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FLUX CORED ARC WELDING: THE HIGH PRODUCTIVITY WELDING PROCESS FOR P91 STEELS

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Abstract

In the power generation industry, the benefits of using modified 9Cr1Mo (P91) steels in reducing structure weight, improving thermal efficiency and reliability, hence saving construction and operating costs are now widely appreciated, but these advantages can only be fully exploited if appropriate welding consumables and processes are available to produce weldments that will complement the integrity of the completed structures.

At present, shielded metal arc welding (SMAW) and gas tungsten arc welding (GTAW) are the most commonly used welding processes in the fabrication of P91 steels, but because they are manual processes, productivity is limited. There are other processes available to improve welding deposition rate and duty cycle. For welding positions and components where mechanised welding is applicable, submerged arc welding (SAW) is a generally preferred and most productive process. However, for all-positional welding and particularly for fixed pipe or site welding, the ideal high productivity process is tubular flux cored arc welding (FCAW). Flux cored arc welding is already well established for welding 1CrMo (P11) and 2CrMo (P22) materials but this is still a relatively new process for P91 steels. Although a FCAW wire classification is in preparation by The American Welding Society (AWS), published performance data are lacking.

This paper describes the potential productivity benefits of using FCAW for P91 steels and presents joint completion rates and time savings in comparison to other arc welding processes. The suitability and quality of the FCAW consumables and process is supported by the presentation of the latest available mechanical testing data, including creep stress-rupture strength, impact and fracture toughness of the weld metals, in comparison with other widely accepted arc welding processes. Using the fracture toughness data, a critical crack assessment has also been carried out to evaluate the acceptability of the FCAW weld metal in light of a fitness for purpose concept.

1. Introduction

Coal and natural gas are expected to remain the major fuel sources for power generation in both mature and developing economies for many years to come. The major challenge facing the designers and manufacturers of both new plant and plant which is to be refurbished and upgraded is to maximise operating efficiency and reduce construction times and costs.

A key factor in any power station is the choice of material designed to operate at the highest possible steam temperature consistent with reasonable component costs, thickness and weights. Over the last 15 years, new generation materials, particularly in the form of modified 9Cr1Mo (P91) have been widely used for replacement equipment and increasingly for new construction.

A range of welding processes and consumables are available to support fabrications [1], but it is only in the last year that an all-position flux cored arc welding consumable, Supercore F91, has become a viable option for both site and shop fabrications. This flux cored wire offers significant benefits in terms of both productivity and welder appeal plus the potential to drastically reduce fabrication times and costs. In order to achieve the desirable features of such a wire, a particular rutile flux system has to be used. It is therefore natural that potential users require reassurance as to the properties of the weld metal and its fitness for purpose in proposed applications.

The two areas of major concern are:

- Creep properties, in particular creep strength and creep rupture ductility.
- Toughness, where a minimum is specified or there is concern about hydrotesting of components at high imposed stresses and at ambient temperatures.

The issue of toughness in P91 weld metals has been extensively reviewed in previous papers [2, 3] and it was argued that toughness is an irrelevant consideration in fabrications designed to operate at temperatures in the range of 500-600°C. These temperatures are far above the range at which any possible risk of fast brittle fracture would be expected. However, a fitness for purpose approach was adopted for consumables then available and this has now been extended to cover FCAW weld metal. The model chosen and analysis carried out are intended to be indicative of results to be expected in practical situations. However, they are not intended to cover every design situation or application and a potential user would be well advised to carry out their own specific analysis. Creep data are also given to provide user/operator confidence at both ends of the temperature spectrum.

2. Welding consumable background

To date, shop and site welding has utilised the GTAW process as a gas shielded process, and the SMAW and SAW as flux shielded processes. In the latter processes, basic flux systems are employed exclusively, with the underlying expectation that these will result in reasonably low oxygen contents and correspondingly clean weld metals. The relationship between welding process oxygen content and weld metal toughness has been extensively reviewed elsewhere [2, 3].

In the present work, the requirement was for a tubular flux cored wire with excellent operability in all positions including the demanding overhead and fixed inclined vertical positions required for the site welding of fixed pipework. In these situations, simple control of the arc, smooth weld metal transfer, flat bead profiles with minimum spatter and easy slag removal are all essential requirements. Such a combination of features is imperative for high productivity welding and can only be achieved using flux cored wire with a rutile (TiO_2) based flux system. However, there are two potential disadvantages associated with this flux system, namely:

- Rutile flux systems have a lower refining capability than classical basic systems resulting in somewhat higher oxygen content (typically 600ppm for rutile FCAW deposits compared with 400ppm for submerged arc welds made using basic fluxes [2, 3]).
- Rutile flux systems use naturally occurring rutile sand as a major ingredient. This is contaminated to a small degree with niobium and vanadium which in turn results in some alloy pick up [4], but this is hidden by deliberate additions of these elements. However, of greater possible importance is the pick up of titanium into the weld metal, which provides a further strong carbide former and yet more matrix strengthening. FCAW weld metals are generally about 5-10% stronger at ambient temperature than weld metals from SMAW and SAW processes and are similar to those of GTAW deposit after similar PWHT. The corresponding toughness is generally lower but creep rupture strength has been seen to be higher than SAW and SMAW. To mitigate the effects of Ti pick-up

(typically 0.02-0.04%Ti), the level of Nb is deliberately controlled to the minimum consistent with meeting weld metal specifications. As explained above, a proportion of this Nb is also derived from the rutile flux system.

