EFFECTS OF SEED OILS, LOAD AND SURFACE TEXTURE ON SLIDING WEAR OF QUENCHED PINS SLIDING ON CARBURIZED DISCS

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ABSTRACT

The effect of load variations, quenched pin, lubricant oil types, carburized disc and disc surface texture on the sliding wear behaviour of a pin–on–disc experiment was investigated. The experiment was carried out with four pairs of quenched pins, four pairs of un-heat treated pins (to serve as control), four pairs of carburized discs and four pairs of un-heat treated discs (to also serve as a control). Each pin was allowed to run against lubricated rough and smooth surface mild steel and carburized discs respectively. The experimental parameters include: loading conditions (1 kg, 2 kg and 3 kg); sliding speed (750rpm); sliding duration (30 minutes);lubricating oil media (castor, cotton, soya, palm, groundnut and SAE 20W/50 oil samples); and room temperature (33^{o}C) respectively. It was observed that the concentration of wear debris increase with load for all tested samples. Except for quenched pin sliding on smooth surface discs lubricated with cotton oil and SAE 20W/50 oil, a comparatively higher wear concentration is noticed for all tested pins and mild steel discs over the corresponding carburized discs for all disc surface textures and lubricating oil types.However, a comparatively higher wear Concentration was recorded for control mild steel pin over the corresponding quenched pins for all lubricating oil types, disc surface textures and mild steel discs except for quenched pins sliding on smooth and rough carburized discs. Groundnut, soya, cotton and palm oils lubricated discs exhibited higher wear rates than SAE 20W/50 and castor oils which demonstrated better anti-wear behaviour for all loading conditions, pin and disc types and textures. Finally, it was also established that rough textured disc surfaces generated comparatively higher wear rate than their corresponding smooth textured disc surfaces.

Keywords: Seed oil, Slide wear, Quenching, Carburizing, Surface texture, Petroleum oil, Load.

INTRODUCTION

Poor lubrication conditions exacerbate wear of interacting mechanical members in relative motion to one another. The prevalence of such tribological contacts of machinery in industrial situation tends to have severe economic consequences. It has been reported that friction and wear had been a cause of huge energy, maintenance and spare part related expenditure (Halling, 1989). According to Darsic et.al (2003), friction and wearing expenditure in some industrialized societies (such as; USA, England, Germany etc.) was put at 2-7 percent of their gross national product, and this translates into several billions of dollars (or Euros) yearly. However, if such economic impact is extrapolated to a developing nation such as Nigeria, it will no doubt have a staggering effect on the national economy. It is in light of the foregoing, the fast depleting crude oil reserve in Nigeria, the growing insecurity in the oil producing Niger-Delta region, and the evident public concerns over toxicity and pollution; necessitated the need to explore other environmental-friendly friction and wear mitigation technologies of which seed oil based lubricants is being considered. Frictional wear could be mitigated by excellent design practices, careful material selection, the use of suitable lubricants, and by improving the hardness property of interacting steel members in relative contact with one another. Record has shown that quenched steel are stronger and harder than normalized steel. This is because in quenching heat treatment steel is much tougher than in any other structural condition, the method of cooling has an influence on the cooling rate and on the resulting structure (Noble, 1996). Record has also shown that carburizing of steel has led to higher surface hardness, increased wear resistance, improved fatigue life, improved abrasion resistance and a higher surface resistance to the softening effect of heat at temperature up to the carburizing temperature. This is because carburizing involves heating while it is in the austenite condition which makes carburizing to be accomplished with less distortion and better dimensional control (Khurmi and Gupta, 2004).

Seed oils show acceptable performance as lubricants because of their excellent lubricity, high viscosity index, high flash point and biodegradability properties (Lou, 2001). It was reported that seed oils and their polar derivative are used with mineral oil as metal working fluids (Faborode, 1996). At different experimental instances, Masjuki and Maleque (1996) reported encouraging results on the effect of palm oil diesel fuel contaminated lubricant on sliding wear of cast irons against mild steel. Similarly, Tekeuchi (1970); Eyre and Fitter (1983); Nakamura and Hirayama (1989); and Child and Sabbagh (1989) also reported various result of lubricated wear experiments with various types of cast iron using different base lubricating oils and additives. However, it is still unknown whether seed oil based lubricating fluids are commercially available for sliding wear experiments. Nonetheless, the purpose of this paper is to compare the sliding wear response of mild steel and carburized discs under the influence of quenched mild steel pins, various loading conditions, seed oil lubricating oil media and surface textures in different sets of experimental conditions.

