KAWASAKI STEEL TECHNICAL REPORT
No.3 (September 1981)

Weldable Martensitic Stainless Steel, RIVER LITE 410 DH, for Structural Use

Keiichi Yoshioka, Noboru Kinoshita, Yutaka Ono, Makoto Kobayashi, Ryuichi Hasegawa, Yoshinobu Ryomoto

Synopsis :

A newly developed weldable 12% Cr stainless steel, RIVER LITE 410DH is superior in toughness, ductility and weldability, with its wide application for welded structures. The chemical composition of the steel is characterized by noticeably low carbon and nitrogen and high manganese with copper addition. Tensile strength of the plate can easily be controlled in any of the three levels of 42-47, 50-55 and 60-70 kgf/mm2 by the selection of heat treatment in mass-production process. The weld heat affected zone of the steel has a low carbon martensitic structure and exhibits good ductility and toughness even if no pre- or post-weld heating is employed. The welding material of type 309 is recommended for MIG welding.

KAWASAKI STEEL TECHNICAL REPORT No. 3 September 1981

Weldable Martensitic Stainless Steel, RIVER LITE 410 DH, for Structural Use*

Keiichi YOSHIOKA** Noboru KINOSHITA** Yutaka ONO**
Makoto KOBAYASHI*** Ryuichi HASEGAWA**** Yoshinobu RYOMOTO*****

A newly developed weldable 12% Cr stainless steel, **RIVER LITE 410DH** *is superior in toughness, ductility and weldability, with its wide application for welded structures. The chemical composition of the steel is characterized by noticeably low carbon and nitrogen and high manganese with copper addition. Tensile strength of the plate can easily be controlled in any of the three levels of 42–47, 50–55 and 60–70 kgf/mm² by the selection of heat treatment in mass-production process. The weld heat affected zone of the steel has a low carbon martensitic structure and exhibits good ductility and toughness even if no pre- or post-weld heating is employed. The welding material of type 309 is recommended for MIG welding.*

1 Introduction

Type 13Cr stainless steels, represented by SUS410 and SUS420, are used mainly for tools, cutters, tableware, motorcycle disc brakes, etc., owing to their high hardness given by heat treatment such as quenching or tempering, though it is inferior to austenitic stainless steels in corrosion resistance.

Today, however, these martensitic stainless steels are not used for welded structures, especially those in heavy section. This is not only due to their poor weldability, but also to poor toughness of heat affected zone, which can be improved by pre- and post-heating. It has been reported that the reduction of interstitial impurity elements such as C and N in the 13% Cr stainless steels with the addition of Ni is effective for avoiding the defects of martensitic stainless steels[1].

Besides good weldability and toughness, sufficient proof strength and tensile strength as well as good formability are also required for steels for structural purposes and their properties requirements differ according to their uses. From a manufacturing point of view, therefore, the stable control of mechanical properties of plates is also an important and difficult problem.

The authors have overcome the above-mentioned defects and difficulties, and have developed a new weldable stainless steel for structural use, **RIVER LITE 410 DH** (hereinafter abbreviated as **R410DH**), in which such low C martensitic structure[2] of high toughness as seen in maraging steel can be obtained in the heat affected zone. This steel is mainly used for welded structures that require rust resistance, such as for ocean-going cargo containers.

The outstanding features of this stainless steel are as follows.

2 Chemical Composition and Manufacturing Process

The chemical composition range of **R410DH** and its typical example are shown in **Table 1**. **R410DH**, containing 12% Cr, is characterized by C and N contents reduced to as low as approximately 0.01%, and by the addition of Mn and a small quantity of Cu.

Fig. 1 shows an outline of the manufacturing process of **R410DH**. The steel is classified into two types according to the process; one is cold rolled and annealed, and the other hot rolled and annealed with 3 mm thickness as the dividing line. The hot rolled and annealed plates can be made with various levels of mechanical properties through different heat treatment conditions.

---

* Originally published in *Kawasaki Steel Technical Report*, 12 (1980) 2, pp. 159–167 (in Japanese)

** Research Laboratories

*** Chiba Works

**** Hanshin Works

***** Technical Division

Table 1 Specification and a typical example of chemical composition of **R410DH**

	C	Si	Mn	P	S	Cr	Cu	N
Specification	≦0.02	≦0.5	1.0 -2.5	≦0.04	≦0.03	10 -13.5	≦1.0	≦0.02
Example	0.01	0.2	1.5	0.025	0.005	11.7	0.4	0.007

