Study Anisotropy of a ductile iron class 80-60-03 hardening

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Abstract: This paper studies the effect of anisotropy in the propagation of surface cracks to identify areas of potential failure, and thus implement methods that increase the resistance of the phases created in the surface hardened cast iron ductile boride by the process. On the other hand assesses the influence of residual stresses using the fracture toughness microindentación by Palmqvist cracks regime taking the perpendicular and parallel cracks generated in the hard surface, with samples of 6 h and 8 h, 900 ° C treatment of boriding, with loads of 1.9 and 2.9 N. Where the value of \( k_c \) (a constant distance of 30 microns. Also the phases present were determined by X-ray diffraction (XRD) and scanning electron microscopy (EDS), finally adherence is determined by the indentation technique HRC.

1. Introduction
The anisotropy and residual stresses in mechanical components of nodular iron castings, originate from various causes such as forming processes, manufacturing and fabrication, welding, machining, casting, heat treatment, cooling and heating irregular, among others decrease the ability loading of the metal pieces [1-2]. Furthermore various investigations have been performed to estimate nondestructive anisotropy and the influence of residual stresses in surface-hardened materials, using the technique using the indentation induced fracture under the regime Palmqvist type, however the evaluation of the cracks parallel and perpendicular generated by microindentation method determines the hardened surface anisotropy in materials used in manufacturing [3-4]. At the same time, it is known that the fracture surface of the treated materials under varying loads of indentation produced cracks in different directions perpendicular and parallel to the surface of the material. Therefore the evaluation of anisotropy in surface hardened metal materials can be obtained by employing the technique Vickers, using the criterion of the fracture toughness (KC) [5-6]. So it is important to control or decrease in the concentrations of residual stresses, in order to study the influence of anisotropy on surface hardened nodular iron by a nondestructive technique and low cost.

2. Experimental
2.1. Surface Hardening Treatment.
Specimens were prepared of a ductile iron Class A 536 Class 80-60-03 With dimensions of 12.7 mm diameter by 50.0 mm long for the treatment of hardening of boride. The treatment was performed in a muffle without conventional inert atmosphere, with temperature 900 °C, with time 6 and 8h.
2.2. Fracture toughness
The study of anisotropy Fe₂B layer on the surface of cast iron class 536 80-60-03 A; was evaluated by employing the technique Vickers, using the criterion of the fracture toughness (Kₐ) [7]. Used models Palmqvist type system for this work, in table 1 presents the models used to evaluate Kc. In order to verify the presence of phase Fe₂B iron on the surface of hardened, an analysis was made of Energy Dispersing Spectroscopy (EDS).

Table 1. Models to evaluate Kc

| Models | References |
|--------|------------|
| \( K_c = 0.015 \left( \frac{g}{a} \right)^{1/2} \left( \frac{E}{H_v} \right)^{2/3} \) | [8] |
| \( K_c = 0.0264 \left( \frac{H_v}{a} \right)^{2/5} \) | [9] |

2.4. Study of Adhesion Layer
Evaluation of adhesion was performed with the technique Rockwell C. The results of the fractured layer is compared with the standard defined quality of adhesion, where HF 1 to HF 4 defines a sufficient adhesion, while the HF 6 and HF 5 show insufficient adhesion (HF is the abbreviation of the German force adherence).

3. Discussion and Results
In figure 1 shows micrographs of hardened nodular iron, revealing the layer Fe₂B and morphology, this shape type of the layer must be high content of alloying elements in this ductile iron.

**Figure 1.** Micrographs of ductile cast iron superficially hardened by the process of boriding to 900 ° C, with times to (a) 8h and (b) 6h.

