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COMPARATIVE ANALYSIS OF ABRASIVE WEAR BETWEEN ALUMINIUM ALLOY AND MILD STEEL IN A PIN-ON-DISC TRIBOLOGICAL TEST

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Abstract
A comparative analysis of the abrasive wear of aluminium alloy and mild steel on the pin-on-disc wear test machine has been successfully carried out. An investigation on the effects of wear, stress and strain on the aluminium alloy and the mild steel was conducted. The wear test carried out determined the difference between rate of wear of the aluminium alloy and the mild steel. The input parameters applied in determining the wear rate were time of wear, sliding distance, track diameter of the disc and mass difference before and after the experiment. The finite element analysis developed the stress and elastic strain distribution obtained on the application of 2 kg load (20 N) on the aluminium alloy and mild steel specimen. The equivalent (Von Mises) stress distribution in mild steel had a maximum stress value of 0.023625 Mpa and minimum stress of 1.444×10^{-5} *Mpa while that of the aluminium alloy yielded a maximum and minimum stress of 0.0365 Mpa and* 8.5×10^{-5} *Mpa respectively. It was evident that the aluminium alloy recorded a higher magnitude of stress than the mild steel. This showed that the aluminium alloy being relatively light was more stressed than the mild steel. It was discovered that the rate of wear was higher in the aluminium alloy than in the mild steel.*

1.0 INTRODUCTION
The tribological study is a branch of engineering that entails the rubbing off of material surfaces. The process which leads to loss of materials is known as wear. A lot of materials have been put to use wrongly, because most engineers have not come to terms with adverse effect offered by conditions like wear, fatigue and corrosion [1]. The alloys of ferrous and non ferrous metals as they are applied in the environment are susceptible to the destructive influence of these material conditions [15][16].

Many types of wear exist. They are abrasive, frictional wear, adhesion and cohesion wear and corrosion wear. The most common is the Abrasive wear which has to do with the loss of material due to a hard particle been forced against a solid surface. A good knowledge of surface engineering will keep us abreast with how to tackle the menace of wear [2]. Surface finishing and application of lubricants on material surfaces will go a long way in checking the ravaging effect of wear.

Tribological studies have been carried out using various tools for its analysis. Experimental and optimization investigations have been conducted using tools such as the Design of experiments, Taguchi Design, Signa to noise ratio, Artificial Neural Network, Response Surface Methodology which comprises of Box-Behnken Design and Central Composite design, Genetic Algorithm and Particle Swarm Algorithm[3]. In the recent past some attention has shifted to the dexterity of applying Finite element analysis in material optimization. This Finite element analysis has a concern in various aspects of engineering.

The finite element method is a computer numerical method that utilizes the act of discretizing solution domain of complex mathematical problems into minute elements and nodes. It is applicable in the formation of new product as well as product refinement [4]. Notably, it handles the identification of nonlinear behaviour of components assembling such as the interaction between specimen pin and circular disc. The wear machine could be tagged nonlinear in behavior because of the nature of the load, torsion, stiffness, deformation, contact and boundary conditions. It involves solving the contact problem between the known areas of the pin and disc with respect to unknown areas [5][19]. This makes the problem quite nonlinear.

Some works have been done using the Finite element method. In optimization of the wear parameters by [6] the Finite Element Method was used to optimize the operating levels involved in the surface roughness of an aluminium alloy. The parameters employed were feed rate, cutting time, cutting speed and material removal rate. The prediction of wear rate is dependent on a number of experimental factors. Some of the factors examined by [7][17] showed a nonlinear influence on the wear rate of an automobile aluminium alloy component. The developed regression equation predicted a wear rate of about 0.013 g/mm from an interaction of process factors such as material removal rate, sliding speed, wear time and variable load.

Also, the effect of sliding distance, variable load, time of wear and surface roughness on abrasive wear was experimented upon by [8][18]. The experiment was performed under a dry lubricated condition of 23°C and 40% environmental temperature and relative humidity respectively. A preliminary result revealed that wear volume increases with increasing sliding distance, time of wear, applied load and surface roughness. Conversely, the result showed a decreasing abrasive wear rate with sliding distance, time of wear, applied load and surface roughness.

This study is geared towards comparing the abrasive wear behavior between aluminium alloy and mild steel in a pin-on-disc wear test machine using finite element analysis. The parameters investigated are effect of wear, equivalent stress and strain.

2.0 MATERIALS AND METHODS

The materials used in this work are Pin-on-disc wear test machine shown in Figure 2, a modelled aluminium alloy specimen is shown on Figure 1, variable weights, stop watch and steel alloy. The ANSYS Finite Element software was used to perform stress and elastic strain analysis of the specimen pin.

