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[1.] J. K. ODUSOTE, [2.] S.I. TALABI, [3.] G. AGODINRIN

EFFECT OF HEAT TREATMENT ON HARDNESS AND WEAR RESISTANCE OF A FAILED AUTOMOBILE BRAKE DISC

[1-2.] Materials and Metallurgical Engineering, University of Ilorin, Ilorin, NIGERIA
[3.] Mechanical Engineering Department, University of Ilorin, Ilorin, NIGERIA

Abstract: *In an attempt to improve the wear resistance of a failed automobile brake disc, different type of heat treatment operation was carried out on the samples of the disc. The samples were heated to 840°C 860°C and 880°C in a muffle furnace, and quenched in water, palm oil and air, separately. Water and oil quenched samples were later tempered at 200°C. The chemical composition of the failed brake disc was obtained by an optical emission spectrometer (OES), while the hardness value was measured using Brinell hardness testing machine. The highest Brinell hardness value of 331 BHN was obtained from the water-quenched sample heated to 880°C. The hardness values of the oil-quenched samples surpass that of air-quenched samples. The tempered samples displayed lower hardness values compared with the hardened samples, although the sample heat treated at 880°C, water-quenched and tempered still possesses high hardness value. The reduction in hardness of most of the samples after tempering suggests possible increase in ductility and toughness. As a result of the heat treatment and subsequent quenching, the retained austenite in the samples transforms to martensite, while the ferrite, flakes of graphite, and cementite were restructured. This shows that the brake disc could be hardened and tempered to obtain optimum hardness with improved ductility and toughness. This will result in better wear resistance, increase service life, and thus reduce brake failure and other related transportation hazard.*
Keywords: *Failed brake disc, Cast iron, Microstructure, Hardness Value, Quenching media*

INTRODUCTION

Failure of engineering materials is an undesirable phenomenon that may result from improper design, material selection, processing or misuse among others [1, 2]. A component or part of a system fails when it ceases to perform its designed functions. It could either be in form of fracture or wear of parts, plastic deformation or general corrosion or degradation. Brake system is an important integral part of vehicle that is very hazardous when it fails in service. The failure could lead to accident that can result in economic losses, vehicle damage, human injuries and even death. Brake disc is a wheel assembly designed to slow down the rotation of the wheel by friction caused by pushing brake pads against the disc drum with a set of calipers. Brake disc is usually made of cast iron but could be made of composites such as reinforced carbon-carbon or ceramic matrix composites [3, 4]. Cast iron is an alloy consists mainly of iron and carbon with Si and other alloying elements. The wear resistance and strength of cast iron can be improved by hardening and tempering [5]. Hardening treatment involves heating an alloy or metal samples to a sufficiently high temperature, holding at that temperature prior to rapid cooling or quenching in water, oil or salt baths [5]. This process will result into high hardness value, better wear resistance and improved strength. However, in order to relieve the internal stresses, and improved ductility and toughness, it is critical to temper the hardened samples. The investigated brake disc sample was observed to have become thinner compared with the un-used sample, prior to fracture. This indicates that the brake may have failed due to excessive wear. Hence, there is need to improve the wear resistance of the automobile brake disc in order to increase their service life. In this present study, hardening and tempering heat treatment have been used as methods of improving the wear resistance of the failed brake disc specimens. Different heating *and quenching regimes using water, oil and air are employed, and the wear behaviour of the quenched and tempered specimens are explained in terms of changes in hardness after the heat treatments and microstructure of the specimens.*

EXPERIMENTAL PROCEDURES

The chemical composition of the failed brake disc sample used for this investigation was obtained using an optical emission spectrometer and the result is presented in Table 1.

Test Specimen Preparation

Fifteen (15) test pieces were prepared for hardness tests and microstructural analyses after heat treatment operations were done on the as-received sample. The test pieces were ground with SiC paper of different grit sizes prior to polishing to 1 µm diamond suspension finish. After polishing, the test pieces were cleaned ultrasonically in acetone, then alcohol, and immediately dried.

Heat Treatment Operation

The test pieces were heated to 840°C, 860°C and 880°C in a muffle furnace, and then quickly taken out of the furnace, and then quenched in water, palm oil and air, separately. The water- and oil-quenched samples were tempered at 200°C to remove the internal stresses and restore ductility. Surface morphologies of the as-received, quenched and tempered samples were examined with optical microscopy, and the hardness tests were also carried out using brinell hardness tester.

Hardness Test

Brinell hardness tester under a static load of 3000kg (29.43KN) with a ball indenter of 10mm diameter was used for the determination of the hardness of the test specimens. Each of the test specimens was flatten after the different heating and quenching regimes, and then mounted on the anvil. The specimens were brought in contact with the ball indenter at a dwell time of 10 to 15 seconds. The hardness of the specimen was determined from the diameter of the resulting impression, which was measured with the aid of a calibrated microscope according to BS240 and ASTME 10-84 standard.

