Technical Report

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Development of Steel Plate Products for High-Efficiency Welding in Building Structures

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Abstract

For safety against earthquake and for high efficient welding in high-rise building constructions, Nippon Steel & Sumitomo Metal Corporation has developed various high performance steel based on the new technology for HAZ microstructure refinement, HTUFF™. This paper presents the performance of two types of HTUFF plates, one is 590 N/mm² class steel for welded box columns and the other is 550 N/mm² class steel for cold-press-formed square steel tubes.

1. Introduction

Along with the trends in steel structures growth to a larger scale, both in height and in span, and increase in seismic design forces, the sections of the members of the primary structural members such as columns and beams and their thickness are growing larger. To improve the cost competitiveness of these steel members, apart from increasing the strength of the steel material, high-efficiency welding has become an important issue in the field of steel structures. [1, 2] Listed as requirements of the high-efficiency welding are the reduction and omission of preheating and postheating in welding operation and improvement in welding operation efficiency by employing high heat input welding. Furthermore, in ultra-high-rise building projects and important facility projects, the use of cold-press-formed square steel tubes to which highly efficient robotic welding is applicable is increasing recently, replacing the conventional welded built-up box-section columns (hereafter referred to as built-up box).

In general, high-efficiency welding and securing welded joint quality are in a trade-off relation. For instance, when the welding operation efficiency is pursued by using high heat input welding, in the conventional steel materials, the microstructure of heat affected zone (HAZ) becomes coarsened, resulting in deterioration of HAZ toughness directly related to the structural performance of steel frame members. On the other hand, through a series of researches conducted after the Southern Hyogo prefecture earthquake in 1995, the performance of the welded joint required to prevent the brittle fracture of steel structure members has become gradually clarified, [3, 4] and projects are increasing wherein structure design engineers specify requirement values of HAZ toughness of the welded joint of primary structural members from the view of securing aseismic performance of buildings.

To satisfy the two needs of high-efficiency welding in welding operation and improvement in toughness of welded joint simultaneously, Nippon Steel & Sumitomo Metal Corporation has developed high HAZ toughness technology, HTUFF™ (High HAZ Toughness Technology with Fine Microstructure Imparted by Fine Particles). [5] HTUFF is the general term for the high HAZ toughness technology that refines the HAZ microstructure by utilizing the pinning effect of the fine particles of thermally stable oxides, sulfides, and the likes dispersed in the steel. [6]

This report focuses on the improved welding efficiency of column members of steel structures, referring to two examples of recent developments utilizing HTUFF technology, namely, the 590 N/mm² class preheating-free-type thermo-mechanical control process (TMCP) steel plate and cold-press-formed square steel tubes of TMCP type 490 N/mm² class and 550 N/mm² class, and presents a survey of future developments.

2. 590 N/mm² Class Preheating-free-type TMCP Steel Plate

2.1 Background of development

The high-performance 590 N/mm² steel plate for building structures (SA440) was standardized by the Japan Iron and Steel Federation (a general incorporated association), formerly the Iron and Steel Club (an incorporated association), in 1996 as a high-strength steel

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guaranteed with low yield ratio (80% or less). Later on, while the application of the steel to built-up box column of ultrahigh-rise buildings was ongoing, triggered by the damage of brittle fracture of welded joint suffered in the Southern Hyogo prefecture earthquake, securing toughness at welded joint has come to be pointed out. In the electroslag welding (ESW) for inner diaphragm and the submerged arc welding (SAW) for corner welding, due to high welding heat input, it is difficult to secure the toughness of welded joint, HAZ in particular. Therefore, in order to improve the toughness of HAZ without impairing welding operation efficiency, by utilizing HTUFF, 590 N/mm^2 class high HAZ toughness steel (BT-HT440C-HF) was developed.[5)]

On the other hand, deterioration of weldability accompanied by the enhancement of strength of steel materials is unavoidable and, for SA440, preheating (100°C or higher for plates exceeding 75 mm in thickness) was needed to prevent weld cracks. In recent years, a method of welding a beam end to a column directly on construction sites, which is generally termed as non-bracket method, has come to be established for the purpose of reducing cost by reducing the number of welded joints and as a result, on-site welding has rapidly increased in 590 N/mm^2 class built-up box columns. As the workload of on-site preheating is high, the need of preheating-free welding is high. To comply with the need, aiming at P_{CM} (cracking parameter, index of cold cracking susceptibility) of 0.22% or below, a steel material of 590 N/mm^2 with high weldability was developed by optimizing the steel compositions and by fully utilizing the steel plate manufacturing technology.[7)] The steel material has obtained the approval of Minister of Land, Infrastructure, Transport and Tourism as a preheating-free SA440 up to the thickness of 100 mm (BT-HT440-SP: 590 N/mm^2 high performance steel plate with high weldability for building structures). Later on, by applying the latest TMCP equipment of CLC-μ[6)], shorter construction period was realized.

