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Typical Properties on SBHS 500 Produced by Nippon Steel & Sumitomo Metal Corporation

Ryuichi ANDO* Mutsuto TANAKA
Masahide TAKAGI Koji HOMMA

Abstract

Nippon Steel & Sumitomo Metal Corporation has been leading the way in the ground design, standardization and realization for SBHS. Nippon Steel & Sumitomo Metal supplied around 22 000 tons of SBHS for the advanced steel bridges in Japan. This paper presents their superior performance along with recent activities on the application.

1. Introduction

As high-performance steel plates that contribute to the construction of rational steel bridges, JIS G 3140: Higher Yield Strength Steel Plates for Bridges (SBHS) was enacted in 2008. Concerning the SBHS steel plates shown in **Table 1**, Nippon Steel & Sumitomo Metal Corporation has been playing the leading role in the formulation of performances required of SBHS and the standardization and practical application of SBHS ever since the enactment of JIS G 3140. The company manufactured and shipped approximately 17 000 tons of steel plates compatible with BHS—the predecessor of SBHS—for Rinkai Chuo Bridge (tentatively named "Namboku Suiro Odanbashi") and Tokyo Gate Bridge (tentatively named "Tokyo-ko Rinkai Ohashi"), both on Tokyo Port Seaside Road. That spurred the movement to enact JIS G 3140 mentioned above and reflect SBHS specifications in various design standards. Consequently, activities to spread SBHS were pressed ahead in diverse fields.

Table 1 Progress in standardization and practical use of SBHS

Year	Events
1994 – 2000	Basic concept of high performance steel for Japanese steel bridges was established by an industry-government-academia bridge research group.
2003	BHS 500 and 700 was proposed based on the established concept.
2004	BHS 500 and 700 were incorporated to NETIS (New Technology Information System).
2005	The Japan Iron and Steel Federation standardized BHS 500, 500W and 700W.
2006	First use of BHS 500 in Japan. Nippon Steel & Sumitomo Metal supplied 1 200 tons of BHS 500 for Rinkai Chuo Bridge on Tokyo Port Seaside Road.
2007	Second use of BHS 500. Nippon Steel & Sumitomo Metal supplied 15 000 tons of BHS 500 for Tokyo Gate Bridge on Tokyo Port Seaside Road.
2008	BHS 500 and 700 were standardized in JIS G 3140 as SBHS was newly employed as designation along with substituteto express high yield strength steel plates for bridges.
2009	Tokyo Metropolitan Government Bureau of Construction approved SBHS for standard material for civil works.[1)]
	Railway Technical Research Institute included SBHS in the Design Standards for Railway Structures and Commentary (Steel and Composite Structures).[2)]
	Japan Society of Civil Engineers published design and fabrication guide for SBHS 500 (W) and SBHS 700 (W) steel bridges.[3)]
2011	SBHS 400 and 400W were added to JIS G 3140.
2014	Specification for highway bridges introduced SBHS as a new material in Part II Steel Bridges.[4)]

* Senior Manager, Plate Products Technical Service & Solution Dept., Plate Technology Div., Plate Unit
2-6-1 Marunouchi, Chiyoda-ku, Tokyo 100-8071

2. SBHS Standard

Table 2 shows extracts of the SBHS Standard. By applying the TMCP (thermo mechanical control process), the SBHS plates up to 100 mm in thickness guarantee high yield strength and large Charpy absorbed energy—100 J in the direction perpendicular to the rolling direction—while securing good weldability through reduction of the weld crack sensitivity (P_{CM}).

In addition, to allow for cold bending work accompanied by a large plastic deformation, steel plates that guarantee larger Charpy absorbed energy as shown in **Table 3** are available.

3. Mechanical Properties of SBHS Delivered by Nippon Steel & Sumitomo Metal

Table 4 shows a record of orders for SBHS steel plates of Nippon Steel & Sumitomo Metal. As the standardization of SBHS by JIS in 2008, the company has delivered approximately 5000 tons of its SBHS steel products, including weathering steels SBHS 400W and SBHS 500W, to local autonomies and expressway construction companies. The SBHS steel plates that feature high strength and good workability have been developed primarily to improve the economics of short- to medium-span bridges. However, SBHS steel plates having high strength, good weldability and cold bending workability, etc. are actually applied to various types of large bridges too. Thus, they contribute to the cutting of construction cost and the improvement of reliability of bridges.

