Study on Underwater Welding (Report 1)

—Its Weldability—

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Abstract

Recently, many studies for developing the underwater welding techniques have been carried out in the advanced countries as a manufacturing process and a repairing method according as a great deal of interest in development for various marine industrial fields has been gradually increased.

But no study on such underwater welding is available at present in our country.

In this study, underwater welding was carried out for welding of domestic structural steel plates (SM41A) of 10 *mm* thickness, using six types of domestic coated arc welding electrodes on a self-made gravity type underwater welding device, resulting in investigation for the underwater weldability of the domestic structural steel plates as well as for the underwater welding properties and practicability of the domestic welding electrodes.

Introduction

Since Humply Davy was firstly successfull in generation of arc under the water in the United States in 1802, the underwater welding has been much studied and developed, and widely utilized in construction of the underwater- and ocean-structures as well as in ship-repairments in the United States, England, Germany and Japan[1),2)], for overcoming the lack and limitation of land resources, and for the energy development and the space utilization in the sea. And also it will be continuously used in manufacturing processing and repairing method for marine structures and in various marine development plans[3)].

In our country, too, the necessity of resources and energy development and the lackness of our land area are in serious problem. So that, a great deal of interest has been taken in marine development but no study is available at present in this field in our country.

In this study, underwater welding was experimentally carried out for welding of domestic structural steel plates (SM41A) of 10 *mm* thickness, using six types of domestic coated-arc-welding electrodes on a self-made gravity type underwater -welding device.

And then the underwater weldability of the domestic structural steel plates and the underwater welding properties and practicability of the domestic welding electrodes were investigated.

Experimental material and procedures

1. Specimens and electrodes

The test plates used in this experiment are domestic structural steel plates (SM41A) of 10 *mm*

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Table 1. Mechanical properties and chemical composition of base metal (SM41A)

Mechanical properties	Yield strength kg/mm^2	Tensile strength kg/mm^2	Elongation %	Charpy impact value kgm/cm^2	Chemical composition (Wt %)	C	Si	Mn	P	S
	19.57	30.5	33	17.6		0.17	0.04	0.83	0.016	0.02

Table 2. Mechanical properties and chemical composition of deposited metals.

Welding electrode	Mechanical properties				Chemical composition (Wt %)				
	Tensile strength kg/mm^2	Yield strength kg/mm^2	Elongation %	Charpy impact value kgm/cm^2	C	Si	Mn	P	S
E 4301	48	41	34	11	0.08	0.10	0.42	0.016	0.010
E 4303	49	43	32	11	0.07	0.15	0.37	0.014	0.013
E 4311	47	43	26	11	0.08	0.24	0.48	0.009	0.009
E 4313	49	44	29	—	0.08	0.28	0.38	0.017	0.011
E 4316	55	44	35	19	0.07	0.41	0.96	0.012	0.009
E 4327	48	41	34	8	0.07	0.34	0.65	0.018	0.012

thickness, the mechanical properties and chemical composition are shown in Table 1.

Each specimen for investigation of underwater weldability was cut to 100×50 *mm* of base metal. The specimens for investigating the hardness distribution and the micro-structure of welded joints were made to observe each cross section in welding direction. The etching solution for macro and micro structure inspections was the mixed liquid of nitric acid 5 *cc* and alcohol 100 *cc*, and the etching time was 90 *sec* and 50 *sec* respectively.

Table 2 shows the mechanical properties and the chemical compositions for six types of coated-arc-welding electrodes which are on the marketing.

The ilmenite type (KSE 4301), lime titania type (KSE 4303), high cellulose type (KSE 4311), high titanium oxide type (KSE 4313) and low hydrogen type (KSE 4316) of welding electrodes have each 4 *mm* diameter and the iron-powder iron-oxide type (KSE 4327), 5 *mm*.

Specially, for the ilmenite type and high titanium oxide type, the welding electrodes of ϕ 3.2 *mm*, ϕ 4 *mm* and ϕ 5 *mm* were used in underwater welding tests, with no waterproof coating on the electrodes.

2. Experimental equipment and procedures

The experimental equipment used in underwater welding is the self-made gravity type welding device, on which the ratio of welding electrode carrying speed, the angle of electrode and the electrode diameter can be freely varied. Its schematic block diagram is shown in Fig. 1.