Although the need of improving welded joint quality and weldability was complied with individually, aiming at further improvement of welded joint quality and the welding operation efficiency, improvement of HAZ toughness in large-heat-input welding was tackled on the basis of BT-HT440-SP (SP steel).

2.2 Outline of product

Due to the growth of a brittle microstructure (MA: Martensite-austenite constituent), accompanied by the addition of alloys for enhancing strength, it was difficult to secure the HAZ toughness of SP steel made pre-heating-free with low C and low P_{CM}. Therefore, in addition to the application of HTUFF, optimization of compositions of steel for thorough reduction of MA was pursued. Below, the developed high HAZ toughness steel (SP-HF) is compared with the conventional steel (SP steel) and its features are shown.

In **Tables 1 and 2**, the chemical compositions and the mechanical properties of the developed steel SP-HF and the conventional steel are shown, respectively. The plate thickness is 40 and 60 mm in either steel and P_{CM} of the developed steel is same with that of the conventional steel. Yielding strength (YS), tensile strength (TS), and yielding ratio (YR) of the developed steel all satisfy the standard of SA440 and the elongation (EL) and the Charpy value (vE_0) of the base metal are almost equal to those of the conventional steel.

In order to confirm the weldability, y-groove weld cracking tests were conducted in conformity to JIS Z 3158. The test condition and the test results are shown in **Table 3**. Cold crack was not found even under the ambient temperature of 0°C and without preheating (number of repletion is two) and excellent weldability was confirmed.

2.3 Performance of large-heat-input welded joint

For the purpose of confirming the development result on HAZ toughness of large-heat-input welded joint, welded joint performance confirmation tests were conducted on actual welded joint base under the cooperation of two fabricators.

In **Table 4**, the list of the welded joint test specimens is shown. The subject welding process is ESW and SAW. For the test of ESW, an H-shaped test specimen (weld length 1 000 mm) was arranged for applying T-joint welding in two lines simultaneously. For the test of SAW, a box-type test specimen was arranged for applying corner welding in two lines simultaneously (Fabricator A), and a one-side open-type test specimen was arranged (Fabricator B). In the test specimen of ESW, the welding conditions of the developed steel and the conventional steel were made same and the combinations of the

Table 1 Chemical compositions

Steel	Thickness (mm)	C (%)	Si (%)	Mn (%)	P (%)	S (%)	P_{CM} (%)
SP-HF Developed steel	40	0.09	0.08	1.56	0.009	0.002	0.18
	60						
SP Conventional steel	40	0.08	0.27	1.56	0.009	0.002	0.18
	60						

Table 3 Results of y-groove cracking test (SP-HF 60 mm)

Test condition			Test results Cracking ratio (%)		
Welding consumable	Welding condition	Preheating temperature	Surface	Section	Root
JIS Z 3312 G59JA1UC3M1T 1.2 mmϕ	100%CO_2 17 kJ/cm	0°C	0%	0%	0%
		0°C	0%	0%	0%
		20°C	0%	0%	0%

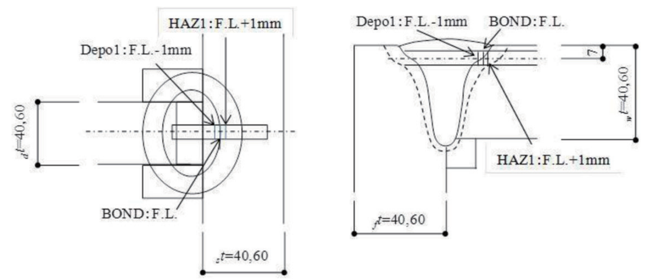
Table 2 Mechanical properties

Steel	Thickness (mm)	YS (N/mm^2)	TS (N/mm^2)	YR (%)	EL* (%)	vE_0 (J)
SP-HF Developed steel	40	495	668	74	47 (No. 5)	287
	60	497	643	77	26 (No. 4)	272
SP Conventional steel	40	517	684	76	50 (No. 5)	336
	60	468	635	74	27 (No. 4)	347
SA440 Specification	19 ≤ ≤ 100	440 ≤ ≤ 540	590 ≤ ≤ 740	≤ 80	26 ≤ (No. 5) 20 ≤ (No. 4)	47 ≤

