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APPLICATION STATUS OF AUTOMOBILE NIOBIUM STEEL SHEETS IN CHINA

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Abstract

Nb microalloyed hot and cold rolled steel sheets are used in the automobile industry. With the development of metallurgical industry in China, the research on Nb alloyed steel began in the 1960s and numerous Nb steel grades have been developed after the 1980s. Hot rolled Nb alloyed steel sheet grades are mainly used according to the following specifications:

- QSTE340TM - QSTE500TM (Nb-Ti) for structural applications,
- 420L - 610L (Nb) for beams,
- RCL420(Nb) for wheels,
- DP steel RS50, 490SXR, 540SXR
- 440QZR and 480QZR (Nb) for drive tubes, etc.

Through precipitation and grain refinement, higher strength, excellent ductility, and stable performance has been achieved for hot rolled Nb alloyed steels. Therefore, these steel sheets have been widely applied in the Chinese automotive industry since the 1990s.

The production of interstitial free steel (IF steel) started in the 1990s in China. Based on IF steel sheets, ULC-BH (Nb) and high strength IF steel (Nb-Ti) were produced by using Ti and/or Nb to fix the interstitials. Due to excellent deep drawing and extra-deep drawing properties, IF steel sheets have been applied in Chinese automotive industry. Another application for Nb steel sheets is cold rolled high yield strength steel sheets (Nb). This paper introduces the categories, properties and application of Nb alloyed steel sheets in the Chinese automotive industry.

Development of Automobile Product Mix in China

Niobium-bearing steel sheets used in automotive industry fall into two categories: hot rolled steel sheets and cold rolled steel sheets. Hot rolled steel sheets find their major application in truck (commercial vehicle) parts such as chassis and van body and in car parts (passenger vehicle) like suspension components and wheels, whereas the cold rolled sheets are mainly used for truck cab and car body applications.

A brief introduction of the development of automobile product mix is presented, which is essential for a better understanding of the steel requirements for the automobile industry as well as the development of steel applications.

First Automobile Works (FAW) was founded in 1953, and supplied the JIEFANG truck with a capacity of 40,000 kg in 1956 and a 50,000 kg capacity truck since 1987. Second Automobile Works (now renamed as DongFeng Motor Corporation) launched the DongFeng 50,000 kg truck in 1978. Medium-heavy duty trucks dominated the Chinese market until the mid-80s, while smaller numbers of light trucks and passenger cars were also produced. In 1985 Shanghai Volkswagen was founded. Since the mid-80s, China accelerated the development of passenger cars, light trucks and mini vans. Simultaneously, the increasing expansion of the expressway net led to the rapid development of medium-heavy and heavy trucks since the mid-90s. The output of automobiles in 2003 was 4,440,000, with the percentage distribution for passenger car, heavy truck, medium truck, light truck and mini van as follows: 45.4, 5.9, 3.1, 15.5 and 3.2, respectively [1].

Considering the state of automobile product mix mentioned above, the cold rolled steel used for medium duty trucks was mainly grade 08Al, as no IF steel was available at that time. Special emphasis was placed on the development of hot rolled HSLA steels sheets including Nb, V and Ti microalloyed grades, which were applied to frames, cross members and major structural parts. As a result of the rapid progress of passenger car production, the cold rolled Nb-bearing sheets (IF steel and HSLA steel sheets) found wide application in the automobile industry.

Beam Steel Sheets During 1950-1980 (Nb Free) [2]

Frame Steel

In 1956, the 30Ti steel grade was used for the production of frames, with a tensile strength (TS) of 45/56 kg/mm^2 and a yield strength (YS) of $\geq$ 32kg/ mm^2.

In 1958, Angang developed the HSLA steel grade 16Mn with a TS of 52 to 62 kg/mm^2 and a YS $\geq$36 kg/mm^2. The increasing strength allowed the use of thinner steel sheets, which contributed to a reduction of the frame weight by 13.12 kg. This was the first weight reduction exercise for truck beams.

In 1980, Shanghai No.3 Steel developed the grade 09SiVL grade by using V as a microalloying element.

