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by applying an extremely-low carbon bainitic steel The developed H-shapes have high strength and high toughness which satises the S 0 specication without any heat treatment Because the steel has excellent cold

shows improved resistance to cold cracking because hardening at heat affected zone (HAZ) is minimized due to the extremely-low C composition. This means that a elimination of preheating (preheating-free welding)[6] can be expected with extremely-low C bainitic steel. Moreover, this steel also exhibited this remarkable effect even in non-steady welding, in which the cooling rate is extremely large, for example, at arc strike. Improvement in the toughness of the HAZ can also be expected to be improved due to a reduction in martensite-austenite constituents (M-A).[5]

In order to take advantage of the features described above, extremely-low C bainitic steel was applied in the development of the new high strength heavy gauge H-shapes.

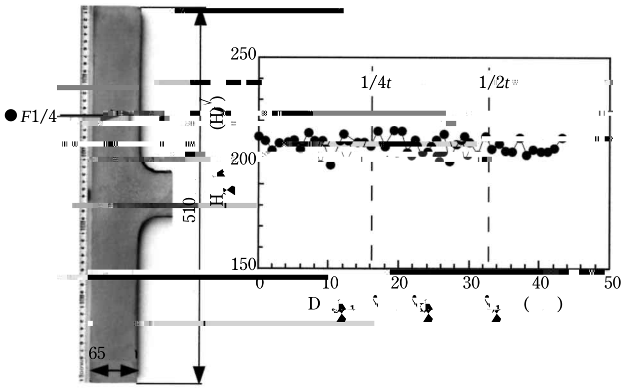

Fig. 4 Macrostructure and hardness distribution of developed H-shapes at flange portion

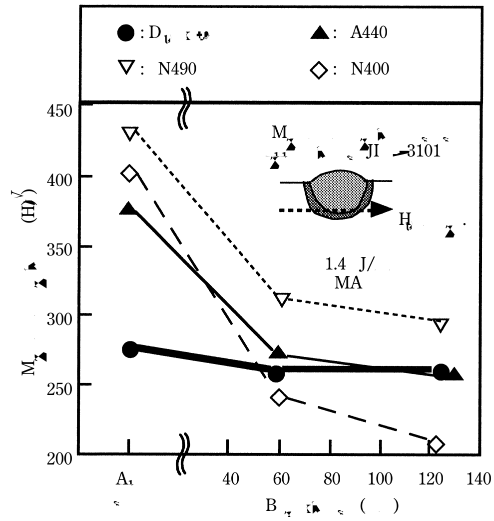

Fig. 5 Maximum hardness observed for unsteady-state welding of short bead length and arc-strike

dance with JIS Z 3158. Samples were taken from the 1/4 flange width area, and test pieces used in the experiment were prepared by decreasing the material thickness to 40 mm. The test conditions and results are shown in [illegible]. Based on the fact that absolutely no cracking occurred, even at atmospheric temperature of 25°C, the manufactured heavy gauge H-shape has an even higher level of cold cracking resistance than the heat-treated type 590 MPa class steel plate (SA440).

[illegible]

To investigate the hardenability behavior of the heat affected zone, a maximum hardness test of HAZ was performed in accordance with JIS Z 3101. In addition to the standard bead length of 125 mm specified in JIS, tests were also conducted with a bead length of 60 mm, in case of a short bead, and in an arc-strike condition with an arc time of 1 s, in a case of spot welding. The results are shown in [illegible] in comparison with the heat-treated type 590 MPa class steel plate (SA440), steels SM440 and SN490. Because martensite formation is suppressed in the developed steel by reducing the carbon content to 0.02%, the effect of the bead length on hardness is extremely small. The maximum Vickers hardness under the arc-strike condition was also low, at 270 points, in comparison with 380 points for the SA440 plate, showing that the developed steel has excellent resistance to hardening of the HAZ.

[illegible]

To study application to practical column materials, column to column and column to beam welding were performed under conditions which can simulate the method emplayed in practical welding and the performance of the joints was evaluated.