MATERIAL AND METHODS

Material preparation

Low carbon steel NST 44-2 grade material was used in the work for all pins and rotating disc specimens. The chemical composition of the steel grade is presented in Table 1. Eight sliding pins and ten discs from low carbon steel material were machined to 2mm diameter and 70mm length. Four out of low carbon steel pins were quenched by heating the mild steel pin above a critical temperature and then quenched in an oil bath (Noble, 1996). While another four of as-machined pins without heat treatment were allowed to serve as the control sample for the experiments. Out of eight as-machined rotating discs, four pair of low carbon steel discs were subjected to Carburizing by introducing carbon into the surface of the steel at a temperature of 550^{o}c while it is in the austenite condition and therefore surface hardened in order to make the surface harder and more abrasion – resistant (Khurmi and Gupta, 2004). Four pair was left unheated; two pairs out of the carburized and unheated discs were polished unidirectional to a smooth surface finish with an Emory cloth of 0.25mm abrasive particle size. While, the surfaces of the remaining two pairs of carburized and unheated discs specimens were roughly finished with an Emory cloth of 0.4 mm abrasive particle sizes respectively. In addition, the properties of the lubricating fluids used in the pin-on-disc experiments are presented in Tables 2, 3 and 4 accordingly (JSRC, 1992, Olorunnishola, 2012 and Ejilah et al, 2010).

Table1. Chemical composition of locally produced low carbon steel rod.

Grade	Colour code	% Carbon	%Silicon	%Manganese
NST 44-2	Yellow	0.14-0.20	0.18-0.28	0.40-0.60

Source: JSRC(1992).

Table 2. Physico-chemical properties of some tropical seed oil at room temperature.

Properties	SAE20w/50	Castor oil	Cotton oil	Groundnut oil	Palm oil	Soya oil
Refractive Index	1.482	1.460	1.471	1.472	1.467	1.475
Specific gravity	0.882	0.989	0.930	0.918	0.912	0.935
Kinematic viscosity	170	98.62	18	24.7	34.7	25.9
Acid value	-	1.05	0.159	0.159	2.46	0.139
Iodine value	-	86.93	114.86	96.1	54	127.1
Saponification value	-	181.62	190.18	190.38	198.46	189.04
Peroxide value	-	0.78	0.94	0.87	0.86	2.5

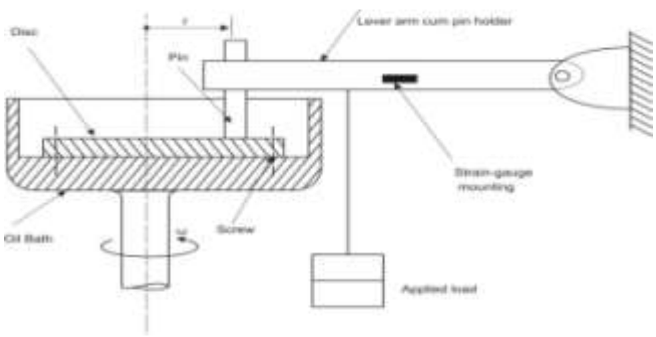
Source: Olorunnishola (2012).

Table 3. Fatty acid composition of seed oils.

Fatty acids	Castor oil	Cotton oil	Groundnut oil	Palm oil	Soya oil
Myristic	-	0.50	-	1.40	0.10
Lauric	-	-	-	-	0.20
Palmitic	-	21.90	8.10	40.1	9.80
Stearic	-	1.90	3.10	5.50	2.40
Arachidic	-	0.10	2.40	-	0.90
Oleic	15.10	36.70	56.0	42.70	28.90
Palmitoleic	-	-	-	-	0.40
Linoleic	9.90	44.90	26.0	10.30	50.70
Bohenic	-	-	3.10	-	-
Lignoceric	-	-	1.10	-	-
Linolenic	-	-	-	-	6.50
Ricinoleic	75.00	-	-	-	-