* Test piece for tensile test: JIS Z 2241

Table 4 List of welded joints test specimens

Welded joint No.	Welding process	Column skin-plate	Inner-diaphragm	Welding consumables	Actual heat input
F-E46 -A -B	ESW	BT-HT440C-SP-HF 40 mm	BT-HT385B 60 mm	JIS Z 3353 YES602-S/FES-Z	-A 792 kJ/cm -B 979 kJ/cm
P-E46 -A -B	ESW	BT-HT440C-SP 40 mm	BT-HT385B 60 mm		-A 833 kJ/cm -B 1 031 kJ/cm
F-E64 -A -B	ESW	BT-HT440C-SP-HF 60 mm	BT-HT385B 40 mm		-A 582 kJ/cm -B 655 kJ/cm
P-E64 -A -B	ESW	BT-HT440C-SP 60 mm	BT-HT385B 40 mm		-A 571 kJ/cm -B 676 kJ/cm
F-S6 -A	SAW-2pass	BT-HT440C-SP-HF 60 mm	-	JIS Z 3183 S621-H1	-A 342 kJ/cm 331 kJ/cm
F-S6 -B	SAW-1pass	BT-HT440C-SP-HF 60 mm	-	JIS Z 3183 S622-H4	-B 489 kJ/cm



(a) ESW (b) SAW

Fig. 1 Specimen and V-notch positions of Charpy impact test

column skin-plate thickness and the inner diaphragm thickness were taken as the parameter. A welding consumable was used commonly to the two cases of combination of thin-column skin plate vs. thick diaphragm plate (40–60 mm) and thick-column skin plate vs. thin diaphragm plate (60–40 mm). As for the test specimen of SAW, the test was conducted for the developed steel only, and the welding procedure was taken as the parameter. In the two kinds of procedures of one pass welding and two pass welding, the combination of the wire and the flux most suited to the welding procedure was employed.

From the test specimens of ESW and SAW, Charpy test pieces were taken from the positions as shown in **Fig. 1** and impact tests were conducted. Following the results of researches made of late [4], notches were provided at three positions: weld fusion line (F.L.) as the base notch position, 1 mm apart from the F.L. to the base metal side and 1 mm apart from the F.L. to the weld metal side (F.L.−1 mm, F.L., F.L.+1 mm). Six tests were conducted at each notch position.

The results of the tests of ESW and SAW are shown in **Fig. 2** and **Fig. 3**, respectively. In the figures, the plots show the Charpy absorbed energy of all test pieces, and the polygonal lines show the average of six test pieces at each notch position. Furthermore, in the figures, the lines showing the target values of toughness, 27J, 47J, and 70J, are added.

From the test results of ESW in Fig. 2, it is found that, as opposed to those of the conventional steel shown with the broken lines, in the developed steel, the toughness at the fusion line and the HAZ have been greatly improved as shown with the solid lines. However, the test results scatter at the fusion line position, and even in the E46-B with higher heat input, even in developed steel, low values were observed. From the results of the observation of the fracture surface, it is confirmed that a brittle cracking propagated, starting at an unavoidable nonmetallic inclusion, therefore, it is considered that, in order to obtain stable performance, the suppression of the heat input is important. Furthermore, in the test results of SAW shown in Fig. 3, although scattering of the test results in HAZ is observed, it is confirmed that high-level welded joint toughness is secured.

In **Photo 1**, the HAZ microstructure of ESW fusion line is shown. The areas in white denote MA, which exists largely in the conventional steel but scarcely in the developed steel. It is considered that the difference in the appearance ratio of MA reveals the difference in the toughness of the fusion zone and HAZ.

From the abovementioned results, it is considered that the 590 N/mm^2 steel plate has been successfully developed that satisfies all needs of strength, yielding ratio, welded joint toughness, and furthermore shortening of construction period.

