KAWASAKI STEEL TECHNICAL REPORT
No.5 (May 1982)

Development of the Narrow Gap Submerged Arc Welding Process - NSA Process

Yukio Hirai, Masaaki Tokuhisa, Itaru Yamashita, Kaname Nishio, Kozo Akahide, Teruo Ukebe

Synopsis :
With main emphasis on improving slag detachability and preventing weld defects in a narrow gap groove, study was made on the submerged arc welding of heavy steel plate, leading to the development of the NSA process that uses an MgO-BaO-SiO2 type high-basicity agglomerated flux, KB-120. With thermal contraction behavior of slag found to be the most important factor that determines slag detachability, the maximum contraction was obtained by suppressing transformation expansion occurring around 700℃ during cooling. It was found that KB-120 can also produce weld metal of low level hydrogen and oxygen. High reliability and productivity of this process has been confirmed by its wide application to the fabrication of pressure vessels, offshore structures and machinery. Since the "one layer-one pass" welding technique is used to build up for steel plates up to 200mm in thickness, the cross sectional area of the groove and arc time are reduced to 1/2 to 1/3 of those in the conventional process. The use of very low hydrogen flux provides additional advantages such as elimination of intermediate post-weld heat treatment and lowering of preheating temperature.

KAWASAKI STEEL TECHNICAL REPORT No. 5 May 1982

Development of the Narrow Gap Submerged Arc Welding Process—NSA Process*

Yukio HIRAI** Masaaki TOKUHISA** Itaru YAMASHITA***
Kaname NISHIO*** Kozo AKAHIDE**** Teruo UKEBE*****

With main emphasis on improving slag detachability and preventing weld defects in a narrow gap groove, study was made on the submerged arc welding of heavy steel plate, leading to the development of the NSA process that uses an MgO-BaO-SiO_2 type high-basicity agglomerated flux, KB-120.

With thermal contraction behavior of slag found to be the most important factor that determines slag detachability, the maximum contraction was obtained by suppressing transformation expansion occurring around 700°C during cooling. It was found that KB-120 can also produce weld metal of low level hydrogen and oxygen.

High reliability and productivity of this process has been confirmed by its wide application to the fabrication of pressure vessels, offshore structures and machinery. Since the "one layer-one pass" welding technique is used to build up for steel plates up to 200 mm in thickness, the cross sectional area of the groove and arc time are reduced to 1/2 to 1/3 of those in the conventional process. The use of very low hydrogen flux provides additional advantages such as elimination of intermediate post-weld heat treatment and lowering of preheating temperature.

1 Introduction

A growing number of weld structures in recent years are built larger in size, ever expanding the market for heavy steel plates. Under these circumstances, fabricators in the field naturally look for good welding materials and a welding process that enables them to handle the complex work procedures at higher efficiency.

Conventionally, fabricators had no other choice but to resort to the submerged arc welding (SAW) and electroslag welding (ESW), and they suffered much from many problems such as long arc time and poor joint properties. Recently a new process has been developed called Narrow Gap Arc Welding Process, completely solving all the conventional problems and meeting the above requirements.

The narrow gap gas metal arc welding process (GMAW) was first developed by the Battelle Memorial Institute around 1970. It began to come into practical use in Japan around 1975 after being improved in wire oscillation mechanism and gas shielding system. This process can reduce the sectional area of the groove by more than one-half of the conventional welding process, but it has some inherent problems such as inadequate side wall wetness, arc instability to magnetic field and disturbance of shielding gas. In this process, the range of proper welding conditions that assure a stable high-quality weld joint is somewhat narrower, requiring high-skill welding techniques. Therefore, the application of this process is limited to several large workshops.

Compared with the GMAW process, the SAW process is well-known for its advantage in forestalling weld defects, especially, porocity and lack of fusion, and it is excellent as a heat source for obtaining reliable weld joints. However, as long as the conventional SAW fluxes are applied to the narrow gap groove, slag removal becomes very difficult. For this reason, the narrow gap SAW process had not been used in the field. The vital point for realizing the narrow gap SAW process is to improve slag detachability. The authors examined fundarmental relations between the physical properties and detachability of slag and developed

* Originally published in *Kawasaki Steel Giho*, **14** (1982) 1, pp. 56–68
** Research Laboratories
*** Welding Rod & Iron Powder Plant
**** Engineering Division
***** Kawaden CO., LTD.

a narrow gap SAW process, called the NSA process (Narrow gap Submerged Arc welding process) using a high-basicity agglomerated flux KB120.

2 Outline of NSA Process

In using the narrow gap SAW process, it is necessary to examine the following items:
(1) Slag detachability
(2) Quality of welded joint
(3) Welding efficiency
(4) Equipment investment.
In the NSA process, these points have been worked out, as shown in **Table 1**, by developing special flux, alloyed wire with reduced impurities and a rectangular nozzle for exclusive use (see **Fig. 1**). The surface of Cu nozzle is spray-coated with ceramics for heat and electric insulation. **Photo. 1** shows sectional macrostructures of 200 mm thick joints welded by the NSA and the conventional SAW process.

The NSA process uses the ordinary SAW AC power source with drooping characteristics and does not require such expensive equipment as in the narrow gap GMAW process. In the case of a U-shaped groove, high-efficiency "one layer-one pass" welding technique can be utilized for heavy steel plates of a maximum thickness of 150 to 200 mm. If the plate thickness is less than 100 mm, a narrow groove angle of 30° to 40° is allowed in the V-shaped groove by employing gas cutting, which is a feature not realized in the narrow gap GMAW process.