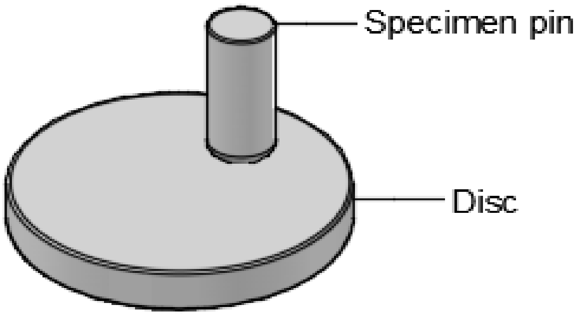

Figure 1: Specimen Pin on Disc

Figure 2: Pin on Disc Wear Test Machine

2.1 Method

The experiment was conducted by mounting the mild steel and aluminium alloy specimen pins whose length and diameter are 25 mm and 14 mm respectively on the lever arm placed directly on the circular disc. The circular disc was designed to be of diameter and thickness of 165 mm and 8 mm respectively as specified by ASTM-G99 standard code for wear experiment [9]. A weight of 2 kg was placed at the load holder to complete the contact action between the pin and the disc. The weight of the specimen pin was taken before and after each experiment. The disc rotated with a speed range of between 1000 and 1500 rpm in running the experiment. As the disc rotates in contact with the specimen pin there exists a detachment of material particles from the contact

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surface of the pin. The pin on disc wear test machine has an in-built weighing balance that helps in recording the amount of the wear or lost material.

2.2 Determination of Wear Rate

The wear rate of the material was determined by using equation (1) obtained from [9]

$$W_r = \frac{M_i - M_f}{S_d} \quad (1)$$

Where; M_i is the initial mass of specimen in mg, M_f is the Final mass of specimen in mg, S_d is the sliding distance in mm, W_r is the Wear rate in mg/mm.

The sliding speed is the product of the angular speed in radians and the track radius. While the sliding distance in the wear experiment is the product of experimental time taken in seconds and the sliding speed. The wear test experiment was conducted between 3 minutes to 7 minutes with sliding speed of between 1100 rpm to 1500 rpm and track diameter of between 50 to 90 mm yielded various sliding distances and wear rates shown in Tables 3 and 4 for aluminium alloy and mild steel specimens respectively.

3.0 RESULTS AND DISCUSSION

3.1 Spectrographic Results

The results obtained from the experimentation conducted in determining the chemical composition and wear rate of the aluminium alloy specimen is shown on Tables 1 and 3. While that of the mild steel specimen is shown on Tables 2 and 4.

Table 1: Chemical composition of Aluminium alloy (AA 6061)

Components	Al	Mg	Si	Fe	Cu	Zn	Ti	Cr	Mn
Percentage weight	96.10	1.30	0.85	0.60	0.45	0.20	0.18	0.20	0.12

Table 2: Chemical composition of Mild Steel

Components	Fe	C	Si	Mn	S	P
Percentage weight	91.60	3.75	4.00	0.35	0.025	0.05

3.2 Wear Test Result

The results obtained from the abrasive wear experimentation conducted on aluminium alloy and mild steel specimens on the Pin-on-Disc wear test machine are as shown on Tables 3 and 4. Upon maintaining the input parameters, it was obvious that the mass difference between the initial mass of the specimen before experimentation and the final mass after experimentation was higher in aluminium alloy than the mild steel. Consequently, the wear rate of the aluminium alloy is higher than that of the mild steel as shown in Tables 3 and 4. This shows that more material particles were lost in the application of aluminium alloy than mild steel, as also reported by [10].

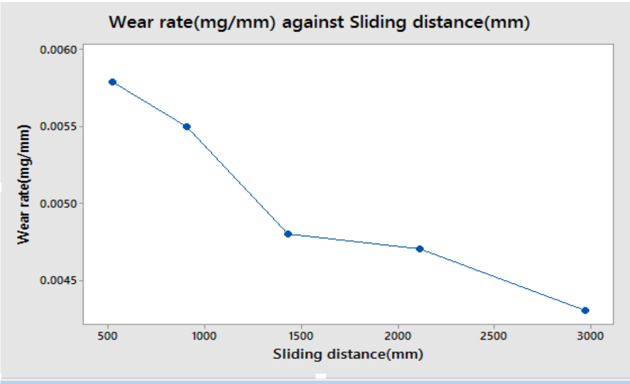

Figure 3: Scattered plot of Wear rate against sliding distance of aluminium alloy