Source: Ejilah et al, 2010

Experimental procedure



The lubricated sliding wear experiment was carried out on an improvised pin-on-disc machine as shown in Figure 1. According to Masjuki and Malegue (1996), the principle of sliding wear is a cantilever loaded pin of 4.5mm diameter against a horizontal rotating disc that is superimposed and bolted in a cylindrical oil bath. The pin-on-disc test rig was allowed to run at a constant speed of 750rpm, and sliding distance of 2.5mm, under a 1Kg load condition for replicate samples of as-machined (i.e. unheated treated) pins to serve as an experimental control and smooth surface finished discs, immersed in a bath of SAE 20W/50 (multigrade oil), for an experimental period of 30 minutes. The lubricating oil samples were collected from the oil bath, digested with concentrated nitric and hydrochloric acid at a ratio of 4:1; and subsequently filtered to reduce surface tension and facilitate ease of absorption into the atomic absorption spectrophotometer (AAS) for the determination of the concentration of iron (Fe) wear debris in milligrams per liters for each sample analyzed (Rangrina, 1989). This experimental procedure was repeated after an intermittent period for the following set of conditions:

Figure 1.Schematic diagram of pin-on-disc apparatus.

- **i.** The load condition is varied from 1Kg to 3Kg after stipulated experimental duration of 30 minutes, for each pin type (i.e. as machined and quenched), lubricant types (i.e. SAE 20W/50 oil, castor oil, cotton oil, palm oil, and soya oil) and surface finish (i.e. smooth and rough surface).
- **ii.** The pin types were varied from as-machined (i.e. control) to quenched pins, after each intermittent experimental period for all loading conditions, lubricant types and surface finish.
- **iii.** Lubricant types was varied after running each experiment for the period of 30 minutes then drained off, and subsequently replaced with other seed oils. The test procedure is repeated for various load conditions, surface finish and pin types respectively.
- **iv.** The surface texture of the disc is varied from smooth to rough after each experimental run for the stipulated duration for varied conditions of load, pin types and lubricating fluids respectively.
- **v.** The disc types were varied from as- machined to carburized discs for the stipulated duration for varied conditions of load, pin types and lubricating fluids respectively.

RESULTS AND DISCUSSION

Wear data

The concentration of wear debris arising from the pin-on-disc experiment for control and quenched pins, smooth and rough seed oil lubricated sliding mild steel and carburized discs under different loading conditions are shown in Table 4 to 7 and Figures 2 and 3 respectively. The corresponding mean wear rate for the pin-on-disc experiment is shown Tables 8 to 9 and Figures 4 to 5 respectively.

Table 4. Wear rate of pins and smooth surface control discs under maximum load

Lubricating oils	Wear rate of smooth disc (mg/l.min)	
	Control pin	Quenched pin
Castor oil	0.084	0.071
Cotton oil	0.110	0.072
Groundnut oil	0.124	0.095
Palm oil	0.101	0.059
Soya oil	0.114	0.088
SAE 20W/50	0.028	0.023

Table 5. Wear rate of pins and rough surface control discs under maximum load

Lubricating oils	Wear rate of rough disc (mg/l.min)	
	Control pin	Quenched pin
Castor oil	0.086	0.049
Cotton oil	0.110	0.077
Groundnut oil	0.125	0.099
Palm oil	0.106	0.072
Soya oil	0.119	0.080
SAE 20W/50	0.035	0.032

Table 6. Wear rate of pins and smooth surface carburized discs under maximum load

Lubricating oils	Wear rate smooth disc (mg/l.min)	
	Control pin	Quenched pin
Castor oil	0.044	0.041
Cotton oil	0.056	0.078
Groundnut oil	0.06	0.081
Palm oil	0.048	0.054
Soya oil	0.052	0.068
SAE 20W/50	0.023	0.036

Table 7. Wear rate of pins and rough surface carburized discs under maximum load

Lubricating oils	Wear rate of rough disc(mg/l.min)	
	Control pin	Quenched pin
Castor oil	0.029	0.032
Cotton oil	0.044	0.048
Groundnut oil	0.065	0.060
Palm oil	0.032	0.035
Soya oil	0.041	0.036
SAE 20W/50	0.028	0.029

Table 8. Mean wear rate of control pin on smooth and rough sliding control and carburized discs at maximum load.

Lubricating oils	Wear rate on disc types (mg/l.min)				Mean wear rate (mg/l.min)	
	Smooth control disc	Rough control disc	Smooth carburized disc	Rough carburized disc	Control disc	carburized disc
Castor oil	0.084	0.086	0.007	0.005	0.085	0.006
Cotton oil	0.110	0.110	0.009	0.007	0.110	0.008
Groundnut oil	0.124	0.125	0.010	0.011	0.1245	0.0105
Palm oil	0.101	0.106	0.008	0.005	0.1035	0.0065
Soya oil	0.114	0.119	0.009	0.007	0.1165	0.008
SAE 20W/50	0.028	0.035	0.004	0.005	0.0315	0.0045

Table 9. Mean wear rate of quenched pin on smooth and rough sliding control and carburized discs at maximum load.

