Dry sliding wear system response of ferritic and tempered martensitic ductile iron

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Abstract. Spheroidal graphite cast iron (SG iron) is the most preferable member of cast iron family due to its strength and toughness along with good tribological properties. SG iron specimens with annealed and martensitic matrix were subjected to dry sliding wear condition and the system response was correlated to matrix microstructure. Respective microstructure was obtained by annealing and quench and tempering heat treatment process for an austenitizing temperature of 1000°C. Specimens were subjected to Ball on plate wear tester under 40N, 50N, 60N load for a sliding distance of 7.54m. Except for quench and tempered specimen at 50N, weight loss was observed in every condition. The wear surface under optical microscope reveals adhesive mechanism for as-cast and annealed specimen whereas delaminated wear track feature was observed for quench and tempered specimen.

Keywords: SG cast iron, dry sliding wear, microstructure, wear morphology

I. Introduction
Spheroidal graphite cast iron (SG iron) or ductile iron (DI) unlike every other cast iron has graphite in the form of spheroids which act as crack arrester, due to which it possesses higher strength and toughness along with better wear resistance. Furthermore it has been proved that the properties of SG iron can be improved by application of suitable heat treatment process leading to transformation of as-cast ferritic or ferritic/pearlitic matrix into pearlitic, martensitic and bainitic. Austempered ductile iron is one of the most favorable materials among all other type because of its excellent strength, toughness, wear resistance, fatigue strength and fracture toughness [1-8]. Tribological investigation carried out on austempered SG iron with varying austempering time and temperature, reported increased wear resistance with increasing austempering temperature and time along with increased hardness during wear due to the bainitic ferrite which is less prone to thermal instability than martensite, might undergo strain hardening [9, 10]. Tempering treatment on ductile iron with boron increased the wear resistance but with increasing boriding time wear rate of boro-tempered ductile iron decreased [11]. Apart from alloying element and heat treatment graphite nodule size and distribution affects the wear resistance of SG iron. According to a study by Sugishita and Fujiyoshi [12] and Zimba et.al [13] presence of large size graphite nodules reduces the wear rate by acting as lubricating agent.
The past results reported are mainly leaned towards austempered ductile iron and the studies were focused on the effect of austempering time and temperature on wear behavior. Hence the present investigation is concentrated to study the wear behavior of as-cast ferritic ductile iron compared with annealed ferritic matrix and quenched and tempered ductile iron subjected to dry sliding condition at higher loads.

II. Experimental details

2.1. Specimen Preparation

In order to investigate the structure-property relationship, ductile iron test blocks with different alloying elements were brought from L&T Kansbahal, India. The chemical composition test blocks by weight percentage is presented in Table 1. In order to carry out the experiment specimens of 25×10×5 mm³ were machined from the test block. Specimens were then austenitized at 1000°C for 90 minutes and then it was cooled down to 700°C and kept there for 5hr 30 minutes followed by furnace cooling to room temperature for annealing heat treatment. On the other hand specimens after austenitization were quenched in mineral oil maintained at 100°C and immediately after quenching, tempered at 500°C for 120 minutes followed by air cooling to room temperature for quenching and tempering heat treatment process. After heat treatment oxide layer from each of the specimen was removed by conventional filling and emery paper polishing method.

| Elements | Content (Wt. %) |
|----------|-----------------|
| C        | 3.61            |
| Si       | 2.1             |
| Mn       | 0.2             |
| S        | 0.007           |
| P        | 0.022           |
| Cr       | 0.03            |
| Ni       | 0.47            |
| Mo       | 0.001           |
| Cu       | 0.009           |
| Mg       | 0.043           |
| Ce       | 0.004           |
| Fe       | Balance         |

2.2. Vickers hardness and wear testing

Vickers hardness was measured by applying a load of 20Kg and dwell time being 10seconds on each heat treated and as-cast specimen. Ducom TR-208-M1 Ball on plate type wear monitor [14-17] with specimen as flat plate and a spherical tipped diamond cone of 120° angle 0.4mm tip diameter was used in order to investigate the wear system response of the as-cast heat treated specimens. The mechanism of Ball on plate wear test is very much similar to that of Pin on disc wear tester. However the minor difference is that in pin-on-disc specimen is in the form of cylindrical pin, held stationary in specimen holder and disc is the counter body which rotates against the pin, whereas in case of Ball on plate wear test instead of pin specimen is a flat one rotates against a counter ball which is fixed. Also, in pin on disc machine only the disc rotates whereas in Ball on plate mechanism both the specimen and indenter
rotate at same relative speed. The Ducom TR-208-M1 Ball on plate type wear monitor along with schematic diagram of pin on disc wear monitor is presented in Fig. 1 (a) and Fig. 1 (b) respectively. Test was conducted at 40N, 50N, 60N loads for a sliding distance of 7.54m at linear velocity of 0.063m/s. The weight loss for corresponding specimens was measured with the help of electronic balance of 0.1mg accuracy, prior to the weight measurement specimens were cleaned ultrasonically with acetone.