With these two areas of possible concern in mind, a testing programme was carried out to assess both high temperature creep performance and low temperature fracture toughness of the FCAW weld metal. The results were compared with data for well established consumables which have a satisfactory application track record extending over many years. Before proceeding with these topics, the productivity benefits of the FCAW process will be reviewed.

3. Productivity benefits of FCAW process

Deposition rate is often used as a measure of potential productivity, although many other factors contribute to operator duty cycle and hence productivity. A graph of comparative deposition rates of different welding processes is shown in Figure 1. It should be pointed out that, although compared here, the solid wire gas metal arc welding (GMAW) process has not found widespread use in the power generation industry mainly due to concerns over lack-of-fusion, sensitivity to welder error and demands for more sophisticated power sources.

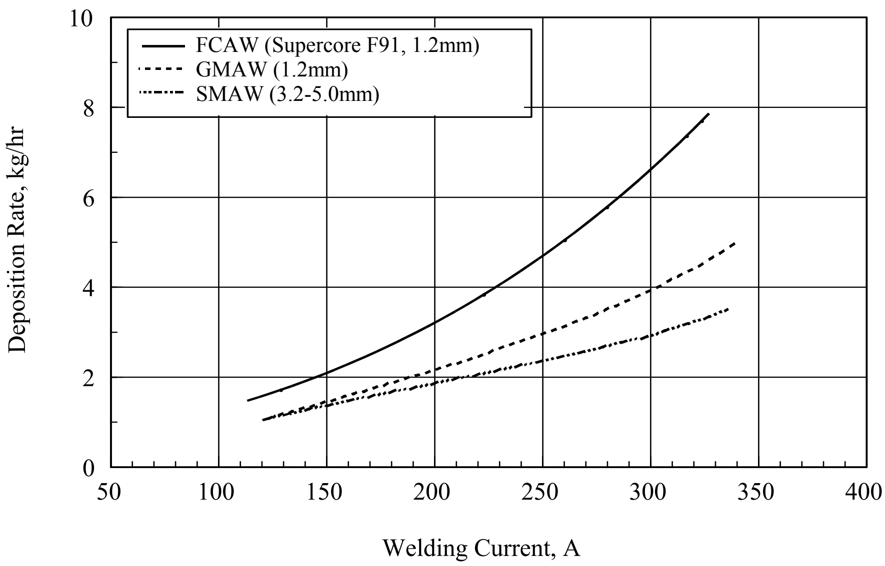

Figure 1. Deposition rate of FCAW process using Supercore F91 compared with SMAW and GMAW processes

Flux cored wire, 1.2mm diameter, is capable of a deposition rate which is competitive with all other arc welding processes except SAW [5]. This advantage is particularly notable for positional welding, where the ease of use and high effective operating currents come into their own. Compared with solid wire gas metal arc welding (GMAW), a faster burn-off rate for tubular FCAW is also promoted by higher current density at the wire tip and I^2R resistance heating of the wire extension from the contact tip. Moreover, the flux cored wire process, which utilises spray transfer, produces reliable fusion and penetration in all welding positions. The duty cycle possible with the FCAW process is also higher than for the GTAW and SMAW processes, which further improves potential productivity compared to these processes. The better duty cycle can be attributed to two main factors: the continuous nature of the process and the all-positional capability of the process without the need for a change in welding parameters. For some applications, especially numerous short welds, the duty cycle of the FCAW process may also compete with SAW if the set-up times and positioning of the joints into the flat position contribute a significant proportion of the time. The ability of the FCAW to weld thick section joints relatively quickly in all position may allow the FCAW process to compete with SAW in these situations.

The FCAW process is expected primarily to replace the SMAW process; the GTAW process will still be required for pipe roots and other small diameter or thin wall pipe, and the SAW process will be preferred for very thick section welds that can be rotated or manipulated into the flat position.

The FCAW process is mainly used in the hand held semi-automatic mode, which provides optimum adaptability and ease of use for both shop and site welding. For joints which lend themselves to mechanisation the productivity of the FCAW process may be further improved by the use of suitable automated equipment, Figure 2.

A comparison of the arc time required for filling and capping large diameter thick wall fixed pipe (not including GTAW root) welded in all position, shows a distinct advantage for FCAW. Using welding times from actual pipe joints, the arc time to complete a joint of 310-360mm (12-14in) internal diameter pipe of ~65mm (~2.5in) wall thickness using Supercore F91 would be reduced by 25-40% compared with SMAW.

