Nickel-base Alloy Overlay Weld with Improved Ultrasonic Flaw Detection by Magnetic Stirring Welding

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Ultrasonic flaw detection is more difficult in Nickel-base alloy welds containing dendrites owing to the decrease ultrasonic transmissibility they cause.

The present paper discusses application of magnetic stirring welding as a means for reducing dendrite growth with consequent improvement in ultrasonic transmissibility.

Single pass and multi-pass welding tests were conducted to determine optimal welding conditions. By PT and macro observation subsequent to welding was carried out, optimal operation conditions were clarified.

Overlay welding tests and UT clearly indicated ultrasonic beam transmissibility in overlay welds to be improved and detection capacity to be greater through application of magnetic stirring welding.

Optimal operation conditions were determined based on examination of temper bead effects in the heat affected zone of low alloy steel by application of magnetic stirring welding to the butt welded joints between low alloy and stainless steel. Hardness in this zone of low alloy steel after the 4^{th} layer was less than 350Hv.

INTRODUCTION

SUS 304 stainless steel and Alloy 182 butt weld joints have stress corrosion cracking sensitivity at high temperature and pressure water with oxygen dissolution. Various preventive maintenance techniques have been established to prevent stress corrosion cracking such as overlay welding on the outer surface of pipe joints to lessen tensile residual stress on the inner surface with consequent compression of stress during welding with water cooling in the pipe. But this method is attended with decreased ultrasonic flaw detection and evaluation capacity owing to the presence of dendrites in the overlay weld metal. Magnetic stirring welding as a means for reducing dendrite growth and test results are discussed in this following .

MAGNETIC STIRRING WELDING

Magnetic stirring welding is schematically illustrated in Fig.1. A magnetic coil that provides a magnetic field in perpendicular direction to the molten pool during welding is placed on the TIG arc welding torch. Lorenz force is generated by interaction of this field with welding current and stirs the molten pool. The stirring is improved through periodic application of this force in periodically reverse direction.

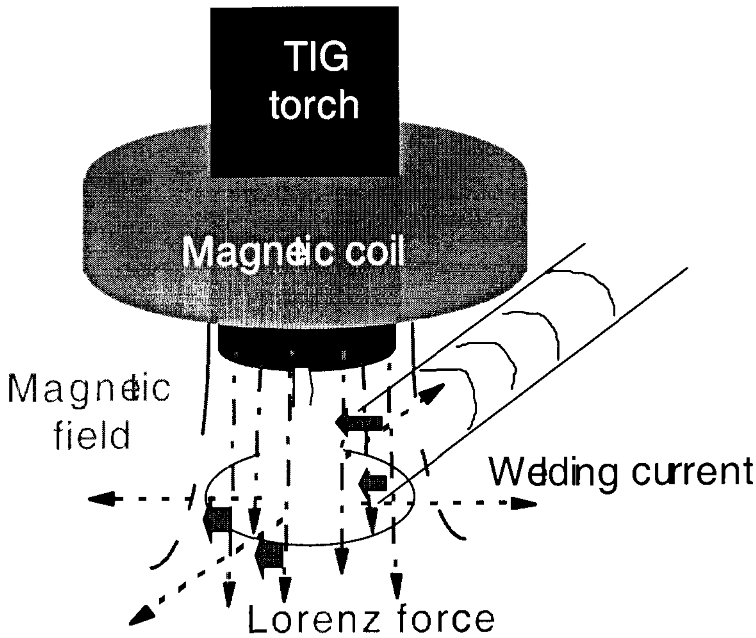


Fig. 1 Magnetic stirring during TIG arc welding

Magnetic stirring of the molten pool disrupts the growth of dendrites. Fig.2 shows how average grain size of overlay welding deposit metal of alloy 82 in magnetic stirring welding is related to transmitted echo amplitude of shear waves (2MHz) at a refraction angle of 45 degrees through overlay welding metal in comparison with conventional TIG arc welding[1]. Grain size in the case of a magnetic stirring welding was found considerably less compared to conventional welding. Ultrasonic transmission was improved through reduction in dendrite growth and fine grain size in magnetic stirring welding.

