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WELDABILITY OF S500MC STEEL IN UNDERWATER CONDITIONS

ABSTRACT

Wet welding with the use of covered electrodes is one of the methods of underwater welding. This method is the oldest, the most economic and the most versatile. The main difficulties during underwater wet welding are: high cooling rates of the joint, the presence of hydrogen in the arc area and formation of hard martensitic structure in the weld. These phenomena are often accompanied by porosity of welds and large number of spatters, which are more advanced with the increase of water depth. In this paper result of non-destructive tests, hardness tests and metallographic observations of S500MC steel joints performed underwater are presented. The weldability of 500MC steel at water environment was determined.

Keywords: *underwater wet welding, weldability, cold cracking, Tekken test*

INTRODUCTION

Underwater welding

Underwater methods of welding can be divided into wet welding and dry welding [1-4]. Additionally, a method of local cavity welding can be distinguished as an intermediate method of dry and wet welding (Fig. 1).

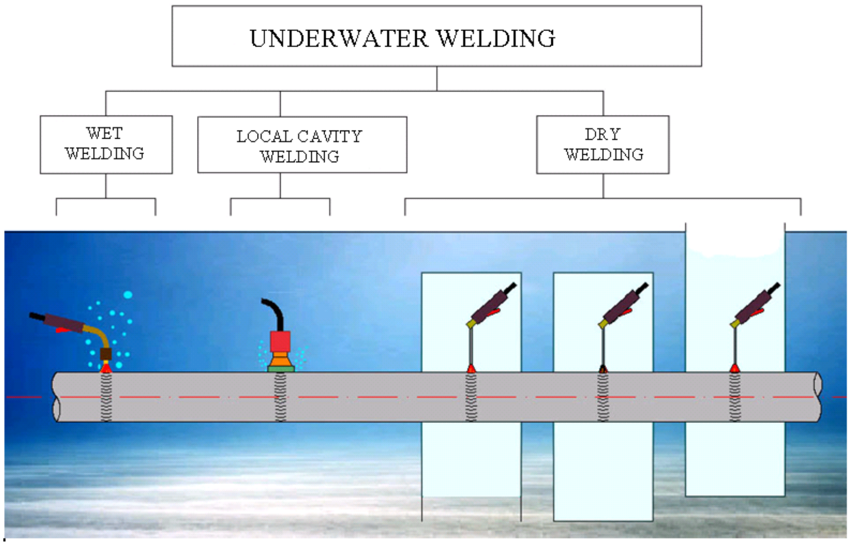

Fig. 1. Classification of underwater welding methods [2]

A characteristic feature of wet welding is the direct contact of the joint formation area with the water environment, which significantly affects the weldability of the material and often results in insufficient quality of the joint, characterised by the presence of various imperfections. Table 1 presents application possibilities of welding processes in underwater conditions.

Table 1. *Application possibilities of welding processes in water environment [1-12]*

Process	Dry welding	Wet welding	Local cavity welding
MMA (111)	yes	yes	possible
SAW (121)	yes	yes	no
MIG/MAG (131/135)	yes	possible	yes
FCAW (136/138)	yes	yes	yes
FCAW-S (114)	possible	yes	possible
Plasma arc welding	possible	no	possible
Laser welding	possible	no	yes
Friction welding	yes	yes	no
Explosive welding	no	yes	no
Stud welding	possible	yes	possible

Not all of processes shown in Table 1 found application in practice. The most popular underwater welding method is MMA method (welding with the use of covered electrodes) due to the fact that it is the most economic and the most versatile for repair and maintenance purposes. The serious disadvantage of this method is creation of a great number of imperfections within the weld, such as cracks caused by large hydrogen amount in the joint and high cooling rates. Such hydrogen cracks can form during underwater welding even in steels of low carbon equivalent C_e=0.3% [13].
The selection of suitable electrodes is extremely significant for the underwater welding. Electrodes should contain easily ionizing compounds, which provide an appropriate amount of gases keeping the arc burning stable. The best welding results can be obtain with the use of rutile electrodes which allow for easy arc initiation and stable glow. Other important factor is the quality and durability of the electrode cover. Austenitic steel cores are often used in underwater welding. Such electrodes provide greater ductility of a weld, but the weld is less resistant to hot cracking during crystallisation process [13,14].

