The Pack Boriding of Lamellar and Nodular Cast Iron Camshafts: Surface and Elemental Analysis by SEM-EDX

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Abstract: The pack boriding is widely used to coat the surfaces by boron compounds at different temperatures. The simplicity and easy applicability of the method makes it to be used widespread. The camshafts are among the most important parts of automobile motors, nowadays. They should be coated with an appropriate technique and hard enough layer of boron to use in industry. There are some limitations of boron layer coating as obtaining the hardest and interconnected layers to produce FeB_2, FeB, and Fe_2B simultaneously, from top to bottom. This sequence decreases the degree of mismatching to matrix. In this study, an attempt has been made to evaluate the degree of mismatching while evaluating the produced compounds as well as surface roughness to be stabile for lowering the abrasive or adhesive wear of materials of interest. SEM and EDX were employed for surface topographic and elemental analysis, respectively. The interpretation was evaluated to differentiate compound as Fe_2B, FeB and FeB_2. The upper surfaces seem to be as Fe_2B which is softer while the lower surfaces seem to be FeB and FeB_2.

Keywords: Grey cast iron, nodular cast iron, FeB, SEM-EDX.

Introduction

Among the commercially available alloys, steels are very stunning to be taken into consideration in such applications because of their versatile microstructure, properties, and low cost [1]. Steel components, found a wide range of applications in different areas including automotive, transportation, construction, packaging, white goods, etc., need to have certain mechanical properties which are generally realized during their productions [2]. Low alloyed steels are versatile in their application and are common used because of their cost and availability [3]. Carbon steels are generally known as ferrous alloys in which carbon concentration differ between 0.12 and 2 wt%. The microstructure and properties of such steels based on their chemical compound [4].

While low carbon steels have been utilized broadly in many applications, some margins in their properties limited their usage in some manufacturing processes [3]. Beside, traditional steels do not satisfy the safety necessities in some aggressive environments where exclusive surface wear resistance is necessary [1]. Most non-successes of engineering components originate from disruption processes such as corrosion, fatigue and wear started at the materials' surface [1]. In terms of corrosion and wear, the surface structure is crucial to the service life of the machine components used in most applications [5]. Sliding wear of metals in machinery components is expensive to industry and is often related to adhesive contact [6]. Wear and corrosion cause a remarkable amount of economic loss. It is of great significance to materials to improve high wear and corrosion resistant alloys in order to reduce loss and meet severe environmental requirements [4].

There has been widespread research on the improvement of surface treatment processes to develop the corrosion resistance, hardness, thermal stability, wear resistance and the thermal stability of steel [7]. While the surface can be hardened by thermal or thermochemical processes, the surface properties can be developed by a hard coating with a deposition process on the surface [5]. In recent years, thermochemical processes, such as carburizing, nitriding and boriding, have been utilized to develop surface properties in ferrous materials, but boriding has some advantages over the other two processes as it improves the adhesive wear, high-temperature resistance and the surface hardness [6].

Boriding is a diffusional surface treatment, which is defined as strengthening of the surface of a workpiece with boron by means of thermo-chemical treatment [8]. Borided surfaces can keep their hardness and wear properties up to 1000 °C. One of the most important features of the borided surface is to keep its hardness even after additional heat treatment [5]. A lot of boriding techniques such as powder-pack boriding, liquid boriding, gas boriding and plasma boriding have been improved. When the powder-pack boriding method is compared with other boriding methods, it is stated that the powder-pack boriding method has some advantageous in terms of cost and convenience efficiency [9]. In recent years, many new modified surface treatment processes, such as plasma paste boronizing treatment, electron-beam boriding treatment and pulse gas tungsten arc treatment, have been explored since traditional boriding processes, such as formal salt boriding and gas boriding have some important problems such as environmental pollution, toxicity, explosive nature, etc. [7].

Boriding is a thermochemical treatment of ferrous metals which results in the formation of iron borides FeB and Fe_2B. The different types of layers may occur depending on the properties of the treated material, boriding technique and parameters used: single phase Fe2B layer or dual phase FeB + Fe_2B layer [4]. Meric et al. concluded that particle size of the powders used in boronizing was a significant processing parameter and in their study the particle size of powder decreased with the increased boride layer thickness [4]. Keddam and Chentouf suggested that the powder-pack boronizing has the advantages of simplicity and cost-effectiveness in comparison with other boronizing processes [11].

Materials and Methods

The grey cast iron and nodular cast iron were chosen as GG25 and GGG60 that are the most common used cast irons in automobile industry. Table 1 shows the elemental composition and mechanical properties of materials. The materials were kindly given by Estas Co. Ltd. which is the biggest camshaft producer of Anatolian region in Sivas, Turkey.