Figure 2. Live demonstration of automatic orbital welding of a fixed 5G (double up) P91 pipe using Supercore F91 FCW*

4. Chemical composition, mechanical and creep properties of the FCAW weld metal

From the above discussion, it can be seen that FCAW can offer not only significant productivity benefits but also welder-friendly operability, particularly in fabrication positions where other high productivity processes are not applicable. Nevertheless, it has also been recognised that these benefits can only be exploited if the deposit composition, hence microstructure is carefully controlled to achieve a reasonable balance of mechanical properties - primarily toughness and creep resistance.

In the design of the flux cored wire, the deposit composition was aimed to be as close as possible to the requirements of the corresponding SMAW weld metal (e.g. AWS E9015-B9). The next revision of AWS A5.29 specification for low alloy flux cored wires will include this grade, and the expected classification for an all-positional wire such as Supercore F91 will be E101T1-B9. AWS specifications are ultimately included in Section II Part C of the ASME Boiler and Pressure Vessel Code.

* The demonstration was jointly carried out by Euroweld Ltd and Liburdi Dimetrics both of the USA, using Dimetrics' OrbiMig® equipment and ∅1.2mm flux cored wire.

Table 1 presents the typical all-weld metal composition of Supercore F91. This composition is typical of a deposit made using usual Ar-20%CO_2 shielding gas. However, Supercore F91 is formulated to work with either Ar-15-25%CO_2 or 100%CO_2 shielding gases with minor changes in composition.

Table 1. Chemical composition of Supercore F91 weld metal

Elements	C	Mn	Si	S	P	Cr	Ni	Mo	Nb	V	N
wt%	0.10	0.8	0.3	0.010	0.015	9.5	0.6	1.0	0.03	0.20	0.05

To ensure that the mechanical properties of the FCAW weld metal are satisfactory and fit for purpose, a series of tests were carried out at ambient and elevated temperatures, including impact and fracture toughness (CTOD) tests as well as hot tensile and stress rupture tests. Using the CTOD (δc) data, a fracture analysis was also conducted which resulted in the prediction of the critical tolerable defect sizes for the FCAW weld metal.

The test weldments were prepared according to AWS A5.29 procedure using a shielding gas of Ar-20%CO_2 with a flow rate of ~20 l/min. The welding parameters were typically 170-180A, 27-28V and a nominal heat input of 1.2-1.4kJ/mm. The pre-heat and interpass temperatures were nominally 250°C (limits: 200-300°C). The joints were built up using two weaved beads per layer. Prior to the tests, the weld metals were subject to post weld heat treatments (PWHT) conforming to AWS specifications for P91 weld metals. To investigate the effects of PWHT procedure on the mechanical properties of the FCAW weld metal, different temperature/time combinations for the PWHT (followed by furnace cool) were applied to weld coupons for tensile and Charpy tests. Whereas for the weld metals used for the CTOD and high temperature tests, the PWHT procedure was fixed at 760°C×2h+furnace cool (FC).

4.1. Ambient/low temperature properties of the FCAW weld metal

4.1.1. Tensile strength and hardness

All-weld metal tensile tests were carried out using standard full-sized specimens with a nominal gauge diameter of 10mm. Typical ambient tensile strength along with the mid-weld section hardness properties are presented in Table 2.

Table 2. Ambient temperature tensile/hardness properties of the FCAW weld metals (Supercore F91)

PWHT °C/h	Rp 0.2% MPa	Rm MPa	A4 %	Z %	Hardness (mid-weld section) HV10
760/2	690	809	20	52	264
760/4	651	777	23	58	250

Data from the above table indicate that the tensile properties of the FCAW weld metal satisfactorily meet the requirements of the appropriate specifications for the P91 weld metals. Compared with other processes, the differences are that the tensile strength of Supercore F91 weld metal is slightly higher than that of the SMAW and SAW deposits and very close to that of the GTAW weld. The elongation is very close to the values achieved by other processes while its reduction of area is slightly lower.

4.1.2. Charpy impact toughness

To cater for fabrications which require hydrotesting, it is generally agreed that the P91 weld metals should provide a minimum toughness at ambient temperature. Charpy impact tests were carried out using full-sized 10×10mm specimens notched at the weld centre. Impact energies of the FCAW weld metal after different PWHT times are given in Table 3. Figure 3 illustrates the effect of PWHT procedure (time (t,h) and temperature (°K)) on the weld toughness.

