Automatic Welding of 3.5% Nickel Steel

Welds with a refined grain structure and with impact resistance at −150 F equal to that of SA203 Gr E steel base metal are produced by automatic submerged arc welding

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ABSTRACT. The welding of 3.5% Ni steel had been limited to shielded metal arc welding process, because low and erratic notch toughness at low temperature generally occurred with processes such as submerged arc welding and gas metal arc welding.

A new process, which we have recently succeeded in developing, makes use of the variation of underbead microstructure by thermal affection in submerged arc welding. The weld joint, excluding the topmost layer, can be composed of microstructure having refined grain by reheating of every underbead—one after another—into the refined structure.

Notch toughness obtained at −150 F (−101 C) is equivalent to or higher than the base metal. The results of tensile test and bend test also proved to be higher than the standard of base metal.

Introduction

3.5% Ni steel is applied for the fabrication of a wide range of low temperature equipment designed for −50 to −150 F (−46 to −101 C). In order to prevent brittle fracture, base metal and weld zone are required to have high notch toughness. However, the shielded metal arc welding process, which had been generally applied in the past, is low and erratic with respect to notch toughness.

The notch toughness of coarse dendritic structure in conventional submerged arc welding is low, and oxygen content in its deposited metal is so high that stress relief embrittlement is possibly caused in postweld heat treatment.

The new welding process has resolved such problems. It makes use of the variation of microstructure of underbead caused by thermal affection on weld bead in submerged arc welding. The weld joint, except for the topmost layer, is composed of fine structure that has high notch toughness, and notch toughness at −150 F (−101 C) is equivalent to or higher than the base metal.

The development and application of the process to practical use is described in this paper.

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Test Procedure

Material

The 3.5% Ni steel used in our experiments was ASME SA203 Gr E steel that is available on the market as 1½ to 2 11/16 in. (38.1 to 68 mm) thick plate. Its chemical composition and mechanical properties are provided in Table 1. The heat treatment of steel plate is normalizing, and test results were obtained after normalizing and postweld heat treatment.

Welding electrode and flux data are provided in Table 2. The electrodes used for submerged arc welding were cored electrodes meeting AWS Standard F715-EC Ni3 and characterized by low carbon, low silicon and a very small amount of titanium.

Welding Apparatus and Groove

The welding process used for testing was submerged arc utilizing the cored electrode described previously. The welding machine is shown in Fig. 1 and includes means for electrode oscillation. The power supply capacity is at a maximum rated continuous 500 A current for the rated voltage. Welding current varies from 350 to 400 A with reversed polarity, and heat input ranges from 35 to 40 kJ/cm (89 to 102 kJ/in.). The weld groove preparation is as shown in Fig. 2.

Table 1—Some Base Metal Properties

	Material	Thickness, mm	Chemical composition, % C	Si	Mn	P	S	Ni	Yield strength, kg/mm²	Tensile strength, kg/mm²	Elongation in 200 mm, %
Code requirement	ASME SA203 Gr E	≦50.8	≦0.20	0.15 ~ 0.30	≦0.70	≦0.035	≦0.040	3.25 ~ 3.75	≧28.1	49.2 ~ 63.3	≧17
		>50.8	≦0.23		≦0.80						
Base metal	ASME SA203 Gr E	38	0.08	0.21	0.56	0.010	0.002	3.51	40.5	53.8	33.0
		68	0.10	0.26	0.60	0.007	0.003	3.40	40.7	55.5	34.0

Table 2—Chemical Composition of Weld Metal

	Welding material	Chemical composition, %								
		C	Si	Mn	P	S	Ni	Cu	Mo	Ti
SAW	AWS A5.23 F715-ECNi3	≦0.12	≦0.80	≦1.60	≦0.030	≦0.030	3.00 ~ 3.75	≦0.30	–	–
	Weld metal, 3.2[a]	0.05	0.10	0.32	0.014	0.008	3.50	0.03	–	0.025
SMAW	AWS A5.5 E8016-C_2	≦0.12	≦0.60	≦1.20	≦0.03	≦0.004	3.00 ~ 3.75	–	–	–
	Weld metal, 5[a]	0.04	0.35	0.95	0.010	0.007	3.28	–	0.29	–

[a]Mean diameter of electrode in mm.

Basic Test

The low temperature notch toughness of the weld joint made by oscillating submerged arc welding was tested by simulating the heat effect on deposited metal created by means of synthetic reheat cycle equipment.

Evaluation of Weld Joint

The weld joint prepared by means of oscillating submerged arc welding was tested substantially in accordance with ASME Code Section IX. The oxygen content in weld metal, which has great influence on stress relief embrittlement, was also measured.

Basic Test Results

Characteristics of the New Process

The notch toughness of base metal or weld metal deposited by the new process improves as it is thermally affected. Oscillating submerged arc welding can build up a flat weld bead inside the groove within appropriate ranges of current and heat input. As a result, the heat-affected zone is developed in a wide range under such weld bead. In this heat-affected zone, a heated portion higher than Acl causes recrystallization, and the microstructure becomes a refined ferrite structure. If every underbead is partly penetrated and partly, at its bottom, the heat-affected zone is controlled as a welding condition, the whole area of the weld joint excluding the topmost layer becomes a refined structure after having been heat affected at least once.

