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ABREX™ Series, Abrasion Resistant Steel Plate of Nippon Steel & Sumitomo Metal Corporation

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Abstract

Abrasion resistant steel plates are used for abraded member material such as construction machines. The abrasion resistant ability had close relation to the hardness of steel, and we improved the high hardness by the adequacy of the alloy element and control of characteristics. We achieved ABREX600 having about 600 Brinell hardness now. On the other hand, we developed the low temperature specifications steel which has good toughness even −40 degrees Celsius to support usage of machines at severe low temperature environment. Furthermore, in consideration of the processing to a structure body, we produce the ABREX™ series corresponding to a wide use, which have high weldability and workability.

1. Introduction

Very hard, abrasion-resistant steel plates that are less subject to abrasion than ordinary steel plates are widely used for bulldozer blades, dump truck vessels, hydraulic shovel/wheel loader buckets, and various other parts of construction equipment and industrial machines that are abraded by impacts of soil, stone, bedrock, etc. while they are in operation. By using abrasion-resistant steel plates, it is possible to not only reduce the weight and enhance the performance of the machine but also cut the running cost of the machine, including the cost of repair, replacement, etc. of parts. On the other hand, abrasion-resistant steel plates are required to have not only superior hardness but also excellent low-temperature toughness to secure sufficient reliability of steel plates in cold regions as well as good weldability and bending workability to allow for efficient fabrication work.

As abrasion-resistant steel plates that meet the above requirements, Nippon Steel & Sumitomo Metal Corporation has newly added the ABREX™ (abrasion Resistance excellent) series to the conventional abrasion-resistant steel plates, WEL-HARD, WEL-TEN™AR, and SUMIHARD (**Table 1**). According to hardness, ABREX is divided into four standard types and three extra-tough types. The salient characteristics of the ABREX series are described below.

Table 1 Type and designation of ABREX series

Type	Designation	Plate thickness (mm)	Brinell hardness (HBW)		Charpy impact test on L dir. (t > 12 mm)	
			Aiming	Range	Test temp. (°C)	Absorbed energy (J)
Standard	ABREX400	4 ~ 100	400	360 ~ 440	–	–
	ABREX450	4.5 ~ 50	450	410 ~ 490	–	–
	ABREX500	4.5 ~ 50	500	450 ~ 550	–	–
	ABREX600	8 ~ 25	600	550 ~ 650	–	–
Extra tough	ABREX400LT	4 ~ 60	400	360 ~ 440	−40	≥ 27
	ABREX450LT	4.5 ~ 25	450	410 ~ 490	−40	≥ 27
	ABREX500LT	4.5 ~ 25	500	450 ~ 550	−40	≥ 21

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2. Basic Performance of ABREX (ABREX 400/450/500/600)

The abrasion resistance of steel plate has long been studied. It is known that there is a strong correlation between abrasion resistance and surface hardness of steel plate.[1, 2] Therefore, the grades of abrasion-resistant steel plates are often decided on the basis of steel plate surface hardness. Ordinarily, the surface hardness of steel plate is expressed as Brinell hardness. Nippon Steel & Sumitomo Metal manufactures ABREX 400, 450, 500, and 600 corresponding to Brinell hardness levels of HBW 400, 450, 500, and 600, respectively.

A simple and economical method of increasing the hardness of steel plate is to obtain the martensite microstructure by quenching. It is known that the hardness of martensite largely depends on the carbon content of steel and that the influence of any other alloying element on martensite hardness is small.[3] As an example, **Fig. 1** shows the influence of carbon on martensite hardness measured using three types of steel with the Mn and Ni contents varied between 1% and 2.5% and 0% and 1%, respectively. It can be seen that the hardness of each type of steel depends on the carbon content, and not on the contents of Mn and Ni.