Microstructural examination

The microstructure of the test specimens before and after heat treatment was observed with an optical microscopy. Prior to examination, both the as-received and the heat treated specimens were prepared for metallographic examination.

RESULTS AND DISCUSSION

Table 1 shows the chemical composition of the failed brake disc. Carbon is about 3.39 wt%, while silicon is about 2.74 wt% indicating that the sample is a greycast iron [5]. Apart from the brittle nature of grey cast irons, they are also susceptible to failure due to external forces, internal pressure, errors or flaws due to fabrication, and corrosion damage [6, 7]. Most of the carbon in grey cast iron is present in the form of continuous network of flake graphite platelets, which are dispersed throughout the metal matrix. This metal matrix controls the mechanical properties of grey cast irons, and also contributes to their relative weakness and lack of ductility [8]. Strength and ductility of grey cast irons could be increased through hardening and tempering operation at appropriate austenitizing temperatures [5]. This will improve the service-life of the grey cast iron components in automobile and other equipment.

Table 1. Chemical composition of the brake disc (wt.%).

Element	Composition (wt.%)	Eleme nt	Composition (wt.%)
C	3.39	Cu	0.027
Si	2.74	W	0.001
S	0.004	Ti	0.170
P	0.011	Sn	0.006
Mn	0.24	Co	0.002
Ni	0.012	Al	0.013
Cr	0.035	Nb	0.001
Mo	0.007	Mg	0.038
V	0.004	Fe	93.30

The hardness of the quenched and tempered specimens (Figures 1 and 2) were higher compared with the as-received specimen, with hardness value of 159 HBN. The hardness values increased with increased heating temperature with highest hardness of 331 HBR at 880°C obtained from the water-quenched specimen. This was followed by oil-quenched (220 HBR) and then air cooled (197 HBR) specimens heat treated at 880°C. The hardness value of the water-quenched sample also corresponds to the microstructural changes of austenite in the as-received to martensite. The hardness values of the tempered samples decreased compared with the un-tempered samples, indicating possible increase in ductility and *toughness. The presence of silicon in the cast iron reduces the solubility of carbon in austenite. Increase in austenitizing temperature increased the amount of carbon in solution [9], and subsequently give rise to higher hardness value as exhibited in water–quenched specimens at 880°C.*

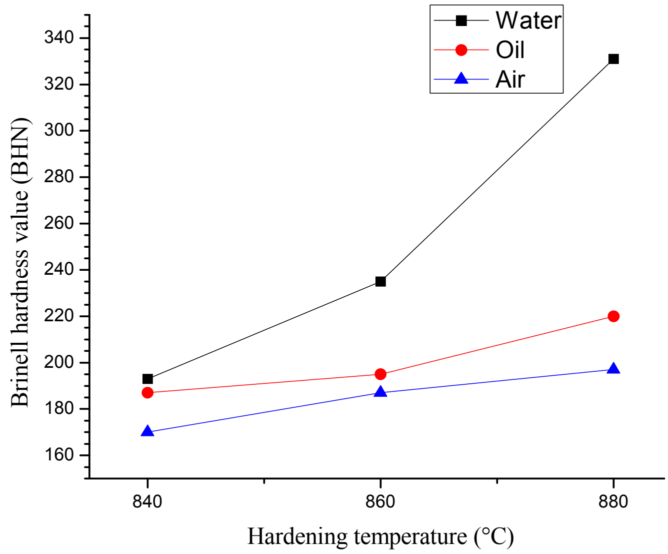

Figure 1: The hardness values of the samples quenched in different media (water, oil and air).

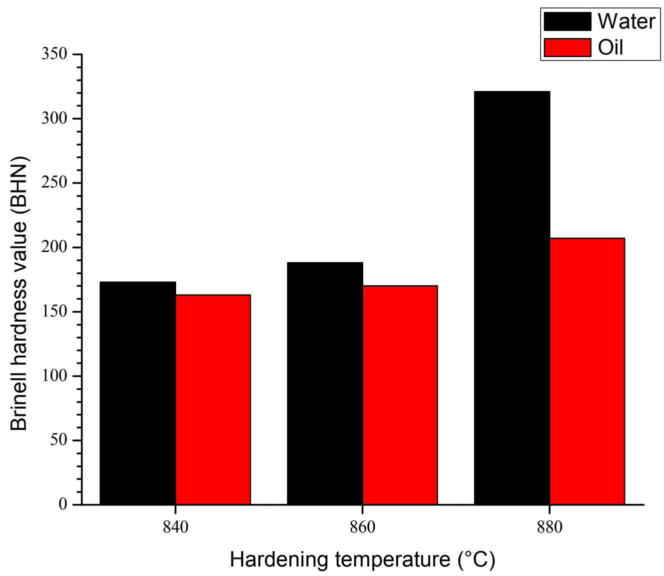

Figure 2: The hardness values (HBN) of the tempered specimens after quenching in water and oil.

