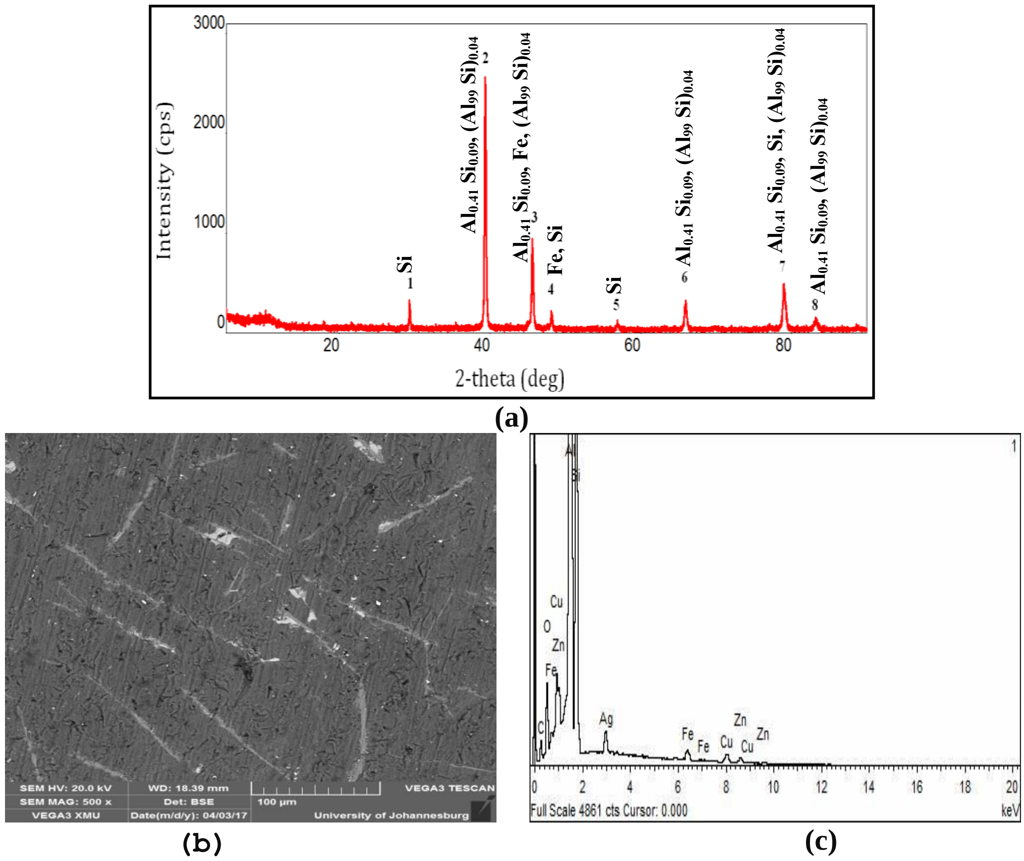


Figure 1: Phase analysis of Al-Si alloy sample by XRD (a), SEM images showing the (b) microstructure, and (c) EDS of Al-Si alloy.

3.1 Wear rates determination by weight loss method

The results of weight losses measured from the dry and wet sliding wear tests performed on the Al-Si samples in DOT4 brake fluid are shown in Figure 2. The testing is compatible with DIN50324 and ASTM. The tests were carried out under varying loads of 3, 4, 6, 8 and 10N. Wear rate increases with the applied normal load for both dry and wet sliding wears, though the wear rate values are much lower in the latter. This agrees with the characteristic behaviour of the cast A6061 alloy in the DOT3 fluid reported previously [12]. The wear rates of the Al-Si specimens subjected to ball sliding actions of the tribometer and measured from weight losses are compared with wear rates calculated from the volume loss and wear rate equations [8]. The wear track width *d* was digitally measured from the high-resolution Zeiss, (MTB 2011 model) optical microscope.