.1 [illegible]

The joints were produced by using a semi-automatic CO_2 arc welding. The welding conditions and details of the welded joints are shown in [illegible] and [illegible], respectively. In case of column to column joints, joints were made up by using the normal welding electrode, KC60 (JIS standard YGW21), for 590 MPa class steel. In the case of column to beam joints, an SN490B class H-shapes with a flange thickness of 28 mm was used as the beam material, and KC50 (JIS standard YGW11) was used as the welding electrode. The fabricated joints were measurement of the hardness distribution, joint tensile strength, and Charpy impact property at the weld metal (WM), bond (fusion line: FL), and HAZ 1 mm from the bond.

Table 4 Results of y-groove weld cracking test according to JIS Z 3158

[illegible] ( )	[illegible]	C [illegible] (A)	[illegible] (V)	(/)	P [illegible] (°C)	C [illegible] (%) [illegible] (%)	C [illegible] (%)	[illegible] (%)
40	JI 3212 D6216 (K A86) 4 φ	170	25	2.5	25	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0
					50	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0

.2 [illegible]

The cross-sectional hardness distributions of the column to column and column to beam joints are shown in [illegible]. No remarkable hardening or softening in HAZ was observed in the welded joints.

[illegible]

The results of tensile test are shown in [illegible]. In the case of column to column joints, the tensile strength was 631 MPa, and fracture occurred in the base material of the heavy gauge H-shape. In the column to beam joint, the tensile strength was 526 MPa, and fracture occurred in the base material of the beam (SN490B). These results confirm that column to column joints and column to beam joints of the developed H-shapes have sufficient strength when welding is performed using the actual welding method.

[illegible]

The results of Charpy impact test at the weld metal (WM), bond (FL), and HAZ 1 mm apart from the bond are shown in [illegible]. In the column to column joints, test pieces were taken from the direction relative to the flange surface of the heavy gauge H-shape, whereas, with the column to beam joints, test pieces were taken from the direction. At the bond and HAZ, the Charpy absorbed energies at 0°C were high, by amount of more than 200 J in both cases, indicating that these parts have sufficient toughness. Moreover, the Charpy value even in the WM was more than 100 J. No effect of the sampling direction could be observed (direction in column to column joints, and direction in column to beam joints), showing that the joints possessed excellent toughness.

Based on these results, it can be concluded that the developed heavy gauge H-shapes provide satisfactory base material performance and joint performance for use as column materials in building structures.

[illegible]

In the design of building structures, the sum of the stress ratios of the axial load and bending stress should be 1 or less.[10], namely

$$\sigma_c/F_c + \sigma_b/F_b \leqq 1 \quad \cdots\cdots\cdots\cdots (1)$$

where, σ_c is average compression stress, F_c is allowable unit stress for compression, σ_b is average bending stress, and F_b is allowable unit stress for bending.

The specifi11 1 Tf 6.5 0 0 6.5 144.05 160.51 Tm 0 0 0 1 k /GS2 gs 16.23 -780W n BT /F11 1 Tf 6.5 0 0 6.5 175.595 121.

ability have been successfully developed through the as-rolled process. The performance of the base material and joints of the developed steel are summarized as follows:

(1) The developed H-shapes have both high strength and high toughness, satisfying the standards for high performance steel (SA440) in the as-rolled condition even in a heavy gauge size of web height of 582 mm, flange width of 510 mm, web thickness of 60 mm, and flange thickness of 65 mm.

(2) The developed steel has excellent weldability, including extremely low susceptibility to cold cracking and hardenability of the HAZ under arc strike condition.

(3) Column to column joints and column to beam joints were fabricated under conditions which simulated the actual welding method, and their joint performance was evaluated. The results confirmed that joints of the new H-shapes have sufficient joint strength and toughness.

(4) The developed 590 MPa class heavy gauge H-shapes are commercialized as RIVER TOUGH 440 under Kawasaki Steel's own standard, and were adopted for the first time in Japan as column materials for a high rise buildings in an urban renewal project in Tokyo.

The authors wish to express their sincere appreciation