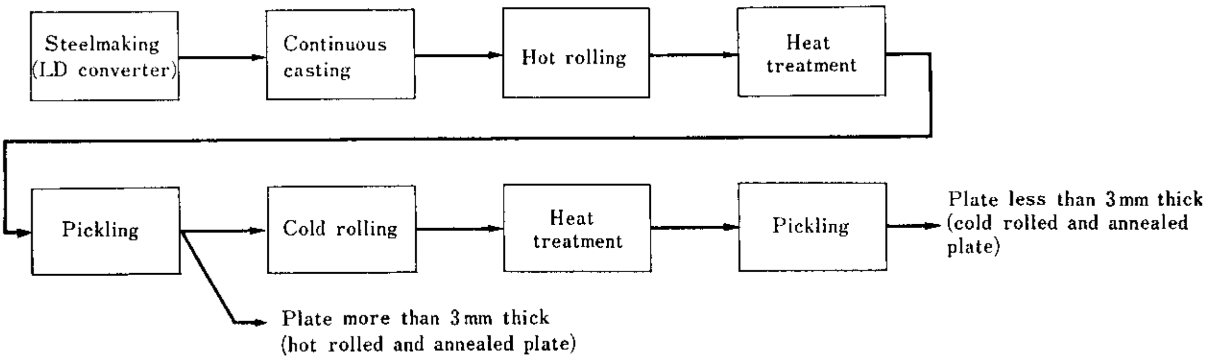


Fig. 1 Manufacturing process of **R410DH**

3 Mechanical Properties of Plate

Fig. 2 shows the dependence of the hardness of hot rolled plates on heat treatment temperature. In the steel without Cu addition, the hardness suddenly decreases in the temperature range of 600–650°C. In the steel with Cu addition, the hardness decreases gradually, and maintains a high level even after heat treatment in this temperature range. **Photo. 1** shows the microstructures of hot rolled plates and annealed plates. In the steel with no Cu addition, only ferrite structure is observed in annealing at 625°C, while martensite remains in the steel with Cu addition.

Thus, by the addition of Cu, decomposition of martensite is suppressed, and the resistance to the softening of mechanical properties is increased, though this mechanism is not clear at present. However, as is clear from **Fig. 3** showing the curves of electric resistivity change caused by isochronal annealing, ε-Cu precipitates in the temperature range of 550–650°C; so, it is possible that the resulting precipitation hardening contributes to the increase of the resistance to the softening.

Although the mechanical properties of **R410DH** differ, as described above, according to the heat treatment conditions after hot rolling or after quenching,

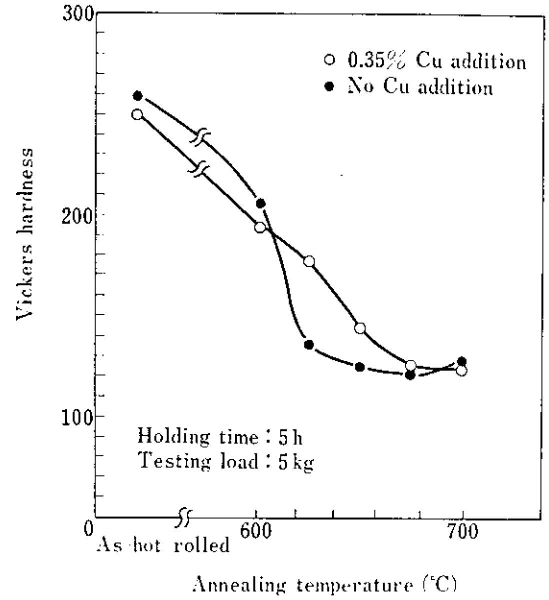


Fig. 2 Relation of Vickers hardness of 6.4 mm thick hot rolled **R410DH** to annealing temperature

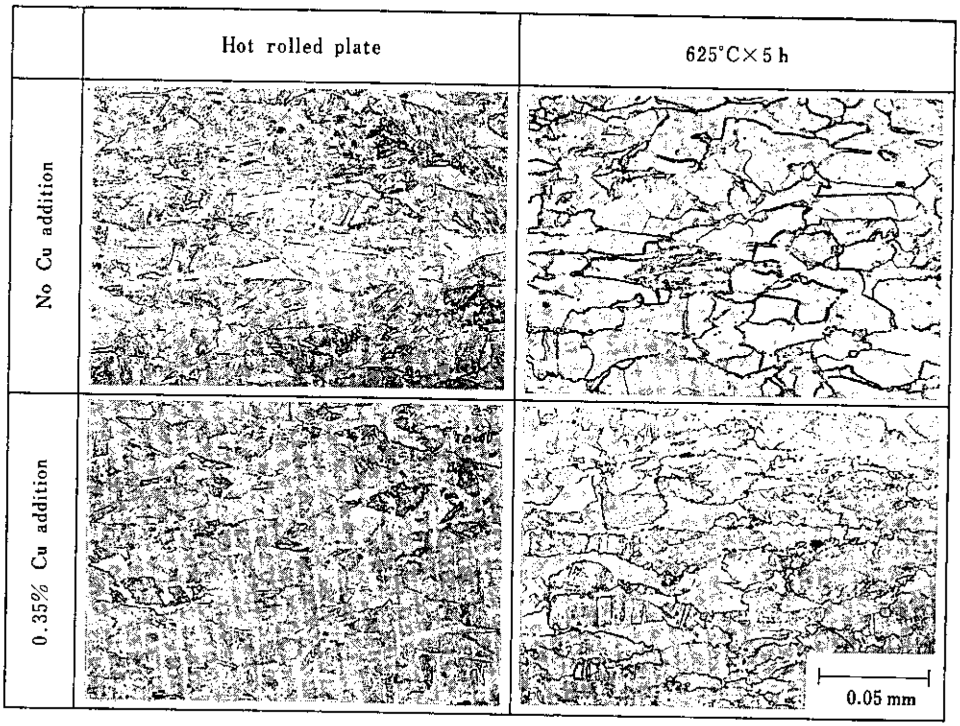


Photo. 1 Microstructures of hot rolled plates and annealed plates of 6.4 mm thick **R410DH** (Etchant: picric acid-hydrochloric acid)

