RESEARCH AND DEVELOPMENT OF HRB400 HOT – ROLLED RIBBED BAR

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Abstract: The paper presents the experimental result of Chengdu Steel’s HRB400 hot – rolled ribbed bar with FeTi, FeV and VN micro – alloying. The effect of Ti, V and VN to the property of rebar and the reason of causing bending cracks are studied. The production cost of using FeV micro – alloying and VN micro – alloying is compared.

Key Words: HRB400 ribbed bar; FeTi; FeV; VN; micro – alloying; bending cracks; cost

1 Introduction

Hot – rolled HRB400 ribbed bar features with high – strength, stable property, good weldability, good aseismatic property, and saving of steel products etc. In the national standards of developed industrial countries for construction steel, Grade II ribbed bar has been eliminated, with inclusions Grade III ribbed bars of more than 400 MPa only. In China, Grade II ribbed bars are now mainly used for construction steel. In order to change this situation as quickly as possible, China is making great efforts to promote the use of HRB400 MPa ribbed bar, so as to realize the upgrading of construction reinforced bars very soon. From midterm of the 1990s, Chengdu Steel has started to produce 400MPa rebars (British standard 460MPa), and from 1999, production was made according to GB1499 – 1998. From 1999 to 2002, 65,000 tons (15,000 tons in 2001; 32,000 tons in 2002) of HRB400 rebars have been produced and sold. Micro – alloying with FeV, FeTi and VN are used respectively. This paper will analyse the effect of different micro – alloying methods to the property of rebars and economic benefits as well as problems occurred during production.

2 Research and Production

2.1 Test of HRB400 20MnTi ribbed bar

From October to November, 1998, 11 heats and 4 heats of tests were done on 10 t electric furnace and 15 t BOF respectively, with FeTi micro – alloying in the furnace or in the ladle, N was blown after tapping and then cast into 266 mm x 266 mm killed ingots. Heat insulating plate, casting powder and heat conservation agent were used for casting protection. The ingots were copped into 75 mm and 90 mm billets by 650 copping mill, then rolled into three sizes of Ø16 mm, Ø25 mm, Ø32 mm, and the mechanical property were checked with new standard.

The range of designed composition and actual fluctuation value of 20MnTi steel is shown in Table 1. The effect of Ti content to strength and ductility is shown in Fig. 1.

2.1.1 Recovery rate of Ti

FeTi is relatively light and is floated on the slag surface, so it is easier to get burning loss in electric
2.1.2 Metallographic structure

It was normal structure F + P. Along with the increase of Ti content, particle martensite of third phase appears and its amount also increased. Longitudinal strip structure was very obvious.

2.1.3 Chemical composition

The fluctuation of main elements, C, Si, Mn, was not large. The fluctuation of C equivalent was 0.42% - 0.51%, satisfying the requirements of new standard and test [10].

2.1.4 Mechanical property

In some heats, the yield strength $\sigma_s$, tensile strength $\sigma_b$, and elongation $\delta_5$ did not meet the requirements of GB1499 - 1988 standard.

2.2 Production of HRB400 20MnSiV rebar with FeV micro-alloying

In 1999, HRB400 rebars were produced according to GB1499 - 1998 with 30 t BOF. The hot metal, with 50% FeV micro-alloying and N-blow from bottom, then cast into 120 mm x 120 mm billets by continuous caster, and finally rolled into various sizes of rebars by open train bar rolling mill. In 2001, after operation of the bar tandem mill, liquid steel was cast into 150 mm x 150 mm billets through continuous caster, then hot charged to tandem mill for rolling. From July 2002, all rollings have been in way of negative-tolerance rolling in order to the market requirements.

After negative rolling was introduced, the strength rebars was often not qualified, so, the lower limit of V content was increased to 0.07%, meanwhile, the top limit of V content was lowered to 0.09%.

For the chemical composition and mechanical property of 20MnSiV ribbed bars before negative tolerance rolling was introduced, please refer to Table 2. For the chemical composition and mechanical property of Ø22 mm 20MnSiV after negative tolerance rolling was introduced, please refer to Table 3.

2.2.1 Recovery rate of V

The average recovery rate of V was 91.32%, and the fluctuation range of recovery rate was 85.23% - 93.61%.

