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Implant Weldability Test in Wet Underwater Welding†

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Abstract

The Implant cracking test has been done with HT60 steel plate using lime-titania type electrode by one pass and two pass welding in underwater and in air welding. Two pass welding has been proved to be effective in increasing lower critical stress because of improvement of microstructure and of decrease in diffusible hydrogen content. These benificial effects have been also observed from microfractography.

KEY WORDS: (Underwater Welding) (Cold Cracking) (Weldability Tests) (Hydrogen Embrittlement) (Covered Electrodes) (Fractography)

1. Introduction

Recent advanced technology promotes the large-sized construction and lightweight structure, and thus sometimes causes various weld defects1). No defect in welding fabrication, however, is the most important demand in the construction of welded structure in both underwater and air welding. There have been many studies and reports concerning underwater welding from view points of various fields. Hasui2, 3) showed that welded zone in underwater plasma welding and submerged-arc welding had excellent mechanical properties. Hamazaki4) showed that the butt-joint weldment free from any defect can be made with water curtain type CO_2 arc welding, and that the bending test of this weldment is good.

However, it is usually considered that the possibility of cold cracking is very high in wet underwater welding because of high hydrogen content absorbed from welding atmosphere containing decomposed water vapor by arc reaction. Moreover, the very rapid cooling during underwater welding increases severely the hardness of welded zone and makes the escape of diffusible hydrogen difficult5), and thus cold cracking or hydrogen embrittlement is very severe in welding of high strength steel.

Different types of weld cracking tests have been utilized to study the prevention method of cold cracking6–9). Among these cracking tests simulating the actual cold cracking, the Implant test10) has many excellent characteristics; a) operation is simple, b) test specimen undergoes the same thermal cycle as the base metal, c) procedure with preheating and postheating is nearly the same as the practical welding, d) many data can be obtained from small amount of steel because of its small-sized test specimen, and is useful for the development of new steel.

In this study, the relation between hydrogen content and critical stress has been studied using the Implant test by means of wet underwater welding. Then their fracture surfaces have been observed in detail with a scanning electron microscope. Moreover, two pass welding has been performed in the Implant test to study the effect of the second pass as the postheating on mechanical and metallurgical properties. These results have been compared with those obtained by one pass welding in underwater and in air welding.

2. Experimental Apparatus and Procedures

2.1 Implant test

Implant testing apparatus available for both in underwater and in air welding is shown schematically in **Fig. 1**. Load was applied by dead weight utilizing lever, and thus constant load was kept during the testing. Test welding was done by gravity welding, in which the second pass welding was started at 20 sec. after the completion of the first pass welding in underwater, and at 80 sec. after that

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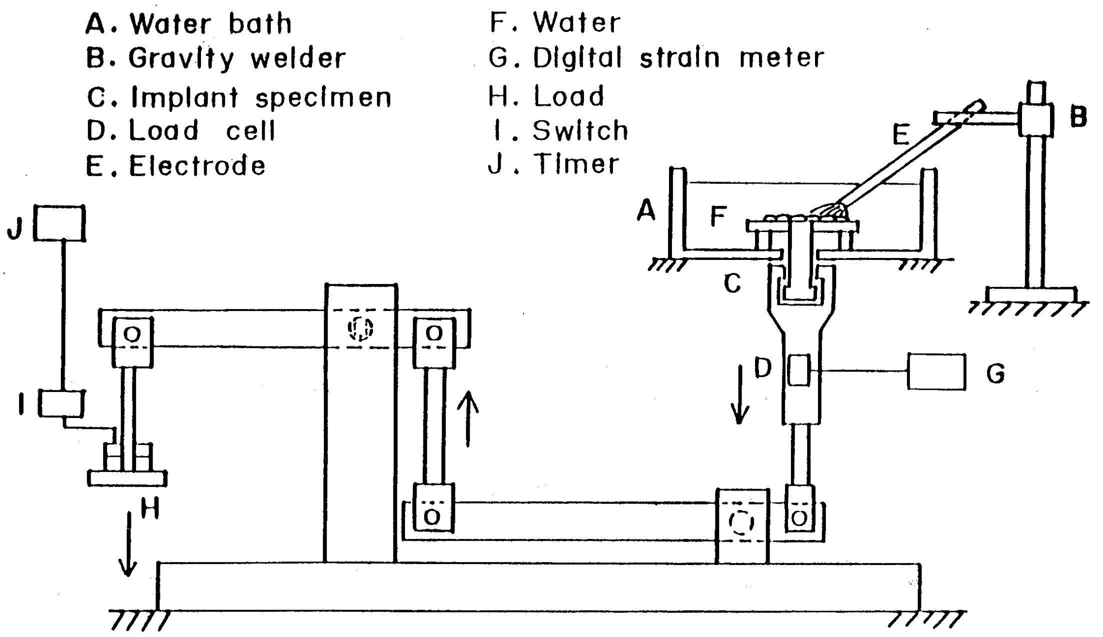