Meanwhile, the trends of the curves obtained from the specimen wear rates (m^2N^{-1}) calculated from the volume loss equations [11] on the similar scale are defined by the equations (1) and (2) for the dry and wet sliding wear characteristics with R^2 = 0.8781 and R^2 = 0.8171 standard deviations respectively.

$$W_{dc} = 2E\text{-}07e^{0.3747Fn} \quad (1)$$

$$W_{wc} = 5E\text{-}08e^{0.481Fn} \quad (2)$$

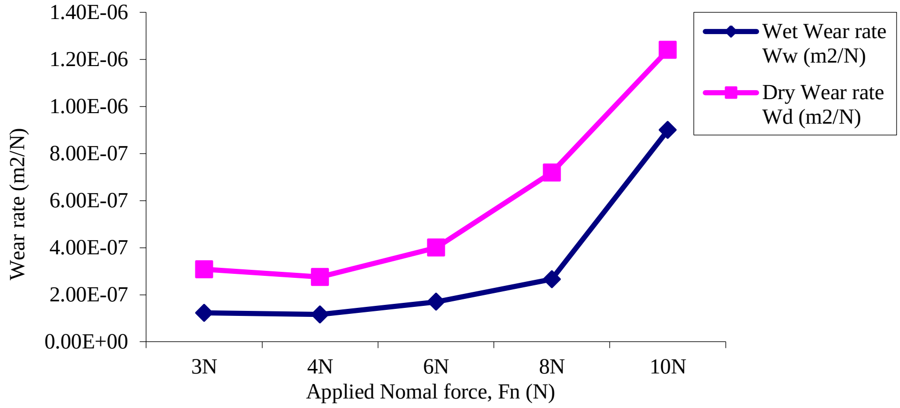


Figure 2: Mass wear rates obtained from the measured weight loss of Al-Si alloy samples in DOT4 brake fluid (wet) and air (dry)

3.2 CoF of dry and wet sliding wear of cast Al-Si sample in DOT4

Table 2 is the summarised data for the CoF for the as-cast alloy in dry and wet environments at various loads. During the dry contact of 3N load, the CoF increased to 1.16 (max) with a mean value of μ = 0.858 obtained at 1910 sec dwelling time of the frictional contact. The wear test was conducted in a wet condition with an application of the same loading was applied to them, thus results are presented in Fig. 2. In this instance, the CoF diminished from 0.627 to obtain μ = 0.233 stability reached after 39.9459 m contact distance (cycle = 2119.36) and 1276 sec sliding time. The increase in the applied load to 4N showed an incremental change in the CoF under the dry contact wear. The μ increased to 1.16 max with a mean value of μ = 0.998 obtained after 959.60 sec sliding time. Meanwhile, this was not so for the wet test in the DOT4 fluid run under 4N load. In this case, there was a reduction in CoF from 0.416 to 0.161 after the 138 sec of contact. A mean μ = 0.193 value was obtained after 766.92 sec sliding time. With further increase in normal load to 6N also influenced CoF value from 1.29 (max) to a mean value of μ = 0.823 after the 641.66 sec total sliding time. The oil reduced the CoF to 0.517 after 546.13 sec and 39.9581 m sliding distance as compared with dry wear. The characteristic of wet wear is different in that, the CoF reached the maximum value of 0.811.

For the period of the dry contact of 8N applied load the μ increased to 1.49 max and a mean value of μ = 1.03 was obtained at 408.22 sec frictional contact time. Comparatively, the CoF fluctuates between 0.423 (6.98 sec) and 0.161 (180 sec) and the stabilised during the wet wear. In this case, the CoF reduced from 0.423 to obtain CoF value of μ = 0.233 stability obtained after 39.94 m contact distance (cycle = 706.56) and 426.30 sec sliding time.

The 10N applied load showed an incremental change in the CoF under the dry contact wear. The CoF initially increased to 1.49 max and with a stable CoF value of 0.823 obtained after 366.4 sec sliding time and 605 wear cycle. On the other hand, for the wet wear test in the DOT4 fluid run under 10N load, the CoF becomes stable at μ = 0.163. Moreover, a mean CoF of 0.193 was obtained at the 347.94 sec total sliding time. The whole results reflect slight similarities in the CoF – time behaviour of Al-Si alloys subjected to a varying small range (of 5 to 9 N) frictional force reported previously by Mathavan and Patnaik [14].

Table 2. Wear parameters of cast Al-Si alloy under dry and wet.

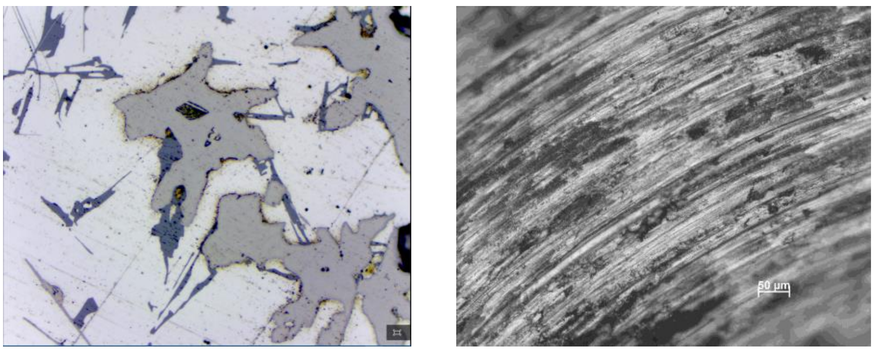
Normal load (Fn)	***3N***	***4N***	***6N***	***8N***	***10N***
CoF (dry)	0.858	0.998	0.823	1.03	0.823
CoF (wet)	0.233	0.193	0.517	0.233	0.193

