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EXPERIMENTAL STUDY OF ELECTRODE SELECTION EFFECTS ON MECHANICAL PROPERTIES OF UNDERWATER WET WELDED-JOINTS

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ABSTRACT

Proper selection of electrodes is a key element to improve quality of underwater wet welded joint. Three different types of electrode for shielded metal arc welding (SMAW) namely E6013, E6019, and E7018 were selected to perform underwater wet welding of the mild steel ASTM A36 plate. Tension and bending test were carried out according to ASTM [4] and AWS D1.1 [5] standards respectively. The yield and the tensile strength of welded joints fulfilled the acceptance criteria. The weld joint using E6013 and E6019 electrodes have satisfied the minimum criteria of elongation, but two specimens of the welded joint using E7018 electrode have failed. Welded joints using E6013 and E6019 have also satisfied the acceptance criteria of bending test, but have failed when using E7018 electrode. The reason why the welded joint using E7018 electrode has failed to fulfill the elongations and bend test might be due to large amount of fine pearlite phase in the HAZ that made the welded joint less ductile.

Keywords: underwater wet welding, electrode selection, mechanical properties.

INTRODUCTION

Underwater wet welding has an important role on repair method of submerged part of damaged marine and offshore structures in an emergency situation. Hydrogen embrittlement and porosity, however, become major problems due to presence of water surrounding welding arc [1]. One of significant factors in an underwater wet welding process is an appropriate selection of electrode [2]. Since an electrode has particular chemical compositions, using different electrodes may lead to different mechanical properties of weldment. Thus, a comparative study has been performed in this present study to determine a proper selection of electrode for underwater wet welding using the ASTM A36 steel.

EXPERIMENTAL PROCEDURE

Material preparation has firstly been carried out by mechanically cut the ASTM A36 steel into 6 samples with dimensions 350mm × 100mm each (Figure-1). Prior to welding, root gap controller and welding fixture have been attached (Figure-2). The three different electrodes, i.e., E6013, E6019, and E7018 which has 3.2 mm in diameters, have been used (Figure-3). The detail of chemical compositions is shown in Table-1. Preparation of underwater wet welding start by preparing artificial seawater with the salinity 35‰ based on standard ASTM D1141-98 Standard Practice for the Preparation of Substitute Ocean Water [3].

The underwater wet welding process has been carried out in the plastic tub where the samples were positioned on the bottom, then filled with sufficient of the artificial sea water (Figure-4). The electrical currents were adjusted to 120 A for the E6013 and E6019 electrodes. Meanwhile, the E7018 electrode had to use a higher ampere of 150A due to difficulties to maintain arc welding in lower ampere. Figure-5 shows the wet-welded joint samples using different types of electrode. The welding samples have been cut into smaller pieces to make specimens for mechanical tests, i.e. tension (Figure-6.a) and bending tests (Figure-6.b), and microscopic examination (Figure-7).


(a) (b)

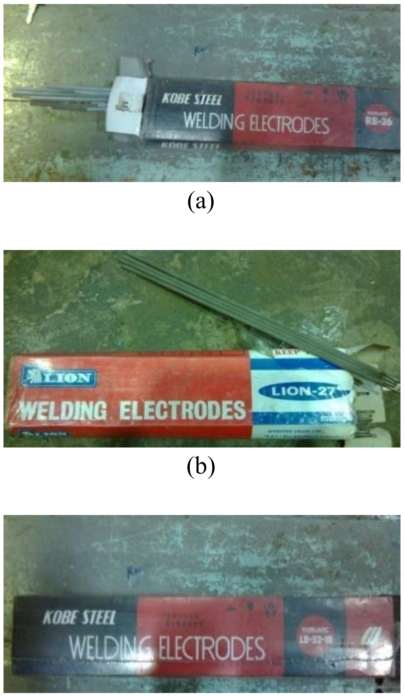
Figure-1. Sample preparation (a) Cutting out of the sample of ASTM A36 steel, (b) beveling.


(a) (b)

Figure-2. Joint fit-up (a) Root gap controller, (b) joint fixture.

Table-1. Chemical compositions of the selected electrodes.