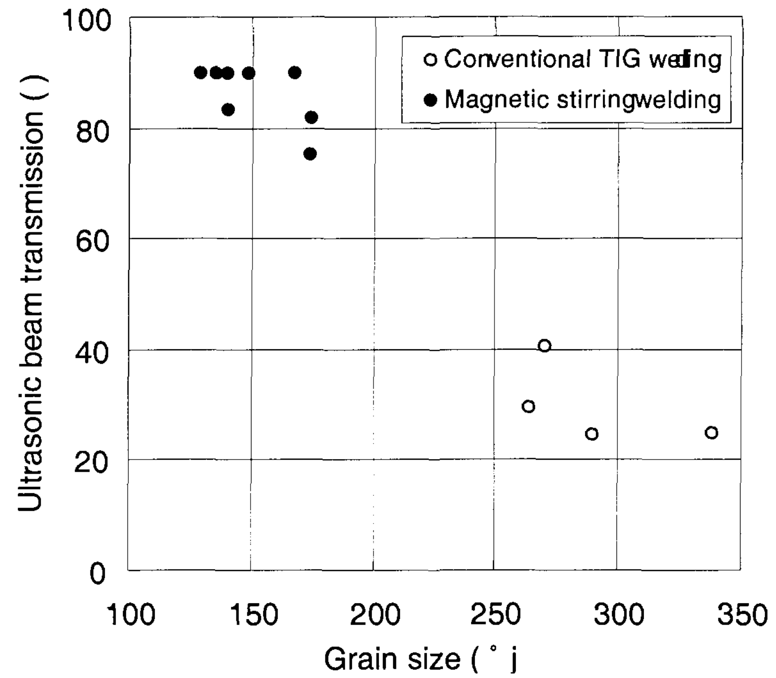
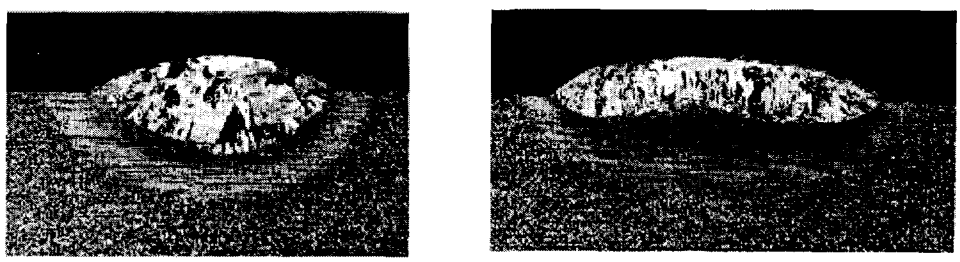


Fig. 2 Relationship of average grain size and ultrasonic pulse amplitude transmitted in overlay-weld metals of Alloy 82 [1]

Magnetic stirring welding was also found effective for preventing weld defects such as hot cracks and the absence of fusion. With deep penetration into the stainless steel base metal by Nickel base alloy filler, hot cracks occur easily and with slight penetration and convexity beads, fusion is readily eliminated. Fig. 3 presents typical welding bead cross sections of conventional TIG welding and magnetic stirring welding. With the welding bead in magnetic stirring welding penetration is slight and the bead is flat and consequently, there are fewer hot cracks. The bead becomes smooth even with increase in welding deposits and there is more fusion with magnetic stirring welding.



Conventional TIG Welding Magnetic Stirring Welding

Fig. 3 Typical welding bead cross sections for conventional TIG and magnetic stirring welding

MATERIALS

The base metals used in this study were JIS SFVQ1A(ASTM A508 cl.3) and JIS SUSF304(ASTM A182 F304) each with 133mm outer diameter and 19mm thickness. Their chemical compositions are indicated in Table 1.

Table 1 Base metal chemical compositions

	C	Si	Mn	P	S	Ni	Cr	Mo	V
SFVQ1A	0.20	0.20	1.29	0.006	0.003	0.82	0.10	0.53	0.005
SUSF304	0.05	0.38	1.07	0.031	0.028	8.23	18.58	-	-

The welded metal was JIS Z 3334 YNiCr-3(AWS A5.14 ERNiCr-3)(Rod diameter of 1.2mm, strand wire Alloy 82 filler wire), with chemical composition shown in Table 2.

Table 2 Alloy 82 filler chemical composition

C	Si	Mn	P	S	Ni	Cr	Cu	Fe	Nb+Ta	Ti
0.031	0.20	2.99	0.003	0.002	71.11	20.23	0.01	2.0	2.82	0.44

EXPERIMENTAL

For quality assessment of overlay welding with magnetic stirring welding, optimal welding conditions were determined and ultrasonic examination and hardness tests subsequent to overlay welding were conducted.