Dry track width (mm)	0.95	1.13	1.31	1.48	1.74
Wet track width (mm)	0.34	0.35	0.47	0.48	0.62
Intensity (dry)	1.03E-06	1.04E-06	1.95E-06	4.18E-06	7.57E-06
Intensity (Wet)	5.80E-07	4.21E-07	4.93E-07	7.85E-07	2.14E-06
Resistance (dry)	967118	958772	512820	239120	132170
Resistance (wet)	3611904	2375296	2029632	1274534	467290

3.3 Optical microscopy and SEM of wear tracks

Figure 3a shows the optical micrograph of the microstructure of the polished cast Al-Si alloy surface (control) prior to the dry sliding and wet sliding wear tests. The optical micrographs of the wear scar of cast Al-Si alloy surfaces under the dry sliding and wet sliding in DOT4 oil impressed with different applied loads (3 and 10N) are presented in Figure 3(b)- 3(e). In all instances of impressed loading, observations show that wear is more severe on the dry surfaces that the oil lubricated interfaces. For more clarity, the SEM images showing wear scar patterns of cast Al-Si alloy under (a) dry and wet sliding in DOT4 oil under 2N applied load are presented in Figures 4a and 4b. The nature of wear defined on this system is sliding wear and comparatively, the volume of materials that were removed from the dry and wet surfaces is considerably large across all varied loads for the specimen in both different (dry and wet) conditions. The asperities observed (Figures 3 and 4) for dry and wet shows direct proportion to the load increase. However, the wet grinding has a lower wear loss when compared to the dry grinding at the same loads.

The SEM images reveal conspicuous wear tracks for both dry and wet across the different loads as shown in the image for 2N loading (Figure 4(a) and (b)). This incidence can be explained in diverse ways which include the consideration for the state of specimen surface finish [18]. It is renowned that lesser wear generally occurs when a rough surface slides against a smooth surface and greater wear when both surfaces are either extremely rough or very smooth because of increased adhesive or abrasive wear constituents correspondingly. Since the test specimen surfaces were prepared by grinding from 3.0 µm to 0.2 µm finishing grit, the Al-Si alloy surfaces in contact with a hard alumina ball experienced sliding wear relative to the load. Table 2 contains the wear parameters and frictional wear data generated from the tribometer with intensity and wear-resistance calculated based on wear equations for all specimens [19].



(a) (b)