Table 3: Wear test parameters for aluminium alloy specimen

S/N	Time, T(mins)	Speed (rpm)	Track diameter (mm)	Sliding distance, S_d (mm)	Initial mass of specimen, M_1 (mg)	Final mass of specimen, M_2 (mg)	Mass difference (mg)	Wear$(M_1M_2)/S_d$ (mg/mm)
1	3	1100	50	518.40	120	117	3	0.00579
2	4	1200	60	904.90	117	112	5	0.0055
3	5	1300	70	1430.00	112	105	7	0.0048
4	6	1400	80	2111.40	105	95	10	0.0047
5	7	1500	90	2969.20	95	82	13	0.0043

Table 4: Wear test parameters for the mild steel specimen

S/N	Time, T(mins)	Speed (rpm)	Track diameter(mm)	Sliding distance(mm)	Initial mass of specimen, M_1 (mg)	Final mass of specimen, M_2 (mg)	Mass difference (mg)	Wear$(M_1\text{-}M_2)/S_d$ (g/mm)
1	3	1100	50	518.40	135	133	2	0.00386
2	4	1200	60	904.90	133	130	3	0.00332
3	5	1300	70	1430.00	130	125	5	0.0035
4	6	1400	80	2111.40	125	118	7	0.00331
5	7	1500	90	2969.20	118	108	10	0.00336

Furthermore, scattered plots were developed to determine the relationship between wear rate and some of the input parameters. It was noticed that the wear rate decreases almost uniformly with an increase in sliding distance as shown in Figure 3. Also, the same trend was seen in Figure 4 where the wear rate decreases with time of wear. These results and graphical trends were similar to that of [8].

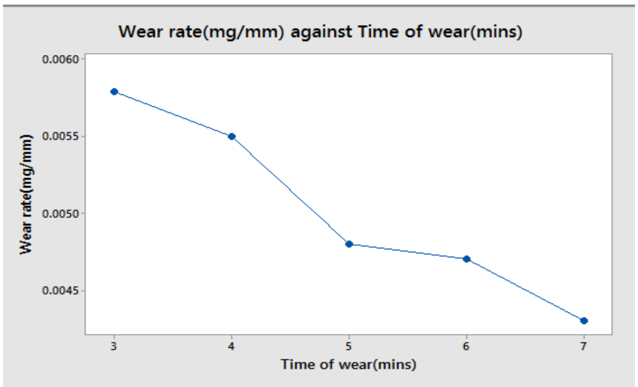

Figure 4: Scattered plot of Wear rate against time of wear of aluminium alloy

The scattered plot of the wear rate of the mild steel against sliding distance is shown in Figure 5. The graphical plot shows that the wear rate decreases with an increase in sliding distance initially and increases after sometime. Similarly, Figure 6 showed that the wear rate of the mild steel decreased with an increase in the time of wear.

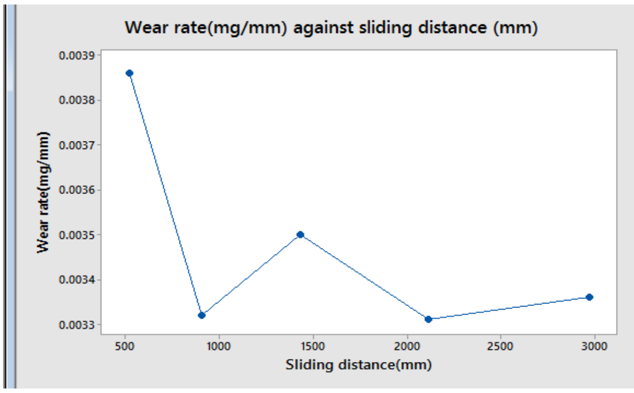

Figure 5: Scattered plot of Wear rate against sliding distance of mild steel

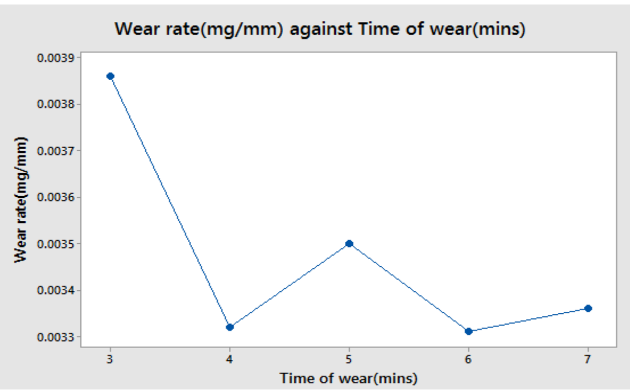

Figure 6: Scattered plot of Wear rate against sliding distance of mild steel

3.3 Finite Element Analysis

3.3.1 Finite element analysis of the aluminium alloy

The static structural tool of the Finite element ANSYS software was applied in this study. The modeled specimen pin was imported into the static structural Workbench environment. The aluminium alloy and mild steel specimens were analysed so as to obtain the stress and strain distribution using finite element ANSYS software [11][20]. A meshed structure of the aluminium alloy shown in Figure 7 comprised of nodes and elements of 3442 and 700 respectively. It was created with a smooth transition of 0.272 ratio having a growth rate of 1.2 and a maximum layer of 5.