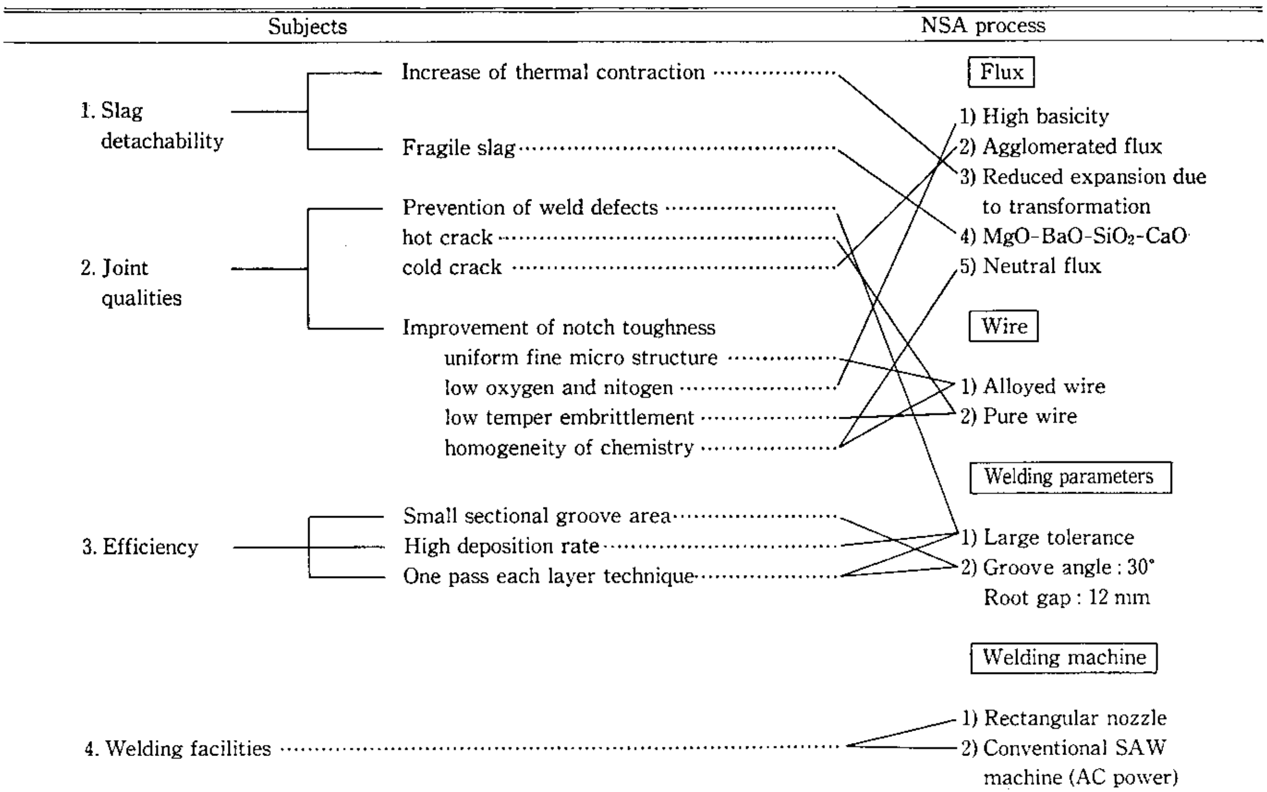
Table 2 is a summary of welding materials for various steels. KB120 is a neutral type flux, and alloy addition to weld metal is performed by using alloyed wire. In order to prevent temper embrittlement in Cr-Mo steel weldment which occurs while the steel structure is in elevated temperature service, impurity elements in the wire (P, Sn, Sb, As, etc.) are reduced to the minimum[2]. Also in order to simplify preheating control and intermediate post-heat treatment for preventing hydrogen-induced cracks, carbonate is added to the flux to reduce hydrogen level in weld metal to less than one-half of the conventional welding process.

3 Development of KB120 High Basicity Agglomerated Flux

3.1 Determination of Basic Composition System

In order to determine the basic composition system of flux which gives excellent slag detachability at the narrow-gap groove, 6 types of flux were provided and

Table 1 Subjects of narrow gap submerged arc welding and their countermeasures in NSA process



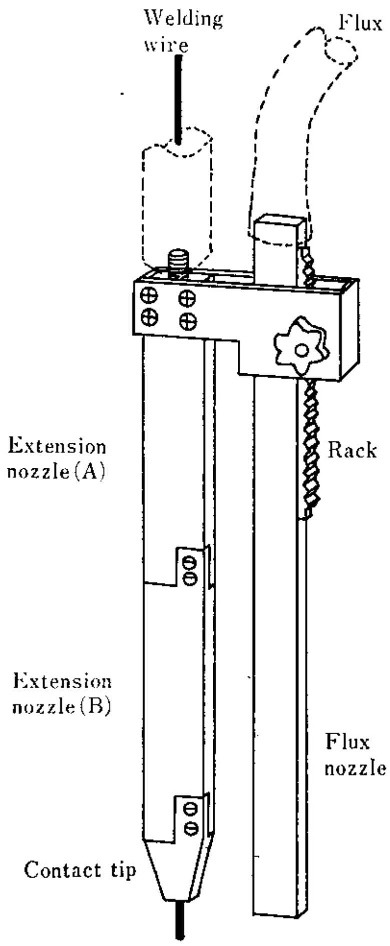


Fig. 1 Rectangular nozzle for NSA process (Thickness: 8 mm)

Table 2 Welding materials for NSA process

Steel grade	Welding Material	
	Wire	Flux
SM 41	KW 30T KW 30C	KB 120
SB 46, 49 ASME SA515 Gr. 60, 70	KW 30T KW 50C	
ASME SA516 Gr. 60, 70	KW 30T KW 50C KW 101B	
ASME SA204, 182 F1 SA336 F1	KW 50C KW 101B	
ASME SA387 Gr. 11, 12 SA336 F11, F12	KWT 105	
ASME SA387 Gr.22 SA336 F22	KWT 210	
ASME SA387 Gr.21 SA336 F21	KWT 310	
60 kgf/mm²HT	KW 101B	
80 kgf/mm²HT	KW 103B	

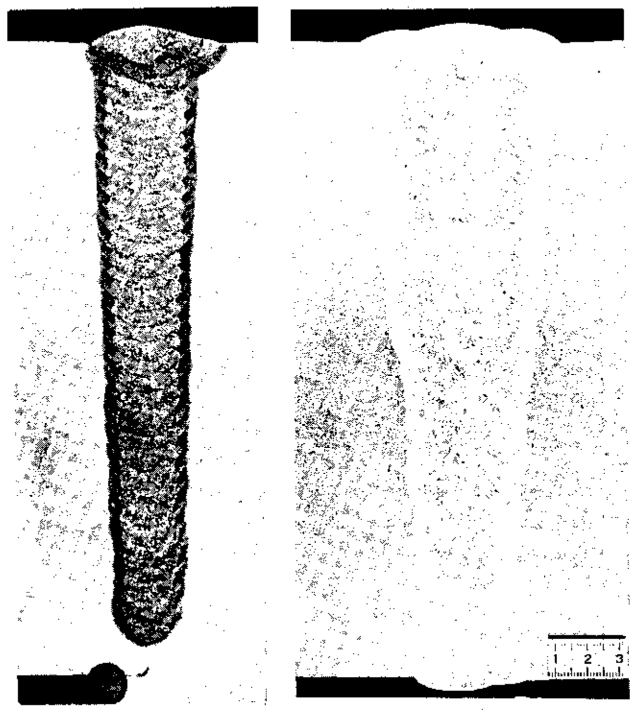


Photo. 1 Macro structure of 200 mm thick welded joint

one-pass welding was performed under the conditions of a root gap of 15 mm, a groove angle of 6°, 600 A, 28 to 30 V, and 25 cm/min. **Table 3** shows the test results of slag detachability, bead configurations, and the slag characteristics.

It was made clear that an excellent slag detachability was shown in the case of acid flux (BF1, BF2 and FF1) which generates a glassy and fragile, though partially, slag, and also in the case of basic flux (BF3) which causes transverse cracks to even crystalline slag. For lowering oxygen content in weld metal and for reducing the slag-weld metal adhesion, the latter basic flux (BF3) is suited to steels requiring high toughness like Cr-Mo steels for pressure vessel service.

