Research on Microstructure and Properties in Welded Joint of 700 MPa grade Low Carbon Micro-alloy steel

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Abstract: High-strength residual heat treatment steel bar was tested with welding thermal simulation in Gleeble3500. Effect of heat input on the microstructure, impact toughness and microhardness of weld heat-affected zone (HAZ) was studied. The results show that with the increase of $t_{8/5}$, microstructure of coarse grain heat-affected zone (CGHAZ) transforms into granular bainite and pearlite in stead of ferrite, feather-like upper bainite and strip-like lower bainite, HAZ impact value increases firstly then decreases and reaches maximum at $t_{8/5}=100$s and the hardness decreases. And when $t_{8/5}$ increased to 60$s$ there were only ferrite and pearlite in the microstructure of CGHAZ. The impact energy of high-strength residual heat treatment steel bar would be at the range of a good level for physical production with the range of $t_{8/5}$ from 20$s$ to 300$s$.

1. Introduction
Hot rolled bars is building, the most widely used in the construction of Bridges, railways and other projects of steel products, with the rapid development of industrial economy, on the performance of construction steel quality put forward higher requirements, accelerate the construction steel varieties optimization and upgrading of [1]. Because of the price expensive alloying elements, in the process of steelmaking trace V, Ti and Nb elements, so as to raise the bar comprehensive mechanical properties of micro alloying method has no cost advantage. In does not add or less under the premise of adding alloying elements, through the adoption of energy-saving component design and minimize method to refine the grain size, a substantial increase in bar since the quenching and tempering heat treatment technology of comprehensive performance [2-3], is widely used in Western Europe, Japan and other countries [4], New Zealand, the seismic grade of steel 500 e V mass fraction by 60%, European original to fatigue experiments prove that the material can be used in seismic requirements, with QTB process of hot rolled bar products have been recognized [5]. At present, our country is to speed up the application of high intensity seismic bar, but the heat treatment process may occur in the welding process of the bar is grain coarsening and tensile strength, yield strength degradation problem [6]. Welding joint performance by the general performance of the weld seam and heat affected zone (HAZ), the organization of the weld performance, you can select the suitable welding material and parameters to match, but under the effect of welding thermal cycle, the HAZ will produce non-uniform and embrittlement, this is often the cause of welding crack or joint performance degradation of the important reasons for the 7. By using thermal simulation technique, this paper discusses the single channel when the welding thermal cycle, $t_{8/5}$ on high strength heat treatment bar HAZ microstructure transformation rule and the influence of mechanical properties change trend, suitable for application in practical production of welding process parameters to provide the reference.
2. Materials and methods

Test Ф 16mm 500MPA grade high strength heat processing rod warmwalzwerk production for baosteel nantong company, QTB waste heat treatment technology on the control of hot rolled bar afterphase transformation, has high strength and good plastic toughness, its chemical composition as shown in table 1.

| element | C   | Si  | Mn  | P   | S   | Cr  | Ni  | Cu  | V   | Nb  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| content | 0.233 | 0.315 | 1.46 | 0.02 | 0.013 | 0.025 | 0.008 | 0.033 | <0.005 | 0.02 |

High strength and heat treatment bar processing into 10mm×10mm×55mm thermal simulation impact specimen, the sample surface roughness Ra1.6. Welding thermal simulation experiment on Gleeble-3500 thermal simulation testing machine, welding thermal cycle simulation, simulated by the single peak temperature is 1320℃, the heating rate of 100℃/s, 0.5s insulation, change the cooling speed, namely \( t_{8/5} \) respectively 10s, 12s to 15s, 20s, 30s, 60s, 100s and 300s.

Preparing metallographic specimen, grinding, polishing and after 4% nitric acid alcohol corrosion about 4s in JMS-7001f HAZ microstructure morphology observed under field emission scanning electron microscopy (sem). Impact toughness test shall be carried out in accordance with the GB/T229-2007 standard, test equipment for JBC-300 material impact tester, test specifications for 10mm ×10mm×55mm, charpy v-notch, groove depth of 2mm, test temperature to room temperature. Impact fracture in JMS - 7001 - f and observed under scanning electron microscopy (SEM) of fracture morphology SEM by PHILIP - XL30 electronic scanners. Measuring the thermal simulation samples vickers hardness of each specimen under HV-1000 micro hardness tester play five points, and calculate the average of the hardness.

3. Experimental results and analysis

3.1 different \( t_{8/5} \) CGHAZ microstructure changes

Figure 1 for high strength and heat processing rod material original organization, give priority to with ferrite and pearlite, with a small amount of inclusions, and the obvious characteristics of rolling strip.