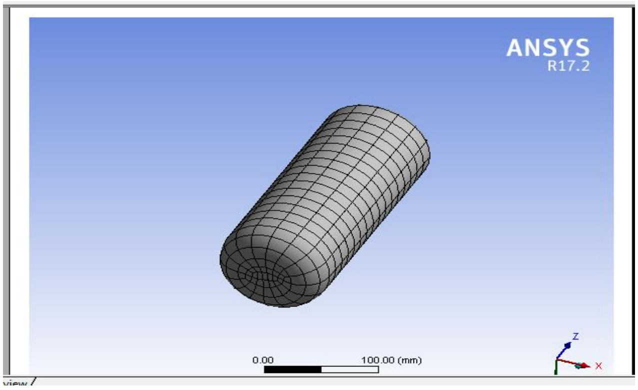

Figure 7: Meshed aluminium alloy specimen

The aluminium alloy examined for Equivalent (Von Mises) stress, had its graphical result shown in Figure 8. Its stress distribution showed that the maximum and minimum stress are 0.0365 Mpa and 0.000085 Mpa respectively. In carrying out the stress and elastic distribution a force of 20N was applied on the aluminium alloy. The elastic strain distribution obtained is shown in Figure 9. The distribution had maximum and minimum strain values of 1.82×10^{-7} and 8.166×10^{-10} respectively.

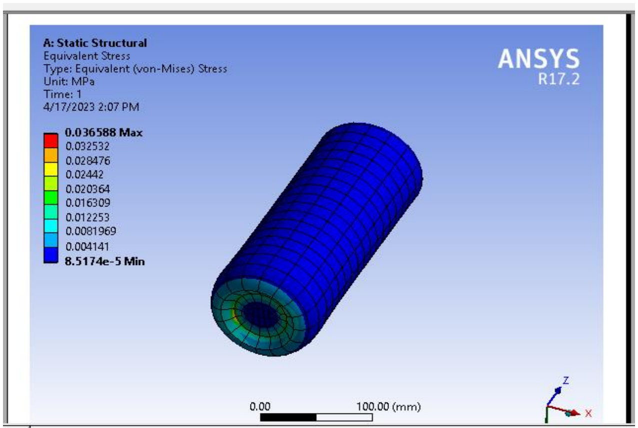

Figure 8: Von Mises stress distribution in Aluminium alloy

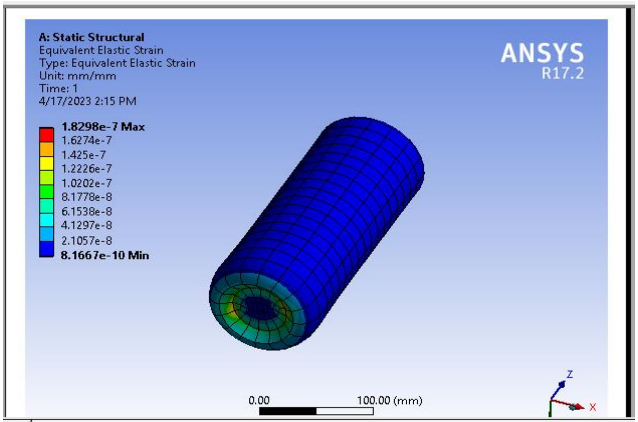

Figure 9: Elastic strain distribution in Aluminium alloy

3.3.2 Finite element analysis of the mild steel

The meshed mild steel specimen pin is shown in Figure 10. The meshing enabled the discretizing of the specimen for an effective and quick solution. The meshed structure had 700 elements and 3440 nodes as obtained in the aluminium alloy meshed structure.