MICROSTRUCTURE

Figure 3a is the optical micrograph of the as-received failed brake disc, which shows the presence of austenite, ferrite, cementite and flakes of graphite. The microstructure of the water quenched specimen (Figure 3b) revealed the presence of finely-dispersed ferrite with dendritic tempered martensite phase in a matrix of eutectic carbides, which gave rise to the high hardness value of water-quenched specimens. However, similar microstructure was observed in oil quenched (Figure 3c) specimens with the ferrite not finely dispersed compared to the water-queched specimen, but were mainly found along the grain boundaries. The amount of tempered martensite phase in a matrix of eutectic carbides was less in both the oil quenched and air cooled specimens (Figure 3d) when compared with the water quenched specimens. During tempering, there was growth of small carbide embedded in a ferritic matrix along with the transformation of retained austenite into martensite. The microstructure of tempered martensite consisted of extremely small and uniformly dispersed cementite particles embedded within a continuous matrix which may be nearly as hard and strong as martensite, but with substantially enhanced ductility and toughness [1, 10].

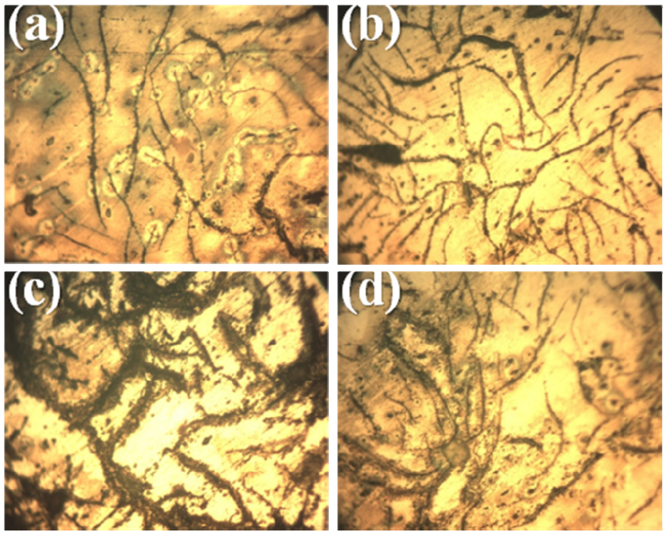

Figure 3: Optical micrographs showing microstructure before and after heat treatment at 880°C and quenching in: (a) As-received; (b) Water-quenched; (c) Oil quenched; (d) Air-quenched

Figures 4a and 4b are micrographs of water and oil quenched and tempered specimens, which show part of austenite matrix formed transformed into martensite and tempered martensite with the presence of cementite which influenced the hardness of heat–treated specimens. In the course of the heat treatment, the austentizing temperature, cooling rate and quenching media usually contribute to the precipitation of small carbide and formation of more uniform refined martensite of the heat–treated alloys. In addition, the presence of higher silicon content in cast –iron *gave rise to greater degree of decomposition of the cementite and coarse flakes of graphite produced [1, 5]. The effect of rapid cooling of water–quenched (tempered) specimens ensured the formation of tempered martensite, indicating significant improvement in toughness and ductility without sacrificing the high hardness value. Thus, from the results, it is proposed that heat treatment should be carried out at 880°C with appropriate quenching and tempering, to improve the wear resistance and toughness of the brake disc.*

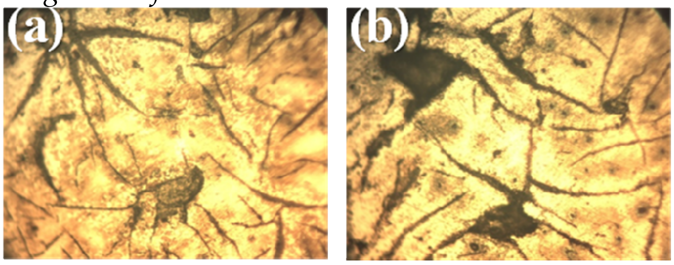

Figure 4: Optical micrographs showing microstructure after hardeningt at 880°C and tempered in: (a) Water-tempered; (b) Oil quenched

CONCLUSION

The hardness values of the failed brake disc specimens have been increased through the use of a quenching medium such as water, oil and air from 159 HBR in the as-received condition to a value in the range of 163-331 HBR depending on the quenching medium used. However, the hardness values of the quenched specimens decreased after tempering indicating improved toughness and ductility. The high hardness value of tempered water quenched specimen at 880°C is believed to indicate improved wear resistance. The tempered specimens also displayed improved microstructure than the quenched samples. Hence, water quenching and tempering of heat treated brake disc sample will improve its service performance, and thus safeguide the life of road users.

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