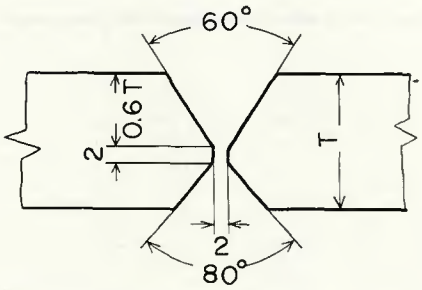


Fig. 2—Weld groove

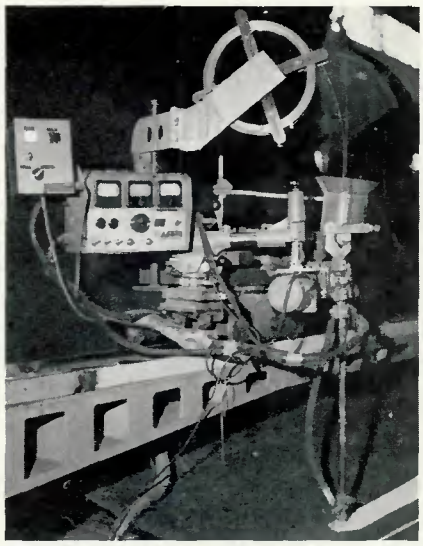


Fig. 1—Welding equipment

Concerning low carbon weld metal containing 3 to 4% Ni, the low temperature notch toughness of solidified dendritic structure is very low, while that of refined structure is superior. The joint constituent of nothing but the latter structure is the outstanding feature of our new welding process.

In the model of built-up layers shown in Fig. 3, the welding condition to give another thermal effect on underbead dendritic structure as well as coarse grain heat-affected zone is expressed as the following:

$$hi \leq (D_{i+1} - D_i) + (a_{i+1} - a_i) + b_{i+1}$$

h, a, b and D may be solved as the functions of welding conditions. The writers take the following simple expression as practical enough:

$$vi > \frac{(I_i - 100) \times 10^2}{(2\theta_{ci} + 3)\ (0.007\theta_{ci} + 3)} (\text{mm/min.})$$

Heat Cycle and Low Temperature Notch Toughness

The thermal effect in the weld joint was produced by reheat cycle equipment. Deposited metal composed of dendritic structure with heat input of 35 kJ/cm was reheated high enough to correspond to a 600–1,300 C (1,112 to 2,372 F) peak temperature heat effect. This metal was then Charpy impact tested before and after postweld heat treatment. This testing was done for both Ti-containing and Ti-free metals. The results are provided in Figs. 4 and 5; microstructures appear in Figs. 6 and 7.

The structure of Ti-containing deposited metal is refined and shows toughness improvement over a wide range of temperature. The Ti-free metal has no improvement, and its structure does not seem easily refined. The critical thing is that 600–650 C (1,112–1,202 F) reheating allows microstructure to be largely unchanged; postweld heat treatment elevates notch toughness. This is quite an effect by multiple heat cycle.

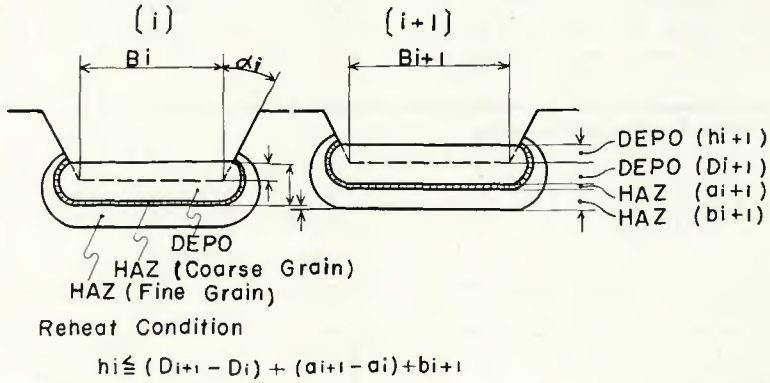


Fig. 3—Model of built-up layer

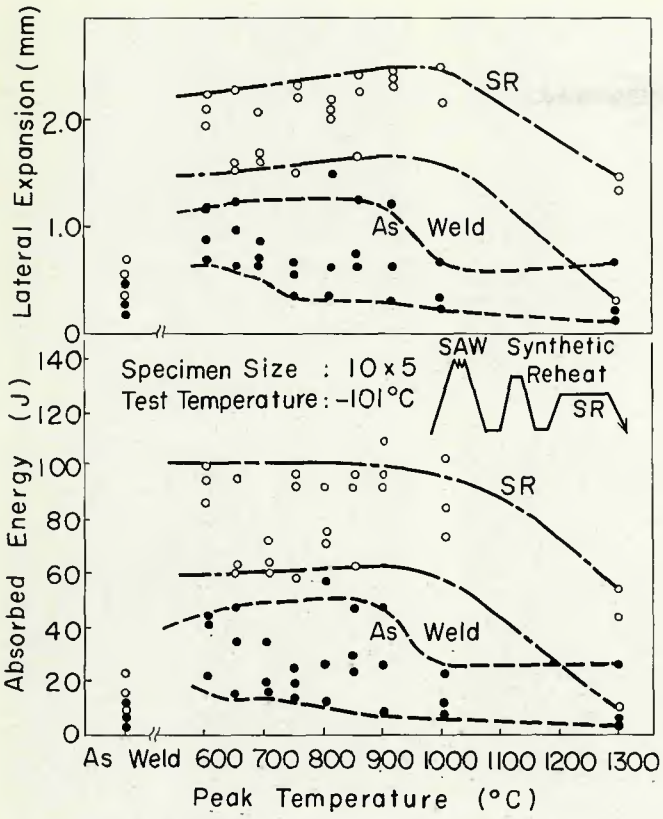


Fig. 4—Impact resistance of synthetically reheated weld metal at −101 C (Ti-containing)