Lubricating oils	Wear rate on disc types (mg/l.min)				Mean wear rate (mg/l.min)	
	Smooth control disc	Rough control disc	Smooth carburized disc	Rough carburized disc	Control disc	carburized disc
Castor oil	0.071	0.049	0.007	0.005	0.06	0.006
Cotton oil	0.072	0.077	0.013	0.008	0.0745	0.0105
Groundnut oil	0.095	0.099	0.014	0.010	0.097	0.012
Palm oil	0.059	0.072	0.009	0.006	0.0655	0.0075
Soya oil	0.088	0.080	0.011	0.006	0.084	0.0085
SAE 20W/50	0.023	0.032	0.006	0.005	0.0275	0.0055

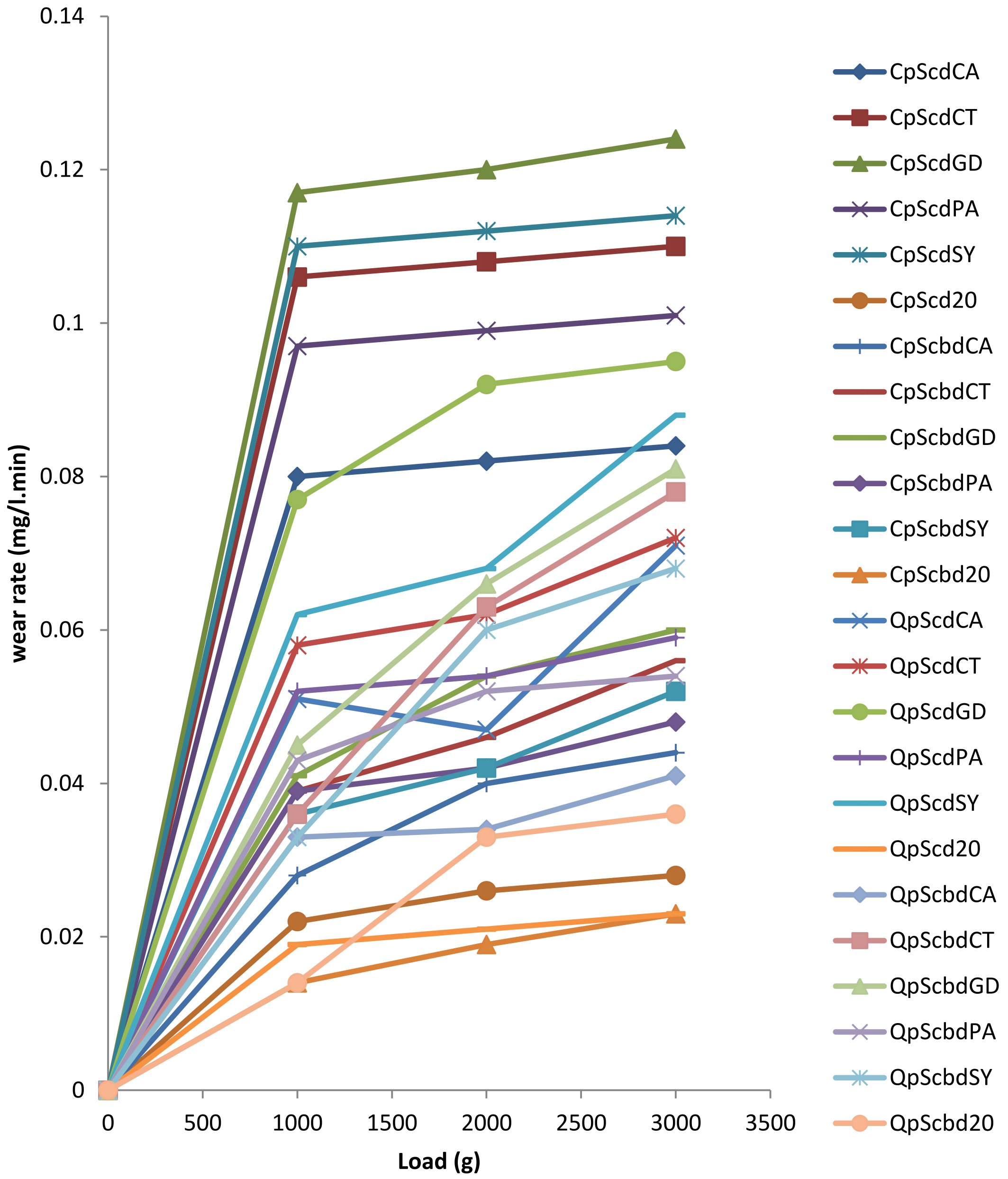


Figure 2: Wear and load profile of control and quenched pins and smooth surface control and carburized discs

