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Steel Products for Construction, Industrial Machinery and Plant†

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Abstract:

In the fields of construction and industrial machinery, the use of higher strength steel is promoted in view of the needs for reducing weight. JFE Steel has been developing and manufacturing steel plates, steel bars and welding consumables having properties suitable specifically for the above-mentioned fields. In the field of power generation plant, materials applicable to highly efficient power generation is required. High Cr alloy steel pipes having improved high-temperature strength and resistance to oxidation have been developing and manufacturing for the heat recovery steam generator. With high appreciation in the market, the production amount of these products have been increasing. This paper describes the product design and the properties.

1. Introduction

In the construction machinery industry, steels with the higher strength levels available are used in equipments such as cranes, dump trucks and power shovels to reduce weight. JFE Steel has developed and manufactured a wide range of steel plates, bars, and welding consumables for this field. In the field of thermal power plants, materials which contribute to high efficiency power generation are required. For this industry, JFE Steel has developed and manufactured high Cr alloy steel tubes with improved elevated temperature strength and oxidation resistance.

This report describes the design concepts and properties of the above-mentioned products.

2. Steel Plates

2.1 New High Strength Steel for Construction and Industrial Machinery "JFE-HITEN 780LE"

To the steel plates for construction and industrial machinery, there is a strong need for high strength for weight reduction in the equipment structure. For example, high strength steel plates with 780 MPa in tensile strength are frequently used in parts such as crane booms and outriggers. The requirements placed on these high strength steel plates have diversified in recent years, as exemplified by low temperature toughness to enable use in cold districts and improved weldability by lowering preheating temperature for welding. Improved formability is also required in many cases. Furthermore, the cost of satisfying these requirements of performance has also become a major premise.

To meet these needs, JFE Steel has developed and commercialized a 780 MPa steel plate, JFE-HITEN 780LE with good weldability and low temperature toughness guaranteed at −40°C which are superior to that of conventional products.

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Table 1 Specifications of JFE-HITEN780LE

Thickness (mm)	YS (MPa)	TS (MPa)	vE_{-40} (J)	C_{eq}* (mass%)
6 –19	≧685	780–930	≧40	≦0.40
19.1–32				≦0.43

* C_{eq} = C+Mn/6+(Cu+Ni)/15+(Cr+Mo+V)/5

Table 2 Typical Chemical composition of JFE-HITEN780LE

(mass%)

C	Si	Mn	P	S	Others	C_{eq}
0.15	0.38	1.18	0.012	0.002	Nb, V, Ti, etc.	0.39

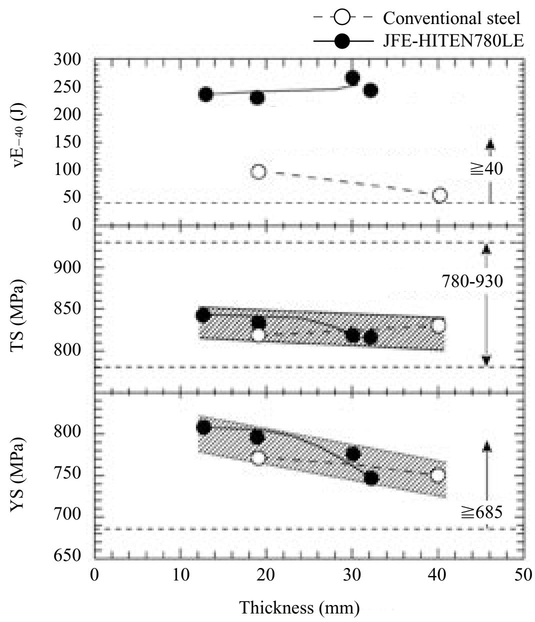

Fig. 1 Mechanical properties of JFE-HITEN780LE

The specifications of JFE-HITEN780LE are shown in **Table 1**. Considering actual use conditions, the maximum thickness of 32 mm is available, and to ensure weldability, the maximum carbon equivalent (C_{eq}) is set at 0.40 or 0.43%, depending on the plate thickness. In consideration of use in cold districts, Charpy absorbed energy at −40°C is guaranteed.

