FLUX CORED ARC WELDING PROCEDURES FOR HIGH WELD METAL TOUGHNESS FOR OFFSHORE STRUCTURES

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Weld metals deposited by self-shielded FCAW in the heat input range of 2 to 4 kJ/mm, in 50 to 63 mm thick joints, were subjected to Charpy V notch and CTOD tests.

It was observed in both tests that the highest values of toughness occurred for joints welded with low heat input in the root and first three passes and with high heat input in the filler passes. In double V joints, the backgouging of the root pass was fundamental to achieve the minimum required values for the mentioned properties.

A minimum CTOD value of 0.5 mm at + 10 C and Charpy energy higher than 60 joules at - 30 C were obtained in some joints.

INTRODUCTION

The self-shielded flux cored arc welding (FCAW) process has two characteristics which make its use advantageous in the construction of offshore structures such as production platforms. The first is that, being a semi-automatic process, its productivity is high compared to shielded metal arc welding. The second is related to its self-shielding capability which makes it suitable for open-air applications.

The use of self-shielded FCAW is possible today in the offshore industry owing to the developments made in some of the consumables, such as Ni additions, in regard to the mechanical properties of their welds, especially the fracture toughness. The history of FCAW developments and general applications of the processes are described by Keeler (1,2) and Boekholt (3).

However, in spite of these improvements it may be difficult, using normal welding procedures, to obtain good weld metal fracture

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toughness particularly with thicknesses above 50 mm. In these cases however some precautions are necessary. Such precautions are related to the compositional and microstructural factors which control the weld toughness. In the case of self-shielded FCAW the most important aspects of these factors, according to Dorling and Rogerson (4), are the Al, Nb and N_2 effects; the type of microstructure in the columnar region, the proportion of grain refined regions in the weld and the tempering and spheroidisation of precipitates which occur mainly during a post weld heat treatment (PWHT), such as the stress relieving treatment.

The aluminum in the consumables for self-shielded FCAW is used in high quantities (>0.5%) to prevent nitrogen porosity in the weld deposits through the formation of aluminum nitride. According to Kaplan and Hill (5) the precipitation of Al N has an adverse effect on weld toughness. The aluminum, a strong deoxidiser, also affects the toughness through its influence on the cleanliness of the deposit and consequently on the formation of a predominantly fragile "bainitic" structure(4).

Niobium, together with some extra amount of carbon, comes from the base metal as the result of dilution. Both elements are deleterious to toughness and must be kept as low as possible. Hence, it is important to take measures (such as using low current, wide root gap etc.) to minimize the dilution especially in the root pass. Also, the backgouging has an important role in this situation.

To counteract the effect of the as-deposited "bainitic" structure it is important to use procedures which increase the proportion of the tougher grain refined regions in the weld metal. Such procedures could be the use of weave technique and/or high heat input welds.

The PWHT is said to be always beneficial to the self-shielded FCAW (2,4). Its effect on toughness is due to the spheroidisation of carbides and tempering of martensitic microphases (4). However it has an economical drawback and hence it is interesting to look for welding procedures for which the PWHT is not needed.

The purpose of this work was to verify the effectiveness of the measures described above in order to achieve adequate toughness at 10 C in thick welds (>50 mm) for offshore structures. In the present case the DnV (6) requirements of 0.35 mm or 0.25 mm for minimum CTOD value in the as-welded (AW) or postwelded heat treated conditions respectively and 35 J for the average minimum charpy energy at -30 C were adopted.

EXPERIMENTAL

Materials and Welding Procedures

Steel. The steel plates used were BS 4360 grade 50D with thickness of 50 or 63 mm.

Consumables. The two self-shielded flux cored wires used are classified according to AWS A5.29-80 as E 71T8-Ni 1 and E 61T8-k6. The wire diameters were 2 mm.

Welding Procedures. The panels for welding were 500 mm wide and 1200 mm long. The weld metals were deposited in the vertical-up position. The type of joint geometry, welding conditions and technique or whether the weld root was backgouged or not are indicated in Table 1. Heavy restraining bars, welded across the panels prevented "butterflying". When used, the PWHT was conducted in a furnace at 600 C for 20 min/10 mm of thickness of the plate.