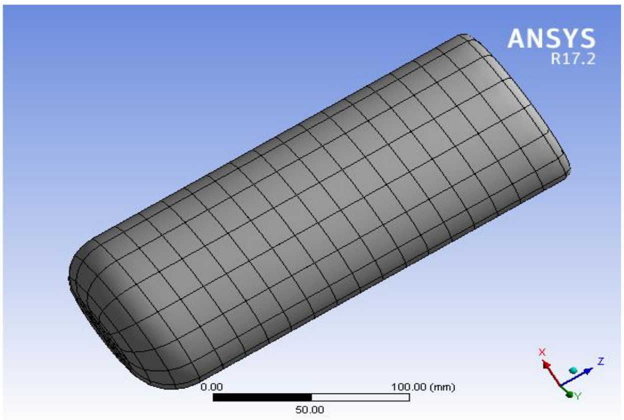

Figure 10: Meshed mild steel

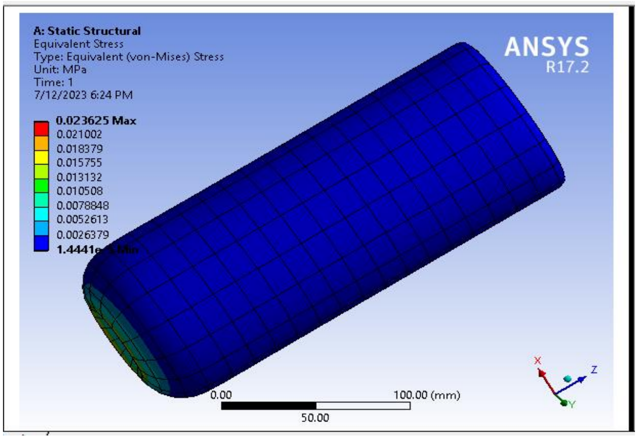

Figure 11: Von Mises stress distribution in Mild steel

The equivalent (Von Mises) stress distribution of the mild steel had a maximum stress of 0.023625 Mpa and minimum stress of 1.444×10^{-5} Mpa as shown in Figure 11. The maximum and minimum stresses obtained for the mild steel is known to be lower than that obtained for the aluminium alloy. This occurred because the aluminium alloy is lighter than the mild steel. Consequently, there was a higher distribution of stress in the aluminium alloy than in the mild steel.

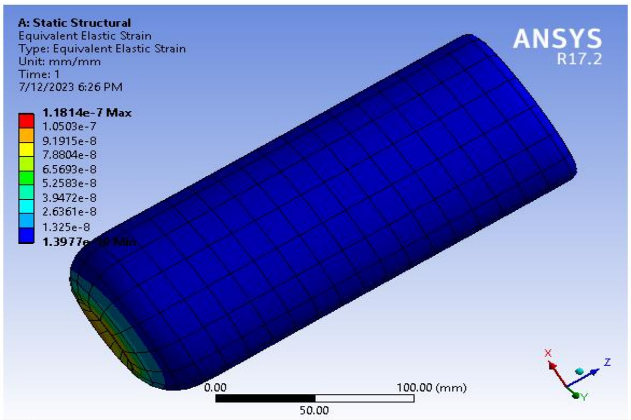

Figure 12: Elastic strain distribution in Mild steel

The elastic strain distribution is shown in Figure 12. The distribution had a maximum strain of 1.1814×10^{-7} and minimum strain of 1.3977×10^{-10}. Again, in comparison, it was noticed that the maximum and minimum strain values are lower than that obtained in aluminium alloy. This is also attributed to higher strength inherent in the mild steel as reported in [5] and [12].

4.0 CONCLUSION

A comparative analysis on the abrasive wear of aluminium alloy and mild steel on the pin-on-disc wear test machine has been successfully carried out. The wear rate of the aluminum alloy was noticed to have uniformly decreased with increase in sliding distance and time. While that of mild steel also decreased with increases in sliding distance and time of wear but not with the uniform trend obtained in alumimium alloy. The finite element analysis provided an opportunity of seeing the behavioural pattern of the stresses obtained on the application of 2 kg load (20 N) on the aluminium alloy and mild steel specimens. The equivalent (Von Mises) stress distribution in mild steel had a maximum stress of 0.023625 Mpa and minimum stress of 1.444×10^{-5} Mpa while that of the aluminium alloy had maximum and minimum stress of 0.0365 Mpa and 0.000085 Mpa respectively. This is a pointer that the lighter material aluminium alloy was more stressed than the mild steel. The study examined the effects of wear , stress and strain on the aluminium alloy and the mild steel. It was discovered that the rate of wear was higher in the aluminium alloy than in the mild steel as shown in Figures 3 and 5. Similarly it was established that the aluminium alloy encountered a higher stress and strain than the mild steel [13] and [14]. That was occasioned by it's relatively lightness of weight of the aluminium alloy.

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