EVALUATION OF FRACTURE TOUGHNESS OF BORIDE LAYERS ON HIGH CHROMIUM STEELS

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https://doi.org/10.37904/metal.2024.4890

Abstract

The boronizing is a thermochemical process in which the boron atoms are introduced into the steel surfaces. This study evaluates the fracture toughness of boride layers developed by powder boronizing of high-chromium steels Sleipner, K 190, Royalloy, Sverker 21 and Sverker 3. The process was carried out at 1323 K, for 10 h, and in solid Durborid powder mixture. First of all, the microscopic and EDS analysis to investigate a chemical composition of boride layers were realized. Subsequently, the Vickers microhardness tester was used to generate the microcracks in borides. The load of 2 N was used for indentation. The microhardness of Fe_2B phase ranged between 1551 HV0.2 and 1726 HV0.2. For the FeB phase, the microhardness ranged between 1974 HV0.2 and 2277 HV0.2. For quantification of the fracture toughness, the Palmqvist method was used, when the values of length of the microcracks that appeared in the corners of the indentations were analyzed. The fracture toughness of the FeB phase was lower compared to the Fe_2B phase. The fracture toughness ranged between 1.98 $MPa \cdot m^{1/2}$ and 2.58 $MPa \cdot m^{1/2}$ for the FeB phase and between 3.87 $MPa \cdot m^{1/2}$ and 4.50 $MPa \cdot m^{1/2}$ for the Fe_2B phase. It was found that the chemical composition of the steel does not have a significant effect on the values of the fracture toughness.

Keywords: Boronizing, boride layers, steel, microhardness, fracture toughness

1. INTRODUCTION

For ferrous alloys, the boronizing process is usually carried out in the temperature range of 800 – 1050 °C, and for 0.5 – 10 h. Using this process, it is possible to improve some properties of steels, such as their surface hardness, corrosion resistance, wear resistance etc. [1, 2]. Boronizing can be realized in gaseous medium [3], in solid medium (powder, paste) [2, 4, 5], in plasma [4, 6] or by electrolysis [7]. During the boronizing process, the boride layers composed of FeB and Fe_2B phases are formed [1]. The Fe_2B phase with a content of 8.83 wt.% B is formed first. The FeB phase with a content of 16.63 wt.% B is formed second in line. In case of high alloy steels, the borides of alloying elements can be present in boride layers [1]. The microhardness of Fe_2B phase is usually ranged between 1500 – 1800 HV [4, 5]. In case of FeB phase, the microhardness is usually ranged between 1800 – 2200 HV [4, 5]. The fracture toughness of a material is important property for its use in mechanical applications. It is a resistance of material to the propagation of cracks under an applied stress [8]. This experiment was realized to investigate the influence of chemical composition of boride layers on their fracture toughness.

2. MATERIAL AND EXPERIMENTAL TECHNIQUES

The experimental materials were high-chromium tool steels K 190, Royalloy, Sverker 21, Sleipner and Sverker 3. These steels have different nominal carbon and chromium contents, and contain also small additions of elements like Mo, V, Si, Mn or W. Nominal chemical compositions of these materials (in wt.%) are in **Table 1**. The steels were powder-pack boronized at temperature 1323 K, for 10 h, in a hermetically sealed container, by using a Durborid powder mixture. A schematic of the sample preparation is in (**Figure 1**). After the boronizing process, the specimens were slowly cooled to a room temperature. The scheme of microstructure of boride layers is shown in (**Figure 2**) [9]. First of all, the boride layers were microscopically analyzed using the Scanning electron microscope and EDS point analysis. The aim of this analysis was to investigate the amount of alloying elements in boride layers. Subsequently, the microhardness of boride layers was analyzed, using a Vickers diamond indenter. The microhardness of boride layers was measured using a microhardness tester with load 2N, on five randomly distributed sites of FeB and Fe_2B. During the microhardness analysis, the microcracks in the corners of indentations were formed. The indentation with the microcracks is shown in (**Figure 3**). The fracture toughness was estimated using the Palmqvist method, when the length of microcracks was analysed by a scanning electron microscope (SEM) Jeol JSM-7600F, using a secondary electrons by an acceleration voltage 15 kV. The fracture toughness was calculated using the equation 1, where the HV is Vickers microhardness, P is load [N] and T is average length of microcracks [10]:

$$K_{IC} = 0{,}0028 \cdot \sqrt{HV} \cdot \sqrt{\frac{P}{T}} \tag{1}$$

Table 1 The chemical composition of analysed steels [wt.%]