Difficulties in wet welding

Performance of welded joints under water is a complex process, which result in inferior quality and mechanical properties of welds. In water environment cooling rates in wet welds are much higher than in those obtained in dry welding. This causes a loss of ductility of weld metal and HAZ. Underwater wet welds contain large number of pores. Porosity may be formed by molecular hydrogen, carbon monoxide or water vapor. Pores are present to some extent in all wet welds. The main factors affecting this phenomenon are water depth, electrode covering and arc stability. High cooling rates favor formation of hard martensitic structures at heat affected zone, especially for steels with a high carbon equivalent. It is also difficult to

avoid the presence of hydrogen in the arc area due to the water vapour surrounding the arc. Water dissociation process produces a large amount of atomic hydrogen entering easily the weld metal. The hydrogen content in the underwater MMA welds is almost three times higher in comparison to welds performed in the air and can reach 50÷80 ml per 100g of deposited metal [5,15].
The effect of hydrostatic pressure on the arc and metallurgical processes is an important parameter that affects the physical and chemical balance and kinetics of reactions in the welding pool. A very important factor influencing the weldability are the manual skills of diver - welder and the lack of visibility caused by water contamination as well as the work at great depths.

EXPERIMENTAL

The susceptibility to formation of cold cracks in S500MC steel welded joints was evaluated using the self-restraint Tekken test.
Research program included:
- preparation of the test stand for welding under water,
- preparation of the technological Tekken test,
- performing the anchor welds,
- deposition of the test welds under water,
- visual testing of the tested Tekken joints,
- penetrant testing of the tested Tekken joints,
- metallographic tests of cross sections,
- hardness tests.

Material

The S500MC steel plate of 15 mm in thickness was selected for the research. Steel plate was thermomechanicaly processed to obtain yield strength of 500 MPa at low carbon equivalent. S500MC steel is designed for marine and offshore structures. The chemical composition and mechanical properties of tested plate are presented in Tables 2 and 3.

Table 2. *Chemical composition and carbon equivalent of S500MC steel, wt %*

C	Si	Mn	P	S	Al	V	Ti	Nb	C_e
0.17	0.28	1.24	0.019	0.018	0.026	0.004	0.019	0.017	0.386

Table 3. *Mechanical properties of S500MC steel*

YP [MPa]	TS [MPa]	E [%]
525	619	20.5

The test joints were prepared in accordance to the standard guidelines [16]. MMA welding was performed at the test stand at small depth of water (0,5 m). Lincoln Electric OMNIA rutile electrodes (E420RC11) with the diameter of 4 mm were used. Chemical composition and mechanical properties of deposited metal are presented in Tables 4 and 5. Welds were made with DC + polarity.
Five Tekken joints were made, three under water (W1, W2, W3,) and two in the air

environment (P5, P6). Welding parameters are presented in Table 6.
Control test of hydrogen content in the deposited metal were performed with the use of glycerin method. Content of diffusible hydrogen in deposited metal obtained in the air environment was at the level of 35 ml/100g Fe, while for welding under water the hydrogen amount exceeds 50 ml/100 g Fe [14].

Table 4. *Chemical composition of deposited metal, wt %*

C	Mn	Si
0.07	0.5	0.5

Table 5. *Mechanical properties of deposited metal*

Requirements	YP [MPa]	TS [MPa]	E [%]	$KV_{ISO\ V}$ (J) at 0ºC
AWS A5.1	min. 331	min. 414	min. 17	not required
ISO 2560-A	min. 420	500-640	min. 20	min. 47
Typical values	520	550	26	60

Table 6. *Welding parameters and conditions of making tested joints*

Sample number	Environment	Welding parameters		Heat input [kJ/mm]
		U [V]	I [A]	
W1	water	30.0	228	1.43
W2	water	34.3	232	1.85
W3	water	32.5	244	1.68
P1	air	24.3	132	1.21
P2	air	22.0	168	1.39

The visual and penetrant testing [17-18] of the welded joints were performed after 72 h of the end of the welding. The occurrence of cracks in axis of all underwater welds (W1, W2, W3) was revealed (Fig. 2). Tekken joints welded in air environment (P1, P2) showed no cracks, but a number of surface pores has been observed (Fig. 3).