When a comparison is made between agglomerated flux and fused flux, the lowering of hydrogen level in weld metal is difficult for high-basicity fused flux, whereas in the case of agglomerated flux, addition of carbonate to flux is possible, and the higher the basicity, the lower the hydrogen level in weld metal. Therefore, the fundamental composition system of KB120 has been determined to be MgO-BaO-SiO_2-Al_2O_3-based agglomerated flux, taking into consideration the intention of applying the NSA process to thick plates of Cr-Mo steel or high-strength steel.

Table 3 Relationship between flux type and slag detachability in narrow gap U-groove welding

Flux			Test results				
Type	No.	Composition	B_L	Slag removal	Bead shape	Slag characteristics	Remarks
Bonded	BF 1	SiO_2-MgO-Al_2O_3	−1.0	Easy	Concave	Glassy+Crystalline	Easily broken
	BF 2	SiO_2-MgO-Al_2O_3-CaF_2	−0.5	〃	〃	〃	〃
	BF 3	MgO-BaO-SiO_2-Al_2O_3	+1.3	〃	〃	Crystalline	Many cracks
	BF 4	MgO-Al_2O_3-CaO-CaF_2	+1.6	Difficult	〃	〃	Not easily broken
Fused	FF 1	TiO_2-BaO-Al_2O_3-SiO_2	−2.6	Easy	Convex	Glassy	Easily broken
	FF 2	Al_2O_3-SiO_2-MnO-CaF_2	+0.2	Difficult	〃	〃	Not easily broken

3.2 Relation between Physical Properties and Detachability of Slag

Many attempts have been repeatedly made to improve the slag removal from a bead surface[4], but no consistent opinion has been established on the correlation between the detachability and physical properties of slag. In some comprehensive investigations high coefficient of thermal expansion, high softening point and fragility are given as one of the main factors improving the slag detachability. However, an opposite conclusion is also drawn in terms of thermal expansion coefficient of slag. In particular, it should be noted that these physical properties are of secondary importance if the chemical bond is formed between slag and bead surface.

Therefore, the relation of the detachability of slag in a narrow groove to the softening point and quantity of thermal contraction of slag has been investigated by using BF3 as a base and with adjustments of ingredients MgO, BaO, SiO_2, etc. Flux compositions are shown in **Table 4**.

Melting points and thermal contraction characteristics of these various types of slags were measured in the following way: Powdery slag kneaded with water was formed into specimens each measuring 10 mm in diameter and 10 mm in height and heated in the Ar atmosphere at a rate of 10°C/min. Then the changes in their shapes were observed by the Silhouette method and recorded, and their softening and melting points were obtained. The results are shown in **Fig. 2** and **Table 5**. The softening temperature was represented by a temperature at which H'/H suddenly became smaller and the melting point by a temperature at which H'/H became 0.5.

Next, in order to investigate their thermal contraction characteristics, these various types of slag were arc-melted in a carbon crucible and made into rod-like specimens each measuring 8 mm in diameter and 50 mm in length. **Fig. 3** shows the thermal expansion measuring equipment. Changes in length of specimens

Table 4 Chemical compositions of flux used

Code	Composition of flux (%)		
	MgO	BaO	SiO_2
BF 5	40	12	20
BF 6	25	13	19
BF 7	22	12	20
BF 8	15	17	22

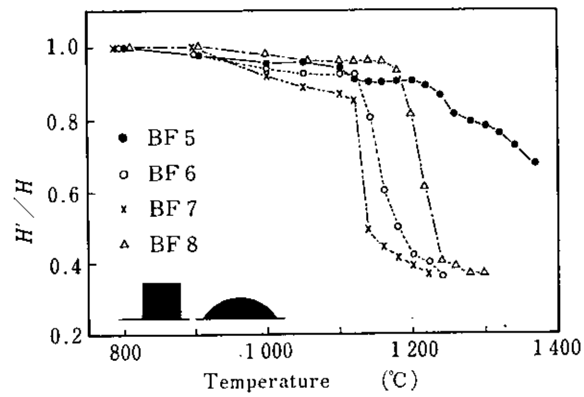


Fig. 2 Physical properties of weld slag determined at elevated temperatures with Silhouette method

Table 5 Relationship between detachability and physical properties of weld slags

Code	Softening temperature (°C)	Melting point. (°C)	Thermal contraction behavior		Weld performance	
			Expansion due to transformation	Total contraction (%)	Bead shape	Slag detachability
BF 5	1 210	1 350	No	1.75	Concave	Very good
BF 6	1 120	1 170	Small	1.23	Concave	Good
BF 7	1 120	1 130	Moderate	0.86	Concave	Slightly difficult
BF 8	1 170	1 240	Large	0.30	Concave	Difficult

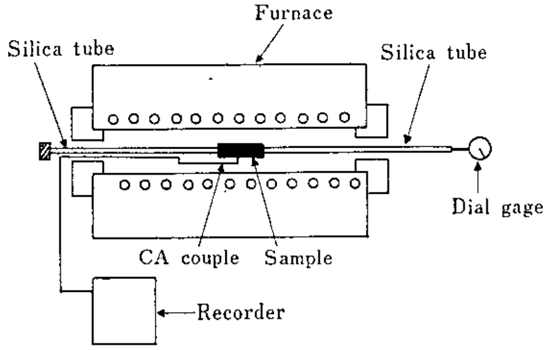


Fig. 3 Apparatus for measuring thermal expansion of slag

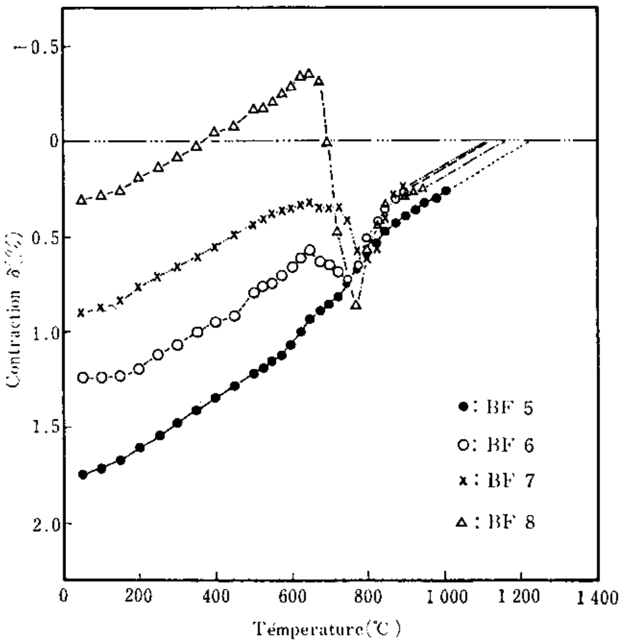


Fig. 4 Contraction behavior of weld slag during cooling

were measured with a dial gage through a quartz tube when they were heated at a rate of about 5°C/min.

For slag detachability in actual welding, it is necessary to take into consideration the thermal contraction characteristics of slag at the cooling period, but here it is assumed that deformation characteristics at the cooling period are similar to those at the heating period, and only the changes in length of specimens during heating were measured. The thermal contraction behaviors of slag under the softening temperature are illustrated in **Fig. 4**. BF5 flux contracts at an approximately uniform rate within the range from 1 000°C to room temperature, but other types of flux (BF6, 7, and 8) develop expansion due to transformation within the range of 700 to 800°C. It is evident that the difference between quantities of expansion due to transformation at this temperature range, rather than the softening temperature and thermal contraction coefficient, greatly affects the quantity of total contraction after cooling.

