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Surface modification of nodular cast iron: A comparative study on graphite elimination☆

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ABSTRACT

In this study, two surface processes, TIG surface melting and chilling, were applied to remove the negative effect of the near-surface graphite phases of nodular cast iron. Afterwards, the treated surfaces were plasma-nitrided and boronized. After graphite elimination processes, plasma nitriding and boronizing, the microstructures were compared with the one of untreated cast iron. The results showed that the chilling process that was applied during the casting process of nodular cast iron did not eliminate the graphite phases from the surface. However, an almost nodule-free surface was obtained by the TIG melting process. It was of no use in nitriding and boronizing the chilled surfaces due to the existence of superficial nodular graphite in the surfaces after completion of the chilling. On the other hand, a continuous uninterrupted compound layer and boride layer were observed on the TIG melted surface.

Under the light of these experimental studies, the TIG surface process is proposed to eliminate the nodular graphite on flat and curved surfaces of nodular cast iron parts before thermochemical surface hardening treatments or hard coating processes are applied to the nodular cast iron surfaces.

1. Introduction

The microstructure of nodular cast iron (NCI) consists of graphite phases built in the iron matrix [1]. When an NCI surface is hardened by well-known methods such as nitriding, boriding or thin film deposition, hard layers take place discontinuously at the surface. Some of the graphite phases placed near the surface interrupt the positioning of the thin hard layer and thus weaken the adhesion between the hard layer and the NCI substrate. It is therefore imperative to avoid the nodular graphite just beneath the surface that will be hardened. The near-surface graphite acts as a source of crack nucleation under impact conditions and can cause crack growth, which accelerates material fraction.

Graphite nodules just beneath the surface that will be thermochemically heat treated are not demanded as they may interrupt the continuity of the hard layer just above the graphite nodules. They weaken the adhesion between the NCI substrate and the hard layers such as layers of boride [2], nitride and thin ceramic film to be deposited on the NCI surface [3]. Discontinuous graphite phases may appear on the subsurface of the boronized NCI [4]. Graphite can also act as a crack nucleator under solid particle erosion [5]. The graphite exposed to the atmosphere may cause graphitic corrosion as well [6].

From the perspective of surface engineering, graphite in NCI can be seen as a potential problem. It is supposed to suggest a suitable method to solve this problem. The technological process to be suggested must be adapted to work within the manufacturing stages of cast iron, and it must only allow surface microstructure modification except for a core section of NCI. It is recommended that the methods should be applied either in the course of casting or prior to machining. These methods are classified as: chilled cast process, TIG melting and energy beam processes (laser and electron beam). The chilled casting method depends on obtaining a ledeburite microstructure in the cast walls by means of circulating coolant. That is why the occurrence of graphite in the outer wall of the cast iron can be prevented by using molds adapted to chillers in the course of casting.

As for the TIG method, the principal feature is that an inert gas and a no-molten tungsten electrode are used. The method is often applied in overlay coatings in order to increase wear resistances of surfaces [7,8] and to allow a special welding process of metals such as aluminum alloys and stainless steel.

The process does not have any negative effect on the surface properties of NCI apart from high heat input. So, a tungsten electrode can be used as if it was a laser. TIG and a laser beam were used in spot modification of an NCI surface [9]. But, having not found a different purpose of TIG in the literature apart from alloying and surface hardening, they have not been suggested for NCI so far.

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Table 1
The chemical composition of the cast iron used in this study.

Cast iron	C (%)	Si (%)	Cr (%)	Ni (%)	Mn (%)	P (%)	Mo (%)	S (%)	Al (%)	Cu (%)	Sn (%)	V (%)
Nodular (GGG40)	3.52	1.54	0.097	0.032	0.286	0.049	0.36	0.033	0.002	0.079	0.009	0.006

Due to limitations in the size of the iron part and high installation costs, the use of energy beam processes is limited when compared to the conventional methods.

The aim of this study is to eliminate superficial graphite nodules of NCI by trying alternative surface engineering methods. The process complications for NCI surface and subsurface microstructures are also metallurgically studied.

2. Experimental procedure

Chilling and TIG melting processes were applied for elimination of graphite phases in the untreated NCI surfaces. Chilling process was applied to a GGG 40 (nodular) test material in the shape of a cylinder with a 2 cm diameter and at a cooling rate of 250 °C/s, in ESTAŞ Camshaft Company in Sivas, Turkey. The chemical composition of the test material is given in Table 1.

GGG 40 was selected as NCI test material for TIG melting process. NCI samples were machined from Y-Block in as-cast [10]. The dimension of the sample was 2 cm × 15 cm × 20 cm.

