Niobium Bearing Structural Steels
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THE NEW TREND FOR WIDE AND HEAVY PLATE USED IN SPECIAL APPLICATIONS

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Abstract

This paper emphasizes the current application of Nb microalloying technology and development of high strength steel plate for building structure using Nb in Wuyang Iron and Steel Co., Ltd. (hereinafter referred to as Wugang). Wuyang proves that the applications of wide and heavy steel plate becomes more extensive with even high adaptability by organic combination of microalloying technologies represented by Nb containing steel and TMCP rolling process.

Preface

Wide and heavy plates are utilized to produce steels for the major steel products in industries such as ship building, bridge building and pipeline steel pipe fabricating. In recent years, wide and heavy steel plate has also been widely used in special fields, i.e., high rise building, power plant structure, offshore oil platform, construction machinery and petrochemical industry. Owing to their advantages of high strength, high toughness, low yield–tensile ratio, lamellar tearing resistance performance, high wear resistance performance, weather resistance performance, such steel plate has been recognized over the world. Especially, after the extensive applications of micro-alloying technologies represented by Nb-containing steel and the TMCP rolling process, a large quantity of products with high tech content and high added value have been successfully developed, achieving higher adaptability and wider application range on wide and heavy steel plate. For example, the wide and heavy plate with 235-460MPa series yield strength for building structures have been widely used in the construction of stadiums and gymnasiums for the Beijing Olympic Games, showing incomparable advantages over other steel classes and steel grades.

Current Development Situation of Nb Containing Steel and Microalloying Technologies in Wugang

Nb Containing Steel Grades and Their Production Capacity in Wugang

By actively adopting Nb microalloying technology and making use of Nb for the purpose of grain refinement, recrystallization delay , ferrite ductile-brittle transition temperature reduction and precipitation strengthening, Wugang has developed a large quantity of wide and heavy steel

plate with superior performance and important applications. Typical products are as follows: X70 pipeline steel with acicular ferrite produced by TMCP for National West to East Natural Gas Transmission Project, CF type low carbon bainite steel produced by non-quenching and tempering process for pressure pipe of National West to East Power Transmission Project , ultra high strength steel of 590-960MPa grade yield strength produced by quenching and tempering process for construction machinery, S355N, A709 HPS485W new type bridge steel and BB503, BB41BF steel for blast furnace shells produced by Nb-Ti composite strengthening process, 390-460MPa grade yield strength steel produced by Nb-V composite strengthening process for building structures and other low alloy high strength steel. The application of Nb microalloying technique not only enriches the wide and heavy steel plate product mix of Wugang, but also improves the actual product quality and competitive power of Wugang. Nb microalloying steel grades of Wugang mainly include bridge and port machinery steel, ship building and offshore platform steel, high rise building steel, construction machinery steel, pipeline steel, boiler and pressure vessel steel, blast furnace shell steel, low alloy high strength steel, pressure pipe steel, lamellar resistant steel (Figure 1 and Figure 2). 2.45 million tons of Nb containing steel has been produced from January, 2005 to August, 2008, which amounts to 40.86% of 5.99 million tons, the total wide and heavy steel plate output of Wugang (Figure 3). In the year 2005, 2006, 2007 and the first eight months of the year 2008, the consumption of Fe-Nb alloy amounts to 266 tons, 270 tons, 374 tons, 388 tons respectively, which increases gradually year by year. From the year 2005 up to now, the consumption of Fe-Nb alloy per ton is 0.216 kg, of which the consumption of Fe-Nb alloy per ton is 0.53kg for Nb containing steel (Figure 4), reaching domestic advanced levels