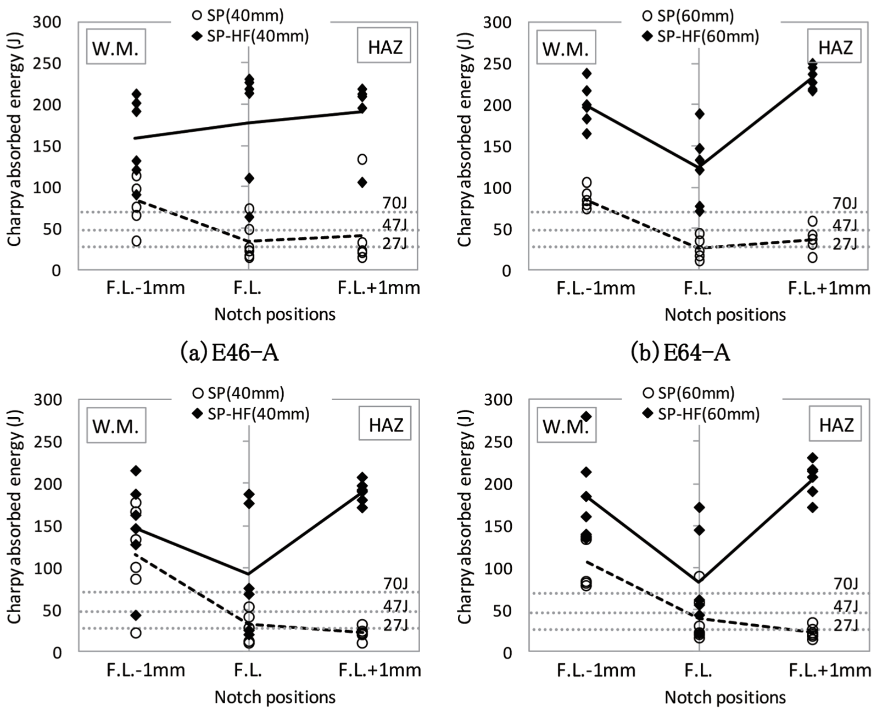
3. 490 N/mm^2 Class and 550 N/mm^2 Class TMCP-type Cold-press-formed Square Steel Tube

3.1 Background of development

The cold-press-formed square steel tube is suited to robotic welding and therefore the productivity of structural frame construction is high and applied to the columns of many building structures.

In the case a general cold-press-formed square steel tube of BCP325 is used as a column, considering the material deterioration of the corner due to cold forming, and in order to suppress the stress to the welded through diaphragm-column joint, additional safety factors, such as the reduction factor for the full plastic strength of the column when local collapse may occur, are imposed by the design code.

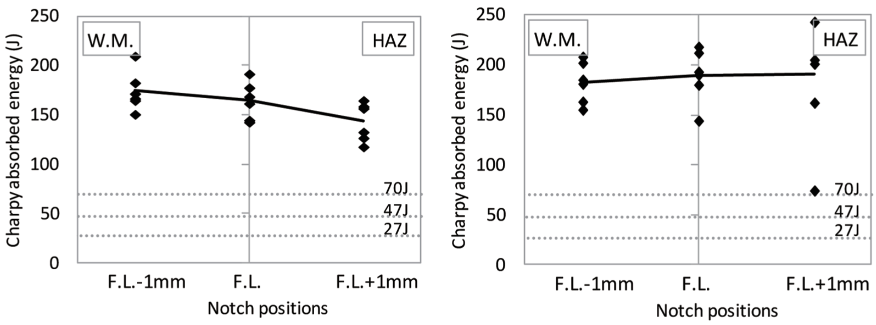
However, in the case of using BCP325T that was standardized as high-performance cold-press-formed square steel tube by the Japan Iron and Steel Federation in 2002, the design code allows dealing with it as built-up box columns by releasing additional safety factors provided that the weld quality at the joining section of BCP325T and the diaphragm is secured by welding in such a manner as to make the weld bead overlap the mother materials and by applying a reheating weld beads thereon. Owing to the effect, the application of BCP325T to column members of major buildings like high-rise buildings where built-up box columns had been mainly



(a) E46-A (b) E64-A

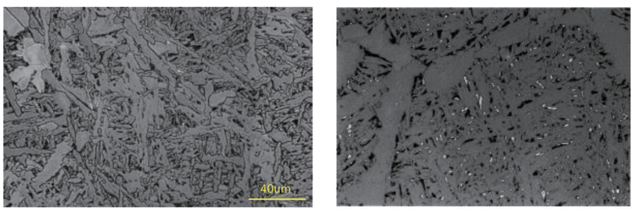
(c) E46-B (d) E64-B

Fig. 2 Results of ESW Charpy impact test



(a) S6-A (b) S6-B

Fig. 3 Results of SAW Charpy impact test



(a) Developed steel(SP-HF) (b) Conventional steel(SP)

Photo 1 HAZ microstructure of ESW fusion zone

used is increasing.[8)]

In the TMCP-type high-performance cold-press-formed square tube “BCHT325BTF,CTF” and “BCHT385BTF,CTF” introduced hereafter, TMCP steel plates to which HTUFF is applied are used as mother materials where toughness and weldability have been improved greatly. With this improvement, even if the same weld layer sequence as BCP325 is used, “BCHT325BTF,CTF” and “BCHT385 BTF,CTF” are considered as cold-press-formed square tubes that allow the same design method of columns as BCP325T. This design method with an appropriate construction procedure has been approved by the Minister of Land, Infrastructure, Transportation and Tourism and evaluated by the Building Center of Japan (a general incorporated foundation). Furthermore, the last two letters of “TF” of the titles of the standards of BCHT325BTF,CTF and BCHT385 BTF,CTF denote “Toughness” and (f_{HAZ}), which is an indicator of weldability, denoting the metal active gas welding heat affected zone toughness, given as a sign to indicate that the indicator value is set at the highest level.[9)]

