WELDING 1-2CrMo AND CrMoV FOR POWER AND PETROCHEMICAL INDUSTRIES

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Welding Consumables for the Power Generating Industries

Low Alloy Steels

Welding consumables for P11, P22 and CrMoV creep resisting steels used in power generation and petrochemical applications

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Figure 1 Turbine hall, Eggborough power station, UK

1 Introduction

During conventional power station and refinery shutdowns, one of the major costs is the repair of CrMo and CrMoV pipework, forgings and castings and the replacement of lifetime expired components. This repair work is often required because of creep damage in the type IV zone of welded joints, particularly in power plant.

Metrode offers a full range of welding consumables designed for both new fabrication and repairs on CrMo and CrMoV creep resisting steels which includes covered electrodes, solid wires, wire/flux combinations for submerged arc welding and all positional flux cored wires (FCW). The use of FCW is particularly important since any method that can provide productivity improvements compared to the conventional TIG (GTAW) and MMA (SMAW) procedures will provide significant economic benefits. This technical profile concentrates on the potential benefits that can arise from the use of the flux cored process, but this process is not suitable for all applications and therefore data on covered electrodes, solid wires and submerged arc fluxes is also included.

2 Applications

2.1 Base materials

The 1CrMo and 2CrMo consumables are used for welding matching composition base materials, in various forms, eg plate, pipe and castings; the 2CrMo consumables are also widely used for welding CrMoV base materials. Table 1 shows the relevant grades of material that can be welded, under the headings of 1CrMo, 2CrMo and CrMoV.

Table 1 Grades of material which can be welded

Product Form	*Standard*	*1CrMo Grade*	*2CrMo Grade*	*CrMoV Grade*
Plate	ASTM A387	Grade 11 & 12	Grade 21 & 22	
	BS 1502	620 – 440 620 – 540	622	
	BS EN 10028	13CrMo4-5 (1.7355)	10CrMo9-10 (1.7380) 11CrMo9-10 (1.7383)	
Pipe	ASTM A335	P11 & P12	P21 & P22	
	BS 3604	620 – 440 & 621	622	660
Forged & bored pipe	ASTM 369	FP11 & FP12	FP21 & FP22	
Tube	ASTM A199	T11	T21 & T22	
	ASTM A200	T11	T21 & T22	
	ASTM A213	T11 & T12	T21 & T22	
	BS 3059	620–460	622–490	
	DIN	13CrMo4 4 (1.7335)	10CrMo 9 10 (1.7380)	
Forging	ASTM A336	F11 class 1, 2 & 3 F12	F21 class 1 & 3 F22 class 1 & 3	
	BS 1503	620–440 620–540 621–460	622–490 622–560 622–650	660–460
	BS EN 10222	13CrMo4-5 (1.7335)	11CrMo9-10 (1.7383)	
Forged fitting	ASTM A182	F11 class 1, 2 & 3	F22 class 1 & 3	
		F12 class 1 & 2		
Fittings	ASTM A234	WP11 class 1, 2 & 3 WP12 class 1 & 2	WP22 class 1 & 3	
Castings	ASTM A217	WC6, WC11	WC9	
	BS 3100	B2	B3	B7
	DIN	GS-25CrMo4 (1.7128) GS-17CrMo5.5 (1.7357)	GS-18CrMo9-10 (1.7379) GS-12CrMo9-10 (1.7380)	GS-17CrMoV5 11 (1.7706)

2.2 Applications

The base materials reviewed in section 2.1 have a range of applications at elevated temperatures for creep-resistance in power plant and high temperature hydrogen resistance in refineries. Typical uses are for boilers, pressure vessels, high pressure piping, heat exchangers, condensers etc, at temperatures up to 550°C (1020°F) for 1CrMo and 600°C (1110°F) for 2CrMo. The industrial sectors these base materials are used in fall into two broad groups – power generation and petrochemical. This Technical Profile concentrates on power generation applications; for petrochemical applications, particularly those with sub-zero impact requirements or temper embrittlement requirements, contact Metrode Technical Department.

2.3 As-welded repairs

There are situations in which it is difficult or impractical to carry out PWHT and procedures have been developed that allow welds to be carried out in CrMo steels without PWHT. The techniques are predominantly used for repairs in the type IV zone of P22 and CrMoV steels. The consumables that are used generally match the 2CrMo consumables but are lower in carbon (<0.05%) to help minimise weld metal hardness.

The welding techniques, commonly called temper bead repairs, are designed to minimise the hardness in the base material HAZ and produce optimum refinement in the base material HAZ. The techniques involve careful bead placement and control of bead size to optimise the refinement produced as subsequent weld beads are deposited. Full details of the procedures and techniques are not covered, but there is as-welded property data presented for the MMA (Chromet 2L) and FCW (Cormet 2L).

3 Consumable specifications

The analysis requirements of the relevant national standards are shown in Table 2 and the mechanical properties in Table 3. The analysis requirements are straightforward and do not generally present any problems. It should be noted that the two specifications listed for solid TIG/MIG wires (AWS A5.28 and BS EN 12070) cannot both be met by the same wire because the Mn range in AWS A5.28 is 0.40-0.70% and in BS EN 12070 is 0.80-1.20%. For this reason, Metrode offers two wires for P11 (1CrMo and ER80S-B2) and two for P22 (2CrMo and ER90S-B3); one is certified to the ASME specification and one to the European specification.

As can be seen from Table 3, there are differences in preheat/interpass and PWHT temperatures from one specification to another and also for different processes. There are also differences in the minimum tensile properties. One of the most notable differences is for the 1CrMo solid wire – the AWS specification has a nominal PWHT of 620°C (1150°F) with a proof stress minimum of 470MPa (68ksi) and UTS minimum of 550MPa (80ksi), whereas the BS EN specification has a PWHT of nominally 680°C (1255°F) and minimum strength of 355MPa (51ksi) and 510MPa (74ksi) respectively.

In addition to the variation in PWHT temperature, all of the standards specify a PWHT time of only one hour; it should be emphasised that these PWHT requirements are for consumable classification purposes and are not necessarily representative of fabrication practice. Although requirements vary from code to code, for fabrication work PWHT will nearly always be applied (there are some exceptions allowed for thin wall and small diameter pipe). In practice, PWHT for both 1CrMo and 2CrMo will be nominally 690°C (1275°F), codes should be referred to for specific requirements. The duration of the PWHT will also vary, being mainly dependent on material thickness; a general guideline being one hour per 25mm (1in) of thickness.

The other big difference between the AWS/ASME standards and the European standards is the impact property requirement imposed by the European standards. Many authorities, particularly for power generation applications, do not have specific impact property requirements. More information is given on toughness in Section 5.4, but it should be noted at this point that the flux cored wires will not consistently achieve the impact requirements of BS EN 12071 particularly after only a one hour PWHT.