Table 3. Typical average Charpy impact toughness of Supercore F91 weld metal

Pre-heat/interpass temperature, °C	PWHT procedure	Charpy energy @20°C, J
250	760°C/2h + FC	25
	760°C/4h + FC	30
	760°C/8h + FC	35

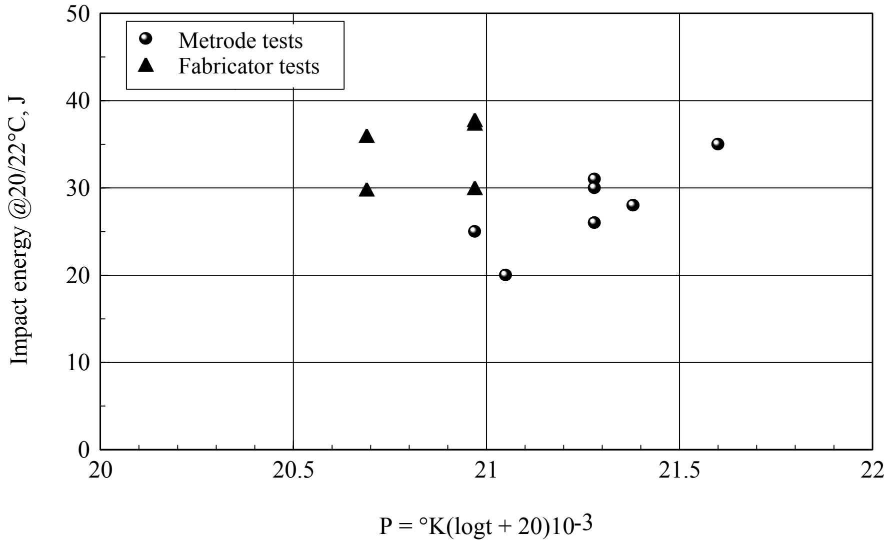

Figure 3. Effect of PWHT on Supercore F91 weld metal impact toughness

Comparing the above data with those achieved by other flux shielded processes, namely SMAW and SAW [3], the FCAW deposit, as expected, produced somewhat lower impact energy values. However, as illustrated by Figure 3, slightly higher PWHT temperature or longer soaking times are beneficial in improving impact toughness.

4.1.3. Fracture toughness (CTOD)

Fracture toughness CTOD tests were conducted in accordance with BS7448 [6]. In order to examine a worst-case microstructural condition, the PWHT procedure chosen for the weld metals was 760°C×2h+FC, which gave the lowest absorbed energy values in Charpy tests, as shown in Table 3. The dimensions of the CTOD specimens are illustrated in Figure 4. All specimens were B×B where B is the plate/weld thickness, and were notched through the thickness of the weld from the top. Based on a minimum water inlet temperature of 7°C for hydrotesting, the tests were carried out at two temperatures, namely 20°C and 0°C. The results in terms of CTOD (δc) and K_Q (provisional value of K_{IC}) are shown in Table 4.
The results indicate that the CTOD values for the FCAW weld metal were in the range of 0.018mm to 0.030mm, with small (but probably insignificant) variation between the values at 20°C and 0°C. However, the important question is: What do these toughness results really translate to in terms of a maximum tolerable flaw size in real structural applications?

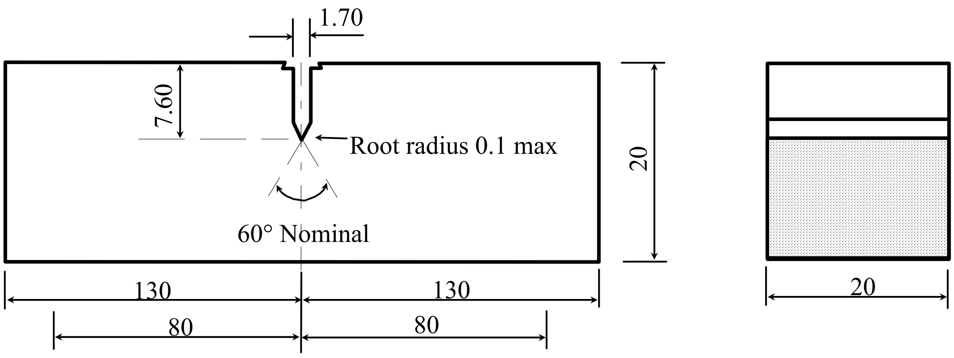

Figure 4. CTOD specimen dimensions

Table 4. CTOD and K_Q values of Supercore F91 weld metal

PWHT procedure	Test temperature, °C	CTOD, mm	K_Q, MPa √m
760°C×2h+FC	20	0.021	75.10
		0.018	61.80
		0.030	76.79
	0	0.029	69.26
		0.021	55.75
		0.025	66.79

4.1.4. Tolerable flaw size analyses

To answer the above question, calculations of the maximum tolerable flaw sizes were carried out using TWI's Crackwise® software [7], which automates engineering critical assessment procedures set out in BS7910 [8]. The model chosen was that used in the previous work [3], namely a fabricated header of 450mm outside diameter and 50mm wall thickness, as shown in Figure 5. The design conditions are taken to be 176 bar at 580°C and hydrotest conditions of 1.25 times design pressure at ambient temperature. This ensured that a comparison could be made between the FCAW and SMAW weld metals under similar conditions.