AWS classification	Type of covering	**Chemical composition** (weight percent)									**Combined limit for**
		C	**Mn**	**Si**	**P**	**S**	**Ni**	**Cr**	**Mo**	**V**	**Mn+Ni+Cr+Mo+V**
E 6013	High titania pottasium	0.2	1.2	1	N.S.	N.S.	0.3	0.2	0.3	0.08	N.S.
E 6019	Iron oxide titania pottasium	0.2	1.2	1	N.S.	N.S.	0.3	0.2	0.3	0.08	N.S.
E 7018	Low-hydrogen pottasium, iron power	0.2	1.6	1	0	0	0.3	0.2	0.3	0.08	1.5



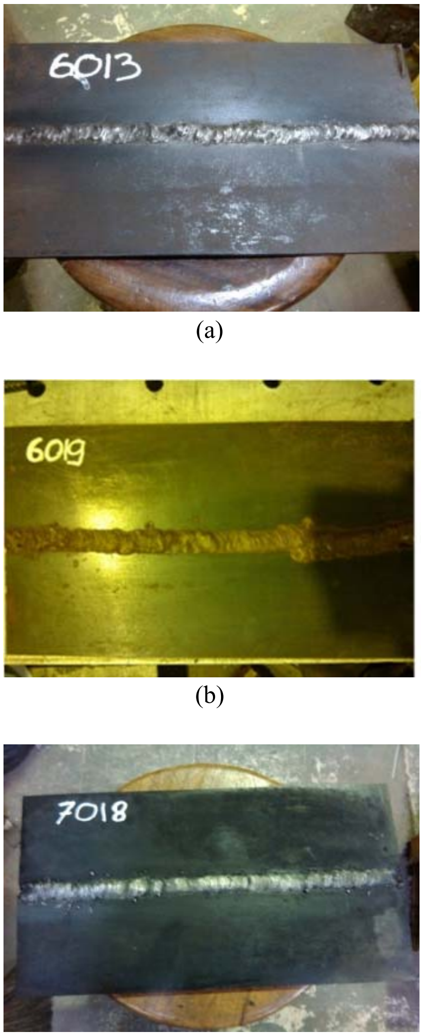
(a)

(b)

(c)

Figure-3. Electrode types: (a) E6013, (b) E6019, and (c) E7018.

Figure-4. Underwater wet welding process in the plastic tub containing the artificial sea water.



(a)

(b)

(c)

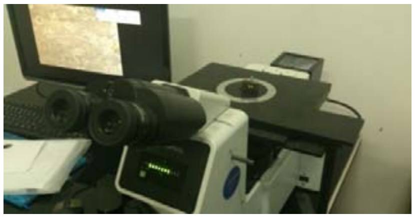
Figure-5. Results of underwater wet welding using (a) E6013, (b) E6019, and (c) E7018.

(a)

(b)

Figure-6. Mechanical tests: (a) tension test (b) bending test.

(a)



(b)

Figure-7. Microscopic examination: (a) specimen (b) stereo microscope.

RESULTS AND DISCUSSIONS

Results of Tension Test

The tensile requirements of the ASTM A36 steel shown in Table-2 have been a benchmark of the tension test results of wet-welded joints. Table-3, -4, and -5 present the tension test results for the wet-welded joints using E-6013, E-6019, and E-7018 electrodes respectively. Comparative analysis of tension tests were carried out using the charts in Figure-9, -10, and -11 with the main mechanical properties to be considered, i.e. yield strength, ultimate strength, and elongation respectively.

Table-2. Tensile requirement ASTM A36 [4].

Mechanical properties	Amount
Tensile strength, ksi [MPa]	58-80 [400-550]
Yield point, min, ksi [MPa]	36 [250]
Elongation in 2 in [50mm], min, %	23

Table-3. Results of tension test of underwater wet-welded joint using E-6013 electrode.

No.	Specimen code	Yield Stress (MPa)	Ultimate Stress (MPa)	Elongation (%)
1	T1.1	357.5	480	25
2	T1.2	355	486.5	26.6
3	T1.3	355	480	23.3
Mean values		**355.8**	**482.2**	**25.0**

Table-4. Results of tension test of underwater wet-welded joint using E-6019 electrode.

No.	Specimen code	Yield Stress (MPa)	Ultimate Stress (MPa)	Elongation (%)
1	T2.1	370	499	24.56
2	T2.2	365	492.5	31.03
3	T2.3	385	490	36.2
Mean values		**373.3**	**493.8**	**30.6**

Table-5. Results of tension test of underwater wet-welded joint using E-7018 electrode.