3.1 Application of limit state design—BHS 500 for Tokyo Port Seaside Road

Nippon Steel & Sumitomo Metal delivered to Tokyo Port Seaside Road approximately 17000 tons of BHS 500 steel plates (maximum thickness: 59 mm), former version of SBHS 500. To secure the required strength, weldability, and fracture toughness, the amounts of addition of C, P, S, N, and alloying elements were reduced as shown in **Table 5** [5]. At the same time, the weld crack sen-

Table 2 Digest of SBHS standard

Designation	Thickness t (mm)	Parameter crack measurement, P_{CM} (%)	Yield strength (N/mm²)	Transverse Charpy impact test	
				Test temp. (°C)	Absorbed energy (J)
SBHS400 SBHS400W	6≦t≦100	≦0.22	≧400	0	≧100
SBHS500 SBHS500W	6≦t≦100	≦0.20	≧500	−5	≧100
SBHS700 SBHS700W	6≦t≦50	≦0.30	≧700	−40	≧100
	50<t≦75	≦0.32			

Table 3 Specification of Charpy absorbed energy for strong cold bending plates

Designation	Bending radius/ thickness	Test temp. (°C)	Charpy absorbed energy (J)	Test direction
SBHS400	≧7	0	≧150	Longitudinal or transverse
SBHS400W	≧5	0	≧200	
SBHS500	≧7	−5	≧150	
SBHS500W	≧5	−5	≧200	

Table 4 Bridges constructed by use of Nippon Steel & Sumitomo Metal's SBHS

	Year	Bridge name	Structure	Client	Steel grade, Thickness, max.
1	2006	Rinkai Chuo Bridge, Tokyo Port Seaside Road	Box girder	Tokyo Metropolitan Gov.	BHS500 59 mm
2	2006–2009	Tokyo Gate Bridge Tokyo Port Seaside Road	Truss-box hybrid, Box girder	Ministry of Land, Infrastructure, Transport and Tourism	BHS500 50 mm
3	2009	Nagata Bridge	Space truss	Tokyo Metropolitan Gov.	SBHS500 67 mm
4	2009	Inba-shosuiro Bridge	Box girder	Chiba Pref.	SBHS500 59 mm
5	2011	Makogo Bridge (Shin-Itsuke Bridge)	Box girder	Tokyo Metropolitan Gov.	SBHS500 50 mm
6	2011	Shin-Miyagawa Bridge	Truss	Mie Pref.	SBHS400W 22 mm
7	2012	Inba-shosuiro Bridge	Box girder	Chiba Pref.	SBHS500 55 mm
8	2012	Otagawa-ohashi Bridge (Otagawa-hosuiro Bridge)	Arch	Hiroshima City	SBHS500 67 mm
9	2012	Takatsuki JCT Bridge, Shin-Meishin Expressway	Bridge pier	West Nippon Expressway Co. Ltd	SBHS500 57 mm
10	2012	Asakegawa Bridge, Shin-Meishin Expressway	Arch	Central Nippon Expressway Co. Ltd	SBHS500 86 mm
11	2012	Tsukiji-ohashi Bridge (Sumidagawa Bridge)	Arch	Tokyo Metropolitan Gov.	SBHS500 80 mm
12	2014	Nutanohara Bridge	Rigid frame	Totsugawa Village	SBHS500W 27 mm

sitivity (P_{CM}) was kept below 0.20%. Consequently, as shown in **Table 6** and **Figs. 1** [5] and **2** [5], steel plates of high yield strength and fracture toughness could be obtained.

For Tokyo Gate Bridge that is symbolic of Tokyo Port Seaside Road, load and resistance factor design (LRFD)—a variation of limit state design—was employed to take advantage of the high yield strength of BHS 500.[6] Consequently, it was reported that BHS 500 steel plates accounting for 50% of the total steel weight were used and thereby the cost of construction of the bridge could be cut by about 12%.[6]

Table 5 Example of chemical compositions (mass%) of BHS 500 [5]

	C	Si	Mn	P	S	N	P_{CM}
Specification	≦0.11	≦0.55	≦2.00	≦0.020	≦0.006	≦0.006	≦0.20
Ladle analysis	0.09	0.30	1.58	0.011	0.003	0.0030	0.19

Table 6 Yield strength and transverse Charpy absorbed energy at −5°C of BHS steels

	Yield strength (N/mm^2)	Transverse Charpy impact test	
		Test temp. (°C)	Absorbed energy (J)
Specification	≧ 500	−5	≧ 100
Actual value (ave.)	574	−5	262

