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INFLUENCE OF THE BORON PHASES ON THE MATERIALS DUCTILITY

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Results of the boride surface layers investigation, obtained by the torsion and bending methods, point to the better ductility of the mono-phase Fe_2B boride layers then the binary-phase FeB + Fe_2B boride layers. This is especially outstanding in the case of peaces that are under higher thermal and mechanical load, where the binary-phase layer because of higher local stresses has higher tendency to fall of, respectively to shell.

Key words: *boronizing, ductility, boride phases*

Utjecaj boridnih faza na duktilnost materijala. Istraživanje duktilnosti boridnih slojeva pomoću metode torzije i savijanja ukazuje da jednofazni boridni slojevi Fe_2B u odnosu na dvofazne boridne slojeve FeB + Fe_2B imaju bolju duktilnost. To naročito dolazi do izražaja kod proizvoda koji su toplinski i mehanički više napregnuti, gdje su veći specifični pritisci, tada je dvofazni boridni sloj sklon bržem otpadanju, odnosno ljuštenju.

Ključne riječi: *boriranje, duktilnost, boridne faze*

INTRODUCTION

Boronizing is a thermochemical process in which the chemical element boron diffuses in the surface layer of steel substrates. In the surface layer of steel substrate, boron forms with the iron Fe_2B, as resirable compound, and FeB as undesirable compound. Boride layers have extraordinary high hardness. FeB is a little bit harder (1800 - 2100 HV0.1) than Fe_2B (1400 - 1600 HV0.1), but much brittle, so its forming have to avoid in the practice.

During boronizing of the forging matrixes, drawing tools and shaping tools it is needed, among other, to determine the toughness of the boronized material. Toughness examination of boronized specimen, performed till now using classical specimens, did not give expected results because the whole specimen has been examined. The obtained results could not represent ductility of the boride layers because the boride layer influence was too small due to the it's small cross section compared to the cross section of the whole specimen [1-4].

The aim of the conducted investigation was to determine the ductility of the boron phases using methods in which the influence of the core on the boride layers will lower (lower result scatterings). For the ductility determination of the boride layers two independent methods were chosen:

- boride layers ductility determination by the torsion method,
- boride layers ductility determination by the bending method.

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INVESTIGATION

Boride layers ductility determination by the torsion method

The first method used was detection of the cracks appearance of the boride layer during torsion cylindrical specimen. Specimens were made from C 15 and 20 CrMo 5 (Č1220 and Č4721), designated in accordance with data in Table 1., and boronized with the appropriate regimes and in

Table 1. **Specimen identification numbers**
Tablica 1. **Označivanje epruveta**

Steel: C 15 (Č1220)		Steel: 20 CrMo 5 (Č4721)	
Boron phases		Boron phases	
FeB + Fe_2B	Fe_2B	FeB + Fe_2B	Fe_2B
Specimen identification numbers		Specimen identification numbers	
0.1	1.1	2.1	3.1
0.2	1.2	2.2	3.2
0.3	1.3	2.3	3.3
0.4	1.4	2.4	3.4
0.5	1.5	2.5	3.5
0.6	1.6	2.6	3.6

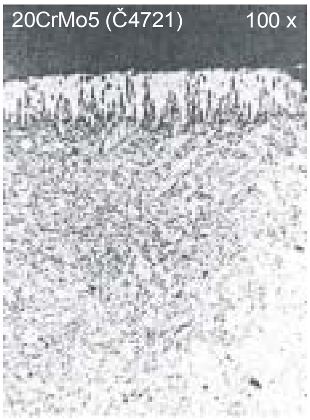

Figure 1. **Boride layer photomicrograph**
Slika 1. **Mikrosnimak boridnog sloja**

the conditions which in one way led to forming of the binary phase FeB + Fe_2B boride layer, and in the other way to forming mono phase boride layer Fe_2B.

Boronizing was performed in solid mediums. First boronizing regime and conditions, which resulted in mono phase boride layer Fe_2B formation, include: boronizing agent with low activity (SiC, B_4C, KBF_4) using lower boronizing temperature T_B = 850 °C and boronizing time t_B = 4 hours.

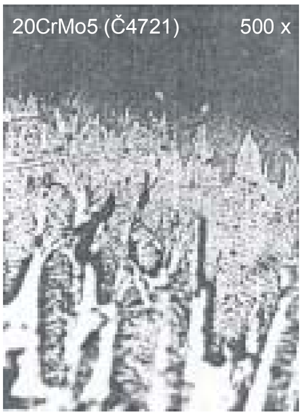

Figure 2. **Boride layer photomicrograph**
Slika 2. **Mikrosnimak boridnog sloja**

Second borinizing regime and conditions, in which the binary phase boride layer FeB + Fe_2B is formed, include boronizing agent with increas-ed activity ($Na_2B_4O_7$, B_4C, KBF_4) using higher boronizing temperature T_B = 950 °C and lower boronizing time t_B = 2 hours.