FAW cooperated with Angang in 1972 and with WISCO in 1980 to develop the hot rolled 10Ti steel for frame applications. Later, WISCO developed the grade T52L (Ti microalloyed). However, these two Ti alloyed steel grades had a very limited application in the automotive industry.

In summary, the major steel grades used in the period from 1950 to 1980 for frame applications were grades 16MnL and 09SiVL.

Cross member Steel

In 1956 plain carbon steel grades such as grades 08, 20 andA3F were used to produce cross members.

In 1967 FAW cooperated with Angang to develop grades 16MnRe and 09MnRe substituting grades 20 and 08, respectively.

In 1972 FAW developed with Angang grade 13MnTiL replacing grade 16MnRe.

In 1974 FAW developed with Angang grade 10TiL replacing grade 09MnRe.

Ti microalloying technology was successfully applied to the production of cross member steel sheets in the 1970s. The average cross member weight was thus reduced by 10.38 kg, constituting the second weight reduction exercise.

Ti steel sheet

In the 1970s, the steel had high sulfur levels and was produced by using Ti as the major microalloying element. The effect of Ti in promoting sulphide shape control was the motivating factor. Ti steel sheets exhibit good cold bendability and formability. However, Ti had high affinity to oxygen, nitrogen, sulfur and carbon. Consequently, melting shop and rolling practices became complex in this time, contributing to an undesirable scatter band of mechanical properties in the final products. For instance, the yield strength of grade 10Ti sheets ranged from 30.5 to 52.5 kg/mm^2 and the tensile strength from 40.5 to 59.5 kg/ mm^2, while grade 13MnTi had a yield strength of 47 to 68 kg/mm^2 and a tensile strength of 55 to 75 kg/mm^2. Nevertheless, a large amount of Ti alloyed steel sheet was consumed by the automotive industry. Each unit of the 50,000 kg truck (1987 Type) consumed 200 kg of the grade 13MnTi sheet material and 196 kg of the grade 10Ti sheet material.

Nb-alloyed Sheet Material for Member Applications

Research and Development of Nb alloyed Steel in China

WISCO began the research and development of Nb alloyed steel in the mid 1960s, and produced 250,000 tons of Nb alloyed steels in 1996. Since 1987, WISCO developed Nb alloyed steel sheet for automotive applications and by 1996 six grades including WL510 for automotive member applications were commercially produced with a total output of around 10,000 tons [3]. Angang began its research on microalloyed steel sheet in 1964, and used domestic ferro-niobium until 1985 when it began purchasing FeNb from CBMM after recommendation by the China Iron and Steel Research Institute (CIRSI). Although many grades of Nb alloyed steel sheets had been developed by Angang only grade 06NbTi (Nb < 0.025%, YS ≥315MPa, TS 415-520MPa) finally found an application in the production of wheels before 1996 [4]. Baosteel commercially operated since the later 1980s and began the research of Nb alloyed steels with technical support from CBMM. By 1995, Baosteel had shipped more than 300,000 tons Nb steels [5]. Nb microalloying technology in combination with controlled rolling and controlled cooling practices were utilized to produce steel sheets for automotive applications. In addition, Jinan Steel and Chongqing Steel had also done some research on Nb alloying.

Nb-alloyed steel sheet for member applications [6]

The first structural automotive Nb alloyed steel grades produced by Baosteel were QSTE340TM - QSTE500TM complying with the specification of SEW092. In 1991, FAW used QSTE340TM to make cross members and QSTE420TM to make frame parts, where alternative microalloying designs, i.e., either Nb ≤0.09 or Ti 0.07-0.14 where applied. The subsequent optimization of the alloy design allowed using the combined microalloying concept Nb+Ti (Nb ≤0.09, Ti ≤0.22). However, QSTE420TM exhibits a high yield strength and a high yield ratio which is not suitable for automotive end-users. Therefore, Baosteel further developed the B420L-B550L grades for the production of members.

In 1992, FAW used grade B510L to make frame parts.

In 1993, FAW used grade B420Lfor cross members.