Table 1. The average chemical compositions and mechanical properties of used materials.

Materials	Composition (wt%)									Mechanical Prop.			
	C	Si	Mn	Cr	Cu	Mo	V	W	Co	$\sigma_ç$	σ_a	E	Hardness
	%	%	%	%	%	%	%	%	%	(MPa)	(MPa)	(MPa)	HV
GG25	3.3	2.3	0.6	-	-	-	-	-	-	250	160	120	220
GGG60	3.7	2.8	0.3	0.4	0.45	-	-	-	-	600	370	170	260

The specimens were kindly prepared by Estas Co. Ltd. according to the dimensions of the schematic illustration in Fig. 1. The average hardness and surface roughness of samples were given in Table 2. The specimens were cut from cams and cams were drilled accordingly for the wear device from the middle. Average surface roughness were evaluated as R_a=0.4 µm. The measured values were typical for all materials as initial state.

Table 2. The initial hardness and surface roughness's of the materials prior to tests.

	GG25	GGG60
Hardness (HV)	220	260
Surface Roughness (µm)	0,5	0,38
Amount of Specimens Measured	36	18

An optical microscope (Nikon Eclipse L150, Japan) was used for optical images with a post processing software. Scanning electron microscope (FE-SEM, TESCAN® Mira3 XMU, Brno, Czechia) was employed to evaluate the surface morphology and energy dispersive spectroscopy (TESCAN® SEM-EDX, Oxford Inca®, UK) was used for determining the elemental compositions and distributions of Fe and B phases.

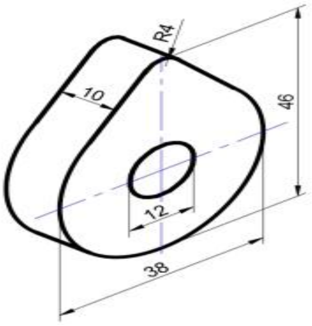


Figure 1. Schematical illustration and dimensions of cams prepared for test.

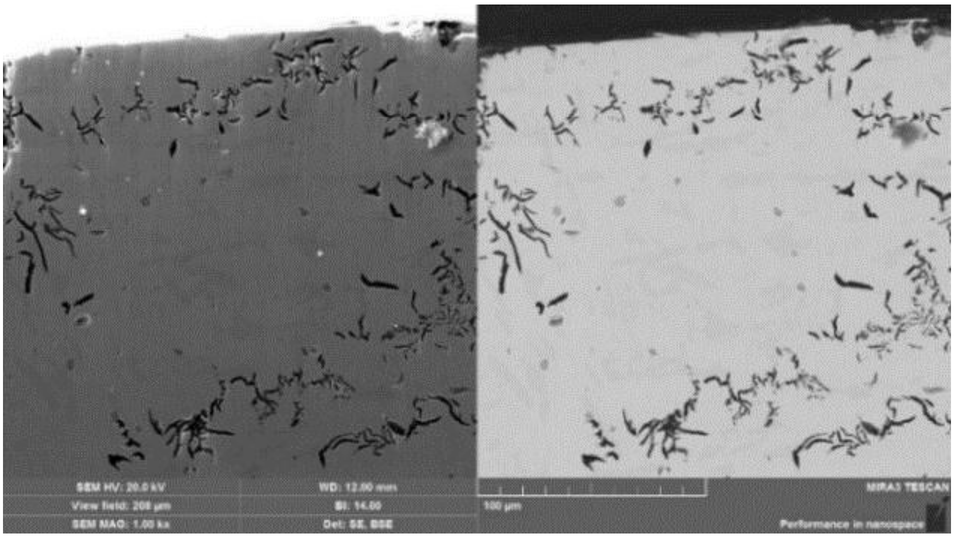


Figure 2. SEM image of induction hardened grey cast iron specimen (1kx)

The routine of grey cast irons are being hardened by induction hardening in gas assisted induction to produce iron carbides in the outermost surface to obtain higher surface hardness for grey cast irons. Scanning electron microscopy images were given in Fig. 2. at 1 kX magnification. The lighter grey regions are iron alloy and black flake like regions are graphite which gives the name as lamellar graphite cast iron. As clearly be evident, the hardened region is not visible since the iron carbides are well distributed on and under the surface and among the lamellar graphite. The surface was polished and lamellas were observable as flakes.

