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EFFECT OF HEAT TREATMENT ON WEAR RESISTANCE OF A GRINDING PLATE

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ABSTRACT: *The effects of heat treatment on the hardness and by extension the wear resistance of locally produced grinding plate of known composition were investigated. Specimens were prepared from the grinding plate and were heat treated at 840°C, 860°C and 880°C and quenched at different rate. Some of the specimens were quenched in water and palm oil, while some of the quenched specimens were tempered at 200°C. The results obtained were corroborated with the microstructure of the specimens examined under an optical microscope. The hardness values of the grinding plate specimens quenched in various media increased with increased heat treatment temperatures, and are higher than that of the as-cast specimen. Water quenched tempered specimens (WT) displayed higher hardness values than the as-cast, whereas oil quenched tempered specimens (OT) possessed lower hardness values. The presence of carbide was evident on the micrographs of the water quenched specimens at all the exposure temperatures, which corroborated the observed increased in the hardness values with increased heat treatment temperatures. However, there was significant reduction in the hardness value of the water quenched tempered specimens compared with the quenched specimens, which indicates a significant improvement in toughness. Thus, water quenched and tempered specimen with relatively high hardness value and improved toughness, will be suitable for use as grinding plate because of its relatively better wear resistance. The hardness of the specimens was found to depend on the formation of carbide precipitates within the matrix structure. There is also possibility of production of structure consisting of graphite embedded in a martensitic matrix through the heat treatment.*

Keyword: *carbide, heat treatment, hardness, microstructure, wear resistance*

INTRODUCTION

Grey iron is a class of cast iron that when broken, the fracture path will be along the graphite flakes. Their surface also has a grey, sooty appearance. The flakes act as stress raisers, thus greatly reducing ductility. Grey iron is weak in tension, although strong in compression, as are other brittle materials. On the other hand, the graphite flakes gives this material the capacity to dampen vibrations by the internal friction (hence energy dissipation) caused by these flakes. Grey iron is thus a suitable and commonly used material for constructing structures and machine tool bases, in which vibration damping is important [Serope, 2008]. The degree of hardness produced in cast iron depends upon the composition of cast iron, nature and properties of quenching medium, quenching temperature, size of the objective to be quenched, homogeneity of austenite, degree of agitation, and rate of cooling, surface condition of metal [Khanna, 2009].

Also, grey cast iron usually exhibit unique characteristics of a combination of good mechanical properties, good friction and wear behaviour, and economical manufacturing processes. The improved wear resistance of grey cast iron during dry sliding at low loading conditions has been attributed to the feeding of the contact surface by graphite ûakes and formation of a graphite ûlm on the contact surface. It has been observed that pearlitic structure of the matrix and an ASTM A type graphite ûake provides the best wear resistance for grey cast iron [White, 1992]. Despite the good characteristic offer by grey cast iron, it was observed that grinding plate made locally used in grinding machine, wear at a faster rate. Thus, this study was aimed at providing ways of improving the service life of these locally made grinding plates through heat treatment. Various heat treatment can be adopt for grey cast iron materials, but not all of this processes can optimize its properties. For example, annealing of grey iron consists of heating the iron to a temperature high enough to soften it and/or minimising or eliminating massive eutectic carbides, thereby improving its machinability. This heat treatment usually reduces mechanical properties substantially (Rajan et al., 1988). Hence, the choice of heat treatment operations used in this research excludes annealing the grey cast iron grinding plate. In this study, heat treatment operations were carried out at different temperatures and quenched using different quenching media (water and palm oil) with some of specimen also tempered. Metallography and hardness test were carried out before and after the heat treatments. The responses of this grinding plate to heat treatment, hardness test and microstructural examination are reported in the present paper.

RESEARCH METHODOLOGY

Chemical Composition Analysis

The grinding plate used was bought in a local market in Ilorin metropolis, Kwara state, Nigeria. The chemical composition of the grinding plate was carried out with an optical emission spectroscope (OES). The result obtained is presented in Table 1.