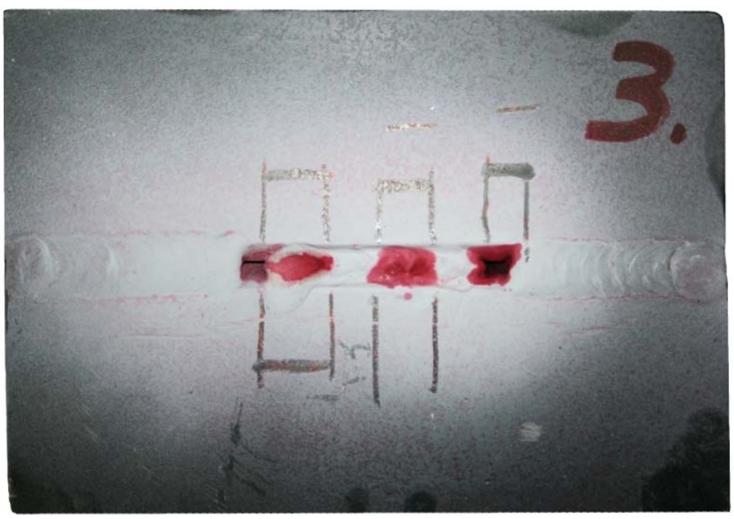

Fig. 2. Sample W3 - welded in the water environment after the penetration test. Cracks in weld axis

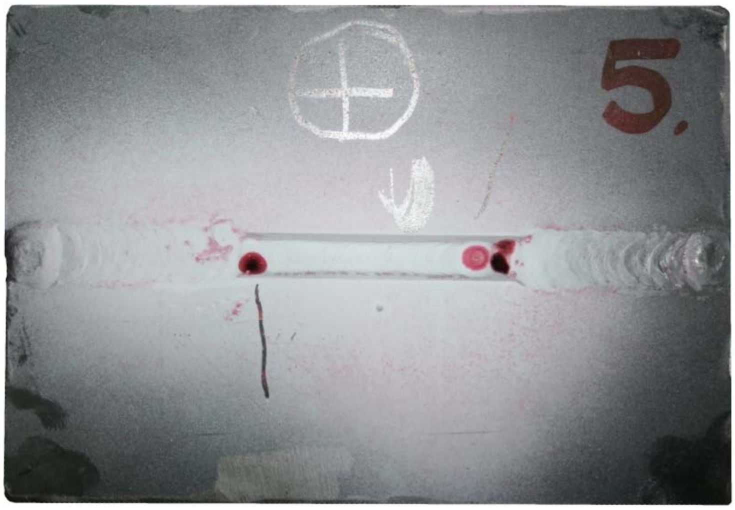

Fig. 3. Sample P1 - welded in the air environment after the penetration test. No cracks, single pores

Metallographic examinations

The macroscopic and microscopic metallographic examinations were performed in accordance with the standard guidelines [19]. Example cross-sections are presented in Fig. 4 and 5. Number of cracks and porosity were detected at all underwater welds. Cracks mainly started at the root of the weld and propagated across weld metal. Fewer cracks were detected at samples made in air environment. The one example of weld metal crack is presented in Fig 5.

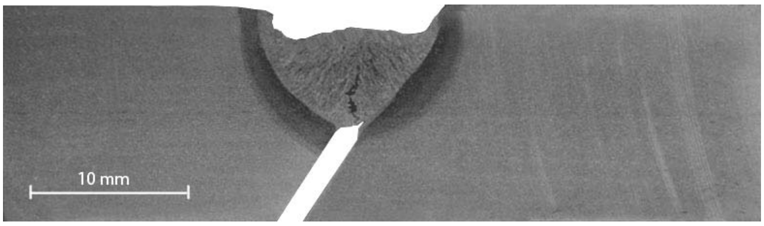

Fig. 4. Cross-section of the W3 test joint with the visible crack initiated in weld root

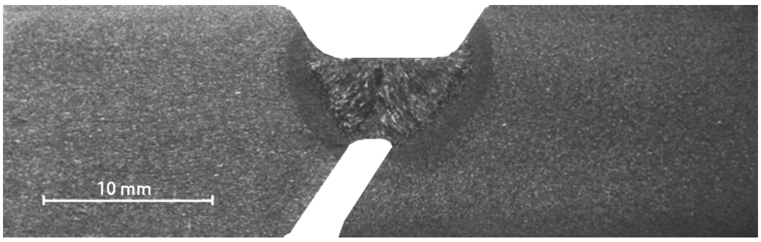

Fig. 5. Cross-section of the P2 test joint with the visible crack initiated in weld root