Steel/chemical element	C	Mn	Cr	Mo	V	Si	W
K 190	2.30	0.30	12.50	1.10	4.00	0.60	-
Royalloy	0.05	1.20	12.60	-	-	0.40	-
Sverker 21	1.55	0.40	11.80	0.80	0.80	0.30	-
Sleipner	0.90	0.50	7.80	2.50	0.50	0.90	-
Sverker 3	2.05	-	12.70	-	-	0.30	1.10

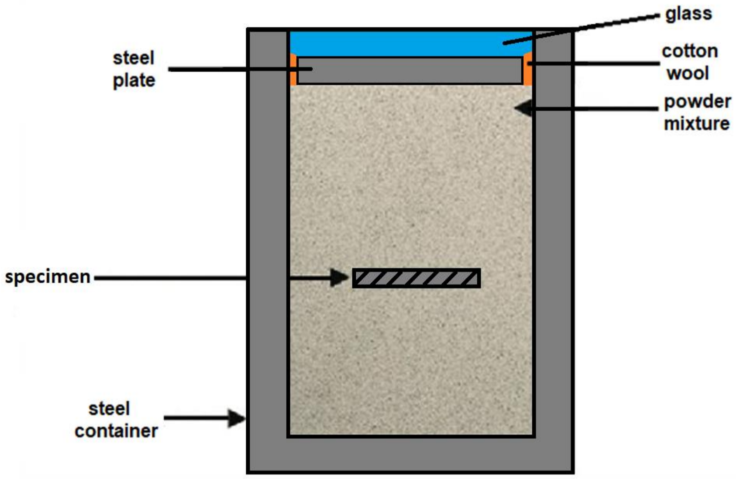

Figure 1 The scheme of Durborid powder mixture boronizing [5]

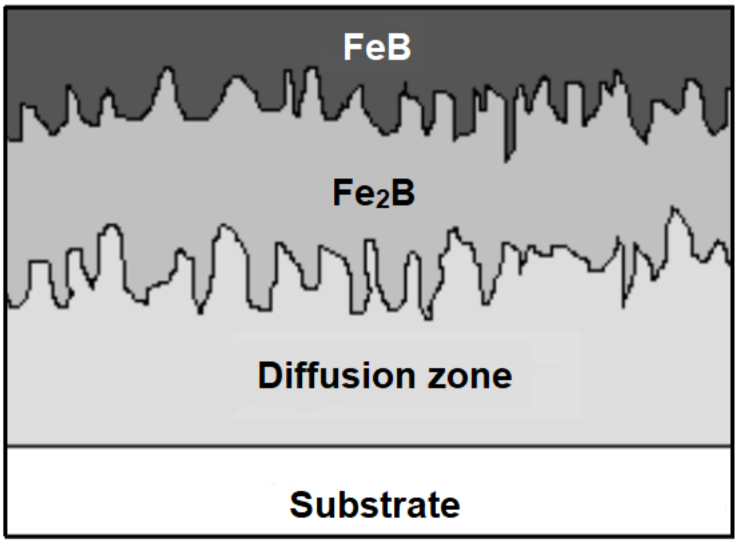

Figure 2 The scheme of microstructure of boride layers [9]

