Niobium Bearing Structural Steels
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DEVELOPMENT OF FIRE-RESISTANT WEATHERING STEEL FOR BUILDINGS IN BAOSTEEL

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Abstract

With the continual development of structural steels, there is greater demand for high performance fire-resistance (FR) structural steel for use in buildings, shopping malls, car park developments etc. Traditional FR steels have been designed with a high Mo alloying content, which leads to a high cost and high price. This paper introduces a new low Mo bearing FR steel design containing Nb and other microalloy elements that is produced via the TMCP process. The new FR steel demonstrates acceptable high temperature strength and ambient temperature mechanical properties.

Introduction

The two major problems that exist in steel structure buildings are corrosion of steel and softening of steel structural members during fire. Under natural weather conditions, the thickness reduction of steels after 5 years due to corrosion can be above 0.1-1mm. It is even worse under long-time or special and man-made adverse environments. Coatings can slow down the corrosion rate, but at a high cost. For example, the coating cost for bridges in 10 years is 2.5 times of the cost for steel structure. Since the anti-corrosive treatment for steels is maintenance-intensive and of high cost, the extensive application of steel structure is restricted to a certain degree.

When the temperature of steel reaches 350°C or above, the yield strength of steel drops to 2/3 or less of the specified room temperature yield strength, thus below the yield strength required for steel structural parts. In order to keep the temperature of steel structural parts below 350°C in case of a fire, the steel structural parts must be sprayed with fireproof material. However, the work of spraying fireproof material is very harmful to the workers' health and is very time-consuming. Moreover, the effective utilization of interior space of buildings is reduced due to the coating of fireproof material. Therefore, to reduce the fire-resistant coating work to steel structure building is more and more strongly demanded.

The Development of FRW steel in Abroad and China

A new steel, fire-resistant (FR) steel, with elevated-temperature yield strength superior to that of conventional steels and fire-resistant steel-frame structures made of such steel were developed.

The fire-resistant coating work has been sharply reduced.

The concept of FR steel started to emerge in 1980s [1] and now, research and production of FR steel have been carried out in the developed countries such as Europe, North America, Japan, Korea and Australia. The products of which include section steel, sheets, strips and steel tubes. Some steel-manufactures of China have carried out the research and production of FR steel and FRW steel as well [2], among which, Baosteel is the earliest one to start the research and production of fire-resistant and atmospheric corrosion resistant constructional steel, and have so far supplied tens of thousands of FRW steel to different users.

Baosteel's FRW Steel Development

The objective of Baosteel to develop FRW steel is to improve the high temperature strength and atmospheric corrosion resistance of structural steel. Meanwhile, Baosteel's FRW steel has the mechanical property, welding property and other properties at room temperature equivalent to those of common constructional steel. The weatherproof property of Baosteel's FRW steel is 3-8 times of common steel, and can be exposed for use under normal climate conditions. The coating property can be improved, with the expiry date of coat on weatherproof steel much longer than that of common steel.

The decrease of its yield strength at 600°C is not more than 1/3 of the stipulated yield strength standard at room temperature, which is a necessary license index to ensure the safety of buildings during a fire, while the common steel can only keep this strength at 350°C at most. With these properties, the use of fireproof coating and fireproof covering material can be reduced by a large margin, so that pollution is reduced, construction period is curtailed, the effective area of building is increased, the cost is lowered and the anti-corrosion maintenance is reduced or eliminated. In a word, it is a kind of "green and environment friendly", commercial steel of sustainable development.

Thus it is clear that the use of FRW steel can solve the two weaknesses of the application of steel in construction (corrosion resistance and fire resistance), and the construction cost can be lowered considerably, which create favorable conditions for the application of steel structure in the field of civil architecture.

In order to ensure the earthquake resistance of building structure, Baosteel's FRW steel can satisfy the low yield ratio requirement in China national norms GB for building industry.

Chemical composition and effects of Niobium on elevated temperature tensile properties of FR steels

A typical laboratory study was conducted to examine whether the elevated temperature tensile strength depend largely on chemical composition. Table 1 shows the chemical compositions of laboratory melted steels.

Table 1. The chemical compositions of laboratory melted steels.

Steel	Base composition	Varied elements
A	0.12C-0.25Si-1.0Mn-0.5Cr	0.5Mo
B	0.12C-0.25Si-1.0Mn-0.5Cr	0.02Nb
C	0.1C-0.25Si-0.9Mn-0.5Cr	0.5Mo-0.02Nb

According to these test results, molybdenum significantly improves the elevated temperature yield strength of steel predominantly composed of ferrite, and a molybdenum addition of about 0.5% is considered essential for FR steels with a tensile strength of 400 to 490 MPa. The addition of niobium to the base steel hardly changes the yield strength and increase the elevated temperature yield strength by 20 MPa. The niobium addition reduces the ferrite grain size and increases the room temperature yield ratio by about 10%.