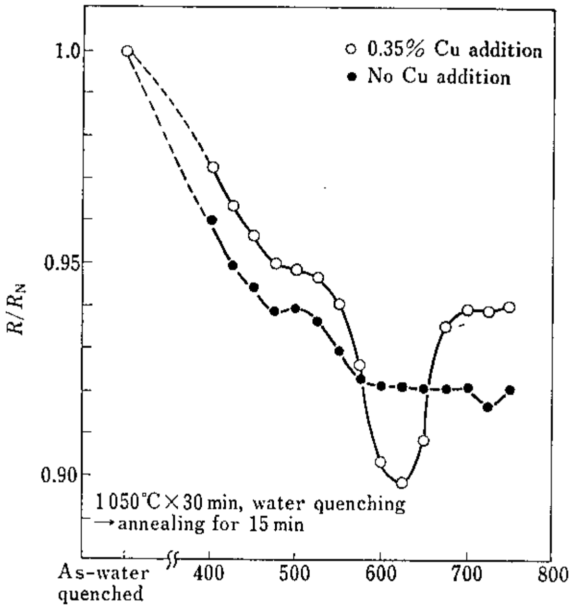


Fig. 3 Isochronal annealing curves of electric resistivity of **R410DH** measured in liquid nitrogen (R: resistivity, R_N: resistivity as quenched)

Table 2 Mechanical properties of hot rolled and annealed 6.4 mm thick plate of **R410DH**

Level of strength	0.2% proof strength* (kgf/mm²)	Tensile strength* (kgf/mm²)	Elongation* (%)	Bendability** (γ=1t,180°)
Low	25-32	42-47	≧35	Good
Medium	35-45	50-55	≧30	Good
High	50-60	60-70	≧18	Good

* JIS No.5 specimen, transverse to rolling direction
** γ: Bending radius
t: Thickness of plate

the products of three strength levels as shown in **Table 2** are manufactured by the heat treatment taken into consideration the reduction of corrosion resistance due to the precipitation of Cr carbide and nitride.

Fig. 4 shows the results of Charpy impact tests on **R410DH** of various plate thickness having 0.2% proof strength of 35 kgf/mm² and tensile strength of 50 kgf/mm². With every ductile-brittle transition temperature lower than −50°C, it is clear that **R410DH** can be used as normal structure members.

In addition, the fatigue properties of the plate are

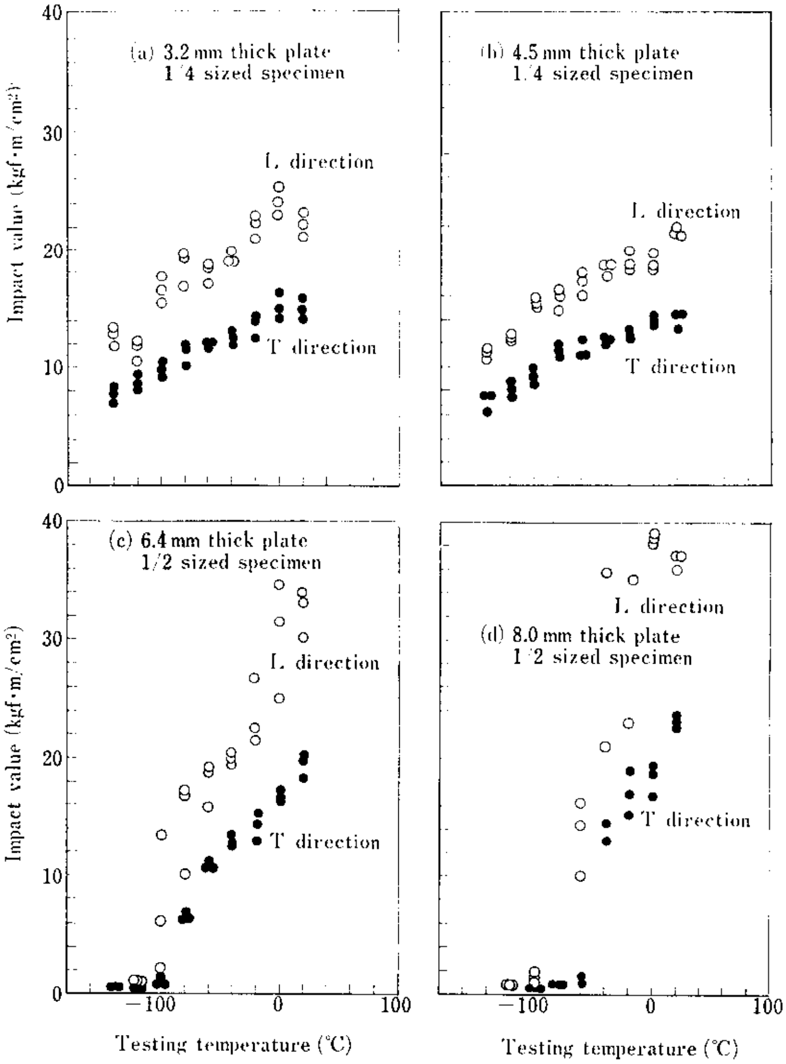


Fig. 4 Results of Charpy impact test on R410DH plate using JIS No. 4 specimen

good, with the fatigue limit more than 1/2 of the tensile strength.