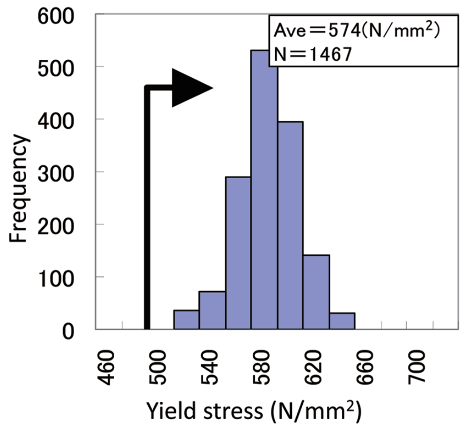


Fig. 1 Typical yield strength of BHS [5]

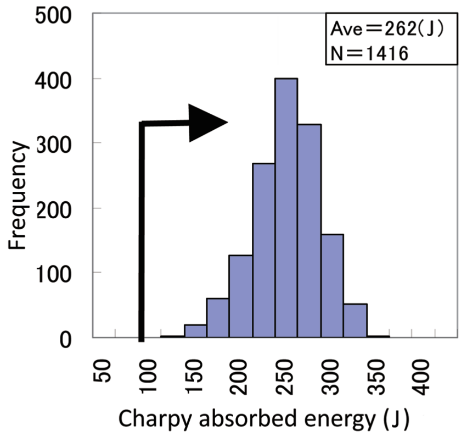


Fig. 2 Typical Charpy absorbed energy of BHS [5]

3.2 Application of severe cold bending work and welding with large heat input—SBHS 500 steel pipe for Nagata Bridge

Nagata Bridge in Tokyo Metropolis is Japan's first road bridge of space truss construction. In order to impart good aesthetic appeal and economics to the bridge, a study was made on the application of SBHS for severe cold bending work that guarantees high strength and Charpy absorbed energy as large as 200 J. Eventually, it was decided to fabricate OD 800 mm steel pipes (inside bending radius: 5 t) from a 67-mm-thick SBHS 500 steel plate, fill them with concrete, and use them as the lower chord members of the truss. **Table 7** shows the change in Charpy absorbed energy of SBHS 500 during plastic strain working. It can be seen that SBHS 500 retained a large Charpy absorbed energy even after 10% plastic strain working and aging treatment that are applied to actual bridges.

In addition, welding with 10 kJ/mm heat input (high limit to conventional SM 570: 7 kJ/mm) was applied to permit omitting the preheating for field welding and shortening the period of construction work.[7] **Table 8** shows examples of conditions for submerged arc welding (SAW) with a large heat input and a cross section of a SAW welded joint, and **Fig. 3** shows an example of measurement of Charpy absorbed energy of a SAW welded joint. It can be seen that even with welding with a large heat input (11 kJ/mm), the joint toughness of 47 J required of Nagata Bridge was secured.

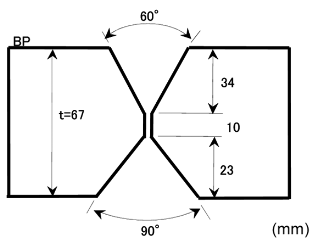
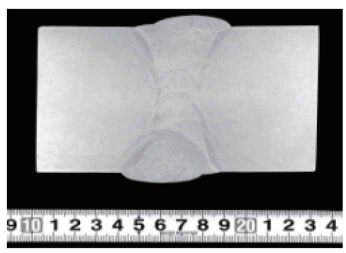
3.3 Use of thicker steel plate—adoption of SBHS 500 about gusset plate connections

An increasing number of SBHS 500 steel plates exceeding 50

Table 7 Charpy absorbed energy after strain aging (250 C × 1 h)

Thickness (mm)	Pre-strain (%)	Charpy impact test at −5 °C	
		Direction	vE (J)
67	0	Transverse	255
	10		185

Table 8 Welding conditions for large heat input SAW and joint section

Heat input	11 kJ/mm
Electrode	Y-DM (diameter: 4.8 mm)
Flux	NF-320M
Groove preparation	
Macroetch cross-section	

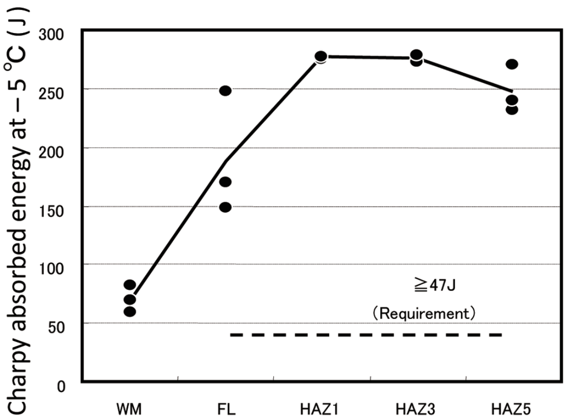


Fig. 3 Charpy absorbed energy at large heat input SAW joint


Fig. 4 Tsukiji-ohashi Bridge applied over 50 mm thickness SBHS500 around panel point sectios

