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WEAR BEHAVIOUR OF NODULAR CAST IRON

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ABSTRACT
For many applications of nodular cast irons, wear properties of the component parts are very important. However, the wear resistance of as-received (as-cast) nodular cast iron is not so encouraging, because of its lower hardness. In this research work, initiative has been taken to improve the surface hardness as well as the wear resistance of the as-received nodular cast iron by pack carburizing technique. Using pin-on-disc type wear test apparatus, wear beaviour of both as-received and pack carburized nodular cast irons were carried out at room temperature in the ambient air. For both cases, various dead loads such as 0.5, 1.0 and 2.0 kg were used. After wear tests, worn surfaces of both pin (specimen) and disc (counter body) were observed in metallurgical microscope and they were photographed. Weight losses of pins under different test conditions were also measured. Experimental results reveal that carburized nodular cast irons are unbelievably more wear resistant compared to that of as-received one under similar test conditions. For both samples, wear patterns were also found to be different.

Keywords: Nodular cast iron, Wear, Surface hardening, Automotive parts.

1. INTRODUCTION
Nodular cast iron is a cast ferrous alloy. Its advantages are numerous. The main advantages of nodular cast irons among all other cast alloys are evident in the area of mechanical properties. It offers designers the option of selecting high ductility (more than 18%) with high tensile strength exceeding 120 ksi, which are comparable to many steels used for various structural applications and tool manufacturing [1-5].

Nodular cast irons are used for manufacturing many critical automobile and agricultural parts such as crankshafts, engine connecting rods, truck axels, power transmission yokes and gears, etc. [3-5]. Because, it offers a unique combination of a wide range of high strength, wear resistance, fatigue resistance and ductility [6,7]. Wear is always a major industrial problem for all transmission parts. In nodular cast irons, graphite nodules are embedded in the ferrous matrix. These graphite nodules behave as a solid phase lubricating agent and minimize the wear rate of the component. But, its matrix hardness (which is very important to provide higher wear resistance) is relatively low. As a result, as-received, i.e. as-cast nodular cast iron cannot provide satisfactory wear resistance. So, various initiatives have been taken to increase the matrix hardness through different heat treatments. In this regard, so far, the popular heat treatment techniques used for hardening nodular cast ions are austempering, martempering, quenching and tempering, etc. [3,8,9]. In the case of traditional hardening treatments, components are hardened thoroughly. As a result, the overall toughness of the component is reduced. In the case of carburizing treatment, the surface hardness of the component is increased selectively through adding more carbon from the external source keeping the core soft and ductile. This technique might be a potential heat treatment process for heavy duty transmission gears and other automobile parts. The aim of this work is to investigate possibility of surface hardening of nodular cast iron by pack carburizing and to characterize the wear properties of carburized nodular cast iron.

2. MATERIALS AND HEAT TREATMENT
In this present research work, wear behaviour of commercially available nodular cast iron was used. The composition of this ferrous cast alloy has been presented in Table 1. Wear test specimens of length 8.7 mm and diameter 4.66 mm were prepared and carburized 1050^{o}C for 4 hours. After carburization, test samples were cooled in the furnace. The carburized samples were then observed in the microscope to confirm the selective increase in carbon content at surface layer of the specimens. One carburized sample was also quenched in water in order to reveal carburized layer from surface toward the core of the test piece as detection of carburized layer is not always easy for furnace cooled samples. The heat treatment schedule is shown in Fig.1.

Table 1: Chemical compositions of nodular cast iron (weight percent).

C	Mn	Si	S	P
3.6	0.21	2.6	0.025	0.036

3. EXPERIMENTAL PROCEDURE

After heat treatment, surface hardness values of as-received and carburized samples were measured, which have been presented in Table 2. Surface hardness of the counter body has also been measured (Table 2). Dry sliding wear tests of all samples of both as-received and carburized and furnace cooled nodular cast iron were carried out at room temperature in the laboratory air. Here it is to be mentioned that, for samples of both conditions, the total sliding distances were kept constant to 8500 m. However, variable dead loads as 0.5, 1.0 and 2.0 kg were used for both groups of samples to know the effect of applied load on the wear rate and wear morphologies.

