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A STUDY ON WEAR BEHAVIORS OF CAM SPINDLES MANUFACTURED FROM CK 45 STEEL AND CAM SPINDLES MANUFACTURED FROM GGG-50 SPHERICAL GRAPHITE CAST IRON AND BORONED

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This study targets mainly to reduce the manufacturing costs of cam spindles and manufacturing of mechanical components with longer service durations through application of surface engineering techniques on cam spindles. Within the frame of this study, we have attempted to establish the performances of cam spindles manufactured from forged steel and SGCI, through performance of wear tests in plate-disk system, metalographic investigations, SEM imaging, EDS analyses and micro hardness scans on test samples having the same sizes with original cam that once obtained from casting of Spherical Graphite Cast Iron (SGCI) are subjected partially to Boronising and partially to hardening in a salt solution and cam spindles currently manufactured from CK 45 through cauterization based reshaping

Keywords: Spherical Graphite Cast Iron (GGG-50), Boronising, Wear

1. INTRODUCTION

Wear is a major problem in machine components that work in friction with one another. And major advancements are attained by the end of everyday in studies performed for providing a solution to this particular problem. The service durations of mechanical components have increased with respect to past, thanks to the modern surface coating methods developed at the end of these current studies. The Physical Vapor Deposition, which is known as one of these modern surface-coating methods is a process realized through first obtaining of vapor from the material through implementation of such methods as vaporization, laser removal and spraying and then concentration of vapor on main material whereby finally a thin film layer is obtained. As the PVD coating temperature normally falls within the range of 350 – 500 C, the coat may be applied only after heat treatment process is completely over. Another modernistic surface processing technique is Boronising. This is a thermo chemical process and is suitable for applications on steels, cast irons and even non-iron metals. The process of Boronising is attained through casting of Boron onto the material under Boron transmitting environments and at very high temperatures.

The Spherical Graphite Cast Iron (GGG-50) showing dramatically major developments from the time when it is first used until today as an engineering material, has its growingly more importance it has in current industrial applications greatly owing to the high resistance characteristics it possesses. Ranking always atop amongst the most vital materials of engineering thanks to its stated characteristics GGG-50 stands as a material that triggers competitive power with such other important abilities as processing, low resistance/weight ratios and etc [3]. At the same time, carbon appears in spherical graphite form in cast iron, which is also referred to as nodular, spheroid and adductive iron. In order to ensure transformation of carbon from lamella shape to the form of a sphere, as a practical rule, the melted iron is subjected to an injection process before finally being cast. As the spheres are formed during solidification, temper generally differs from casting. Besides, the fact that the graphite shape is sphere and not lamella makes cast iron less elastic and more resistant. The major slice in application areas of GGG-50 materials belongs to car manufacturing and architectural design. The material also finds applications in pipe manufacturing and mining and metallurgical industries, during such specialized manufacturing applications as cut off frames, melting pots or hot iron rollers [4].

The surface hardening procedures for spherical graphite cast irons typically consist of soft annealing, normalization, hardening in salt solution, induction or laser annealing and hardening, nitrification, aluminum application and Boronising stages [5]. Boronising of GGG-50 materials usually takes place for 1 to 10 hours in solid, liquid and gas environments within a temperature range of 750 – 1000 C. Boron coated cast irons have a lesser coefficient of friction comparing to steels. The surface hardness values of boroned materials reach up to 1300 to 2000 HV due to formation of borides, chemically formulated as FeB and Fe_2B [2,6]. GGG-50 materials with surfaces being boroned are used in many application areas such as textiles manufacturing equipment, moulds and moving mechanical parts and etc.

2. TEST STUDY

In this study, the GGG-50 material produced in the form of cam profiles was subjected to Boronising through thermo chemical processes and then compared to CK 45 steel, which is currently manufactured as cam spindles forthwith upon surface hardening through induction. For this purpose, all samples were subjected to corroding process and scan electron microscopy (SEM) and EDS analysis techniques were employed in structural characterization of corroded surfaces and cross sections. In addition, micro hardness measurements were performed for all the samples being tested. The sizes of cams used in time of tests are given in Figure 1 while the chemical compositions of GGG-50 and Ck 45 samples are listed in Table 1, below.