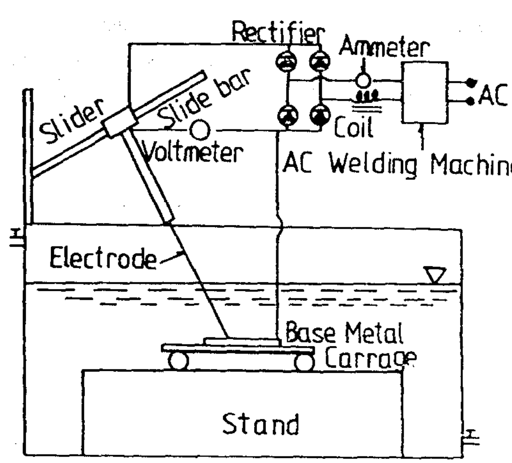

Fig. 1. Schematic block diagram of experimental underwater welding apparatus (gravity type).

The AC arc welder of 250 A used in this underwater welding device can be commutated from AC to DC by full wave rectification with a diode rectifier attached. The straight polarity (DCSP) was taken through underwater welding in the city water filled in a tank (600×600×1000 *mm*) at the room temperature. There was no great difference between the cases of using city water and sea water[4]. The depth from water surface to welding position was set to 20 *cm*, which was thought enough to get the same result of underwater welding within the depth of 5 *m* (the water pressure 0.5 kg/cm^2) from the surface[5]. The circumstance of underwater-welding arc is surrounded with many air bubbles and such generated bubbles prevent to observe the bead condition and arc and molten pool behaviors. So that, two bars were set up as a guide, and then the straight beads could be obtained by moving straightly along the guide with a gap[6].

For investigation of weldability, the selected welding conditions are welding current 90∼210 A, welding speed 28 *cm/min* (ratio of electrode carrying speed=bead length/electrode length used =1) and the angles of welding electrodes were set to 40°, 60° and 80°.

Then the bead appearance examination and the X-ray inspection were done under the proper welding current using each welding electrode type, and also the micro-structures for six-pass underwater welds welded under the optimum welding condition were observed on an optical microscope.

The hardness distribution of the underwater weld welded under the optimum welding condition was investigated at every 0.5 *mm* interval point along the longitudinal position of 1 *mm* depth from the up and down surfaces of the welded zone, as well as the center line.

Results and consideration

1. Examination of underwater weldability

Fig. 2 shows the effect of electrode angle on bead appearance of underwater welds of SM41A

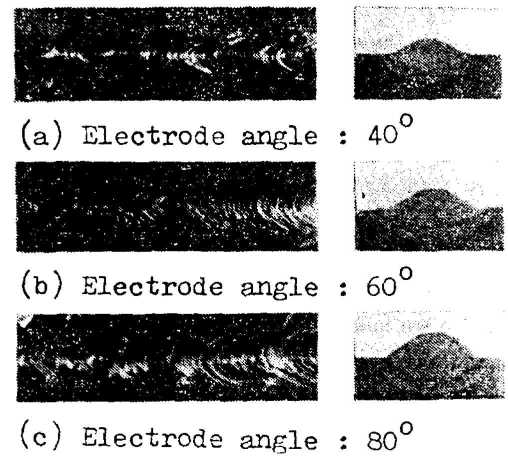

Fig. 2 Effect of electrode angle on bead appearance of underwater welds of SM41A as ilmenite type electrode (φ 4 *mm*) is used.

as ilmenite type welding electrode was used. The arc current was 160 A, and the angles of electrode were 40°, 60° and 80°, respectively, as shown in the figure. The bead appearance and weld penetration were good in any angle of welding electrode.