Table 2 Analysis requirements of relevant national standards

Alloy	*Process*	*Specification*	*Analysis, wt% (single values are maximum)*										
			C	*Mn*	*Si*	*S*	*P*	*Cr*	*Mo*	*Cu*	*Ni*	*Nb*	*V*
1CrMo	*TIG/MIG*	*AWS A5.28: ER80S-B2*	0.07-0.12	0.40-0.70	0.40-0.70	0.025	0.025	1.20-1.50	0.40-0.65	0.35	0.20	--	--
		BS EN 12070: W/G CrMo1Si	0.08-0.14	0.80-1.20	0.50-0.80	0.020	0.020	0.90-1.30	0.40-0.65	0.3	0.3	0.01	0.03
	MMA	*AWS A5.5: E8018-B2*	0.05-0.12	0.90	0.80	0.03	0.03	1.00-1.50	0.40-0.65	--	--	--	--
		BS EN 1599: E CrMo1	0.05-0.12	0.40-1.50	0.80	0.025	0.030	0.90-1.40	0.45-0.75	0.3	0.3	0.01	0.03
	SAW	*AWS A5.23: EB2*	0.07-0.15	0.45-1.00	0.05-0.30	0.025	0.025	1.00-1.75	0.45-0.65	0.35	--	--	--
		BS EN 12070: S CrMo1	0.08-0.15	0.60-1.00	0.05-0.25	0.020	0.020	0.90-1.30	0.40-0.65	0.3	0.3	0.01	0.03
	FCW	*AWS A5.29: E81T1-B2M*	0.05-0.12	1.25	0.80	0.03	0.03	1.00-1.50	0.40-0.65	--	--	--	--
		BS EN 12071: TCrMo1 PM2	0.05-0.12	0.40-1.30	0.80	0.020	0.020	0.90-1.40	0.40-0.65	0.3	0.3	0.01	0.03
2CrMo	*TIG/MIG*	*AWS A5.28: ER90S-B3*	0.07-0.12	0.40-0.70	0.40-0.70	0.025	0.025	2.30-2.70	0.90-1.20	0.35	0.20	--	--
		BS EN 12070: W/G CrMo2Si	0.04-0.12	0.80-1.20	0.50-0.80	0.020	0.020	2.3-3.0	0.90-1.20	0.3	0.3	0.01	0.03
	MMA	*AWS A5.5: E9018-B3*	0.05-0.12	0.90	0.80	0.03	0.03	2.00-2.50	0.90-1.20	--	--	--	--
		BS EN 1599: E CrMo2	0.05-0.12	0.40-1.30	0.80	0.025	0.030	2.0-2.6	0.90-1.30	0.3	0.3	0.01	0.03
		National Power	0.04-0.10	0.5-1.2	0.50	0.015	0.020	2.0-2.5	0.9-1.2	0.15	--	--	--
	SAW	*AWS A5.23: EB3*	0.05-0.15	0.40-0.80	0.05-0.30	0.025	0.025	2.25-3.00	0.90-1.10	0.35	--	--	--
		BS EN 12070: S CrMo2	0.08-0.15	0.30-0.70	0.05-0.25	0.020	0.020	2.2-2.8	0.90-1.15	0.3	0.3	0.01	0.03
	FCW	*AWS A5.29: E91T1-B3M*	0.05-0.12	1.25	0.80	0.03	0.03	2.00-2.50	0.90-1.20	--	--	--	--
		BS EN 12071: TCrMo2 PM2	0.05-0.12	0.40-1.30	0.80	0.020	0.020	2.00-2.50	0.90-1.30	0.3	0.3	0.01	0.03
		National Power	0.04-0.10	0.5-1.2	0.50	0.015	0.020	2.0-2.5	0.9-1.2	0.15	--	--	--

Table 3 Mechanical property requirements of relevant national standards

Alloy	*Process*	*Specification*	*Preheat – interpass °C (°F)*	*PWHT °C/h (°F/h)*	*0.2% proof stress MPa (ksi)*	*UTS MPa (ksi)*	*Elongation %*	*Impact Properties av / min J @ +20°C (ft-lb @ 68°F)*
1CrMo	*TIG/MIG*	*AWS A5.28: ER80S-B2*	135-165 (275-325)	605-635/1 (1125-1175/1)	470 (68)	550 (80)	19	--
		BS EN 12070: W/G CrMo1Si	150-250 (300-480)	660-700/1 (1220-1290/1)	355 (51)	510 (74)	20	47 / 38 (35 / 28)
	MMA	*AWS A5.5: E8018-B2*	163-191 (325-375)	676-704/1 (1250-1300/1)	460 (67)	550 (80)	19	--
		BS EN 1599: E CrMo1	150-250 (300-480)	660-700/1 (1220-1290/1)	355 (52)	510 (74)	20	47 / 38 (35 / 28)
	SAW	*AWS A5.23: F8 PZ EB2*	135-165 (275-325)	690/1 (1275/1)	470 (68)	550-700 (80-100)	20	--
		BS EN 12070: S CrMo1	150-250 (300-480)	660-700/1 (1220-1290/1)	355 (52)	510 (74)	20	47 / 38 (35 / 28)
	FCW	*AWS A5.29: E81T1-B2M*	161-191 (325-375)	675-705/1 (1250–1300/1)	470 (68)	550–690 (80–100)	19	--
		BS EN 12071: TCrMo1 PM2	150–250 (300–480)	660–700/1 (1220–1290/1)	355 (52)	510 (74)	20	47 / 38 (35 / 28)
2CrMo	*TIG/MIG*	*AWS A5.28: ER90S-B3*	185-215 (375-425)	675-705/1 (1250-1300/1)	540 (78)	620 (90)	17	--
		BS EN 12070: W/G CrMo2Si	200–300 (390–570)	690-750/1 (1275-1380/1)	400 (58)	500 (73)	18	47 / 38 (35 / 28)
	MMA	*AWS A5.5: E9018-B3*	163-191 (325-375)	676-704/1 (1250-1300/1)	530 (77)	620 (90)	17	--
		BS EN 1599: E CrMo2	200–300 (390–570)	690-750/1 (1275-1380/1)	400 (58)	500 (73)	18	47 / 38 (35 / 28)
		National Power	200–300 (390–570)	690/1 (1275/1)	480 (70)	590 (86)	17	47 / 38 (35 / 28)
	SAW	*AWS A5.23: F9 PZ EB3*	190-220 (375-425)	690/1 (1275/1)	540 (78)	620-760 (90-110)	17	--
		BS EN 12070: S CrMo2	200–300 (390–570)	690-750/1 (1275-1380/1)	400 (58)	500 (73)	18	47 / 38 (35 / 28)
	FCW	*AWS A5.29: E91T1-B3M*	161-191 (325-375)	675 - 705/1 (1250–1300/1)	540 (78)	620–760 (90–110)	17	--
		BS EN 12071: TCrMo2 PM2	200–300 (390–570)	690–750/1 (1275–1380/1)	400 (58)	500 (73)	18	47 / 38 (35 / 28)
		National Power	250–350 (480–660)	690/1 (1275/1)	480 (70)	590 (86)	17	47 / 38 (35 / 28)

4 Welding processes and consumables

Very few joints are completed using a single welding process, for example a TIG root may be used with a MMA hot pass followed by a FCW fill; Table 4 shows the full range of Metrode products and data sheets are given in appendix 1.

Table 4 1CrMo and 2CrMo consumables

Alloy	*Process*	*Consumable*	*AWS*	*BS EN*
1CrMo	*TIG/GTAW*	1CrMo	A5.28 ER80S-G	BS EN 12070 WCrMo1Si
		ER80S-B2	A5.28 ER80S-B2	-
	MIG/GMAW	1CrMo	A5.28 ER80S-G	BS EN 12070 GCrMo1Si
		ER80S-B2	A5.28 ER80S-B2	-
	MMA/SMAW	Chromet 1	A5.5 E8018-B2	BS EN 1600 ECrMo1B
		Chromet 1L	A5.5 E7015-B2L	BS EN 1600 ECrMo1LB
		Chromet 1X	A5.5 E8018-B2	BS EN 1600 ECrMo1B
	SAW	SA1CrMo (wire)	A5.23 EB2	BS EN 12070 SCrMo1
		LA121 (flux)	--	BS EN 760 SAFB1
		LA491 (flux)	--	BS EN 760 SA FB 255 AC
		L2N (flux)	--	BS EN 760 SF CS 2 DC
	FCW	Cormet 1	A5.29 E81T1-B2M	(BS EN 12071 TCrMo1 PM2)
2CrMo	*TIG/GTAW*	2CrMo	A5.28 ER90S-G	BS EN 12070 WCrMo2Si
		ER90S-B3	A5.28 ER90S-B3	-
	MIG/GMAW	2CrMo	A5.28 ER90S-G	BS EN 12070 GCrMo2Si
		ER90S-B3	A5.28 ER90S-B3	-
	MMA/SMAW	Chromet 2	A5.5 E9018-B3	BS EN 1600 ECrMo2B
		Chromet 2L	A5.5 E8015-B3L	BS EN 1600 ECrMo2LB
		Chromet 2X	A5.5 E9018-B3	BS EN 1600 ECrMo2B
	SAW	SA2CrMo (wire)	A5.23 EB3	BS EN 12070 SCrMo2
		LA121 (flux)	--	BS EN 760 SAFB1
		LA491 (flux)	--	BS EN 760 SA FB 255 AC
		L2N (flux)	--	BS EN 760 SF CS 2 DC
	FCW	Cormet 2	A5.29 E91T1-B3M	(BS EN 12071 TCrMo2 PM2)
		Cormet 2L	A5.29 E91T1-B3LM	BS EN 12071 TCrMo2L PM2

4.1 TIG/GTAW

Solid TIG wires are mainly used for welding small diameter pipework and for root runs in larger diameter thicker walled pipes. Small diameter spooled wires are sometimes used for orbital auto-TIG welding of pipework.