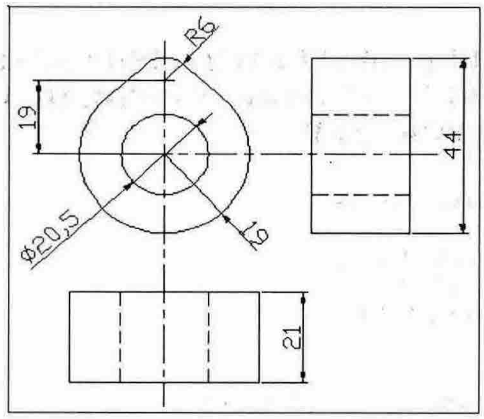


Figure 1. Sizes and appearances of cams taken as basis for performance of tests

Boronising in a powder environment, which is a type of solid Boronising being one of the Boronising methods in general Boronising processes, is selected as the Boronising method for this study. In order to perform Boronising, boric acid (H_3BO_3) and Borax ($Na_2B_4O_7 10H_2 0$) were mixed together homogenously by 32% and 69% respectively and then were left in a furnace being heated up to the temperature of 850°C for 6 hours for dewatering in order to have crystal output. Later on, the mixture was grinded in a mill with 90 mesh sized grids and poured with 75% Borax – Boric Oxide by weight and 20% ferro silis and 5% of pure Aluminum with same sizes in order to obtain the Boronising material. Once the Boronising process is completed, the materials were left to air-cooling at standard room temperature and then were dipped into hot water in order to remove the remnants of Boronising process for two hours.

During the process of hardening through induction applied for Ck 45 test samples, conductor coils were tightly wrapped around the surfaces subject to hardening and then electric current is fed to the coils. An electric current is formed on the surface of part by means of induction, whereby the surface was heated until it reaches to water release temperature. Following this, the hardening process was completed through spray application of lubricant as chilling agent over heated areas. The resultant hardness values of parts measured during hardness value measurements conducted forthwith upon completion of hardening process were measured at 58 HRC. During the crack inspections carried out consequently, no cracks were found on any of the test samples.

For the conduct of corroding process, all samples made available for tests were exposed to wear in a plate-disk system with dry friction and rotations varying from 90 to 110 rpm but under a constant load of 800 grams. Each sample was subjected to wear for 3 hours and weighed in the balance at every half an hour time in order to establish the amount of wear.

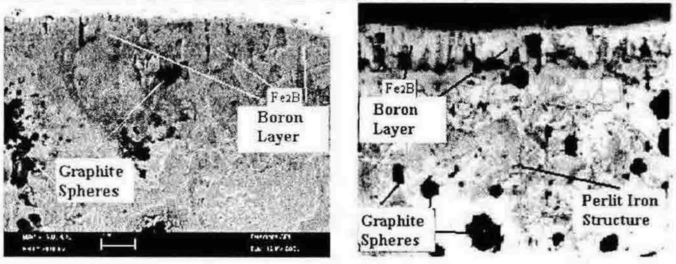
Table 1. Chemical compositions of samples used in the tests (in percentage)

	C	Si	Mn	P	S	Cr	Ni
GGG-50	3.87	2.56	0.421	0.018	0.013	0.025	0.009
Ck 45	0.496	0.213	0.635	0.015	0.024	0.044	0.082
	Mo	Cu	Al	Co	Ti	Sn	
GGG-50	0.001	0.689	0.007	0.001	0.012	0.001	
Ck 45	0.011	0.068	0.012	0.008	0.001	0.024	

3. TEST RESULTS

3.1. Metalographic Study Results

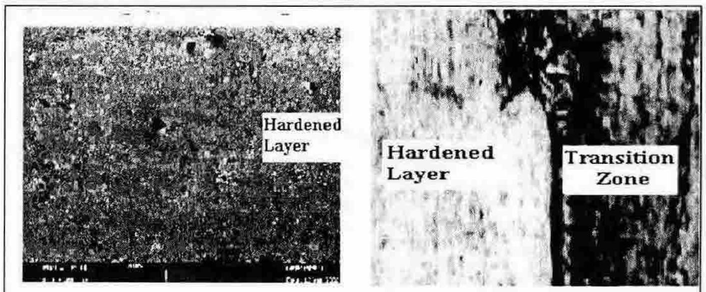
After metalographically polished surfaces are cauterized with 2% Nithal and cleansed with alcohol, microstructure imaging and EDS analyses were carried out for the samples with the help of an optical microscope and SEM image device. As a result of microstructure investigations made, the boride layers were clearly exposed in samples that were subjected to Boronising. Figure 2 shows the SE photos belonging to the samples. In addition, EDS analyses were performed on regions to which these images belong and these sample EDS analyses are shown in Figure 3 below.