(1) Determination of optimal welding conditions

These conditions were clarified based on the results of single pass and multiple pass welding tests. Evaluation of bead appearance was made based on Liquid penetrant and visual tests. Under various welding conditions, bead height and penetration were found from macro observation of sections. Welding conditions were selected based on the following: Occurrence of hot cracks and absence of fusion and bead height less than 1.3mm.

The temper zone of conventional TIG welding without pre- or post- heat treatment is 1.3-2.5mm.(2) In all cases, temper zone depth must exceed bead height for evaluation of the temper bead welding method. Thus, bead height in this study was less than 1.3mm. Welding conditions are listed in Table 3.

Table 3 Welding conditions

Welding current (A)	Welding voltage (V)	Travel speed (mm/min.)	Wire feed speed (mm/min.)	Heat Input (kJ/mm)	Deposit Area (mm^2)	Magnetic field (Gauss)	Magnetic frequency (Hz)
100-150	10.9-11.4	130-150	700-900	0.47-0.73	4.1-6.1	8A (500)	6

Note Shield gases : Argon gas 100%

Welding position : All positions

Deposit Area : A ~ WFS/TS (A=0.2^2 ε ~ 7 at 1.2mm strand wire)

(2) Ultrasonic examination and hardness test following overlay welding

Overlay welding was conducted on SFVQ1A piping 133mm in diameter, as shown in Fig. 4.

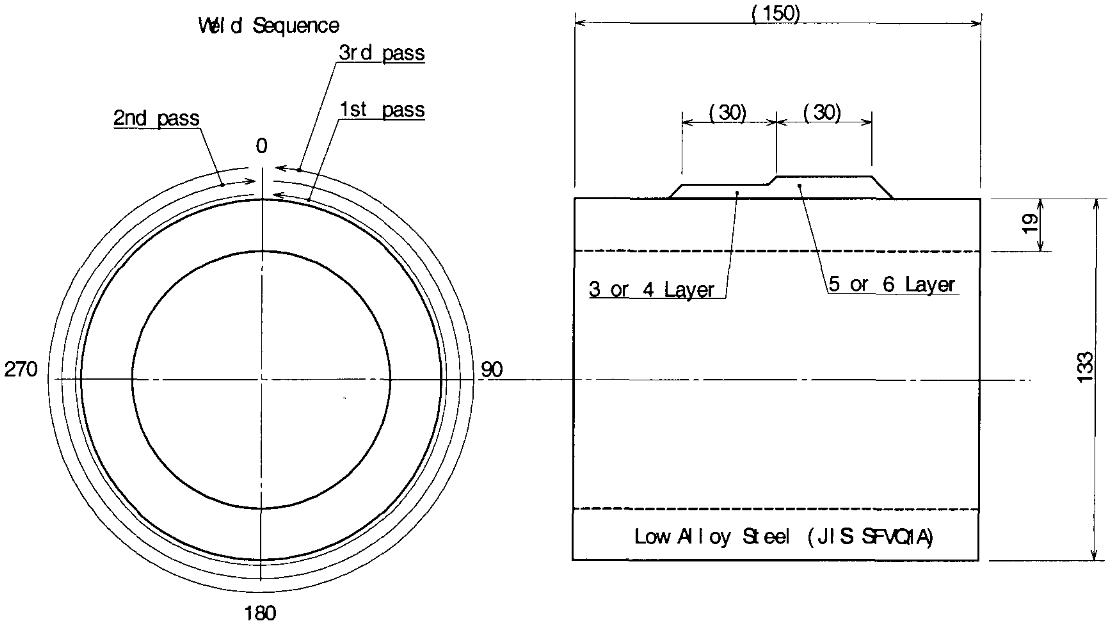


Fig. 4 Overlay welding test

Ultrasonic beam attenuation of magnetic stirring welding was compared with conventional TIG welding by pitch and catch methods. Two angle probes mounted on the inner and outer surfaces emitted and received shear wave ultrasonic beams, and maximum transmitted pulse amplitude was recorded. The emitter probe was the non-focus type with frequency of 2 MHz at refraction angle of 45 degrees (transducer dimension :10X10 mm). This probe was also used as receiver for each scan. This test method is shown in Fig. 5.