The typical chemical composition of the developed steel is shown in **Table 2**. The low temperature toughness of 780 MPa class high strength steel plate has been dramatically improved by integrating the technologies of microalloying and thermo-mechanical control process (TMCP) followed by controlled heat treatment, as represented by JFE Steel's *Super*-OLAC (on-line accelerated cooling) technology.

The strength and low temperature toughness of this plate are shown in **Fig. 1**. It has an adequate strength as a 780 MPa high tensile strength steel, combined with toughness significantly exceeding that of conventional steel plates. As shown in **Table 3**, it also possesses outstanding formability, with no cracking in the bending test whose bending radius is 1.5 times of the plate thickness, even in the more severe test condition with 200 mm width.

Table 3 Bending test results of JFE-HITEN780LE (Bending radius : 1.5 t)

Thickness (mm)	Specimen size, $t \times w$ (mm)	Direction	Result
12.8	(Full thickness)×38	L	Good
		C	Good
	(Full thickness)×200	C	Good
32.0	(Full thickness)×38	L	Good
		C	Good
	(Full thickness)×200	C	Good

The developed steel plate is the first in the world to guarantee toughness at −40°C in the field of high strength steel plates for construction and industrial machinery, and thus, in addition to applicability in cold districts, is also an outstanding product in terms of impact resistance and safety. Because C_{eq} is reduced to secure weldability, the preheating temperature in CO_2 welding can be reduced to 25°C or lower, making it an excellent product in terms of weldability as well. Moreover, with good formability, it can be applied in a wide range of parts.

2.2 New Abrasion Resistant Steel "JFE-EH-LE Series"

High abrasion resistance is strongly desired in parts such as the bed of a dump truck and the bucket of an excavator which are subject to abrasion by ore, rock or sand. Because abrasion resistance has a correlation with surface hardness, abrasion resistant steel plates with high surface hardness are used in this type of application.

Low temperature toughness and good weldability have also been demanded in abrasion resistant steel plates in recent years. For these needs, JFE Steel has developed two abrasion resistant steel plates, JFE-EH 360LE and JFE-EH500LE, which offer excellent economy and have improved weldability in comparison to conventional products, combined with low temperature toughness guaranteed at −40°C.

The specifications of JFE-EH360LE and JFE-EH 500LE are shown in **Table 4**. As well as JFE-HITEN 780LE, the maximum plate thickness of 32 mm is avail-

Table 4 Specifications of JFE-EH360LE and 500LE

Grade	Thickness (mm)	HBW (10/3 000)	C_{eq} (mass%)
JFE-EH360LE	6 –19	361–440	≦0.40
	19.1–32		≦0.43
JFE-EH500LE	6 –19	477–556	≦0.55
	19.1–32		≦0.58

Charpy absorbed energy value is guaranteed at −40ºC

Table 5 Typical chemical composition of JFE-EH360LE and EH500LE

(mass%)

Grade	C	Si	Mn	P	S	Others	C_{eq}
EH360LE	0.15	0.41	1.20	0.013	0.002	Nb,V,Ti,etc.	0.39
EH500LE	0.26	0.31	1.33	0.010	0.002	Nb,V,Ti,etc.	0.53