In obtaining a martensitic microstructure by quenching, it is necessary to secure a suitable hardenability of steel. As an index of hardenability, the multiplying factor (DI)[4] shown in Equation (1) (Grossmann's equation) is used. In addition, index $V_{C\text{-}90}$[5] shown in Equations (2) through (5) is used. $V_{C\text{-}90}$ signifies the critical cooling rate at which 90% martensitic microstructure can be obtained. It permits the consideration of the hardening effect of boron (B), which cannot be determined by Grossmann's equation.

$$DI = D_{IC}\sqrt{C}\,(1+0.86Si)(1+3.3Mn)(1+2.3Cr)(1+0.36Ni)(1+3.2Mo) \quad (1)$$

$$\log V_{C\text{-}90} = 2.94 - 0.75\beta \quad \text{(B added)} \quad (2)$$

$$\beta(\%) = 2.7C + 0.4Si + Mn + 0.45Ni + 0.8Cr + 2Mo \quad (3)$$

$$\log V_{C\text{-}90} = 2.94 - 0.75(\beta' - 1) \quad \text{(B not added)} \quad (4)$$

$$\beta'(\%) = 2.7C + 0.4Si + Mn + 0.45Ni + 0.8Cr + Mo \quad (5)$$

Using the above indexes and considering the weldability of steel plate described later, Cr, Mn, Mo, B, and other elements that help increase the hardenability of steel plate are added considering the hardness grade and plate thickness. In particular, as can be seen by a comparison between Equations (2) and (4), the addition of B markedly increases the value of $V_{C\text{-}90}$ with the contents of the other elements kept the same. Since even a very small amount of B increases the hardenability of steel appreciably, ABREX is added with a suitable amount of B.

Table 2 shows the representative mechanical properties of ABREX 400–600 designed and manufactured as has been described above. **Figure 2** shows the microstructure of ABREX 400. Having a hardened structure, the steel plate has the prescribed hardness.

For the purpose of evaluating the abrasion resistance of ABREX, a gouging abrasion test and scratching abrasion test were conducted. In the gouging abrasion test, the test piece is pressed against a grindstone, which is turned to abrade the test piece. It simulates the condition under which a large load and a strong impact are applied to the bucket of a shovel, etc. while it is excavating and crushing rock, ore, etc. The test conditions were as follows: grindstone rotating speed, 30 rpm; applied load, 29.4 kg/cm^2; and test time, 20 min. The grindstone used was the one exclusive for testing under high temperatures. Considering the generation of frictional heat, the ambient temperature was set at 200°C, which is a severe abrasive condition.

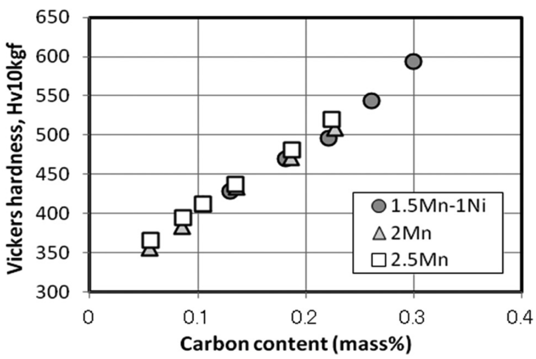

Fig. 1 Effect of carbon content on martensite hardness

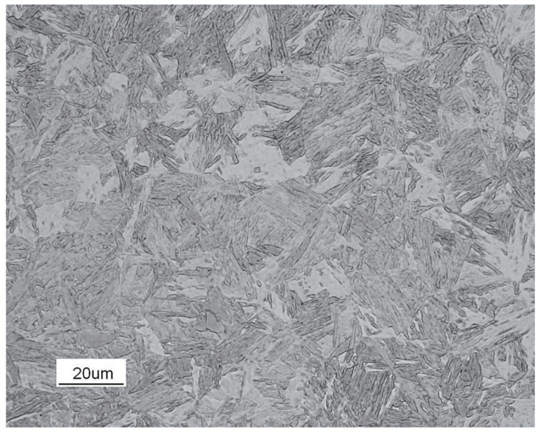

Fig. 2 Microstructure of ABREX 400

Table 2 Typical mechanical properties of ABREX 400 – 600

Designation	Thickness (mm)	Carbon equivalent		Brinell hardness (HBW)	Mechanical properties			
					Tensile test		Charpy impact test	
		C_{eq}	CEN		YS (N/mm^2)	TS (N/mm^2)	Test temp. (°C)	Absorbed energy (J)
ABREX 400	25	0.38	0.38	414, 417, 416	1075	1322	0	73
ABREX 450	25	0.51	0.54	458, 453, 459	1192	1469	0	57
ABREX 500	25	0.54	0.57	513, 509, 520	1373	1552	0	43
ABREX 600	25	0.70	0.71	611, 606, 601	–	–	0	18

$C_{eq} = C + Mn/6 + (Cu + Ni)/15 + (Cr + Mo + V)/5$
CEN: Eq.(6)(7)