Results and Discussions

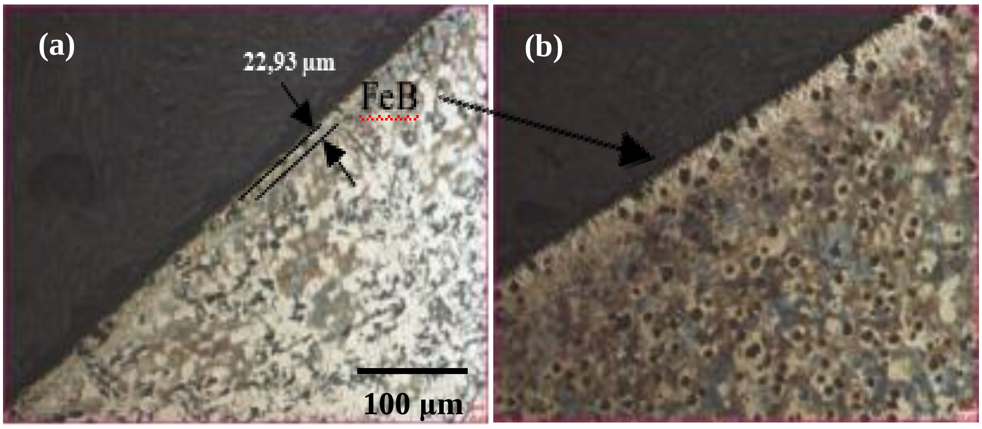
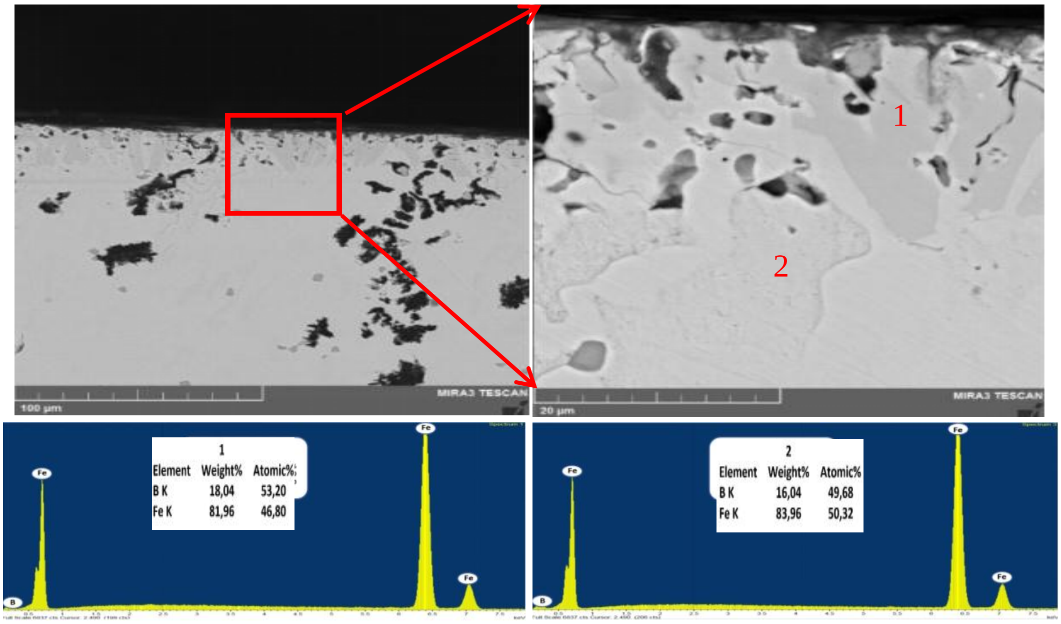


Figure 3. The optical microscopy microstructural images of a) grey cast iron, b) nodular iron casting (100x)

Fig. 3 shows the optical microscopy images of grey cast iron (a) and nodular cast irons coated by pack boriding. The FeB layer was seen on surface as 24 micron while coating on nodular cast iron is twice in thickness. The graphite flakes inhibits the growth of FeB that may have transformed to Fe_2B or FeB_2 due to diffusion controlled reaction order. Nodular iron casting has spheroids which are smaller in nodules which may give rise to increased thickness of FeB layer up to 50 microns. FeB is seen as layers rather than comb-like structure of FeB_2 which can be the reason for increasing hardness while decreasing the roughness.

Fig. 4 indicates the SEM image of grey cast iron and red square is the higher magnification of the near-surface region. (1) and (2) regions show the EDX point analysis. As seen from EDX spectra (1) and (2), the increased Fe versus B indicate that (1) is more B containing compound as FeB mixed with FeB_2 in a small amount. (2) region shows more Fe containing phase that is under the surface which may be a mixture of FeB and Fe_2B. More the iron in area, the lighter the area seen on SEM be backscattered electron imaging.