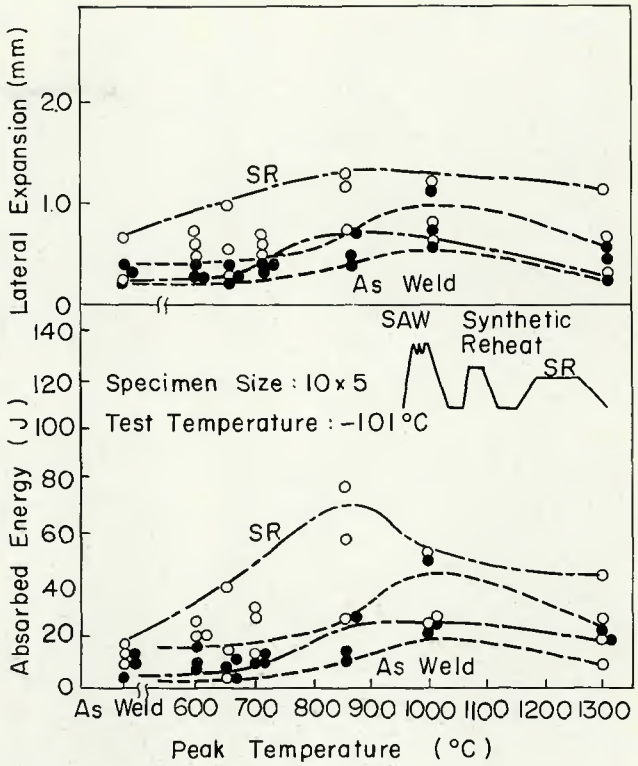
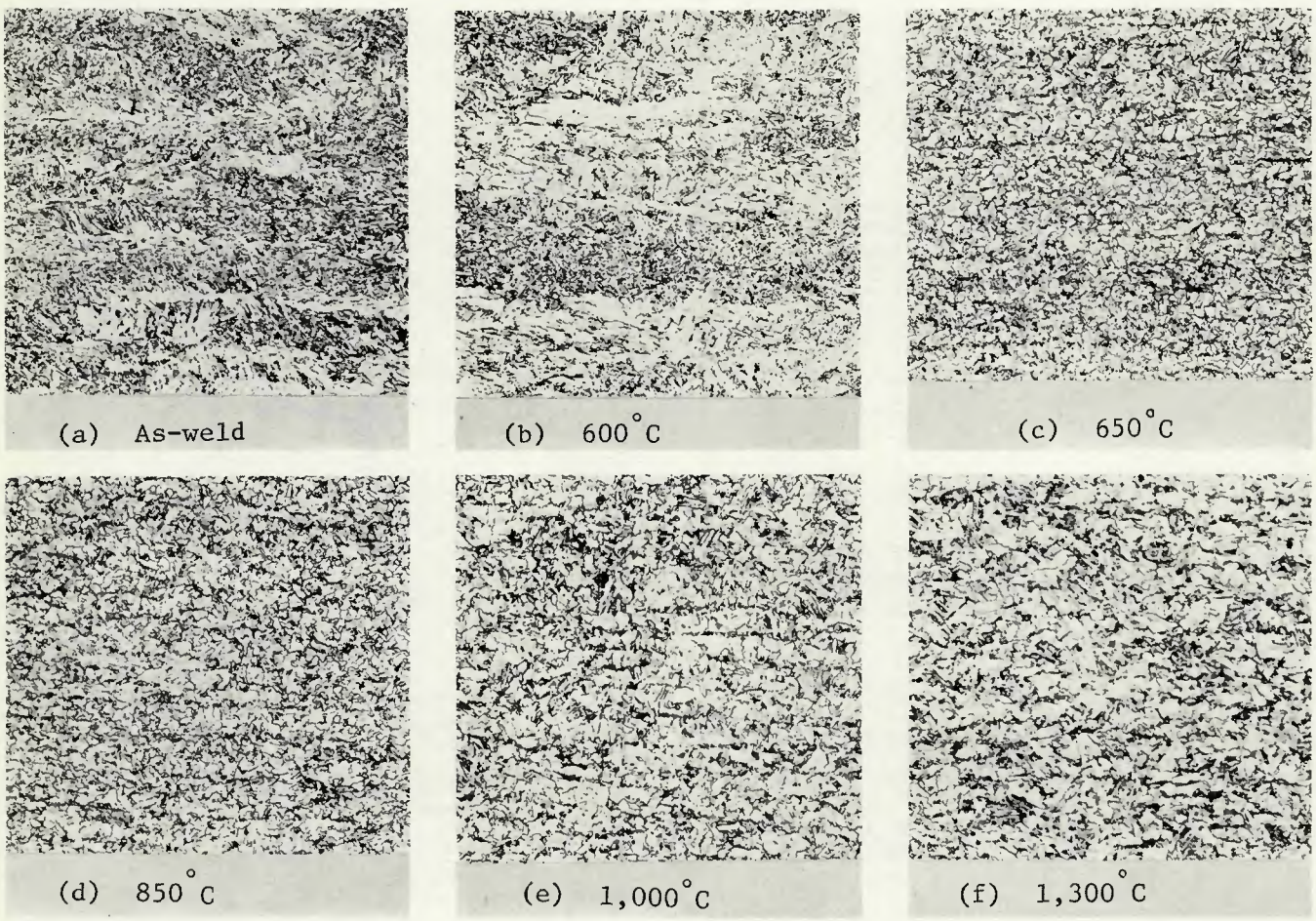


Fig. 5—Impact resistance of synthetically reheated weld metal at −101 C (Ti not contained)



6—Microstructure of synthetic reheat cycle (Ti-containing)