No.	Specimen code	Yield Stress (MPa)	Ultimate Stress (MPa)	Elongation (%)
1	T3.1	355	500	20.96
2	T3.2	357.5	497.5	23.43
3	T3.3	347.5	495	14.28
Mean values		**353.3**	**497.5**	**19.6**

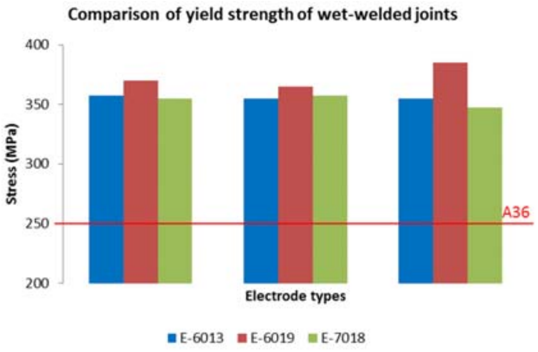


Figure-8. Comparison chart of yield strength of underwater wet-welded joints with different types of electrode.

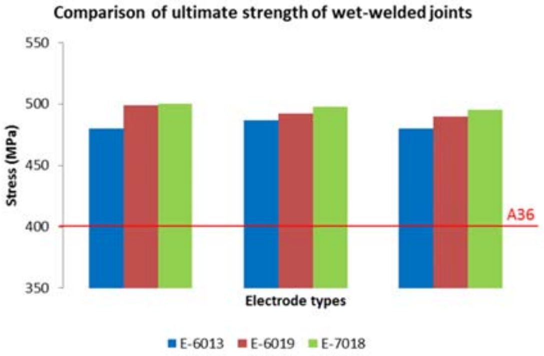


Figure-9. Comparison chart of ultimate strength of underwater wet-welded joints with different types of electrode.

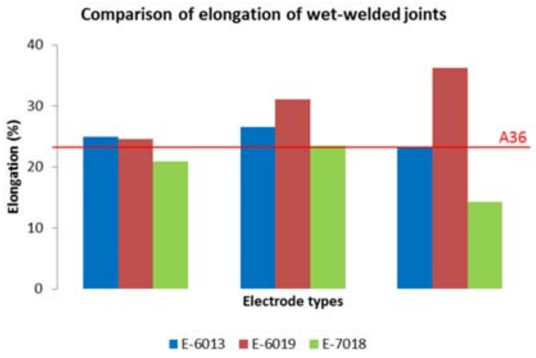


Figure-10. Comparison chart of elongation of underwater wet-welded joints with different types of electrode.

Figure-8 shows that the yield strength of all variant of wet-welded joints has exceeded the minimum requirement, i.e. of 250 MPa. The wet-welded joint using the E-6019 electrode has had the highest yield strength, ranging from 365 MPa to 385 MPa. While, the other wet-welded joints using the E-6013 and E-7018 electrodes, had almost the same yield strength, i.e., of 350 MPa.

The ultimate strength of the wet-welded joints has also fulfilled the minimum requirement of the A36 steel, i.e. of 400 MPa, as shown in Figure-9. The wet-welded joints using the E-6019 and E-7018 electrodes have had the ultimate strength ranging from 490 MPa to 500 MPa. Whereas, the wet-welded joint using the E-6013 electrode had lowest ultimate strength among the others, i.e. 480 MPa.

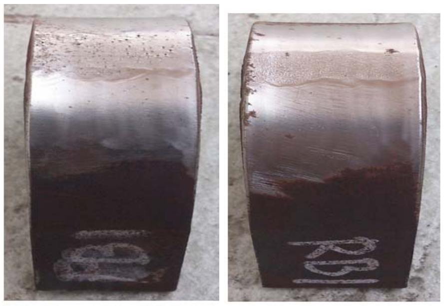
All variant of the wet-welded joints have almost satisfied the minimum requirement of elongation, i.e. 23% with exception of two specimens of the wet-welded joints using the E-7018 electrode that lower than the minimum requirement, as illustrated in Figure-10. The wet-welded joint using E-6019 electrode had highest elongation, ranging from 24% to 36%.

Results of Bending Test

Bending test may qualitatively represent ductility of a weld joint. The acceptance criteria of AWS D1.1 Structural Welding Code - Steel sub chapter 4.8.3.3 [5] shown in Table-3 were used to evaluate ductility of the wet-welded joints qualitatively.

Table-6. Acceptance criteria of bending test [5].