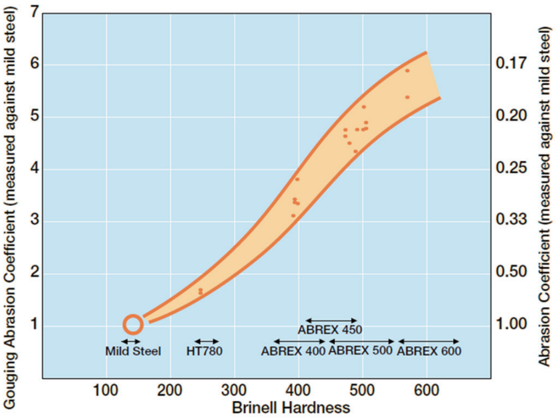

Fig. 3 Gouging abrasion property of ABREX

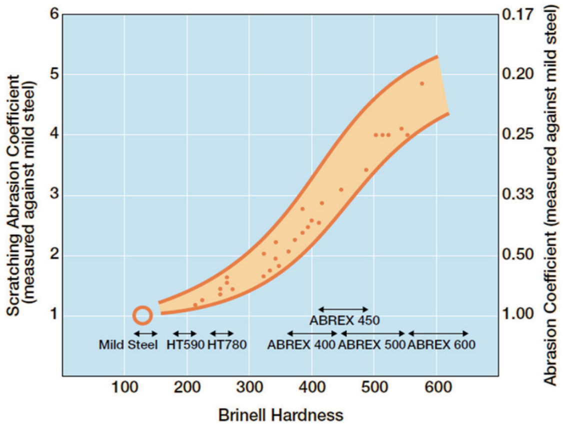

Fig. 4 Scratching abrasion property of ABREX

Table 3 Typical mechanical properties of ABREX 400LT – 500LT

Designation	Thickness (mm)	Carbon equivalent		Brinell hardness (HBW)	Mechanical properties			
					Tensile test		Charpy impact test	
		C_{eq}	CEN		YS (N/mm^2)	TS (N/mm^2)	Test temp. (°C)	Absorbed energy (J)
ABREX 400LT	60	0.60	0.55	390, 393, 393	1 162	1 207	−40	63
ABREX 450LT	25	0.50	0.52	469, 469, 469	1 089	1 465	−40	43
ABREX 500LT	25	0.53	0.56	507, 510, 507	1 198	1 680	−40	38

On the other hand, the scratching abrasion test measures the amount of abrasion of the test piece that is turned in water-bearing sand. It simulates the condition under which the surface of a steel plate (e.g., dump truck vessel) is scratched by relatively small stones. In this test, the test piece was turned at a speed of 3.7 m/s in water-containing silica sand. **Figure 3** shows the gouging abrasion test results, and **Fig. 4** shows the scratching abrasion test results. Compared with the reference mild steels, the ABREX steel plates display 3–5 times better abrasion resistance in the gouging abrasion test and 2–4 times better abrasion resistance in the scratching abrasion test. Note that since the test results shown above were obtained in simulated abrasive environments, they do not always agree with the actual abrasion resistance of ABREX.

3. Low-Temperature ABREX Steel Plates (LT Series)

In the case of the construction equipment, it can reasonably be expected that the steel plates used in it are subject to very strong shocks. In particular, for construction equipment to be used in cold regions, it is necessary to give due consideration to the low-temperature toughness of its steel plates. Therefore, with respect to high-strength, abrasion-resistant steel plates also, Nippon Steel & Sumitomo Metal has developed the LT series of steel plates that guarantee toughness at −40°C.

In general, with the increase in hardness of steel plates, the toughness of steel plates decreases. However, by reducing the effective grain size of steel, increasing the toughness while maintaining the hardness is considered possible. The low-temperature toughness of ABREX steel plates has been improved by reducing the effective grain size through the refinement of grains of the prior structure and through the optimization of the martensite transformation temperature by proper adjustment of addition of elements.

Table 3 shows the representative mechanical properties of ABREX 400LT, 450LT, and 500LT that are designed and manufactured as described above. As abrasion-resistant steel plates, they have excellent low-temperature toughness at −40°C while maintaining superior hardness.