Two wire specifications are offered for each of the two grades. These are 1CrMo and 2CrMo, which conform to the European specifications and ER80S-B2 and ER90S-B3 which conform to the AWS/ASME specifications.

Welding is normally carried out using pure argon shielding gas, but at the alloy content of these wires, gas purging is not necessary for pipe root runs.

4.2 MIG/GMAW

As with the TIG wires two specifications are offered. However the MIG process is not widely used except under shop conditions for general fabrication. If a continuous wire semi-automatic process is required, flux cored wires are recommended, see Section 4.5.

4.3 MMA/SMAW

Electrodes are widely used both for site repairs and for new shop fabrication because of their versatility and flexibility. Although the FCW process is being more widely used, particularly in the power generation industry.

The CrMo electrodes offered are all-positional basic low hydrogen types with moisture resistant coatings, which give low hydrogen levels of less than 5ml/100g of deposited weld metal. They are supplied in hermetically sealed metal tins and can be used direct from the tins without redrying. Vacuum sealed site packs, which contain smaller quantities suitable for use in a single shift, are available to special order. Electrodes which have been exposed can be dried to restore them to the original as-packed condition.

There are three types of electrode for both the 1CrMo and 2CrMo alloys: the standard product (Chromet 1 & Chromet 2), a low carbon type (Chromet 1L & Chromet 2L) and a temper embrittlement resistant version (Chromet 1X & Chromet 2X). The low carbon types are primarily used for joints that will be left as-welded or for petrochemical applications where hardness is critical. The temper embrittlement resistant versions are also generally used for petrochemical applications but are not covered in detail here: contact Metrode for data on these products.

4.4 Submerged arc

Submerged arc welding is a high productivity process suitable for use with thicker components that can be placed in the flat position, or that can be rotated. For this reason it is mainly confined to the fabrication of larger components under workshop conditions and is seldom used for on site repairs.

Submerged arc wires designated SA1CrMo and SA2CrMo are available in 2.4, 3.2 and 4mm diameters and the recommended flux is LA121. This is a basic agglomerated flux with a Boniszewski Basicity Index of about 3.1 and essentially neutral with respect to Mn and Si pickup/burnout. This wire/flux combination is capable of producing high quality low hydrogen weld deposits, provided correct flux storage and handling procedures and suitable welding procedures are used. The flux is supplied in sealed moisture resistant metal drums but if it has become damp or has been stored for long periods, it can be redried to give low moisture content.

There are other Metrode fluxes that are also suitable for use with the SA1CrMo/SA2CrMo wires – LA491 and L2N, but the LA121 flux is recommended. For optimum bead appearance, the L2N provides benefits and it has the advantage of being a fused flux so is not prone to moisture absorption.

4.5 Flux cored wire

The flux cored wires manufactured by Metrode are rutile all-positional wires. Using a rutile flux system limits the potential toughness but has significant advantages in terms of positional welding capability. The following sections expand on the characteristics and advantages of the Cormet flux cored wires.

4.5.1 Power utility approval of Cormet

A programme of work carried out by National Power (now Innogy), PowerGen (now E-on) and Nuclear Electric in the UK (collectively the Electricity Generators Welding Panel, EGWP) identified the flux cored wire (FCW) process as having the required attributes for in-situ repairs. FCW's have a number of advantages over MMA and solid wire MIG welding:

- high productivity compared to MMA
- all-positional capability in the spray mode without the need for synergic pulsed MIG equipment
- all-positional capability without the lack of fusion defects sometimes associated with solid wire MIG
- easily detached slag compared to MMA.

As a result of the EGWP project on 2CrMo, of the six FCW's submitted and tested, only Cormet 2 was approved by National Power (now Innogy) for in-situ repairs on 2CrMo/CrMoV material. PowerGen (now E-on) also accept the use of Cormet 2 on a project by project basis.

Following this work and the acceptance of Cormet 2 for in-situ repairs, Cormet 1 and Cormet 2 are being more widely considered for initial fabrication. For thick section joints in the flat position, submerged arc welding still provides the best productivity but for fixed pipework and other positional joints, Cormet 1 and Cormet 2 provide a high productivity alternative to TIG and MMA procedures.

4.5.2 Productivity

Deposition rate is often used as a guideline to rank the relative productivity of different welding processes. Figure 2 shows the relative deposition rates for MMA, MIG and FCW. At the typical current used for positional welding, the FCW process shows a distinct advantage: ~1kg/h (2.2lb/h) for MMA; 1.5–2kg/h (3.3–4.4lb/h) for MIG and 2-3kg/h (4.4–6.6lb/h) for FCW.

For a true comparison, duty cycle should be taken into account, so joint completion rates are a more useful guideline. From reports by National Power (Innogy) and engineering contractors, reductions in joint completion rate of 25–40% have been seen for FCW in comparison to MMA, on 310-360mm (12-14in) internal diameter pipe of ~65mm (~2.5in) wall thickness. Time savings of this order can be very important, especially in shutdown situations where any reduction in time can be vital in getting the power plant back on line.

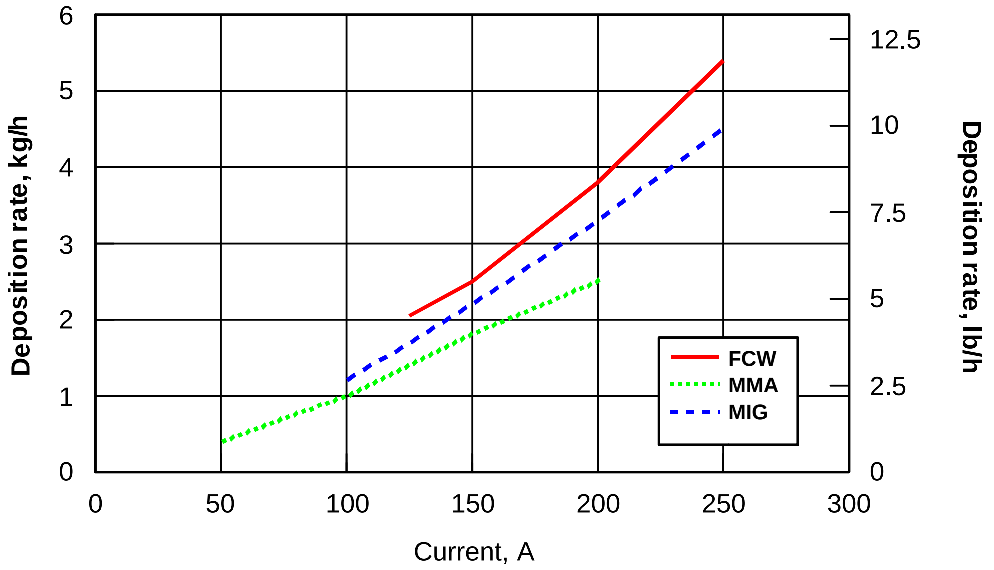

Figure 2 Deposition rates for three welding processes

4.5.3 Practical procedural guidelines

The FCW process can be relatively quickly adapted to by skilled welders and the nature of the process allows the same parameters to be used for welding in all positions. This section covers the main procedural welding parameters and general guidelines on welding technique; some examples of weld procedure records are given in Appendix 2.

4.5.3.1 When to use Cormet

The Cormet 1 and Cormet 2 wires should be considered for use on both positional and flat joints, or for filling excavations often encountered on repair work. The minimum thickness that FCW is normally considered for is ~15mm (0.6in) and for pipework the minimum diameter is normally ~200mm (8in).