Fixing the electrode angle to 60° and using ilmenite type welding electrode of φ 4 *mm*, only in the case of changing welding current to 90 A, 160 A and 210 A, respectively, the effects of the welding current on bead appearance of underwater welds were shown in Fig. 3. In case of

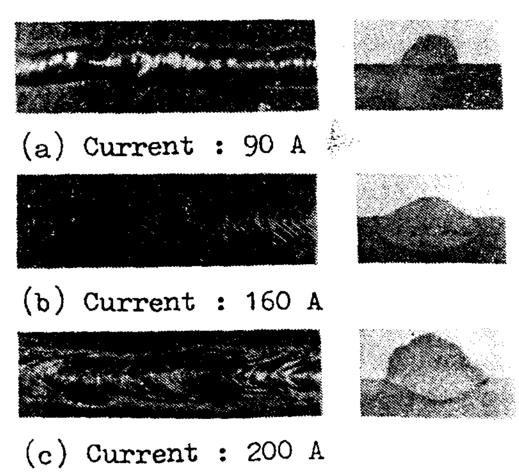

Fig. 3 Effect of welding current on bead appearance of underwater welds of SM41A as ilmenite type electrode (φ 4 *mm*) is used.

figure (a), the lack of weld penetration is shown due to poor current, and figure (c) shows the ununiform bead appearance as well as undercut because of the excess of welding current. Meanwhile, in figure (b), there is no weld defect and the bead appearance is sound, resulting in good weld with the proper current range of 160 A.

Fig. 4 is the case of having used the ilmenite type electrodes with different diameters of ϕ 3.2 *mm*, ϕ 4 *mm* and ϕ 5 *mm* and with angle of 60° under welding currents of 120 A, 160 A and 200 A, respectively. In this case, the bead appearance was also good at any welding current and with any diameter of welding electrode.

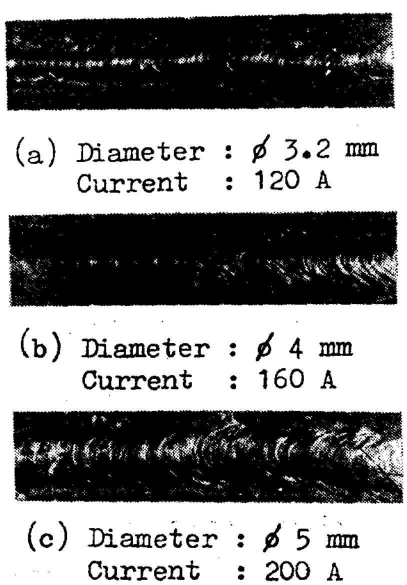

Fig. 4 Effect of diameter of electrode on bead appearance of underwater welds of SM41A as ilmenite type electrode is used.

Fig. 5 shows the range of arc current relating to welding electrode diameter in order to get experimentally the good underwater welds showing sound bead appearance. In case of ilmenite type welding electrode, the proper range of welding current becomes narrower with the increase of welding electrode diameter. In case of high titanium oxide type welding electrode, it was confirmed that the proper range of welding current according to welding electrode diameter

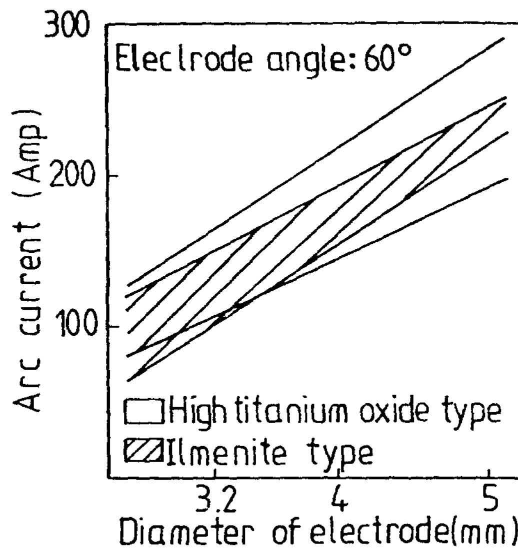

Fig. 5 Effects of arc current and diameter of electrode on appearance of welds of SM41A.

becomes wider than that of the former.

2. Bead appearance and X-ray inspection of underwater welded joint

Fig. 6 reveals the bead appearance and their X-ray inspection results of underwater welds of SM41A, using the ilmenite type, lime titania type, high cellulose type, high titanium type and low hydrogen type of welding electrode (ϕ 4 *mm*) and the iron-powder iron-oxide type welding electrode (ϕ 5 *mm*) under each proper welding condition selected experimentally for good underwater welds.