4. Workability

4.1 Weldability

For abrasion-resistant steel plates containing relatively large amounts of carbon and other alloying elements, preventing weld cracks, especially cold cracks, in them during assembly into steel structures is an important problem. It is considered that cold cracking is the result of the concurrence of three factors: hardening of weld zone, accumulation of diffusible hydrogen, and constraining stress. Of them, the hardening of weld zone has much to do with steel, and as an index of cold crack sensitivity, C_{eq} or P_{CM} that is based on the alloying element content of steel is often used. Although both C_{eq} and P_{CM} are useful indexes, their validity differs according to the content of carbon. In this connection, it has been suggested that P_{CM} be used in the low-carbon region ($C \leq$ approx. 0.12%) and P_{CM} be supplemented with C_{eq} in the high-carbon region. At Nippon Steel & Sumitomo Metal, the CEN carbon equivalent [6] that permits expressing the cold crack sensitivity in a wider carbon content region is also used as an index of cold crack sensitivity (see Equations (6) and (7), below). As a means of preventing low-temperature cracking of steel plate, preheating of the steel plate is often used. To lower the preheating temperature, the company designs the steel chemical composition that minimizes CEN.

$$\mathrm{CEN} = \mathrm{C} + \mathrm{A(C)}\left\{\frac{\mathrm{Si}}{24} + \frac{\mathrm{Mn}}{6} + \frac{\mathrm{Cu}}{15} + \frac{\mathrm{Ni}}{20} + \frac{(\mathrm{Cr}+\mathrm{Mo}+\mathrm{Nb}+\mathrm{V})}{5} + 5\mathrm{B}\right\} \quad (6)$$

$$\mathrm{A(C)} = 0.75 + 0.25 \tanh\{20(\mathrm{C} - 0.12)\} \quad (7)$$

Table 4 Controlled thermal severity weld cracking test results

Designation	Thickness (mm)	Cracking	
		SMAW	GMAW
ABREX 400	25	No	No
ABREX 450	25	No	No
ABREX 500	25	No	No

SMAW: Shielded metal arc welding
GMAW: Gas metal arc welding

Table 5 Wide bend test results

Designation	Thickness (mm)	Width (mm)	Bend direction	Bend angle	Cracking*	
					3t	5t
ABREX 400	25	120	Longitudinal	180°	○	○
ABREX 450	25	120	Longitudinal	180°	○	○
ABREX 500	25	120	Longitudinal	180°	△	○

* ○ : No cracking, △ : Some small, localized cracking

Table 4 shows the results of a lap joint weld crack test conducted to evaluate the weldability of ABREX steel plates. All the steel grades tested show good weldability. Note, however, that since ABREX is higher in strength than ordinary steels, it is more sensitive to low-temperature cracking. In welding ABREX steel plates, therefore, it is important to select a suitable welding material and control the preheating temperature properly. When preheating is impossible or needs to be omitted, an austenitic welding material, such as SUS 309, may be used. For ABREX 600, it is necessary to use a two-phase stainless steel-based welding material, such as DP-8, and apply preheating depending on the circumstance.

4.2 Bending workability

Since abrasion-resistant steel plates are harder and stronger than ordinary steel plates, they have inferior elongation. Therefore, they tend to show low flexibility. **Table 5** shows examples of the results of a bending test using wide test pieces of ABREX. Compared with the ordinary bending test, the wide plate bending test is characteristic in that the across-the-width plastic constraint is stronger, that is, a harsher bending condition. In the test, the test pieces did not occur with a bending radius of 5t (five times of plate thickness), showing good flexibility. In actual bending work, however, it is important to provide suitable measures to prevent the steel plates from cracking.

5. Conclusion

Nippon Steel & Sumitomo Metal integrated WEL-HARD and WEL-TEN AR, the abrasion-resistant steel plates of former Nippon Steel Corporation, and SUMIHARD, the abrasion-resistant steel plate of former Sumitomo Metal Industries, Ltd. Then, the company launched the ABREX series of abrasion-resistant steel plates, including newly developed types.

Through fusion of the technologies of the former two companies, the basic grades of abrasion-resistant steel plates have been added with new products boasting world-class hardness (5 to 6 times harder than ordinary steels), high-toughness types applicable in cold regions, and thin abrasion-resistant steel plates.

The ABREX abrasion-resistant steel plates are used mainly in construction equipment and mining machines that are necessary for civil engineering works and resources development and in crushers, industrial equipment, etc. for resources recycling. They help to reduce the wear of steel structures, extend the cycle of maintenance of steel equipment, and reduce the weight of steel machines, and so on. In the future, we intend to continue the development and improvement of abrasion-resistant steel plates to meet the diversified customer needs.

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