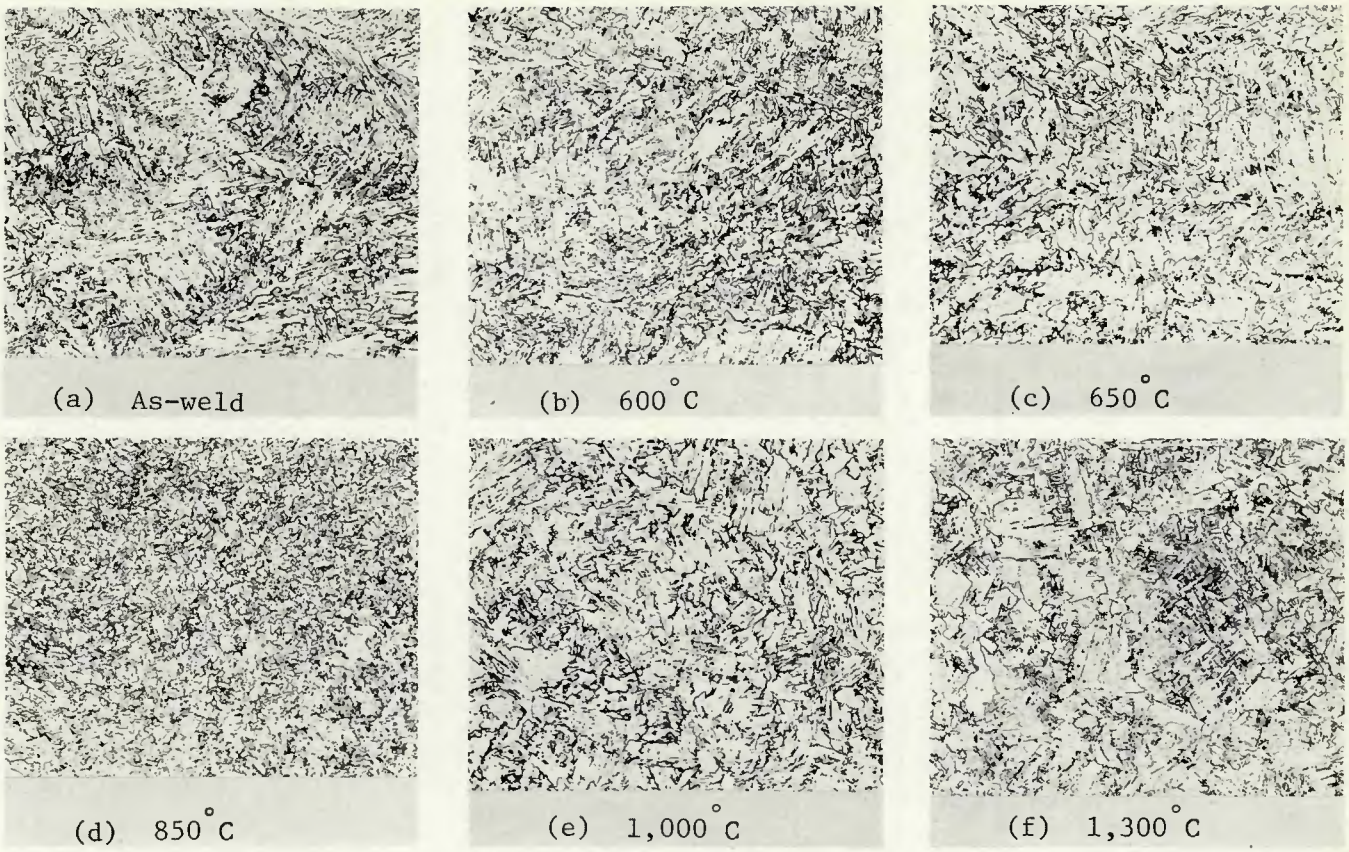


Fig. 7—Microstructure of synthetic reheat cycle (Ti not contained)

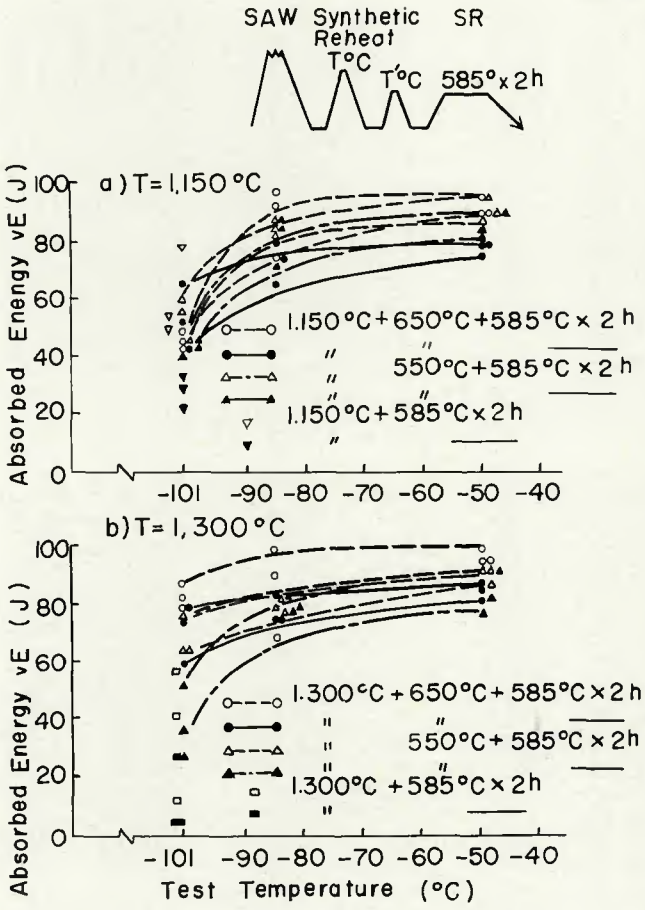


Fig. 8—Impact resistance of multiple synthetically reheated weld metal (half-size)