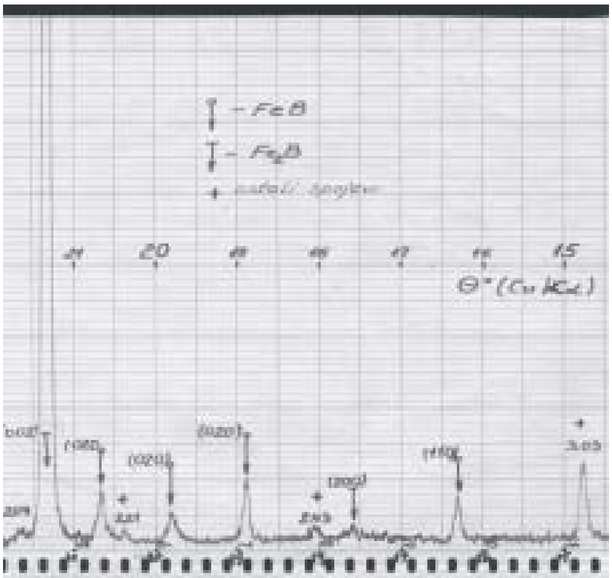

Figure 3. **Part of the specimen 2.1 diffraction pattern, diffraction angle Θ ° (Cu/Kα) = 15 ° to 40 °**
Slika 3. **Dio difraktograma uzorka br. 2.1, Θ ° (Cu/Kα) = 15 ° do 40 °**

Besides classical metallographic technique (Figure 1. and Figure 2.), the examination of the formed boride layers were performed by the scanning electron microscopy - microsonde (Figure 3. and Figure 4.).

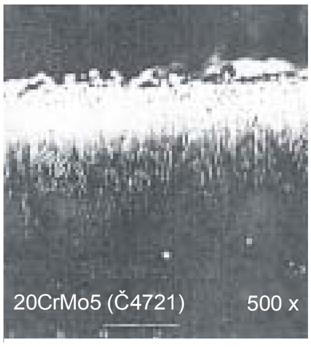

Figure 4. **Boride layer photomicrograph on SEM**
Slika 4. **Slika boridnog sloja na scanning mikroskopu**

For the boride layer type determination, surface layer of the specimens were also examined by the X-ray diffraction method.

Figure 3. shows the X-ray diffraction pattern of the specimen No. 2. 1. Surface layer, formed on the specimen, has structure and parameters of FeB (↨) and Fe_2B (↧) boride compounds, so as some of Fe_3 (B, C) and Fe_{23} (B, C)$_6$ carbide type compounds.

Specimen used for torsion method ductility examination is shown in Figure 5..

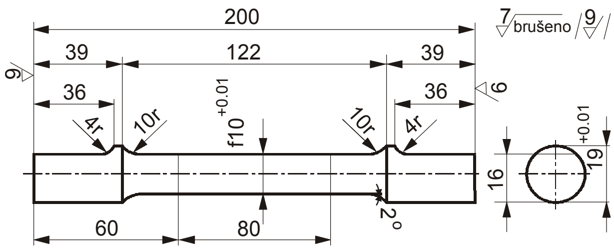

Figure 5. **Specimen for torsion method ductility examination**
Slika 5. **Epruveta za ispitivanje duktilnosti boridnog sloja torzijom**

Ductility examination by torsion method was done with testing machine and additional equipment shown in Figure 6. [5, 6].

Figure 6. **Ductility examination by torsion method**
Slika 6. **Oprema za ispitivanje duktilnosti pomoću torzije**

Table 2. **Results of the ductility examination by torsion for steel C 15**
Tablica 2. **Rezultati ispitivanja duktilnosti torzijom za čelik C 15**

Steel: C 15 (Č1220)			
$FeB + Fe_2B$		Fe_2B	
Specimen No.	Torsion angle α	Specimen No.	Torsion angle α
0.1	25	1.1	33
0.2	20	1.2	32
0.3	24	1.3	34
0.4	22	1.4	35
0.5	22	1.5	32
0.6	23	1.6	30
Mean value:	x_1 = 23.67 °	Mean value:	x_2 = 32.67 °

Results of the ductility examination by torsion method are shown in Table 2. and Table 3., as in Figure 7..

Table 3. **Results of the ductility examination by torsion for steel 20 CrMo 5**
Tablica 3. **Rezultati ispitivanja duktilnosti torzijom za čelik 20 CrMo 5**

Steel: C 15 (Č1220)			
$FeB + Fe_2B$		Fe_2B	
Specimen No.	Torsion angle α	Specimen No.	Torsion angle α
2.1	33	3.1	34
2.2	27	3.2	35
2.3	29	3.3	34
2.4	29	3.4	36
2.5	28	3.5	35
2.6	29	3.6	33
Mean value:	x_1 = 29.17 °	Mean value:	x_2 = 34.50 °

From results of the ductility examination by torsion method can bee concluded that the torsion angle of both specimen, one made from carbon steel C 15 (Č1220) and the other from alloyed steel 20 CrMo 5 (Č4721), in case of mono phase boride layer Fe_2B is higher than in case of binary phase boride layer $FeB+Fe_2B$. It can be seen from the mean value of torsion angle x_1=22.67° and y_1=29.17° for binary phase boride layers, so as x_2=32.67° and y_2=34.5° for mono phase boride layers.