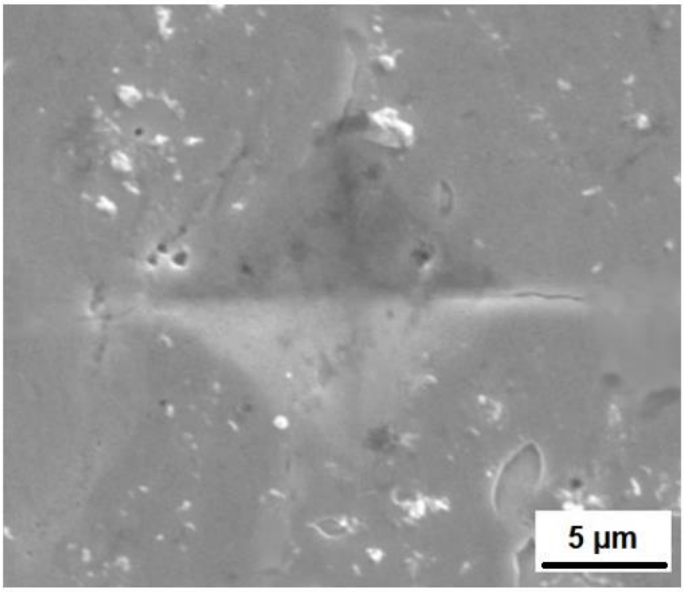

Figure 3 The indentation with the microcracks

3. EXPERIMENTAL RESULTS AND DISCUSSION

First of all, the boride layers were microscopically analysed. The microstructure of boride layer in case of Royalloy steel is shown in (**Figure 4**). Subsequently, the EDS analysis to quantification of chemical composition of boride layers was used. The chemical composition of boride layers is shown in **Table 2**. The microhardness of Fe_2B phase ranged between 1581 ± 27 HV0.2 (Sverker 21 steel) and 1626 ± 83 HV0.2 (K 190 steel). For the FeB phase, the microhardness ranged between 1885 ± 78 HV0.2 (Royalloy steel) and 2150 ± 105 HV0.2 (Sverker 21 steel) (**Figure 5**). As we can see, there is no strong dependence between chemical composition of boride layers and its microhardness. The fracture toughness of the FeB phase was lower than that of Fe_2B for all analyzed steels, (**Figure 6**). The fracture toughness of FeB phase ranged between 1.79 ± 0.11 MPa·m$^{1/2}$ (Sverker 21 steel) and 2.01 ± 0.17 MPa·m$^{1/2}$ (Royalloy steel). For the Fe_2B phase, the fracture toughness ranged between 4.05 ± 0.18 MPa·m$^{1/2}$ (K 190 steel) and 4.35 ± 0.20 MPa·m$^{1/2}$ (Sverker 21 steel). By comparing the mean values of the fracture toughness of the boride layers for particular steels certain, but insignificant differences can be seen. It follows from the realized experiments that the chemical composition of the boride layers does not have a significant effect on the values of the fracture toughness, except the boron content. Similar method for fracture toughness determination of borides was used in many publications. One of typical trials was an experiment that realized by Campos-Silva et al [11]. They analysed the fracture toughness of the Fe_2B boride layer on the surface of AISI 1045 steel, with the chemical composition (in mass%) 0.50% C, 0.9% Mn, 0.04% P, 0.05% S. The estimated value of the fracture toughness of the Fe_2B phase was around 4.1 ± 0.6 MPa·m$^{1/2}$. Similar results were achieved by Erdogan too, during boronizing the H13 steel (0.42% C, 5.04% Cr, 1.33% Mo, 1.06% V, and 0.88% Si, all in mass%) [12]. The fracture toughness of the FeB phase was in the range of 1.32 – 1.38 MPa·m$^{1/2}$ and the fracture toughness of Fe_2B phase was in the range of 5.01 – 5.23 MPa·m$^{1/2}$ [12]. When we compare the achieved results with the results achieved by boriding steel with a similar chemical composition, we find that the current results are in agreement with the another literature data.

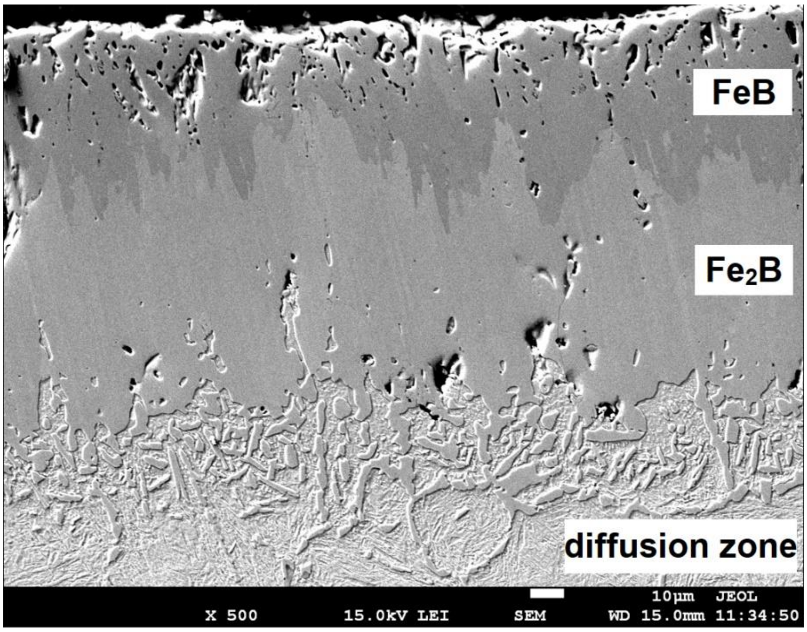

Figure 4 The microstructure of boride layers, Royalloy steel

Table 2 The chemical composition of boride layers on the surfaces of analysed steels [wt.%]

	Mn		Cr		V	
Steel	**FeB**	**Fe_2B**	**FeB**	**Fe_2B**	**FeB**	**Fe_2B**
K 190	0.12	0.13	10.64	14.33	2.29	3.39
Royalloy	0.89	1.02	10.33	11.25	-	-
Sverker 21	0.13	0.11	9.78	10.52	0.32	0.65
Sleipner	0.17	0.15	8.79	9.57	0.22	0.53
Sverker 3	-	-	11.15	11.78	-	-