Heat Treatment

Fifteen specimens were prepared from the as-cast grinding plate. The fifteen specimens were grouped into three; each with five specimens. Each group of specimens was heated to 840°C, 860°C and 880°C respectively, and soaked at this temperature for 45 minutes. From the first group, one of the specimens was cooled in air (N_{840}); two out of the remaining four were quenched in water, while the remaining two were quenched in oil. One out of the two specimens quenched in water and oil were tempered for 30 minutes at 200°C and cooled in air. The above steps were repeated for the other groups. The specimens produced were tagged accordingly: heat-treated at 840°C and quenched in water (WQ_{840}), heat-treated at 840°C, quenched in water and tempered at 200°C (WT_{840}), heat-treated at 840°C, and cooled in air (N_{840}), heat-treated at 840°C and quenched in oil (OQ_{840}), heat-treated at 840°C, quenched in oil and tempered at 200°C (OT_{840}), heat-treated at 860°C and quenched in water (WQ_{860}), heat-treated at 860°C, quenched in water and tempered at 200°C (WT_{860}), heat-treated at 860°C, and cooled in air (N_{860}), heat-treated at 860°C and quenched in oil (OQ_{860}), heat-treated at 860°C, quenched in oil and tempered at 200°C (OT_{860}), heat-treated at 880°C and quenched in water (WQ_{880}), heat-treated at 880°C, quenched in water and tempered at 200°C (WT_{880}), heat-treated at 880°C, and cooled in air (N_{880}), heat-treated at 880°C and quenched in oil (OQ_{880}), heat-treated at 880°C, quenched in oil and tempered at 200°C (OT_{880}).

Hardness Test

The specimens which have been subjected to various heat treatment processes and the as-cast sample were prepared for hardness test. Brinell hardness tester was employed to determine the hardness of the specimens. The hardness of the specimens was indicated by the depth of penetration of the indenter on each of the specimens. The diameter of the impression was measured with the Brinell reading microscope and the corresponding Brinell hardness number was obtained from the standard hardness table. Average values were recorded after repeating the test for each one of the test specimens.

Metallography

The microstructures of the samples were examined using metallurgical optical microscope at X200 magnification after the samples have been prepared according to standard. After polishing, the specimens were etched with Natal and rinsed with water.

RESULTS AND DISCUSSION

Table 1 presents the chemical composition of the grey cast iron sample used for this investigation.

Table 1: Composition of the As-cast Grinding Plate Specimen

ELEMENTS	COMPOSITION (wt. %)
C	2.79
Si	1.46
Mn	0.24
P	0.09
S	0.1
Cu	0.18
Ni	0.06
Cr	0.57

Hardness

The hardness values of the specimens, which were subjected to different heat treatment processes, are presented in Tables 2 and 3. The graphical illustrations of the effect of the different heat treatment processes on the hardness of the specimens are shown in Figures 1-5. The hardness of the as-cast specimen is 341HB. The hardness values of the heat-treated specimens were found to be higher than that of as-cast specimen at all exposure temperatures except for the OT specimens (321HB). This shows that the heat treatment temperatures of the specimens quenched in oil and tempered at 200°C have no significant effect on the hardness of the specimens (Figure 5). Therefore, this heat treatment processes are not suitable for optimizing the wear resistance of the grinding plate, hence its performance in service. With respect to WT_{840}, $WT_{860,}$ and WT_{880} specimens, the hardness values increased with increased exposure temperatures, with highest value obtained for WT_{880} (454HB).This results showed that the hardness value is dependent on the heat treatment temperature. However, these specimens were tempered for stress relief and possible improvement in toughness. Water quenched specimens tempered at 200°C showed higher hardness values than both the as-cast and oil quenched tempered specimens. Although, there was a significant reduction in the hardness value of the water quenched tempered specimens compared with the untempered specimens, the reduction in hardness values indicates a significant improvement in toughness and consequently improved wear resistance of the specimens. Hence, WT specimen displayed relatively high hardness value with improved toughness, thereby making it more suitable for use as grinding plate with better wear resistance.