Specimen Preparation and Test Methods

CTOD. Square section (T vs T, where T is the plate thickness) specimens of the subsidiary geometry were used to measure the weld metal toughness by the CTOD test. The specimens were notched to a depth of 0.3 T, through thickness of the weld and parallel to the welding direction. The as-welded specimens were subjected to a post-weld hydrogen soak (150 C/48 h) to eliminate the effects of diffusible hydrogen on the CTOD tests (2). The fatigue pre-cracking of these welds was done using the minimum to maximum load ratio of 0.5, as suggested by Bramat and Doucet (7). The CTOD tests were conducted in three-point bending in accordance with BS 5762 (8). The test temperature was +10 C, the minimum design temperature for Brazilian waters. The CTOD was obtained from clip gauge displacements records using the theoretical formula of Ref. 8. The CTOD was calculated at the initiation of an instability, when it occurred, or at the start of the maximum load plateau when considerable ductility occurred.

Charpy. Standard 10x10x55 mm Charpy V test specimens were taken at 2 mm below the plate surface and at the weld root. The test temperatures were 0, -10, -20, -30 and -40 C.

Metallographic Measurements The relative proportions of the columnar (CR) and fine-grained (FGR) regions were determined by measuring, under optical microscope, the widths of each region near the fatigue pre-crack. For these measurements the specimen of the lowest CTOD value of each weld metal tested was used.

RESULTS

Chemical Composition

The weld metal compositions are given in table 2

Tensile Tests

The tensile properties for the weld metals obtained with the various welding procedures (Table 1) are given in Table 3 where each value represents the average of two all-weld specimens.

CTOD

The CTOD data for the welds in the as-welded and PWHT conditions are given in Table 4.

Charpy Tests

The results of Charpy-V tests for the welds in the as-welded condition are given in Table 5.

Metallography

The amounts of fine grained regions obtained for each welding procedure are shown in the last column of Table 4.

DISCUSSION

The data in Tables 4 and 5 show that better results were obtained for the E 61T8-k6 wire (welds n. 41, 42, 43, 44, 65, 77, 79, 97 , 99 and 100).Also, it can be seen that only the welds 97, 100 and 101 fulfilled both the CTOD and Charpy requirements (The weld 99 failed in the Charpy test at the root region).

The use of the weave technique and high heat input when depositing the filling passes - and consequently increasing the amount of fine grained regions in the weld - brings about good results in the Charpy test of sub-surface regions, as can be seen comparing the welds 41 (E 61T8-k6, weave bead, 56% FGR) and 43 (E 61T8-k6, stringer bead, 43% FGR) or 40 (E 71T8-Ni 1, weave bead, 55% FGR) and 38 (E 71T8-Ni 1, stringer bead, 46% FGR). Although the minimum CTOD values are improved using the above techniques they are not high enough to meet the specified requirements in the as-welded condition.

These results seem to be related to the fact that the toughness of the fine grained regions is better than that of the columnar region (4). Hence, better subsurface Charpy V-notch test results are obtained with techniques, such as high heat input and weave bead deposition, which give high amounts of fine grained regions in the weld metal.

The use of backgouging (double V welds) or single V grooves (without backgouging) together with low welding currents in the first 3 layers of each side of the root (welds n. 97, 99, 100 and 101) gave better CTOD values than those welded with high currents in the root passes and/or not backgouged. An exception is the weld n. 98 (E 71T8-Ni 1) wich, in spite of the precautions taken, did not meet the specifications. The beneficial effect of backgouging has been related to the removal of the embrittled material of the root pass of the weld. This local brittleness is due more probably to the precipitation of Al N and Nb C , in the latter case from dilution, than to strain aging effects as, usually, less than 5 ppm of nitrogen is in solution in self-shielded FCAW deposits (4). Thus, it is important to keep the dilution low during the welding of the subsequent passes near the root of weld when the deposition of more than one pass per layer is not possible and weaving is still difficult. In practice, this can be done using low welding current and increasing the electrode stickout.

Finally, it can be concluded from Table 4 that the PWHT was beneficial for the fracture toughness in almost all cases. Again the exceptions were the welds deposited from E 71T8-Ni 1 wires.

CONCLUSIONS

The E 61T8-k6 wire gave higher Charpy and CTOD results than the E 71T8-Ni 1 one.

The subsurface Charpy impact energy is very sensitive to the microstructure regeneration. Therefore the use of arc energy between 3.0 and 4.0 kJ/mm is important in the filling passes together with the weave technique.

Although the fracture toughness of these weldments was improved using the comments above, this property is more sensitive to root pass embrittlement. So, the backgouging of the root pass is important in double V joints or, preferentially, single V joints should be used.

The PWHT is always beneficial and should be used in thick joints when the economical conditions permit.