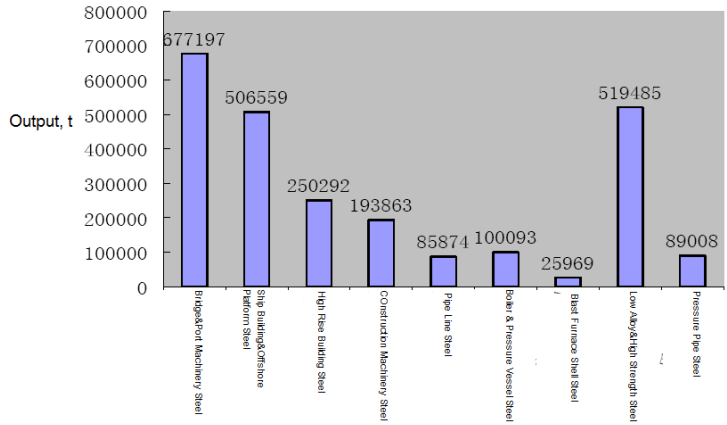

Figure 1. Output of each Nb-containing steel grade in Wugang from 2005 to date.

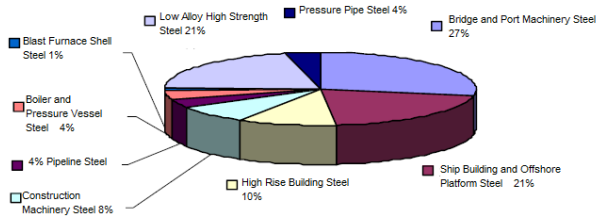

Figure 2. Percentage of Nb-containing steel grades output in Wugang from 2005 to date.

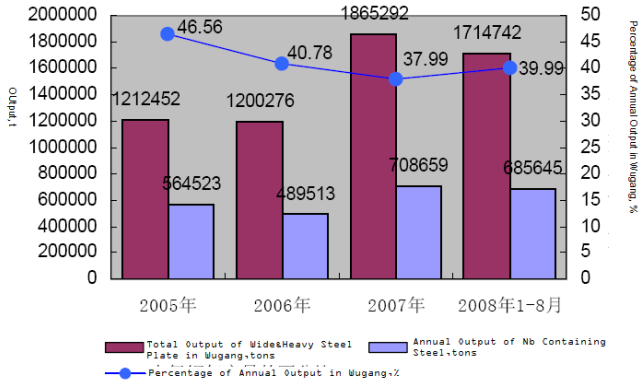

Fig.3 Annual output of Nb-containing steel in Wugang and its percentage

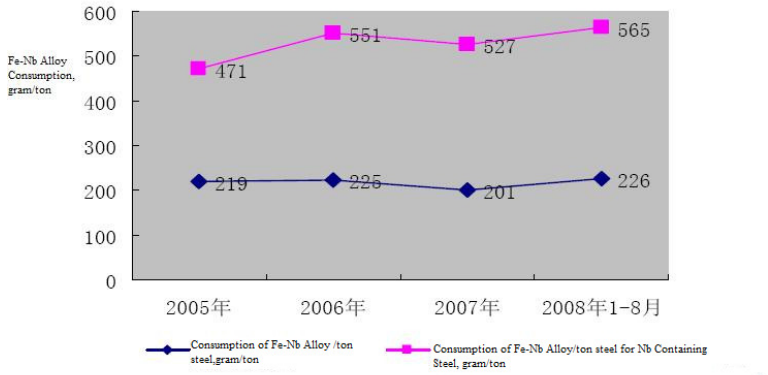

Fig.4 Consumption of Fe-Nb alloy/ton steel in Wugang

Classification of Low Alloy Steel Microalloying in Wugang

There are four types of Nb microalloying combinations at Wugang, i.e., Nb only, Nb-V composite strengthening process, Ni-Ti composite strengthening process, Nb-V-Ti composite strengthening process. Nb is the most important microalloying element. To add Nb only is the first choice for 500MPa tensile strength grade controlled rolling steel. Owing to the action of Nb (C,N) precipitated phase, the original austenite grain will become finer, leading the formation of much more refined recrystallization grain, thus gaining ideal combination of high strength and high toughness.

