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# Boronizing for Electro-Metallurgical Tungsten Carbide/Steel Composite†

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The paper studies the electro-slag melting and casting tungsten carbide/steel composites, first the sample is quenched and tempered, then boronizing treatment is performed by solid powder method and microstructure and mechanical property of boronizing samples by different temperature are compared. The results show that, by XRD the composition of samples are founded, including FeB, $Fe_2B_2$, CoB and $Ni_3B$. It is found that properties of sample are the best at 950 ºC for 7 h boronizing. After boronizing treatment, Vickers hardness at surface of samples is 50 % higher than samples which quenched and tempered only and 100 % higher than original samples.

**Keywords: Boronizing, Tungsten carbide/steel composite, Hardness, Bending strength.**

## INTRODUCTION

Boronizing is a new heat treatment process developed in recent years, during which boron is penetrated into the surface of the material and form boride. By boronizing method, many transition metal represented by steel materials may obtain metal and nonmetal surface modification. Components that treated by boronizing have a high hardness, wear resistance and good corrosion, which greatly extend its service life[1]. Based on DGJW20, influence of boronizing process on organization and mechanical properties of materials' surface is studied, which provide fundamental research for reducing roller cracking wear and extending mill service life.

## EXPERIMENTAL

### Test materials and methods

**Test materials:** The steel substrate materials is GCr15 bearing steels, the steel bonded carbide DGJW20 is prepared by electro-slag melting and casting and this technology has three main steps *e.g.*, (i) the preparation of consumable electrode; (ii) the melting of the consumable electrode and (iii) rapid cooling crystallization[2,3].

Solid powder boronizing method is used which has low cost and easy technology: boronizing ingredient are boron supplying agent $B_4C$, active agent $KBF_4$, filling agent SiC and charcoal dust, mass ratio is 1:1:17:1.

**Technical process:** DGJW20 is incised and polished as the original sample and its size is 6 mm × 6 mm × 35 mm. The sample are pretreated, heat preservation for 20 min at 980 ºC and quenching, then heat preservation for 2 h at 200 ºC, as shown in Fig. 1. Then the sample be stand-by after removing the oxide layer by polishing.

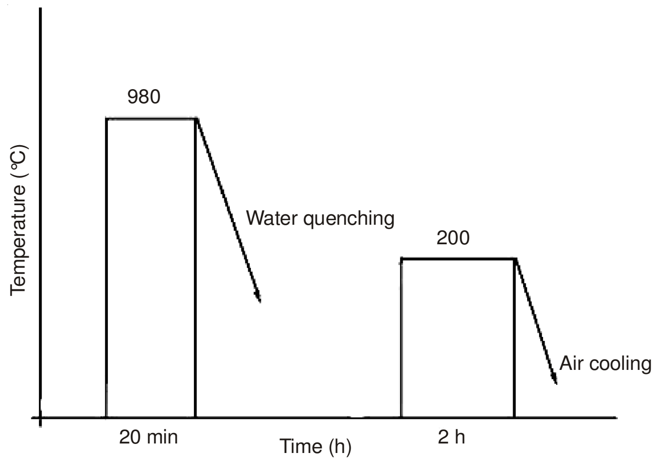


Fig. 1. Quenching and tempering process curve of DGJW20

According to the previous formula, first put boriding medium at the bottom of ceramic crucible, then put the sample into crucible, around which is filled with boriding medium

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and then seal up with refractory cement. Boronizing heating equipment is $SX_2$-2.5-12 electric furnace. The highest temperature are 920, 950, 965 and 980 ºC, heat preservation for 7 h. The study[4] shows that the longer heating time is, the thicker diffusion layer is, the better performance is. The sample is cooling in furnace after boronizing, then removing the boronizing medium on the sample surface.

## RESULTS AND DISCUSSION

### Test results and analysis

**Original sample and heat treatment sample:** Hardness is an important mechanical properties of metal material, which has the ability to resist deformation. Vickers hardness of the original sample and heat treatment sample show as follow, loading force is 98N, loading time is 35 s (Table-1).

After sample's quenched, tiny carbides disperse on the substrate, so hardness of the heat treatment sample is improved. High carbon high alloy martensite is obtained and hardness is improved again[5].

TABLE-1
VICKERS HARDNESS OF THE ORIGINAL SAMPLE AND HEAT TREATMENT SAMPLE (HV10/35)

| Sample | 1# | 2# | 3# | Average value |
|---|---|---|---|---|
| Original sample | 503 | 493 | 503 | 500 |
| Heat treatment sample | 803 | 762 | 762 | 776 |

Put the sample on the universal material testing machine after it is grinded and measures the bending strength by three point bend method. The results are showed in Table-2.

