Application of flux-cored wires for improved productivity in offshore duplex pipe work

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This article describes the development and application of all-positional rutile flux-cored wires (FCW) for welding duplex stainless steels.

Background research is presented to illustrate the key aspects of consumable development to optimise formulation to achieve both impact toughness requirements and welder friendly operability characteristics. Specifically, for 22 Cr duplex pipework, it is shown that a minimum of 40 joules (average), 30 joules minimum individual can be achieved at –50°C in impact testing for a variety of procedures welded with duplex FCW. Satisfactory corrosion properties are demonstrated in G48A pitting tests. The effect of heat input and interpass temperature is considered.

In terms of service application, deposition data and productivity criteria have been developed for a series of pipe sizes, thickness and welding positions to establish production benefits. Procedural data is used to verify performance on three major offshore contracts with varying specification requirements. Production experience and defect rates are analysed for contracts at the Amec Wallsend fabrication yard. Production defect rates are contrasted with that previously achieved with both the Manual Metal Arc (MMA) and Tungsten Inert Gas process (TIG).

Wt %	C	Si	Mn	Cr	Ni	MO	N2
Spec min	-	0.70	0.70	21.0	8.0	2.75	0.13
Spec max	0.04	1.00	1.00	23.0	10.0	3.25	0.17
Typical	0.035	0.80	0.90	22.2	9.0	3.0	0.14

Table 1 Chemical composition range for OK Tubrod 14.27.

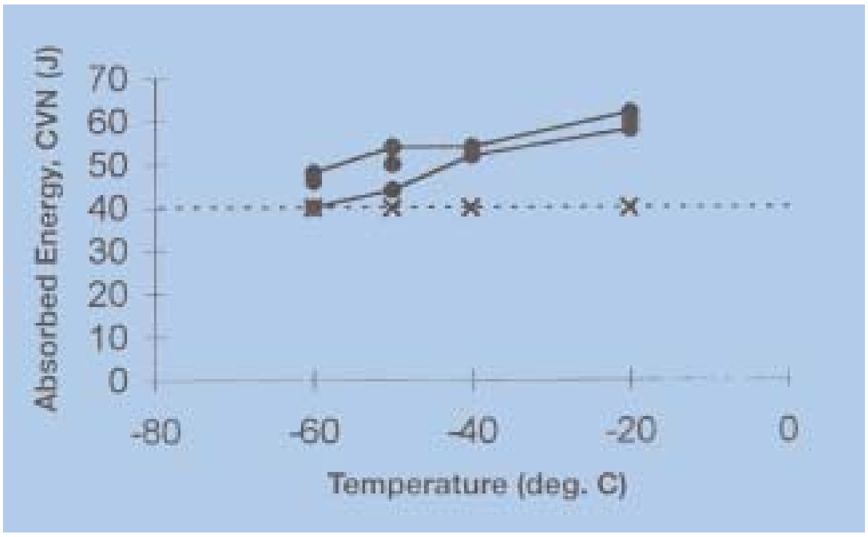


Fig. 1. All weld metal Charpy transition curve for OK Tubrod 14.27.

Introduction

The welding of Duplex Stainless Steels (DSS) is now generally well understood with the corresponding effects on material properties such as toughness and corrosion performance extensively documented (References 1 and 2). The challenge for consumable manufacturers now is to provide the fabrication industry with improved productivity and reduced costs whilst still maintaining mechanical and corrosion properties.

This article considers the development and application of all positional rutile duplex flux cored wires specifically to focus on the needs for pipework fabrication in the offshore industry. An analysis of production experience is presented relating to various contracts completed at the AMEC fabrication yard at Wailsend,United Kingdom.

Consumable development and basic background

Product development and manufacture of all-positional duplex cored wires have been carried out at the Esab Utrecht plant since 1988. The base formulations and production technology are therefore well established. The challenge for the development of OK Tubrod 14.27, an all positional rutile FCW for 22% Chromium DSS was four fold:

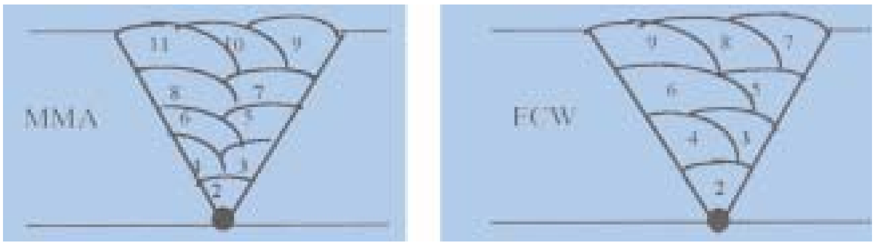
1. To provide stiff supportive slag characteristics suitable for stringer bead welding with particular reference to ASME 5G/6G pipe welding application.
2. To allow easy, self releasing slag.
3. To attain acceptable cap bead profiles particularly in the overhead and inclined overhead positions.
4. To achieve a deposited oxygen content which was compatible with acceptable impact properties at the –40°/–5O°C test temperature range.

Notwithstanding the above requirements, these characteristics must be developed within the framework of a chemical composition suitable for matching 22% Chromium DSS. For reference, the chemical composition is summarised in Table 1.

In conjunction with several major offshore fabricators, product development was successful in achieving a fine balance of operability requirements resulting in consumable approval with RINA, Controlas, GL, LRS, TÜV and DNV classification societies.

Assessment of impact properties was carried out using a DIN 32-523-3, buttered all weld metal test plate deposited in the downhand position. Welding was carried out at a nominal heat input of 1.0 KJ/mm with a maximum interpass temperature of 180°C. The resultant charpy impact transition curve is given in Figure 1 which shows the target 40 joules transition temperature is exceeded in the –50°C to –60°C range.

Further work considered the effect of heat input for this weld metal type by contrasting the performance in V-butt welds at a nominal 1.3 kJ/mm in the downhand position with 1.8 kJ/mm in the vertical position. In this case welding was carried out on 22% Cr Duplex plate using a maximum interpass temperature of 180°C. Charpy impact transition curves were determined for the cap regions, as illustrated in Figure 2 which shows the average curves,



3.2 mm Ø	DC+ve	1.2 mm Ø	DC +ve
85 amps	22 V	140 amps	24 V
10 passes		8 passes	
Total arc time	26 mins	Total are time	9 mins 31 secs
Heat input (average)	1.0 kJ/mm	Heat input (average)	0.8 kJ/mm

Table 2. Economic comparison. Direct comparison for basic MMA with rutile FCW. Pipe details: 6" OD, 16 mm wall, 60º included V butt, interpass 150°C –170°C, Welding position 5G.

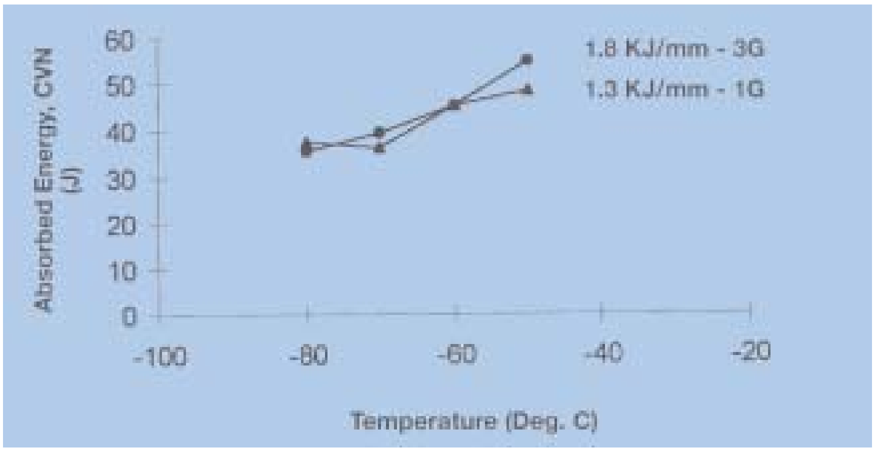


Figure 2. Effect of heat input on average Charpy energy for Cap V-butt welds for OK Tubrod 14.27.

indicating consistent properties over the range of heat inputs considered particularly at the –50°C test temperature.

A similar assessment was made with respect to interpass temperature comparing pipe butts fabricated with 180°C maximum interpass with that of 250°C maximum. Whilst the impact properties remain unchanged there was a noticeable deterioration in slag control and surface finish in the critical included overhead position effectively limiting the practical positional performance at the higher interpass temperatures.