4 Properties of Welded Joint

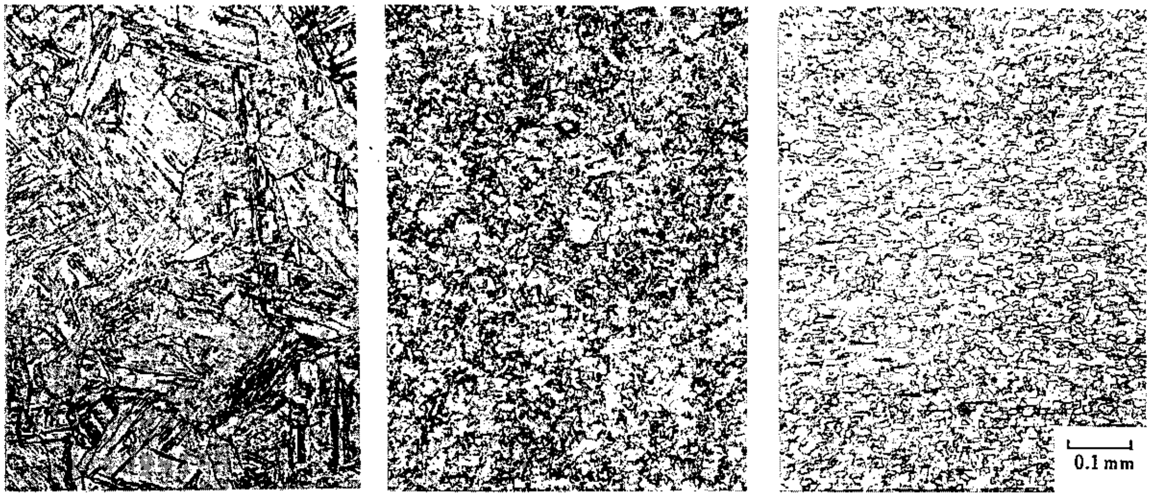
Generally, gas shielded arc welding process is classified into two kinds, depending upon the thickness of the steel plate to be welded; TIG welding for a plate less than 3 mm thick, and MIG welding for a plate 3 mm thick and over. The welding processes are respectively described in the following sections.

4.1 TIG Welding

Photo. 2 shows the microstructure of TIG welded joint welded without a welding material on a 2 mm thick **R410DH** plate. The weld metal has a martensitic structure, and the heat affected zone has a composite structure of martensite and ferrite, finer than that of the mother metal. Corresponding to these structures, the hardness of weld metal and that of the heat affected zone are as high as approximately 260 H_V, as shown in **Fig. 5**.

Table 3 shows the mechanical properties of the cold rolled and annealed sheet and of the TIG welded joint of **R410DH**. The breaking points of tensile specimens are always at the mother metal regardless of using a backing shield gas of Ar, indicating the sound weldability of the joint.

The results of Charpy impact tests on the 2 mm thick mother metal, its TIG weld metal, and its heat affected zone are shown in **Fig. 6**, compared with that on TIG weld metal of AISI409 sheet. The Charpy impact properties of the TIG weld metal of **R410DH** are good, not depending on gas shield conditions, and the energy



Weld Metal   Heat affected zone   Mother metal

Photo. 2 Microstructures of TIG welded joint of 2 mm thick **R410DH**
(Welding material: not used, etchant: picric acid-hydrochloric acid)

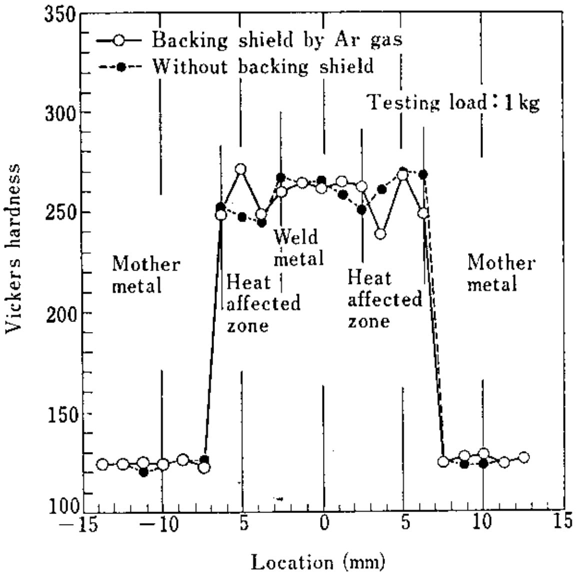


Fig. 5 Vickers hardness of TIG welded joint of 2.0 mm thick **R410DH**

Table 3 Tensile properties* of cold rolled and annealed plate, and its TIG welded joint** of **R410DH**