In 1994, FAW made trials with grade B550L to increase the strength of member parts.

In 1994-1995, FAW and Baosteel conducted trial productions of the dual phase (F+B) steel grades B490SXR, B540SXR (Nb≤0.045) which were developed to make cross members for medium size trucks and frame parts for light trucks.

WISCO began in 1993 to produce grades WL510 and WL440, and in 1995 to produce the Nb alloyed steel grade WL540 for member parts.

In 2000, Angang produced a family of A510L (Nb steel) grade and in 2002 developed with FAW grade A610L (Nb-Ti) designed particularly for heavy truck applications.

The grades QSTE420TM, 510L and 610L are used for frame parts while QSTE340TM, QSTE380TM and 420L are used for cross members. All these grades contain niobium. Their chemical compositions and mechanical properties are given in Table I.

In 2004, the total output of automotive steel sheets for structural applications by four steel producers in China, namely, Panzhihua Steel, Angang, Baosteel and WISCO reached 800,000 tons. The share of Nb and Nb-Ti alloyed steel was 470,000 tons or 58.75%. The output of the Nb-only added steel grade 510L was 420,000 ton. Presently most of the steel used for frame parts in heavy trucks is grade 510L and 610L, some are made from V alloyed steel (P510L) and Mn alloyed steel (16MnL). The steel grades for cross members are Nb-bearing QSTE340TM and QSTE380TM or 420L. However, steel of much higher strength for member parts is under development.

The Nb-bearing beam sheet exhibits excellent performance.

- Stable properties. Table II presents the properties of grade B510L produced by Baosteel since 1995 [6].
- Low ductile to brittle transition temperature (DBTT). The impact test of grade WL510 from WISCO is shown in Table III [8]; the DBTT is less than –100ºC.
- High fatigue resistance. Table IV gives the result of fatigue test of grade WL510, whose fatigue resistance is superior to grades16MnL and T52L.

Table I. The chemical composition and mechanical properties of Nb-bearing beam steel.

Grade	Composition (wt.%)							Mechanical properties			
	C	Si	Mn	P	S	Nb	Ti	YS Mpa	TS Mpa	A_{50} %	180° Cold bend B ≥ 35mm
QSTE340TM	≤0.12	≤0.50	≤1.30	≤0.030	≤0.020	≤0.09	≤0.22	≥340	420-540	≥25	d=0.5t
QSTE380TM	≤0.12	≤0.50	≤1.40	≤0.030	≤0.020	≤0.09	≤0.22	≥380	450-590	≥23	d=0.5t
QSTE420TM	≤0.12	≤0.50	≤1.50	≤0.030	≤0.020	≤0.09	≤0.22	≥420	480-620	≥21	d=0.5t
420L	≤0.12	≤0.50	≤1.20	≤0.030	≤0.025	≤0.04		≥305	420-520	≥25	d=0.5t
510L	≤0.16	≤0.50	≤1.60	≤0.025	≤0.025	≤0.04		≥355	510-610	≥24	d=0.5t
610L	≤0.12	≤0.50	≤1.70	≤0.030	≤0.025	≤0.09	≤0.22	≥500	550-700	≥22	d=t

(d: Bending diameter, t: Thickness, B-Width)

Table II: The properties of grade B510L

Grade	σ_s /MPa			σ_b /MPa			σ_s/σ_b			δ_5 / %		
	min max	AVG	σ	min max	AVG	σ	min max	AVG	σ	min max	AVG	σ
B510L	405 495	451	16.2	520 600	558	14.0	0.78 0.86	0.80	0.016	24 32	27	1.8

Table III: Impact results of grade WL510

Temperature (°C)	RT	0	-20	-40	-60	-78	-100
Akv (J)	50	51.2	46.9	48	40.7	36.7	29.8
Fibrous structure (%)	100	100	100	100	100	100	85

Table IV: Fatigue resistance of grade WL510

Grade	Thickness /mm	σ_r /MPa	σ_b /MPa	σ_r/σ_b
WL510	6.5	450	560	0.80
16MnL	6.5	426	633	0.67
T52L	6.0	400	512	0.78

Other Hot Rolled Nb Steel Sheets

Steel for passenger car wheels

Angang produced grades LQ330 and LQ370 (Ti or Nb microalloyed, Nb ≤ 0.02%).