For acceptance, the surface shall contain no discontinuities exceeding the following dimensions:
1/8 in. (3 mm) measured in any direction on the surface
3/8 in. (10 mm) - the sum of the greatest dimensions of all discontinuities exceeding 1/32 in. (1 mm), but less than or equal to 1/8 in. (3 mm)
1/4 in. (6 mm) - the maximum corner crack, except when that corner crack resulted from visible slag inclusion or other type fusion type of discontinuities, than the 1/8 in (3 mm) shall apply
Specimens with corner cracks exceeding 1/4 in. (6mm) with no evidence of slag inclusion or other type fusion type of discontinuities shall be disregarded, and a replacement test specimen from the original weldment shall be tested.



(a) (b)

Figure-11. Surface condition of specimen of wet-welded joint using E-6013 electrode after: (a) face bend test (b) root bend test.

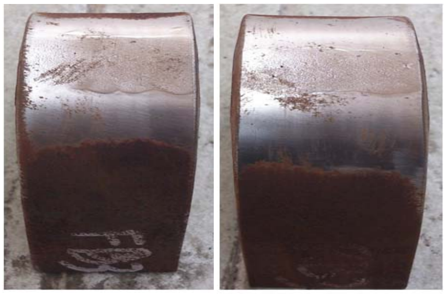

(a) (b)

Figure-12. Surface condition of specimen of wet-welded joint using E-6019 electrode after: (a) face bend test (b) root bend test.

Figure-13. Surface condition of specimen of wet-welded joint using E-7018 electrode after face bend test.

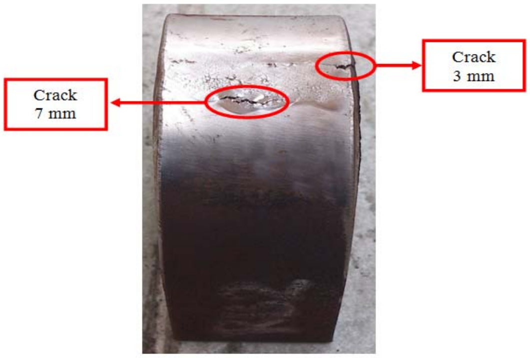


Figure-14. Surface condition of specimen of wet-welded joint using E-7018 electrode after root bend test.

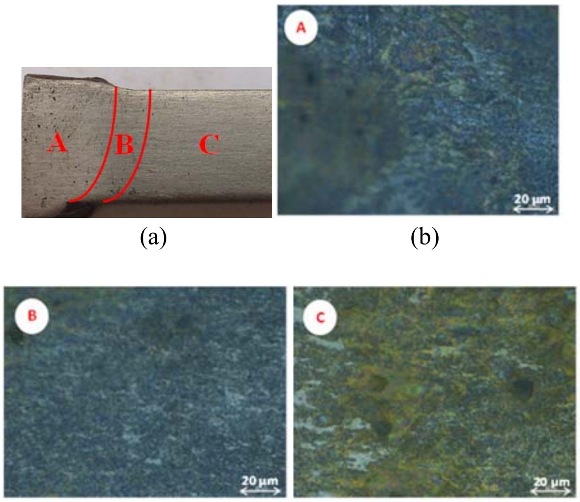
Figure-11 demonstrates the specimen surface condition of the wet-welded joint using E-6013 electrode after applying face and root bend tests. No discontinuities have found in the surfaces that had the dimension greater than stated in the acceptance criteria. The type of discontinuity found on the specimen surface was porosity that the dimensions can be disregarded. From these evidences, the bend test results of the wet-welded joint using E-6013 electrode have fulfilled the acceptance criteria.

Figure-12 displays the surface condition of specimen of wet-welded joint using E-6019 electrode after applying face bend and root bend tests. Only small porosity found on the surfaces that can be omitted. Thus, the wet-welded joint using E-6019 has fulfilled the requirement of bend test.

On the other hands, the wet-welded joint using E-7018 electrode has failed to satisfy the acceptance criteria of bend test. The cracks have found on the surface of specimens which have dimension greater than specified in the acceptance criteria. Figure-13 shows surface condition of specimen that indicates an elongated crack along the fusion line after applying face bend test. After root bend tests, two major cracks found on the specimen surface as illustrated in Figure-14, i.e. an elongated crack along fusion line located in the center with length of 7 mm and 3 mm of edge crack.

Results of Microscopic Examination

Figure 15, - 16 and -17 show microscopic examinations in the wet-welded joint using E-6013, E6019, and E7018 electrodes respectively. Three different regions, i.e. the weld metal, denoted by - A, the heat affected zone (HAZ), denoted by – B, and the unaffected base metal, denoted by - C, have been observed. It has been found that ferrite which has brighter color and pearlite which has darker one, were the main phases in those three regions. It seems that no martensitic phase was found, thus it was in accordance with the material to be used, i.e. low carbon steel.