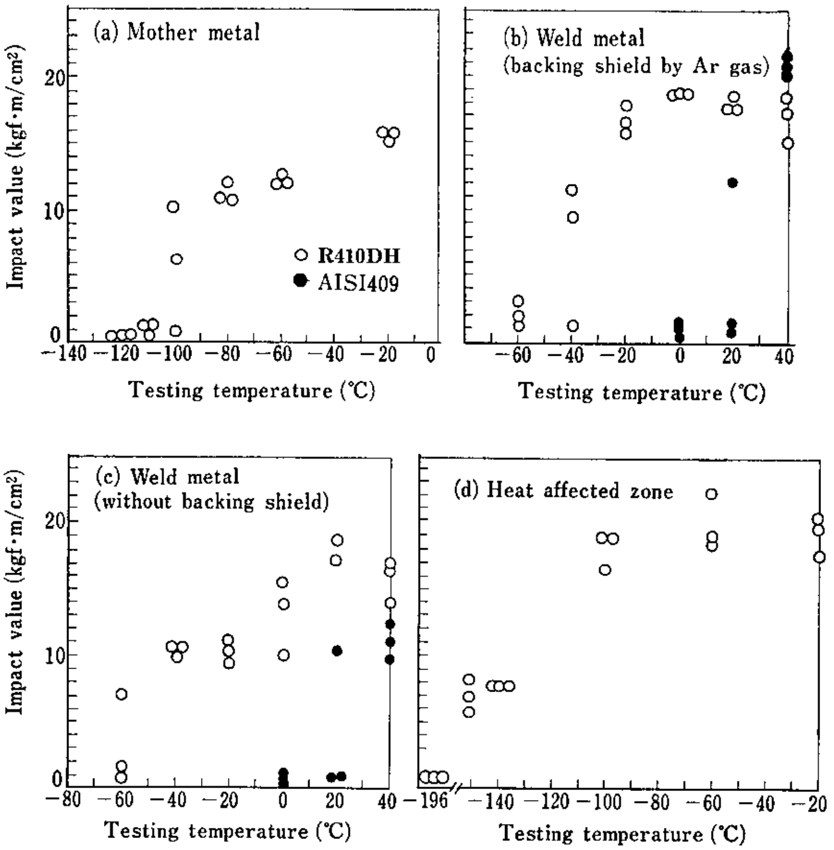
	Thickness (mm)	0.2% proof strength (kgf/mm²)	Tensile strength (kgf mm²)	Elongation (%)
Plate	1.0	31.5	44.2	33.3
	2.0	29.5	43.8	35.0
TIG welded joint (backing shield by Ar gas)	1.0	28.9	42.9	24.1
	2.0	29.6	45.1	25.3
TIG welded joint (without backing shield by Ar gas)	1.0	31.1	44.0	27.1
	2.0	28.4	43.8	26.8

* JIS No.5 type specimen transverse to rolling direction
** Welding material is not used

transition temperature is approximately −40°C. On the other hand, the energy transition temperature of TIG weld metal of AISI409 is higher than room temperature; AISI409 is inferior in toughness to **R410DH**. Moreover, the transition temperature in the heat affected zone of **R410DH** is approximately −120°C, and it is superior in toughness to mother metal. This may be due to the structure of the heat affected zone, which consists of a mixture of low-carbon martensite and a small quantity of ferrite, much finer than that of the mother metal, as shown in **Photo. 2**.

Table 4 shows the results of the chemical analysis of N and O in the TIG weld metal of the cold rolled and annealed **R410DH** sheet. When the sheet is relatively thick, N in the weld metal remarkably increases unless the backing shield of Ar gas is applied. On the other hand, O increases by as much as approximately 20 ppm irrespective of the plate thickness unless a backing shield of Ar gas is applied.

In higher Cr ferritic stainless steels having extra low C and N contents (for example, 18–30% Cr steels having less than 100 ppm (C + N), TIG weld metals pick up N from the atmosphere on the back surface of a plate unless the backing shield of Ar gas is



Welding material : Not used
Impact specimen : JIS No.4 specimen with reinforcement in place

Fig. 6 Results of Charpy impact test on 2.0 mm thick plate and its TIG welded joint of **R410DH**

Table 4 T and O contents of the weld metal of TIG welded joints* of **R410DH** cold rolled and annealed plate

	1.0 mm thick		2.0 mm thick	
	N	O	N	O
Backing shield by Ar gas	98	67	96	53
Without backing shield	99	82	140	78

* Welding material is not used

applied[3,4], and their toughness is remarkably lowered. In **R410DH**, however, backing shield conditions have little influence upon the impact properties, as shown in **Fig. 6**. This may be attributable to the (C + N) content in **R410DH** amounting approximately to 200 ppm, a not low level enough to ignore an influence by N pick-up of about 50 ppm, and also to the fine microstructure of the weld metal.

Thus, the greatest feature of the TIG welding of **R410DH** is that the welded joint is excellent in toughness even if welded without backing shield of Ar gas, and this is very useful for actual work. In addition, since the toughness of the weld heat affected zone is excellent, the 2 mm thick sheet, for example, may be applied to the use of welded structures even at such a low temperature as −80°C if an austenitic stainless, welding material such as Y-309 is used.