4.5.3.2 Shielding gas

Both Cormet 1 and Cormet 2 are designed for use with Ar-20%CO_2 (with or without 2%O_2 addition) shielding gas. Shielding gases with lower CO_2 contents, eg Ar-5%CO_2, are not recommended because the lower CO_2 content does not give optimum arc transfer characteristics and also increases the risk of porosity. The Cormet 1 and Cormet 2 wires will also operate satisfactorily using 100% CO_2 shielding gas, although there will be a minor increase in spatter and slightly coarser arc transfer compared to Ar-20%CO_2.

BS EN 439 covers shielding gas classification and the recommended shielding gas according to this standard is M21 (Ar-20%CO_2) or M24 (Ar-20%CO_2-2%O_2). Typical examples of the commercially available shielding gases recommended for use with Cormet 1 and Cormet 2 are:

- Argoshield Heavy (previously Argoshield 20) - BOC
- Coogar 20 – Air Products
- Krysal 20 – Distillers MG
- Corgon 20 - Linde

If the shielding gas is changed from the recommended M21/M24, then the effect on weld metal composition should be considered. The Cormet 1 and Cormet 2 wires are both certified to analyses carried out using Ar-20%CO_2-2%O_2 shielding gas. If alternative gases are used, then it will have an effect on weld metal composition, especially the deoxidants Mn and Si; the major alloying (Cr and Mo) will remain fairly constant. As the CO_2 content is increased, more Mn and Si are burnt out, see Table 5. The recommended shielding gas flow rates are 20–25 l/min (0.7–0.9 ft^3/min).

Table 5 Example of variation in deposit analysis with shielding gas for flux cored wire

	Ar-5%CO_2	Ar-20%CO_2	100%CO_2
C	0.049	0.049	0.041
Mn	1.14	1.02	0.90
Si	0.37	0.29	0.19

4.5.3.3 Electrode stickout

The electrode stickout is defined as the distance between the contact tip and the workpiece. The electrode stickout is important to obtain sufficient preheating of the wire, which ensures freedom from porosity. Generally, the stickout should be in the range 15-25mm (0.6-1.0in) for both 1.2mm (0.047in) and 1.6mm (1/16in) diameter wires.

4.5.3.4 Current and voltage

The Cormet 1 and Cormet 2 wires provide excellent all-positional operability on standard MIG welding machines (using DC+ polarity), without the need for synergic pulsed MIG machines.

Both the Cormet 1 and Cormet 2 wires are designed to be used in the spray transfer mode throughout their operational range. The parameter box for 1.2mm (0.047in) wire is shown in Figure 3, with the region for all-positional welding highlighted; this parameter box is based on Ar-20%CO_2 shielding gas and is applicable to both Cormet 1 and Cormet 2. Although welding procedures usually refer to welding current, most MIG machines are controlled by wire feed speed (WFS); the approximate WFS for a 1.2mm (0.047in) diameter wire is also shown on Figure 3. The WFS given is only intended for guidance because the relationship between current and WFS is not fixed but is also dependent on electrode stickout.

The welding parameters will have a marginal effect on weld metal composition but within the recommended parameter range this will be of limited significance.

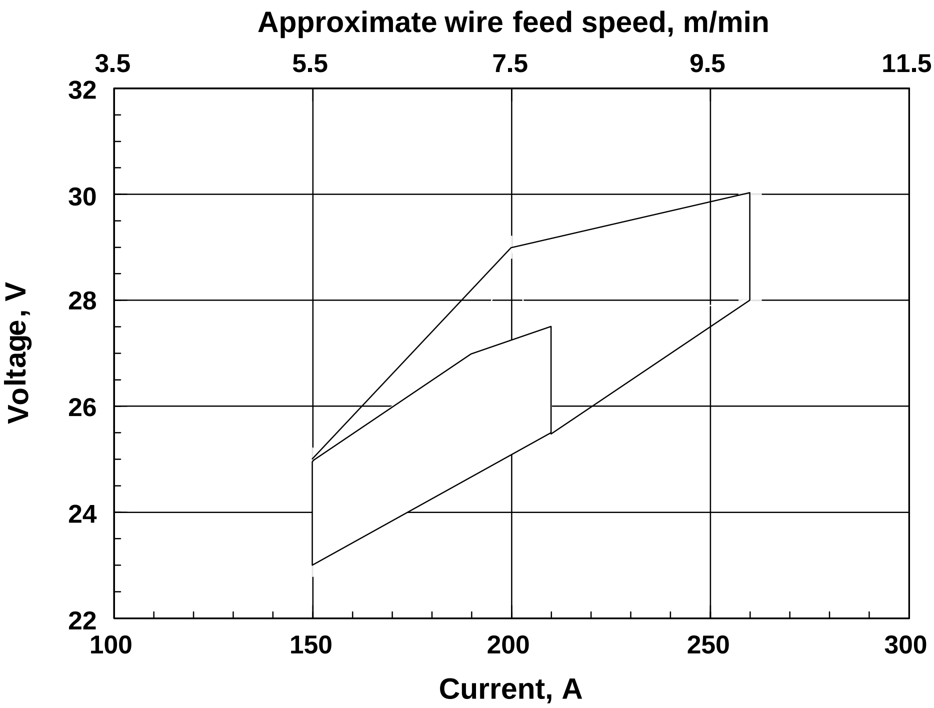

Figure 3 Parameter box for 1.2mm (0.047in) diameter wire using Ar-20%CO_2 shielding gas

4.5.3.5 Welding gun manipulation

When welding in the flat (ASME: 1G, BS EN: PA) or on HV fillet welds (ASME: 2F, BSEN: PB), the welding should be carried out as for MMA using a backhand/pulling technique, Figure 4. When welding positionally, eg vertically (ASME: 3G, BS EN: PF) or pipe joints (ASME: 5G/6G, BS EN PF/HL045), then the gun is generally held perpendicular to the joint although an angle ~10° from the perpendicular can help weld pool control, Figure 5.

Weaving is sometimes required to ensure weld pool control especially when welding positionally; when a weave is used the weave width should generally be limited to about 10–12mm (0.4–0.5in).

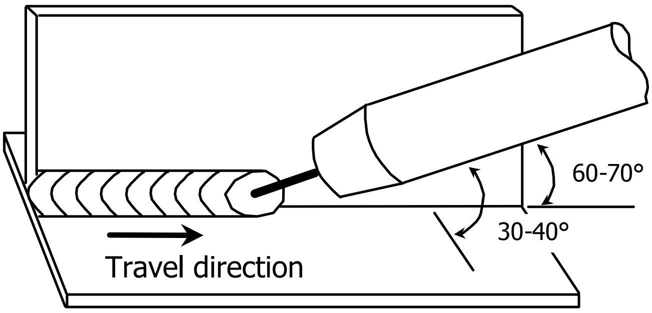

Figure 4 Gun angles for flat and HV welding

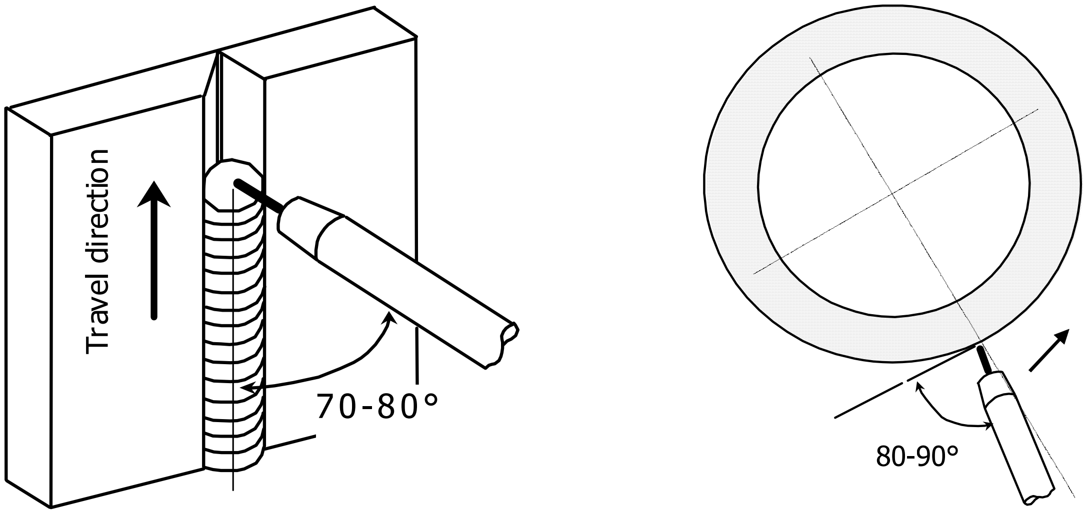

Figure 5 Gun angles for positional welding

4.5.3.6 Wire feeding

With any continuous wire process, consistent uninterrupted wire feeding is important to ensure satisfactory welding; in this respect the set-up of the machine is probably more important with FCW than with solid wire. The wire feed rolls need to be set at the correct pressure; a common mistake is to over-tighten the feed rolls and crush the wire. Dual feed roll systems are generally preferred with grooved or knurled drive rolls. To prevent problems before they occur, eg 'bird nesting', it is important to ensure that wire guide tubes are fitted correctly on the wire feeder. Another practical point that has proved beneficial is to cut the wire at an angle rather than straight across, this helps to provide positive arc ignition rather than the wire stubbing into the plate.