The above-mentioned physical properties of slag and weldability are summarized in **Table 5**. None of the flux has caused undercuts or convex beads. BF5 flux surpasses others in slag detachability. When BF6 and BF8 are compared for slag detachability, BF8 which has both higher softening temperature and melting point is inferior to BF6. This fact reveals that slag detachability has not necessarily been improved even when slag has a higher softening temperature and melting point. An evident correlation exists between thermal contraction characteristics and slag detachability. Namely, BF5 which develops little expansion due to transformation at the cooling period has the best slag detachability, whereas slag removal is practically impossible for BF8 which shows great expansion due to transformation.

From the above, it has become clear that an important factor for improving slag detachability is the quantity of expansion due to transformation during the cooling period, rather than the softening temperature and melting point of slag, and that improvement in slag detachability can be accomplished effectively by eliminating expansion due to transformation. KB120 flux has been developed based on BF5 as a fundamental ingredient.

3.3 Diffusible Hydrogen Content in Weld Metal

Diffusible hydrogen contents in weld metal by KB120 flux and KW103B Ni-Cr-Mo bearing wire measured by JIS Glycerin Method and the gas chromatogram method corresponding to IIW mercury method are shown in **Table 6**. Diffusible hydrogen content for KB120 has decreased to less than one-half

Table 6 Diffusible hydrogen content in deposited metal (Wire: KW 103B)

Flux		Diffusible hydrogen content (ml/100g of deposited metal)	
		JIS glycerine method	IIW mercury method
KB 120 for NSA process	Normal type	1.2	3.5
	Extra low hydrogen type	0.5	2.8
KB 80C (Agglomerated flux for HT 80)		0.2	2.0
Fused flux for HT 80		3-5	—

of that for fused flux sold on the market. If special treatment is applied by achieving high resistance to moisture adsorption, the level of hydrogen will be further lowered to that of KB80C, which has been used without any cracking problems for ASTM A514 steel structures.

4 Discussion on Actual Application of NSA Process

4.1 Groove Shape

From the viewpoint of welding efficiency, it is desirable that the groove angle and root gap are smaller, but their optimum values are settled due to deterioration of slag detachability and generation of hot cracks. **Fig. 5** shows the relation of slag detachability to the root gap and groove angle in the U-shaped groove. As the groove angle and root gap are increased, slag detachability improves, and in particular the effect of the groove angle is great. Judged from the balance between slag detachability and productivity, the optimum groove angle and root gap may be 3° and 12 mm, respectively.

For steel plate of below 70 mm in thickness, an X-shaped or V-shaped groove with a groove angle of 30° to 40° has advantages, as shown in **Fig. 6**. Namely, its sectional area becomes smaller and slag removal becomes easier than in the case of the U-shaped groove. **Table 7** shows the relation of the groove angle to slag detachability and hot cracking tendency at the first pass of a V-shaped groove joint. The effects of arc voltage on slag detachability and undercut generation are more noticeable, as the groove angle becomes smaller. For this reason, the optimum groove angle of a V-joint in practical use is considered to be 30° to 35°. In longitudinal seam welding of pressure vessels, however, weld distortion is greater than in circumferential welding; hence it is necessary to allow a slight margin of an extra 2° to 5° to the groove angle.

4.2 Standard Welding Conditions

Table 8 shows standard welding conditions of U-shaped and 30° V-shaped grooves determined for obtaining sound weld beads without undercuts, hot cracks, and lack of fusion.

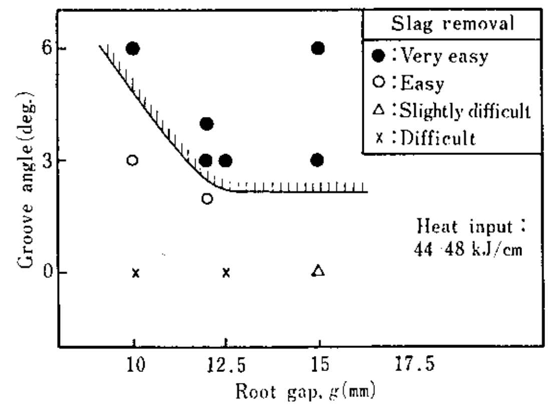


Fig. 5 Effect of groove preparations on slag detachability

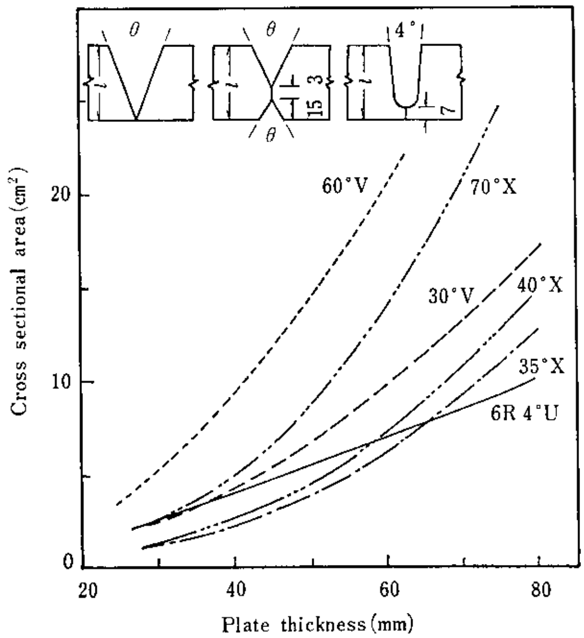


Fig. 6 Relationship between plate thickness and cross sectional area of various types of groove

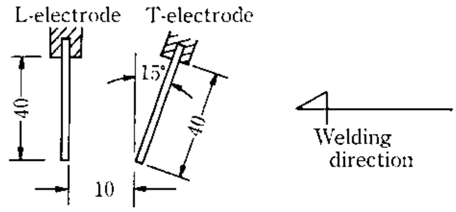
Table 7 Effect of bevel angle on weld performance in V-groove joint (Wire dia.: 3.2 mm, Current: 450 A, Travel speed: 15 cm/min)

Bevel angle (deg.)	Optimum arc voltage for root pass (V)	Weld defects	Slag detachability
20	22 - 23	Hot crack, undercut	Slightly difficult
25	22 - 24	Slight undercut	Slightly difficult
30	22 - 25	No defect	Easy
35	23 - 27	No defect	Very easy
40	24 - 30	No defect	Very easy