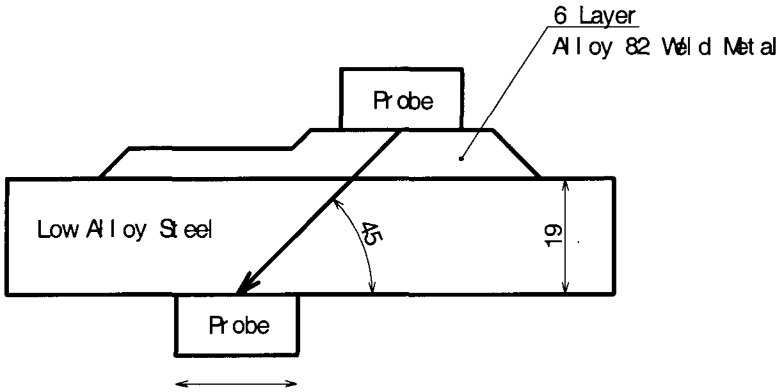


Fig.5 Test method for ultrasonic beam attenuation

Echo height from EDM notch (length 10mm, width 0.5mm, depth 1.9mm : 10% depth of base material thickness) was measured using the angle probes at 45 degrees refraction for shear waves by direct scan. The non-focus type probe (transducer dimension ; 10x10mm) was used for shear waves of 2 MHz by the single probe technique, as shown in Fig. 6.

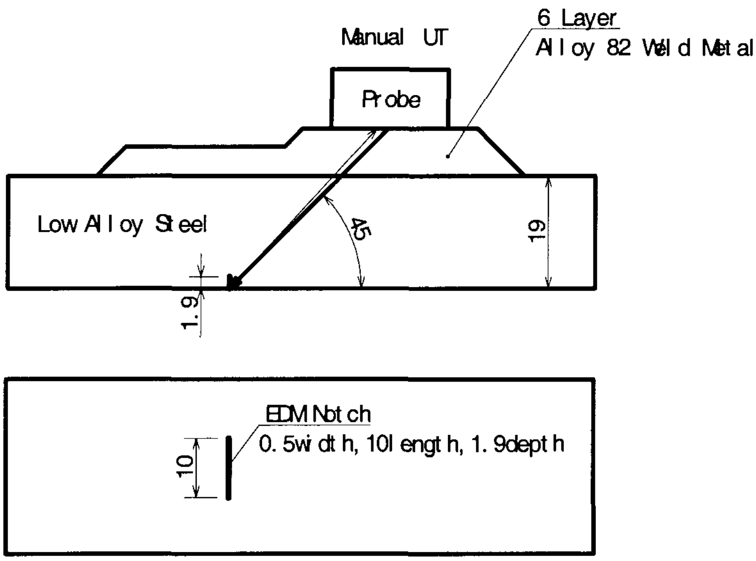


Fig.6 Method for determining echo height from EDM notch

The capacity for flaw detection by EDM notch was found by immersion using the focus-type probe at 2MHz frequency (transducer dimension :20 mm diameter, focus range :10.5–50 mm depth), as shown in Fig. 7.

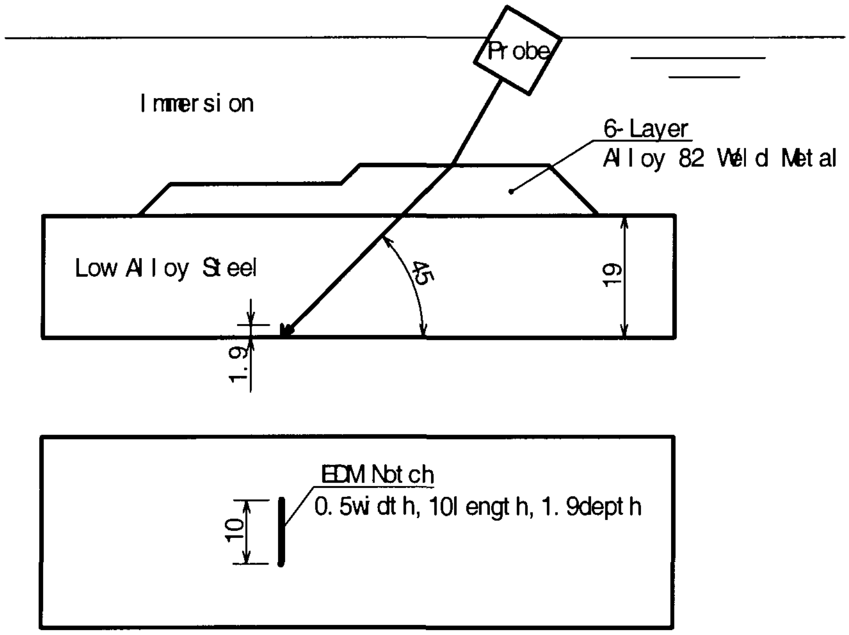


Fig.7 Immersion Test

Vickers hardness of the heat affected zone was examined subsequent to 3-6 layer overlay welding. The sites of hardness measurement are indicated in Fig.8. Number of the welding layer required for temper of heat affected zone was found based on hardness data.