2.2.2 Metallographic structure

It was normal structure F + P, grain size was
between grade 9 ~ 10. Along with the increase of rolling sizes, grain size was decreased from grade 10 to grade 9.

2.2.3 Mechanical property

The mechanical property accorded with requirements of GB1499 - 1988 standard. Under maximum force of actual measurement, the fluctuation of total elongation $\sigma_e$ is between 12.9% ~ 19.6%, satisfied national standard which is not less than 2.5%.

2.2.4 Bending property

After stipulated 180° bending of rebars, no cracks occurred for rebars less than Ø25. However, for rebars more than Ø25 mm, for Ø28 ~ Ø32 mm in particular, bending cracks often occurred (same for Grade II rebars) for a certain period of time. The worst case was hot charged rolling of billets. After the rebars with cracks were laid down for a period of time, the test was remade, and cracks phenomena disappeared, meanwhile, elongation was improved correspondingly. Through effective process measures, above - mentioned problems were basically solved.

2.3 Test of HRB400 20MnSiV (N) ribbed bar with VN micro - alloying

In December 2002, 24 heats of test was made to produce HRB400 ribbed bars with VN microalloying, using PANGANG produced VN12 (V: 79.54%, N: 12%). N was blown from bottom, then cast into 150 mm x 150 mm billets through continuous caster, and finally hot charged to tandem mill for negative rolling. The chemical
composition and mechanical property of ribbed bars are shown in Table 3.

2.3.1 Recovery rate of V

The average recovery rate of V was 94.07%, and the fluctuation range of recovery rate was 88.78% - 96.95%.

2.3.2 Mechanical property

The mechanical property accorded with GB1499 - 1998 standard. The percentage with a yield strength > 520 MPa accounts for 83%.

3 Analysis and Discussion

3.1 The effect of Ti content to strength and ductility in 20MnTi steel

From 3 curves of $\sigma_s$, $\sigma_b$, and $\delta_s$ in Diagram 1, we can learn: When Ti < 0.04%, $\sigma_s$ and $\sigma_b$ did not reach 400 MPa and 570 MPa respectively as required by new standard.

When Ti > 0.08%, $\delta_s$ dropped dramatically to less than 18%, even less than 14% as required by the standard. The decreasing extent is up to 10% to 15%. Several samples were taken from same heat, the fluctuation of $\delta_s$ is up to 8% up and down.

When Ti is between 0.05% and 0.07%, the standard could be reached.

The chemical activity of Ti is large and easy combine with O, N and S. The remainder will form TiC and increase strength. Therefore, the fluctuation of effective Ti is large and the property of steel is very difficult to be uniform[1].

3.2 The effect of V content to the yield strength in 20MnSiV steel

In order to study the effect of V content to the yield strength in 20MnSiV steel, we have made statistical analysis of composition and mechanical property of $\phi$20 mm 20MnSi Grade II ribbed bars and $\phi$20 mm 20MnSiV Grade III ribbed bars (non - positive tolerance rolling) in 40 heats. For 20MnSiV rebars with an average vanadium content of 0.058%, the average yield strength was 480MPa, 76MPa higher than same size of 20MnSi rebars (average yield strength of 404MPa). This means, each 0.01% higher of vanadium content in the steel, 13.1MPa of yield strength will be improved for the ribbed bars.

3.3 The effect of VN alloy to the strength of ribbed bars and the role of N in the steel

From Table 3, we can learn, under similar $C_{eq}$ conditions, the average yield strength and tensile strength of 20MnSiV(N) steel with an average V content of 0.057%, is 544 MPa and 687 MPa respectively. 28 MPa and 16 MPa higher respectively than the average yield strength of 516 MPa, and tensile strength of 671 MPa of 20MnSi rebars with an average V content of 0.080%. Therefore, with the addition of VN alloy, on the precondition that V addition is 0.023% lower, the strength of ribbed bars are improved obviously and no change for ductility. Among them, N plays a big role.

N and V in the alloy will form into carbonitride in the steel. The dissolution and precipitation temperature of carbonitride is higher than carbides. During rolling, deformation - induced precipitation will occur for the carbonitride in the steel. This will inhibit the growth of austenite grain, on the other hand, it will also inhibit or retard the recrystallization of austenite, thus refine austenite, then refines the grain of ferrite[2]. Furthermore, the stability of carbonitride is higher than that of carbide, the distribution is more fine and dispersed and can strengthen the property of steel more effectively.

