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Materials Today: Proceedings XX (2016) XXX–XXX

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PMME 2016

Tribological Characterization of Centrifugally Cast Graphite Cast Iron under Dry and Wet conditions

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Abstract

The study is concerned with wear behaviour of centrifugally cast flake graphite iron, spheroidal graphite iron and compacted graphite iron in both dry and wet conditions. The test was conducted according to the ASTM G99 standards, to investigate the wear behaviour in dry and wet conditions by keeping time and sliding speed as constants but for varying loads. The graphite iron classified as flake graphite cast iron, spheroidal graphite cast iron, and compacted graphite cast iron depending upon the shape and distribution of graphite particles in the metal matrix. The variations of the co-efficient of friction and wear rate were experimentally measured. From the experimental results, the following things became clear. Initially the co-efficient of friction varies and later it converges to a certain value because of the debris, the debris grows and comes between the pin and disc surfaces. From the result it is clear that SGI has the highest wear in both dry and wet conditions. The graphite acts as an inherent lubricant for cast iron automatically coming in between the pin and disc surface and along with external lubrication it was found to decrease the co-efficient of friction by 10 times.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

Keywords: Cast iron, Centrifugal casting process, Microstructure, Wear, Co-efficient of friction

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Introduction

The indispensable use of cast iron in production of automobiles has been aptly demonstrated, in recent times. Due to its high melting point it is being used in the engine components, and due to its wear resistant properties it is being used in making other components of automobiles as well. There are many casting methods to obtain cast iron components but most preferred method is centrifugal casting especially for cylinder liner because it gives high dense and closely packed grain structure in cast products. Many automobile components such as brake drums and hydrodynamic journal bearings are also made of cast iron through centrifugal casting process and are subject to high levels of wear.

B.K Prasad [1] studied the influence on various parameters such as load, sliding speed and test environment on the wear behavior of cast iron. Examination of wear surfaces, subsurface regions and debris particles were also carried out to understand the operating wear mechanisms and further substantiate the observed response of the samples. K. Hirasata et al. [2] studied the dry friction and wear characteristics of several kinds of cast irons under the conditions of high sliding speed and high contact pressure. It was observed that the wear rate of each cast iron under severe sliding conditions was strongly influenced by the change in hardness with the rise in friction-induced temperature. The co-efficient of friction of each cast iron converged to some constant value with the increment of sliding distance, and this converged value was independent of the contact pressure and decreased with the increment of sliding speed. H.S. Desai Gowda et al. [3] studied the influence of centrifugal process on the graphite morphology, mechanical and wear properties on flake graphite iron (FGI), spheroidal graphite iron (SGI) and compacted graphite iron (CGI). It was observed that Disk and Pin combinations of the same structures show a higher co-efficient of friction and wear than the other two combinations, SGI and FGI material pairs produced the least wear. A.R Ghaderi et al. [4] studied three different cast irons, gray, nodular and compact iron, with different chemical compositions were subjected to austempering to investigate the effects of composition, austempering and graphite morphology on tribological behaviour. The wear test results indicated that the austempered cast iron shows superior wear resistance than pearlitic gray iron, particularly at the lower speed. Aravind Vadiraj et al. [5] studied the wear behavior of base cast iron and alloying gray cast iron of various compositions with high volume fraction of graphite. Study shows that base cast iron was having two to three times higher wear rate than alloyed gray cast iron. Wear track analysis showed three body abrasive wear mode resulting in debris generation and smudging along the wear tracks. M.Hatate et al. [6] conducted dry slip–rolling contact wear test and wet slip–rolling contact fatigue test of several austempered cast irons with various graphite shapes using a Nishihara-type wear testing machine. It was found that changing graphite shape from spheroidal to flake was found to result in a considerable increase in wear loss in both dry and wet conditions. Decrease in graphite nodularity results in increase in wear loss at the initial wear stage.

The present study is concerned with wear behavior of three different types of cast iron namely flake graphite cast iron (FGI), spheroidal graphite cast iron (SGI) and compacted graphite cast iron (CGI) cast centrifugally under varying load, constant time and constant speed in dry and wet (lubrication) conditions. The loads were 20N to 40N in steps of 5N, the time duration for test was 10 min and sliding speed taken was 6.67 m/s.

Nomenclature

kV	kilo Volt
mm	mille meter
Mag	magnification
µm’	micro meter

Materials & Methodology

The base alloy was melted in an induction furnace of 500 kg capacity. The base iron composition is kept almost the same for all irons for this study. The casts were prepared by centrifugal casting process of three types of cast irons namely spheroidal, flake and compacted graphite cast iron.