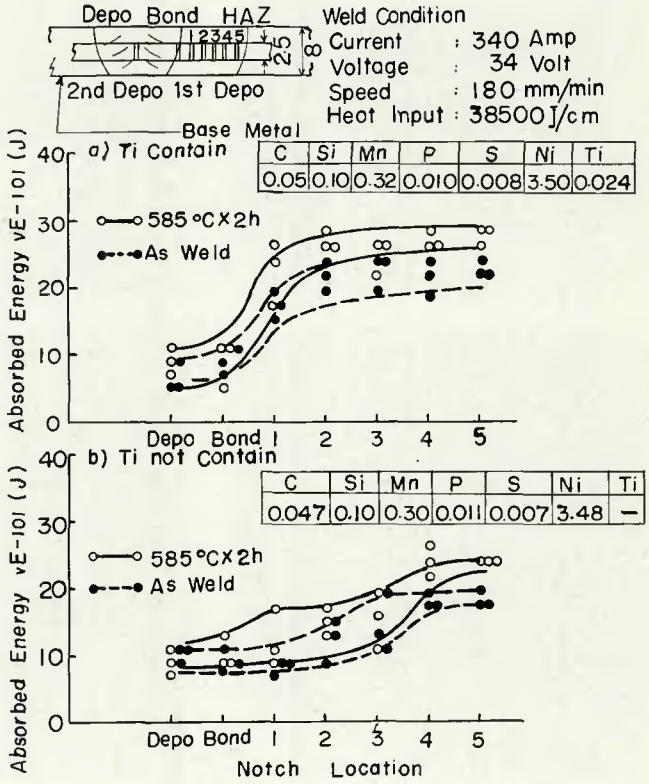


Fig. 9—Notch location on reheated deposited metal and vE-101

As indicated by the microstructures shown in Fig. 6, the effect of Ti content on the refining of structure is great. However, if peak temperature is raised up to 1,300 C (2,372 F) by reheating and then postweld heat-treated, notch toughness remains unchanged. If the same metal is subjected to another 550-650 C (1,022 to 1,202 F) reheating and then postweld heat-treated, notch toughness is recovered as shown in Fig. 8. High toughness is recovered through a heat cycle of 1,300 C, 550 C and postweld heat treatment. Therefore, in the model of built-up layers in Fig. 3, the welding condition that the coarse grain heat-affected zone of underbead is to be reheated must be satisfactory.

Influence of Chemical Composition on Mechanical Properties

The weld deposits of Ti-containing metal, which influences refining, and Ti-free metal were heat-affected respectively to determine low temperature notch toughness at each area; the results are shown in Fig. 9.

In case Ti is present, it is understood that an area reheated to high temperature and coarsening to become brittle is very limited. This is in keeping with the results of Fig. 4.

Test Results of Weld Joint

Characteristics of Submerged Arc Weld Joint

Microstructure. The refined grain structure produced by oscillating submerged arc welding is given in Fig. 10 which illustrates the detailed structure of each area of a joint with 50 mm (2 in.) thickness that is reduced from 68 mm (2 11/16 in.). We understand that some dendritic structure of coarse ferrite is found in the topmost layer, but the remaining area is of refined grain structure developing mostly fine ferrite.

Tensile Test Result. The results of tensile testing of the joint at room temperature are provided in Tables 3 and 4, and satisfy the standard values of base metal of SA 203 Gr E steel. Rupture occurrence is found mostly on the area of deposited metal. This is because the test material contained low carbon and low silicon.

Hardness Test Result. An example of hardness testing of the joint with 38 mm (1½ in.) thickness is provided in Fig. 11. No noticeable hardening was found in the deposited metal, bonded zone and heat-affected zone.

Impact Test Result. The result of impact testing on the deposited metal of a 38 to 68 mm (1½ to 2 11/16 in.) thickness automatic welding joint is provided in Fig. 12. Also, results obtained by conventional submerged arc welding joints are indicated for comparison. In conventional submerged arc welding, beads to be built up by one layer in two passes are divided at the center, and the intended refined structure forms at the center of deposited metal where the notch is located in the case of a test sample prepared in accordance with ASME Section IX. However, because the dendritic structure remained, the absorption energy was too erratic to be put to practical use.

The result of impact testing of heat-affected zone is provided in Fig. 13. The heat-affected zone is improved by the reheating effect to show higher notch toughness than the base metal. This is another characteristic of oscillating submerged arc welding.