3.4 The economic benefit of VN micro - alloyed steel

With VN12 alloy, the V addition in the steel
will be 0.023% less comparing with the steel with 50% VFe micro-alloy and the recovery rate of vanadium increases by 2.75% (94.07% - 91.32%). Calculated according to the current market price, the cost of VN micro-alloyed steel will be 31.9 Yuan/t lower than V micro-alloyed steel.

3.5 The control to the bending property of rebars

The bending cracks of rebars occurred in many steel plants in China. According to the literature published, the main reasons are residual stress during rolling, inclusions in the steel, over-temperature of rolling. Similar problems also occurred in the ribbed bars of our company. For example, scale occurred along the wedge of transverse ribs due to over-use of rolls, pit occurred along the root of transverse ribs during rolling, which lead to concentrated stress at this location; over-inclusions of subsurface of bars, and over-temperature of rolling etc. We have taken related measures and bending cracks were reduced to some extent. However, the problem of bending cracks were not solved ultimately, sometimes the problems were very serious. There are more cracks occurred for hot-charged billets than cold-charged ones. After the rebars with bending cracks were laid down for a period of time, test was remade and no cracks occurred and the elongation was also improved correspondingly. Based on this, we have made analysis in combination with our existing process. We think the problem is the nitrogen—blowing time from ladle bottom is too long. The original defined nitrogen—blowing time is 2 minutes and 30 seconds. The production plant increased the time to 3 minutes and 5 seconds in order to reduce the inclusions in the steel. A large amount of free nitrogen existed in the steel due to long nitrogen blowing. There were no elements in 20MnSi steel to combine with nitrogen, and nitrogen—combining element V in 20MnSiV steel is very limited. When the billets are hot charged or cold—charged after shortly laid—down, the free nitrogen in the steel has no time for precipitation and stay in the steel. Because N is a brittle element and the cooling of large—sized rebars are slow and grain size is big, if cold bending test is performed just after rolling, cracks are very easy to occur. In order to verify our analysis result, we have performed nitrogen blowing test. If nitrogen blowing time is 3 minutes and 5 seconds, when Ø25 mm rebars are rolled, crack rate of cold bending is up to 29%; if nitrogen blowing time is from 2 minutes to 2 minutes and 20 seconds, when Ø25 mm rebars are rolled, crack rate of cold bending is only 0.8%. Through several months’ production practice, cold bending cracks of Ø25, Ø28 mm and Ø32 mm rebars occurred very seldom. Therefore, in order to improve the ductility of steel, ladle argon blowing will be applied.

3.6 Existing problems

Since negative tolerance rolling was applied, the V addition in 20MnSiV steel have been increased. As far as mechanical property of rebars are concerned, yield strength are mostly more than 520 MPa, leading to \( \sigma_s(\text{actual}) / \sigma_s(\text{small}) \) ratio over 1.30. Same problem also exists in tested 20MnSiV (N) steel. We will try to adjust the composition range of C, Mn and V in order to meet the requirements of \( \sigma_s(\text{actual}) / \sigma_s(\text{small}) \) ratio stipulated in GB1499—1998.

4 Conclusions

(1) The test of HRB400 20MnTi ribbed bars shows: The chemical activity of Ti is large and easy to combine with O, N and S. Therefore, the fluctuation of effective Ti is large and the property
of steel is very difficult to meet the requirements of national standard.

(2) Under existing production process of Chengang, HRB400 rebars were produced with 50% FeV micro-alloying and negative tolerance rolling, controlling the vanadium content in the steel between 0.07% ~ 0.09%, the property of rebars can meet the requirements of GB1499 – 1998.

(3) Comparing with 50% FeV micro-alloying, producing HRB400 rebars with VN12 micro-alloying, the V content in the steel can be decreased from average 0.080% to 0.057%. The average recovery rate of V can be improved 2.75%, and the cost of vanadium alloy can be saved by 31.9 Yuan/t.

(4) The bending cracks occurred in Chengdu Steel are mainly due to over-blowing of nitrogen (3 minutes and 5 seconds) from ladle bottom, which leads to the increase of free nitrogen in the steel. The occurrence of bending cracks can be prevented effectively if the nitrogen blowing time is controlled within 2 minutes and 20 seconds.

References:
