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A Study on the Development of Underwater Wet Welding Electrodes

MIN-NAM KIM *
* *Department of Mechanical Engineering, Pukyong National University, Busan, Korea*

KEY WORDS: Underwater Wet Welding Electrode, Flux Ingredient, Operability, Weld Metal, HAZ, Mechanical Properties

ABSTRACT: *Underwater wet arc welds were experimentally performed on the KR-RA steel plate as base metal by using four different types of flux coated electrodes: KT33, UWEE, UWCS, and TN20. UWEE, the individually designed flux coated underwater electrode, had good operability when compared with other domestic terrestrial electrodes, and imported goods. The hardness value and the portion of martensite of HAZ were increased,by using a rapid cooling rate, Mechanical properties were also examined experimentally with a multi-pass butt-welding specimen test. The individually designed flux coated electrode UWEE could be used in practice for underwater wet welds.*

1. Introduction

There are three approaches to weld repair underwater: wet welding, dry welding at 1 atm, and dry hyperbaric welding. Underwater wet welding is done at ambient pressure with the welder/diver in the water without any mechanical barrier between the water and weld arcs. Simplicity of the process makes it possible to weld on even the most geometrically complex node sections. Even if underwater wet welding procedures have been qualified and the development of the underwater wet welding electrode is advanced, the wet welding process will still be required, if satisfactory wet welded structural repairs are to be made (Cotton, 1983; Dexter, 1990). The underwater wet arc welding process using shielded metal arcs is being used more often quite recently in off shore industry repairs (Tsai, 2001). The electrode manufactures rarely disclose the chemical compositions of commercial welding electrodes, especially the flux ingredients and the covering materials of the underwater wet electrodes. During the course of this study we could not find any domestic underwater wet electrodes. We had been trying to design a new underwater wet electrode for underwater wet welding purpose, (Kim et al., 1999; Kim et al., 2000). since the primary objection of this electrode investigation is to determine the feasibility of improving wet welding quality (Kim et al., 2001 ; Sanchez et al., 1995). It has been necessary to develop more expert technologies to make quality underwater wet welds, and the comprehensive welder/diver training is essential to fully achieve high quality, structurally sound, underwater wet welds (Grubbs et al., 1976; Masubuchi et al., 1983).

The specification for underwater welding defines four types of welds, A, B, C, and O (AWS D 3.6M, 1999). Each type of welds has a set of criteria for the weld properties that must be established during qualifications, and a set of weld soundness requirement that are to be verified during construction (Dexter et al., 1990). This paper addresses the reliability of wet welds using the newly developed underwater electrodes for type "B" underwater wet welds.

2. Experimental Procedures and Materials

2.1 Underwater wet welding fixtures

Fig.1 shows the arrangements of experimental equipments. The experiments were done in city water and the surfaces of base metal were situated at a water depth of 1500mm. The DC power source was a HICO TR-500 welder, Hyosung Industries Co., LTD. rectifier with a capacity of 600 amperes. The electrode holder for most underwater arc welds was the product of BROCO, INC. Br-20. The BR-20 Welding Stinger is designed to hold the electrode at the optimum angle to the work pieces, delivering quality welds while reducing operator fatigue. The movable jaw design accepts a wide range of electrode diameters. We used the Neptune 2 full face mask for diver/welder and Neptune diving and underwater communication systems for the underwater wet arc welding experiment.

2.2 Materials

2.2.1 Base metal

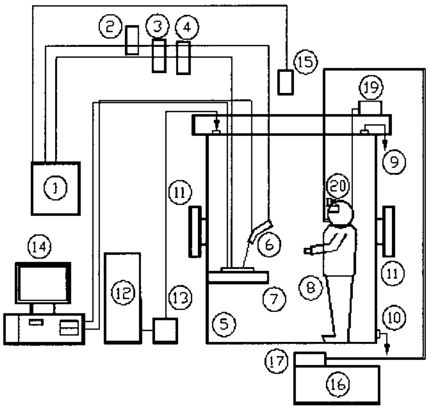
Base metal was the KR-RA steel for ship constructions of

The first author : Min-Nam Kim
Email : mnkim@pknu.ac.kr

11mm in thickness. Tables 1 and 2 show chemical compositions and mechanical properties of base metals. The carbon equivalent of steel used for experimental welds is determined by the following formula (Dexter et al., 1990):

$$Ceq = C + Mn/6 + [Cr+Mo+V]/5 + [Ni+Cu]/15$$

Experimental test specimens were made 250mm × 125 mm by a cutting machine, and manufactured at a 45 degree angle by a milling machine for underwater butt welds.



① DC arc welding machine
② On/off magnet switch
③ Ampere meter
④ Voltage meter
⑤ Chamber
⑥ Electrode holder
⑦ Work bench
⑧ Driving dress
⑨ Over flow pipe
⑩ Drainage
⑪ Sight glass
⑫ Cooling water tank
⑬ Circulating pump
⑭ Data acquisition system
⑮ Welding machine power on/off switch
⑯ Air compressor
⑰ Precision air filter
⑱ High pressure hose
⑲ Communication phone box
⑳ Diver's full mask

Fig. 1 Schematic diagram of experimental equipments

2.2.2 Welding electrodes

Filler metals for underwater wet arc welds were four different kinds of wet welding electrodes: KT33, UWEE, UWCS, and TN20. The flux coated underwater electrode with SWRY-11 core wires (UWEE) was individually designed. (KT33) was a terrestrial electrode from Korea, and the other two electrodes (UWCS, TN20) were made by BROCO, Inc., of the US and THYSSEN, of Germany. Table 3 shows the flux ingredient ratio of the individually designed underwater electrode UWEE. Table 4 shows chemical composition of covering elements examined by XRF-1700 X-ray analysis.

Table 1 Chemical composition of base metal (KR-RA)

Chemical composition (wt %)					
C	Si	Mn	P	S	Ceq
0.13	0.25	0.57	0.017	0.01	0.22

Table 2 Mechanical properties of base metal (KR-RA)

Mechanical properties			
Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Bend test
323.4	446.8	24.0	Good

Table 3 Typical composition ratio of constituents of coverings on the UWEE electrodes (wt %)

Constituents of covering	Ratio	Constituents of covering	Ratio
Titanium dioxide	3	Dextrine	1
Ferromanganese	9	Starch	6
Silicate	5	Iron powder	7
Feld spar	15	Ilmenite	1
Rutile sand	35	Calcite	21
Mica	2	Talc	1

2.3 Welding parameters

The position of experimental welds for bead and groove welds was placed on an almost horizontal plane. The weld metal was deposit from the upper side. All the underwater welds were made by manual methods. Direct current and Straight polarity were used on most welds. Straight polarity weld is recommended for underwater wet welding, since reverse polarity results in accelerated corrosion of the electrode holder. The effects of welding speed and current on the underwater wet weldability were decided based upon previous experimental welding results(Kim et al., 2001).

All welds were made at 250mm per minute with 150 amperes and 30 volts. An preliminary evaluation was with single bead-on-plate tests. Finally, the evaluation included multi-pass welds in plate-groove welds. The multi-pass welds were made to establish how well the electrodes could be deposited on their own deposits and on diluted weld metal. The deeper groove was also considered a measure of the underwater manual welding quality. Judging from the previous underwater wet bead welding process, the experiments shall be made using the welding conditions shown in Table 5.

Table 4 Chemical composition of covering (wt.%)

Object	KT33	UWCS	UWEE	TN20
Si	26.85	32.67	23.18	25.51
Ti	22.96	7.64	14.65	26.22
Ca	13.89	9.44	26.21	15.36
Mn	10.99	10.75	9.51	10.04
Al	8.77	0.89	3.22	7.77
K	7.23	3.48	3.98	8.87
Na	4.41	12.76	7.30	1.14
Fe	3.36	15.30	10.05	3.92
Mg	1.00	6.90	1.64	0.27
Zr	0.30	0.04	0.10	0.31
Nb	0.14	0.05	0.10	0.17
P	0.04	0.04	-	-
Rb	0.03	-	-	-
Sr	0.03	-	0.03	-
S	-	0.05	0.03	0.02
Mo	-	-	-	0.32
Cr	-	-	-	0.07

2.4 Water proofing

The individually designed underwater wet electrode (UWEE) was manually waterproofed with Urethane Conformal coating (UC-100) purchased from Nabakem Chemical Co., in Korea, or it was waterproofed by being dipped in a Urethane banish solution (UV404) from Korea Chemical Co. Two dips were used. The electrode was held in the solutions for 20 seconds to insure good coverage and was then dried for an hour between dips. The waterproofing was removed from the contact points of the electrode by sand paper before welding. This was done at the point of contact for the starting of electrode and also the uncoated portion of the electrode which fixed up the electrode holder.

3. Results and Discussion

3.1 Operability

3.1.1 Slag removal

Slag removal was judged as good when the slag was removed completely by scraping a chisel along the surface of the underwater bead welds. The TN20 was stuck in slag and was difficult to remove ; UWEE and UWCS were easier to scrape than the others. The KT33 electrode was considered unsatisfactory because fragments of slag remained on the surface after cleaning, particularly near the fusion line. This could prove to be a problem in multi-pass groove-plate welds. Photo 1 shows the appearance of the slags in underwater manual bead welds.

Table 5 Typical underwater welding conditions

Electrode dia	3.2mm
Current(A)	150
Voltage(V)	30
Welding speed(cm/min)	30
Bead length/ Electrode length used	0.9
Welding angle(°)	75
Electrode source	DCSP
Welding position	Flat

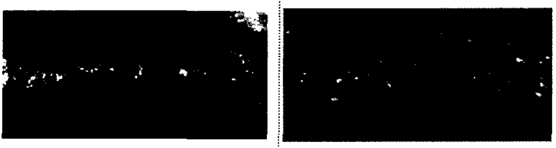
3.1.2 Bead appearance

Bead appearance was rated good, fair and poor. These are qualitative ratings based upon the judgment of the welder. The desired appearance was a bead of uniform width which was neither too convex nor concave (Sadowski, 1977). Photo 2 shows typical bead appearance of multi-pass groove-plate welds. It was labeled good in the UWCS electrode, and poor in the TN20 electrode. Bead appearance, however, was too dependent upon the diver/welder manual underwater welding skill,

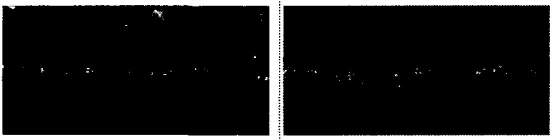
3.1.3 Arc stability

Arc stability was based upon the ability of the electrode to burn completely without interruption, and, if interrupted, to be re-ignited readily. Fig.2 shows an example of the HP-VEE programs for measuring arc stability during the experimental wet welding process. The oscillograms of welding current and arc voltage, which show stability of underwater wet welding arc generated under the same welding conditions, are shown in Fig.2. In welding (a), a fluctuation of arc voltage is observed at very short intervals, but a regular fluctuation, such as shown in (c), which is the most stable among the four electrodes, is not found. In welding (b), the arc-voltage oscillograms shows a relatively regular fluctuation. The oscillograms of UWCS electrode was desirable, but the TN20 electrode demonstrated unstable arcing in this experimental study. This phenomenon was considered a difference in voltage and ampere fluctuation between the types of electrodes, which was caused by a change of metal transfer, which is influenced by flux ingredients and coating materials.

Compared with imported electrodes, the arc stability of individually designed underwater electrodes was not inferior but competitive. But when compared among themselves, the oscillograms of welding current and arc voltage in underwater wet arc welds was almost identical. From these results, it may be understood that the underwater wet welding arc can be kept stable without an arc break or short-current, and there is no problem in underwater manual wet welds for the expert diver/welder.

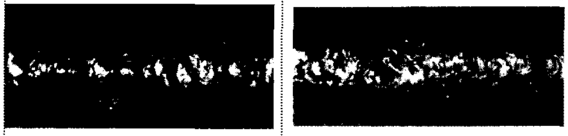


(a) KT33 (b) UWEE

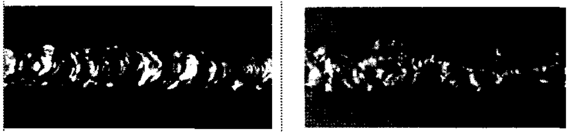


(c) UWCS (d) TN20

Photo 1 Appearance of slags

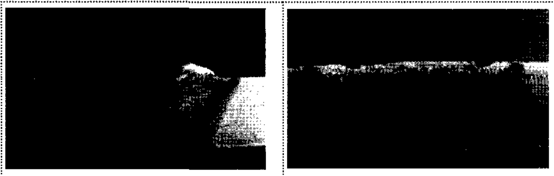


(a) KT33 (b) UWEE

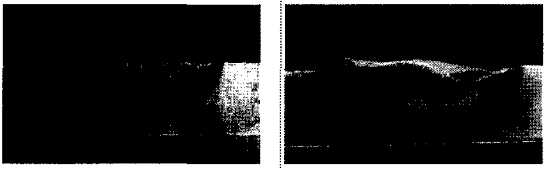


(c) UWCS (d) TN20

Photo 2 Appearance of multi-pass welds



(a) KT33 (b) UWEE



(c) UWCS (d) TN20

Photo 3 Sectional macro-structure of welds

3.1.4 Ease of operations

The two variables which are controlled by the diver/welder in manual wet welding are the downward force applied to the electrode and the welding travel speed. These two variables were important factors in good operability of wet welds: therefore, the ability of the diver/welder was much more important than the type of electrode used in underwater wet arc welding. All four types of electrodes had almost equal arcs starting, but the UWCS electrode was considered to have a soft touch operation.

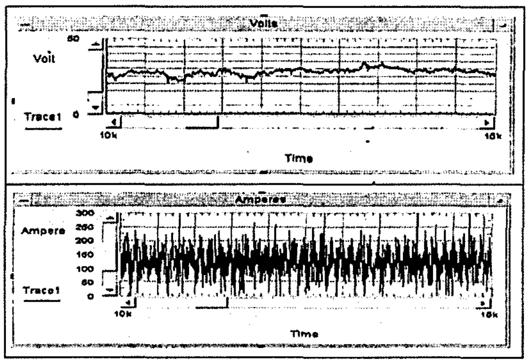
3.2 Cracking and undercut

All welds were examined at 10X magnification for surface cracking. Selected welds were sectioned, polished, etched, and examined for underbead cracking at a magnification of 10X. All welds were examined for undercut. Cracking and underbead were not observed in any of the welds made. Examples of the cross sectional macro-structure of the multi-pass groove-plate welds were given in Photo 3. Undercutting was not observed in any of the welds made with the imported electrodes. The newly developed electrode UWEE did not display undercutting.

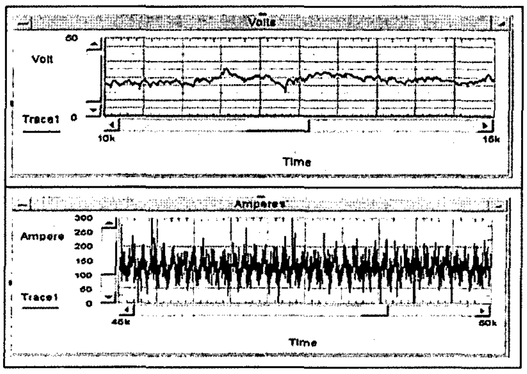
3.3 Mechanical properties

3.3.1 Hardness distributions

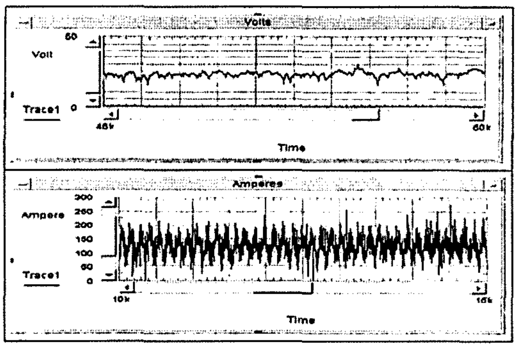
The maximum hardness in the heat-affected zone of underwater wet welds is one of the most important parameters used to estimate the mechanical properties. The value of this parameter reflects a standardized base for the appropriate selection of the base metal and welding conditions to prevent the crack. Weld metal hardness has also been excessive when the wrong filler metal is chosen. In this experimental study, the only area of hardness considered excessive were just under the cap in the HAZ of the underwater wet last bead deposited. These hardness test results verify that wet welding could provide an annealing from bead to bead, much as that produced in dry welding. Fig.3 shows the hardness distribution of the welding boundary according to type of underwater electrodes. For comparison, the hardness distributions of the HAZ were increased rapidly at almost the same degree, the maximum hardness was Hv330.3 in the KT33 electrode and Hv 300.6 in TN20 electrode. This was remarkably low. The maximum hardness value of the UWEE electrode was Hv 306.0. On the other hand, the average hardness value of underwater weld metals were about Hv 230.



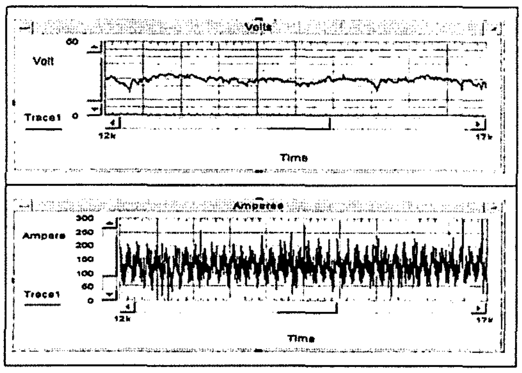
(a) KT33



(b) UWEE



(c) UWCS



(d) TN20

Fig. 2 Oscillograms of underwater wet welds

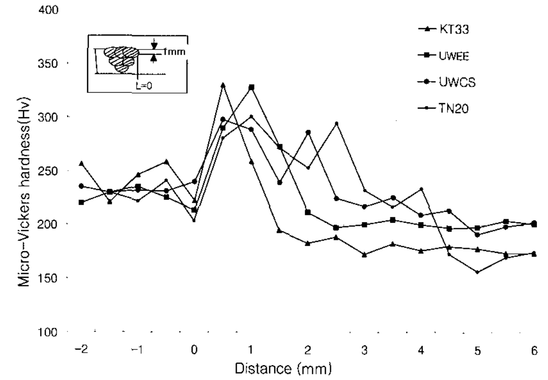


Fig. 3 Hardness distributions of underwater welds

3.3.2 Tensile strength

Mechanical properties of the multi-pass underwater wet groove welds (Position PA(1G), which had been welded in 6 passes from each face of base metal, were tested. Results of the tensile test of underwater wet welded joints are shown in Table 6.

As the sound underwater wet welded specimens were broken at the base metal (Kim et al., 2000), the specimens with V-notch of 2mm in depth at weld metal had a joint efficiency of more than 100%. However, the elongation becomes lower than that of base metal in every case.

The tensile strength of the electrodes was satisfactory. The weld metal tensile strength exceeds that of the base metal by an average of approximately 15%. Weld ductility for the four kinds of electrodes was obviously less than that of the base metals. Tensile strength exceeded that of the base metal, which should compensate somewhat for the lower elongation of the weld metal.

3.3.3 Bend test

Table 7 shows the results of the face bend test of weld metals. Every specimen could not be bent to 180 degree without surface cracking. Therefore, the joint welded by this experimental underwater process had not sufficient bend ductility. I believe that the seriousness of this problem could be reduced considerably by using improved electrodes and base metal of advanced steel as well as trained, qualified topside divers and welders.

3.3.4 Impact test

Table 8 shows Charpy impact values of the underwater welds. The impact value shown in the table is an average of the values for several specimens. According to these results, considered that there is no problems as to impact value for practical use, provided underwater wet arc welds are done by well-trained topside divers and welders.