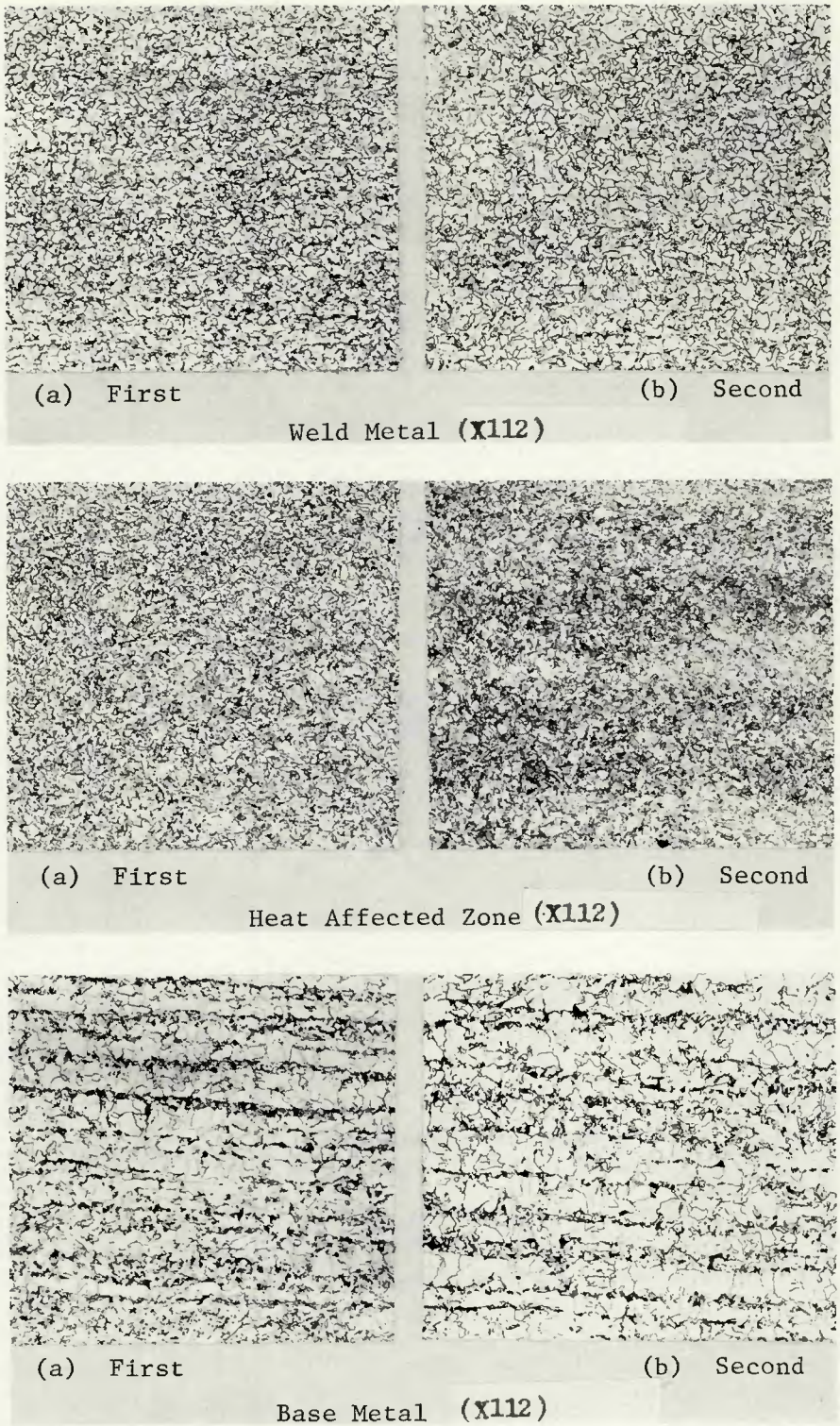


Fig. 10—Microstructure of SAW joint. Base metal is SA203 Gr Et 50. Sample location: 1st-12.5 mm depth from top surface; 2nd-2 mm from back surface

Table 3—Mechanical Properties of Base Metal

Thickness mm	Heat treatment	Yield strength, kg/mm²	Yield strength, kg/mm²	Elongation in 200 mm, %
Code requirement		≧28.1	49.2 ~ 63.3	≧17
38	585 C × 3 H	42.1	51.6	28.1
		41.9	51.6	30.8
	900 C × 1.5 H	43.0	52.0	25.4
	+585 C × 3 H	41.6	52.2	27.4
68	585 C × 13 H	42.1	52.6	30.5
		42.1	53.0	30.3
	900 C × 2 H	44.8	54.9	26.8
	+585 C × 13 H	44.2	54.7	27.3

Table 4—Mechanical Properties of SAW Weld Joint

Thickness mm	Heat treatment	Yield strength, kg/mm²	Tensile strength, kg/mm²	Elongation in 50 mm, %	Side bend test (R = 19 mm)	Fracture location
38	585 C ×3 H	44.6	55.4	50.0	Good	Base metal
		43.7	54.7	51.0	"	Weld metal
50[a]	585 C ×9 H	41.4	53.7	48.8	"	"
		42.6	54.1	46.4	"	"
68	585 C ×13 H	44.1	54.7	42.5	"	"
		43.4	54.0	41.4	"	"

[a] 68 mm reduced.

The tendency to higher notch toughness is illustrated in Fig. 14. The bonded zone cannot be improved, but the heat-affected zone can be improved up to the equivalent to or higher than the base metal. By the thermal effect on notch toughness, as explained by the values of bonded zone, the structure becomes coarser and more deteriorated than rolled base metal if reheated to approximately 1,300 C (2,372 F), but equivalent or greatly improved results are obtained upon reheating at a temperature less than that.

Measurement Result of Oxygen Amount

When postweld heat treatment is performed at a high temperature, oxygen contained in the deposited metal causes stress relief embrittlement.

Table 5 gives the measurement results of the deposited metal of a 38 mm (1½ in.) thickness joint. Analyzed values of acid flux for general use instead of high basic flux, as well as conventional shielded metal arc welding electrode, are given for comparison. The measurement of the deposited metal in the oscillating submerged arc welding joint indicates a very low value, a half or less under that of the conventional welding which gives 500