The niobium – molybdenum micro alloyed steel increased the elevated temperature yield strength by 101 MPa, which is slightly larger than the sum of increases brought about by the single additions of niobium and molybdenum. The yield strength ratio and room temperature yield strength are not appreciably different from those of the molybdenum steel. A small amount niobium addition improves strength at room and elevated temperatures without deteriorating weldability. The combined addition of Nb and Mo is thus considered as a powerful means for enhancing the tensile properties of FR steels for buildings.

Properties and Characteristics Delivery Property Index

At present, Baosteel can supply two grades of FRW steels - B400RNQ (mechanical property at room temperature equivalent to Q235B) and B490RNQ (mechanical property at room temperature equivalent to Q345B).

Table 2. Properties and characteristics delivery property.

Grade	Tensile property				Impact property			High-temperature tensile	
	YS, MPa	TS, MPa	YR	El, %	Temp. □	Impact Energy,J	Direction	Temp. □	Yield Strength
B400RNQ	≥235	400~510	≤0.80	≥22	0	≥27	L	600	≥157
B490RNQ	≥325	470~610	≤0.80	≥22					≥217

The mechanical properties of Baosteel's series of FRW steel (B400RNQ and B490RNQ) at room temperature can completely satisfy and exceed the requirements of national standards Q235B and Q345B, and its shaping and processing properties are equivalent to or better than Q235B and Q345B. The requirement of high-temperature behavior is executed according to the relevant

Japanese standard for fire-resistant steel. Meanwhile, the yield ratio can satisfy the requirement in China national norms GB for building industry in regard to earthquake resistance.

Corrosion Resistance

By adding weatherproof chemical elements, a 50-100μm thick compact oxide layer with good adhesiveness to base metal is formed between the rust layer and the base of steel. The existence of compact oxide film prevents the infiltration of oxygen and water in the atmosphere into the base steel and slows down the development of rust in depth and breadth into the steel, so that the atmospheric corrosion resistance of steel is improved greatly. Besides, due to the stability of the rust layer, the coat of non-exposed weathering steel is not apt to fall off. Baosteel is the largest supplier of weathering steel in China at present, and is leading in the research and production of weathering steel in China. The weather resistance of Baosteel's FRW steel is presently of the highest grade among the weathering steel. The results of indoor accelerated corrosion test with Baosteel's B490RNQ, Cor-Ten A, and common steel are as follows:

Humid Heat Test

Humid heat test, also known as moisture test, is an accelerated test simulating the humid and hot climate conditions (the atmospheric conditions in the tropics). The humid heat corrosion test is mainly used to consider the function of condensate water film. Due to humidity and temperature fluctuation or temperature change during long distance transportation, the moisture in the air often condenses into a water film on material surface, resulting in the corrosion of material or aggravation of corrosion. The test is usually conducted in the humid heat box.

- Test standard: ASTM D2247-80
- Test conditions:
  (1) Test temperature: 38±1°C
  (2) Test humidity: 100%
- Test sample dimension: 150×75×3 (L×W×T), mm

Table 3. Test results of 480 hours.

Steel grade	Corrosion weight loss velocity $g/(m^2*h)$	Relative corrosion rate (%)
B490RNQ	0.039	38.2
Cor-Ten A	0.038	36.8
Q345B	0.103	100.0

Periodic Infiltration Corrosion Test

The periodic infiltration corrosion test is the intermittent immersion test in chemical soaking test methods, also known as alternate immersion test, which is to immerse the sample into the liquid corrosion media and expose it in the air alternately. It is a test simulating the alternation of rainy days and sunny days. The intermittent immersion provides the conditions for accelerated corrosion by the solution, since during most of the exposed time, a frequently renewed and almost oxygen saturated solution film can be kept on the surface of test sample; moreover, during the alternation of dry and wet state, the evaporation of moisture concentrates the corrosive constituent in the solution.

- Test standard: TB/T 2375
- Test conditions:
  (1) Test temperature: 45±1°C
  (2) Relative humidity: 70±5%
  (3) Test solution: 10^{-2}mol/L $NaHSO_3$
- Test cycle: 72 hours

Table 4. Test results.

Steel grade	Corrosion weight loss velocity, $g/(m^2*h)$	Relative corrosion rate, %
B490RNQ	0.91	45.7
A3	1.98	100.0

When the corrosion rate of contrastive test sample of A3 steel is 100, the corrosion rate of test sample of B490RNQ is less than 50, markedly lower than that of the contrastive test sample, which indicates that under the test conditions stipulated in the standard, the weatherproof property of B490RNQ is better than that of common steel A3.

Salt-water spray test

The salt-water spray test is an accelerated test simulating the corrosion by saline water or marine climate. It is usually stipulated that the salt-water spray test adopts the salt spray of 5% NaCl, pH 6.5-7.2, test temperature 35±2°C and relative humidity above 95%. The test sample is placed inside the salt spray box with the tested side upward and 20±5° to the vertical direction. The salt water shall be sprayed for 8 hours continuously every 24 hours.

- Test standard: GB 10125-88
- Test sample dimension: 150×75×4 (L×W×T), mm
- Test cycle: 96 hours, 480 hours

Table 5. Test results of 96 hours.