Table 8 Standard welding condition for NSA process

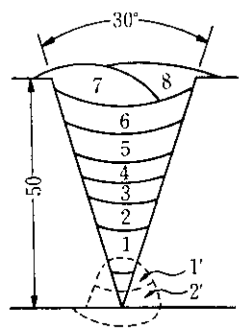
a) U-groove

Groove width (mm)	Single electrode process Current (A)	Voltage (V)	Travel speed (cm/min)	Flux height (mm)	2-electrode process Electrode	Current (A)	Voltage (V)	Travel speed (cm/min)	Flux height (mm)
12	425	27	18	50	L T	425 —	27 —	18 —	50
14	500	28	25	50	L T	500 500	29 25	— 45	50
16	550	29	25	50	L T	550 550	30 26	45	50
18	600	31	25	50	L T	600 600	32 28	45	50
20	625	32	23	50	L T	625 625	33 29	40	50
22	625	34	23	50	L T	625 625	35 31	40	50



b) V-groove

No. of passes	Current (A)	Voltage (V)	Travel speed (cm/min)
1	425	25	10-15
2, 1'	500	27	20-25
3, 2'	550	29	20-25
4	550	29	20-25
5	600	30	20-25
7	650	31	20-25
7, 8	500	27	20-25



Welding sequence in 30° V-groove joint

4.3 Tolerance for Variation in Welding Conditions, Groove Shapes and Electrode Positions

4.3.1 Variation in welding conditions

Generally, in a narrow gap welding, fluctuation in arc voltage has a great effect on bead configurations, and the occurrence of undercuts and lack of fusion. In the case of the NSA process, however, sound beads are obtained at an arc voltage of 25 to 30 V as shown in **Photo. 2**, which indicates a considerably wide tolerance for arc voltages. At a low voltage of less than 25 V, convex bead configurations have been formed, whereas at a high voltage of more than 32 V, undercuts have been observed. In both cases, slag removal becomes slightly difficult and weld defects such as lack of fusion are liable to occur in the immediately succeeding weld pass.

4.3.2 Variation in root gap

Photo. 3 shows the sectional macro-structures of welded joint deposited under constant welding conditions (600 A, 32 V and 20 cm/min) and with variation of root gap, g, from 12 to 26 mm. Within a wide range of 12 to 21 mm, excellent bead configurations and side wall fusion have been obtained. **Fig. 7** shows penetration width P_W under constant welding conditions (600 A and 20 cm/min) and with variation of root gap, g, and arc voltage. P_W decreases with increasing g, but even if $g = 20$ mm, a P_W of more

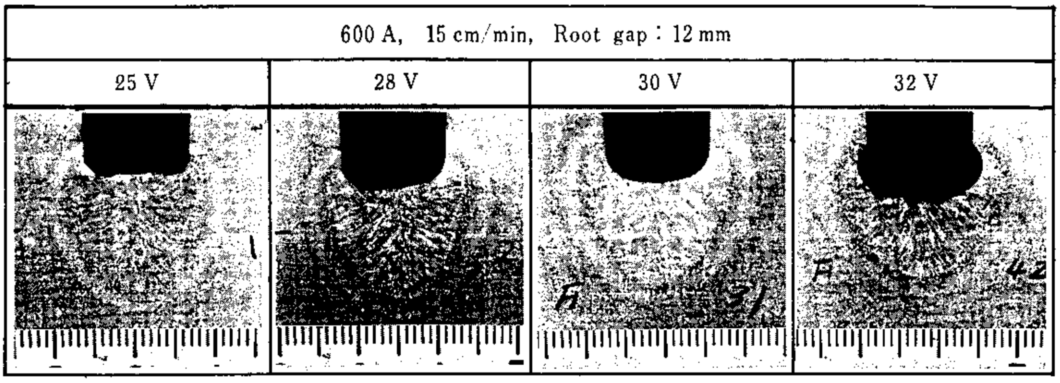


Photo. 2 Effect of arc voltage on bead configurations

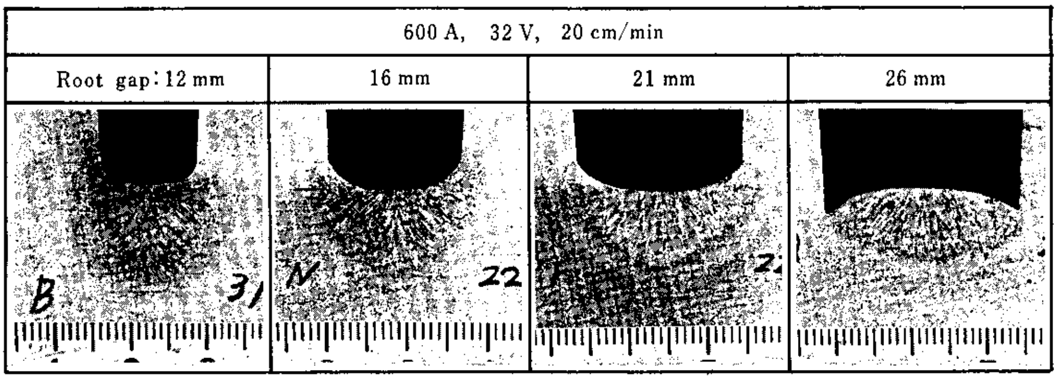


Photo. 3 Effect of root gap width on bead configurations

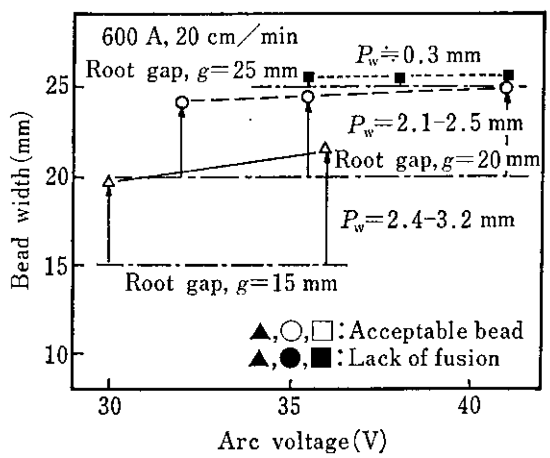


Fig. 7 Effect of arc voltage and root gap on bead penetration width

than 2 mm is obtained. In case of $g = 25$ mm, P_W is as small as 0.3 mm and lack of fusion has occurred; therefore, if the groove gap exceeds 20 mm, it will be necessary to change the "one layer-one pass" method to "one layer-two passes" method. Since a comparison between $g = 15$ mm and $g = 20$ mm indicates that P_W is about 2 to 3 mm in both cases, side wall fusion in a narrow gap SAW process is considered to depend on the secondary melting effect by moving molten metal, rather than on direct arc melting. Consequently, the NSA process is a stabilized welding process judged from the standpoint of preventing lack of fusion, and can be performed successfully under the same welding conditions, even if edge preparation accuracy is somewhat lower as in the case of gas cutting.

4.3.3 Variation in electrode position

Photo. 4 shows cross-sectional bead configurations when deviation, l, has occurred between the groove center line and the wire working position. When $l = 1.5$ mm, beads have normal configurations as if there were no deviation. If $l = 3$ mm, undercuts will occur at the groove wall side where the arc has come too close, but in this state, deviation of wire working position from the groove center can be noticed at a glance, because the electrode nozzle comes contact with the groove wall.