Fig. 1 Implant testing apparatus

in air welding. The load was applied at about 10 sec. after the completion of the second pass welding in underwater welding, and at about 120 sec. after that in air welding, when the temperature of heat-affected zone was about 150°C in both cases. The applied load was calculated from the output of a digital strain meter connected to load cell, and the applied stress was calculated by dividing the load by cross area at the bottom of notch of the specimen, namely 19.6 mm^2.

The shape of the Implant test specimen is shown in **Fig. 2**, where spiral notch was machined in order to avoid scattering of data due to an error of fusion penetration. The diameter at the bottom of notch was 5 mm, its tip radius was 0.1 mm, its angle was 40° and its pitch was 1 mm.

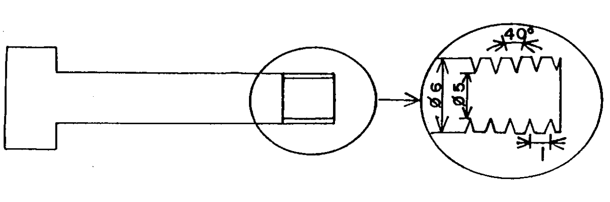

Fig. 2 Shape of spiral notch specimen

2.2 Materials used and welding conditions

The material used for the Implant test specimen was commercial 60 kgf/mm^2 class steel (HT60) of 19 mm thickness. Backing plate for the Implant test was mild steel (JIS SS41; 200 mm width x 300 mm length) of 19 mm thickness, and test welding was done on the backing plate. Electrode used for gravity welding was lime-titania type (JIS D5003) of 4 mm diameter available for high strength steel, which was sufficiently dried, but was not waterproofed. Their chemical compositions and mechanical properties are shown in **Table 1**. Welding conditions are shown in **Table 2**, and used in city water at the depth from 100 to 150 mm in the flat position.

Table 2 Welding conditions

	In-air welding	Underwater welding
Welding current	170-180 A	220-230 A
Arc voltage	25-30 V	25-30 V
Welding speed	100-150 mm/min	100-150 mm/min
Interpass temp.	150 °C (80 s)	50 °C (20 s)

3. Experimental Results and Discussions

3.1 Implant test

Figure 3 shows the relation between applied stress and fracture time in one pass and two pass welding in the both cases of underwater and air welding. This relation clearly shows the delayed fracture phenomenon except for the case of two pass welding in air, and it proves that this delayed fracture was caused by hydrogen absorbed during welding. Therefore, the lower critical stress, $(\sigma_{cr})_{imp}$, is very important to evaluate the crack susceptibility. The $(\sigma_{cr})_{imp}$ in underwater one pass welding is about 35

Table 1 Chemical compositions and mechanical properties of specimen and deposited metal

1) Chemical compositions (wt %)