The Nb-Ti composite strengthening process can make full use of the role of niobium. Ti will turn into a nitride which is stable under high temperature, restraining the grain growth of austenite at the welding seam, especially in the heat affected zone (HAZ) close to the welding seam fused boundary. During reheating before hot forming, the improved HAZ toughness can tolerate the need for the high heat input welding process. In addition, free N is eliminated from steel due to the formation of TiN, from which the aging performance of the steel will also benefit. At this time, Nb exists in the form of carbide, but does not form carbonitrides. At the same reheating temperature, more Nb is dissolved, the role of Nb is enhanced, and thus the surface quality of the continuous slab is improved. Nb-V composite strengthening process is often applied for normalizing type low alloy high strength steel and steel plate of 390-500MPa yield strength grade produced by TMCP. In normalized heavy plate, it is difficult to achieve the required strength by only adding Nb, so it is necessary to add a small amount of V. The toughness of such plate is mainly determined by the Nb content and TMCP process. The contribution of V to the strength is achieved by the precipitation strengthening of V(C,N) and no obvious deterioration has been shown on toughness.

By using the method of adding Nb-V-Ti and a reasonable amount of Cu, Ni and Mo for alloying, higher strength grade can be reached without sacrificing toughness. For example, for low carbon

bainite steel and acicular ferrite steel, the hardenability of the steel can be improved by V addition, which is favorable for strength improvement by ACC. In accordance with actual conditions, Wugang has optimized the process parameters such as reheating, rolling and cooling , ensured the full play of the advantage of Nb microalloying function, making the technology play an important role in refining the microstructure, improving strength, toughness, weldability and special application performance. The classification of low alloy steel microalloying in Wugang is given in the table below.

Development of Steel Plate for Building Structure in Wugang

Developing Trend of Steel Plate for Building Structure

Steel structure is becoming the main construction component of modern buildings, which represents the development trend of building structures in a period henceforth. Especially the considerations of various aspects of safety, economical efficiency, architectural aesthetics and space utilization efficiency for high rise heavy steel structure and wide span space steel structure require diversified property requirements, i.e., high strength, high toughness, low yield-tensile ratio, high heat input welding, fire resistance and weather resistance. It is in this field where low alloy high strength steel is mainly applied, especially the steel grade in which micro-alloying elements, represented by Nb, give full play to grain refinement.

High Strength and High Toughness

In recent years, with the development of heavy, high rise, wide span space structure and non-symmetrical structure, the bear weight of the structures becomes heavier and heavier. In order to reduce the thickness and weight of the structures and lower the welding costs, high strength steel plates of yield strength 390MPa, 420MPa, 460MPa have been applied in building structures in large quantities. For instance, Q460E/Z35 plates of 110mm thickness have been used on the Main Stadium of 2008 Beijing Olympic Games-Bird's Nest. Q420C/Z15 steel plates have been used on the National Olympic Swimming Gym-Water Cube. Tens of thousands of tons of Q390D/Z35, Q420D/Z35, Q460E/Z35 wide and heavy steel plates up to 135mm thickness have been used on New CCTV Tower.

Since defects cannot be completely avoided on actual structures, in order to maintain sufficient plastic deformation on the material before crack propagation, higher impact toughness at low temperature is required if high strength steel is applied. This is because the required integral engineering value J of fracture mechanics is almost increased in the square of yield strength when the yield strength of the material is higher. High strength steel for building structure is generally required to have good low temperature impact toughness at -20°C or -40℃.

Low Yield-Tensile Ratio

For steel products at the same yield strength level, the lower the yield-tensile ratio is, the more uniformly the material will distribute its plastic deformation over a wider range, avoiding the reduction of the entire plastic deformation capacity due to stress concentration. Therefore, then

the higher the earthquake resistant capacity of the material will be. For 345MPa steel normally used for building structures, the yield-tensile ratio of the steel can be easily controlled to values below 0.83 by either CR or TMCP process. But high strength steel containing Nb has to be rolled at lower temperature. Significant grain refinement is used to improve strength and toughness, which does not help much on tensile strength improvement and the yield-tensile ratio will be increased with the improved yield strength as a result. For high strength steel of building structure application, other measures are necessary to improve strength while reducing yield-tensile ratio. It is a new subject for TMCP process research.