WISCO produced grade RCL420 (Nb ≤ 0.03%) and the hot rolled dual phase steel grade RS50 (Nb 0.01-0.06%).

Hot strip for automobile drive tube

Hot rolled strip is used to make heavy truck drive tubes via electric resistance welding. In the 1990s only a few types of steel strips were available for drive tube manufacturing. In 1991 the two automobile makers, FAW and Dong Feng Motor had a close cooperation with Baosteel for a trial production of grade BQZ-1 (Ti ≤ 0.15%), and with WISCO for a trial production of grade 08Zh (Ti = 0.04-0.11%). At that time, Nb-bearing steel strip corresponding to grade 16MnNb was imported from Japan. Baosteel developed grades B440QZR and B480QZR (Nb 0.008-0.015%) designated for drive tube manufacturing.

Steel sheet for rear axle housing

Rear axle housings of heavy trucks used to be made of cast iron. Now, for some truck models steel sheet is utilized and manufactured by stamping and welding. Baosteel and WISCO developed the following steel grades for rear axle housing applications:

- B44QK (Nb-Ti) for light trucks.
- WQK540 (Nb ≤ 0.05%) for medium-heavy trucks.

Cold Rolled Nb Steel Sheets

Development of cold rolled Nb steel sheet for the Chinese automotive industry

Before 1980, the principal cold rolled material came from the 08AL family of steels representing a variety of drawing grades.

China developed P-alloyed steels in the 1980s [9], with a variety of tensile strengths such as 340, 370, 400 and 420 MPa. The bake hardening steel BH340 was developed in the 1990s [10]. These steel grades reflect the development of HSLA steels, but showed unsatisfying formability.

The high pace in the modernization of the automobile production and the demand of parts with more complex shape required a higher formability cold rolled material. Japan commercialized the IF steels in the 1980s. In 1990, the global output of IF was up to 7 million tons. Based upon this IF steel development, ultra-low carbon high strength steel and ultra-low carbon bake hardening steels were developed. Electro-galvanized and hot-dip galvanized steel was produced using IF steel as a substrate.

From the mid-1980s to the mid-1990s the major car models produced in China included the Santana, Jetta, Audi100 (Germany), Fukang ZX, Peugeot 504 (France), Xiali (Japan) and Cherokee (USA). Twenty to 40 kg of galvanized sheet was used in the car bodies of the Santana and Jetta. The volume fraction of galvanized sheet has meanwhile reached 81% of the total body-in-white (BIW) weight of the model Audi 100. Electro-galvanized (EG) sheet is used for outer surface parts while hot-dip galvanized (GI) sheet is applied for inner parts. An estimated 79.4% of total BIW weight of the model Fukang ZX is made of galvanized sheet containing 75.8% GI sheet. The body of the Xiali car is made of EG Zn-Ni and galvannealed (GA) material where outer surface parts are made of BH steel. For the Cherokee, the share of galvanized sheet amounts to 70% of the BIW weight, where outer surface parts are made from EG and inner parts are made from GI material. High strength GI sheets are also used (YSof 343 or 412 MPa). More than 40% of the passenger car bodies are made of IF steels (including mild steel, high strength steel, BH steel and coated IF based sheets), and drawing grades include EDDQ and SEDDQ.

From the later 1990s until now, foreign automobile producers increased their investments for car production in China by means of joint ventures or cooperations. Numerous brands of passenger cars are currently being produced in China with the following implications for the use of cold rolled automotive steel:

1. The application of coated steel sheet has increased. For some car models, the entire body is made of coated steel sheet, while others use GI or GA to make outer parts.
2. The application of BH sheets on outer parts has increased.
3. The steel strength for inner parts has increased. Most of steel sheets have a tensile strength of 440MPa, while some reinforcement parts utilize 590 MPa steel or even more than 1000 MPa tensile strength.