3.2 Outline of product

As shown in **Tables 5–8**, BCHT325BTF,CTF and BCHT385BTF, CTF consist of total four standards, namely two levels of standard strength of 325 and 385 N/mm^2, and two types of B and C that distinguish between the existence or nonexistence of the specification guaranteeing the through-thickness characteristics. The toughness in

Table 5 Chemical compositions

Steel	Thickness (mm)	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Ti (%)	N (%)
BCHT325BTF	16 ≤	≤ 0.18	≤ 0.55	≤ 1.65	≤ 0.030	≤ 0.015	0.005 ≤	0.002 ≤
BCHT325CTF	≤ 40				≤ 0.020	≤ 0.008	≤ 0.025	≤ 0.006
BCHT385BTF	16 ≤	≤ 0.20	≤ 0.55	≤ 2.00	≤ 0.030	≤ 0.015	0.005 ≤	0.002 ≤
BCHT385CTF	≤ 60				≤ 0.020	≤ 0.008	≤ 0.025	≤ 0.006

Table 6 Mechanical properties

Steel	YP (N/mm^2)	TS (N/mm^2)	YR (%)	EL*			vE_0 (J)	
				Thickness (mm)	Test piece*	(%)	Flat	Corner
BCHT325BTF	325 ≤	490 ≤	≤ 80	t = 16	1A	17 ≤	70 ≤	70 ≤
BCHT325CTF	≤ 445	≤ 610		16 < t ≤ 40		21 ≤		
BCHT385BTF	385 ≤	550 ≤	≤ 80	t ≤ 32	1A	15 ≤	70 ≤	70 ≤
BCHT385CTF	≤ 505	≤ 670		t > 32	4	20 ≤		

* Test piece for tensile test: JIS Z 2241

Table 7 Weld properties

Steel	Thickness (mm)	C_{eq} (%)	P_{CM} (%)	f_{HAZ} (%)
BCHT325BTF BCHT325CTF	16 ≤ t ≤ 40	≤ 0.38	≤ 0.24	≤ 0.46
BCHT385BTF BCHT385CTF	t < 19	≤ 0.44	≤ 0.29	≤ 0.46
	19 ≤ t ≤ 50	≤ 0.40	≤ 0.26	
	50 < t ≤ 60	≤ 0.42	≤ 0.27	

Table 8 Through-thickness characteristics

Steel	Reduction of area (%)	
	Average	Each
BCHT325CTF BCHT385CTF	25 ≤	15 ≤

terms of Charpy absorbed energy of 70 J or higher at 0°C, the highest grade for building structural materials, is guaranteed not only for the flat plate area but also for the corner area. Furthermore, differently from the maximum thickness of 50 mm of the conventional cold-press-formed square tube of BCHT385B,C with the standard strength of 385 N/mm^2, the maximum thickness of BCHT385BTF, CTF was increased to 60 mm.

As for weld characteristics, the metal active gas welding heat affected zone toughness indicator (f_{HAZ}) is specified in addition to carbon equivalent (C_{eq}) and cracking parameter (P_{CM}). In the welded joint with the diaphragm, the Charpy absorbed energy of “70 J or higher at 0°C” is indirectly ensured in the corner weld HAZ simply by employing the welding procedure that is same with that to BCP325 and controlling the heat input and the interpass temperature, and for the purpose of preventing brittle fracture in HAZ, f_{HAZ} is suppressed to below 0.46%, reduced by 0.12% from that of BCP 325T, and furthermore, the upper and the lower limits of contents of Titanium (Ti) and Nitrogen (N) are specified so as to suppress the coarsening of the crystal grain with Ti-N precipitates. [10]

3.3 Weld joint performance and structural performance as column member

Being endowed with the aforementioned performance, BCHT 325BTF,CTF and BCHT385BTF,CTF are exempted from the application of the additional safety factors specified in the design code that is required when the general cold-press-formed square tubes are used for columns and can be designed in the same condition with that of built-up box column. [8]

In the welding of the diaphragm, such complicated works as needed for BCP325T like minute control of the weld bead form and the troublesome work when mending welding is required are eliminated, and the welding operation and the control can be streamlined. Furthermore, even when a cold-press-formed tapered square steel tube is used for a joint, there is a merit of robotic welding.