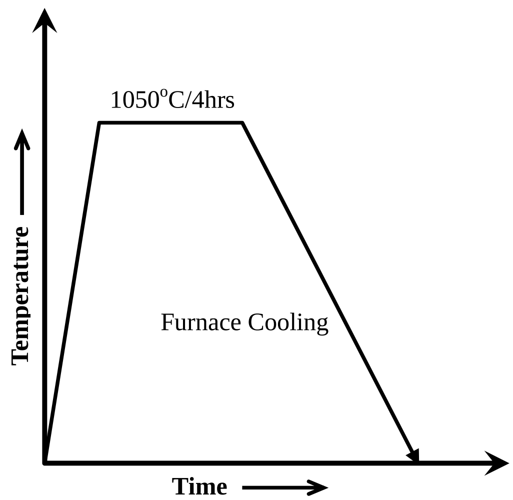

Fig 1. Schematic diagram showing the heat treatment cycles used for carburizing.

Table 2: Hardness values of as-received cast iron, carburized cast iron and steel counter body.

Sample Identification	Hardness Value (RC)
As-received Cast Iron	24
Carburized Cast Iron	33
Steel Counter Body	50

After wear tests, weight losses were measured. Worn samples were also observed under microscope to know the wear behaviour and they were photographed.

4. RESULTS AND DISCUSSION

The average surface hardness values of steel counter body and as-received nodular cast iron samples were respectively RC50 and RC24. After carburizing and air cooling, the surface hardness of the as-received nodular cast iron increased to RC33. The reason of this increased surface hardness was due to increase in the carbon content during pack carburizing. During carburizing, carbon diffused in the ferritic matrix of the cast iron from the carburizing media and changed the microstructure as shown in Figs.2 and 3. Before carburizing as-received nodular cast iron showed ferritic matrix embedded with graphitic nodules of various sizes and distributions. After carburizing, the shape, size and distribution graphite nodules were almost unchanged, however, austenite grains near the surface area absorbed more carbon from the surrounding pack carburizing media at high temperature. As a result of higher carbon content in the austenite grains at surface area of the specimens, austenite of surface area transformed to pearlite rather than to ferrite. The carburized case with higher carbon content is clearly visible in Fig.3.

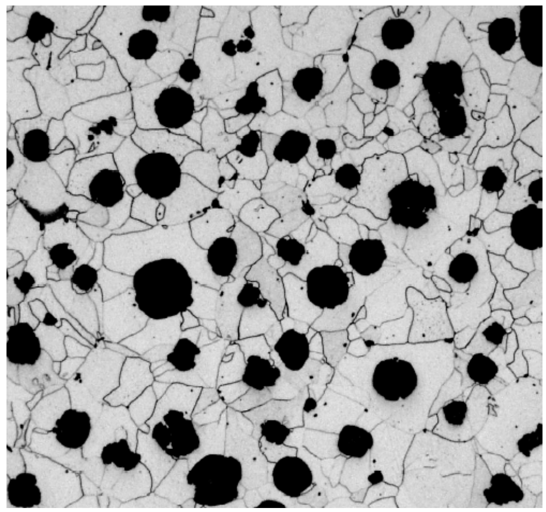

Fig 2. Micrograph of as-received (as-cast) nodular cast iron with ferritic matrix.

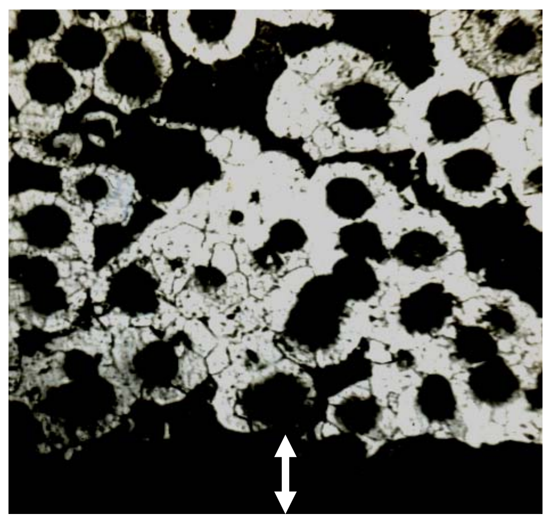

Fig 3. Micrograph of carburized and furnace cooled nodular cast iron. Here, carburized zone is pearlitic (indicated by arrow), whereas core is ferritic.