As mentioned above, the NSA process has wide tolerance for variation in welding conditions, groove shapes and electrode positions; and even without such strict operation control as is required in the narrow

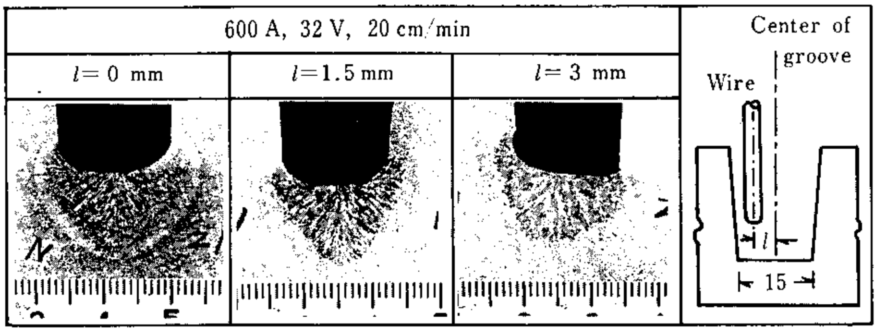


Photo. 4 Tolerance of wire working position in narrow groove

gap GMAW process, the NSA process ensures stabilized welding.

4.4 Measures for Preventing Hot Cracks

Since "pear-seed" shaped beads are liable to generate in the narrow gap welding, consideration should be given to prevention of hot cracks. **Fig. 8** shows a summarized relation between the bead shape factor and the hot cracking tendency, when the welding conditions and root gap are changed. The C content of steel has a great effect on the generation of hot cracks in the first pass bead. Both in Al killed steel ($C = 0.10\%$) and ASTM A515 steel ($C = 0.26\%$), hot cracks have occurred at sides where bead shape factor f (bead depth/bead width) is larger and a higher current has been employed. In order to prevent hot cracks, it is necessary to select the welding conditions of a lower current and a smaller f value. Particularly when high carbon steel is welded with a small root gap of 12 mm, it is necessary to weld with a lower welding current of 400 A and at low speed.

When high carbon steel is welded at a narrow gap it is desirable to perform adequate preheating treatment, and to select the welding conditions of a lower current and lower speed for several passes from the first layer and, in the succeeding passes, gradually increase the current. This is the way to prevent weld defects and improve work efficiency. The following measures will prove effective for preventing hot cracks:

(1) To use low carbon steel as backing material,
(2) To fill iron powder or cut-wire in the interior of the first pass groove, and
(3) To butter the initial layer of weld zone with E7016 electrode.

4.5 Measures for Preventing Cold Cracks

When heavy-gaged high strength steel such as Cr-Mo and HT80 is welded, high preheating temperature at more than 200°C is normally selected to prevent cold cracks in weld metal and HAZ. In the NSA process, which employs KB120 high-basicity agglomerated

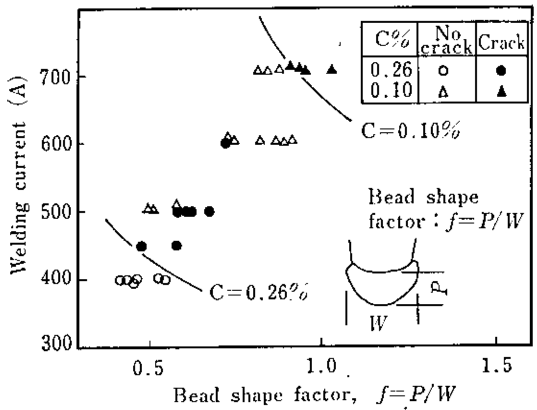
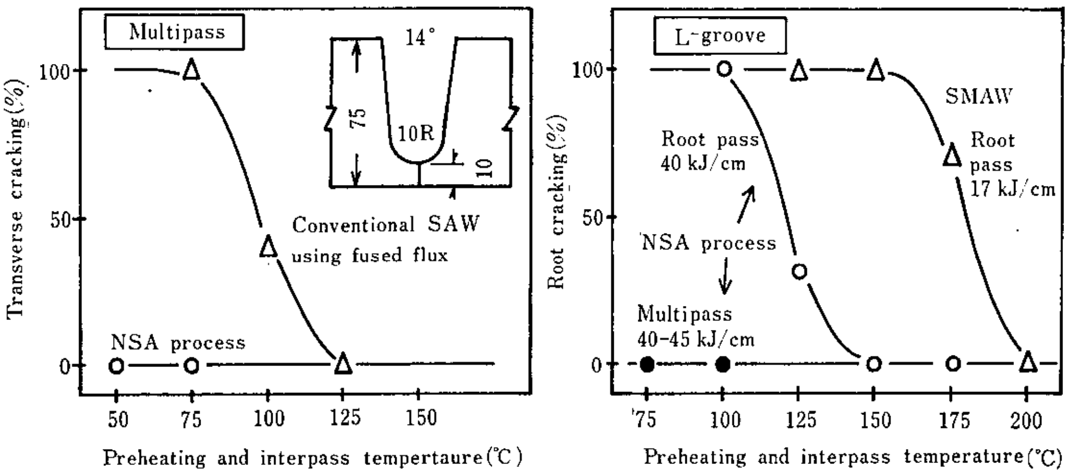


Fig. 8 Relationship between hot cracking tendency and bead shape factor for high and low carbon steels

flux, it is possible to lower this preheating temperature. **Fig. 9** shows the results of the U-groove multipass weld cracking test and ⊬-groove restraint weld cracking test on ASTM A387-22 Cl.2 steel (75 mm in plate thickness) performed in accordance with the WES3005. From **Fig. 9**(a) which shows a comparison with the results of commercially-available fused flux, it can be seen that the NSA process allows great reduction in the preheating and interpass temperatures for preventing weld cracking. This beneficial effect is derived from the lower diffusible hydrogen level in weld metal by KB120 than that obtained by commercially-available fused flux. **Fig. 9**(b) shows the results of single pass weld cracking test, which indicate that the preheating temperature for preventing cold crack is 200°C in shielded metal arc welding, whereas 150°C in the NSA process. When continuous multipass welding is performed, no cracking will occur even if the preheating temperature is only 75°C, as shown in **Fig. 9**(a) and (b).

In field application of the NSA process to $2\frac{1}{4}$Cr-1Mo steel, an advantage is obtained by welding at a lower preheating and interpass temperature of 150°C and



(a) U-groove multipass weld cracking test (b) L-groove restraint cracking test

Fig. 9 Restraint weld cracking test results of NSA welding materials for ASTM A387 Gr. 22 steel (Test procedure: WES 3005)

skipping the step of intermediate post-weld heat treatment in the middle of manufacturing operation.