Flake Graphite Iron (FGI) was obtained by pouring the untreated liquid metal into a horizontal rotating mould, with a desired quantity based on the thickness of the liner to be obtained. As mould rotates the centrifugal force so generated holds the melt against the wall and pushes the lighter, non-metallic impurities towards the inside of the liner which is later removed by cleaning process. After the solidification, the casting machine is made to stop and the liner is removed from it. The composition of FGI is shown in Table 1.

Spheroidal Cast Iron (SGI) was obtained when the base iron was superheated to a temperature of 1600 °C to take care of temperature drop during the melt treatment followed by teeming. The molten metal was treated by adding 1.4% Mg-Fe-Si nodulariser, 0.6% Mg-Fe-Si ladle inoculation and 0.2% Mg-Fe-Si post inoculation (ferrosilicon will be 70-75%). The Spherodizing process was carried out by applying the sandwich method in an open ladle. The magnesium (nodularizing) alloy is placed on a pocket in the bottom of an open pre heated ladle. The melt is poured on the other side to react with magnesium alloy effectively and then tapped at 1500 °C to a preheated ladle. The metal so prepared was cast by centrifugal casting process. The composition of SGI is shown in Table 2.

Compacted Graphite Iron was prepared by melting base iron with low sulphur content at approximately 1600 °C. The melt treatment was carried out with the addition of 0.9% Mg-Fe-Si post inoculation (Ferrosilicon will be 70-75%) and re-sulphurisation by late addition of a known quantity of iron sulphide to promote the formation of vermicular graphite. The metal so prepared was cast by centrifugal casting process. The composition of CGI is shown in Table 3.

Table 1. Chemical composition of Flake Graphite Iron.

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Weight%	3.61	2.52	0.8	0.41	0.07	0.31	<0.0020	<0.0123	0.018
Element	Ti	V	Pb	Sn	Mg	Cu	Zn	Fe	Ceq
Weight%	-	<0.0010	0.00410	0.0032	-	0.25	0.0065	92.300	4.59

Table 2. Chemical composition of Spheroidal Graphite Iron.

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Weight%	3.57	2.57	0.438	0.0230	0.0063	0.0240	<0.0020	0.240	0.018
Element	Ti	V	Pb	Sn	Mg	Cu	Zn	Fe	Ceq
Weight%	0.00019	<0.0010	0.00410	0.0032	0.036	0.54	0.0065	92.300	4.57

Table 3. Chemical composition of Compacted Graphite Iron.

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Weight%	3.61	2.40	0.33	0.045	0.0026	0.0259	<0.005	<0.0123	0.014
Element	Ti	V	Pb	Sn	Mg	B	Zn	Fe	Ceq
Weight%	0.0091	0.0085	0.0083	0.0036	0.015	0.54	<0.005	<93.1	4.425

2.1 Microstructure

This stage was carried out to confirm the identities of the three different types of cast iron as flake graphite cast iron, spheroidal graphite cast iron, and compacted graphite cast iron. Initially small specimens were cut from the three centrifugally cast liners of CGI, FGI and SGI, one face of the specimen was chosen. The chosen face was rubbed on emery papers from grade 60 to 2500 and grade 1/0 to 6/0 to remove all scratches. After rubbing with emery papers the chosen face of the specimen was polished on cloth using polishing machine to remove any remaining scratches. The above steps were followed for all the three specimens. The finished specimen with mirror finish was placed under an optical microscope (Nikkon LV40 with clemex image analyzer) and its microstructure was analysed at different locations. By looking at the microstructure we were able to confirm the identities of the three samples as flake graphite cast iron, spheroidal graphite cast iron and compacted graphite cast iron.

2.2 Wear Test

Three samples of each kind of cast iron were prepared with a length of about 30mm and diameter of 6mm with a tolerance of +0.05mm to -0.05mm. The test was conducted according to the ASTM G99 standards. The test was carried out at room temperature by keeping the velocity and time constant at 6.667 m/s and 10 minutes respectively and varying the load from 20 to 40N in steps of 5N. Wear tests were performed on samples to study the effect of centrifugal process through comparison of wear and co-efficient of friction using a Pin-on-Disk type wear testing machine (model TR-20LE, Ducom make). Track diameter of 125mm (FGI/SGI/CGI) was used for all studies. The disk made up of hardened steel. The disk and test pin were polished to a roughness value (Rz) of about 0.8μm prior to all the runs. The disk and the pins were degreased before the commencement of test. The test was conducted for a duration of 10 minutes. The test was conducted for dry and with lubrication. For wet condition wear test, 20w40 grade oil droplets were applied on the disc during the test.