As shown in Fig. 6, it seems through such bead appearance and X-ray inspection results that the cases of figures (a), (b) and (d) using the proper welding electrode such as ilmenite, high titanium oxide and lime titania types respectively assures good underwater welds without weld defects such as blowhole, undercut and spatter as found especially in the case of figure (c) or (e). These results are well coincident with Hasui et al's report[4] in which the ilmenite and high

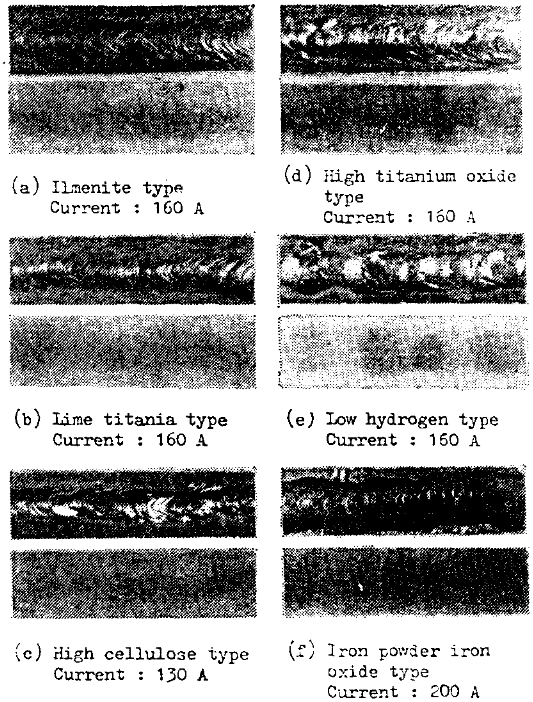

Fig. 6 Bead appearance and X-ray inspection result of underwater welds of SM41A according to each electrode (ϕ 4 *mm* for (a)-(e) and ϕ 5 *mm* for (f)) is used.

titanium oxide types of welding electrodes are suggested as the best ones for underwater welding.

3. Macro and micro structure inspection of underwater weld

Fig. 7 shows the typical macro structure of six-pass underwater weldment as welded with lime titania type electrode.

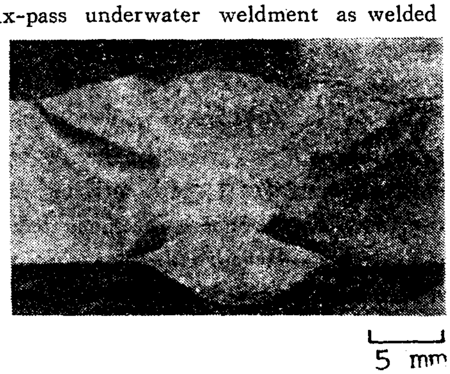

Fig. 7 Macro-structure of underwater welds of SM41A as lime titania type electrode is used.

As shown in the figure, any undercut was not found and enough weld penetration could be obtained. It can be observed that the structures of welded zone, HAZ and deposite metal are much affected by continued reheating at weld zone according to the order of the first pass to the sixth back pass.

Fig. 8 shows the micro-structures of base metal and underwater welded zone of SM41A as lime titania type welding electrode was used.

Fig. 8 (a) shows the micro-structure for area 'A' of base metal indicating ferrite and pearlite structure. The area 'B' in the HAZ at 0.5 *mm* distance from the bond reveals the micro-structure of martensite, bainite, pearlite and coarse structure which was developed at small amount