5 Mechanical Properties of Welded Joint by NSA Process

Since the narrow gap welding process is mainly applied to heavy steel plates and forgings such as those for pressure vessels, great importance is attached to susceptibility to cold cracks and mechanical properties of the joint. Particularly in recent years, very high toughness values have come to be required for Cr-Mo steels to minimize temper embrittlement during use, reflecting the social trend toward "safety first". In developing welding materials for the NSA process, the above-mentioned circumference was taken into consideration, and high-basicity flux was selected in combination with impurity-reduced wire. Thus, the

Table 9 Chemical compositions and mechanical properties of NSA weld metal (Heat input: 40–45 kJ/cm)

Steel	Welding material		Chemical compositions of weld metal (%)										
	Wire	Flux	C	Si	Mn	P	S	Cr	Mo	Ni	As	Sb	Sn
A516 Gr.70	KW 30T	KB 120	0.06	0.45	1.35	0.016	0.005	—	—	—	—	—	—
HT 60	KW101B	KB 120	0.06	0.33	1.46	0.010	0.003	—	0.44	0.72	—	—	—
HT 80	KW103B	KB 120	0.05	0.28	1.35	0.008	0.004	0.71	0.43	2.20	—	—	—
A204	KW 50C	KB 120	0.09	0.37	1.53	0.010	0.003	—	0.51	—	0.002	0.001	0.001
A387 Gr.11	KWT105	KB 120	0.11	0.42	0.80	0.006	0.005	1.31	0.51	—	0.003	0.001	0.002
A387 Gr.22	KWT210	KB 120	0.10	0.25	0.63	0.007	0.003	2.42	1.01	—	0.003	0.001	0.002

Welding material		P WHT	Tensile strength (kgf/mm²)		Absorbed energy (kgf·m)		vT_{r40} (°C)	$vT_{r40}+1.5\Delta vT_{r40}$ (°C)	Hv
Wire	Flux		RT	450°C	vE_0	vE_{-40}			
KW 30T	KB 120	As weld	58	—	17.9	15.1	−60	—	195
		625°C×6 h	54	—	19.2	14.6	−55	—	175
KW101B	KB 120	As weld	65	—	19.8	10.6	−55	—	209
KW103B	KB 120.	As weld	85	—	10.6	8.6	−60	—	257
KW 50C	KB 120	650°C×5 h	57	49	16.7	9.2	−53	−35	179
		690°C×5 h	56	48	17.2	9.5	−59	−35	170
KWT105	KB 120	690°C×5 h	63	53	15.8	10.0	−64	−58	203
		690°C×12 h	59	48	16.2	8.6	−50	−34	197
KWT210	KB 120	690°C×12 h	62	48	15.0	10.3	−56	−17	194
		690°C×26 h	59	47	14.8	8.9	−49	−21	186

levels of oxygen, nitrogen and grain boundary embrittling elements (P, As, Sb, Sn, etc.) in weld metal are kept in very low levels.

Table 9 shows an example of the chemical composition and mechanical properties of NSA weld metal for various types of steels.

6 Examples of Field Applications of NSA Process

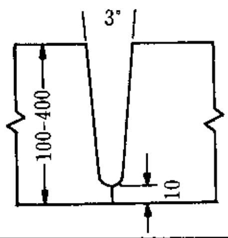
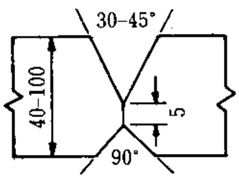
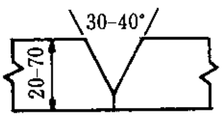
Along with increasing energy saving needs while attaining more efficient welding work and lower welding cost, the NSA process has been developed and applied to large-sized steel structures such as pressure vessels, heavy machineries etc. In recent years, application of the process to steel plates of less than 100 mm in thickness has also been increasing, because attention has been focused on the high productivity, excellent slag detachability and high toughness achieved by the NSA process. **Table 10** shows structures to which the NSA process has been applied, and an example of groove shapes used.

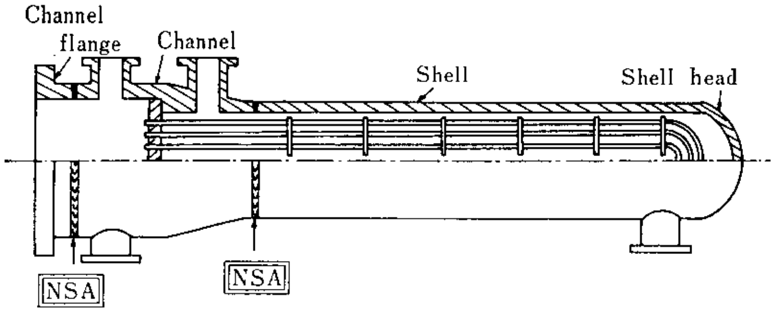
Photo. 5 shows an example of practical application of the NSA process to circumferential welding of 12 units of heat exchangers using 123 mm thick ASTM A336 F22 forged steels. **Table 11** shows a comparison in efficiency between the NSA process and the conventional SAW process in the above-mentioned case. It indicates that the required number of passes and arc time for the former have been reduced to one-third and one-half, respectively, of the latter. No defects have been detected under X-ray and ultrasonic inspection after welding, thereby confirming that its probability against defect generation is less than those of the conventional processes. This is attributable to the fact that in the NSA process, continuous buildup sequence can be made by the "one layer-one pass" method up to immediately before the final layer, thereby forestalling the defects caused by operator's error concerning electrode positioning in the conventional process. There is another advantage in that the preheating and interpass temperatures are reduced from 200°C to 150°C, with the intermediate post-weld heat treatment omitted when post-heating around 200°C is performed immediately after welding.

For circumferential welding, it is necessary to determine the proper setting position of the electrode in circumferential direction. **Fig. 10** shows a relation between the inclined angle in the groove welding on plates and the bead configuration. When the downward slope is changed to the upward slope, the bead surface tends to change from a concave to a convex shape. From the above it is advisable to have a downward slope of about 3° in the external welding where bead configuration is important, and to put electrode at a position having an upward slope of about 3° in the internal welding that requires deep penetration as in the case of the first pass following back chipping.

The maximum plate thickness recorded in the field

Table 10 Recent applications of NSA process

Joint preparation	Type of structures	Steel grade	Thickness (mm)	Welding wire
	Heat exchanger	ASTM A336 F22 C1.2	123	KWT 210
	Centrifugal casting mold	JIS SC46	250	KW 50C
	Press cylinder	ASTM A148	254	KW 101B
	Impeller shaft	JIS SF50	200	KW 50C
	Semi-sub type drilling rig	EH 36	42	KW 30T
	LNG carrier vessel	N 36E	43	KW 30T
	Pipe for off-shore structure	API 5LX X 52	50	KW 36
	Water heating facilities for nuclear power station	SM 50 & SF 50	20–70	KW 50C
	Boiler	SB 46, 49 49M	20–50	KW 30T KW 50C