AMEC selection criteria

Over the last 8 years Amec have gained extensive experience with TIG, MMA and submerged are welding (Sub-Arc) of DSS. Assessment of the relative deposition rates was carried out, in conjunction with ESAB, and is summarised in Figure 3. Sub-Arc welding remains the dominant process for all downhand and rotated work, similarly TIG for the thin wall, small diameter pipework. It was apparent that the major improvements in productivity and cost reductions could be made for positional welding replacing MMA. At typical welding currents the flux cored process offered potentially a six-fold increase in deposition rate over conventional 2.4 mm Ø TIG and a three-fold improvement compared to 3.2 mm Ø basic MMA types.

In comparison with basic MMA types the rutile FCW also offered potentially:

1. Considerably reduced grinding/dressing time due to the rutile nature of the slag system.
2. Reduced deposited weld metal costs due to the significantly improved efficiency of the process.

An initial comparison was carried out in the 5G position to contrast the performance of basic 3.2 Ø MMA consumables compared with 1.2 mm Ø rutile FCW OK Tubrod 14.27. A nominal 6" diameter, 16 mm wall pipe was prepared with 60° included V angle. Welding was carried out after conventional TIG root and hot pass in two halves to afford a direct, side by side, comparison under closely monitored conditions. Full details of the economic comparison are given in Table 2. In summary, joint filling was carried out in 10 passes with the MMA consumable compared to 8 passes with FCW OK Tubrod 14.27. Actual arc time was reduced from 26 minutes for the Manual process to 9 minutes 31seconds for the semi-automatic process a reduction over 60% clearly confirming the potential for productivity improvements. In order to assess the cap profile likely to be achieved a grooved plate technique was developed which allowed a direct comparison with the TIG and MMA process. The most critical position with respect to pipe welding is generally the inclined overhead position which became the standard position for comparison.

Figure 4 shows the typical profiles obtained for all three processes. A clear advantage can be seen for the FCW option over conventional MMA.

Following the initial evaluation, to maintain the flexibility of the MMA process essential for the wide variety and complex nature of pipework contracts, the semi-automatic process was the favoured option.

The final choice and evaluation lay between two options:

1. All-positional rutile FCW using conventional power sources and simple Ar, 20% CO_2 shielding gas.
2. Conventional solid wire MIG using pulsed/synergic power sources and complex helium based shielding gas.

Operability assessment strongly favoured the spray transfer, low spatter, welder friendly nature of the gas shielded FCW which in combination with AMEC's long track record of application for low alloy structural applications, was the final option selected.

Figure 5 shows a typical weld procedure qualification summary for OK Tubrod 14.27 which shows excellent impact and corrosion properties.

Contract experience

Since the initial evaluation and introduction of OK Tubrod 14.27 AMEC have now completed seven major contracts for Duplex pipework as summarised below:

Shell: Pelican, Anasuria, Curlew
BP: ETAP
Phillips: Ekofisk, Judy, Gim

Pipe sizes in the range 6" to 24" nominal OD with corresponding thickness from 12 mm minimum to 60 mm maximum have been completed using the FCW process. Production experience over this period covered 15,000 meters of Duplex pipework totalling 260 tonnes of product. The average defect rate for all Duplex pipework using OK Tubrod 14.27 was established as 0.044% in contrast to all other pipework averaging 0.59%.

Table 3 summarises the average defect rate achieved for the various projects under consideration which highlights the significantly lower defect rate achieved for Duplex pipe butts welded with OK Tubrod 14.27

Conclusion

The introduction of the all-positional OK Tubrod 14.27 for Duplex pipe work has made a major effect on welding productivity at AMEC Process and Energy.

Specifically, this paper has shown that Duplex FCW has given:

1. Consistent corrosion and mechanical properties, particularly impact requirements, have been achieved, meeting all current specification requirements.
2. Satisfactory cap weld profiles have been achieved in production butts over a range of welding positions and pipe sizes.
3. Improved deposition rates and productivity for positional

Project	Structural butts	All other pipework	Duplex pipework
Anasuria	1.5	0.89	0.002
Girn	0.6	0.0	0.010
Ekofisk	1.5	1.83	0.02
Curlew	0.62	0.06	0.01
Etap	0.52	0.0	0.06

Table 3. Defect rate analysis for pipework contracts at AMEC Wallend.