Table 2 presents the results of fracture toughness for the two models used for this study. Factor values for the stress intensity iron boride Fe₂B to \( \frac{\pi}{2} \) radians and \( \theta \) obtained by the equation; K. Niihara and Laugier M.T.; With 6 and 8 hours of treatment at a distance from the surface of 30 microns.
Table 2. Values of fracture toughness perpendicular and parallel

| Temperature (°C) | Time (h) | Load (N) | K. Niihara (MPa m\(^{1/2}\)) | Laugier M.T. (MPa m\(^{1/2}\)) |
|------------------|----------|----------|-----------------------------|-------------------------------|
|                  |          |          | \(\pi/2\)                  | \(\pi/2\)                     |
| 900              | 6        | 1.9      | 3.70±1.12                   | 5.38±0.81                     |
|                  |          |          | 3.89±1.09                   | 4.19±1.07                     |
| 900              | 8        | 1.9      | 3.56±1.18                   | 4.31±0.90                     |
|                  |          |          | 3.39±1.21                   | 4.00±1.35                     |
| 900              | 6        | 2.9      | 3.87±1.23                   | 5.05±0.21                     |
|                  |          |          | 3.74±1.39                   | 4.19±1.07                     |
| 900              | 8        | 2.9      | 3.96±1.09                   | 4.31±0.90                     |
|                  |          |          | 3.79±2.02                   | 4.11±1.15                     |

Moreover the percentage of the anisotropy is obtained in Table 3. To verify the dependence of the anisotropy with resistance to cracking Fe\(_2\)B borided layer, it was necessary to set the value of stress intensity factor critical of the form \((KC) > (KC) > (KC) (\theta)\), being \(\pi/2\) and \(\theta\) the angle between the direction of crack propagation and the surface [11]. Depending on the shape coefficient of the grains of boride ductile cast iron, the degree of anisotropy of the resistance to cracking is determined through equation \(\frac{(k_c(\theta)) - k_c(0))}{k_c(0)} = 30 – 80\% [11-12].

Table 3. Evaluation percentage of Anisotropy.

| Temperature (°C) | TIME | Load (N) | Average values of K\(_C\) (MPa m\(^{1/2}\)) | Degree anisotropy (%) |
|------------------|------|----------|---------------------------------------------|----------------------|
|                  |      |          | \(\pi/2\)                  | \(\pi/2\) |                   |
| 900              | 6    | 1.9      | 4.68±1.05                   | 4.17±1.38            | 12.2  |
| 900              | 8    | 1.9      | 3.98±1.14                   | 3.88±1.17            | 2.5   |
| 900              | 6    | 2.9      | 4.56±0.82                   | 4.05±1.23            | 12.5  |
| 900              | 8    | 2.9      | 4.28±1.04                   | 4.05±1.38            | 5.6   |

EDS analysis obtained by SEM shown in figure 2. The results show that the alloying elements that are in phase with the formation Fe2B, carbon and silicon do not dissolve significantly during the phase and does not diffuse through the boride layer, being displaced to the diffusion zone, and forms together with boron, and solid solutions as silicoborides and boron cementite.

Figure 2. EDS spectrum of surface-hardened nodular iron
The technique is performed by the indentation test Rockwell-C [10]. The indentations generated by this technique compressive stress and tension in the impact surface resulting in cracking, peeling, adhesion and different morphologies which studying this ductile cast iron, figure 3 has a sufficient adhesion HF 3.

![Image](image.png)

**Figure 3.** (a, b) Rockwell C indentations, evaluation of the adhesion of surface-hardened of cast iron ductile.

4. Conclusions
The values presented in the fracture toughness are slightly larger in the direction perpendicular to the surface where the cracking occurs at the vertices of the indentation. This indicates that at a constant distance indentation, there is no influence of residual stresses in the crack resistance behavior, remaining $K_c$ invariant in relation to residual stress. Furthermore, the degree of anisotropy remains below 30%. It is therefore important to the estimated residual stress experimentally along the layer thickness borurada to determine quantitatively the influence of the efforts in the crack growth of the total Fe$_2$B phase. Besides the characteristics of the formation of cracks obtained are presented by the anisotropy of the layer formed on the surface, likewise is a reflection of its non-uniform composition, and the crystallographic and morphological anisotropy. Furthermore, the anisotropy and fracture toughness may be related residual stresses.

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