To assess the worst toughness situation, the lowest measured CTOD value, namely δ_C = 0.018mm at 20°C, was used in the Crackwise® calculations. The results indicate a maximum tolerable surface flaw size of 125mm in length and 12.5mm in depth for a longitudinal seam weld, i.e. equal to ¼ of the wall thickness (Figure 5). The corresponding failure assessment diagram is given in Figure 6 while Figure 7 illustrates the effect of primary membrane stress on the maximum tolerable flaw depth. In Figure 6, any point which falls inside the failure assessment line can be considered safe whereas any point outside the line is potentially unsafe [9]. The results indicate a good defect tolerance despite the relatively low fracture toughness.

4.2 High temperature properties of the FCAW weld metal

4.2.1. Hot tensile strength

Without doubt, high temperature properties are the most important features for the P91 weld metals. Although hot tensile tests are not representative of service conditions for P91 steel

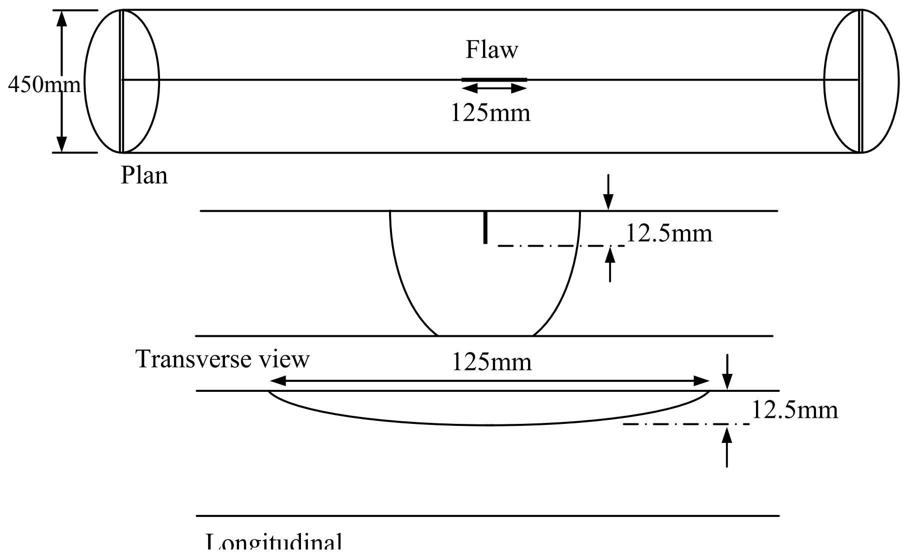

Figure 5. Schematic showing header with maximum tolerable surface breaking flaw in longitudinal seam weld

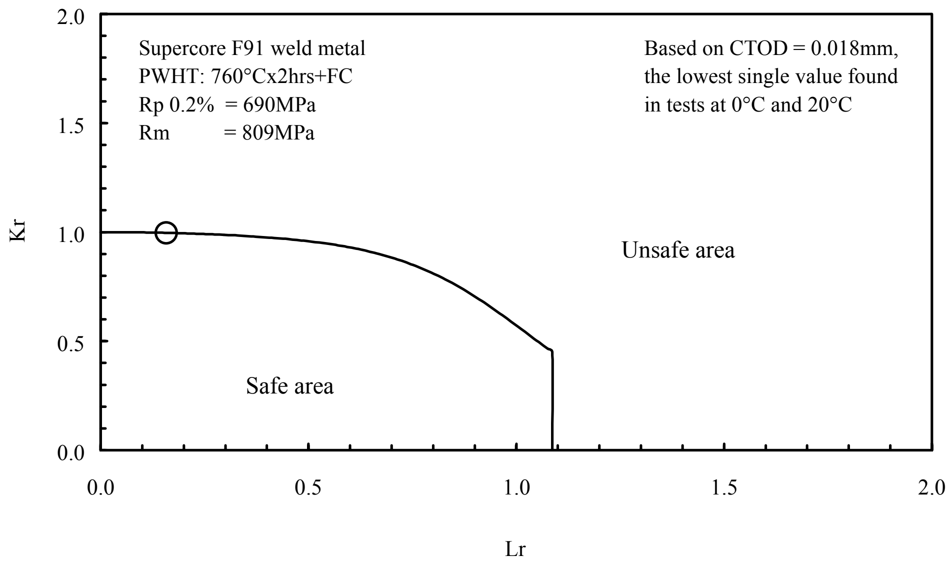

Figure 6. Failure assessment diagram for Supercore F91 weld metal*

components owing to the short duration of the test, they provide a convenient method for comparison of weld metals with base material data in a short term test. All-weld metal hot tensile tests were carried out at temperatures of 550, 600 and 650°C. Prior to the tests, the weld coupon was subject to a PWHT of 760°C×2h+FC. Table 5 lists the test results and Figure 8 compares these data with SMAW values and base material requirements.