	C	Si	Mn	P	S	Ni	Cr	Cu	Sn	Nb	Ceq[1)]	PCM[2)]
HT 60	0.14	0.46	1.32	0.016	0.013	0.07	0.15	0.27	0.019	0.036	0.41	0.25
D5003	0.07	0.38	0.99	0.017	0.012	—	—	—	—	—	—	—

1) $\mathrm{Ceq} = \mathrm{C} + \frac{\mathrm{Si}}{24} + \frac{\mathrm{Mn}}{6} + \frac{\mathrm{Ni}}{40} + \frac{\mathrm{Cr}}{5} + \frac{\mathrm{Mo}}{4} + \frac{\mathrm{V}}{14}$

2) $\mathrm{PCM} = \mathrm{C} + \frac{\mathrm{Si}}{30} + \frac{\mathrm{Mn} + \mathrm{Cu} + \mathrm{Cr}}{20} + \frac{\mathrm{Ni}}{60} + \frac{\mathrm{Mo}}{15} + \frac{\mathrm{V}}{10} + 5\mathrm{B}$

2) Mechanical properties

	Yield point (kgf / mm^2)	Tensile strength (kgf/mm^2)		Elongation (%)
		Smoothed	Notched	
HT 60	44	64	82	33
D5003	49	54	—	31

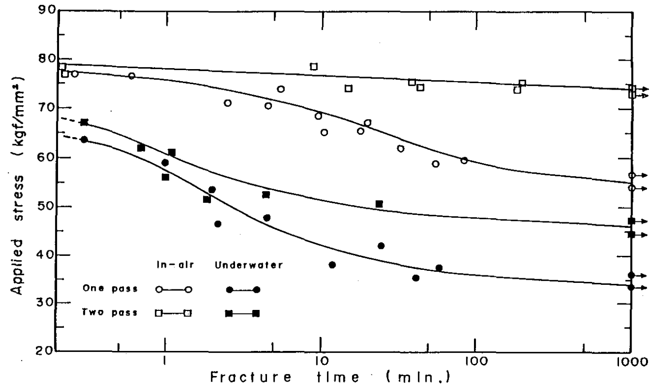

Fig. 3 Relation between applied stress and fracture time

kgf/mm^2, and about 55 kgf/mm^2 in air one pass welding. The difference is considered to be attributed to the hardened microstructure and much diffusible hydrogen remaining due to very rapid cooling in underwater welding. Two pass welding improved $(\sigma_{cr})_{imp}$ from 35 kgf/mm^2 in one pass welding to 45 kgf/mm^2, namely by about 30%, in underwater welding, and improved $(\sigma_{cr})_{imp}$ from 55 kgf/mm^2 in one pass welding to 75 kgf/mm^2, namely by about 40%, in air welding. This improvement is considered to be attributed to the decrease in both hardness and diffusible hydrogen content as shown in **Fig. 4** due to the postheating effect of the second pass welding. By the way, measuring method of diffusible hydrogen was based on JIS Z 3113, but collecting liquid used here was mercury instead of glycerine and the collection of diffusible hydrogen was continued for 408 hrs when the evolution of hydrogen bubbling stopped. In Fig. 4, the diffusible hydrogen content is compared with that measured at 48 hrs specified in JIS.