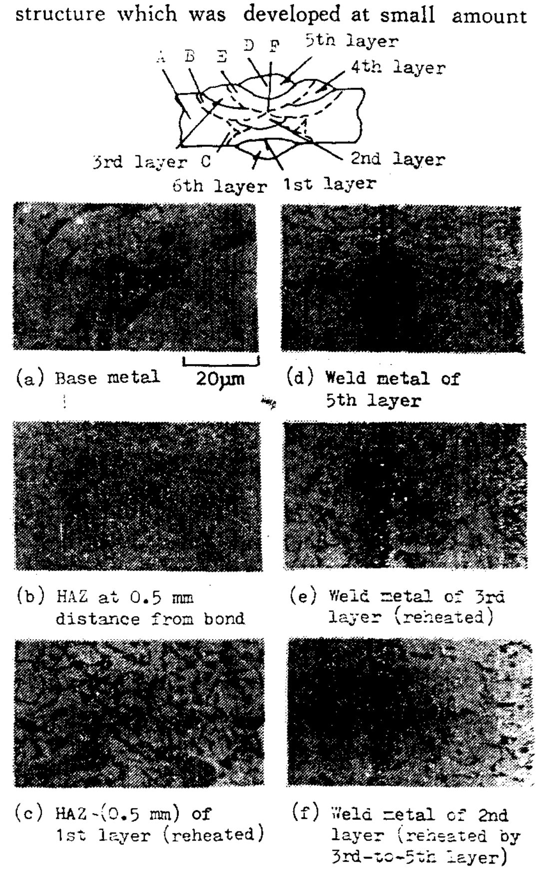

Fig. 8 Micro-structure of base metal and underwater welds of SM41A as lime titania type electrode is used.
Welding current: 200 A.

of intergranular ferrite, as shown in Fig. 8 (b).

The area 'C' shows the first pass HAZ which was reheated by the 2nd and 6th passes of welding, and so this area is composed of the structure of martensite. bainite, pearlite and ferrite around the boundaries of coarse ferrite, as shown in Fig. 8 (c).

The area 'D' of the deposite metal of the 5th layer reveals the structure of ferrite, at grain boundaries, developed normally from bainite and pearlite, as shown in Fig. 8 (d).

The area 'E' shows the reheated zone which was refined by reheating due to the 3rd to 5th layer pass of welding, and so it has the structure of fine ferrite and pearlite, as shown in Fig. 8 (e).

As shown in Fig. 8 (f), the area 'F' shows the deposite metal of the 2nd layer reheated by the 3rd to 5th layer pass welding, and this shows the finer ferrite and pearlite structure.

Especially no weld defect was found microscopically in any area.

4. Hardness distribution of underwater weld

Fig. 9 and Fig. 10 indicate the results of micro-Vickers hardness distribution for six-pass underwater welded zone as welded by using lime titania type welding electrode. The hardness distribution of longitudinal direction at the cross section of welded zone is shown in Fig. 9 and the one of vertical direction is in Fig. 10.

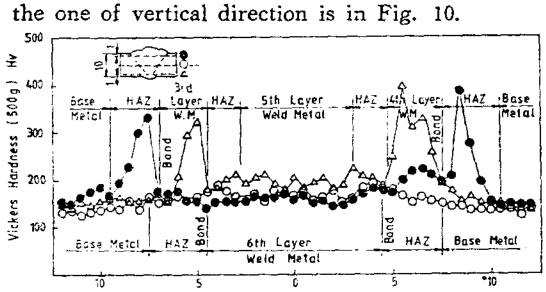

Fig. 9 Typical longitudinal hardness distribution of underwater weld (6th-pass welding) of SM41A in case of 200 A.

As shown in Fig. 9, it was found that the hardness peaks occur between the first HAZ near base metal side and the bond near the surface up or down.

It seems that this was because the hardness increased by the first or the second pass layer of welding was decreased due to reheating by the continued pass layer of welding (as shown in 'F' area of Fig. 8 and in the center area of deposit metal on the center line of Fig. 9), but the hardness increased by the third, fourth or sixth pass layer of welding was not so (as shown in 'B' and 'C' area and in the 1 *mm* depth from the periphery surface of Fig. 9).

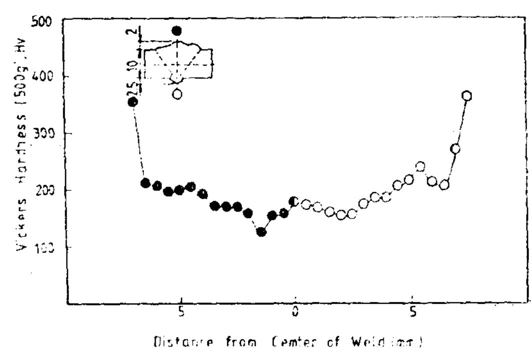

Fig. 10 Vertical hardness distribution of underwater weld (6th-pass welding) of SM41A in case of 200 A.

The similar results above were obtained in the case of using the other type of welding electrodes..