Typical micro structures of base material, weld metal and HAZ are presented in Fig. 6. The S500MC steel microstructure consist of fine ferrite grains with only traces of pearlite structure. The weld metal structure consists of ferrite grains at column arrangement with the outline of Widmanstätten structure. Acicular bainite and quasi-pearlite structure was revealed in heat affected zone. The grain growth of former austenite is clearly visible.

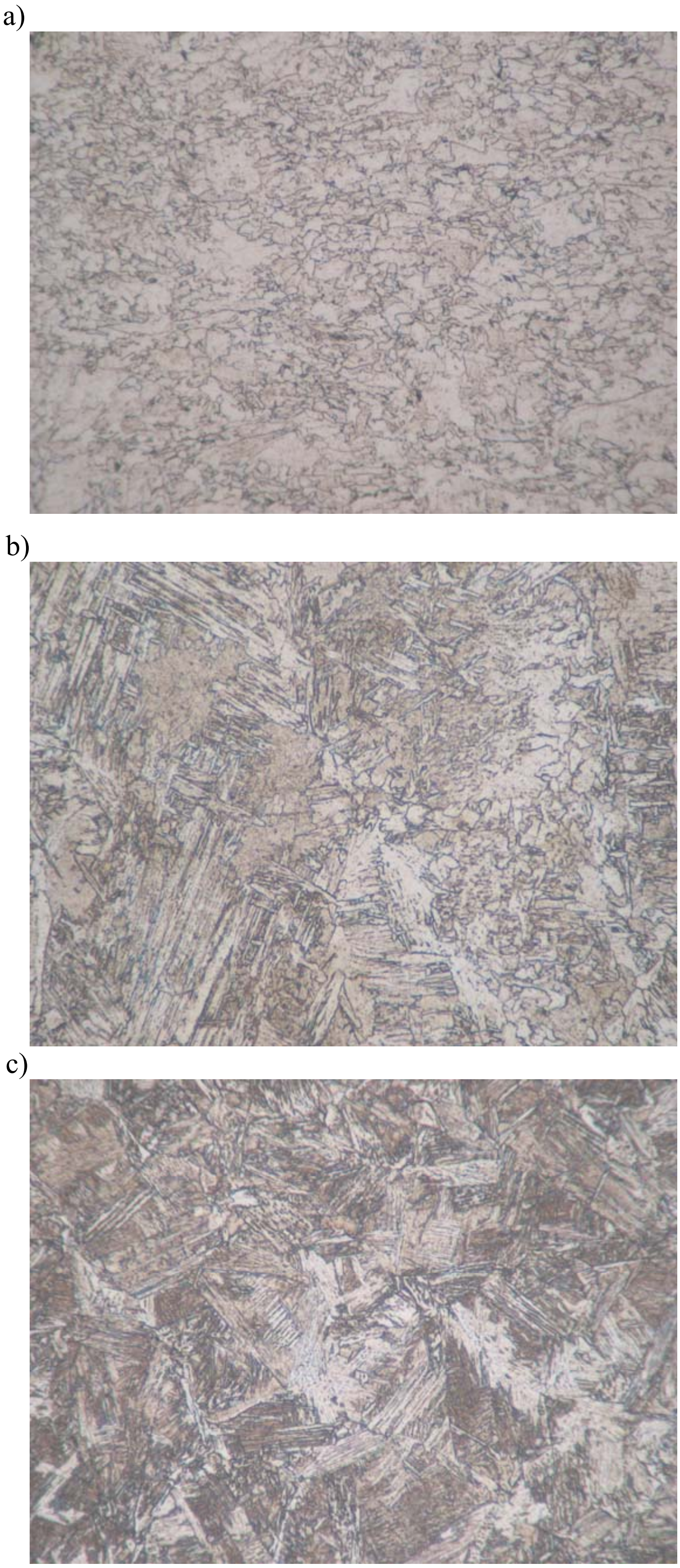

Fig. 6. Microstructure of S500MC steel joints welded underwater; a) base material, b) weld metal, c) overheated area in HAZ

Vickers hardness tests were performed according to the standard [20] using 98 N load (HV10). Examples of hardness distribution across test welds are presented in Fig. 7 and 8. The maximum hardness values were observed in heat affected zones of the joints. The maximum HAZ hardness do not exceed 250HV for joints made at air environment, while HAZ of underwater joints reach 320HV (but not exceed border value of 350HV10).