Figure 1 high strength heat processing rod material organization

Figure 2 to experience different \( t_{8/5} \) CGHAZ of the organization. When \( t_{8/5} = 10s \) and 12s, small welding heat input, CGHAZ organization for feathery bainite and a small, dispersion, short strip of bainite ferrite and the hybrid organization (figure 2a, b). When \( t_{8/5} = 15s \), 20s, feathery bainite main organization form (figure 2 c, d), \( t_{8/5} = 60s \) bainite is the main form of granular bainite, increasing with the welding heat input, the granular bainite gradually reduced, increasing pearlitic structure (as shown in figure e, f). As you can see from figure 2g, when \( t_{8/5} = 100s \), CGHAZ organization of pearlite and
ferrite, pearlite content is higher, and intragranular ferrite morphology of acicular ferrite. When $t_{8/5}$ increases to 300s (figure 2h), CGHAZ organization of pearlite and ferrite, intracrystalline have rough widmanstatten structure, with $t_{8/5}$ to 100 s (figure 2g) when compared to grain obviously bulky.
3.2 The HAZ of microhardness analysis under different cooling rate

Under a cold quickly, from the parent metal to the hardness of heat affected zone coarse grain zone all showed a trend of increase, and with the increase of cooling speed, the highest hardness of heat affected zone increased gradually. When $t_{8/5}$ to 300s, the cooling speed is 1°C/s, HAZ microhardness value of basic and identical, this is due to the cold speed too slow, HAZ generated is pearlite and ferrite structure. When the cooling rate is more than 10°C/s, HAZ hardness value is greater than the parent metal, and with the increase of cooling rate, this trend, the more obvious, such as in the largest cooling speed (30°C/s), HAZ maximum hardness is 370 hv, is 1.74 times that of the parent metal hardness. When energy welding string cable so easy to form a hard brittle organization, this is against the comprehensive performance of HAZ, a string cable should be avoided in the actual welding energy.

3.3 The fracture morphology analysis under different heat input

Figure 3 for the high strength heat treatment bar parent metal and $t_{8/5}$ respectively 100s, 30s and 12s typical impact fracture surface SEM topography. Figure 3(a) high strength heat treatment fracture morphology of bar for shaft toughening nest morphology, fracture toughness, the impact energy of 170j. Figure 3(b) for $t_{8/5}$=100s HAZ fracture morphology: for tearing toughness nest morphology and fracture of coexistence mixed fracture, its are main the feature is the significant of section of the core of river pattern, which is surrounded by large areas of toughening nest around. Compared with the parent metal figure 3(a) toughening litter number significantly reduced, or by the river and fan in the shape of a small plane cleavage. Figure 3(c) for $t_{8/5}$=30s when fracture morphology and $t_{8/5}$=100s when the fracture morphology of similar, but the cleavage fracture of river pattern is clear. Figure 3(d) for $t_{8/5}$=12s fracture morphology, fracture mainly presents the accurate cleavage fracture morphology, tongue shaped pattern, empty and inclusion quantity many, as the typical brittle fracture morphology, room temperature impact energy is only 30J. With the decrease of the $t_{8/5}$, fracture morphology from the typical toughening nest to ligulate pattern, and number of toughening fossa region and area reducing, surface level, increase in the number of cleavage fracture zones in crystalline light gray, increasing, the number of holes and inclusions can reflect its HAZ impact with $t_{8/5}$ lower and lower, and this are shown in table 2 of the regularity of room temperature impact energy changes with the heat input.
4. Conclusion

(1) High strength and heat processing rod CGHAZ on $t_{8/5}<15s$ for feathery bainite, short strip of bainite and ferrite organization, with the increase of welding heat input, CGHAZ organization into granular bainite, pearlite and ferrite hybrid organization, when $t_{8/5}>60s$, CGHAZ organization of pearlite and ferrite.

(2) Welding thermal cycle of high strength heat treatment has remarkable effect on the toughness of the bar with the increase of heat input, HAZ room temperature impact energy increases after the first decreases, and reached the maximum when the $t_{8/5}=100s$, the impact fracture morphology from quasi cleavage fracture morphology to tear also toughening fossa fracture coexistence mixed fracture morphology of reconciliation. But along with further increases to $t_{8/5}=300s$, the HAZ impact energy, and no obvious deterioration of toughness. High strength and heat processing bar in $t_{8/5}$ to 20s to 300s impact toughness can satisfy the requirement of practical production, and in the same welding thermal simulation under the condition of its excellent impact performance than micro alloy bars.

References:
[1] EN10080. steel for the reinforcement of concrete weldable reinforcing steel general[S]. Brussels, 2005.
[2] Shome M , Gupta O P , Mohanty O N. A modified analytical approach for modelling grain growth in the coarse grain HAZ of HSLA steels[J]. Scripta Materialia, 2004, 50(7): 1007-1010.
[3] Yang Lina, Han Jingkuan, Wang Nianrong, et al. Developmentsituations of LNG terminals in China[J]. Oil & Gas Storage andTransportation, 2016, 35(11): 1148−1153（in Chinese）
[4] Wang Zhongwei. Preliminary study of process, microstructure andproperties of low temperature nickel steel with reduced nickelcontent[D]. Shanghai: Shanghai Jiao Tong University, 2015.
[5] Meng Yang, Ren Qun, Ju Xinhua. Evaluation of dislocation density by local grain misorientation in deformed metals[J]. Transactions of Materials and Heat Treatment, 2014, 35(11): 122–128. (in Chinese)

[6] Su Xiaohu, Li Zhuoxin, Li Hong, et al. Microstructure to properties of coarse grained heat affected zone in deposited weld metal of metal cored wire E120C-K4[J]. Transactions of the China Welding Institution, 2019, 40(10): 48-53. (in Chinese)