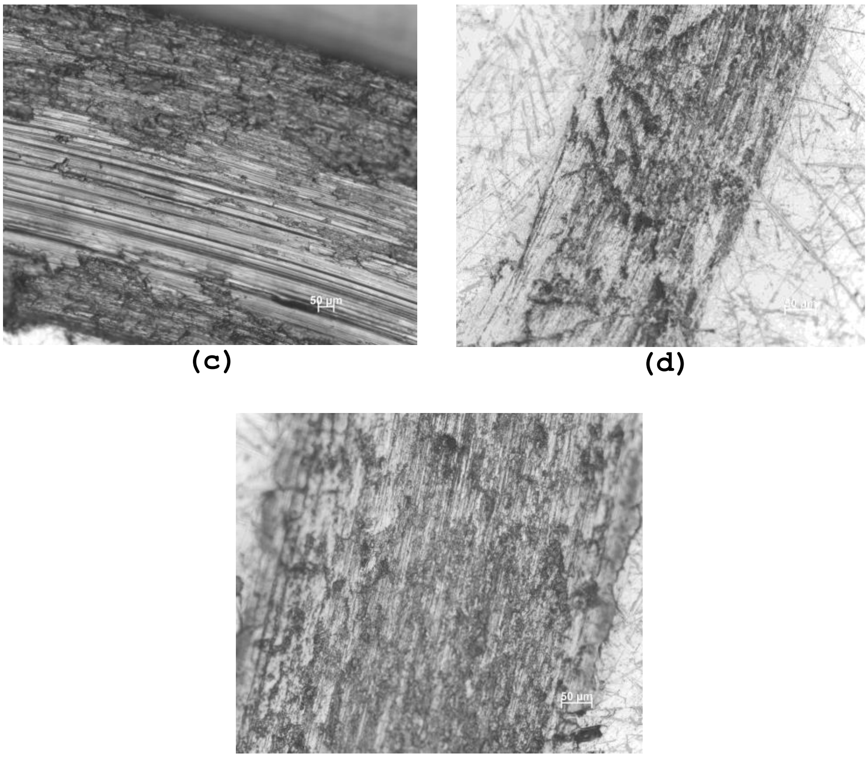


Figure 3: Optical micrographs of surfaces (a) before and wear scar patterns after dry sliding with (b) 3N , (c) 10 N and wet sliding with (d) 3 N and (e) 10 N loads.

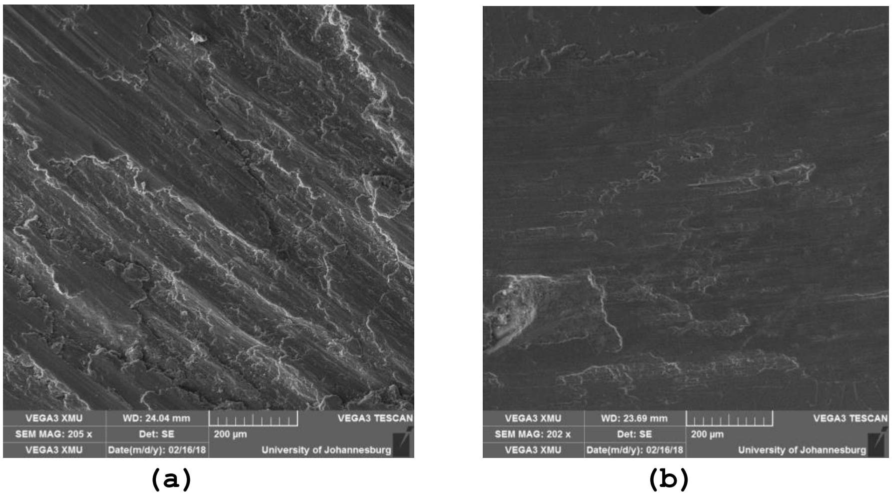


Figure 4: SEM images showing wear scar patterns of cast Al-Si alloy under (a) dry and (b) wet sliding in DOT4 oil under 2N load.

The trends of some other wear parameters (wear track width, wear intensity, and wear resistance) with normal force variation (3, 4, 6, 8 and 10N) in the case of cast Al-Si alloy subjected to dry and wet sliding in the DOT4 fluid are compared and presented in Table 2. It shows the wear track width variation with applied load. The wear track width increased with increasing applied wear loads for both dry and wet sliding wear experiments even-though the values obtained are smaller as in the case of the wet sliding wear. It also shows that the impact of wear intensity is higher on the dry sliding that the wet sliding of the ball on the Al-Si alloy. The resistance is the hindrance to wear and it is measured by the inverse of wear intensity. Also, the wear resistance had been simply defined by Ludema, [16] as the reciprocal of wear volume (in cm^3). The wear resistance reduces with increase in applied load values for both dry and wet sliding conditions. In the present case, the wear resistance of the test cast Al-Si sample is comparatively higher in DOT 4 fluid than for the previously reported cast A6061 samples tested in DOT3 [11, 20]. It was reported in previous studies that Al-Si alloys wear resistance improves with the increased in Si content and as well as load-bearing capacity [17].

4. Conclusion

This study carried out a comparative analysis of the wear characteristics of as-cast Al-Si alloy in DOT 4 fluid using both dry and wet sliding procedures. Data are obtained for the relationships of mass wear, wear rate, wear intensity and wear-resistance. The basic conclusion is that increased normal force loading of aluminium alloy sample leads to a significant decrease of the wear-resistance in both dry and wet sliding contacts. The present study reports a higher wear resistance of cast AlSi sample in DOT 4 fluid than the previously reported cast A6061 tested in DOT3. Also, higher values of CoF were observed in AlSi alloy as the load increases while lower wear rates characterised the AlSi alloy in DOT4 with and without lubrication than the A6061 wear in DOT3 previously reported. A vista of study for future consideration of the cast Al-Si alloy in DOT 4 fluid, having in view their operation under various exploitation conditions of interaction that is in a multiphase system.