TABLE-2
BENDING STRENGTH OF THE ORIGINAL SAMPLE AND HEAT TREATMENT SAMPLE (MPa)

| Sample | 1# | 2# | 3# | Average value |
|---|---|---|---|---|
| Original sample | 733 | 812 | 658 | 734 |
| Heat treatment sample | 634 | 678 | 680 | 664 |

After sample is heat treated, its bending strength decreases and hardness increases, which is in accordance with the change rule of the heat treatment. After fine grinding and polishing, forms of organization under the metallurgical microscope are shown in Figs. 2 and 3.

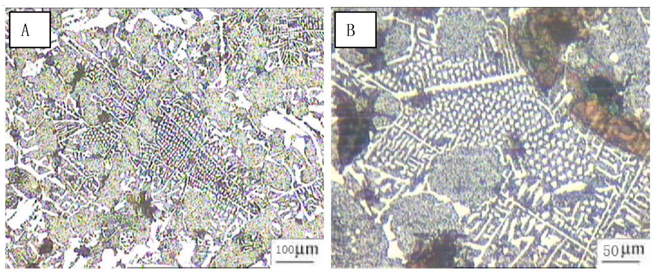


Fig. 2. Original structure of DGJW20

Based on the Fe-W-C ternary alloy phase diagram and the reaction in the electro-slag melting and casting, combining the Figs. 2 and 3, it can draw the following conclusions:

DGJW20 consists of three parts: the matrix phase, undissolved tungsten carbide and eutectic ledeburite; while carbide

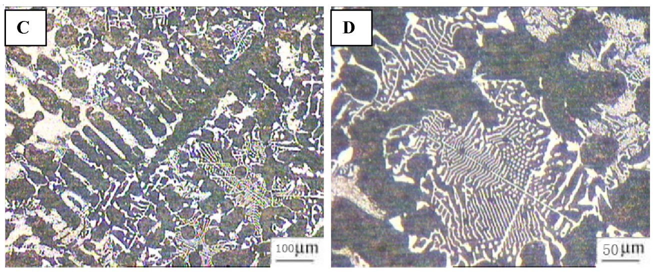


Fig. 3. Quenching tempering organization of DGJW20

of DGJW20 contains four patterns: fishbone-like carbide, dendritic carbide, conglomerate carbide and particle carbide[5].

**Boronizing sample:** When surface boronizing agent is cleaned up, Vickers hardness and bending strength are measured. Every group has three samples, based on test results of the original sample, quenching and tempering sample, vickers hardness data are transformed into graph (Fig. 4) as follows:

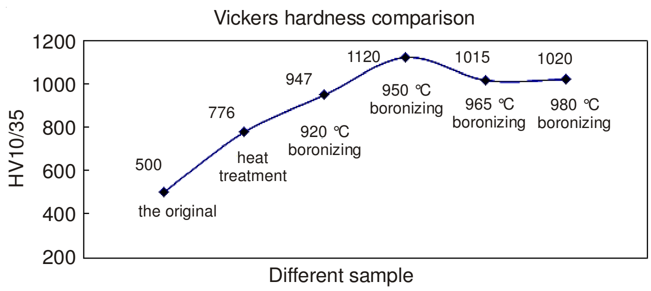


Fig. 4. Vickers hardness curve

Bending strength change curve is shown in Fig. 5. From the Fig. 5, after a series of processing, sample surface hardness reach maximum when boriding at 950 ºC and bending strength is improved compared with quenching tempering sample. Bending strength varies from 660-740 MPa, which indicates that DGJW20 has excellent resistance to high temperature. When sample is quenching at 980 ºC and tempering at 200 ºC, its hardness increases and toughness drops, which fit with bending strength changing rule of steel when it is annealed.

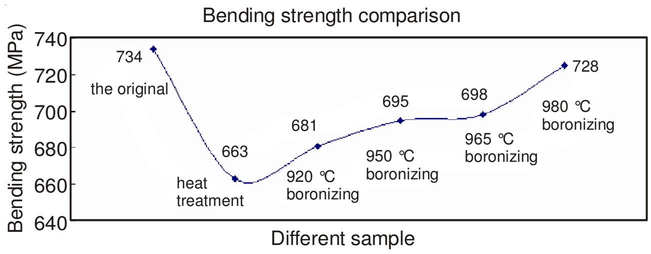


Fig. 5. Bending strength curve

Original phase of DJGW20 is shown as Fig. 6, which include $Fe_3W_3C$, $W_2C$, WC, austenite Fe, α-Fe, $Fe_3C$. Based on Fig. 2, matrix phase is black pearlite, eutectic ledeburite is composed of austenite and $Fe_3W_3C$. Undissolved tungsten carbide is white part.