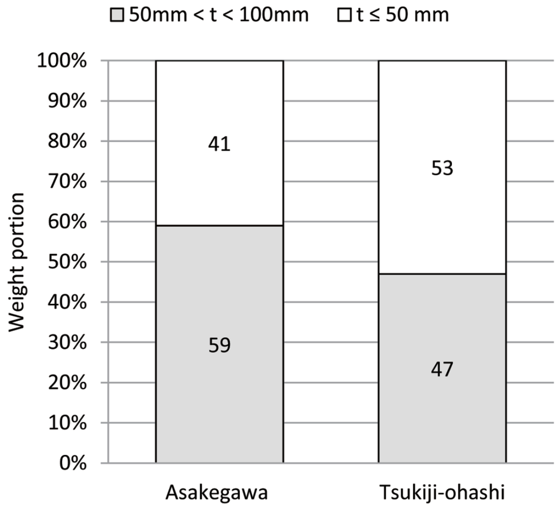


Fig. 5 Weight portion of over 50 mm thickness SBHS500 used for Asakegawa and Tsukiji-ohashi Bridge

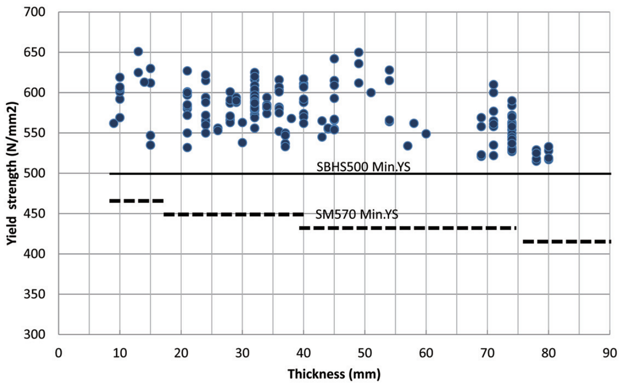


Fig. 6 Yield strength of SBHS500 shipped for Tsukiji-ohashi Bridge

mm in thickness are being used around the gusset plate connections of bridges. In Asakegawa Bridge on New Tomei Expressway and Tsukiji Ohashi Bridge (tentatively named "Sumidagawa Bridge") in Tokyo (**Fig. 4**), steel plates exceeding 50 mm in thickness account for approximately 50% as shown in **Fig. 5**. The largest thickness of SBHS steel plates used was 86 mm for Asakegawa Bridge and 80 mm for Tsukiji Ohashi Bridge. **Figure 6** shows the yield strengths of SBHS 500 steel plates shipped for Tsukiji Ohashi Bridge, together with the low-limit yield strengths of SM 570 steel plates. It can be seen that the SBHS steel plates show superior yield strength regardless of thickness.

4. Conclusion

We have so far described the material characteristics and practical applications of SBHS 500 of Nippon Steel & Sumitomo Metal. The cumulative quantity of shipment of SBHS, including BHS for Tokyo Port Seaside Road, exceeded some 22000 tons. The maximum thickness of SBHS steel plates demanded today has reached 100 mm or so. However, since enactment of JIS G 3140, those steel plates have been used mainly to improve the qualities of complicated weld zones or replace SM 570 partly with SBHS to reduce the required plate thickness. Namely, the application of SBHS for rationalization of the entire system of steel bridges—the primary purpose of SBHS—has not been materialized. Promoting the use of SBHS for that particular purpose is considered important from the standpoint of further spreading SBHS.

We believe that striving to improve the economics and reliability of the entire system of bridges by taking advantage of high performance of SBHS matches the need for development and maintenance of bridges in the future. In addition, in Japan—one of the most earthquake-ridden countries in the world, reducing the weights of steel bridge structures through the use of SBHS having superior yield strength is considered an effective means not only of improving the earthquake resistance of bridges but also of helping to build a sustainable infrastructure. It is expected that SBHS will become widespread from the standpoint of materializing a very robust country.

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Ryuichi ANDO
Senior Manager
Plate Products Technical Service & Solution Dept.
Plate Technology Div.
Plate Unit
2-6-1 Marunouchi, Chiyoda-ku, Tokyo 100-8071


Mutsuto TANAKA
Senior Manager, Head of Dept.
Plate Products Technical Service & Solution Dept.
Plate Technology Div.
Plate Unit


Masahide TAKAGI
Senior Manager
Bridge Products Engineering Dept.
Construction Products Development Div.
Construction Products Unit


Koji HOMMA
Senior Manager, Head of Dept.
Bridge Products Engineering Dept.
Construction Products Development Div.
Construction Products Unit