Table 2: Hardness Values of Quenched Specimens

Temperature °C	Brinell Hardness Number (HB)		
	Water	Oil	Air
840	421	363	350
860	441	363	363
880	454	444	388

Table3: Hardness Values of Tempered Specimens at 200°C

Temperature °C	Brinell Hardness Number (HB)	
	Water	Oil
840	388	321
860	388	321
80	363	321

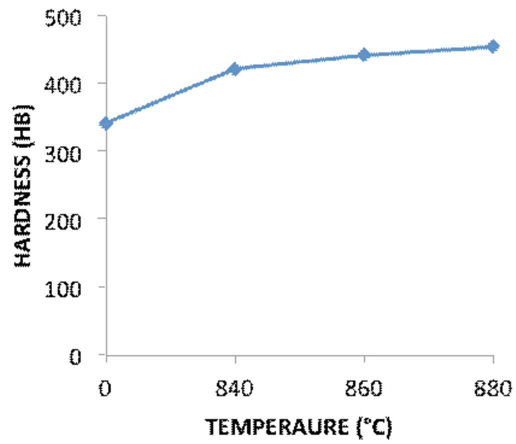

Figure 1. Effect of heat treatment temperatures on the hardness of water-quenched specimens

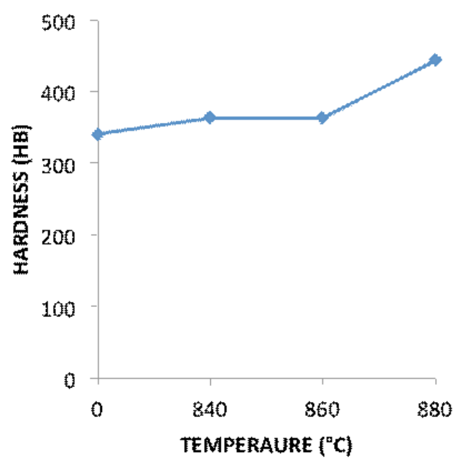

Figure 2. Effect of heat treatment temperatures on the hardness of oil-quenched specimens

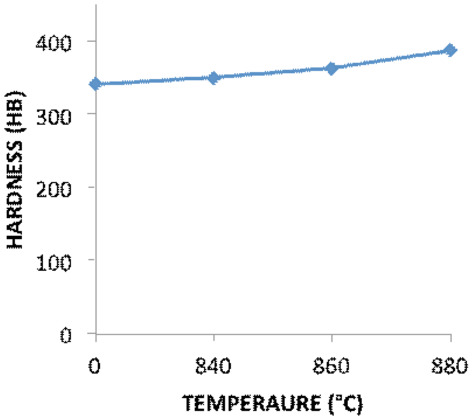

Figure 3. Effect of heat treatment temperatures on the hardness of AQ specimens

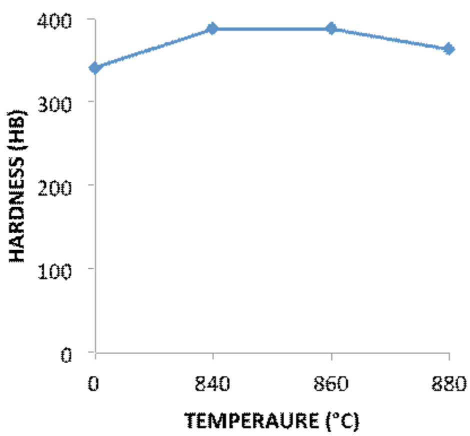

Figure 4. Effect of heat treatment temperatures on the hardness of water-quenched and tempered specimens

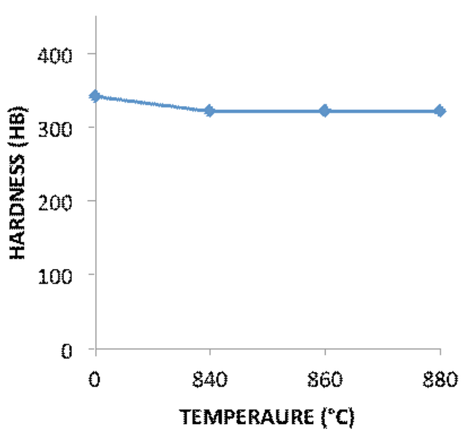

Figure 5. Effect of heat treatment temperatures on the hardness of oil-quenched and tempered specimens