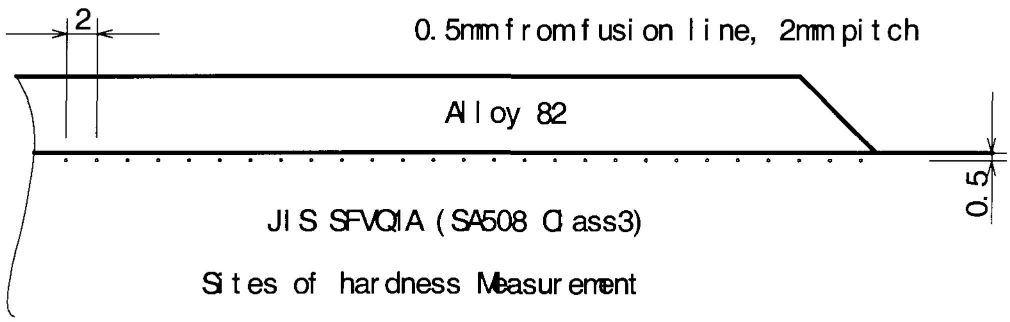


Fig.8 Hardness test

RESULTS AND DISCUSSION

(1) Determination of optimal welding conditions

These conditions are shown in Fig. 9. The horizontal axis indicates heat input and the vertical axis, deposit area. Hot cracking was evident at high heat input and low deposit area for stainless steel base metal. Fusion was absent at low heat and high deposit area for stainless steel base metal. Bead height exceeded 1.3mm at low heat input and high deposit area. Hot crack occurrence and the absence of fusion is are evident from Fig.10. Optimal welding conditions were the following:

Welding current : 120-140 A, Welding voltage :11V, Travel speed 140mm/min.