In Fig. 10, it is found that the hardness at the top or bottom surface in contact with cold water was the maximun of Hv 350. This is seemingly due to cooling effect of surrounding water during and post underwater welding.

Conclusion

The obtained results of a study on weldability in underwater welding of domestic structural steel plates (SM41A) of 10 *mm* thickness using various type of domestic welding electrodes are summarized as follows;

1) In the case that welding electrode carrying speed ratio is 1 and angle of welding electrode is 40°, 60° or 80°, the welding electrode

angle has no great influence on bead appearance in underwater welding.

2) In the case that welding electrode diameter is constant, the increase of welding current results in increasing the heat input to affect the bead appearance so much, but the good bead appearance for a good underwater weld welded under an experimentally-selected proper welding current for a certain diameter of welding electrode could be obtained.

3) The range of proper welding current and the diameter of electrode have a correlation in the case of using high titanium oxide type welding electrode in underwater welding, and the range of the proper welding current is relatively wide.

4) The four types of electrodes (ilmenite, lime titania, high titanium oxide and iron-powder iron-oxide types) except low hydrogen type and high cellulose type welding electrodes can assure a stable arc generation during underwater welding resulting in good underwater weld. Especially lime titania type, high titanium oxide type and ilmenite type welding electrodes can produce a good weldability for better underwater welds with no weld defects.

5) Macro- and micro-structures for underwater welded zone are shown as martensite and bainite structure and fine ferrite and pearlite structure, and no weld imperfection in good underwater weld is found microscopically.

6) In the 3rd, 4th and 6th pass underwater welding at the top and bottom surface layers of specimen plate, the hardness peaks exist between the first HAZ near base metal side and the neighbouring bond while the other zone has almost a uniform distribution of hardness.

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水中熔接에 관한 硏究(Ⅰ)

—水中熔接性을 中心하여—

南 起祐・鄭 鎬信・蓮井 淳・吳 世奎

最近 各 方面의 海洋開發에 대한 關心이 높아짐에 따라 海洋構造物의 加工 및 補修手段으로서 水中熔接技術의 開發硏究가 先進國 등에서 시작되고 있으나 國內에서는 아직 이 方面의 硏究를 찾아 볼 수 없다.

本 硏究에서는 두께 10 *mm*의 國産構造用鋼板(SM41A)에 대하여 自作한 重力式熔接裝置에 의하여 6種의 國産被覆아아크熔接棒을 써서 水中熔接을 실시하여 그 熔接性을 調査하였고, 各 系統의 熔接棒의 實用性을 檢討하였다. 重要硏究 結果는 다음과 같다.

1. 運棒比가 1일 때 熔接棒의 角度 40°, 60°, 80°인 경우 熔接棒角度가 비이드(bead) 外觀에 큰 影響을 미치지 않는다.
2. 熔接棒直徑이 一定할 때 熔接電流의 增加에 따라 入熱量이 增加하므로 비이드外觀에 큰 影響을 미치나 熔接棒直徑에 대한 各 適正電流에서의 비이드外觀은 良好하게 나타난다.
3. 水中熔接에서 高酸化티탄系 熔接棒을 使用하였을 경우, 適正熔接電流와 直徑 사이에는 相關性이 存在하며, 그 適正熔接電流의 範圍는 比較的 넓다.
4. 低水素系 및 高셀룰로우스系 熔接棒을 除外한 4種(일미나이트系, 라임티타니아系, 高酸化티탄系, 鐵粉酸化鐵系)의 경우, 熔接棒의 安定한 水中아아크가 維持되고, 良好한 水中熔接이 얻어졌다. 특히 라임티타니아系, 高酸化티탄系 및 일미나이트系는 熔接缺陷이 없는 良好한 水中熔接이 可能하다.
5. 水中熔接部에 대한 매크로(macro)組織과 微視顯微鏡組織은 마르텐사이트와 베이나이트組織을 나타내고, 그 外는 微細한 페라이트, 퍼얼라이트組織으로서 熔接缺陷이 없는 良好한 熔接部를 갖는다.
6. 試驗表面層인 3層, 4層 및 6層 熔接에서의 본드부근의 熱影響部에 各各 硬度의 피이크가 있으며, 그 외의 部分은 대체로 硬度가 均一함이 確認되었다.