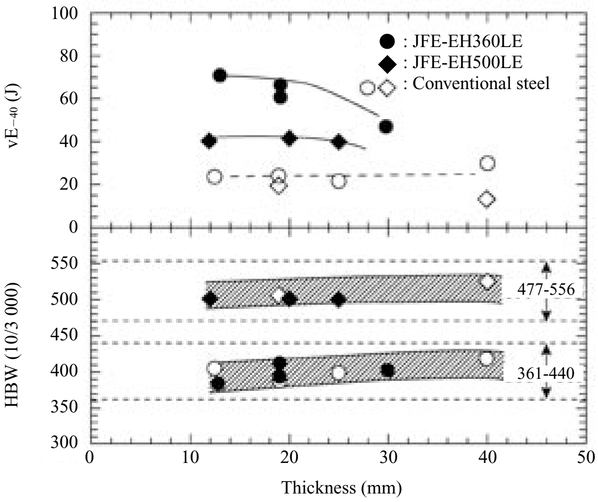

Fig. 2 Brinell hardness test results and Charpy impact test results of JFE-EH360LE and EH500LE

able which is sufficient to actual use conditions, and the absorbed energy value at −40°C is guaranteed and C_{eq} is reduced for weldability.

The chemical compositions of the developed steels are shown in **Table 5**. The optimum C content, C_{eq}, and hardenability were selected in consideration of the balance of surface hardness and weldability, and microalloying elements were added to refine prior austenite grain size. The hardness and low temperature toughness of these steel plates are shown in **Fig. 2**. It indicates that the developed steels have surface hardness equivalent to that of the conventional steel plates, combined with extremely good low temperature toughness for abrasion resistant steel plates.

JFE-EH360LE and JFE-EH500LE are the first abrasion resistant steel plates in the world with guaranteed toughness at −40°C, and can be used in cold districts as well as JFE-HITEN780LE.

3. Tubular Products

3.1 Super 9Cr Tubes for Thermal Power Plant Boilers

Modified 9Cr-1Mo steel tubes with high strength at elevated temperatures and oxidation resistance (ASME SA213 T91, abbreviated SA335 P91 or super 9Cr steel) are frequently used in high temperature boilers for high efficiency power generation.

Table 6 Permissible variation

Tolerance of outside diameter (mm)			
ASME 450		Super hot	
OD	Tolerance	OD	Tolerance
≦101.6	+0.4 −0.8	≦50.8	±0.25
		≦76.8	±0.30
		≦101.6	±0.40

Tolerance of wall thickness			
OD (mm)	Wall thickness (mm)	SA450 (%)	Super hot (%)
≦101.6	≦2.4	0/+40	0/+35
	≦3.8	0/+35	0/+28
	≦4.6	0/+33	0/+24
	4.6<	0/+28	0/+22

ASME450 : Standard specification for general requirements for carbon, ferritic alloy, and austenitic alloy steel tubes

Super hot : Hot-finished seamless tube with narrow dimensional tolerance

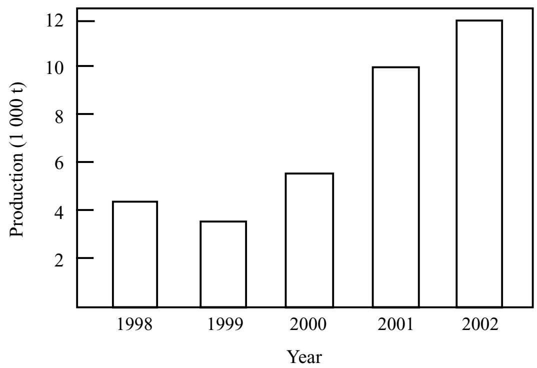

Fig. 3 Supply trend of modified 9Cr steel pipe

Since beginning production of steel tubes by the Mannesmann rolling process in the second half of the 1980s, JFE Steel's achievements in this field include (1) development of high dimensional accuracy steel tubes (Super Hot Tube; shown in **Table 6**) with narrow dimensional tolerance of outer diameter and wall thickness, (2) development of production technology for ultra-long tubes with lengths of over 22 m for application to heat recovery steam generators with environment-friendly and high generating efficiency, (3) development of production technology for ultra-heavy wall steel pipes with 35–50 mm thickness for applications such as main steam pipes and headers, and (4) improvement of NDI equipment for allover quality assurance system, etc. as products which respond to the requirements of the times. As a result, the company has steadily accumulated its supply record, as shown by the example in **Fig. 3**.