4.2 MIG Welding

4.2.1 Welding material

Now, in general welded structures, consideration should be taken not only on the joint for two pieces of **R410DH** but also the joint for **R410DH** and other steel plate. In particular, the weldability of weld metal depends upon the welding materials used, and therefore, their choice is important. Although martensitic, ferritic, and austenitic stainless welding materials can be considered as a consumable electrode for MIG welding of **R410DH** plates, austenitic stainless welding

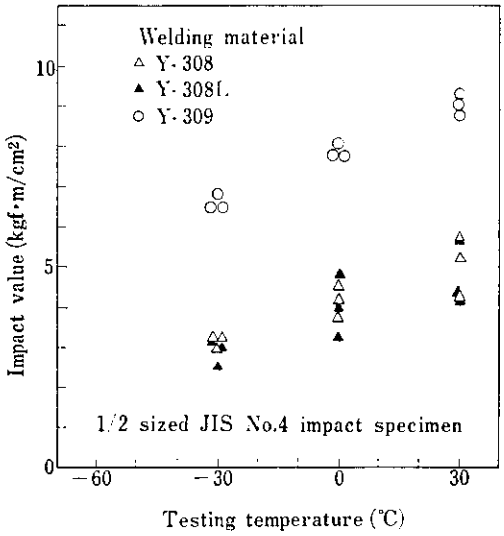


Fig. 7 Results of Charpy impact test on weld metals of butt welded joint of **R410DH**

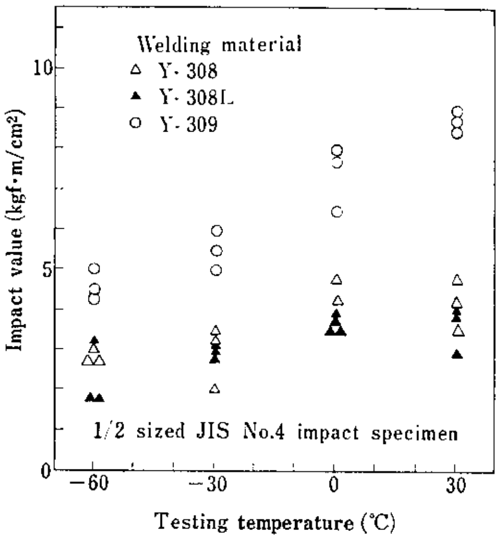


Fig. 8 Results of Charpy impact test on weld metals of butt joints of 6.4 mm thick **R410DH** and 8 mm thick SCW49

Table 5 MIG welding condition for butt-joint (6.4 mm thick **R410DH**, 6.4 mm thick **R410DH**-8 mm thick SCW49)

Current	250-290 A
Voltage	23-25 V
Travelling speed	300-350 mm/min
Number of pass	1
Pre-and post-heating	not used
Root opening	2 mm, double square groove or single bevel groove
Shielding gas	Ar 15 l/min+CO_2 3-5 l/min
Welding material	1.2 mmϕ wire of Y-308, Y-308L and Y-309

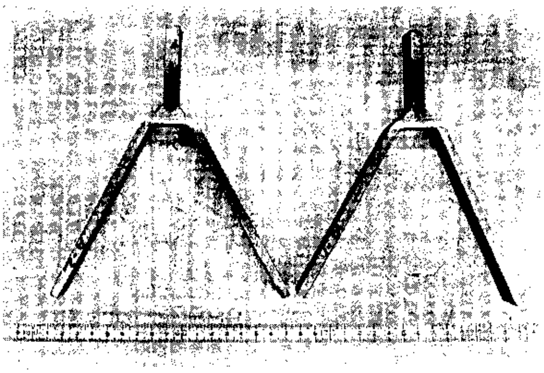


Photo. 3 Appearance of T-shaped fillet joints after bend test (web: 8 mm thick SCW49, flange: 6.4 mm thick **R410DH**, welding material: Y-308)

materials only may be available, considering usefulness for the welding including a joint of two dissimilar materials.

Fig. 7 shows the results of Charpy impact tests on the weld metal of the butt joint of 6.4 mm thick **R410DH** plates, welded under the conditions shown in **Table 5** using the welding materials of Y-308, 308L and 309. **Fig. 8** shows the results of Charpy impact test on the weld metal of the butt joint for connecting a 6.4 mm thick **R410DH** plate and an 8 mm thick plate of cast steel, SCW49. Regardless of joints, the absorbed energy of the weld metal welded by Y-309 is twice as high as those by Y-308 and 308L over the entire range of test temperature.

Fig. 9 shows the relation between Cr- and Ni-equivalent and austenite amount in weld metals, plotted in Schaeffer's diagram[5,6]. The Cr- and Ni-equivalents, calculated by Delong's equation[6], were determined by chemical analysis of weld metals, and the austenite amount by the magnetic measurement. Both the weld metal of **R410DH** and that of the joint of the dissimilar plates, welded by Y-309, possess good toughness since both of them include a structure having approximately 85% austenite, while both, welded by Y-308 and 308L, have a structure consisting of approximately 10% austenite and 90% (martensite + ferrite) or martensite, and their toughness is inferior to some degree. However, even when Y-308 or 308L are used, their weldability is so sufficient from a practical point of view, that no crack is observed in any of the bent specimens of the T-shaped fillet welded joints as shown in **Photo. 3**.