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TABLE 1 - Summary of Welding Procedures

WELD CODE	WIRE AWS CLASS.	GROOVE	No. OF PASSES	CURRENT, VOLTAGE AND WELDING SPEED (A-V-mm/s)		MEAN HEAT INPUT
				ROOT	REMAIN	(kJ/mm)
38 (a)	71T8-Nil	X,60	41	170-19-0.98	170-19-1.57	2.1
39 (a)	71T8-Nil	X,60	29	180-19-1.07	170-19-1.10	3.0
40 (b)	71T8-Nil	X,60	20	160-19-0.93	170-19-0.78	4.1
41 (b)	61T8-k6	X,60	19	170-19-1.12	170-19-0.90	3.6
42 (b)	61T8-k6	X,60	25	170-19-1.18	170-19-1.08	3.0
43 (a)	61T8-k6	X,60	38	170-19-1.03	170-19-1.53	2.1
44 (a)	61T8-k6	V,60	41	170-19-0.73	170-19-1.08	3.0
45 (a)	71T8-Nil	V,60	44	170-18-0.55	170-19-1.03	3.1
65 (b)	61T8-k6	X,60	23	150-17-0.65	180-19-0.95	3.6
77 (b,c)	61T8-k6	X,60	32	165-18-0.68	180-19-1.02	3.3
79 (b)	61T8-k6	X,60	26	170-18-0.68	180-18-1.00	3.2
97 (b,c,d)	61T8-k6	X,45	28	140-19-0.88	180-21-1.07	2.9
98 (b,c,d)	71T8-Nil	X,45	28	140-19-0.68	180-20-0.95	2.9
99 (b,c)	61T8-k6	X,45	20	190-18-1.02	175-21-1.17	3.3
100 (b,d)	61T8-k6	V,45	20	140-19-0.50	170-20-0.77	4.0
101 (b,d)	71T8-Nil	V,45	20	140-19-0.55	170-20-0.93	3.4

Note. (a) - stringer bead
(b) - weave bead
(c) - backgouged
(d) - first 3 layers of each side deposited with 1.9kJ/mm (140A-20V-1.5 mm/s)

TABLE 2 - Chemical Compositions of Weld Metal Deposits (wt %)

WELD CODE	C	Mn	Si	Ni	Mo	V	Nb	Ti	P	S	Al	N
38	0.06	1.24	0.39	0.91	0.040	0.008	0.0550	0.0014	0.011	0.002	0.92	0.055
39	0.07	1.22	0.38	0.93	0.030	0.002	-	0.0022	0.014	0.002	0.86	0.035
40	0.06	1.25	0.38	0.93	0.040	0.007	0.0020	0.0028	0.010	0.002	0.74	0.020
41	0.06	0.83	0.10	0.54	0.040	0.008	0.0035	0.0070	0.011	0.002	0.91	0.018
42	0.06	0.65	0.08	0.50	-	-	-	-	0.009	0.002	1.05	0.037
43	0.06	0.72	0.08	0.50	0.022	0.022	-	0.005	0.009	0.002	1.07	0.030
44	0.06	0.77	0.10	0.61	0.045	0.006	-	0.0022	0.007	0.002	0.95	0.037
45	0.06	1.24	0.37	0.94	0.040	0.006	-	0.0026	0.009	0.002	0.92	0.026
65	0.07	0.76	0.12	0.56	0.040	0.002	-	0.0018	0.009	0.003	0.86	-
77	0.06	0.75	0.08	0.56	0.024	0.002	0.0020	0.0060	0.012	0.003	0.65	-
79	0.08	0.79	0.08	0.55	0.024	0.002	0.0020	0.0060	0.027	0.004	0.68	-
97	0.08	0.61	0.10	0.57	0.020	0.005	0.0020	0.0060	0.010	0.003	0.92	-
98	0.07	1.03	0.25	1.04	0.013	0.005	0.0020	0.0070	0.008	0.004	0.84	-
99	0.08	0.64	0.11	0.56	0.020	0.010	0.0080	0.0060	0.011	0.003	0.88	-
100	0.07	0.81	0.09	0.64	0.006	0.007	0.0040	0.0060	0.016	0.003	0.91	-
101	0.05	1.09	0.23	1.02	0.010	0.010	0.0040	0.0070	0.008	0.002	0.83	-