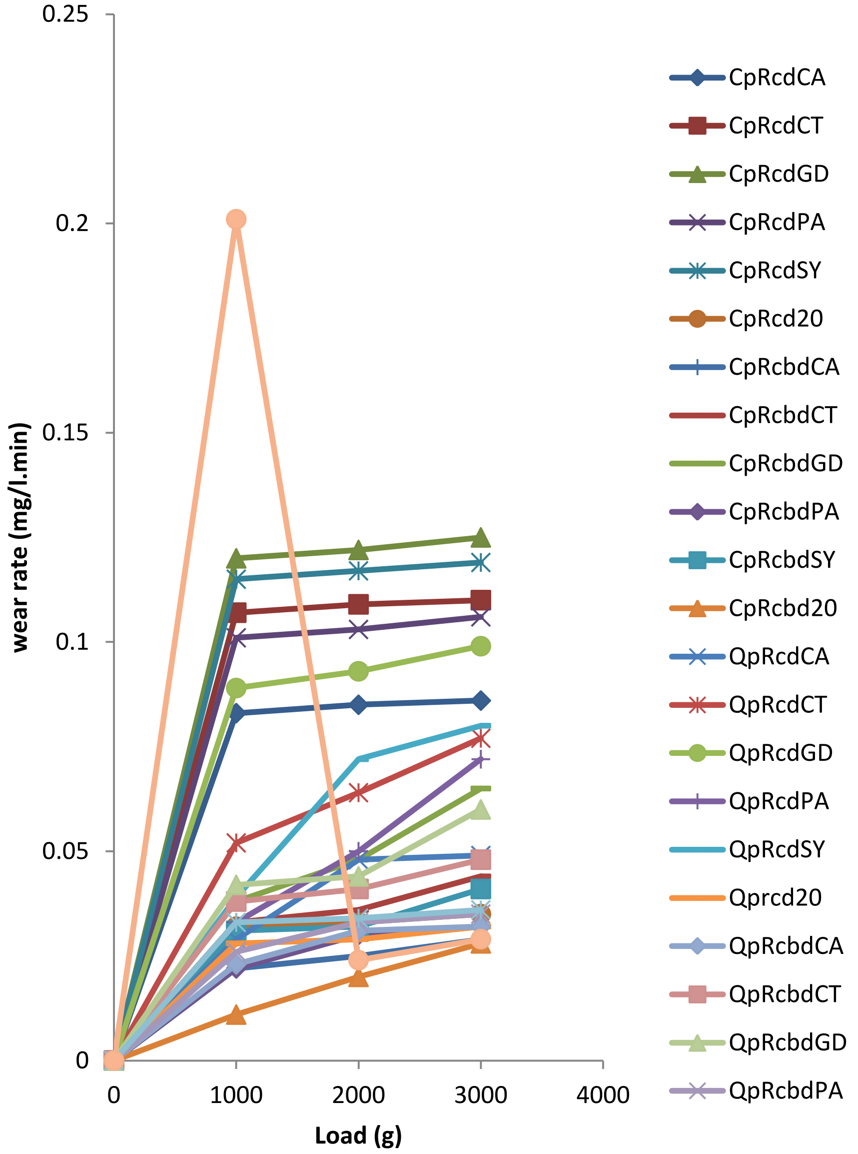


Figure 3: Wear and load profile of control and quenched pins and rough surface control and carburized discs