To ensure that wires have good feedability, in-house tests are carried out at Metrode using a wire feed test rig. This allows a continuous test period of 10-20 minutes on a mechanised traverse; during this period the current and voltage load on the wire feed motor are recorded. This provides a convenient method of carrying out consistent and reproducible tests which ensure that all the wires feed consistently and reliably.

5 Properties

In general terms the mechanical properties of welds made with different consumable types are similar. The exception is toughness and typical impact values for the different consumable types can be found in Section 5.4. Solid wire gas shielded processes give the best toughness, followed by covered electrodes and submerged arc welds. Deposits made using FCW give lower values but these are more than adequate for the power generation industry. However, the petrochemical industry sometimes specifies more demanding requirements and tends to prefer the use of consumables which give higher impact values. For those areas of application where temper embrittlement is a potential problem, special consumables Chromet 1X and 2X are available. For information and data on these products, the Metrode Technical department should be consulted.

The properties of the P11 and P22 consumables can be discussed under three main headings: deposit analysis, hydrogen and mechanical properties.

5.1 Weld metal analysis

The analysis requirements of the national specifications and of known user specifications are given in Table 3. The typical analyses of the Metrode consumables are listed in Table 6.

Table 6 Typical analysis of P11 and P22 consumables and weld deposits

Alloy	*Consumable*	*Analysis **	*C*	*Mn*	*Si*	*S*	*P*	*Cr*	*Mo*	*Cu*
1CrMo	*ER80S-B2*	Wire	0.1	0.5	0.5	0.010	0.015	1.3	0.5	0.1
	1CrMo	Wire	0.1	1.0	0.6	0.010	0.015	1.2	0.5	0.1
	MIG 1CrMo	Deposit 95/5	0.09	0.8	0.5	0.010	0.015	1.1	0.5	0.1
	MIG 1CrMo	Deposit 80/20	0.09	0.7	0.45	0.010	0.015	1.1	0.5	0.1
	Chromet 1	Deposit	0.07	0.8	0.3	0.012	0.015	1.2	0.55	0.1
	SA1CrMo	Deposit LA121	0.07	0.8	0.25	0.010	0.015	1.2	0.55	0.1
	Cormet 1	Deposit 95/5	0.05	0.7	0.3	0.012	0.012	1.3	0.55	0.1
	Cormet 1	Deposit 80/20	0.06	0.65	0.25	0.012	0.012	1.3	0.55	0.1
	Cormet 1	Deposit 80/20/2	0.06	0.55	0.2	0.012	0.012	1.3	0.55	0.1
2CrMo	*ER90S-B3*	Wire	0.1	0.5	0.5	0.010	0.015	2.4	1.0	0.1
	2CrMo	Wire	0.1	1.0	0.6	0.010	0.015	2.4	1.0	0.1
	MIG 2CrMo	Deposit 95/5	0.08	0.8	0.5	0.010	0.015	2.4	1.0	0.1
	MIG 2CrMo	Deposit 80/20	0.09	0.7	0.45	0.010	0.015	2.4	1.0	0.1
	MIG 2CrMo	Deposit 80/20/2	0.08	0.6	0.4	0.010	0.015	2.3	1.0	0.1
	Chromet 2	Deposit	0.07	0.8	0.3	0.012	0.015	2.2	1.0	0.1
	SA2CrMo	Deposit LA121	0.07	0.8	0.25	0.010	0.015	2.2	1.0	0.1
	Cormet 2	Deposit 80/20/2	0.06	0.7	0.3	0.012	0.012	2.2	1.0	0.1

* Shielding gas: 95/5=Ar-5%CO_2, 80/20=Ar-20%CO_2, 80/20/2=Ar-20%CO_2-2%O_2.

As discussed in Section 5.2 and 5.4, shielding gas and welding parameters can have marginal effects on deposit composition of the flux cored wires and the flux will affect the sub-arc deposit analysis.

5.2 Weld metal hydrogen

With gas shielded processes (TIG and MIG) hydrogen control is not generally a problem. With the flux shielded processes (MMA, FCW and SAW) more caution is required to ensure low hydrogen weld metal is deposited.

5.2.1 MMA

The MMA electrodes are manufactured with moisture resistant coatings that can be used directly from the tin. Over the period of a normal eight hour shift the electrodes will normally provide low hydrogen weld metal; after this it is recommended that the electrodes are redried.

5.2.2 Flux cored wire

Using standard parameters and Ar-20%CO_2 shielding gas, both Cormet 1 and Cormet 2 are capable of producing low hydrogen weld deposits direct from sealed packaging. In this case low hydrogen level is taken as < 5ml/100g of weld metal (BS 5135 Scale D). The behaviour of both Cormet 1 and 2 are the same, but the actual hydrogen content will depend on weld procedure especially current and electrode stickout. The graphs in Figure 6 show the relationship between weld metal hydrogen and welding current and electrode stickout. The use of 100%CO_2 shielding gas produces a marked reduction in weld metal hydrogen, but welding characteristics will also deteriorate compared to Ar-20%CO_2.

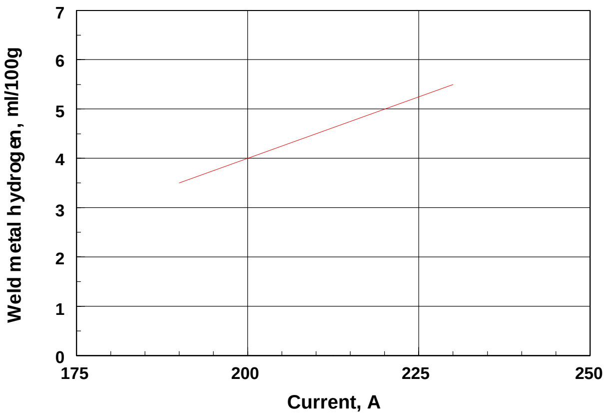

Figure 6a Effect of current on weld metal hydrogen

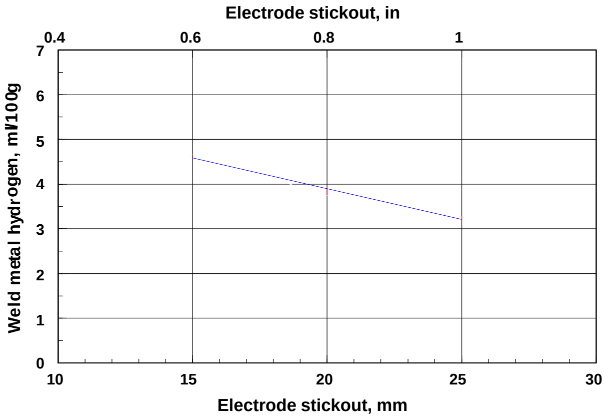

Figure 6b Effect of electrode stickout on weld metal hydrogen

With respect to weld metal hydrogen levels, resistance to moisture absorption is also important. In order to maintain both Cormet 1 and Cormet 2 in optimum condition, it is recommended that part used spools are repacked and returned to a heated store (60%RH maximum and 18°C minimum). Figure 7 shows the effect of exposure at up to 90%RH on the deposited weld metal hydrogen content.