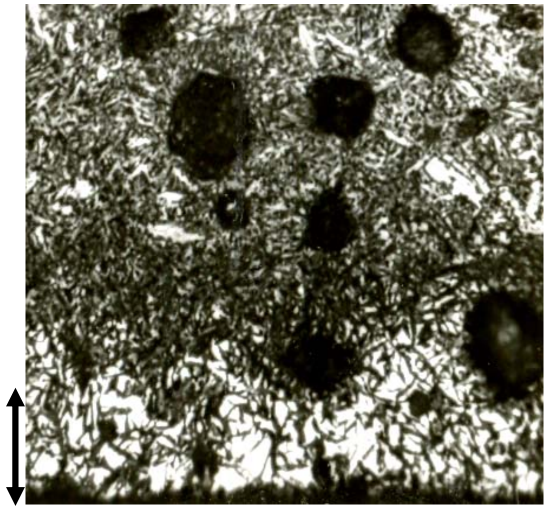

Fig 4. Micrograph of carburized and quenched nodular cast iron. Arrow is indicating the zone of high carbon needle-like martensitic structure (carburized case) at surface and low carbon lath martensitic structure is seen in the core.

When high carbon ferrous alloy is quenched from sufficiently high temperature, the high carbon zone transforms to needle-like martensitic structure, however, low carbon area either remains unchanged or transforms to low carbon lath martensitic structure, which is also very clear in Fig.4.

Wear tests were carried out on pin-on-disc type apparatus schematic diagram of which is given in Fig.5. Many investigators used this type of set-up for dry sliding wear test [8,9]. Here, hardened steel block was used as counter body and test specimen was as pin.

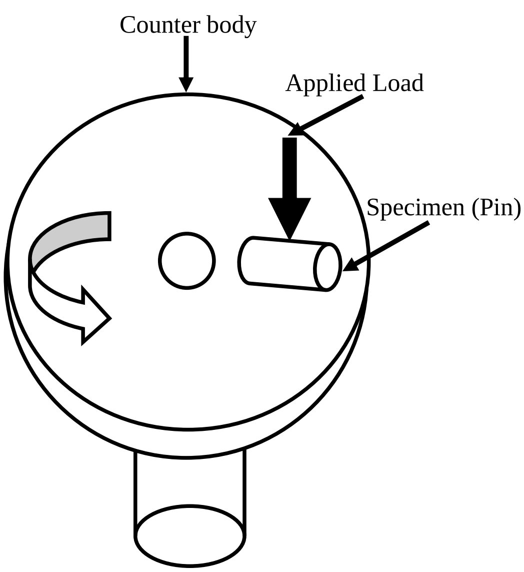

Fig 5. Schematic diagram showing pin-on-disc type wear test set-up.

In order to know the effect of applied load on the wear rate, wear tests were carried out under three different applied loads as 0.5, 1.0 and 2.0 kg. The test results have revealed that increased hardness by carburizing caused significant decrease in the wear rate. The reason is that during carburization, carbon diffused from the surrounding carburizing media and increased the carbon content at the surface area. In the case of ferrous alloys of similar structures, increase in carbon means increase in hardness and strength. Increase in hardness means reduced wear rate, which can be easily understood from the following equation [10]:

$$v = kWx/H \qquad (1)$$

Where v is volume of worn material, k is non-dimensional wear co-efficient, W is applied load, x is sliding distance and H is the hardness of the worn surface.

Table 3: Weight loss of as-received and carburized nodular cast iron samples after 8500 m sliding friction in contact of steel counter body under various applied loads.