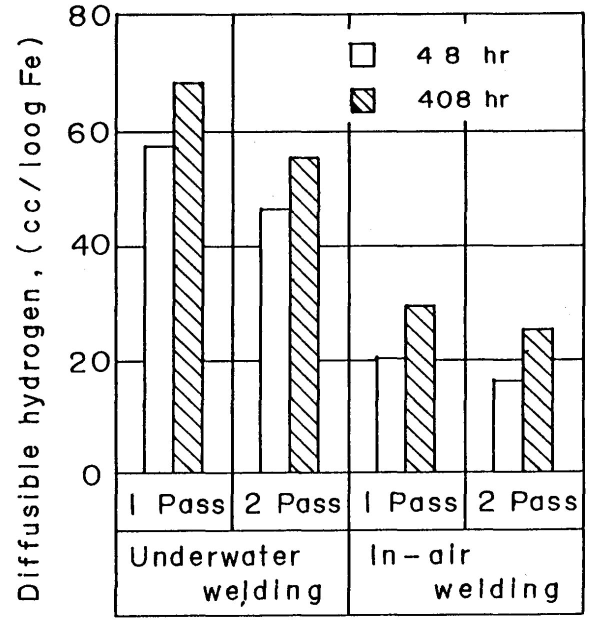

Fig. 4 Diffusible hydrogen at 48 hrs and 408 hrs

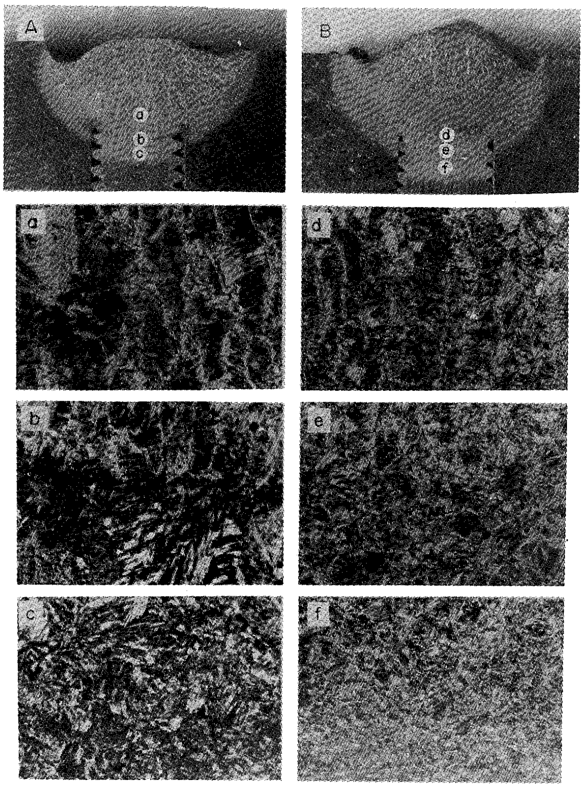

Fig. 5 Macro and microstructures of weld zone (Underwater welding)

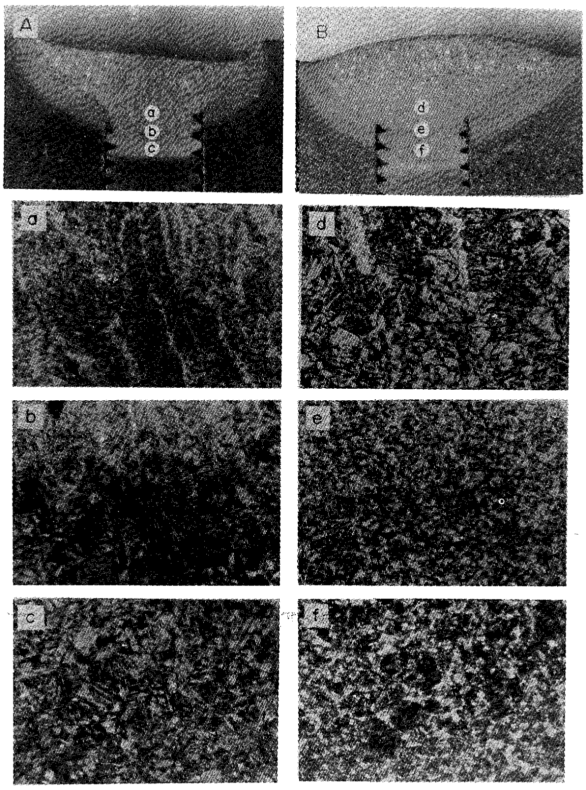

Fig. 6 Macro- and microstructures of weld zone (In air welding)