Results indicate that the hot tensile strength of Supercore F91 weld metal is comparable with weld metals from other well established processes and significantly higher than the minimum requirements for the base material.

* Lr is a dimensionless number showing the ratio of applied stress to the yield strength of the material, while √δr is the ratio of applied stress intensity to material toughness, CTOD (δc) [9].

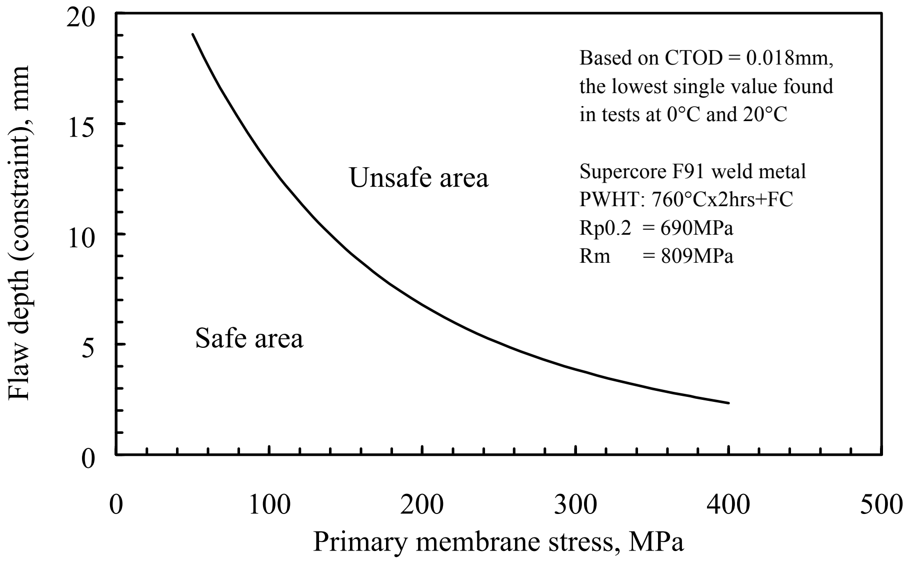

Figure 7. Effect of primary membrane stress on maximum tolerable flaw depth of Supercore F91 weld metal

Table 5. Hot tensile properties of Supercore F91 weld metal

Test temperature, °C	Rp 0.2%, MPa	Rm, MPa	A4, %	Z, %
550	402	495	18.0	71
600	277	405	30.5	83
650	182	292	25.5	87

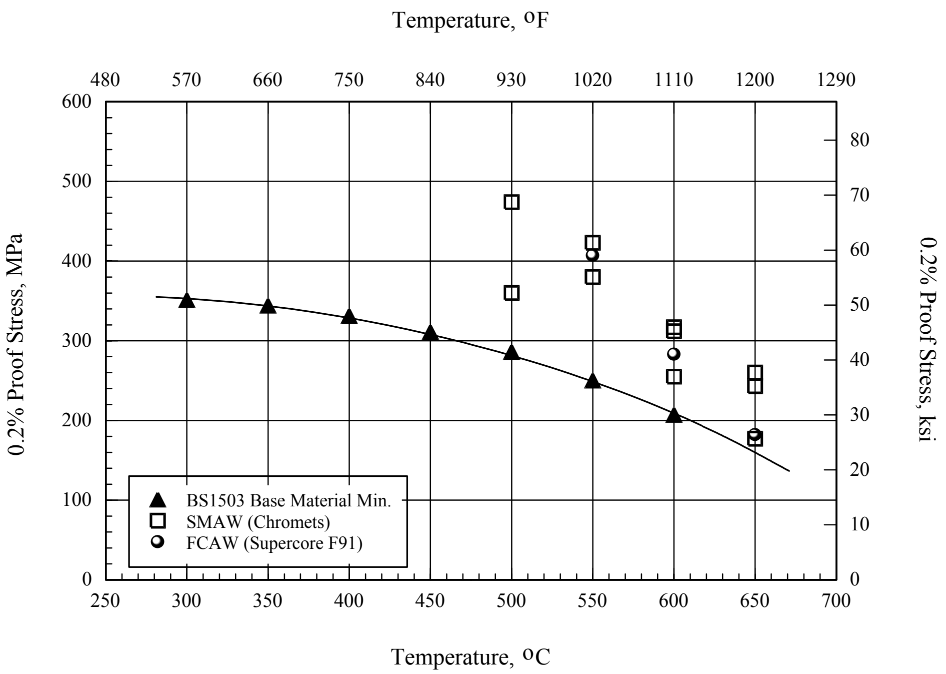

Figure 8. Hot tensile property comparison of Supercore F91 weld metal with SMAW deposits and base material minimum requirements

4.2.2. Creep stress-rupture properties

To provide an assessment of the creep strength of the FCAW weld metal, a series of 3 pairs of stress-rupture tests were carried out at temperatures initially set at 550°C, 600°C and 650°C, aiming for rupture at nominally 100h and 1000h at each temperature. These would present a useful range of values to populate a Larson-Miller curve. For comparison, a similar test matrix was also included for a representative P91 SMAW electrode (Chromet 9-B9 – E9015-B9).