SEM image of boroned GGG-50 magnified by 4000 times

Optical Microscope image of boroned GGG-50 magnified by 50 times

Figure 2. SEM and Optical Microscope images of boroned SGCI



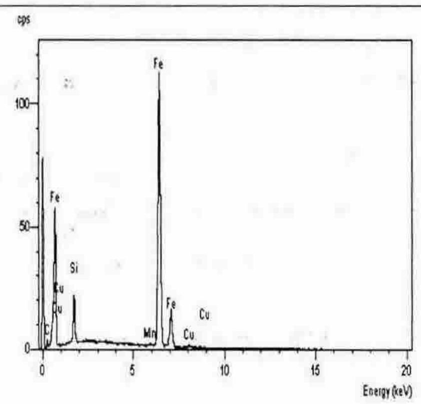
SEM image of Ck 45 steel magnified by 650 times

Optical Microscope image of Ck 45 steel magnified by 200 times

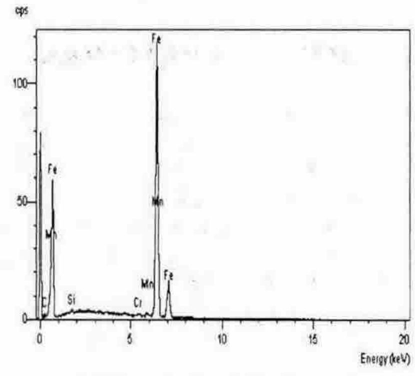
Figure 3. SEM and Optical Microscope images taken from Ck 45 steel cross sections

As shown in Figure 2, the structure formed in a jagged shape illustrated in whitish color represents the boroned layer consisting of Fe_2B phase. The thickness of the boroned layer was established as approximately 4,5 μm according to the scale given in the SEM photo and underneath it comes the diffusion zone. At sections below the diffusion zones graphite spheres and the Pearlitic structure appearing in the form of a fingertip lies, be the latter a flexible and middle hard structure that exist in the cast iron. The thickness of boroned layer varies depending on the Boronising temperature and time. In addition, the Boride layer forming after Boronising process also differs between FeB, Fe_2B or FeB and Fe_2B phases, according to the method or type used in Boronising. This increases the availability and mechanical characteristics of GGG-50.

When the microstructure of the Ck 45 test sample manufactured from cauterized steel with surface hardened through induction method, the whitish colored layer illustrated at far left corner is the hardened layer and the blackish colored region just beside it represents the transition zone. At the far right is the soft tissue appearing. The SEM Photo of the sample illustrates the microstructure of hard section. Hardened layer thickness was established to be around 3mm (Figure 3).



EDS analysis of boroned GGG-50



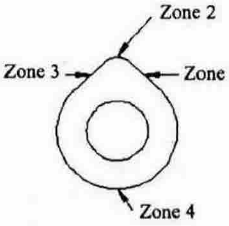
EDS analysis of Ck 45 steel

Figure 4. EDS analyses of test samples

Although the boron-coating layer appears clearly to the eye, the Boron element is not detectable in the EDS Analysis performed, in the SEM Photo of the boroned test sample illustrated at Figure 3. This is possibly because that the Boron has an atomic number 5. However, the pixel intensities from the aspect of weighed elements of both hardened GGG-50 and Ck 45 test samples are apparent in the figure.

3.2. Study of Wear Behaviors

Before beginning to proceed with corroding process, test samples were weighed on a balance with a reading accuracy of 0.001 grams and later exposed to dry friction for three hours in each case in the plate-disk corroding system under a permanent load of 800 grams at 90, 110 and 130 rpm, chronologically. Attempts were made by the end of every half hour toward locating the amount of wear by simply weighing the samples being subjected to corrosion. The corroding agent used for the purpose of the corroding process is the SAE 4140 (42 CrMo 4) steel. The worn surfaces of samples were investigated on a per zone basis due to the fact that different wear mechanisms were encountered at different zones during the course of SEM imaging performed on test samples. These zones are depicted in Figure 5 below. In addition to this, Figure 6 shows the SEM photos belonging to the worn surfaces while Figure 7 show the wear graphs of samples at 90 and 110 rpm.