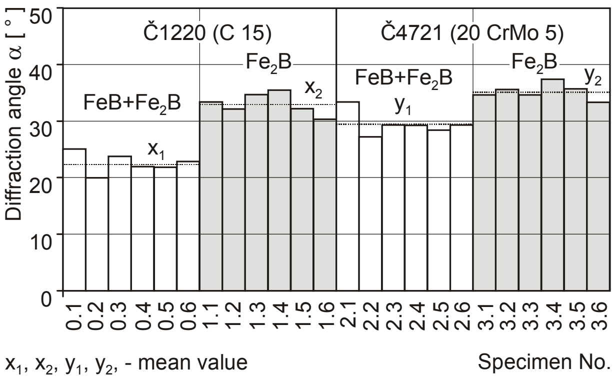

Figure 7. **Results of the ductility examination by torsion method**
Slika 7. **Rezultati ispitivanja duktilnosti slojeva torzijom**

Table 4. **Specimen pieces designation and boronizing regime**
Tablica 4. **Odlučivanje i režimi boriranja epruveta**

No.	Boride phase	Specimen No.	Heat treatment
1	Fe_2B	4.0	Boronizing method I (SiC, B_4C, KBF_4) T_B = 850 °C t_B = 4 hours
2		4.1	
3		4.2	
4		4.3	
5		4.4	
6		4.5	
7		4.6	
8		4.7	
9		4.8	
10		4.9	
11	$FeB + Fe_2B$	5.0	Boronizing method II ($Na_2B_4O_7$ + B_4C + KBF_4) T_B = 950 °C t_B = 2 hours
12		5.1	
13		5.2	
14		5.3	
15		5.4	
16		5.5	
17		5.6	
18		5.7	
19		5.8	
20		5.9	

Boride
layers ductility determination by the bending method

The second method used for ductility determination is bending deformation of the tin flat specimen (0.85x 10x100 mm), previously boronised in suitable mediums, described before.

Specimen pieces designation was done in accordance with Table 4..

The results boride layers ductility examination by the bending are given in Figure 8. and Figure 9..

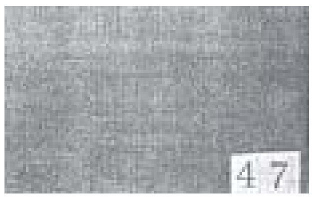

Figure 8. **Typical Fe_2B boride layer cracks after examination performed using bending method**
Slika 8. **Tipične pukotine boridnog sloja Fe_2B nakon ispitivanja savijanjem**

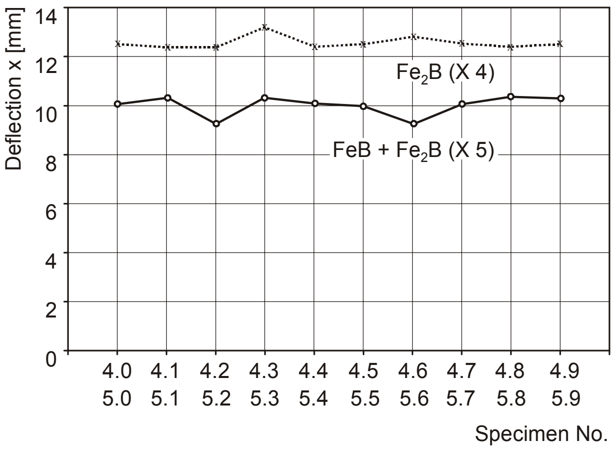

Figure 9. **Results boride layers ductility examination by bending**
Slika 9. **Rezultati ispitivanja duktilnosti slojeva savijanjem**

CONCLUSIONS

Values obtained by measuring the deflection x_4 and x_5 (Figure 9.) show that method of boride phase ductility determination by bending (so as previous method) gives better results in the case group of specimen (x_4) with mono phase boride layer Fe_2B comparing to the group of specimen (x_5) with binary phase boride layer Fe_2B+FeB.

The most probable cause of better mechanical properties, ductility as wearing resistance, mono phase comparing to binary phase boride layers (even though the hardness is higher by binary phase FeB+Fe_2B boride layers) is different thermal expansion coefficients.

During work pieces (specimens) treatment cooling forms compression stresses are in the Fe_2B layer and tension stresses in FeB layer. The stresses with different sign can produce micro cracks in boride phase vertical to the layers as between two layers.

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