3.2 Macro- and microstructure

Figure 5 shows the macro- and microstructure of the Implant test specimen in underwater welding, where the mark (A) means one pass welding and the mark (B) does two pass welding. The marks from (a) to (f) in the macrostructures correspond to each of those marks designated in the microstructures. The weld metal, shown in (a), gives remarkable columnar structure. Coarse grained zone in HAZ near fusion boundary and general HAZ are shown in (b) and (c) respectively, both of them give clear martensitic structure. On the other hand, columnar structure in (d) becomes globular a little. The microstructures in (e) and (f) give the tempered martensite. These changes in (d) to (f) were caused by improvement due to the heat treatment of second pass welding.

Figure 6 shows the macro- and microstructure of the Implant test specimen in air welding, where the all marks have the same meaning as in Fig. 5. The columnar structure in weld metal shown in (a) is not so remarkable as in Fig. 5. The HAZ microstructures shown in (b) and (c) are general martensite, but not so coarse grained as in Fig. 5. On the other hand, the columnar structure in (d) is made considerably globular, and the HAZ microstructures in (e) and (f) change from martensite into bainite.

Therefore it is understood that the second pass welding improves the microstructure made by the first pass welding. Moreover the second pass welding decrease the hardness of the welded zone made by the first pass welding as shown in **Table 3**. This effect is one of the causes of increase in $(\sigma_{cr})_{imp}$.

Table 3 Cooling time and maximum vickers hardness

		Cooling time from 800 to 500°c (sec)	Maximum vickers hardness (Load 1 kgf)	
			weld metal	H A Z
Underwater welding	1 pass	3.0	330	460
	2 pass		300	400
In-air welding	1 pass	8.5	220	390
	2 pass		205	280

3.3 Fractography

Figure 7 shows examples of microfractographs by scanning electron microscope for the Implant test specimen in underwater welding. Most of the fracture surface

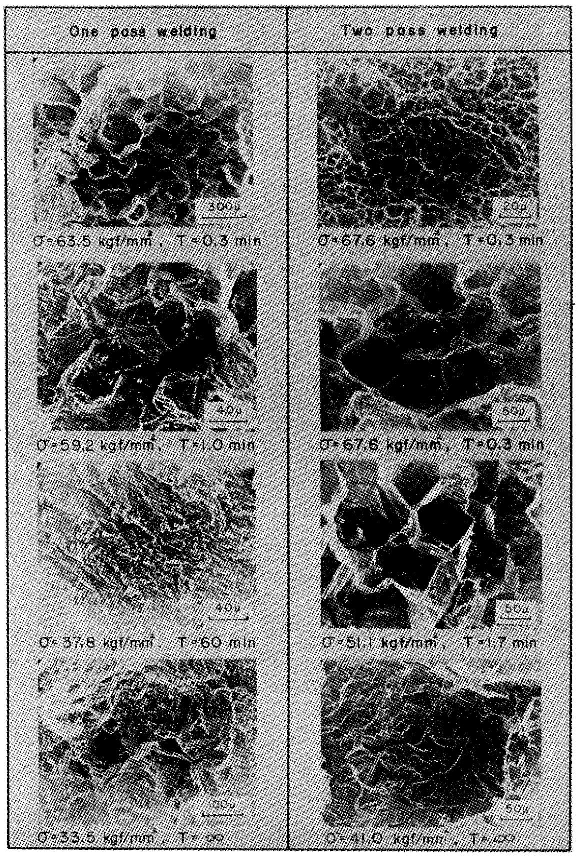

Fig. 7 Typical fractographs of Implant test (Underwater welding)