Zone 1 : Corroding agent's peak climbing surface

Zone 2 : Cam's peak point

Zone 3 : Corroding agent's peak declining surface

Zone 4 : Sub zone

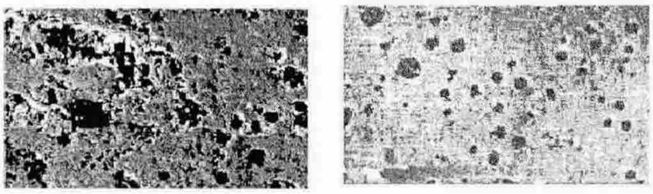


Photo of boroned GGG-50 zone 1 magnified by 1000 times

Photo of boroned GGG-50 zone 1 magnified by 1000 times

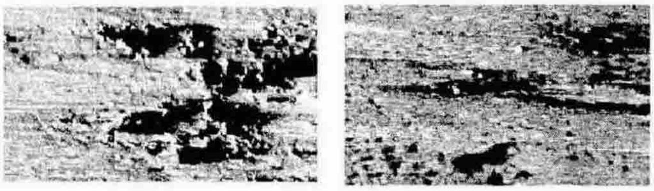
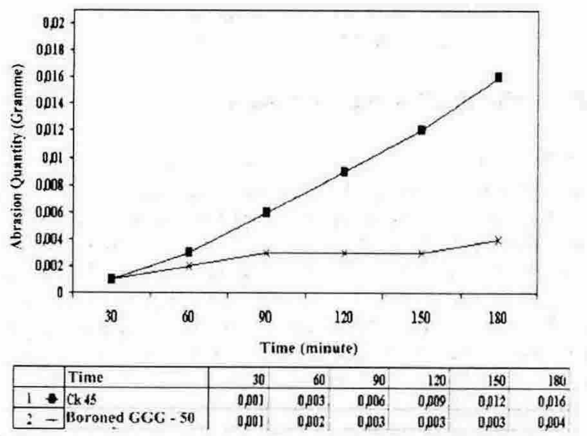


Photo of Ck 45 Steel zone 1 magnified by 1200 times

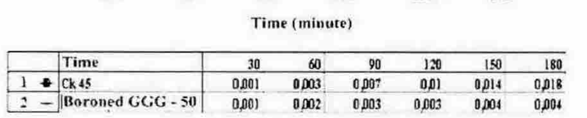
Photo of Ck 45 Steel zone 2 magnified by 1200 times

Figure 6. SEM photos taken from zones of test samples subject to wear



	Time	30	60	90	120	150	180
1 ■	Ck 45	0,001	0,003	0,006	0,009	0,012	0,016
2 —	Boroned GGG - 50	0,001	0,002	0,003	0,003	0,003	0,004

With a look at Figure 6, it is argued that the pressing (normal) force increasing from minimum to maximum values on the Corroding Agent's Peak Climbing Surface (Zone 1) and accordingly the force of friction coerces the uneven (rough) points to a plastic shape change and entail to adhesive wear characterized with material overlay. Furthermore, some micro cold welding points are created at some points and breaks occur when the flow threshold is exceeded. The micro particles that break off from the Corroding Agent's Peak Climbing surface causes the peak surface corrode by excessively constraining the cam's peak (Zone 2) with the help of pressure and frictional forces that have reached at their maximum values atop the cam. The wear occurring at this zone therefore appears as both adhesive and abrasive, partly.



	Time	30	60	90	120	150	180
1 ■	Ck 45	0,001	0,003	0,007	0,01	0,014	0,018
2 —	Boroned GGG - 50	0,001	0,002	0,003	0,003	0,004	0,004

Wear Graph of samples working at 110 rpm

Figure 7. Wear Graphs of Test Samples

As shown in Figure 7, each of the test samples were subjected to wear for 180 minutes in total and by the end of every 30 minutes, they were weighed and their respective amounts of wear were recorded. As may clearly be seen from the graphs, the amount of wear increases as the number of rotations per minute rises up. Basing on the data obtained from the corroding test, the maximum amount of wear took place on the CK 45 steel with 0.020 grams, which is followed by 0.005 grams in boroned GGG-50.

3.3. Micro-hardness study

As the pearl edge could not have been located over the coating area, which is attributable to the fat that the coating thickness was very small at areas and therefore no traces were forms, the hardness values of Boron coating layers were measured from the surface while the micro-hardness values for other samples were carried out through cross sections. The resulting data obtained from these measurements are as shown in Figure 8.