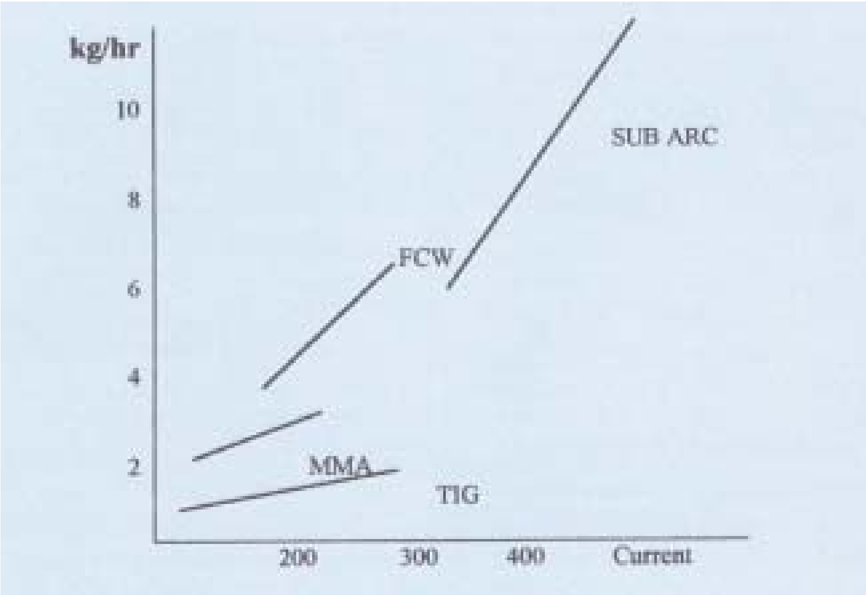


Figure 3. Deposition rate comparison for consumable processes for welding duplex stainless steels.

welding over the TIG and MMA process-conservatively, flux cored wires have been proven to be at least twice as fast as corresponding MMA.

4. Reduced defect and repair rates in comparison to the MMA process.

In summary. OK Tubrod 14.27 is now the preferred option for positional welding of Duplex pipework at AMEC Process and Energy.

References

1. Duplex stainless steels 91. October 1991 Beaune. France. Edited by J Charles and S Bernhardson.
2. Duplex Stainless Steels 94, November 1994. Glasgow, Scotland. Edited by T G Gooch.

Acknowledgements

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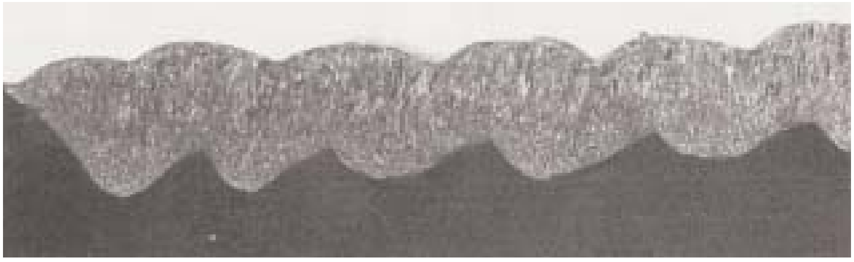
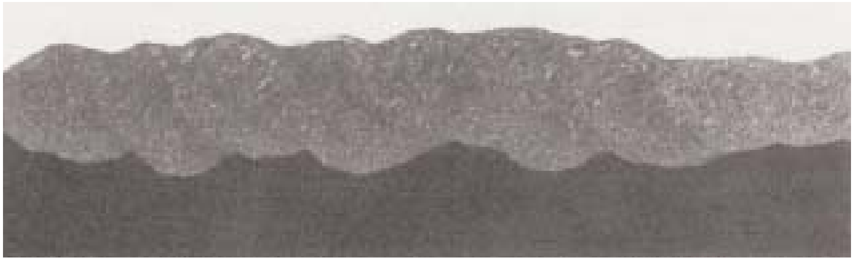