2.3. Microstructural and wear morphology investigation

In order to correlate the wear response with matrix structure standard metallographic technique was followed for microstructural investigation. Specimens were first polished with belt polisher followed by 1/0, 2/0, 3/0, 4/0 grades of emery paper and finally cloth polishing was done with alumina slurry followed by diamond polishing. Metallographic images were taken with the help of computer integrated optical microscope at 100X magnification. The worn surfaces of each specimen under various loading conditions were observed under optical microscope at 200X.

III. Results and Discussions

3.1. Microstructural investigation
Fig. 2 illustrates the microstructures of respective as-cast and heat treated specimens. Both the as-cast (Fig. 2(a)) and annealed (Fig. 2(b)) specimens have graphite nodules embedded in ferritic matrix whereas quench and tempered (Fig. 2(c)) specimen had tempered martensitic matrix with graphite nodules lodged in it.

3.2. Hardness and Wear properties
The Vickers hardness for respective specimens was presented in Fig. 3(a). It can be noticed that although the as-cast and annealed specimen, both were having ferritic microstructure, the annealed specimen was softer than the as-cast one. This can be attributed to the fact that, the stresses developed in as-cast specimen during solidification and specimen machining had been removed during annealing treatment. The quench and tempered specimen had the highest hardness value due to the hard tempered martensite matrix. Fig. 3(b) depicts the wear system response of respective as-cast and heat treated specimen with respect to their hardness values. The as-cast ferritic matrix observed to lose weight marginally when load is increased to 50N than that at 40N. On further increase in load to 60N no weight loss was observed and can be due to the work hardening effect as the specimen was ductile one. On the other hand annealed specimen which is free from stresses developed during machining and solidification appeared to lose weight continuously at every load. The rate of wear in annealed specimen as compared to the as-cast specimen was less due to the higher hardness value of the former specimen and work hardening effect when operated under 50N load. At the same time the quench and tempered specimen gained some weight at 50N load and on further increasing the load to 60N again there was weight loss at the same rate. As compared to the ferritic matrix wear rate of quench and tempered specimen was very less due to the hard tempered martensitic matrix [19].

3.3. Wear morphology
In order to investigate the wear mechanism, micrographs of worn surfaces of as-cast and heat treated specimens were taken with the help of optical microscope at 200X, and presented in Fig. 3. Direction of wear track was shown by the black arrows in each case. Micro cracks along with broken wear platelets were observed in as-cast specimen at 40N (Fig. 4(a)), due to the surface work hardening. Similar kind of phenomenon was also observed for annealed specimen at 40N (Fig. 4(b)). The graphite nodules appeared to expand in the transverse direction as well as shear deformation in the direction of wear. The features noticed in case of as-cast and annealed specimen suggest the adhesive wear
principle. On the other hand the quench and tempered specimen at 40N (Fig. 4(c)) adhesive mechanism of wear was observed indicated by the particle pull out phenomenon and continued to remove particles from the specimen and eventually deposited on the surface leading to broken delaminated wear track [20], however no micro cracks were observed in this case. Further increase in load i.e., to 50N no difference in wear mechanism was found for as-cast and annealed specimen, Fig. 4(d) and (e) respectively, except more micro cracks formation due to increase in surface hardness while operating under such high load. Similarly no change in wear phenomenon was observed for quench and tempered specimen, Fig. 4(f), except formation of micro cracks. Further increment of load to 60N did not affect the wear principle but only to surface hardness which can be clearly seen in Fig. 4(g) for as-cast, Fig. 4(h) for annealed and Fig. 4(i) for quench and tempered specimen. Fig. 5 showed EDAX analysis of worn surface of the quench & tempered specimen at 50N, taken under NOVA NANOSEM 450, field emission scanning electron microscope. It was observed that oxide layers were formed on the wear track, which led to the gain in weight as mentioned in the previous section.
Ductile iron specimens with ferritic and tempered martensitic matrix were undergone Ball on plate wear system. The results of the study can be concluded as follows.

1. Soft ferritic matrix was less resistant to wear due to lower level of hardness, whereas tempered martensitic matrix with higher hardness value was more resistant to wear.

2. Adhesive wear phenomenon was observed for specimens with soft ferritic matrix along with micro cracks due to the hardening of surface while operating under high load and kept on increasing with increase in load.

IV. Conclusion
3. Hard quench and tempered specimen showed adhesive wear mechanism featured by particle pull out from the wear surface leading to formation of another layer over the specimen and finally breakage of the wear plate.

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VI. References

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