MICROSTRUCTURE

The microstructural analysis results of the samples tempered at 200°C together with the as-cast specimen were presented as shown in Figure 6 (Plates 1 to 7). The hardness as well as the wear resistance properties of the specimens was found to depend on the formation of carbide precipitates within the matrix structure. There is also possibility of production of structure consisting of graphite embedded in a martensitic matrix through the heat treatment. The presence of graphite within the matrix structure usually improves wear resistance depending on its shape (Sugishita and Fujiyoshi, 1981). Heat treatment of grey iron usually alters the matrix microstructure with little or no effect on the size and shape of the graphite achieved during casting (www.key-to-steel). The microstructure of the unalloyed iron generally consists of M_3C carbides (Alp and Wazzan, 2005). Figure 6 (Plates 1-7) shows that the cooling rate of the heat treated specimens have dramatic effect on the size and distribution of the graphite crystals as well as the volume fraction of carbide precipitates. As shown in Plate 1, graphite flakes were formed in a ferritic or pearlitic matrix, depicting that a grey type of cast iron is formed. An evidence of carbide formation was also observed on the WQ_{880} and WQ_{860} specimens (Plates 2-3). The presence of chromium may be responsible for the formation of carbide in the matrix, which ultimately is responsible for the observed high hardness when compared with the as-cast specimen (Robert, 1994). As seen in Plate 4, the volume fraction of carbide in WT_{840} specimen reduces, hence the observed reduction in hardness value compared to the quenched specimens. Similarly, Plates 5-7 (OT_{840}, OT_{860} and OT_{880} specimens) also revealed reduction in the volume fraction of carbide, and hence the lower hardness values compared to the WT specimens as shown in Table 2.