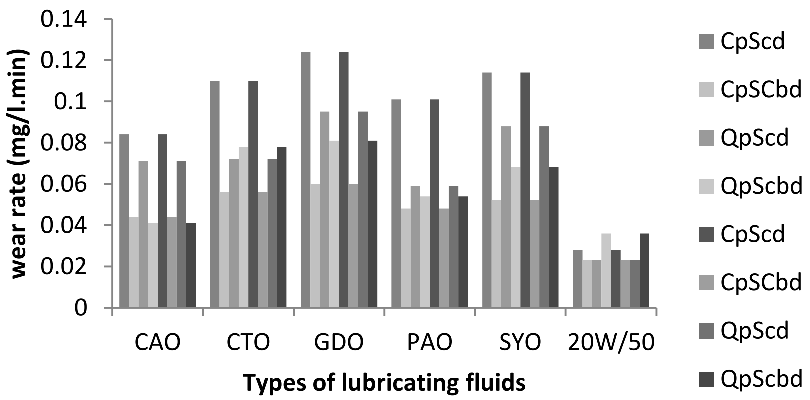


Figure 4: Comparative wear rate at maximum loading condition of control and quenched pins on smooth control and carburized discs

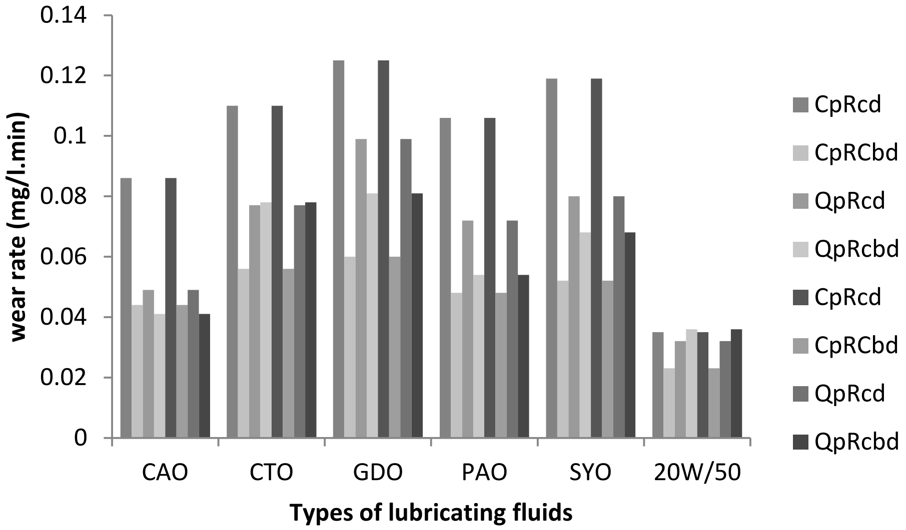


Figure 5: Comparative wear rate at maximum loading condition of control and quenched pins on rough control and carburized discs

Legends:

CpScd = control pin and smooth mild steel disc
QpScd = quenched pin and smooth mild steel disc
CpRcd = control pin and rough mild steel disc
QpRcd = quenched pin and rough mild steel disc
CpScbd = control pin and smooth carburized steel disc
QpScbd = quenched pin and smooth carburized steel disc
CpRcbd = control pin and rough carburized steel disc
QpRcbd = quenched pin and rough carburized steel disc
CA = castor oil lubricant
GD = groundnut oil lubricant
CT = cotton oil lubricant
PA = palm oil lubricant
SY = soya oil lubricant
20 = SAE 20w/50 multigrade oil lubricant

Effect of load as a function of sliding wear

Figures 2 and 3 show the effect of load variation on pins and discs wear. It could be seen that the wear debris concentration for all tested pins and discs, surface finish and lubricating types increase with load. This trend agrees with the findings of Prasad (2009). According to Halling (1989) increases in load cause an increase in frictional force, and wear and temperature. Subsequently, this phenomenon could lead to severe wear. The transition from mild to severe wear is attributed to the interaction of the plastic zone beneath the contacting asperities (Shaw, 1968)

Effect of quenching as a function of sliding wear under maximum load condition

It could be observed from Table 4 and Figure 2 that the concentration of wear debris arising from the use of the rolled as -machined (control) low carbon steel pins sliding on smooth mild steel (i.e control) disc lubricated with castor oil, cotton oil, groundnut oil, palm oil, soya oil and SAE 20W/50 oil respectively is 15.5%, 34.5%, 23.4%, 41.6%, 22.8% and 17.9% higher than the corresponding quenched pin. While the concentration of wear debris arising from the use of the rolled as -machined (control) low carbon steel pins sliding on smooth carburized disc lubricated with cotton oil, groundnut oil, palm oil, soya oil and SAE 20W/50 oil respectively is 39.3%, 35%, 12.5%, 30.8% and 56.5% lower than the corresponding quenched pin. Nonetheless it could also be observed that castor oil, recorded a comparatively higher wear concentration (i.e. 6.8%) than the quenched pin under a similar operational condition.