Applied	**Weigth Loss, gm**	
Load	**As-received Sample**	**Carburized Sample**
0.5 kg	0.01	0.007
1.0 kg	0.06	0.010
2.0 kg	0.95	0.060

With increase in applied load, wear rate of samples of both conditions increased, Table 3. The reason is that with increase in load means increase in stress on contact surface of the test specimen. As a result, specimens under both conditions gradually experienced more intensive friction. So, specimens of both conditions showed more weight losses as dead loads were gradually increased.

Fig 6. Wear pattern on steel counter body used for as-received nodular cast iron sample.

Detail investigation on worn steel counter body revealed that the wear patterns of counter body used for cast iron samples of both conditions were almost similar (microcutting type abrasive wear), Figs.6-7. However, wear patterns on worn samples were somewhat different, Figs.8-9. For as-received condition adhesive type wear morphology was dominant. On the other hand, carburized samples showed mixed (adhesive and abrasive) type wear mechanisms. In most cases of dry sliding wear test, wear patters of samples and counter bodies are controlled by the surface hardness of the respective component. It has been mentioned that the average hardness of counter body was around RC50. Compared to this value, the hardness values of as-received and carburized test specimen (respectively RC24 and RC33) were very low, which could not dominate over hardness of counter body. As a result, worn particles from counter body of sufficiently high hardness could not be plastically deformed or adhered with the counter body. So, counter body showed abrasive type wear patterns for both sample conditions.

Fig 7. Wear pattern on steel counter body used for carburized nodular cast iron sample.

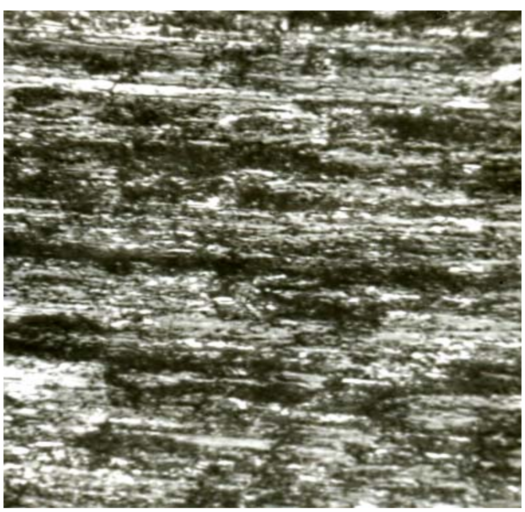

Fig 8. Wear pattern on as-received cast iron tested in contact with steel counter body.

However, hardness of carburized sample specimen (RC33) was significantly higher than that of as-received specimen (RC24). As a result, as-received sample showed adhesive wear and the carburizing effect changed the wear pattern to mixed mode.

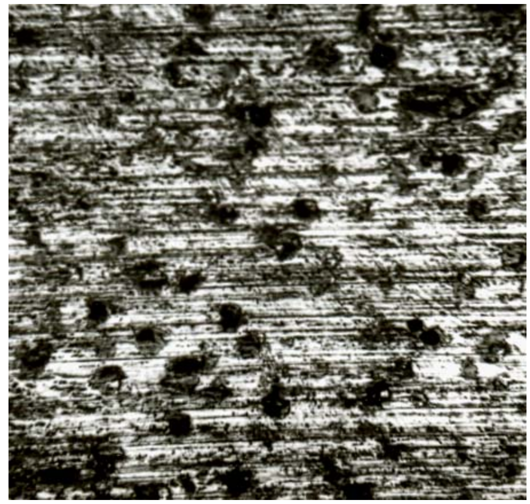

Fig 9. Wear patter on carburized nodular cast iron tested in contact with steel counter body.

5. CONCLUSIONS

In this present work the effects of carburizing on the wear behaviour of as-received nodular cast iron has been investigated. After experimental work, the following conclusions have been drawn.

1. Experimental results showed that surface modification by carburizing encouragingly increased the wear resistance of the as-received nodular cast iron under similar test conditions.
2. Carburizing increased the surface hardness of the cast iron and changed the wear pattern of as-received nodular cast iron from adhesion dominating one to mixed mode.
3. For both sample conditions, wear pattern of steel counter body was found to be abrasive type.

6. ACKNOWLEDGEMENT

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