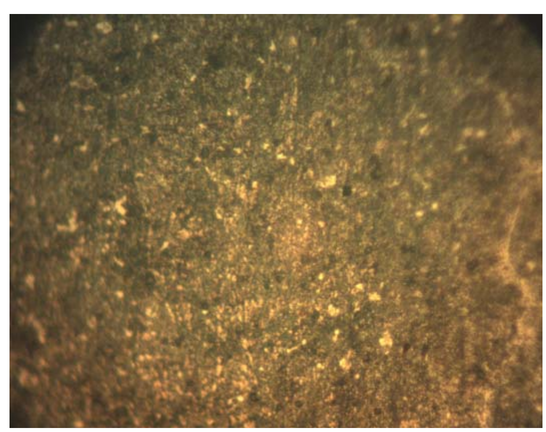

Plate 1: As- cast specimen

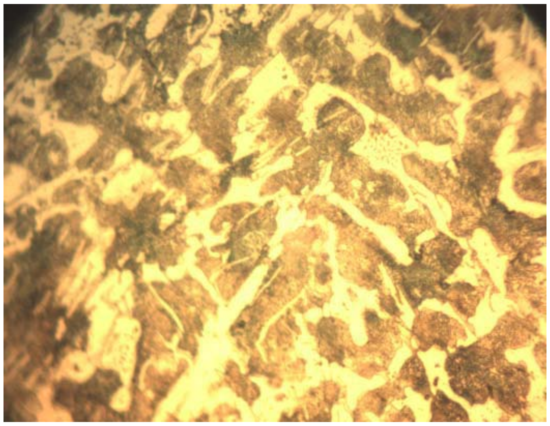

Plate 2: Water-Quenched specimen at 880°C

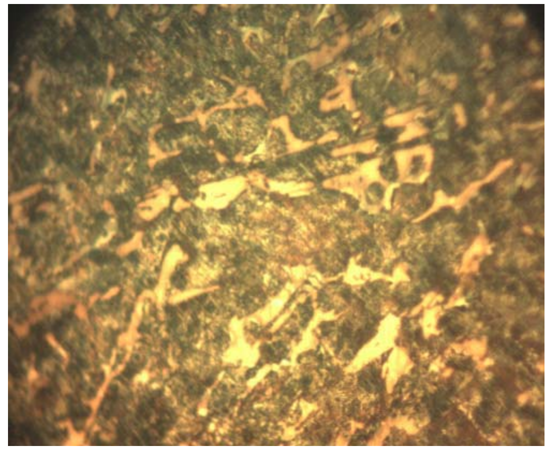

Plate 5: Oil Tempered at 880°C

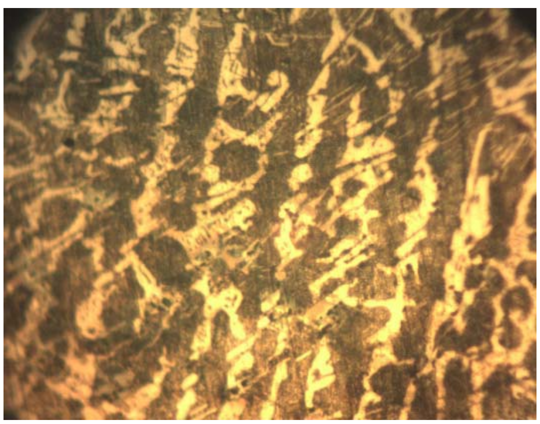

Plate 3: Water-Quenched specimen at 860^{0}C

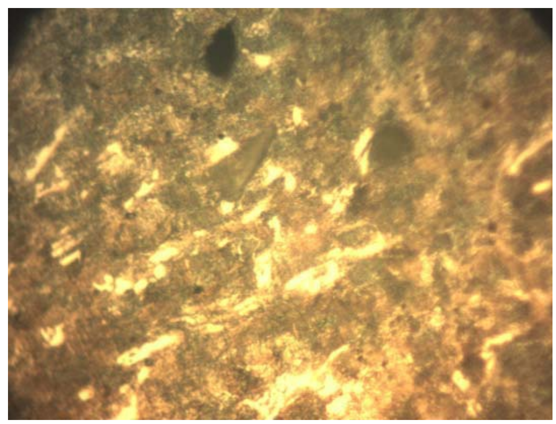

Plate 6: Oil Tempered at 860°C

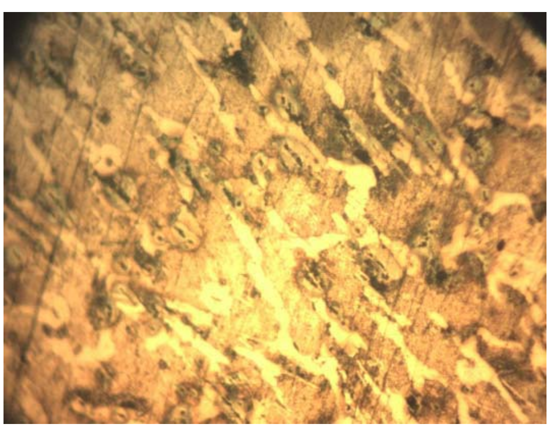

Plate 4: Water Tempered at 840°C

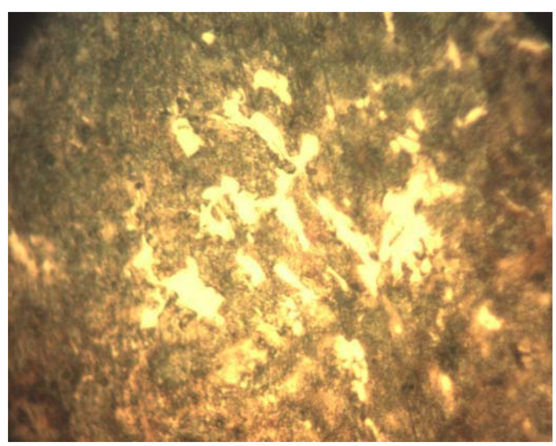

Plate 7: Oil Tempered 840°C

CONCLUSIONS

The hardness values of grinding plate specimens quenched in various media increased with increased heat treatment temperatures, indicating that both the heat treatment temperatures and quenching media has significant effect on the hardness values. However, these values are higher than that of the as-cast specimen.

Water quenched tempered specimens also displayed higher hardness values than the as-cast, whereas oil quenched tempered specimens possessed lower hardness values, which were constant throughout the exposure temperatures. Although, lower hardness value indicates a possible improvement in toughness but specimens with higher hardness values will likely possess better wear resistance.

The cooling rate of the heat treated specimens has dramatic effect on the size and distribution of the graphite crystals as well as the volume fraction of carbide precipitates. The presence of carbide was evident on the water quenched specimens at all the exposure temperatures, and hence the observed increased in the hardness values with increased heat treatment temperature. The highest hardness value was obtained on the water quenched specimen at 880°C, indicating better wear resistance. However, in an attempt to relief stresses developed during quenching and to balance between toughness and hardness, quenched specimens were tempered at 200°C. The results showed that the WT specimens still possessed high hardness value similar to air cooled specimens. Thus, the best heat treatment operation for better improvement in wear resistance of the grinding plate is heating at 840°C, followed by water quenching and tempering (for stress relief).

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