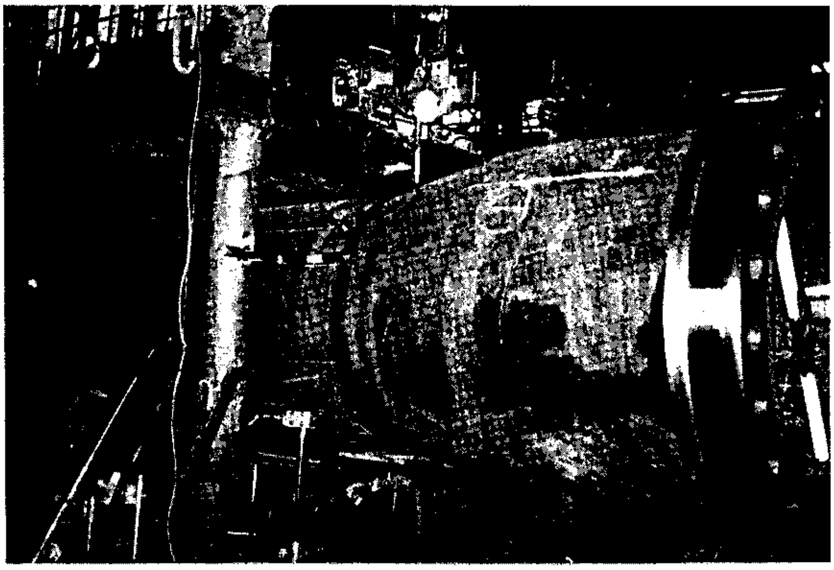


Photo. 5 Circumferential welding of heat exchanger using NSA process (ASTM A336 F22, wall thickness: 123 mm)

Table 11 Comparison of efficiency between NSA process and conventional SAW

Welding process	Conventional SAW	NSA process
Cross sectional area of groove (cm^2)	45.6	19.2
Total pass	79.5	25
Arc time (h)	20.5	12.5

application of NSA process is 254 mm, but it has been confirmed that on the laboratory scale, welding can be performed without problem on A336 F22 steels of 400 mm in thickness (made from hollow ingot) for reactor use.

On the other hand, controlled rolling steels having a yielding point of 36 kgf/mm^2 have begun to be used recently on the upper decks of semi-sumberged-type oil drilling rigs and LNG carriers, and these joints are required to have high impact values of more than 3.5 kgf·m at a temperature of $-20°$ to $-60°C$. Con-

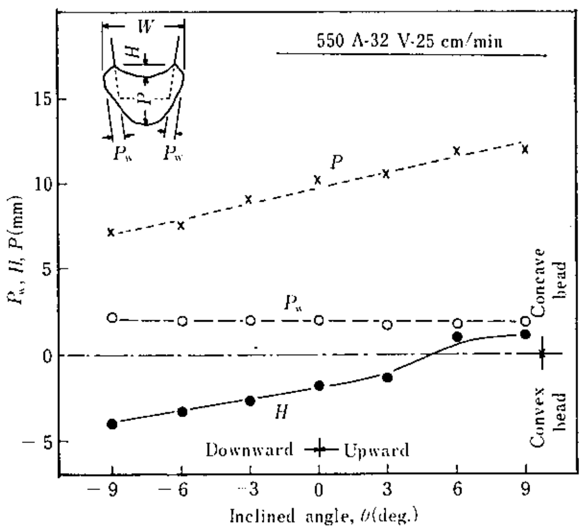


Fig. 10 Effect of inclined angle of plate on bead configurations

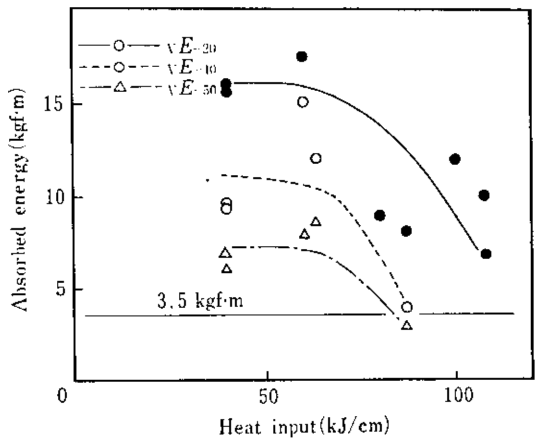


Fig. 11 Effect of heat input on toughness of weld metal deposited using KB 120 and KW 30T

sequently, for steel plates of 30 to 51 mm in thickness, weld heat input is limited and multipass welding is performed for maintaining joint toughness. Conventional SAW flux poses some problems of the deterioration of slag detachability and welding efficiency. As one of the measures to solve these problems, KB120 narrow gap welding flux is used, and it has been confirmed that high toughness can be obtained without lowering welding efficiency. **Fig. 11** shows an example of relations between weld heat input and the toughness of weld metal by the combined use of KB120 flux and KW30T Ti-bearing wire.

It was not long ago when the NSA process was first applied to field work, but there are application records already ranging from carbon steel to high grade steel. It is expected that the NSA process will yet expand its fields of application in future by actively utilizing its features for high efficiency and quality.

7 Conclusion

Experimental examination was made on improving slag detachability while preventing weld defects in the narrow gap submerged arc welding of heavy steel plates for structural use. As a result, the NSA process has been developed that uses KB120 high-basicity agglomerated flux, alloyed wire and rectangular nozzle.

On the basis of the finding that the quantity of expansion due to slag transformation during the weld cooling period is the governing factor of slag detachability, the authors have solved one of the greatest problems in the narrow gap submerged arc welding. Further, taking into consideration the fact that the objects of application of the NSA process are extra-heavy steel plates which are liable to develop hydrogen-induced cracks, efforts have been made to prevent weld cracks by lowering the hydrogen level in weld metal to less than one-half of the conventional welding process. Through the combined use of high-basicity flux and impurity-reduced wire, the levels of oxygen, nitrogen and temper-embrittling elements in weld metal have been reduced, thereby obtaining high quality joint properties.

This procedure has been applied in the field to high-grade steels such as ASTM A336 F22 and to high-carbon steels of ASTM A148 and JIS SC46, and it has been confirmed that high productivity and high reliability are obtainable and the lowering of preheating temperature and the omission of intermediate post-weld heat treatment can be accomplished. Recently there has been a gradual increase in the number of cases where the NSA process is applied to control-rolled steels with a yield point of 36 kgf/mm^2 for low temperature service, by utilizing its advantage of producing high-toughness weld metal and its applicability to as-gas-cut narrow-gap groove joints.

Acknowledgement

The authors would like to thank Kawasaki Works of Chiyoda Chemical Engineering & Construction Co., Ltd. for their kind cooperation and valuable technical advice given in the course of field-application of the NSA process to heat exchangers made of 2¼Cr-1Mo steels.

References

1) I. Sejima et al.: "Developments and Applications of Narrow Gap Welding Processes in Japan", IIW Com. XII-JIW International Colloquium in Nagoya, 1981
2) R. Bruscato: "Temper Embrittlement and Creep Embrittlement of 2¼Cr-1Mo Shielded Metal-Arc Weld Deposits", *Welding Journal*, **49** (1970) 4, 148–156S
3) J. Tsuboi et al.: "Studies on submerged Arc Welding of HT80 Heavy Steel Plates", *Journal of Japan Welding Institute*, **42** (1978) 4, 7, 8
4) I. Vornovitskii et al.: "On the Influence of the Coefficient of Thermal Expansion of Slag on the Ease of Removal from the Weld Metal", *Welding Production*, (1973) 3, pp. 35–37