A TIG melting process was carried out with a zirconium alloyed-tungsten electrode of 2 mm diameter with different electrode traveling speeds at a voltage of 120 ± 5 V and with amperage of 5 ± 1 A, under an argon atmosphere. The electrode traveling speed was estimated by dividing the length of the melted surface distance by the duration between the start and stop of arcing. It is well known that the welding capability of the cast iron is not good due to abandoned carbon containing. Therefore, prior to the melting process of the surface, the test material was preheated to 400 °C to prevent cracks caused by rapid heating (thermal shock). The temperature of the melted surface was measured by an optical temperature sensor during the processes. Fig. 1 shows the melted surface at different electrode traveling speeds.

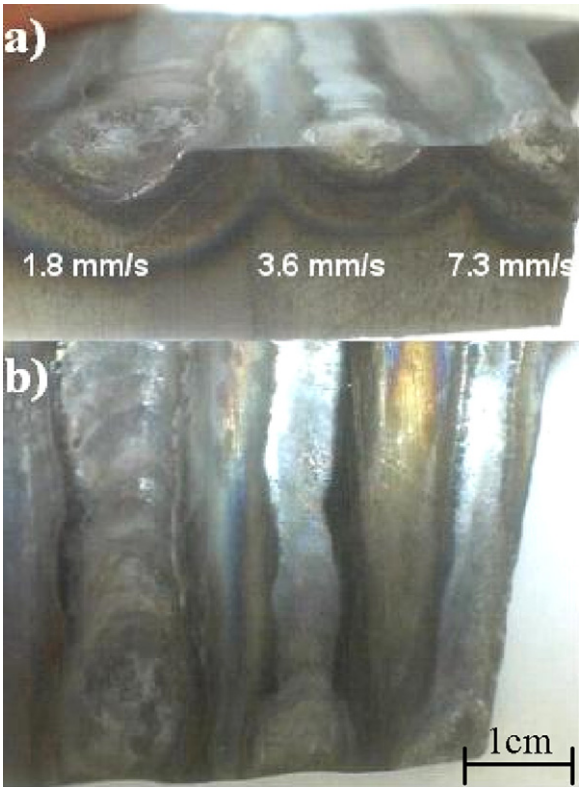

Fig. 1. The melted surfaces of GGG 40 using the TIG process at different electrode speeds. (a) Cross-section of the melted surface and (b) top view of the melted surface.

After the modification processes, each sample surface was cleaned and polished. They were plasma-nitrided and boronized under the conditions given in Tables 2 and 3, respectively. The nitrided and boride layers on modified surface were examined in order to test whether the layers occurred on the graphite areas or not.

Thus, for examination of the nitride and boride layers on the graphite areas the samples were sectioned, polished and etched with 2% Nital for 7 s and then examined by optical microscope and SEM. The cross-sectional microhardness distributions of the sample surfaces were conducted with a microvickers indentator under the load of 100 gf.

3. Results and discussion

The results showed that the chilling process applied during the casting process of GGG40 sufficiently did not eliminate the graphite phases from the surface. Instead, it led to ledeburite transformation of the iron matrix. The graphite phases were still available in the cross-sectional microstructure of the treated surface (Fig. 2). Fig. 3 also gives some evidence for this type of constitution, and hardness measurements of each morphological structure support that the constitution consisted of mixed phases such as martensite, pearlite, primer cementite and retained austenite as well as SEM observations. The average hardness values of the phases occurring in the chilled one can be seen in Table 4.

The penetration depth of the molten layer on the sample's surface is varied by changing the electrode traveling speed in the TIG melting process. For example, the penetration depth with an electrode traveling speed of 3.6 mm/s was almost 1.5 mm, but when

Table 2
The parameters of plasma nitriding applied to the test materials.

Evacuation pressure [mbar]	2×10^{-2}
Vacuum pressure [mbar] in progress	5
Process temp. [°C]	550 ± 5
Process gas	Cracked-NH_3
Gas flow rate [Nlt/min]	0.1
Time [h]	4
Pulse type	Asymmetric bipolar
Power [kW]	1.606
Voltage [V]	680
Pulse width [ns]	1616
Frequency [kHz]	50
Positive bias [V]	+37
Negative bias [V]	≈−680
Period [μs]	20
Current density [mA/cm^2]	3
Cooling media	Vacuum
Cooling rate [°C/min]	2

Table 3
Parameter of the boronizing process.

Boron bearing agent	Ekabor®
Protective gas	Argon
The gas flow rate	3 lt/min
Boronizing method	Paste-boronizing
Furnace	Electrical resistant
Boronizing time	3 h
Boronizing temperature	950 ± 5 °C