Figure 3 also show higher wear behaviour for control pin on lubricated rough surface discs. The result at maximum load condition suggest a 43%, 30%, 20.8%, 32.1%, 32.8% and 8.6%, higher wear profile of control pins sliding on mild steel disc lubricated with castor oil, cotton oil, groundnut oil, palm oil, soya oil and SAE 20W/50 over the corresponding quenched pins. While the result at maximum load condition suggest a 10.34%, 9.1%, 9.4% and 3.6%, higher wear profile of quenched pins over the corresponding control pins as the pins slide over castor oil, cotton oil, palm and SAE 20W/50 lubricated carburized discs respectively. Whereas for groundnut oil and soya oil the wear rate values of 7.7% and 12.2% of control pins were slightly higher than the corresponding quenched pins. The high wear profile of control pins over corresponding quenched pins sliding over the control discs could be explained in terms of the softening of the steel component due to the refinement of its grain structure. According to Noble (1996), the strength of quenched pin is higher than unheated steel of similar composition. Furthermore, micro structure results show a microstructure consisting ferrites and pearlite of smaller grain size and spacing between platelets of carbide in the pearlite compared to the unheated counterpart.

The higher wear profiles of the cold worked control pins and mild steel disc are usually enhanced by their strength and natural solubility. Nonetheless, this is at the expense of ductility and impact toughness (Noble, 1996). Furthermore, Rabinowicz (1966) and Halling (1989) had opined that metal pairs with low metallurgical compatibility tend to exhibit low friction and wear. Therefore, it could be argued that the high wear profile of control pin in lubricated sliding, suggests a high metallurgical compatibility (mutual solubility) with the sliding discs.

Effect of carburizing as a function of sliding wear under maximum load condition

It could be observed from Figure 2 that the concentration of wear debris arising from the use of the rolled as -machined (control) low carbon steel pins sliding on smooth mild steel (i.e. control) disc lubricated with castor oil, cotton oil, groundnut oil, palm oil, soya oil, and multi-grade oil respectively is 47.6%, 49.1%, 51.6%, 52.5%, 54.4% and 17.9% higher than the corresponding pins sliding on carburized disc. With the exception of cotton oil and SAE 20W/50 oil, the result at maximum load condition suggest a 42.3%, 14.7%, 8.5%, and 22.7% higher wear profile for quenched pins and smooth surface as- machined discs over the corresponding pins sliding on carburized disc lubricated with castor oil, groundnut oil, palm oil and soya oil respectively. Whereas the wear profile for the quenched pins sliding on cotton oil and SAE 20W/50 oil lubricated mild steel disc is 8.3% and 56.5% lower than the corresponding carburized disc.

Figure 3 also show higher wear behaviour for quenched pin on lubricated rough surface as-machined discs over the corresponding carburized discs. The result at maximum load condition suggest a 34.7%, 37.7%, 39.4%, 51.4%, 50% and 9.4% higher wear profile for quenched pins and rough surface as-machined disc over the corresponding carburized disc lubricated with castor, cotton oil, groundnut oil, palm oil soya oil and SAE 20W/50 oil respectively. Figure 5 also show that the concentration of wear debris arising from the use of the control pins sliding on rough as-machined disc lubricated with castor oil, cotton oil, groundnut oil, palm oil, soya oil and multi-grade oil respectively is 66.3%, 60%, 48%, 69.8%, 65.5 and 20% higher than the corresponding control pins sliding on carburized disc. It was noticed that the pins sliding on carburized steel discs generally exhibit lower wear concentration compared to pins sliding on mild steel discs. According to Chattopuhgang (2004) and Khurmi and Gupta (2004), carburizing can be accomplished with a minimum of distortion and excellent dimensional control, because it does not involve heating into the form martensite. Gahur (1985), established that quenching is not required for the production of a hard case, therefore the absence of quenching requirement with attendant volume changes produces less distortion and deformation in carburizing than conventional hardening and this could bring about decrease in wear rate of sliding members.