All-weld test specimens of 8mm gauge diameter and 40mm gauge length were extracted from the mid-section of weld coupons after a PWHT the same as used for the CTOD tests. The testing was conducted under constant load conditions.

The short-term tests were loaded at stresses for expected rupture life of 10-100hrs based on the median for P91 parent material. These initial tests indicated that the FCAW weld metal was noticeably stronger than the SMAW, so the stresses were appropriately adjusted for the longer term tests. The 650°C test was also raised to 660°C to increase the parametric value at this point. Results for the FCAW weld metal are given in Table 6, and these are presented with the SMAW and base material data on the Larson-Miller plot, Figure 9.

Table 6. Stress-rupture test results of P91 FCAW weld metal (Supercore F91)

Test temperature, °C	Stress, MPa	Rupture time, h	A5, %	Z, %
550	295	308	25.0	76.3
	265	2782	13.4	42.3
600	205	287	20.9	61.9
	175	1361	5.6	15.2
650	140	101	14.0	24.4
660	100	535	7.5	17.9

5. Discussion and practical significance

5.1. Productivity and FCAW weld metal toughness

From the above presented data, it can be seen that the toughness of the FCAW weld metal is slightly lower than those from other well-established fluxed processes, namely SMAW and SAW processes. However, actual welding procedure qualifications by fabricators and contractors indicated an increase in impact toughness values on test assemblies welded in both the flat and vertical positions (Figure 3). This may be attributed to a higher degree of interbead tempering [10]. Further, as mentioned earlier, additional toughness increases have been observed by increasing the temperatures (up to 775°C) and/or soaking times. Compositional control permits PWHT at these elevated temperatures while leaving sufficient margin to ensure that the Ac_1 is not approached or exceeded.

Nevertheless, the key question is: Are these weld metals still tough enough and fit for purpose? The productivity benefits, up to 50% reduction in welding time, are such that flux cored wires, including Supercore F91, are now being used by both pipe fabricators and on-site contractors [10]. Because of the special features associated with this flux cored wire, it is probably unreasonable to expect the toughness to match that of SMAW deposits. However, in the light of the fitness for purpose calculations, it would appear that some reduction in toughness can be tolerated.

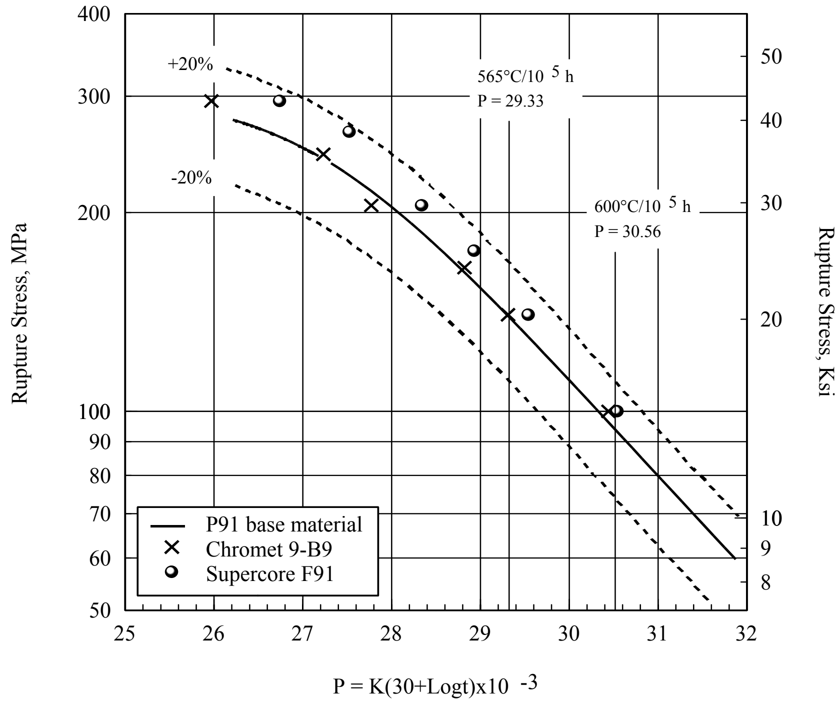

Figure 9. Larson-Miller plot of all-weld metal stress-rupture test results at 550-660°C for FCAW (Supercore F91) and SMAW (Chromet 9-B9)

Using accepted engineering critical assessment procedures, analysis of the fracture toughness data from CTOD tests indicates that critical flaw sizes for the FCAW weld metal are very similar to those reported in the previous work for SMAW weld metals [2], the slight difference being dependent upon a small reduction in fracture toughness (0.018mm rather than 0.021mm) and some increase in the weld metal tensile strength.