The weld joint performance of BCHT385BTF and its structural performance as a column member are described below. The chemical compositions of the test specimens provided for the evaluation of the weld joint performance of BCHT385BTF are shown in **Table 9**, and the mechanical properties of the flat plate area and the corner area are shown in **Table 10**. Furthermore, the welding conditions are shown in **Table 11** and the heat input and the interpass temperature records in fabricating the specimens of plate thickness of 60, 50, and 28 mm are shown in **Fig. 4**. No significant difference in the heat input is noticed among the plates, however, the interpass temperature tends to increase as the thickness goes higher and it is shown that the interpass temperature of the maximum thickness plate of 60 mm is reaching a temperature almost equal to the upper control criterion of 250°C.

In **Fig. 5**(a), positions of test specimens of welded joint for Charpy impact tests are shown and, in **Table 12**, the results of the impact tests for the welded joint at the test temperature of 0°C are shown. The test specimen is of V notch type of JIS Z 2242 and the test specimen was sampled from the position at 6 mm below the outer surface where the test specimen has its center. Although the toughness of the welded joint tends to deteriorate in general when the heat input and the interpass temperature go higher, it is shown that the mean values of the three data of the Charpy absorbed energy of HAZ of plates including the plate of maximum thickness of 60 mm where the interpass temperature has reached almost the upper criterion are 150–180 J in the flat area and in the corner area and show high toughness well over 70 J.

In **Fig. 6**, Vickers hardness distribution results of the welded

Table 9 Chemical compositions of specimens (BCHT385B)

(%)

Spec. No.	Section $D \times t$ (mm)	C	Si	Mn	P	S	Ti	N	C_{eq}	P_{CM}	f_{HAZ}
T60	□750×60	0.14	0.27	1.45	0.016	0.003	0.014	0.004	0.40	0.22	0.42
T50	□650×50	0.14	0.28	1.30	0.013	0.003	0.011	0.003	0.37	0.22	0.39
T32	□450×32	0.14	0.28	1.31	0.011	0.002	0.011	0.003	0.37	0.22	0.37
T28	□500×28	0.14	0.28	1.30	0.013	0.003	0.011	0.003	0.37	0.22	0.39
T19	□500×19	0.14	0.28	1.27	0.009	0.002	0.011	0.003	0.37	0.22	0.36

Table 10 Mechanical properties of specimens

Spec. No.	Flat area (JIS Z 2241 4 (t > 32 mm), 1A (t ≤ 32 mm))				Corner area (JIS Z 2241 14B)			
	YP (N/mm²)	TS (N/mm²)	EL (%)	YR (%)	YP (N/mm²)	TS (N/mm²)	EL (%)	YR (%)
T60	441	574	33.3	76.8	609	680	19.0	89.5
T50	408	563	36.2	73.3	581	647	19.6	89.8
T32	457	601	23.3	76.0	602	671	17.2	89.7
T28	433	601	24.5	73.2	599	691	16.0	86.8
T19	463	617	21.1	75.0	641	714	16.3	89.8

Table 11 Welding conditions

Joint	Groove angle (deg.)	Root gap (mm)	Root face (mm)	Welding wire	Heat input (kJ/cm)		Maximum interpass temperature (°C)
					Flat	Corner	
Column-diaphragm	35	7	0	G59JA1U C3M1T	≤ 40	≤ 30	≤ 250