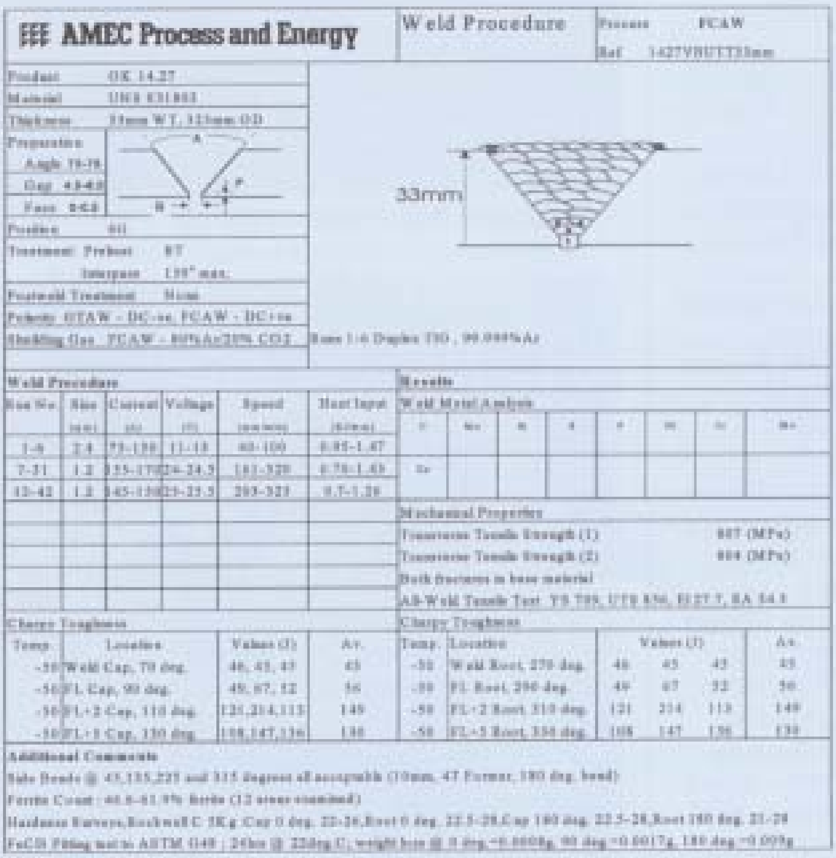
FCW



MMA

TIG

Figure 4. Typical cap profiles from grooved plate tests for TIG, MMA, FCW processes



AMEC Process and Energy — Weld Procedure — Process FCAW — Ref 1427VHUTT33mm

Product: OK 14.27
Material: UNS S31803
Thickness: 33mm WT, 323mm OD
Preparation: Angle [illegible]; Gap [illegible]; Face [illegible]
Position: 6G
Treatment: Preheat RT; Interpass 150° max.
Postweld Treatment: None
Polarity: GTAW - DC-ve, FCAW - DC+ve
Shielding Gas: FCAW - 80%Ar/20% CO2; Runs 1-6 Duplex TIG, 99.998%Ar

33mm

Weld Procedure

Run No.	Size (mm)	Current (A)	Voltage (V)	Speed (mm/min)	Heat Input (kJ/mm)
1-6	2.4	75-150	11-13	60-100	0.85-1.47
7-31	1.2	135-170	24-24.5	181-320	0.78-1.45
32-42	1.2	145-150	25-25.5	293-323	0.7-1.26

Results — Weld Metal Analysis: [illegible]

Mechanical Properties
Transverse Tensile Strength (1): 807 (MPa)
Transverse Tensile Strength (2): 804 (MPa)
Both fractures in base material
All-Weld Tensile Test: YS 709, UTS 856, El 27.7, RA 54.1

Charpy Toughness

Temp.	Location	Values (J)	Av.
-50	Weld Cap, 70 deg.	46, 45, 43	45
-50	FL Cap, 90 deg.	49, 67, 52	56
-50	FL+2 Cap, 110 deg.	121, 214, 113	149
-50	FL+5 Cap, 130 deg.	108, 147, 136	130

Charpy Toughness

Temp.	Location	Values (J)			Av.
-50	Weld Root, 270 deg.	46	45	43	45
-50	FL Root, 290 deg.	49	67	52	56
-50	FL+2 Root, 310 deg.	121	214	113	149
-50	FL+5 Root, 330 deg.	108	147	136	130

Additional Comments
Side Bends @ 45,135,225 and 315 degrees all acceptable (10mm, 4T Former, 180 deg. bend)
Ferrite Count: 40.6-61.9% ferrite (12 areas examined)
Hardness Surveys, Rockwell C 5Kg: Cap 0 deg. 22-26, Root 0 deg. 22.5-28, Cap 180 deg. 22.5-28, Root 180 deg. 21-29
FeCl3 Pitting test to ASTM G48; 24hrs @ 22deg C, weight loss @ 0 deg.=0.0008g, 90 deg.=0.0017g, 180 deg.=0.009g

Figure 5. Typical AMEC weld procedure qualification summary for duplex pipework.