High Heat Input Welding

Simplifying welding procedures and increasing welding efficiency is a continuing target in steel structure fabrication. Wide and heavy steel plate with high heat input welding performance is the development trend of steel for building structures henceforth. Some domestic steel structure fabricators have already used two wires and three wires in submerged arc welding with heat input up to 90 KJ/cm approximately. When performing high heat input welding on normal steel products, hot cracking and HAZ embrittlement may occur at the weld beads. The only way to improve the weldability of such steel products is to optimize the chemical composition design and improve the production process. Wuyang has obtained good original toughness. The HAZ grain growth is inhibited on medium and heavy steel plate by reducing solid solution nitrogen content, adding nitrogen fixation elements such as Ti and/or Ca which form high temperature resistant nitride alloying particles and lowering the carbon equivalent to values below 0.41%, taking appropriate measures like controlled rolling process. Thus 345MPa yield strength plate possesses 85-100KJ/cm high heat input welding performance.

Fire Resistance and Weather Resistance

After the 9/11 event, various countries throughout the world raised exigent and stringent requirements on fire resistance of building steel structures. High temperature strength and fire resistance of building structural steel have become a research focus. Fire resistant steel for building structures is generally required to maintain its yield strength at values above two-third of the yield strength value at ambient temperature when the steel is heated up to 600°C. Research both at home and an abroad shows that the Mo+Nb combination can improve the high temperature resistant creep property of steel, which meets various technical requirements of fire resistant steel and possesses good weldability. At present, Wuyang, WISCO and Angang have already developed conforming products, but all have few application references due to lack of appropriate building design codes.

Weldable weather resistant steel of normal grades have been developed for many years, but have less applications on building structures, which needs further study on their application performance.

Current Production Situation of Steel Plate for Building Structure in Wugang

Wugang, as a large enterprise producing extra heavy plate for a long history, abundant, solid and

strong production technology and technological equipment in China, has undertaken detailed and constructive investigation and studies on steel plate for building structure. Developments including such plates in all strength grades such as 235, 345, 390, 420, 460MPa and all quality grades, such as C,D,E, established the series of product system for building structural steel. In China, they have drafted the industrial standard Steel Plate for High Rise Building Structure (YB4104-2000) and national standard Steel Plate for Building Structure (GB/T19879-2005) and set up the China's standard system of steel plate for building structure. Many famous buildings have been built by Wugang steel plate in succession, i.e., Shanghai Oriental Pearl TV Tower, Guangzhou TV Tower, Terminal 3 Building of Beijing International Airport, New CCTV Tower, National Grand Theater of China. Esp., the development of the special steel plate Q460E/Z35 specific for the main stadium of Beijing 2008 Olympic Games--the Bird's Nest resolved the technical problems such as internal porosity and thickness effect of extra heavy plate with comprehensive technology reaching international advanced level.

Wugang adopts Nb as the microalloying element for all the building structural steel in order to achieve high strength and high toughness on steel plate while reducing carbon equivalent value for welding in order to improve the weldability of the steel product.

Table 1. Melt analysis of high strength building structural steel, wt%.