Table 6 Result of tensile test

Electrode	Peak		
	Load(kN)	Tensile Strength (N/mm^2)	Elongation (%)
KT33	5.52	511.35	8.68
UWEE	5.43	516.75	8.94
UWCS	5.38	512.25	8.01
TN20	5.73	545.57	7.84

Table 7 Results of free bend test

Test specimen	Angle of bend(degree)	Elongation(%)
KT33	30	10.3
UWEE	28	12.1
UWCS	24	7.1
TN20	34	9.7

Table 8 Results of impact test

Test specimen	Average impact value (J/㎠)
KT33	44.15
UWEE	55.62
UWCS	53.19
TN20	49.22

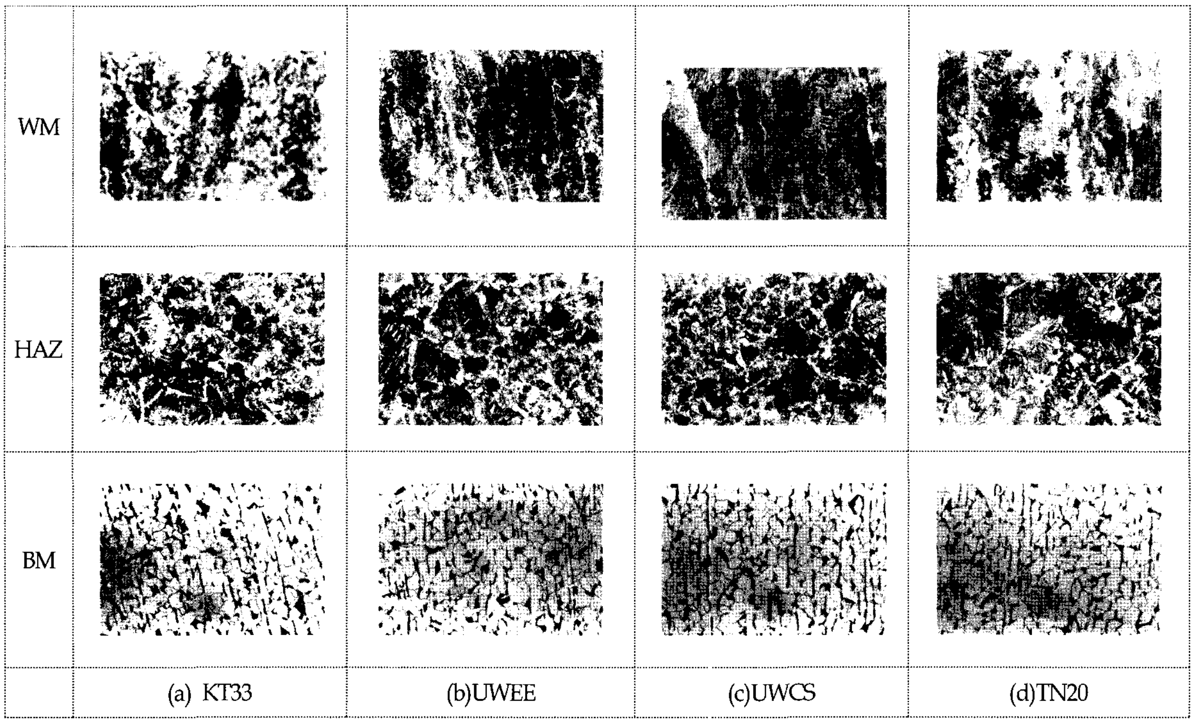
4. Micro-structures of Weld Metal and Heat-affected-zone

For underwater wet welding, there is a major increase in the cooling rate, which could better accommodate the shifts in weld metal composition due to reduced hardening. Since the cooling rate affects the inclusion distributions, different levels of ingredients are needed to maximize the amount of acicular ferrite (Sanchez, 1995).

Photo 4 shows micro-structures of the underwater butt welds by the last pass butt welds. In every case of the weld metals, the structure consists of banite, pearlite, and a little ferrite at the grain boundary. At the heat-affected zone adjacent to the bond, the structure becomes a coarse network of ferrite which is composed of banite, pearlite, and a little martensite. Structure of the base metal is composed of ferrite and pearlite. The UWEE electrode could be modified to achieve a favorable micro-structure.

5. Summary and Results

The feasibility of the improved underwater electrode was experimentally studied. The results obtained in this series of experimental underwater wet arc welds show that UWEE could have such a degree of integrity that its use may be



(a) KT33 (b)UWEE (c)UWCS (d)TN20

Photo 4 Micro-structure of underwater wet welds justified for limited application in underwater structure or ship repair. Such application would include permanent nonstructural repair in low carbon equivalent steels and temporary structural repairs, performed on an emergency basis, where replacement or rewelding of the required area may be deferred until the next scheduled dry docking.

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