Wire feed speed : 80mm/min., Magnetic field : 6-8A, Magnetic frequency : 6Hz

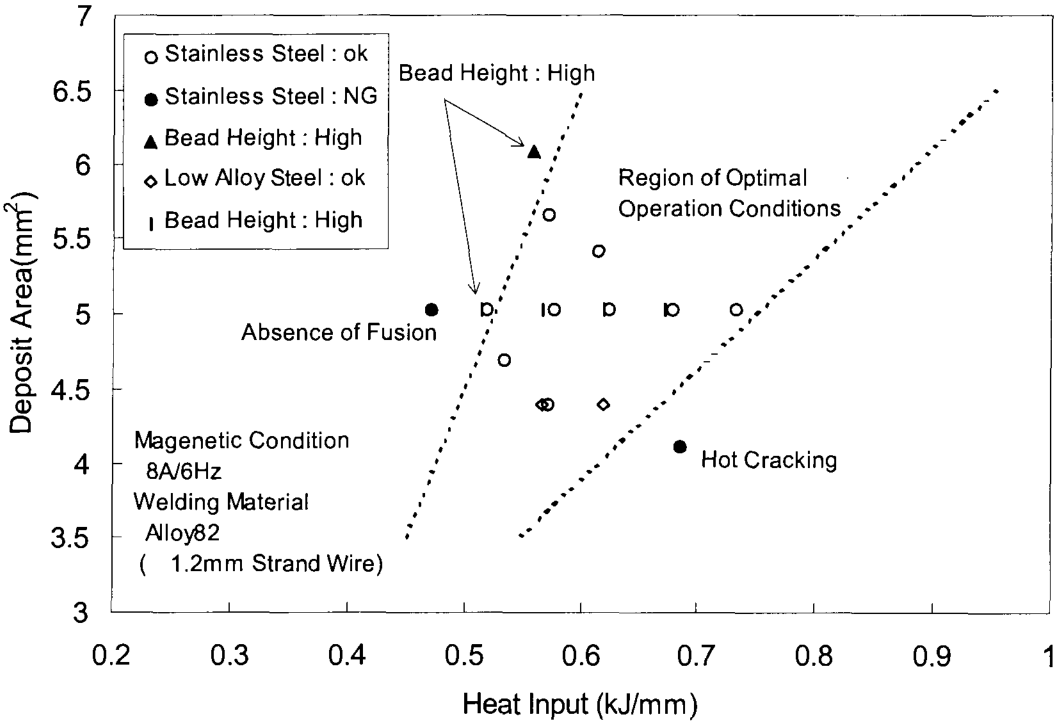
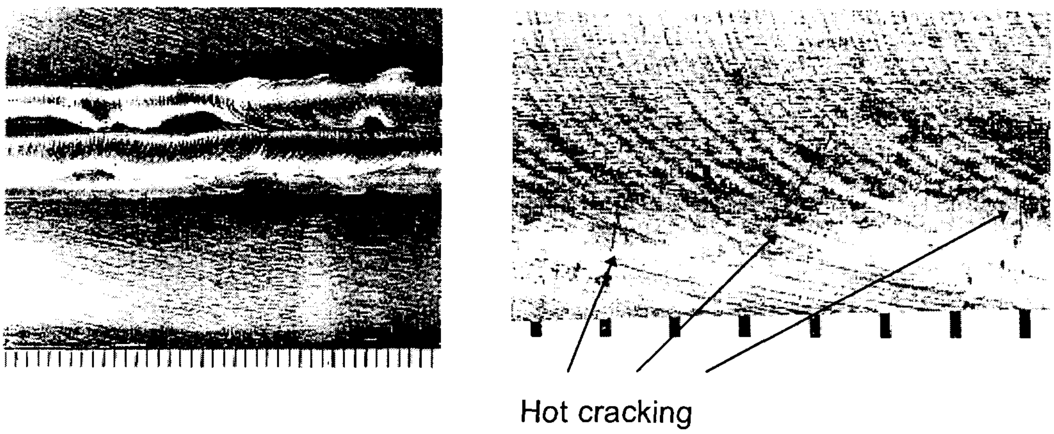


Fig.9 Determination of optimal welding conditions



Absence of fusion hot cracking

Fig.10 Occurrence of hot cracking and absence of fusion

(2) Ultrasonic examination and hardness test subsequent to overlay welding

Welding conditions for overlay welding are indicated in Table 4.

Table 4 Welding conditions for overlay welding

Layer	Welding current (A)	Welding voltage (V)	Travel speed (mm/min)	Wire feed speed (mm/min)	Heat Input (kJ/mm)	Deposit Area (mm^2)	Magnetic field (Gauss)	Magnetic frequency (Hz)
3-6	130	11.2	140	80	0.63	5.0	8A	6
4,6	120	11	140	80	0.57	5.0	8A/6A	6

Ultrasonic beam attenuation of magnetic stirring welding was compared with conventional TIG welding by pitch and catch methods. The results are shown in Fig. 11. At base metal ultrasonic beam transmission of 100%, ultrasonic beam transmission of magnetic stirring welding was 70-80% for all welding positions, and ultrasonic beam transmission of conventional TIG welding was 35%. Ultrasonic beam transmission was thus clearly shown to be improved by magnetic stirring welding.