Steel Grade	Thickness (mm)	C	Si	Mn	Al	Nb	V	Ti	Delivery Conditions
Q235GJ	8~100	0.12 ~0.14	0.20 ~0.40	0.60 ~0.90	0.015 ~0.045	0.015 ~0.025	-	-	TMCP or Normalizing
Q345GJ	8~150	0.12 ~0.15	0.20 ~0.40	1.30 ~1.50	0.015 ~0.045	0.015 ~0.025	-	-	TMCP or Normalizing
Q390GJ	8~135	0.13 ~0.16	0.20 ~0.40	1.35 ~1.50	0.015 ~0.045	0.025 ~0.035	0.030 ~0.040	-	TMCP or Normalizing
Q420GJ	8~135	0.14 ~0.17	0.20 ~0.40	1.45 ~1.60	0.020 ~0.045	0.030 ~0.040	0.050 ~0.060	-	TMCP or Normalizing
Q460GJ	8~110	0.15 ~0.18	0.20 ~0.40	1.50 ~1.60	0.020 ~0.045	0.035 ~0.045	0.070 ~0.080	0.015 ~0.020	TMCP or Normalizing

Q460E/Z35 Development

The main stadium of Beijing 2008 Olympic Games is known as Bird's Nest because of it unique

outline. The stadium construction required a new type of steel product for building structure, i.e., 110mm thick Q460E/Z35 steel plate. In the history of architecture both at home and abroad, 460MPa grade extra heavy steel plate has never been used. There was no successful experience for reference either to produce the steel plate or to weld the steel structure during construction. The technical requirements of Q460E/Z35 heavy steel plate for Bird's Nest are indicated within Table 2.

Table 2. Property Requirements of Q460E/Z35 Steel Plate for Bird's Nest

Thickness (mm)	Rm (Mpa)	$R_{p0.2}$ (Mpa)	$R_{p0.2}$、/R m (%)	A (%)	Z (%)	Cold Bending Test b=2a	-40℃AKv longitudinal J
110	550~720	≥420	≤0.83	≥20	≥35	Bending 180°	≥54

The performances like 460MPa yield strength, -40°C low temperature impact value, Z35 lamellar tearing resistance all set up the records of low alloy and high strength steel, i.e., yield - tensile strength ratio ≤0.83, elongation ≥20%, GB/T1591 standard requirements broken through for the thickness up to 110mm. As the plate thickness increases, the strength and toughness of the steel plate are hardly maintained due to smaller reduction ratio, reduced cooling rate after rolling, which is unfavorable for grain refinement, and further the thickness effect. The steel plate of same strength grade, thickness and technical requirements for building structure was first produced and applied both at home and abroad. The building structural steel produced by iron and steel enterprises in Japan and European countries of same strength grade has not reached such a large thickness or such a high Z-direction performance.

Major Technical Measures for Q460E/Z35 Steel Plate Production

Implementing the principle of Fine Furnace Charging, Fine Steelmaking, Fine Rolling and Fine Finishing, Wugang ensured all properties of Q460E/Z35 steel plate meeting the design specification of Bird's Nest. Wugang strictly follows a quality plan and in-plant controlled quality standard to control all the production links as well as a series of guarantee measures of process and technology.

1) Microalloying Composition Design

The following figure shows the relation between chemical analysis, carbon equivalent value and microalloying content.

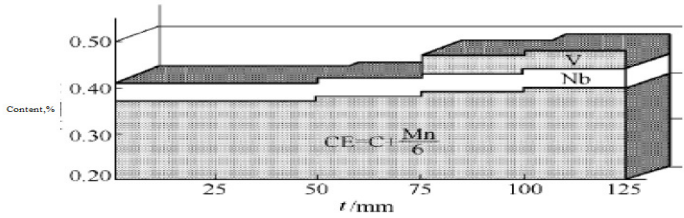

Figure 6. Relation between thickness, carbon equivalent value and microalloying element content for Q460E steel plate.

The technical conditions of 110mm thick Q460E/Z35 steel plate for the national stadiums required a carbon equivalent value for welding Ceq ≤0.50%, but the actual value was controlled below 0.47%. The composition design selected Nb+V combination strengthening process for microalloying, thus obtaining good microstructure and the perfect combination of strength, ductility, toughness, reducing the carbon equivalent value for welding and at the same time, improving the weldability of steel product. By optimizing chemical analysis and the production process, maintaining high strength, the carbon equivalent value is as low as possible. Smooth construction and welding at the site was ensured and the contradiction between high strength and low carbon equivalent value was resolved.