Fig. 5 represents the borided coatings of nodular cast iron specimens and their EDX analysis. The average coating region seems to be around 50 microns measured by SEM. The nodules have an average diameter of 25 microns which is small in amount but contains a high amount of carbon equivalent. The decarburization of surface may lead to increase in thickness of Fe_2B or FeB_2 layers. These EDX analysis points can be attributed to different compounds.



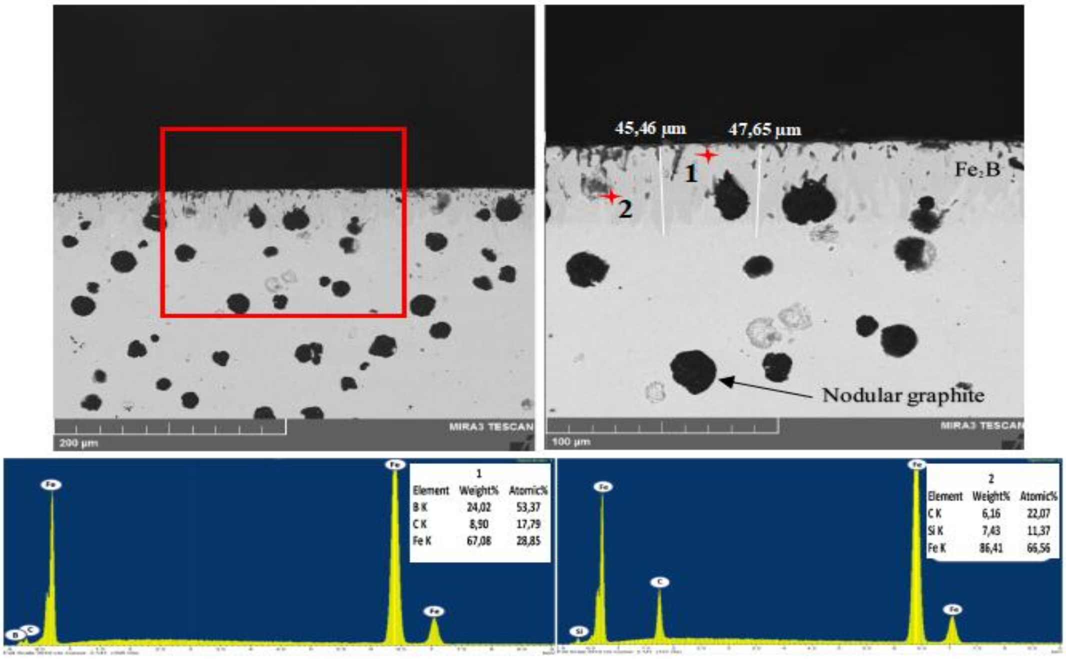
1

Element	Weight%	Atomic%
B K	18,04	53,20
Fe K	81,96	46,80

2

Element	Weight%	Atomic%
B K	16,04	49,68
Fe K	83,96	50,32

Figure 4. SEM-EDX analysis of borided grey cast iron specimens.



1

Element	Weight%	Atomic%
B K	24,02	53,37
C K	8,90	17,79
Fe K	67,08	28,85

2

Element	Weight%	Atomic%
C K	6,16	22,07
Si K	7,43	11,37
Fe K	86,41	66,56

Figure 5. SEM-EDX analysis of borided nodular cast iron specimens.

(1) remains for upper surface point that can be concluded as Fe_2B while point (2) remains for lower surface point that can be attributed to carbon rich region. This point seems to be as Fe_3C in the highest limit of C in Fe matrix with a possibly very small amount of B. The comb-like structure along the surface may be attributed to higher B content as FeB_2. This

phenomenon makes the inner surface harder while the upper surface remains softer that is evident to be higher roughness due to decarburized or deboronized surface.

Conclusions

The following conclusions can be derived from this study;

- The pack boriding occur to some extent for grey and nodular cast iron camshaft materials and can be applied to these materials to improve the hardness.
- The average thickness of boriding layer reached to 25 microns for lamellar cast iron samples, while reaching to 50 microns for nodular cast iron samples.
- The boriding layer consists of FeB+ Fe_2B layers as comb-like structure due to the position and amount of carbonized spheroids rather than graphite flakes seems to be more.
- SEM and EDX were very good tools to evaluate the atomic percent of Fe and B to interpret the compound formation either for upper or lower part of surface as indicated by FeB, FeB_2 and Fe_2B to produce correct mismatch layers from top to bottom.

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