TABLE 3 - Mechanical Porperties of Weld Metal Deposits

WELD CODE	YIELD STRESS (MPa)		TENSILE STRENGTH (MPa)		ELONGATION 25mm		REDUCTION OF AREA (%)	
	AW	PWHT	AW	PWHT	AW	PWHT	AW	PWHT
38	480.2	421.4	578.2	545.9	30.0	31.0	73.0	73.0
39	439.0	411.6	550.8	530.2	31.0	34.0	72.0	73.0
40	443.0	410.6	551.7	532.1	30.0	32.0	76.0	78.0
41	402.8	331.2	478.2	444.9	35.0	36.0	73.0	78.0
42	383.2	332.2	487.1	453.7	35.0	35.0	75.0	78.0
43	373.4	335.2	487.1	446.9	-	33.0	70.0	74.0
44	373.4	333.2	470.4	438.1	31.0	30.0	74.0	75.0
45	469.4	401.8	564.5	526.3	31.0	32.0	76.0	77.0
65	380.2	-	476.3	-	36.0	-	76.0	-
77	439.0	400.8	529.2	509.6	33.1	39.5	-	-
79	443.9	410.6	537.0	511.6	35.2	35.3	-	-
97	386.7	328.1	487.5	441.9	35	31	74	77
98	42829	390.0	545.9	500.4	28	31	74	73
99	390.0	-	490.7	-	26	-	68	-
100	930.0	331.5	480.9	448.4	30	33	76	78
101	442.4	406.1	544.9	510.1	28	32	70	75

TABLE 4 - CTOD Values of Weld Metals at 10 C

WELD CODE	AS WELDED CTOD (mm)			MEAN	AFTER PWHT CTOD (mm)			MEAN	FGR IN THE FATIGUE CRACK %
38	0.08	0.11	0.12	0.10	0.57	0.90	1.16	0.88	46
39	0.09	0.13	-	0.11	0.21	0.52	0.61	0.45	45
40	0.09	0.15	0.28	0.17	0.16	0.16	0.31	0.21	55
41	0.18	0.18	0.44	0.27	0.49	0.49	0.59	0.52	56
42	0.17	0.20	0.21	0.19	0.44	0.93	0.96	0.78	59
43	0.09	0.09	0.12	0.10	0.41	1.43	> 1.70	1.18	43
44	0.31	0.40	0.51	0.41	1.45	>1.61	> 1.64	>1.57	49
45	0.14	0.15	0.16	0.15	0.21	0.21	0.25	0.22	46
65	0.14	0.16	0.23	0.18	0.28	0.39	0.54	0.40	64
77	0.18	0.60	0.62	0.47	0.38	0.64	0.96	0.66	54
79	0.06	0.15	0.18	0.13	0.26	0.90	1.44	0.87	56
97	0.43	1.69	1.69	1.27	1.20	>1.62	> 1.65	>1.49	44
98	0.16	0.17	0.23	0.19	0.59	0.65	1.54	0.93	55
99	0.61	0.70	0.83	0.71	-	-	-	-	51
100	0.47	1.18	1.68	1.11	1.27	>1.63	> 1.68	>1.53	49
101	0.40	0.56	0.94	0.63	0.23	0.93	1.21	0.79	44

TABLE 5 - Charpy V-Notch Energy of Weld Metals, in Joules *

WELD CODE	TEST TEMPERATURE (C)				
	0	-10	-20	-30	-40
38S**	77	62	35	16	-
38R***	39	28	20	11	-
39S	98	75	63	46	-
39R	21	49	28	11	-
40S	118	112	63	68	-
40R	39	21	23	13	-
41S	171	166	144	141	-
41R	76	44	43	11	-
42S	116	114	77	56	-
42R	107	75	37	44	-
43S	61	54	31	19	-
43R	50	49	34	21	-
44S	64	46	27	21	-
44R	53	18	19	22	-
45S	50	39	40	21	-
45R	64	51	23	13	-
65S	-	-	-	133	-
65R	-	-	-	24	-
77S	188	-	154	133	113
77R	51	-	19	12	11
79S	206	-	187	164	155
79R	64	-	19	17	15
97S	-	-	154.8	82.3	-
97R	-	-	111.7	61.7	-
98S	-	-	105.8	100.0	-
98R	-	-	17.6	15.7	-
99S	-	-	150.9	126.4	-
99R	-	-	39.2	18.6	-
100S	-	-	111.7	79.4	-
100R	-	-	124.5	57.8	-
101S	-	-	118.6	86.2	-
101R	-	-	83.3	75.5	-

Note: * - average of 3 specimens
** S - subsurface specimens
*** R - weld root specimens