2) Metallurgical Process of Clean Steel

Low P content, low S content and stringent N content control could not only significantly increase the fracture toughness of steel, but also improve the quality of continuous cast slab and reduce the thermal deformation resistance during rolling. The building structure steels were all produced by clean steel production process, i.e., reducing the gas and inclusion content in the steel, improving the comprehensive performance of steel plate, especially improving lamellar resistance performance. Furnace charging materials such as scrap were carefully selected before charging into furnace to reduce the amount of external inclusions brought into steel. During the melting period in the EAF, measures of enhancing slag making, slag fluidizing, slag-free tapping from the eccentric bottom were taken to control P content below 0.012%. During the refining in the LF, white slag was made. Argon was intensively blown for better stirring and mixing of steel liquid and slag. During VD treatment, S content was controlled below 0.005% while Ca treatment was also implemented to improve inclusion shape.

3) Defect-free Casting Process for Large Ingot

In order to maintain a certain reduction ratio, all the steel plate to be supplied was rolled from ingots. With larger thickness ingots, metallurgical defects such as segregation, porosity and pinhole would occur during solidification. Due to this reason, Wugang studied and developed the defect-free casting process for larger ingots. By applying technical measures like rational ingot type design, proper casting temperature and speed and shroud casting, the internal quality of the

large ingot was significantly improved.

4) Stringent Control Rolling and Controlled Cooling Process

Steel plate produced by microalloying technology, controlled rolling and controlled cooling had a good grain refining result. In order to maintain -40°C low temperature toughness and reduce the plate thickness effect, stringent controlled rolling at the non-recrystallization area and subsequent controlled cooling were performed to refine ferrite grain, improve the strength and toughness of steel plate, induce carbonitride precipitation of Nb,V,Ti by deformation and increase the matrix strength.

5) Heat Treatment

The microstructure of normalized steel plate was relatively uniform. Under the condition where the yield strength was slightly lowered, the central performance of the steel plate in the thickness direction was improved, impact toughness of heavy steel plate significantly improved, resulting in the best combination of strength, plasticity and toughness. The microstructure of Q460E/Z35 steel plate was improved by normalizing. The negative effect of controlled rolling was eliminated and good comprehensive performance was achieved.

Conclusion

The developing trend of wide and heavy steel plate product should have high cleanliness, high strength, high toughness, good weldability and process workability. Taking the TMCP process as the core technology, the development of production technology for wide and heavy steel plate tends to continually improve the optimization of micro-alloying, combination of deformation rate and temperature, on-line accelerated cooling and heat treatment. Products satisfying the individualized demand of customers will be developed.

Wuyang actively adopts Nb microalloying technology, optimizes process parameters of reheating, rolling, cooling and heat treating according to its own conditions, makes full use of Nb micro-alloying in many aspects such as grain refinement, strength improvement, toughness improvement, weldability improvement and special application performance, and has developed a series of high strength steels for building structure.

In addition to the domain position of production capacity for building structural steel as low alloy and microalloyed steels, special applications like boilers for power stations, offshore platforms, construction machinery and the petrochemical industry are possible. These are important application fields for Nb containing microalloying steels in the future.

References

1. Development Trend of Low Alloy High Strength Heavy and Wide Plate, Chang Yuefeng, Wang Zubin, Zhao Wenzhong, Vol 8, 2007, Iron & Steel.

2. Structural Steel Welding-Performance and Metallurgy of Low Alloy Steel, written by Shuusan Ueta, translated by Jing Hongyang, published by Beijing Metallurgical Industry Publishing House, 2004.

3. Nb Containing Steel Production Technology-How to Improve Steel Performance by Using Nb, written by Hiroshi Takechi, translated by: Fu Junyan, published by Metallurgical Industry Publishing House, 2007.