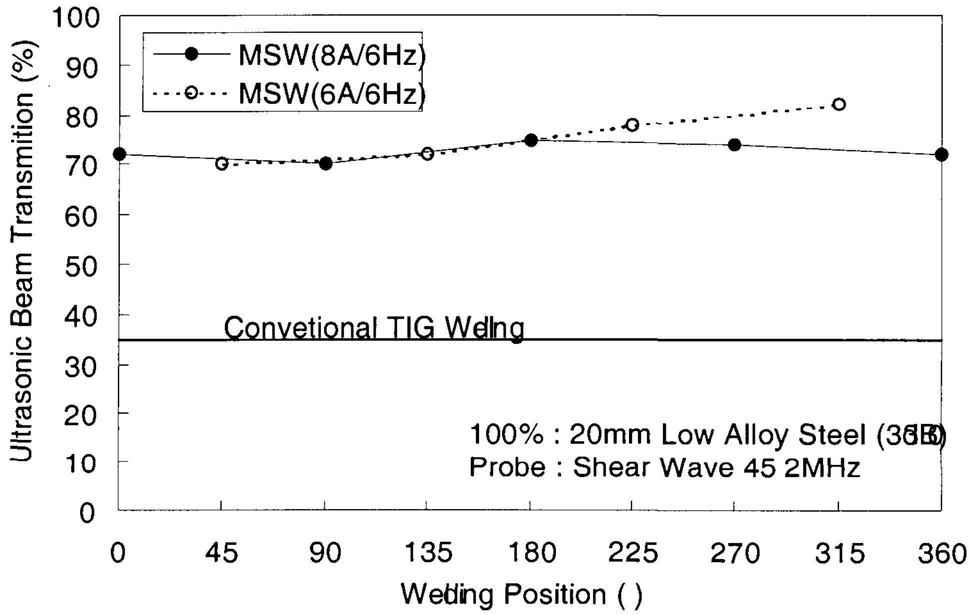


Fig.11 Ultrasonic beam transmission

Echo height from EDM notches on the inner surface was measured by the angle probe at 45 degrees refraction with a shear wave ultrasonic beam of 2 MHz frequency by direct scanning from outer surfaces. The results are shown in Fig.12 where 0dB is reflection from the reference block (2.4mm diameter, 20mm depth) . Immersion results are presented in Fig.13 where 0dB is echo from 0 degree notch of magnetic stirring welding.

Flaw detection capacity was found enhanced by two times as much 6dB by magnetic stirring welding.

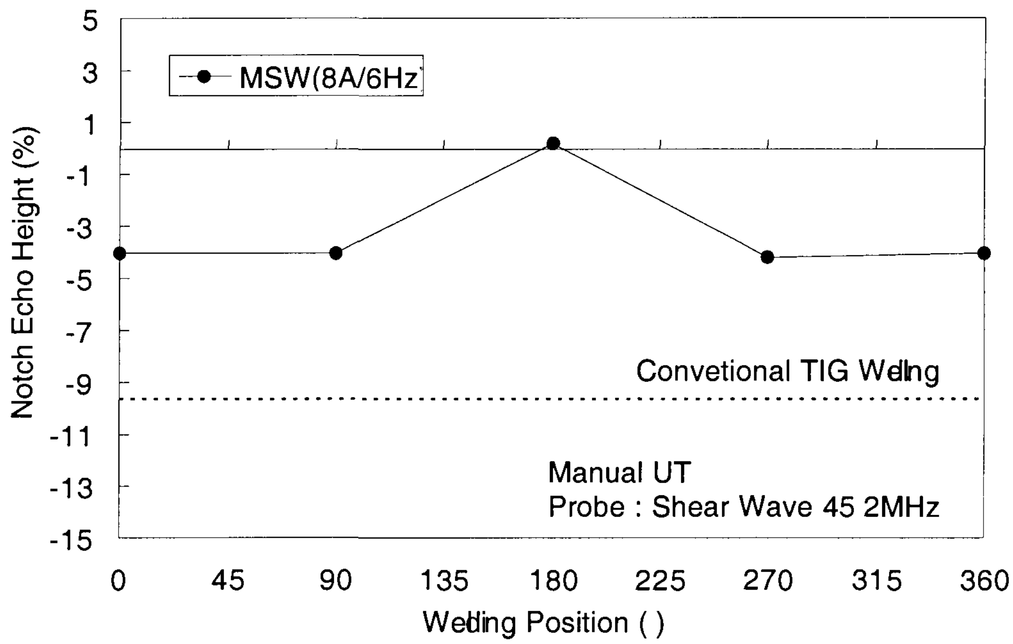


Fig.12 Manual UT(Notch echo height)