3. Results and Discussions

3.1 Microstructure

From observing the microstructures it was found that depending upon the shape of graphite on the surface cast iron is classified as flake graphite cast iron, spheroidal graphite cast iron, and compacted graphite cast iron. It was found that if the shape of the graphite is in the form of flakes then its flake graphite cast iron. It was found that if the shape of the graphite is in the form of nodules or circular then its spheroidal graphite cast iron. It was found that if the shape of the graphite is in the form of flakes and nodules i.e. mixture of flakes and nodules then its compacted graphite cast iron. Figures 1. (a), 1. (b) and 1. (c) Shows the microstructure of SGI, FGI and CGI respectively.

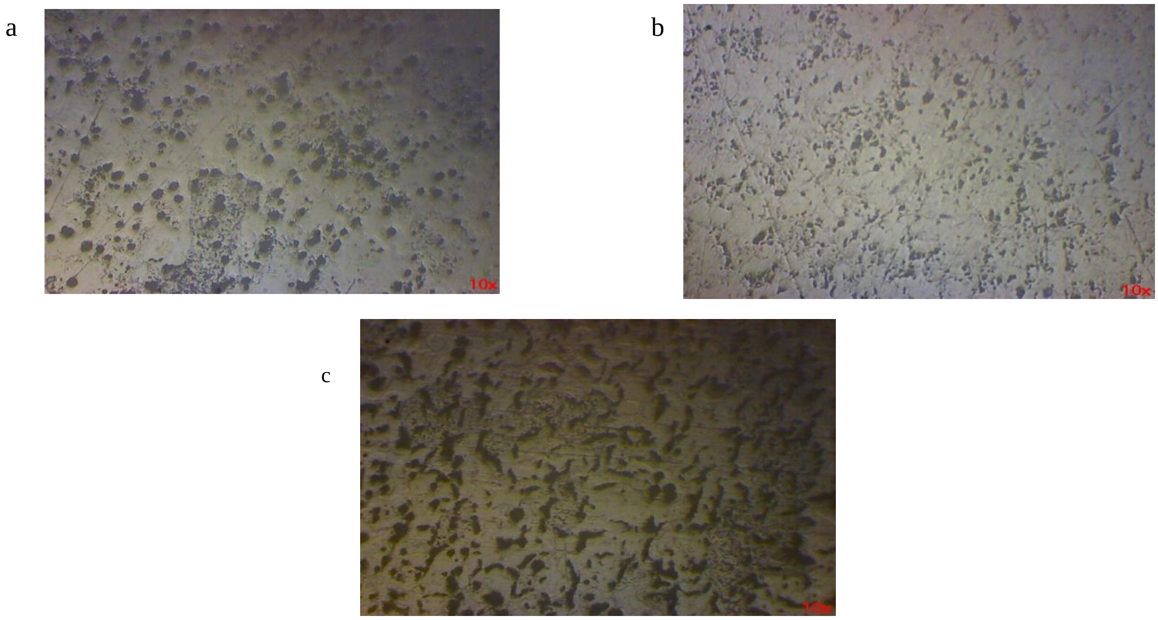

Fig. 1. (a) Microstructure of Spheroidal graphite iron; (b) Microstructure of Flake graphite iron; (c) Microstructure of Compacted graphite iron

3.2 Wear Properties

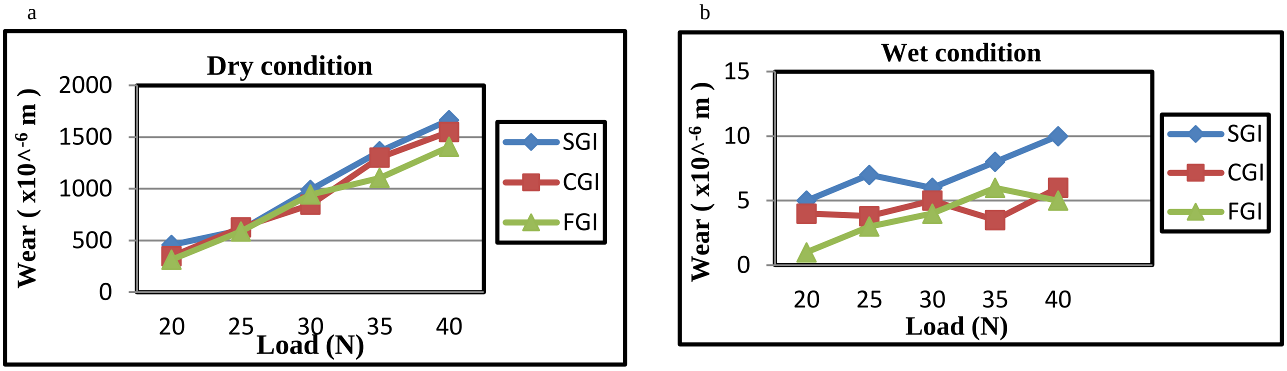

Fig.2.(a) Effect of load variation on the wear of SGI, CGI, FGI in Dry Condition; (b) Effect of load variation on the wear of SGI, CGI, FGI in Wet Condition.