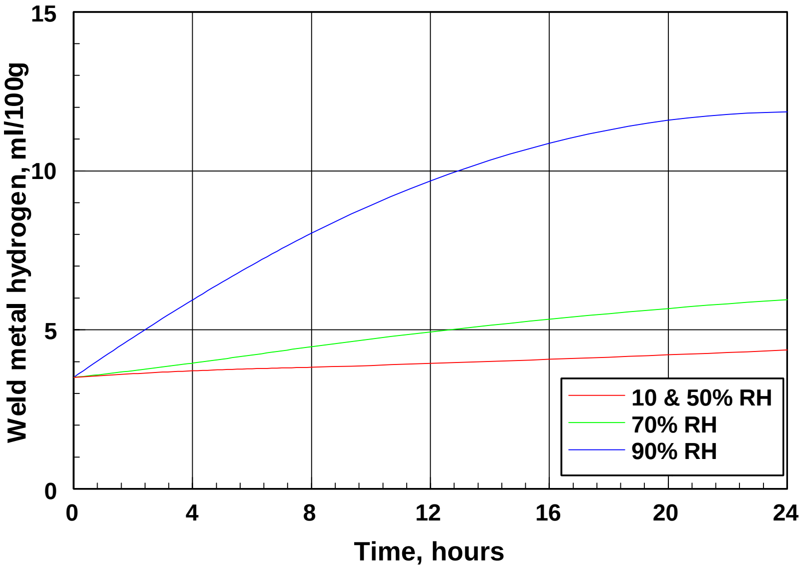

Figure 7 Effect of exposure on weld metal hydrogen

5.3 Tensile properties

The tensile requirements of the relevant national standards have already been listed in Table 3; typical tensile properties for Metrode's consumables are listed in Tables 7 and 8. The strength of the weld metal is generally well above the requirements and the base material minimum. Transverse tensile tests would certainly be expected to fail in the base material (remote HAZ).

Table 7 Typical room temperature tensile properties for Metrode 1CrMo consumables

Process	*PWHT °C/hr (°F/hr)*	*0.2% proof stress, MPa (ksi)*	*UTS, MPa (ksi)*	*Elongation %*		*RoA %*	*Hardness HV*
				4d	*5d*		
P11 material min	Tempered 650 min (1200 min)	205 (30)	415 (60)	20	--	--	--
13CrMo4-5 material min	Tempered 630-740 (1165-1365)	295 (43)	440-590 (64-86)	--	18	-	--
1CrMo TIG	690/24 (1275/1)	440 (64)	575 (83)	32	29	75	200
ER80S-B2	620/1 (1150/1)	560 (81)	660 (96)	27	23	75	--
TIG	690/2 (1275/2)	500 (73)	600 (87)	34	30	80	215
	690/9 (1275/9)	485 (70)	590 (86)	28	24	70	190
	710/3 (1310/3)	420 (61)	525 (76)	35	31	80	180
1CrMo MIG	640/1.5 (1185/1.5)	545 (79)	660 (96)	25	22	70	220
(95/5 or	640/6 (1185/6)	495 7(2)	620 (90)	27	25	70	205
80/20 gas)	690/24 (1275/24)	440 (64)	560 (81)	31	27	70	185
Chromet 1	As-welded	625 (91)	695 (101)	24	21	70	250
	690/1 (1275/1)	575 (83)	615 (89)	24	22	70	220
	690/12 (1275/12)	475 (69)	565 (82)	28	25	75	190
Chromet 1L	As-welded	570 (83)	655 (95)	27	24	70	220
	690/1 (1275/1)	520 (75)	600 (87)	29	24	70	210
SA1CrMo + LA491	700/10 (1290/10)	360 (52)	480 (70)	40	34	70	180
Cormet 1	690/1 (1275/1)	550 (80)	620 (90)	24	21	70	210
	690/4 (1275/4)	530 (77)	600 (87)	24	21	70	205

Table 8 Typical room temperature tensile properties for Metrode 2CrMo consumables

Process	*PWHT °C/hr (°F/hr)*	*0.2% proof stress, MPa (ksi)*	*UTS, MPa (ksi)*	*Elongation %*		*RoA %*	*Hardness HV*
				4d	*5d*		
P22 material min	Tempered 675 min (1250 min)	205 (30)	415 (60)	20	--	--	--
11CrMo9-10 material min	Tempered 670-770 (1240-1415)	310 (45)	520-670 (75-97)	--	20	--	--
2CrMo TIG	640/1 (1185/1)	710 (103)	830 (120)	24	20	70	290
	690/1 (1275/1)	600 (87)	715 (104)	24	17	70	235
ER90S-B3	690/1 (1275/1)	560 (81)	675 (98)	25	22	235	--
TIG	690/7 (1275/7)	525 (76)	630 (91)	30	26	75	220
2CrMo MIG	640/1.5 (1185/1.5)	630 (91)	750 (109)	24	21	65	245
	640/6 (1185/6)	615 (89)	740 (107)	26	22	65	235
	690/4 (1275/4)	540 (78)	655 (95)	26	23	70	220
Chromet 2	625/1 (1155/1)	590 (86)	725 (105)	17	16	60	--
	690/1 (1275/1)	575 (83)	665 (96)	24	21	70	230
Chromet 2L	690/1 (1275/1)	555 (80)	635 (92)	25	21	70	215
SA2CrMo +	690/1 (1275/1)	545 (79)	650 (94)	23	21	70	225
LA491X	690/7 (1275/7)	500 (73)	605 (88)	28	24	75	205
SA2CrMo +	690/1 (1275/1)	500 (73)	610 (88)	27	23	73	210
LA491	690/7 (1275/7)	455 (66)	540 (78)				
Cormet 2	700/2 (1290/2)	615 (89)	700 (102)	22	20	65	235
Cormet 2L	As-welded	--	--	--	--	--	275
	690/2 (1275/2)	--	--	--	--	--	230

5.4 Impact properties

For the power generating industry there is not a great emphasis placed on impact properties of the CrMo materials. The BS EN standards for the classification of 1CrMo and 2CrMo consumables require minimum impact properties at +20°C (+68°F), see Table 3.

At ambient temperature the impact properties of the 1CrMo and 2CrMo consumables can vary considerably depending on the welding process and PWHT. For some of the processes (eg FCW), there is the additional complication that the transition temperature occurs at about room temperature so small changes in temperature can produce significantly different impact properties. Tables 9 and 10 show typical impact properties for the Metrode range of consumables. Additional data in the form of transition curves are shown for the MMA and FCW processes in Figures 8 and 9.

Table 9 Typical impact properties for 1CrMo Metrode consumables

Consumable	Process (gas)	PWHT °C/h (°F/h)	Temperature °C (°F)	Impact energy J (ft-lb)	Lateral expansion mm (inch)
1CrMo	TIG	690/4	-15	>200	>2.00
		690/24	-15	115	1.50
ER80S-B2	TIG	620/2	-20	>200	>2.00
			-40	140	1.90
1CrMo	MIG (95/5)	690/4	-15	135	1.90
		690/24	-15	90	1.35
	MIG (80/20)	690/4	-15	120	1.80
		690/24	-15	50	0.80
Chromet 1	MMA	690/12	-20	125	1.85
Chromet 1L	MMA	As-welded	+20	120	1.70
		690/1	-18	100	1.50
Cormet 1	FCW	700/1.5	+20	50	0.80
		700/4	+20	70	1.25

Table 10 Typical impact properties for 2CrMo Metrode consumables

Consumable	Process (gas)	PWHT °C/h (°F/h)	Temperature °C (°F)	Impact energy J (ft-lb)	Lateral expansion mm (inch)
2CrMo	TIG	690/1	-30	25	0.30
ER90S-B3	TIG	690/1	-20	>200	>2.00
		690/7	-18	160	2.00
			-40	125	1.80
2CrMo	MIG (95/5 or 80/20)	690/4	-20	90	1.20
			-40	60	0.85
Chromet 2	MMA	690/1	+20	160	1.90
			-20	50	0.55
Chromet 2L	MMA	690/1	-10	125	1.60
SA2CrMo	SAW (LA491)	690/1	-20	45	0.60
		690/7	+20	130	1.75
			-18	15	0.30
Cormet 2	FCW	700/1.5	+20	75	1.25
		700/14	+20	95	1.45
Cormet 2L	FCW	As-welded	+20	50	0.80