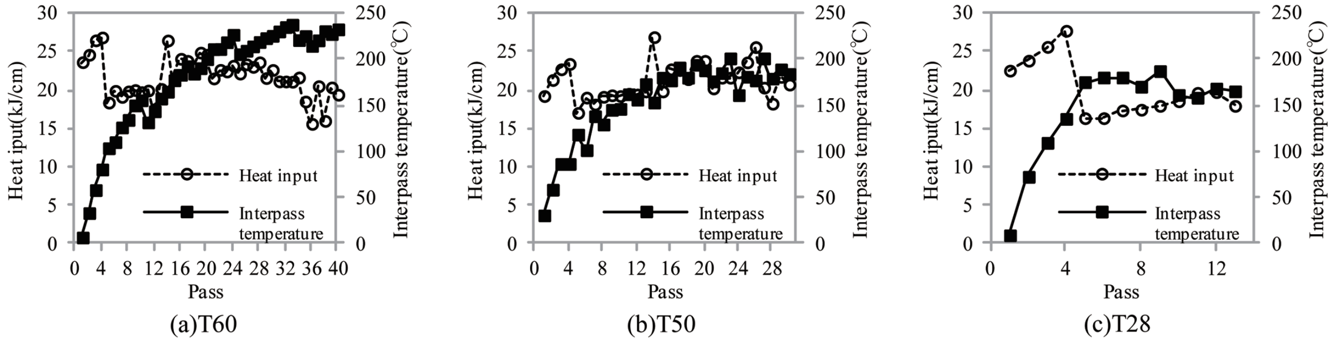


Fig. 4 Heat input and interpass temperature records

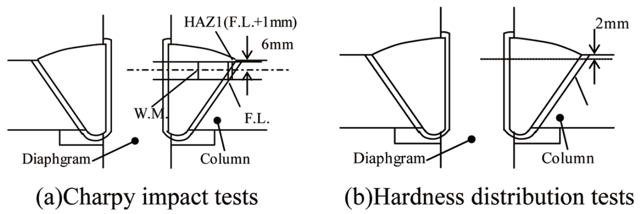


Fig. 5 Positions of specimens for Charpy impact tests and hardness distribution tests

Table 12 Charpy impact test results of welded joints

Spec. No.	Column-diaphragm joint					
	Flat area			Corner area		
	HAZ (F.L.+1 mm)	F.L.	W.M.	HAZ (F.L.+1 mm)	F.L.	W.M.
T60	198	148	90	150	141	93
T50	180	177	92	187	146	78
T28	157	192	129	171	160	99

joints are shown. The position of the measurement of the hardness was 2 mm inside and below the outer surface as shown in Fig. 5(b) and the test force was 98 N. The maximum hardness of the welded joint was about 230HV in both test bodies.

The structural performance as column member provided with a through diaphragm was evaluated by a bending test. Load was applied to form 45° bending, where extreme fiber stress occurs on the corner, in order to evaluate the welded joint performance at the corner that is most crucial to fracture. For the BCHT385BTF that was the subject of the test, the steel material and the welding consumables identical with those used for the weld joint performance evaluation were used under the same welding conditions. As an example,

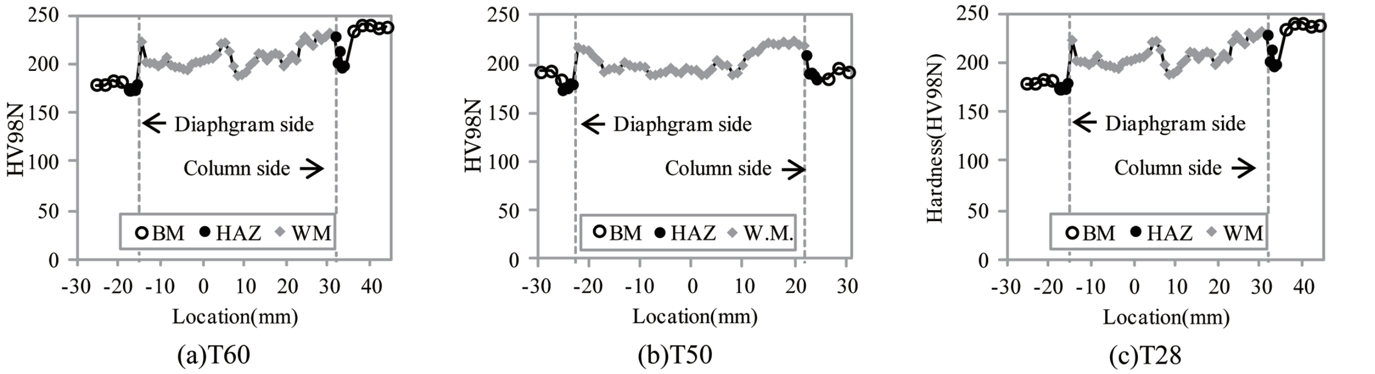


Fig. 6 Hardness distribution tests results of welded joints

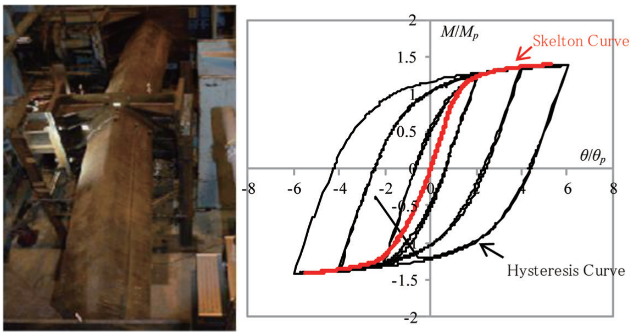


Fig. 7 Hysteretic behavior of BCHT385BTF (thickness 60 mm)