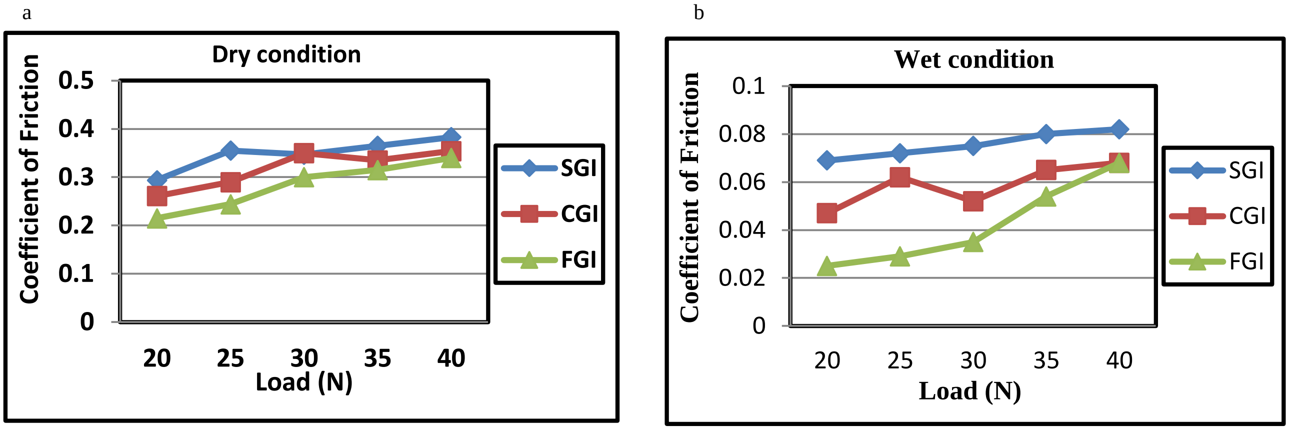

Fig.3. (a) Effect of load variation on Co-efficient of Friction of SGI, CGI, FGI in Dry Condition; (b) Effect of load variation on Co-efficient of Friction of SGI, CGI, FGI in Wet Condition

Fig. 2(a) shows the plot of Wear vs Load of the Graphite Cast Irons for Dry condition. It can be seen that as the load applied increases the wear of the specimens also increases. Spheroidal graphite cast iron has the highest wear and Flake graphite cast iron has the lowest wear. Now due to the introduction of 20w40 grade oil, in wet condition it can be observed that the wear has drastically come down when compare with the dry condition, which can be concluded from Fig. 2(b) Coming to the Co-efficient of friction it can be seen that as the load increases the Co-efficient of friction also increases. Spheroidal graphite cast iron has the highest Co-efficient of friction and Flake graphite cast iron has the lowest Co-efficient of friction in both dry and wet conditions that is depicted in Fig 3(a) and Fig. 3(b). But the graphite acts as an inherent solid lubricant for cast iron, mechanically coming in between the wear surface of pin and disc and along with external lubrication it was found to decrease the Co-efficient of friction by 10 times and also the wear as compared with dry condition.