5. References

[1] Akinwamide, S.O., Lemika, S.M. and Abiodun, B., 2019. Study of Microstructural and Mechanical Properties of Stir Cast Al (SiC-Mg-TiFe) Composite. *Fluid Dynamics & Materials Processing*, *15*(1), pp.15-26.

[2] Islam, M.A. and Farhat, Z.N., 2011. Effect of porosity on dry sliding wear of Al–Si alloys. *Tribology International*, *44*(4), pp.498-504.

[3] Stadler, F., Antrekowitsch, H., Fragner, W., Kaufmann, H., Pinatel, E.R. and Uggowitzer, P.J., 2013. The effect of main alloying elements on the physical properties of Al–Si foundry alloys. *Materials Science and Engineering: A*, *560*, pp.481-491.

[4] Olofsson, J., Svensson, I.L., Lava, P. and Debruyne, D., 2014. Characterisation and investigation of local variations in mechanical behaviour in cast aluminium using gradient solidification, Digital Image Correlation and finite element simulation. *Materials & Design (1980-2015)*, *56*, pp.755-762.

[5] Andoko, F., Puspitasari, P. and Gapsari, F., 2018. The analysis of strength and fracture morphology of Al-Si compound made from moulding sand formulation with bentonite binding material and Portland cement. *Journal of Achievements in Materials and Manufacturing Engineering*, *89*(1).

[6] Stojanovic, B., Babic, M., Mitrovic, S., Vencl, A., Miloradovic, N. and Pantic, M., 2013. Tribological characteristics of aluminium hybrid composites reinforced with silicon carbide and graphite: A review. *Journal of the Balkan Tribological Association*, *19*(1), pp.83-96.

[7] Ajibola O.O, Oloruntoba D. T., Adewuyi B.O., 2015. "Design and performance evaluation of wear test jig for aluminium alloy substrate in hydraulic fluid". *African Corrosion Journal*, 1(1), pp 40-45.

[8] Ajibola O O., Ige O O.,. Olubambi P A (2018), Wear and Corrosion of Wrought A6061 Aluminium Alloy in DOT3 Brake Fluid. *International Journal of Engineering & Technology*, 7(2) pp512-519.

[9] Ajibola O.O, Oloruntoba D. T., Adewuyi B.O., 2016 "Investigation of corrosion of cast aluminium alloy piston in brake fluid". *African Corrosion Journal*, 2(2) pp 1-11.

[10] Ajibola O.O, Oloruntoba D.T, and Adewuyi B.O, 2014. Metallurgical study of cast aluminium alloy used in hydraulic master brake calliper. *International Journal of Innovation and Scientific Research*. 8(2):324-333.
[11] Ajibola O.O, Adewuyi B.O, and Oloruntoba D.T, 2014. Wear behaviour of sand cast eutectic Al-Si alloy in hydraulic brake fluid. *International Journal of Innovation and Applied Studies*, *6*(3), p.420-430
[12] Ajibola O.O, and Oloruntoba D.T., 2015, Wear and corrosion of cast Al alloy piston with and without brake oil. *Indian Journal of Materials Science*, Article ID 763618, p10.
[13] Ajibola O.O, Oloruntoba D.T, and Adewuyi B.O, 2015, Effects of moulding sand permeability and pouring temperatures on properties of cast 6061 Aluminium alloy. *International Journal of Metals*, Article ID 632021, p13.
[14] Mathavan J.J and Patnaik, A. 2016, *Mater. Sc. Eng*. 149, 2016
[15] Sahin, Y. and Özdin, K., 2008. A model for the abrasive wear behaviour of aluminium based composites. *Materials & Design*, *29*(3), pp.728-733.
[16] Ludema, K.C., 1992. Sliding and adhesive wear. *ASM handbook*, *18*, pp.236-241.
[17] Torabian, H., Pathak, J.P. and Tiwari, S.N., 1994. Wear characteristics of Al-Si alloys. *Wear*, *172*(1), pp.49-58.
[18] Garzino – Demo G.A, Lama F.L, 1995, Friction and wear of metallic and non – metallic surfaces, *Surface and Coatings Technology*, Vol 76–77, Part 2, 487-493, 1995
[19] Ajibola O.O, Oloruntoba D. T., 2015, Effect of MgFeSi inoculants on properties of Cast 6061 Al Alloy for brake master piston application, *Indian Journal of Materials Science,* Article ID 756219, p10.
[20] Anton-Paar G74IB001EN-B TRB User Manual, Tribometer Software Version 7, pp1-141, www.anton-paar.com

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