It should also be noted that most of the automobile plants in China can supply only 20-50 or maybe 100 types of parts, which mainly concern closures and some other inner parts. However, many of the required CKD inner parts are still imported. Therefore, it can be readily assumed that a large amounts of the IF, BH and coated steel sheets will be consumed to make outer parts, while the demand for HSLA, DP and TRIP steels used for inner parts is very small.

Development of IF steel in China

Baosteel began developing IF steel in 1988 and commercialized its products in 1990. In 1992, Baosteel developed grade ST16, followed by grades BSC2, BSC3 and ST14-T. In 1994, high surface quality sheet ('O5') was successfully developed. The ultra-low carbon high strength sheet steel B1F340 was developed in 1996 and ULC-BH in 1999. In 2001, Baosteel produced 700,000 tons of IF steel (crude steel). Before the mid-1990s Baosteel was capable of supplying only 30-50% of the cold rolled sheets needed for car body and most of coated steel sheets were imported. From 1996 to 1998 Baosteel cooperated with FAW on improving IF steel properties and was thereafter capable of supplying more than 90% of cold rolled sheet needed for car bodies [11]. With the expansion project put into action in 2000, Baosteel produced a variety of IF, ULCHSS, ULCBH and EG, GI and GA sheets satisfying the requirements for car body application. As a result, the amount of imported sheet material was reduced remarkably. In 2004, the output of IF steel (crude steel) was 1,480,000 tons of which 20.5% was Nb-Ti IF steel. The IF steel family includes Ti-IF (Ti ≤0.20%), Nb+Ti-IF (Nb+Ti ≤0.20%) and ULC-HSS (Ti ≤0.20% or Nb+Ti ≤0.20%) and ULC-BH (Nb ≤0.10%). Nb-alloyed galvanized (GI) sheet includes EDDQ DC56D+Z (Nb≤ 0.10%, Ti ≤0.10%), HSLA steel H300LAD+Z to H420LAD+Z (Nb ≤0.09%, Ti ≤0.15%) as well as HR340LAD+Z and HR420LAD+Z (Nb ≤0.09%). The latter two grades are GI coated hot rolled HSLA steels. Also GA material is being produced.

WISCO began to develop the IF steel WIF (Ti 0.03-0.08%) in 1990 and mass production started in 1998. The output of WIF in 2000 was 50,000 tons. Later WISCO developed the deep drawing galvanized IF steel WSX (Nb <0.015%, Ti <0.08%) and also the galvannealed IF steel WSXH (Nb <0.015%, Ti <0.08%). The new cold rolling and galvanizing lines will be taken into service soon.

Angang began to produce IF steel in 2002 and reached an output of 700,000 tons in 2004, of which 500,000 tons is applied in the automotive industry. 10% of the IF steel is Nb-Ti IF. The No.1 cold rolling mill had been upgraded, No.2 has been taken out of service, and a new one will be finished soon. A joint venture with ThyssenKrupp Steel has already produced GI and GA sheets.

Guangzhou Iron & Steel Company set up a joint venture with JFE to produce hot-dip galvanized sheet.

Other cold rolled Nb steel sheet for the Chinese automotive industry

HSLA steel

Baosteel produces B340LA and B410LA (Nb ≤0.09%) having tensile strengths of more than 440 MPa and 590 MPa, respectively. These two steels are used for reinforcement parts in passenger car.

High yield strength steel

WISCO offers grades GQ280 (Nb ≤0.06%), GQ320 (Nb ≤0.08%) and GQ350 (Nb ≤0.08%) with tensile strengths of more than 380 MPa, 415 MPa and 420 MPa, respectively. These steels are used for the production of reinforcement-brackets and other parts.

DP, TRIP steel

So far, China does not mass-produce Nb-alloyed DP and TRIP steels. Northeastern University together with BenXi Steel performed trial productions of DP steel for wheels. Some Si-Mn DP steels such as B340/590DP and B400/780DP by Baosteel have been used in the automobile industry for reinforcement parts.

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