In general, the main peak skewing to the high angle, cell shrinkage, spacing decreases. After boronizing, sample's main peak height drops and width decreases, which indicate that grains are gathering and growing up and lattice density is decreasing. Considering that abandoned bearing steel is used

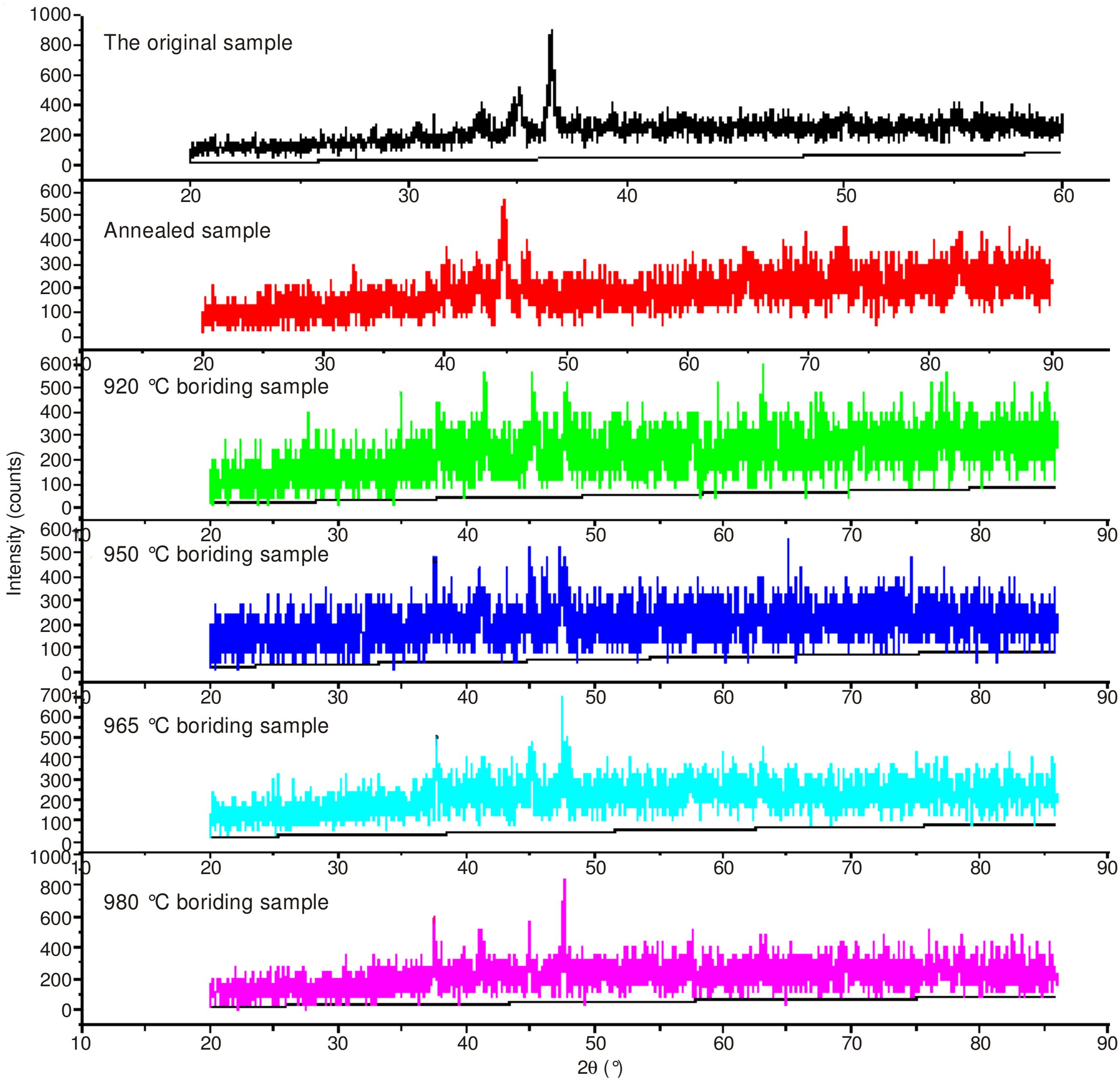


Fig. 6. XRD diagrams of original, heat treatment and boronizing sample

as basis material, so impurities are so much. By XRD analysis, surface layer's elements are FeB, $Fe_2B$, CoB, $Ni_3B$, $Na_3BO_3$, $Cr_3B_4$, $B_{13}C_2$, $V_2B_3$, $LiBO_2$ and $Mo_2B$, *etc*.

## Conclusion

When sample is quenching at 980 ºC and tempering at 200 ºC, DGJW20's hardness increases for 20 %, but bending capacity declines. WC particle sizes distribute more uniform with metalloscope. Boronizing layer is obtained on the surface of sample. By XRD analysis, the ingredients are FeB, $Fe_2B$, CoB and $Ni_3B$ *etc*. Test result shows that boronizing effect is the best at 950 ºC and heat preservation for 7 h. After boronizing treatment, Vickers hardness at surface of the sample is 50 % higher than sample's quenched and tempered only and 100 % higher than original sample. After boronizing treatment, compared with improvement of surface hardness, matrix hardness decreases 10 % after heat treatment. After boronizing, quenching can avoid too much difference between matrix and surface hardness.

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