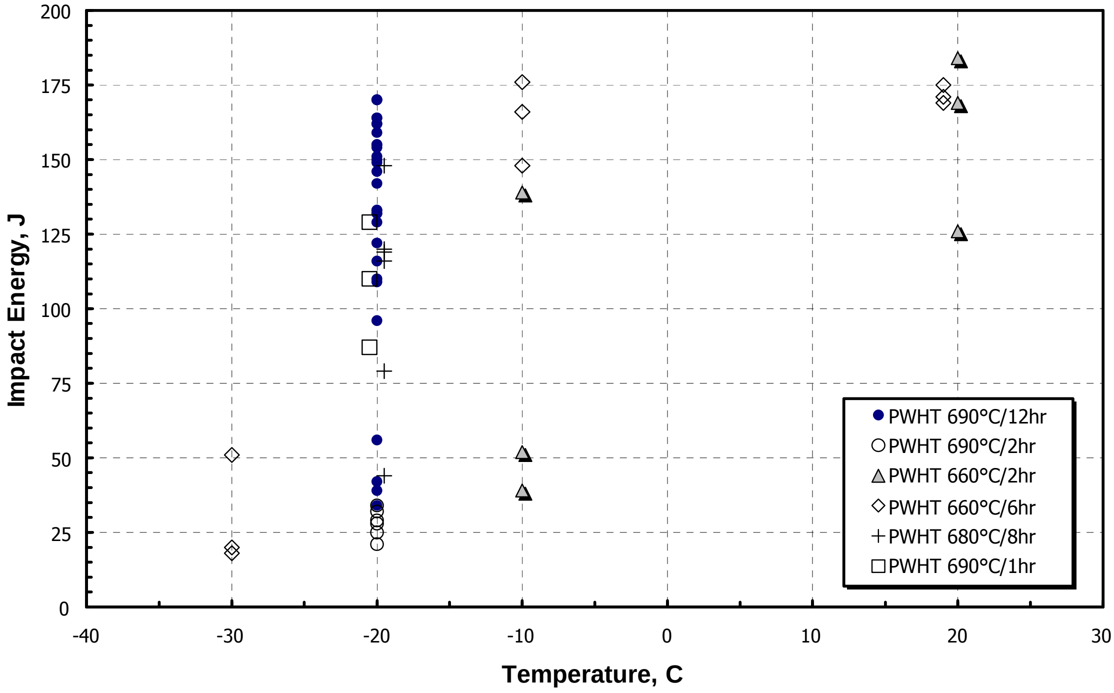

Figure 8a Chromet 1 impact properties

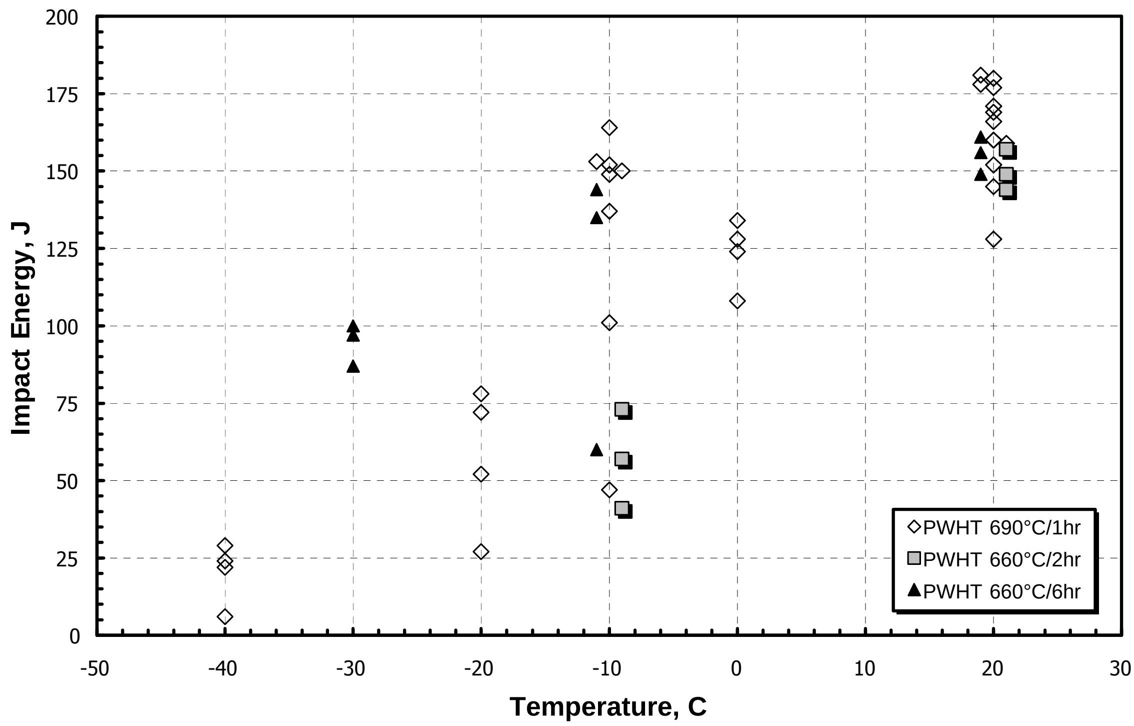

Figure 8b Chromet 2 impact properties

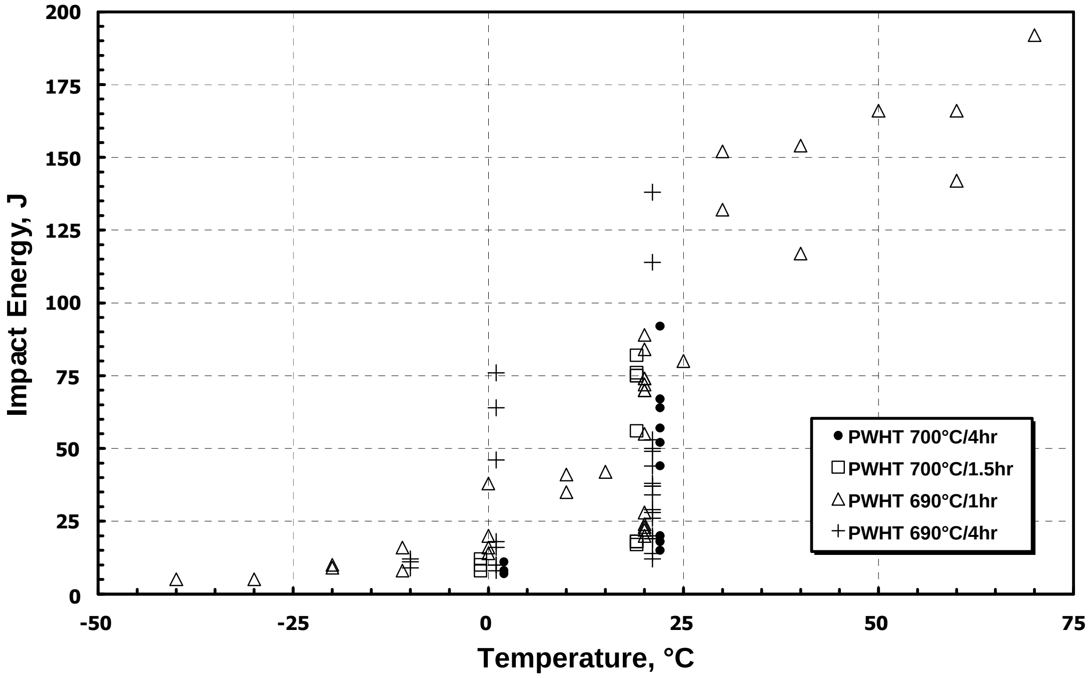

Figure 9a Impact transition data for Cormet 1

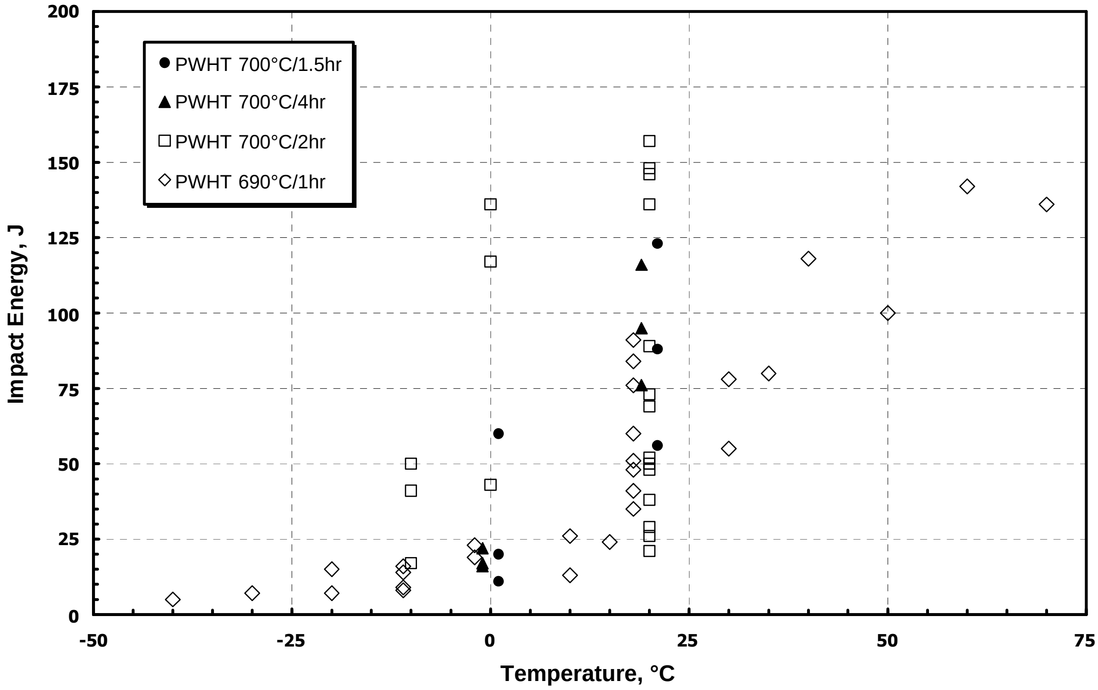

Figure 9b Impact transition data for Cormet 2

5.5 Hot tensile properties

Hot tensile data is not necessarily representative of service conditions but it provides a convenient means of comparing weld metal properties with the requirements of the base material. Figure 10 shows data for P11 TIG and MMA consumables in comparison to the minimum requirements of the 13CrMo4-5 (forged type P11) base material.

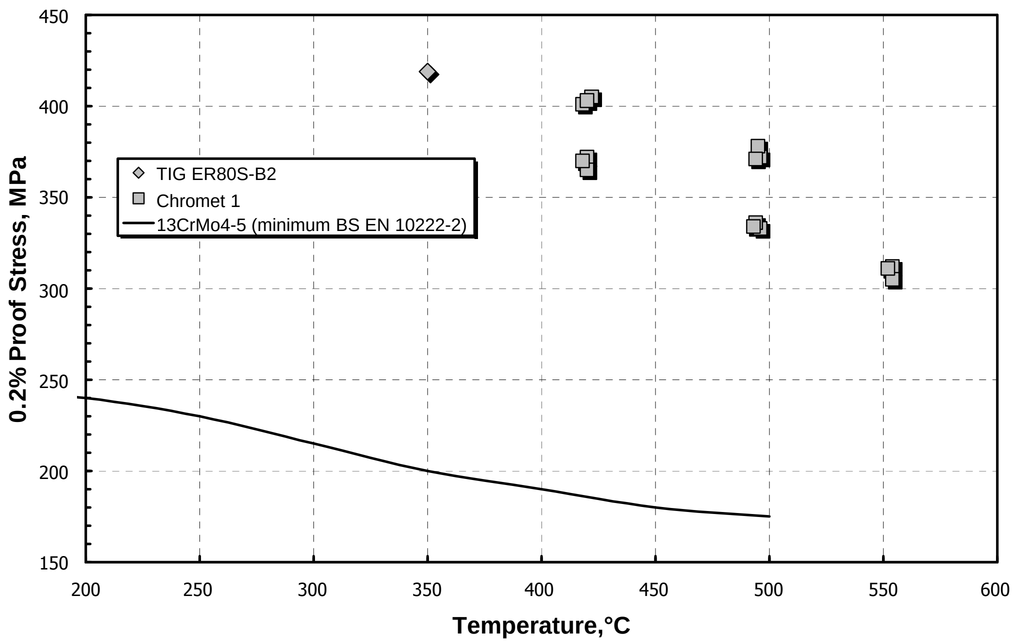

Figure 10 Hot tensile properties for P11 consumables

5.6 Stress rupture properties