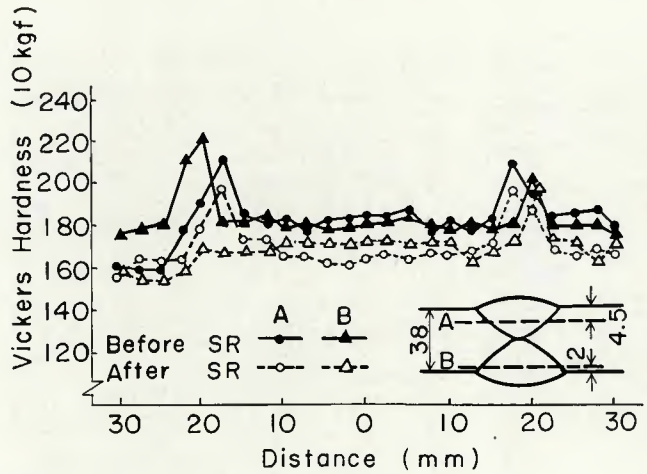


Fig. 11—Hardness of weld joint

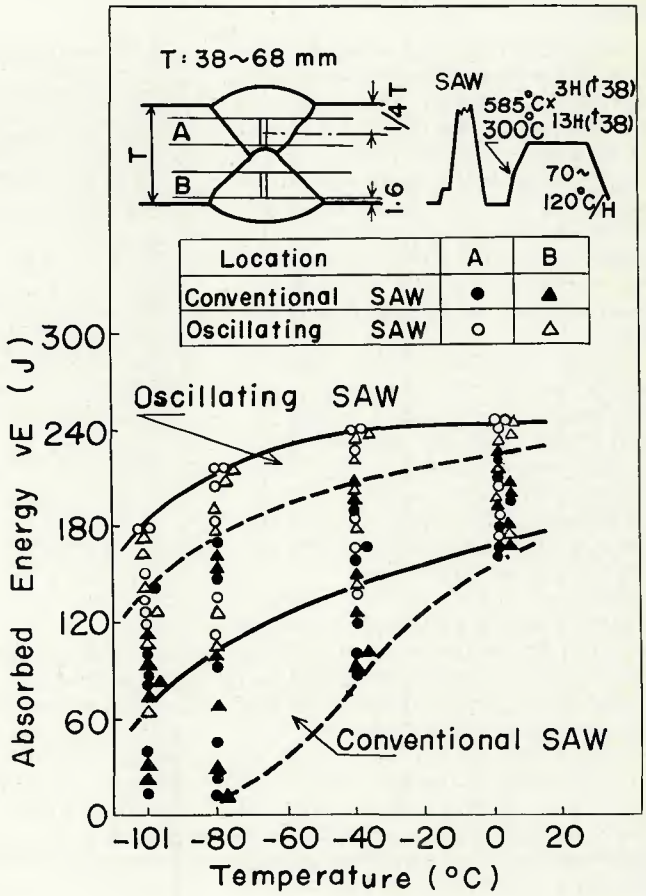


Fig. 12—Impact resistance of weld metal

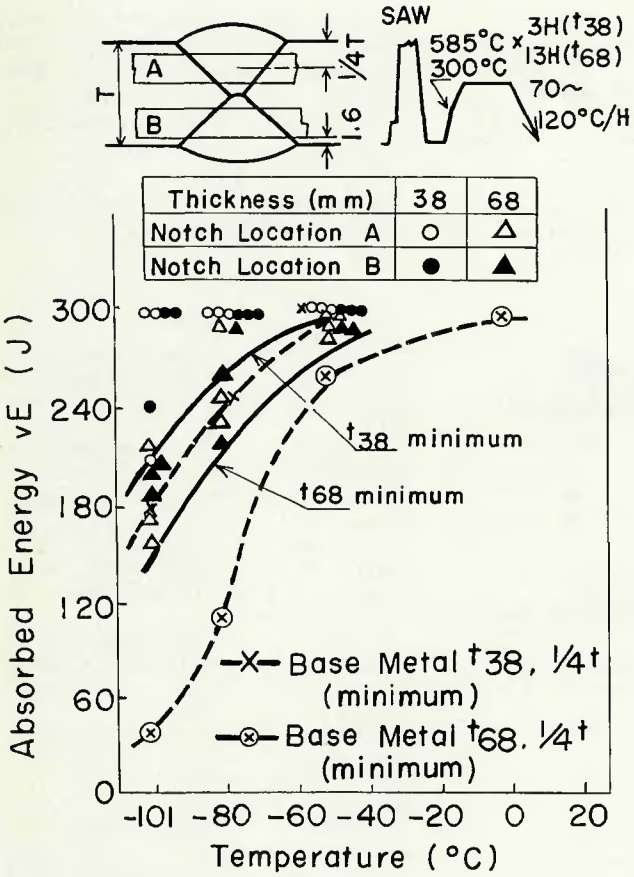


Fig. 13—Impact resistance of heat-affected zone

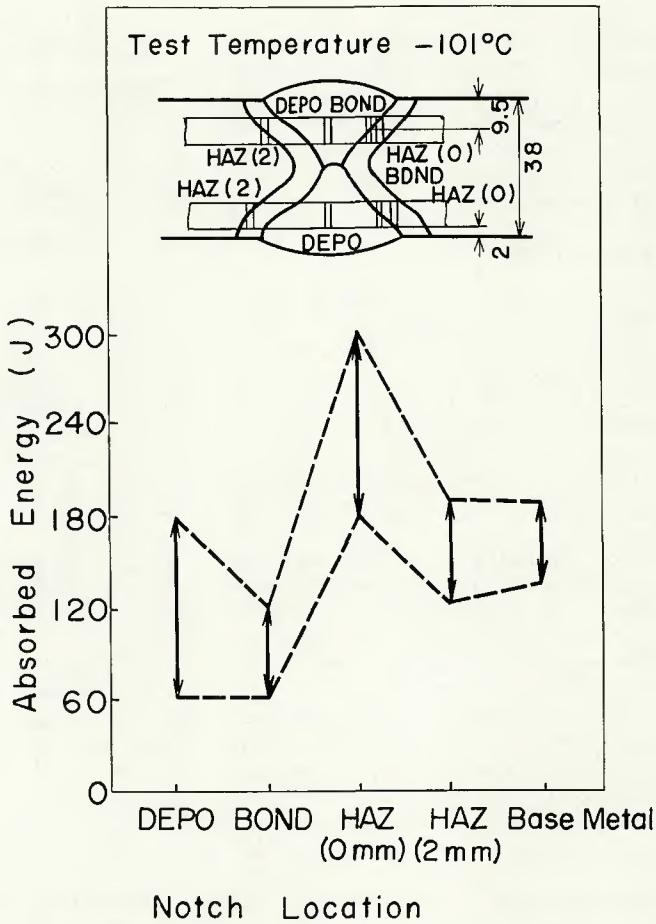


Fig. 14—Impact resistance of some notch locations at −101 C

Table 5—Amount of Oxygen in Weld Metal

Process	Flux	Location of sample	Oxygen content ppm
	Acid	Refined zone, ¼t	470
		Final pass, dendrite	238
SAW	Basic	Straight bead, ¼t dendrite	220
		Oscillate SAW, ¼t refined	208
SMAW	—	Refined structure, ¼t	385

to 600 ppm.