Steel grade	Corrosion weight loss velocity $g/(m^2*h)$	Relative corrosion rate (%)
B490RNQ	1.742	75.0
Cor-Ten A	2.083	89.7
Q345B	2.322	100

Table 6. Test results of 480 hours.

Steel grade	Corrosion weight loss velocity $g/(m^2*h)$	Relative corrosion rate, %
B490RNQ	1.625	58.9
Cor-Ten A	1.888	68.4
Q345B	2.759	100

The series of accelerated corrosion tests demonstrate that Baosteel's FRW steel possesses excellent corrosion resistant properties. Compared with common constructional steel, the longer the service time is, the more obvious the advantages are.

Weldability

Baosteel's FRW steel has good weldability, and can be used for construction without being pre-heated. Its weldability is equivalent to or even better than the conventional constructional steel of the same strength grade. Whether they are of manual shield metal-arc welding (SMAW), gas shielded metal-arc welding (MAG), or submerged-arc welding (SAW), satisfactory mechanical properties of joints can all be achieved. All welded joints of the FR steel have sufficient strength and good bend properties at room temperature and 600°C. The Charpy impact absorbed energy in the weld metal (WM), heat affected zone (HAZ) and fusion line (FL) are high enough in SAW joints and SMAW joints. See Table 2.

Table 7. Properties of various welded joints.

Welding process	Tensile strength		Bend		Charpy impact energy Akv, J		
	TS, N/mm^2	Fracture location	Bending direction (d=3a, 100º)	Judgment	WM	FL	HAZ
SMAW	520,550	Base metal	Surface bend	Good	218	240	225
SAW	520,505	Base metal	Surface bend	Good	98	85	110
MAG	495,480	Base metal	Surface bend	Good	180	106	168

The project practice demonstrates that Baosteel's fire-resistant weathering steel can be used for different forms of joints in constructional steel structure.

Fire Resistance

Figure 1 shows the temperature dependence of strength.

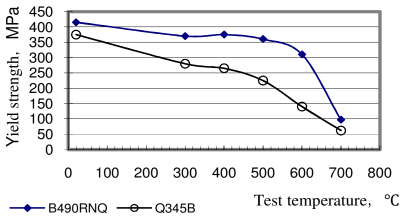

Figure 1. Series elevated temperature tensile property.

The high temperature behavior of B490RNQ is better than that of Q345B with the same strength level by a remarkable margin. The FR steel B490RNQ has a smaller decrease of strength at elevated temperature than the conventional steel Q345B, retaining more than two-thirds of the room temperature yield strength even at 600°C.

<u>Fire test</u>

The residential building block of Shanghai Zhongfu City Project used more than 5000 tonnes of B490RNQ produced by Baosteel. According to the fire fighting requirement, 2 pieces for each of the 2 kinds of solid structural parts made of Baosteel's FRW steel B490RNQ underwent fire tests in Tianjin National Fixed Fire Extinguishing System and Fire-Resistant Structural Parts Quality Supervision and Inspection Center. The test standard is followed GB/T9978-1999 fire test method for constructional structural parts.

Test conditions:

- Furnace temperature control: the fire test adopts open firing, so that the flame effect that the test sample experiences is similar to that in a real fire.
- Test load: the load is set according to the actual load bearing of the project. The axis withstands the pressure, and the load value is 2000KN and 2500KN.
- Fire receiving sides: four side faces and bottom side
- Test structural parts: Φ400×10, steel tube wrapped with 50mm thick C20 pea gravel concrete in the outside, and Φ350×10, steel tube wrapped with 50mm thick C20 pea gravel concrete on the outside.

(If fire resistant steel is not used, in order to guarantee the 3h fire resistant extreme limit, 100-150mm thick concrete must be wrapped in the outside.)

B490RNQ possesses excellent fire resistant properties. According to the requirements of the national fire fighting standard, the fire resistant extreme limit of the structural parts of high-rise buildings must reach 3 hours. To reach 3-hour fire resistant extreme limit with the structural parts made of common steel (the deformation of structural parts after 3 hours at the elevated temperature of 1100°C shall be less than 40mm), the refractory wrapping must be 100mm thick at least. While the use of structural parts made of Baosteel's FRW steel can reduce the thickness of refractory wrapping by more than 1/2, and there is no deformation after 4 hours at the elevated temperature of 1100°C, which indicates that both of the fire resistant extreme limits of the two kinds of structural parts Φ350×10 and Φ400×10 made of Baosteel's B490RNQ reach 4 hours, going beyond the highest requirement in fire fighting for buildings. The relevant architectural experts have given a high appraisal to the results.

Conclusions

Since 1999, Baosteel's FRW steel has been supplied to many users for the construction of industrial buildings and civil architecture. During that period, Baosteel has carried out many welding tests, process evaluation and fireproof tests jointly with the relevant owners and engineering units. The practice proves that Baosteel's FRW steel can satisfy completely the users' requirement in terms of welding, shaping, earthquake resistance, fire resistance and weather resistance, and is the premium product among the constructional steel.

References

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