For weld metals that are to be used at elevated temperatures, then the high temperature properties are of particular importance. Figure 11 shows representative stress rupture data for P22 consumables and how it compares to typical base material values. In service, the creep performance of a weld joint is generally controlled by the HAZ, with rupture occurring in the type IV zone.

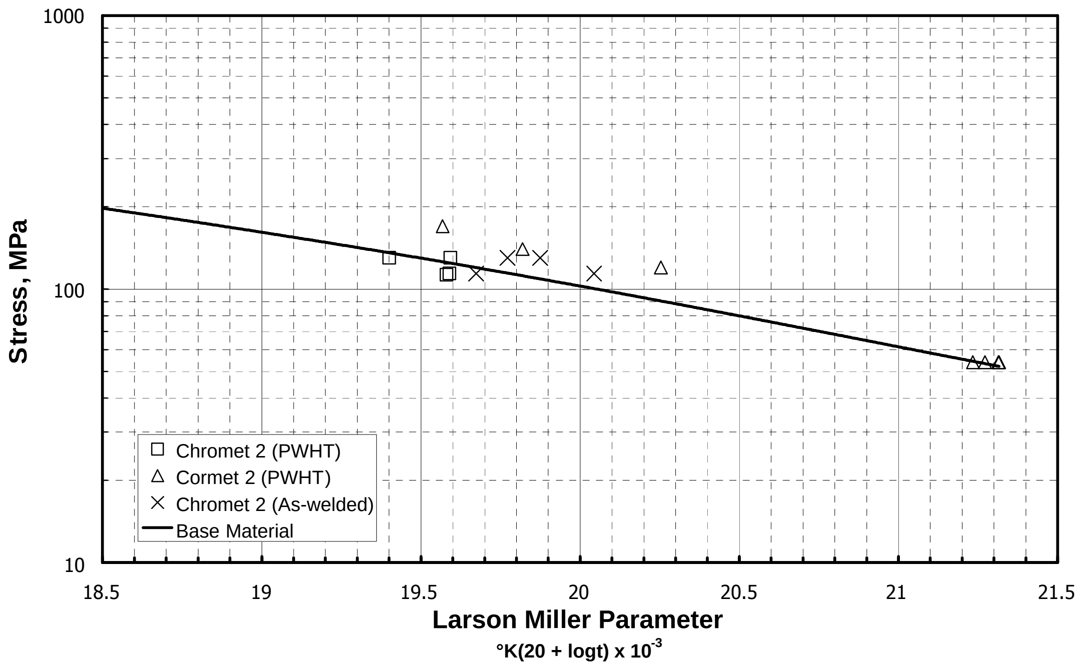

Figure 11 Stress rupture data for P22 consumables

6 Further reading

Mitchell, K: 'Cored wire repair welding in the power industry'; Welding & Metal Fabrications, Aug 1998

Mitchell, K; Allen, D and Coleman, M: 'Development of flux cored arc welding for high temperature applications'; EPRI Conference, TR-107719, 1996.

Widgery, D: 'Tubular wire welding'; Abington Publishing, Cambridge, UK, 1994