The above effect shows itself in that notch toughness does not drop as previously described, even after a long period of stress relieving.

Application to Production Equipment

Oscillating submerged arc welding has been already applied to the production of a large sized low temperature column, in which efficient workability and high joint efficiency are verified. The equipment was 4,000 mm (157 in.) in diameter, weighed 200 tons and was made from 17-57 mm (0.67-2¼ in.) thick steel plate of SA203 Gr E, and this has been designed and fabricated in accordance with ASME Code Section VIII Div. 2.

Figures 15 and 16 show work in progress on longitudinal and circumferential weld seams. The fabrication of low temperature equipment calls for satisfactory joint tensile strength and low-temperature notch toughness.

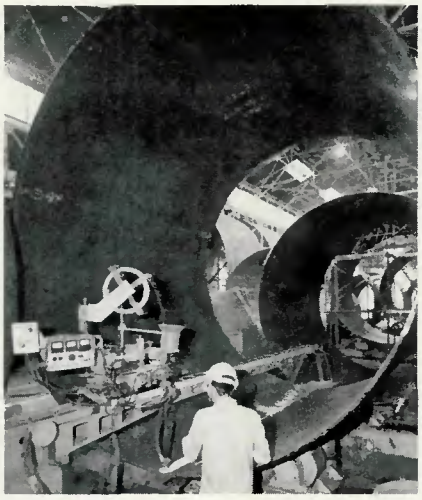


Fig. 15—Welding works (longitudinal seam)

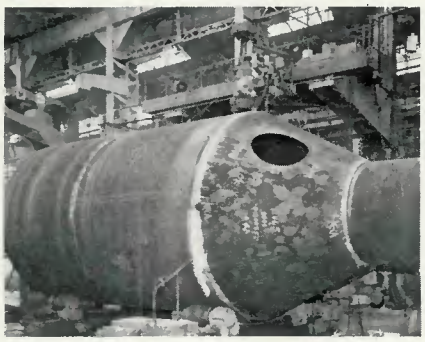


Fig. 16—Welding works (circumferential seam)

Figure 17 shows Charpy impact test results for the SA203 Gr E steel plate applied in this test, and for a conventional SMAW weld joint, and the SAW joint in question. Results show that the SAW joint provides low temperature notch toughness equivalent to or higher than the base metal.

Conclusion

1. The use of oscillating submerged arc welding produces weld metal with improved low temperature notch toughness.
2. Except for its uppermost layer the entire joint produced by oscillating submerged arc welding has refined grain structure and not dendritic structure as seen in the conventional process.
3. The quality of the weld joint by oscillating submerged arc welding was tested in accordance with ASME Section IX, and all test results satisfied the specified values of the base metal.
4. Low temperature toughness, in particular, of the joint produced by oscillating submerged arc welding is equivalent to or higher than the base metal (SA203 Gr E steel).
5. This process was applied to large sized low temperature columns, and results verified its applicability and superiority.

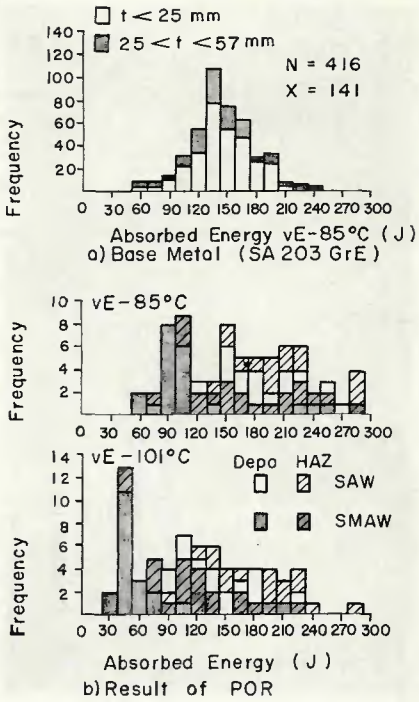


Fig. 17—Histogram of 2 mm Charpy V-notch impact test result.

Acknowledgment

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. . . A Last Call to Brazing Paper Authors . . .

September 15 is the deadline for mailing the 500-word abstracts of papers that you may want to have considered for presentation at the 10th International AWS-WRC Brazing Conference in Detroit, Michigan, during April 3-5, 1979. The Conference is being held in conjunction with the 60th Annual Meeting of the American Welding Society during April 2-6, 1979, and the 1979 AWS Welding Show during April 3-5.

"An Invitation to Authors" concerning the presentation of brazing papers at the 10th International AWS-WRC Brazing Conference appeared on page 67 in the February 1978 issue of the **Welding Journal.** *The Invitation was accompanied by an "Author's Application Form for Brazing Papers" on page 68.*

Abstracts should be mailed to the American Welding Society, 2501 N.W. 7th Street, Miami, Florida 33125. They should be accompanied by a completed "Author's Application Form for Brazing Papers" in those instances where the Form is available to authors.