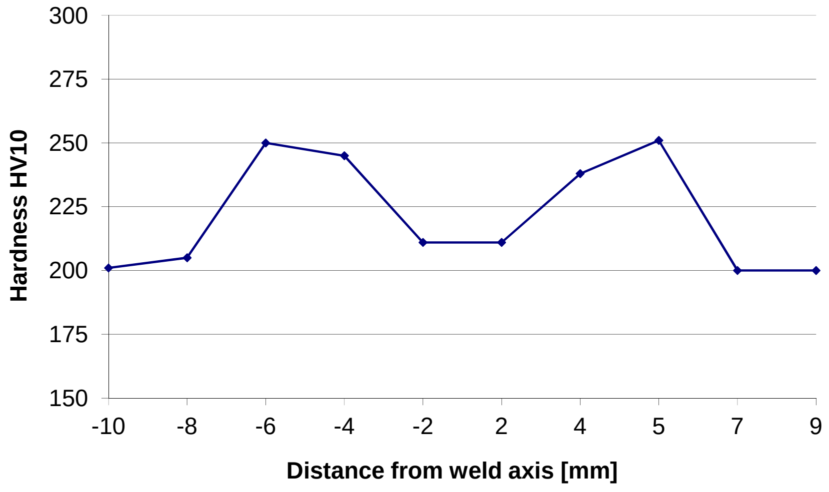

Fig. 7. Hardness distribution across P2 test joint. HV max = 250

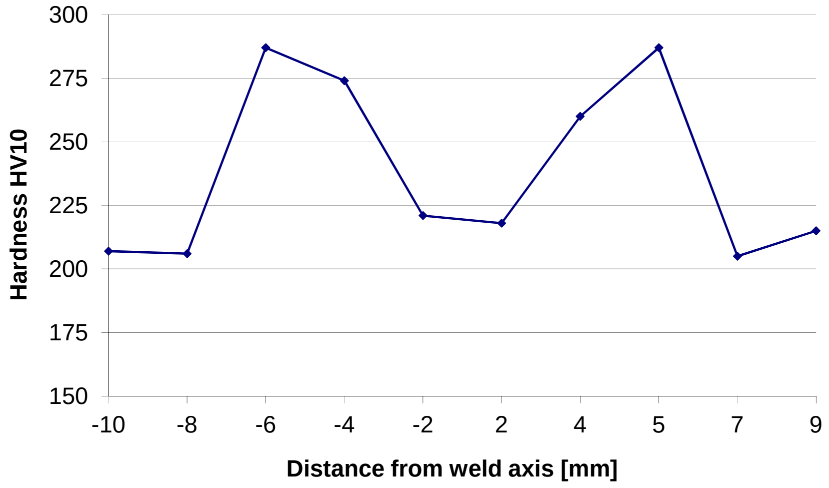

Fig. 8. Hardness distribution across W2 test joint. HV max = 287

SUMMARY

In all welded joints made under water the cracks in welds were formed. The cold cracks in the weld were observed while the HAZ proved to be free of cracks. This effect is in accordance to the information contained in the literature, concerning the weldability of steels after thermomechanical treatment. No cracks in joints welded in air atmosphere were observed during visual and penetrant tests, however metallographic examinations revealed cracks initiated in weld root.

The results of this study indicate, that investigation of the tendency to cold cracks formation should be continued in the following areas:
- wider range of values of welding current,
- other types of consumables (electrodes with oxide coating and austenitic type electrodes).

CONCLUSIONS

- S500MC steel is characterised by high susceptibility to cold cracking formation in welds in the conditions of wet underwater welding.
- The maximum hardness of HAZ did not exceed the value of 350HV.
- In all Tekken joints performed by applying wet welding method numerous cold cracks were observed, while in joints performed in air conditions the cracks were revealed in a one case only.

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