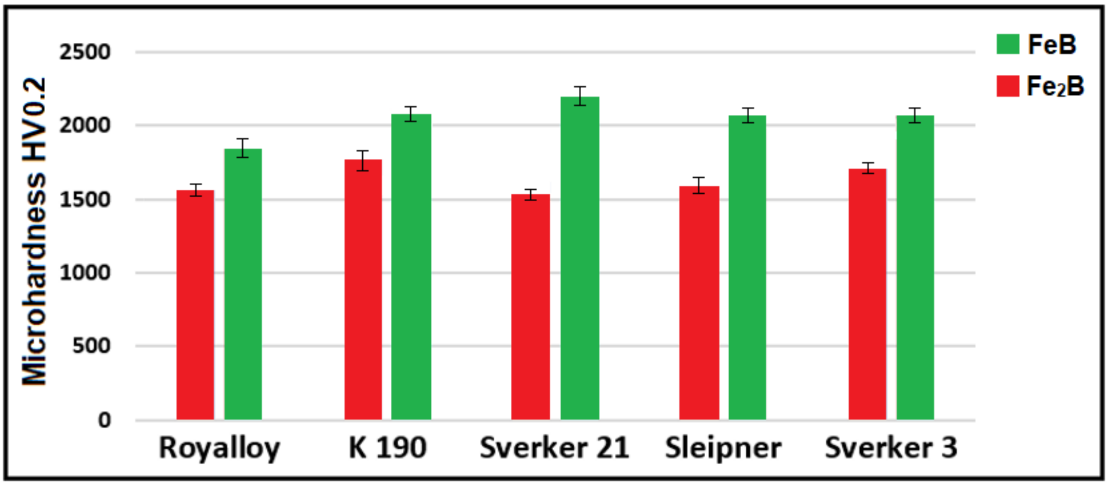

Figure 5 Microhardness of boride layers in case of analyzed steels

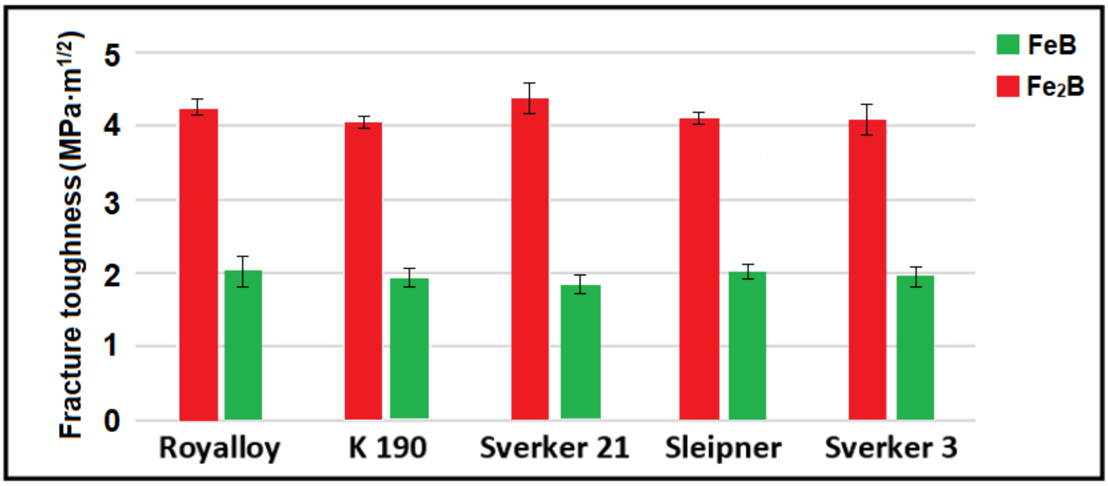

Figure 6 The average values of fracture toughness of analyzed steels

4. CONCLUSIONS

In this paper, the fracture toughness of boride layers in case of K190, Royalloy, Sverker 21, Sleipner and Sverker 3 steels was analyzed. The following conclusions can be derived from the obtained results:

- The samples were boronized in Durborid powder mixture at 1323K for 10h
- The microhardness of the Fe_2B phase was ranged between 1581 ± 27 HV0.2 and 1626 ± 83 HV0.2
- For the FeB phase, the microhardness was ranged between 1885 ± 78 HV0.2 and 2150 ± 105 HV0.2
- To quantificate the fracture toughness of boride layers the Palmqvist method was used
- The fracture toughness of FeB phase was ranged between 1.79 ± 0.11 $MPa·m^{1/2}$ and 2.01 ± 0.17 $MPa·m^{1/2}$
- For Fe_2B phase, the fracture toughness was ranged between 4.05 ± 0.18 $MPa·m^{1/2}$ and 4.35 ± 0.20 $MPa·m^{1/2}$

- The chemical composition of boride layers did not have a significant effect on the values of the fracture toughness. It seems that the only important factor influencing the fracture toughness of borides is their crystallography and boron content.

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