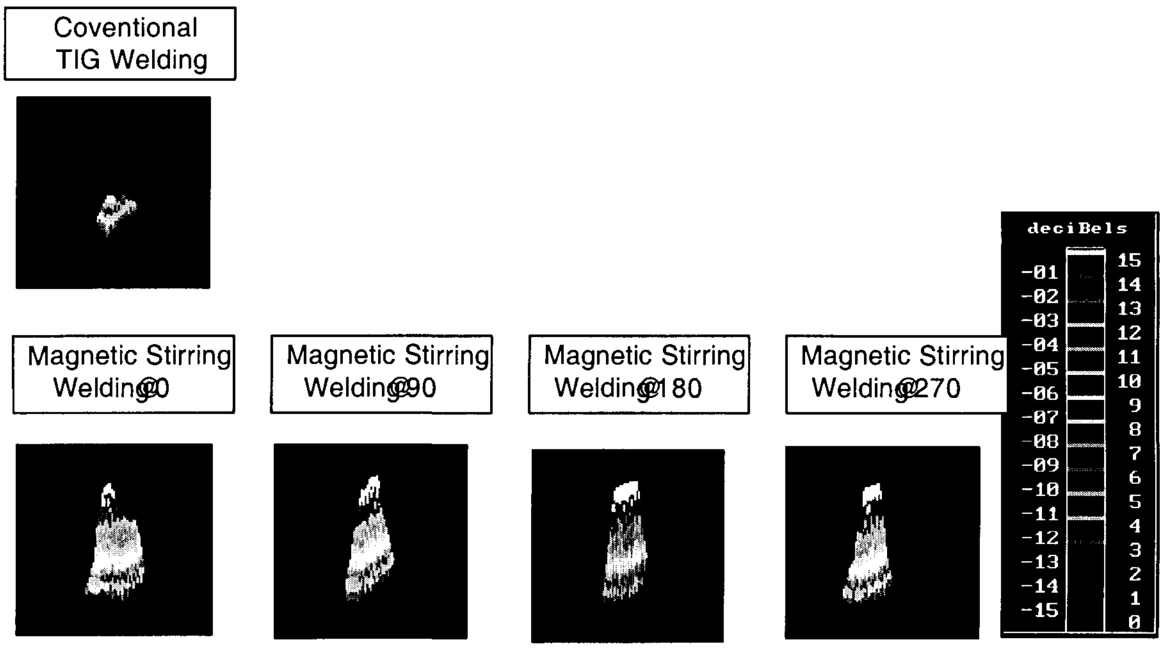


Fig.13 Immersion results

Hardness data are indicated in Fig.14. Hardness following measurement of that of the 3rd layer was more than 350Hv. Temper of 3rd layer overlay welding was inadequate for making this measurement. Overlay welding with consideration to temper is thus necessary after the 4th layer, where hardness of the heat affected zone is less than 350Hv in magnetic stirring welding.

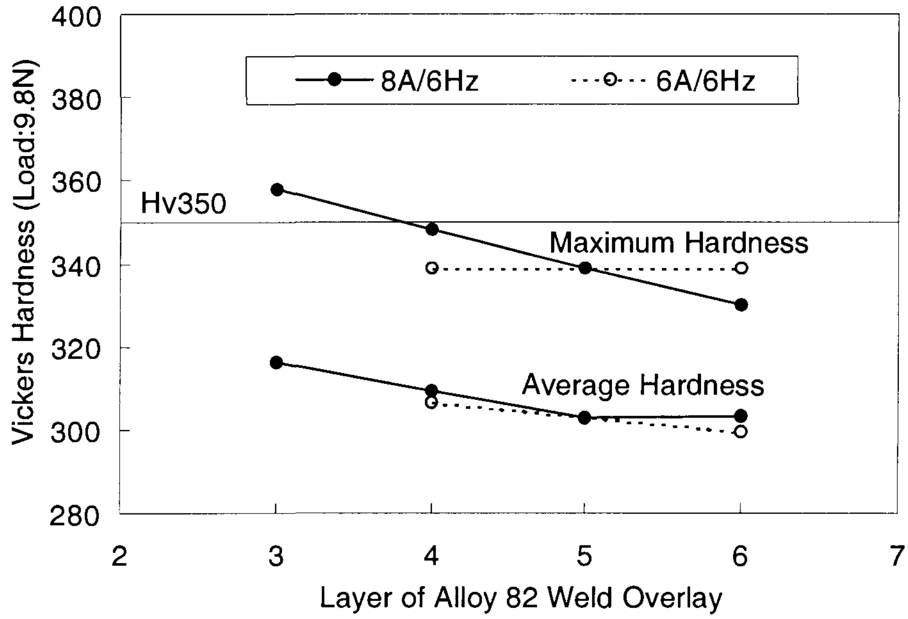


Fig.14 The results of hardness test

CONCLUSIONS

Overlay welding for dissimilar weld joints with magnetic stirring welding was examined and the results indicated the following:

(1) Optimal conditions
Welding current : 120-140 A, Welding voltage :11V, Travel speed 140mm/min.
Wire feed speed : 80mm/min., Magnetic field : 6-8A, Magnetic frequency : 6Hz
Layers : Minimum 4

(2) Ultrasonic beam transmission of overlay-welds is clearly enhanced. Defect detection capacity is considerably improved by magnetic stirring welding.

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