Effect of lubricating oils on wear of pins and discs

Under maximum loading condition, the mean wear rate of the pins and lubricated discs samples are presented in Figures 4, 5, and Tables 8 and 9 respectively. Table 8 shows that the mean wear rate of control pins sliding on mild steel and carburized discs lubricated with groundnut oil (0.1245mg/l.min, 0.0105mg/l.min), soya oil (0.1165mg/l.min, 0.008mg/l.min), cotton seed oil (0.110mg/l.min, 0.008mg/l.min), palm oil (0.1035mg/l.min, 0.0065mg/l.min), castor oil (0.085mg/l.min, 0.006mg/l.min) are higher than the SAE 20W/50 oil (0.0315mg/l.min, 0.0045mg/l.min) lubricated discs. Table 9 also shows that the mean wear rate of quenched pins sliding on mild steel and carburized discs lubricated with groundnut oil (0.097mg/l.min, 0.012mg/l.min), soya oil (0.084mg/l.min, 0.0085mg/l.min), cotton seed oil (0.0745mg/l.min, 0.0105mg/l.min), palm oil (0.0655mg/l.min, 0.0075mg/l.min), castor oil (0.06mg/l.min, 0.006mg/l.min) are higher than the SAE 20W/50 oil (0.0275mg/l.min, 0.0055mg/l.min) lubricated discs. The lubricating film behaviour could be understood in terms of oil viscosity, saponification value and oleic acid content respectively.

However, it could be seen from Table 2 that SAE 20W/50 and castor oils exhibit comparatively higher viscosities than the other lubricating oils employed in the tests. Bartz (1994) was opined that the thickness of load supporting film is governed by viscosity, therefore high oil viscosity brings about decrease in wear rate of sliding members. According to Halling (1989) and Masjuki and Malegue (1996), the relatively higher saponification value, oleic acid contents of the seed oil (refer to Tables 2 and 3) could bring about a reduction in wear due of their propensity for soap formation on metallic surfaces in relative motion to one another. Furthermore it was observed that the SAE 20W/50 and castor oils exhibited the highest anti-wear behaviour. This is firstly due to; the presence of additive components (such as Zn, Ca, and synthetic polymers) introduced to the SAE 20W/50 oil formulation to improved detergency and lubricity, and secondly to; the high content of the hydroxyl mono unsaturated fatty acid (i.e. ricinoleic acid) present in castor oil also could be responsible for the low wear behaviour (Elf, 2004; Asadauskas and Perez, 1997; USDA, 1993).

Effect of surface texture on wear of pins and discs

The effect of surface texture on wear of pins and discs are shown in Tables 4 to 7. It could be observed that as the control and quenched pins were ran over smooth to rough surface mild steel discs, evidence of higher wear concentration was noticed. However, this is with exception of control pin sliding on cotton oil lubricated discs, and quenched pin sliding on castor and soya oils lubricated rough surface control discs. Furthermore, as the control and quenched pins were ran over smooth to rough surface carburized discs, evidence of lower wear concentration in favour of rough surface was noticed. However, this is with exception of control pins sliding on discs lubricated with groundnut oil and SAE 20W/50 oil. The ploughing-off of larger area of contact of interlocking surface asperities, and their displacement when in contact with harder surfaces in relative sliding motion could be responsible for the high wear behaviour. Therefore, the formation of wear is an indication that fracture and plastic deformation has taken place (Halling, 1989).

CONCLUSION

The comparative study of the sliding wear response of smooth and rough surface textured mild steel disc and quenched pin on one hand and the smooth and rough surface textured carburized disc and quenched pin on the other hand, under the influence of varied loading conditions and lubricants shows that:

i. Wear debris concentration for all tested pins and discs increase with compressive load.
ii. With the exception of quenched pin sliding on smooth surface discs lubricated with cotton oil and SAE 20W/50 oil, a comparatively higher wear concentration is noticed for all tested pins and mild steel discs over the corresponding carburized discs for all disc surface textures and lubricating oil types.
iii. Groundnut, soya, cotton and palm oils lubricated discs exhibited higher wear rates. However, SAE 20W/50 and castor oils demonstrated better anti-wear behaviour for all lubricating oil types, disc types and textures.
iv. A comparatively higher wear Concentration was recorded for control mild steel pin over the corresponding quenched pins for all lubricating oil types, disc surface textures and mild steel discs except for quenched pins sliding on smooth and rough carburized discs.
v. Rough surface discs are more prone to higher wear rate than their corresponding smooth surface.

ACKNOWLEDGEMENT

The authors appreciate the technical assistance received from the Department of Mechanical Engineering Technology, Federal Polytechnic, Bauchi, Abubakar Tafawa Balewa University and National Metallurgical Development Centre, Jos for the use of their facilities such as; the pin-on- disc sliding wear test rig, atomic absorption spectrophotometer and heat treatment furnace respectively.

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