3.3 SEM Analysis

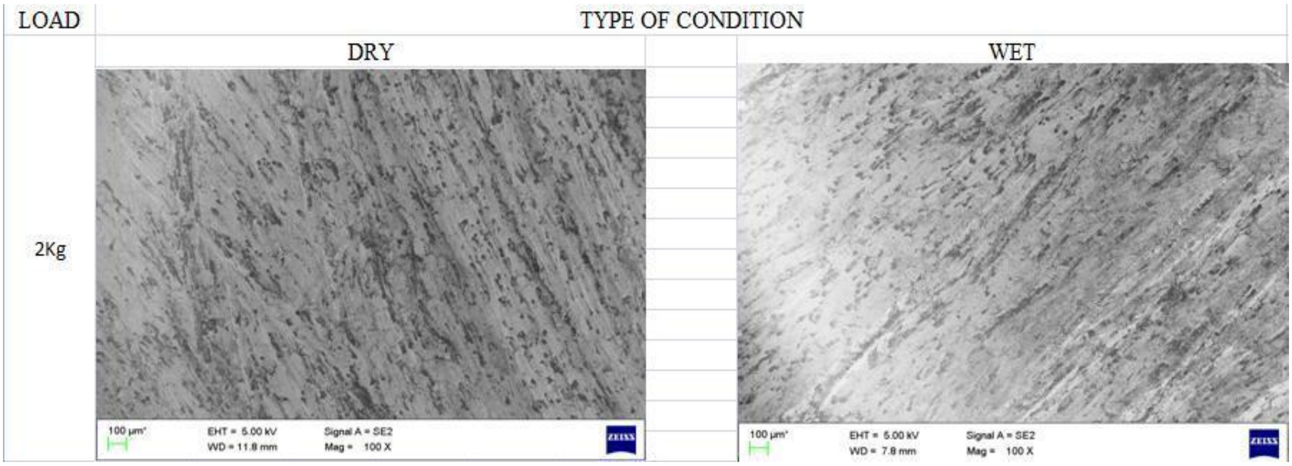

Fig.4. SEM images of SGI with an applied load of 2Kg in both dry and wet conditions.

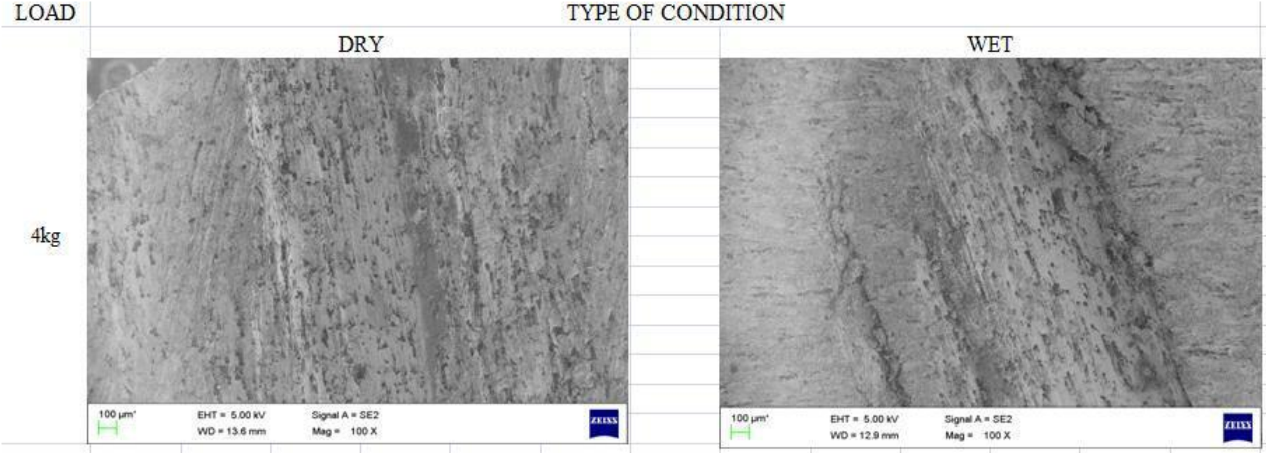

Fig.5. SEM images of SGI with an applied load of 4 Kg in both dry and wet conditions.

From the SEM micrographs of the slid specimens shown in Fig.4 and Fig.5 the major wear mechanisms can be studied. From Fig.4 it can be seen that the wear track intensity and depth is very high in dry condition and where as in wet condition the wear tracks are less intense and depth seems low. More debris formation seems to be present in dry condition and less in wet condition. Presence of graphite seems to be identical on both dry and wet surfaces but the depth of wear tracks and number of wear tracks in dry condition appear to be advanced. From Fig.5 it can be observed that the wear track intensity and depth is very high in dry condition and in wet condition the wear tracks are less intense and depth seems to be low. Debris formation seems to be present in dry condition but absent in wet condition. Presence of graphite seems to be less on dry surface and more in wet surface but it seems to have spread similarly on both surfaces.

4. Conclusion

The following conclusions are drawn from the experiment:

- After performing wear behaviour investigation it was found that FGI exhibited least wear CGI moderate wear and SGI exhibits the maximum wear.
- Graphite is a self-solid lubricant and by addition of 20w40 oil, an extra lubrication is provided between

the surfaces which drastically reduces the wear and co-efficient of friction in all load conditions.

- SGI has the highest wear in both dry and wet conditions as compared to FGI and CGI. In wet conditions the co-efficient of friction is reduced by around 10 times as compared to co-efficient of friction in dry conditions.

Acknowledgement

We thank our Director, Dr. N. R. Shetty, Principal, Dr. H. C. Nagaraj and Management of Nitte Meenakshi institute of Technology, Bangalore, India for motivating and providing research facilities at the institute.

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