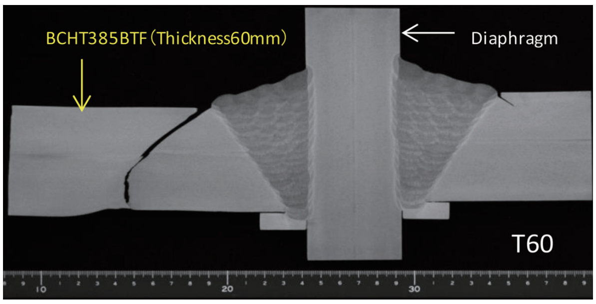


Photo 2 Macrostructure around fracture origin (thickness 60 mm)

the hysteretic behavior of BCHT385BTF of the plate of maximum thickness of 60 mm is shown in **Fig. 7** and the macrostructure of the fractured section is shown in **Photo 2**. In either test body, it is confirmed that the crack that originated in the neighborhood of the welded joint propagates toward the base steel plate of the column in a ductile manner and penetrates the base steel plate thoroughly after the plate of the column underwent plastic deformation sufficiently accompanied by necking.

In **Fig. 8**, the results of the 45° three-point bending test of BCHT385BTF are shown. The accumulated plastic deformation multiplying factor is taken on the vertical axis and the equivalent depth-thickness ratio $1/\alpha$ is taken on the horizontal axis where α is calculated by the following formula.

$\alpha = (\sigma y/E)\cdot(D/t)^2$

where σy, yielding strength of the flat area of the test body; E, Young's modulus; D, diameter of the test body; t, plate thickness of the test body; and it was confirmed that all test results sufficiently exceed the required deformability performance of the column mem-

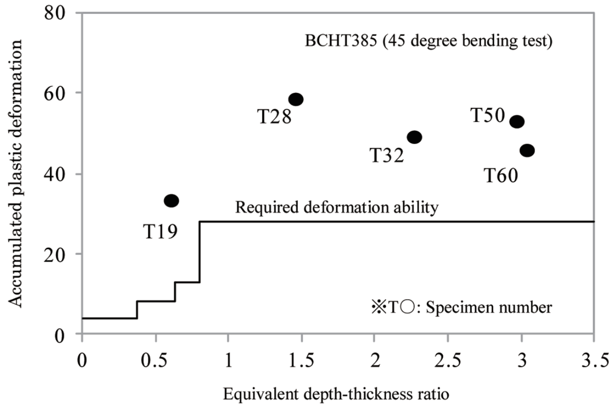


Fig. 8 Effect of depth-thickness ratio on accumulated plastic deformation (BCHT385BTF)

ber shown in the document [11].

From the above results, it is found that BCHT385BT is a cold-press-formed square tube that secures excellent toughness at its welded joint even if the welding procedure under the condition same with that of the general BCP is employed, and has excellent deformability performance without developing early brittle fracture in HAZ.

Furthermore, for further information about the weld joint performance and the structural performance of the column member of BCHT325BTF,CTF, the reference document [12] is recommended to be referred to.

4. Prospect of Future

In order to sustain the development of the welding technology to further improve its operation efficiency from the standpoint of material, it is necessary to elucidate the performance required to welded joint, namely the performance required to the toughness and the strength of welded joint, by envisioning the desirable aspects of the structural performance of buildings and the plastic deformability of steel frame members and, by employing the approach method based on mechanical outlook.

As to the systematic approach like this to the elucidation of the required performance of welded joint, presently only the researches on beam end welded joint of 490 N/mm^2 class steel (carbon dioxide gas shielded arc welding or mixed-gas shielded arc welding) [3] and electroslag welding of a diaphragm to the inside of a built-up box [4] are available and the required performance to welded joint of high strength steel material in particular has still remained unclear. In view of such circumstances, in April 2015, the Japan Iron and Steel Federation established the "Technical Committee for the researches on required performance of welded joints in steel frame (Chairperson: Satoshi Yamada, Professor of Tokyo Institute of Technology) and started the research, entrusting the Japanese Society of Steel Construction (a general incorporated association) with the research. Furthermore, as to the strength of weld joint, although the strength equal to or above that of the mother material has been considered necessary within the framework of the Building Standards Act (Notice HEI 12 KEN KOKU No.1464), in recent years, the research on the positive employment of welding consumables with strength lower than that of the mother material, so called undermatched welds, is being promoted extensively. [13, 14]

Hence forth, the authors are determined to continue the development of materials aiming at improving the efficiency of welding operation and the weld joint quality compatibly to a higher level while elucidating the required weld joint performance to secure the seismic resistance of buildings.

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