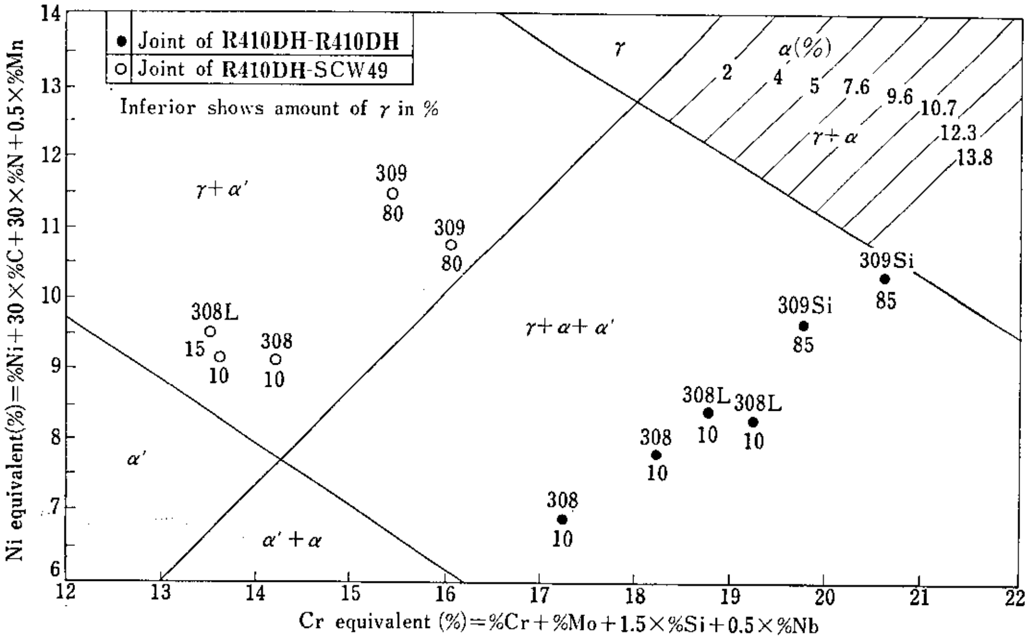
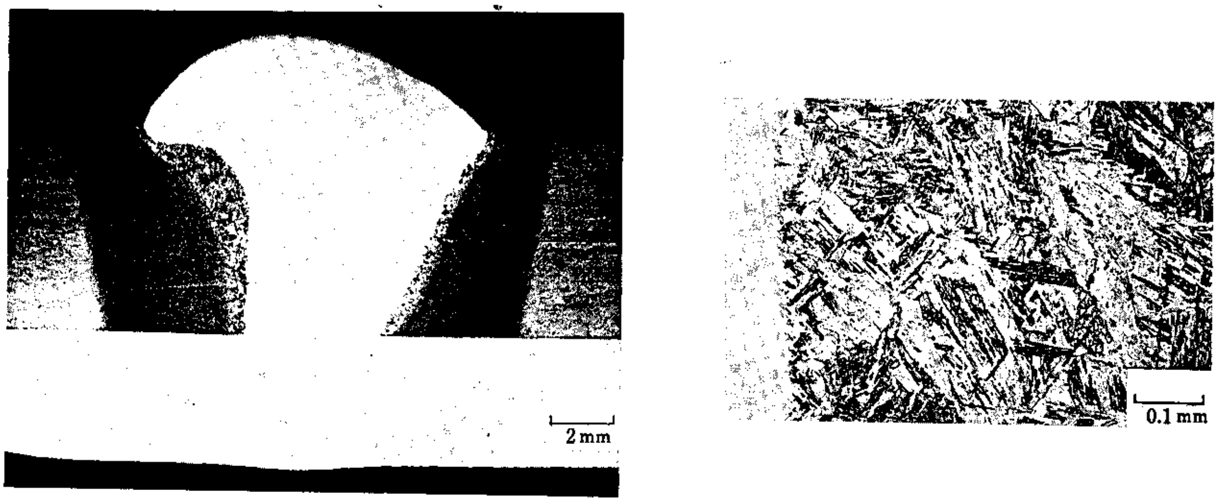
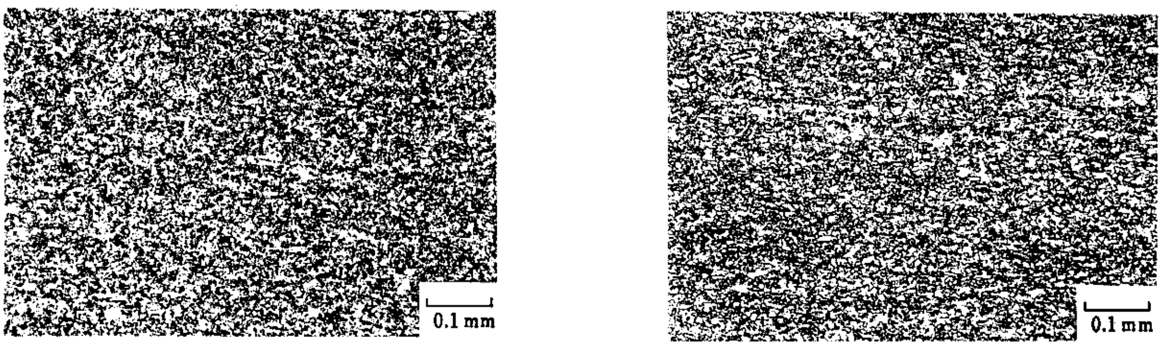


Fig. 9 Cr- and Ni-equivalents and γ content of weld metal of butt welded joint in Schaeffler's diagram



a)Macrostructure (single bevel groove)

b)Coarse grained region



c)Fine grained region

d)Mother metal

Photo. 4 Macro- and microstructures of MIG welded joints of 6.4 mm thick **R410DH** (Joint geometry: single bevel groove, welding material: Y-309, backing plate: SUS304, etchant: picric acid-hydochloric acid)

Therefore, although the Y-308 and Y-308L are also available as a welding material for a structural use, Y-309 is recommended rather than Y-308 or 308L, especially for a use which requires a more sufficient joint performance, or includes joints of dissimilar materials.