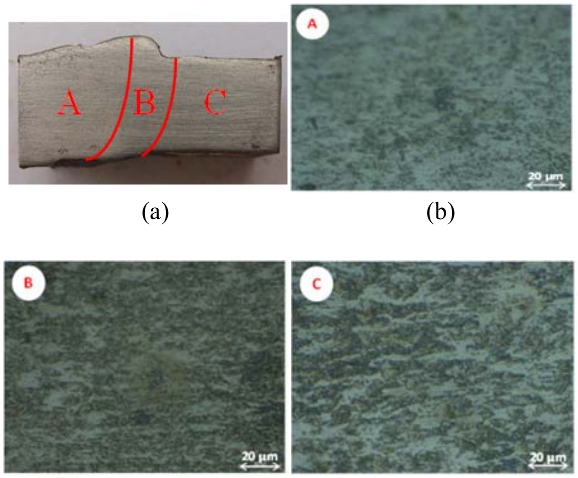


(a) (b)
(c) (d)

Figure-15. (a) Specimen for micro-photograph of welded joint using E6013 electrode (b) micro-structure of weld metal (c) micro-structure of HAZ (d) micro-structure of base metal.

Furthermore, in the weld metal region (Figure-15.b) it seems that ferrite phase had fine size and was homogenously distributed among pearlite phase. However, in the HAZ region (Figure-15.c) and the base metal region (Figure-15.d), ferrite phase has rather coarse size and were agglomerated.

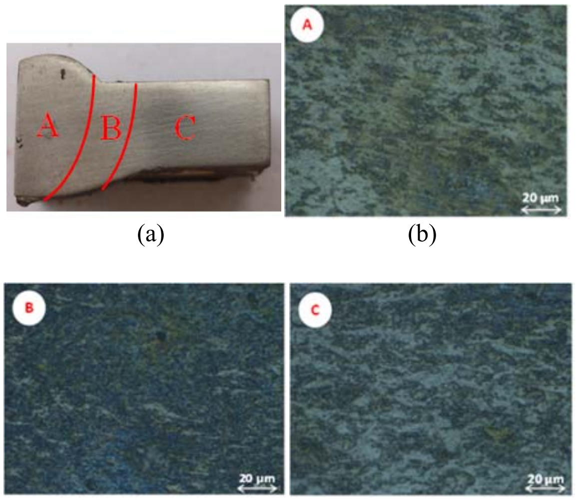
The microstructures of wet-welded joint using E-6019 electrode, as shown in Figure-16, seem that grain size of ferrite and pearlite phases were finer. Perhaps, it might be the reason why yield strength of welded joint was somewhat higher than other wet-welded joints.



(a) (b)

(c) (d)

Figure-16. (a) Specimen for micro-photograph of welded joint using E6019 electrode (b) micro-structure of weld metal (c) micro-structure of HAZ (d) micro-structure of base metal.



(a) (b)

(c) (d)

Figure-17. (a) Specimen for micro-photograph of welded joint using E7018 electrode (b) micro-structure of weld metal (c) micro-structure of HAZ (d) micro-structure of base metal.

Figure-17 shows the microstructure of wet-welded joint using E-7018 electrode. Ferrite was likely more dominant in the weld metal region (Figure-17.a). Meanwhile, in the HAZ region (Figure-17.b), the amount of fine pearlite was the highest among other regions. Moreover, the amount of fine pearlite was also highest among other welded joints. With high amount of fine pearlite might have effect in increasing strength, but in the other hands, it might reduce ductility in some degree. Probably, this is the reason why welded joint using E-7018 has lower ductility as well as failed to fulfilled requirement for bending test.

CONCLUSIONS

From tension test, all welded joints resulted from underwater wet welding using three different types of electrode had yield and ultimate strengths which were satisfied the requirements. Elongations of all welded joints have also fulfilled the requirements, except for two specimens using E-7018 electrode.

Results of bending test shows that in general, underwater wet welding have also been in agreement with the requirements. However, welded joint using E7018 electrode was failed to fulfill the bending test requirement because the elongated cracks were found with length exceeding the maximum limits.

From microstructure observation, it seems that large amount of fine pearlite in the HAZ is likely responsible causing wet-weld joint using E7018 electrode less ductile that may result in reducing elongation and increasing crack susceptible.

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