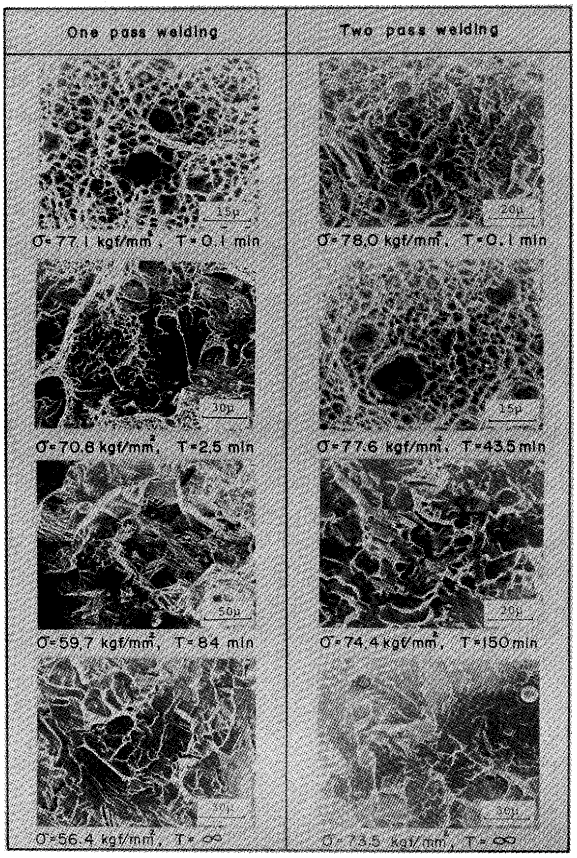

Fig. 8 Typical fractographs of Implant test (In air welding)

shows quasi-cleavage affected by hydrogen in both one pass and two pass welding. Only near the notch in the case of one pass welding, however, intergranular fracture surface was often observed. Dimple region was formed near the center of the fracture surface in the case of two pass welding, which also confirms that $(\sigma_{cr})_{imp}$ was improved by the second pass welding.

Figure 8 shows examples of microfractographs in air welding, where the majority of the fracture surface shows dimple pattern.

However, the decrease in applied stress had a tendency to increase the quasi-cleavage affected by hydrogen. Exceptionally, near the notch in the case of one pass welding, intergranular fracture surface was observed.

Therefore, there observed more quasi-cleavage affected by hydrogen and intergranular fracture in underwater welding than in air welding, and this also confirms that hardened microstructure and high diffusible hydrogen caused by rapid cooling are decisive for the cold cracking.

4. Conclusion

In this study, the Implant cracking test was done with HT60 steel plates using limt-titania type electrode by one pass and two pass welding in underwater and in air welding. Main conclusions obtained are as follows:

(1) Two pass welding in underwater improved $(\sigma_{cr})_{imp}$ from 35 kgf/mm^2 in one pass welding to 45 kgf/mm^2, namely by about 30%. On the other hand, two pass welding in air improved $(\sigma_{cr})_{imp}$ from 55 kgf/mm^2 in one pass welding to 75 kgf/mm^2, namely by about 40%. Generally $(\sigma_{cr})_{imp}$ in underwater welding was about 65 to 70% of that in air welding.
Moreover, diffusible hydrogen content was decreased by about 20% due to two pass welding.

(2) Two pass welding in underwater changed the microstructure in weld metal from columnar structure into globular structure and from martensite into tempered structure in HAZ. On the other hand, two pass welding in air changed the HAZ microstructure from martensite into bainite. Therefore, two pass welding improved the microstructure in weld metal and HAZ, and further decreased the hardness of welded zone made by the first pass welding. Especially the decrease in the hardness of HAZ was remarkable.

(3) Most of the fracture surface in underwater welding

showed quasi-cleavage affected by hydrogen, and in one pass welding, intergranular fracture surface was observed only near the notch. On the other hand, majority of the fracture surface in air welding was dimple pattern, and the decrease in applied stress had a tendency to increase the quasi-cleavage affected by hydrogen. These fractographies also suggested that two pass welding was effective in improvement of $(\sigma_{cr})_{imp}$.

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