4.2.2 Heat affected zone

Photo. 4 shows the macrostructure of the cross section of a 6.4 mm thick **R410DH** butt joint, welded by Y-309 under the conditions shown in **Table 5**, and the microstructure in its heat affected zone. The weld heat affected zone is distinctively divided into a coarse grained region and a fine grained region; the coarse grained region is of martensitic structure of more than 90%, while the fine grained region is of fine composite structure of ferrite and martensite.

Fig. 10 shows the results of Charpy impact tests on the heat affected zone of **R410DH**, compared with that of AISI409. Since AISI409 has a single structure of ferrite from a room temperature up to its melting point, the microstructure of the heat affected zone is remarkably coarsened, and its toughness is so deteriorated that the energy transition temperature is higher than 100°C. On the other hand, both of the energy transition temperatures in the coarse grained region and the fine grained region of the heat affected zone of **R410DH** are as low as approximately −90°C, and it is clear that **R410DH** can be used as weldable stainless steel for structural use even if pre- or post-heating is not used for welding.

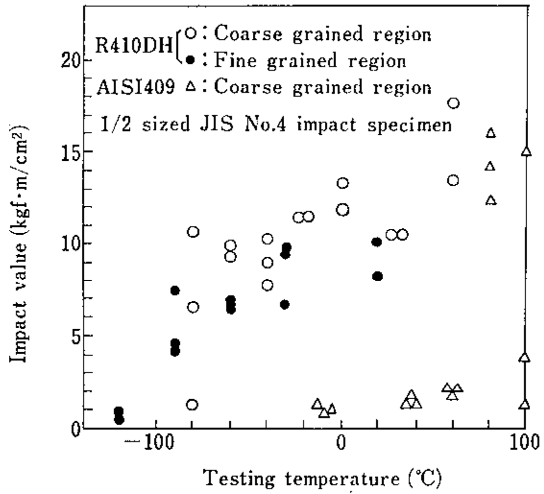


Fig. 10 Results of Charpy impact test on heat affected zone of MIG welded joint of 6.4 mm thick **R410DH** and AISI 409

Table 6 An example of tensile properties* of 6.4 mm thick plate and its MIG welded joint** of **R410DH**

Tensile properties	Plate	MIG welded joint
0.2% proof strength(kgf/mm^2)	38.0, 35.7	35.8, 36.4
Tensile strength(kgf/mm^2)	53.9, 52.4	53.2, 53.6
Elongation (%)	31, 36	22, 22

* JIS No.5 specimen transverse to rolling direction

** Welding material : Y-309

Table 6 shows the results of the tensile tests of the plate having tensile strength of 50 kgf/mm^2 and its MIG welded joint. The 0.2% proof strength and the tensile strength of the welded joint are nearly the same as those of the mother metal, and no deterioration in the strength is recognized. In addition to this, the breaking point is at the mother metal.

Further, the fatigue properties of the welded joint are good, and the fatigue limit is more than 1/2 as large as the tensile strength.

5 Conclusion

R410DH, the low-carbon Cu-added 12% Cr stainless steel developed as weldable stainless steel for structural use, has remarkably improved weldability of a welded joint, which had been the weak point of conventional martensitic stainless steels. In addition, tensile strength of the plate can be easily controlled in any of the three levels of 42–47, 50–55 and 60–70 kgf/mm^2 by the selection of heat treatment in mass-production process. Since Cr content of the stainless steel is as little as 12%, however, its corrosion resistance is not sufficient, compared with that of the austenitic stainless steel, and therefore, it is suitable for welded structures in comparatively mild corrosion environments.

References

1) H. Abo, T. Okazaki, S. Noguchi, I. Kimura, H. Yamamoto, T. Muta: *Seitetsu Kenkyu*, No. 292 (1977), pp. 12258–12265
2) R. F. Decker, C. T. Novak and T. W. Landig: *J. Metals*, **19** (1967) 11, p. 60
3) K. Yoshioka, Y. Oka, N. Kinoshita, M. Takeda, Y. Ono and N. Ohashi: *Tetsu-to-Hagané*, **63** (1977) 9, A135
4) H. Igawa, T. Nakao, K. Nishimoto and M. Terashima: *Preprints of the National Meeting of J. W. S.*, No. 23 (Autumn, 1978), p. 72
5) A. L. Schaeffler: *Welding J.*, **20** (1947) 10, 601S
6) W. T. Delong, G. A. Ostrom and E. R. Szumachowski: *Welding J.*, **29** (1956) 11, 521S