3.2 W-added 2.25%Cr Steel Tubes

In 2001, a W-added 2.25%Cr steel was registered in the ASME standard as a new steel grade for boiler tubes

Table 7 Chemical composition of T23

(mass%)

C	Mn	P	S	Si	Cr	Mo	V	Nb	W	B	N	Al
0.04–0.10	0.10–0.60	Max. 0.030	Max. 0.010	Max. 0.50	1.90–2.60	0.20–0.30	0.20–0.30	0.02–0.08	1.45–1.74	5–60 ppm	Max. 0.030	Max. 0.030

Table 8 Tensile properties

	T23		T22	
	YS (MPa)	TS (MPa)	YS (MPa)	TS (MPa)
Spec.(RT)	≧400	≧510	≧205	≧415
RT	505	613	286	495
400°C	434	558	280	498
550°C	403	455	249	395
600°C	354	401	199	298

(ASME SA213 T23; shown in **Table 7**). This material is a 2.25%Cr-Nb-V steel with a high W content and has significantly improved high temperature strength in comparison to the conventional 2.25%Cr-1%Mo steel.

JFE Steel applied a patent[1)] for the chemical composition of this steel in 1986. The company began studying standardized production in the 1990s and is now gradually increasing its record of shipments. The features of the steel tube manufactured by JFE Steel are as follows:

(1) Good weldability without preheating or post-heat treatment owing to low C composition.

(2) High resistance to cracking in heat affected zone (HAZ) owing to low C - low N composition.

(3) High creep rupture strength at elevated temperatures owing to minimized Al content.

Since the various physical properties of this material such as thermal conductivity, coefficient of linear expansion, etc. are on the same order as the conventional 2.25%Cr-1%Mo steel, and it has the distinctive features of high strength at room temperature/at elevated temperature (**Table 8**) and high temperature creep strength, when applied to the same parts as conventional steel tubes, thin-wall/lightweight steel tubes can be used. As a result, substantial economic benefits can be expected, including reduction of costs of welding, steel product purchasing and installation/transportation.

JFE Steel's high Cr alloy steel tubes are produced on a manufacturing line which has respective advantages and superiority in the steelmaking and casting process for pipe-making material, hot rolling process, and quality assurance system, and are high quality products with high reliability.

4. Microalloyed Steel Bars and Wire Rod Material for Industrial Machinery

4.1 High Strength Microalloyed Steel for Direct Cutting

Microalloyed steels which make it possible to omit heat treatment of carbon steel and alloy steels have been widely used in recent years. This section describes a new 900 MPa class steel for direct cutting, NH48MV, which was developed by JFE Steel as a substitute for the quenched and tempered material SCM 440. Main applications are injection molding machines which use large-diameter round bars, die-cast tie-bars, screws, and cylinders, output shafts for gearboxes, and various other types of shaft. In order to obtain high strength, solid-solution strengthening by dissolving Mn and Cr in the matrix and precipitation strengthening by precipitating fine carbides of V in the matrix are used simultaneously. An example of chemical composition is shown in **Table 9**.

Among mechanical properties, this steel has tensile strength of 930–990 MPa independent of bar diameter and a stable hardness (HB) of 270–280, as shown in **Table 10**. In quenched and tempered materials, mechanical properties are lower in the material interior. In contrast, the developed steel has a high degree of internal homogeneity through the entire cross-section, as seen in **Fig. 4**, resulting in the very uniform properties mentioned above. The impact value decreases somewhat in larger-diameter bars, but a value of approximately 60 J/cm is secured in 100 mm dia. bars. As shown in **Fig. 5**, machinability (tool life) is improved in comparison to the quenched and tempered SCM 440.