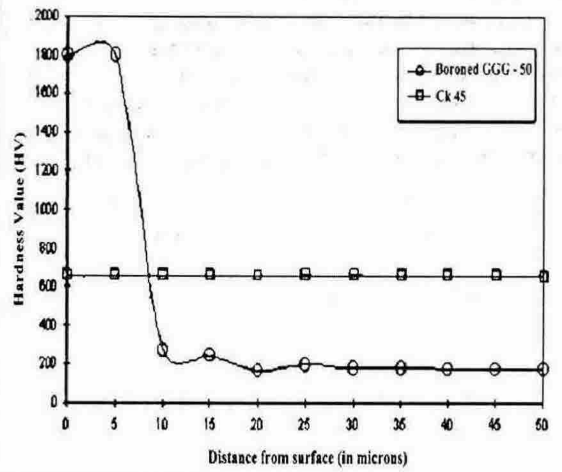


Figure 8. Results of Micro-hardness scan performed over samples used during tests

Hardness values in the case of boroned samples tend to increase up to a maximum from the outer surface toward the coating depth but later on, to reduce making a parabola down to the hardness value of the main material.

4. CONCLUSION AND REMARKS

Basing on the results obtained, it is possible to say that GGG-50 surfaces incorporating the common characteristics of steels and cast irons may be boroned thermo-chemically, using Boron compounds. The availability of heat treatments normally applied to steels was also encountered as higher in GGG-50 when compared to other cast irons. No significant transitional forms in spherical graphite cast irons similar to steels were encountered as a result of metalographic studies performed. Instead of this, a whitish colored zone was detected, containing silica.

The hardness rises up to its maximum value in the samples being coated, moving from outer surface to a certain depth and later on, showing linearity, reduces to the hardness value of the matrix with a parabolic reduction. The maximal hardness figures were measured on outer surfaces with boride layers present. Generally speaking, the coating layers forming up on surfaces of GGG-50 materials were found to possess a composite character during both the optical microscope and SEM studies performed. It is therefore of common conclusion that the quantities of graphite spheres that exist within the coating layer decreases. The gray colored zone that appear in the close surrounding of spheres detected in GGG-50's microstructure with the help of optical microscope and SEM images were predicted to appear due to the graphite's lubricant effect, thanks to which, the coefficient of friction decreased vastly in time of wear.

Relying on the data shown in the foregoing tables, it is possible to state, by the end of the corroding tests being performed, that Boron coating yielded better results than other samples used during tests. A thorough investigation of microstructures of traces of wear existing on surfaces reveals deep lines along the trace, which are thought to have arisen due to a possible scraping. It is also among common observations that more wear had taken place at the initial contact point of the corroding agent with the cam's edge and the side section of the cam compared to other zones and sections, particularly because of the test sample profiles selected. As a result of heat released due to friction in time of wear, oxidation is possible. And based on this finding, it is possible to state that wear has an oxidizing character.

The studies concentrated on wearing behaviors in both Ck 45 steel and Boroned GGG-50 show that the C 45 gets worn by around 0.016 grams in 180 minutes, while the boroned GGG-50 gets worn only by 0.004 grams, when the number of rotations per minute is fixed as constant. When compared according to time change, Ck 45 steel shows a permanent wearing behavior while the boroned GGG-50 shows a wearing behavior only in between 90 to 150 minutes. As obvious, there is no objection against manufacturing of cam spindles already produced for the industry from boroned GGG-50 material, but there are many advantages brought therewith.

Materials manufactured from GGG-50 are hardened and coated with Boron through thermo-chemical processes, with great success. However, recent studies report that the chemical composition of GGG-50 materials has a major effect on the quality of coating. For instance, it has been reported by many researchers that there exist some objections against Boronising of silica containing steels. GGG-50 materials are known to contain higher levels of silica. It is also known that there exist more parameters in Boronising of GGG-50 materials than those recommended or steels. The boride layer formed up on the surfaces of GGG-50 materials containing no or low levels of alloying elements create a carbon based intermediate zone in the coating – matrix intermittent surfaces, which leads to partial breaks on coating layer due to the weakness of this layer. However, addition of 1% of copper prevents deposition of carbon and entails to formation of a mono phased Fe_2B phase. In this case, the coating layer so formed shows a composite character with distribution of graphite spheres. And thus, the coefficient of friction is reduced down at considerably lower levels compared to the case of steels. Therefore, it is possible to conclude that Boronising applications on GGG-50 materials may well be carried out at industrial levels, save that proper composition and process parameters are selected.

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