The defect tolerance is high by virtue of the following:

- The membrane stress is based on elevated service temperature and is therefore relatively low at ambient temperatures;
- A full PWHT has been carried out and no significant residual stresses remain;
- The model is based on a smooth longitudinal seam weld with minimal stress concentration factors.

It is worth considering two other types of weld, namely circumferential welds and nozzle welds. In the former case, the applied transverse stresses are only 50% of those on a longitudinal weld and the model would predict an even larger defect tolerance. However, circumferential welds can be subject to additional bending and/or system stresses and where these can be predicted or measured for a practical application they should be included in the model. Secondly, nozzle welds, if they are present in critical areas, will give rise to significant stress concentrations, with corresponding reductions in tolerable defect sizes. If these are believed to constitute a risk at ambient temperature, then consideration may have to be given to choosing a welding process/consumable combination with a higher inherent toughness and/or carrying out more rigorous NDE to ensure detection of possible critical defects. It must be emphasised that low temperature brittle fracture can only be a potential problem when components are stressed at or below ambient temperature. It is not an issue at operating temperatures.

5.2. Weld metal hot tensile and stress-rupture properties

The reported tests have shown that the elevated temperature proof and rupture stress values of the FCAW multipass weld metal lie within the envelope required for equivalent parent material. These properties were similar to or even higher than those obtained for the SMAW weld metals and were considered satisfactory, since failure in transverse tests on weldments occurs characteristically at the HAZ type IV zone in the long term unless weld metal creep strength is severely compromised.

Hot tensile proof stress values of the FCAW and SMAW welds converge quite steeply towards the P91 minimum at 650°C, which would confirm the effectiveness of stress relief during PWHT at ~100°C above this temperature. Except for some apparent convergence at the longest 660°C test, the rupture stress trend for the FCAW was higher than SMAW, the latter closely matching the median trend for P91 parent material.

Hot tensile ductility and shorter-term stress-rupture ductility were comparable to parent material. However, as commonly found in weld metals, stress-rupture ductility declined quite noticeably with rupture time to a variable extent, whereas in P91 parent material, this decline would be expected typically beyond about 5×10^3-10^4h [11, 12]. Rupture ductility of SMAW weld metals (not reported here) showed similar time-temperature behaviour to FCAW.

Rupture ductility control and enhancement are desirable but elusive goals, however, this subject is not only beyond the scope of the current paper, but also constrained by limited data on the micro-mechanisms involved. Creep extensometry was not applied to the tests carried out here, but the characteristically low secondary creep rate of weld metal was evident from the displacement curves, especially in the longer tests. A multipass weld is a composite of anisotropic and locally dissimilar thermal histories, which are presumed to include weak "type IV" regions and very strong but probably creep-brittle "peak HAZ" regions [13, 14]. Overall, it is perhaps fortunate that the whole is found fit for purpose.

The higher rupture stress of the FCAW weld metal is presumed to derive from the presence of residual titanium. Since it forms stable carbonitrides like niobium, a positive influence was anticipated, and the compensatory reduction of Nb was justified. No previous reports of the effects of Ti in P91 weld metal are available, but a similar level (200ppm Ti) was found to have no effect on 650°C rupture life in a low nitrogen 11%Cr rotor steel [15], and contrary to the weld metal here, fracture appearance transition temperature (FATT) was noticeably reduced.

6. Summary

All-positional flux cored wires can offer an important and high productivity option for welding P91 steels, especially for fabrications involving difficult welding positions such as fixed pipe and site welding. While an AWS classification is anticipated, such wires have recently become commercially available and one of these, Supercore F91, is now being used in practical applications. In comparison with SMAW, the FCAW process has a significantly higher deposition rate in conjunction with the advantages of continuous welding. For a large diameter thick wall fixed pipe joint, reductions in joint completion rate of 25-40% compared with SMAW can be achieved by employing Supercore F91.

Mechanical and fracture toughness test results indicate that the FCAW weld metal is slightly stronger than that from SMAW and SAW processes, while the impact toughness is slightly lower. The calculated maximum tolerable flaw sizes using the lowest CTOD value at 0°C and 20°C are large and very close to the values for SMAW deposits with similar CTOD values.

Any defects of significance should be readily detectable with current NDE technologies. However, it should be pointed out that the model and analysis presented in the current work are not intended to cover every design situation or application and a potential user is advised to carry out their own specific analysis for critical structures.

At elevated temperatures, the proof stress of the FCAW weld metal was similar to SMAW, while stress-rupture strength was higher, probably because of the influence of residual Ti derived from the rutile flux system. Rupture strength of both FCAW and SMAW weld metal was within the envelope expected for parent material. As is usually found in weld metals, rupture ductility decreased at shorter durations than parent material. However, given the high creep strength found, the "type IV" HAZ would be the weakest region of a weldment in the long term.

Acknowledgements

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