Table 9 Chemical composition of NH48MV

(mass%)

C	Si	Mn	P	S	Cr	V
0.46–0.50	0.10–0.30	1.30–1.60	≦0.020	0.020–0.050	Added	Added

Table 10 Mechanical properties of NH48MV (60–190 mmϕ)

YS (MPa)	TS (MPa)	El (%)	Hardness (HB)	Impact energy (J/cm^2)
610–670	930–990	16–22	270–284	40–64

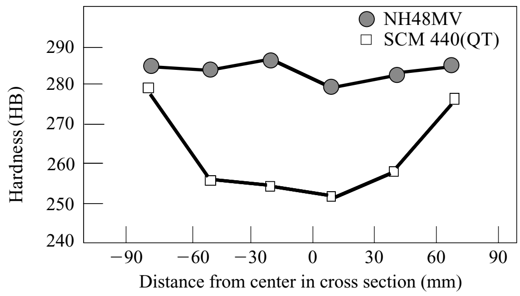

Fig. 4 Hardness distribution in 190 mmϕ bar

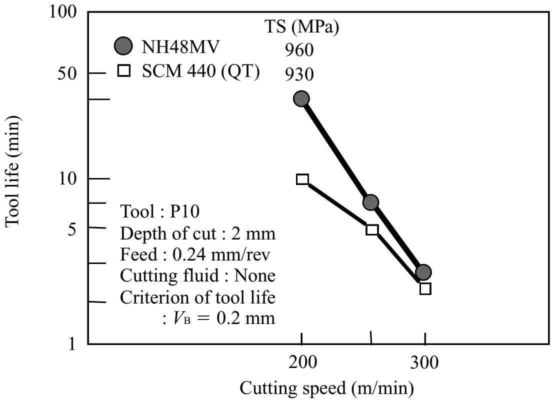

Fig. 5 Result of tool life test in cutting

4.2 Bainitic Microalloyed Steels for Hot Forging

The machine structural parts made of carbon and alloy steels are conventionally manufactured by quenching and tempering. From the viewpoints of resource saving, cost reduction and energy saving, however, JFE Steel developed bainitic microalloyed steels as substitute materials which enable omission of these heat treatment processes. They are the microalloyed steels with bainite structure in the as-hot forged and air cooled condition. High toughness is obtained by reducing the C content, while high strength is secured by adding Mn, Cr and V together with grain refinement through the addition of Ti. **Tables 11** and **12** show examples of chemical composition and mechanical properties, respectively. These steels are applied to machine parts (shafts) of construction machinery.

4.3 TQF Steel Bars

The TQF steel bars with strength combined and toughness is produced by direct quenching (accelerated cooling) in a water cooling device after finishing rolling, which make tempered martensite structure in the surface layer and fine ferrite-pearlite structure in the interior by the self-tempering effect of the retained heat in the interior after the bar has passed through the water cooling device. As advantages, uniform austenitization can be obtained in a short time in high frequency quench heating by the customer, and deviations in the depth of and hardness in the hardened layer are slight. Fatigue durability is also satisfactory. **Figure 6** shows an example of the cross-sectional hardness distribution of an 85 mmϕ. TQF bar. This steel is used in piston rods, pins, and shafts for construction equipments such as power shovels, bulldozers.

Table 11 Examples of chemical composition of bainitic microalloyed steels

(mass%)

Steel	C	Si	Mn	P	S	Cr	Ti	V
TBH800	0.18	0.29	1.78	0.016	0.025	0.59	Added	Added
TBH900	0.25	0.20	1.89	0.016	0.058	0.59	Added	Added

Table 12 Examples of mechanical properties of bainitic microalloyed steels

Steel	Size	YS (MPa)	TS (MPa)	El (%)	RA (%)	Hardness, HB	Charpy impact value, vE_{20} (J/cm^2)
TBH800	60 mmϕ	566	820	21	51	247	78
TBH900	60 mmϕ	683	930	18	49	287	64

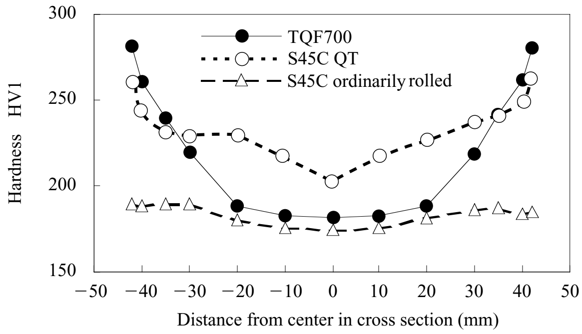

Fig. 6 Example of hardness distribution in 85 mmϕ bars

5. Low Spattering Welding Technology

A rapid progress has been made in realizing automation and higher efficiency in gas shielded metal-arc welding, and the reduction of spatter during welding has also been strongly required. To meet this need, JFE Steel has developed various types of welding solid wire which minimize spatter generation, the examples of which are shown in **Table 13**. All of these welding solid wires are produced using a manufacturing technology developed exclusively by JFE Steel, in which K is added to the interior of the wire during its drawing process.

Gas shielded metal-arc welding methods are broadly classified as CO_2 gas shielded arc welding which is a low cost, high efficiency method, and Ar-CO_2 gas shielded arc welding, which enables high quality welding. The welding solid wires KC-50DH and KC-55G are used in CO_2 gas shielded arc welding. The addition of K decreases the potential gradient of the welding arc, sup-

Table 13 Low spatter welding wires

JIS Z3312	Shielding gas	Strength	Brand name
YGW-11	CO_2	490 MPa	KC-50DH
YGW-18	CO_2	540 MPa	KC-55G
YGW-15	Ar-20%CO_2	490 MPa	KM-50SH
YGW-17	Ar-20%CO_2	420 MPa	KM-50S

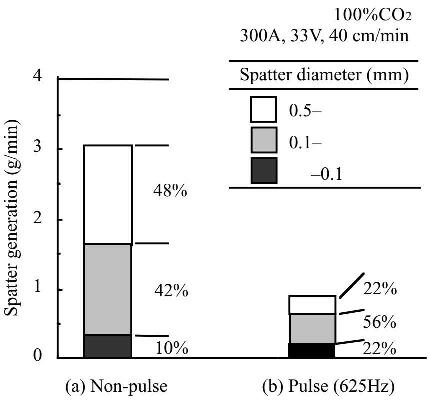

Fig. 7 Spatter generation in non-pulse and pulse CO_2 arc welding

pressing concentration of arc at the bottom of a droplet (molten part of the wire tip formed by heat of the welding arc), which reduces spatter. KM-50SH is used in Ar-CO_2 gas shielded arc welding. The addition of K promotes spray transfer, realizing low spatter welding. With KM-50S, which is used in pulse Ar-CO_2 gas shielded arc welding, the addition of K achieves spatter-less welding.

For CO_2 gas shielded welding, JFE Steel developed a high frequency pulse welding method which reduces spatter by approximately 70%, as shown in **Fig. 7**. This device achieves ultra-low spatter by causing vibration of the suspended droplet using a high frequency pulse in the welding current and optimization of the chemical composition of wire, and further, by refining the size of the transferred droplet by applying a strong electromagnetic pinch force during the pulse peak period.

6. Conclusions

All of the products described herein have been highly evaluated in the Japanese and foreign markets for their unique product design matched to customer needs, high performance and high quality. As a result, their production volumes are increasing. The terms of construction/industrial machinery and plant products encompass a wide range of objects with diverse requirements. For the future, JFE Steel is committed to developing products with a high degree of uniqueness which meet these diverse market needs by applying state-of-the-art equipment and an advanced quality control system.

Reference

1) Kawasaki Steel Corp. Jpn. Kokoku 6-6771.