METRODE
WELDING CONSUMABLES
A Lincoln Electric Company

Metrode Products Limited

Technical Profiles

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P36 welding consumables
for the power generation industry

Figure 1 Welding P36 feedwater piping using 1NiMo.B electrodes

1 Introduction

One of the major challenges facing the power generation industry is to achieve targets for increased efficiency demanded by both mature economies and developing nations. Environmental regulations requiring reduced CO_2 emissions coupled with inevitable pressures on reliability, availability and maintainability are all major driving forces. Material developments continue to play a significant role in new projects as well as improvements to existing power plant.

P36 has only recently been added to the ASTM standards but it has been available for many years and was used in conventional power stations as early as the 1960's. The material is predominantly used for feedwater piping systems with operating temperatures of 340°C (645°F) maximum and more typically ~250°C (480°F), Figure 1.

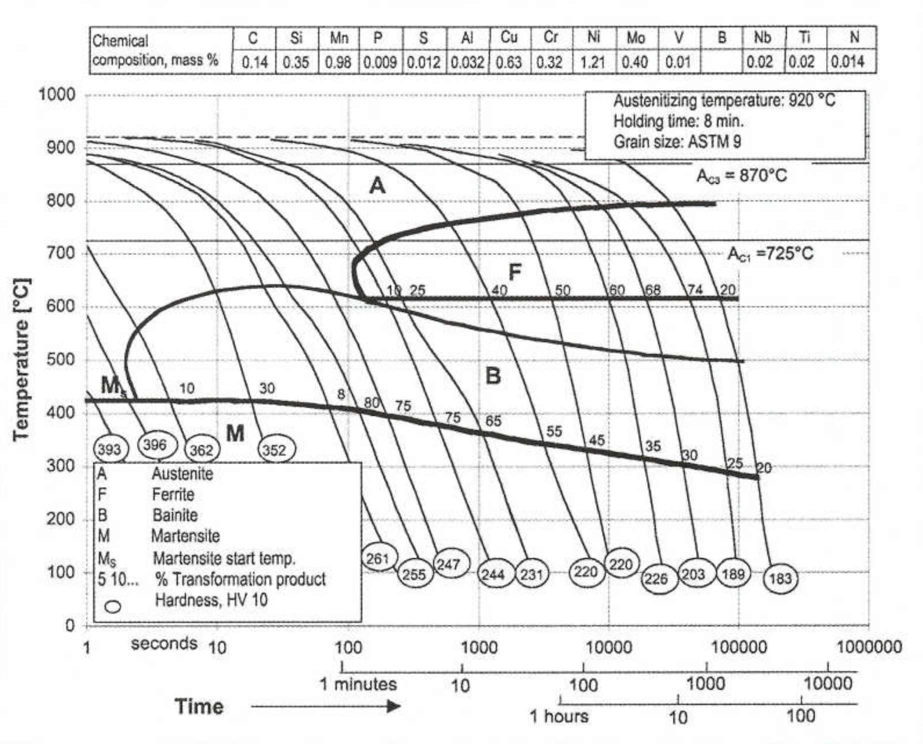
This technical profile presents the range of Metrode welding consumables used for the welding of P36 steels, together with information on specifications, welding processes and properties.

2 Background to P36

2.1 Background to alloy design

There was work carried out as early as the 1930's on steels containing Ni and Cu, by the 1970's a steel that is recognisable as P36 had been established. Improvements in steel making practices have helped improve the cleanliness and properties of the steel in more recent years but the main alloying is essentially the same.

The addition of Cu was found to provide higher strength steels but made the steel susceptible to hot-shortness; subsequently the hot-shortness could be overcome by adding approximately twice the amount of Ni. The Ni addition not only helped to overcome hot-shortness but also provided an additional increase in strength which was supplemented by Mo additions. The final strengthening effect is produced by means of grain refinement which is aided by a Nb addition.



Chemical composition, mass %	C	Si	Mn	P	S	Al	Cu	Cr	Ni	Mo	V	B	Nb	Ti	N
	0.14	0.35	0.98	0.009	0.012	0.032	0.63	0.32	1.21	0.40	0.01		0.02	0.02	0.014

Figure 2 P36 CCT diagram [Ref. V+M "The WB36 Book"].

Using typical industrial practice the P36 alloy is normalised at 900-980°C (1650-1800°F), which produces an austenitic structure without iron carbides but only partially dissolved Nb carbides and the Cu fully in solution. During cooling the carbides precipitate in a bainitic structure. Tempering at 610-640°C (1130-1180°F) allows the Cu to precipitate in the form of fine particles. The final microstructure is bainite and ferrite with normally 40-60% bainite, although the exact proportions will depend on cooling rate, Figure 2 shows the CCT diagram for a typical P36 steel.

The P36 alloy is designed to compete against standard CMn pipe steels (e.g A106) and P1 (16Mo3) for service at temperatures in the range 200-450°C (390-840°F) and most commonly 250-300°C (480-570°F). In this temperature range design is based on strength and not on creep properties. Figure 3 shows the advantage of using P36 compared to other alloys in terms of the minimum proof stress requirements of BS EN 10216-2 and also ASME allowable stresses. Based on the design requirements of ASME B31.1 the comparative wall thickness of a 480mm internal bore pipe operating at 320°C (610°F) and 370bar is shown in Figure 4; this clearly shows the potential reduction in wall thickness that P36 allows in comparison to other candidate materials.

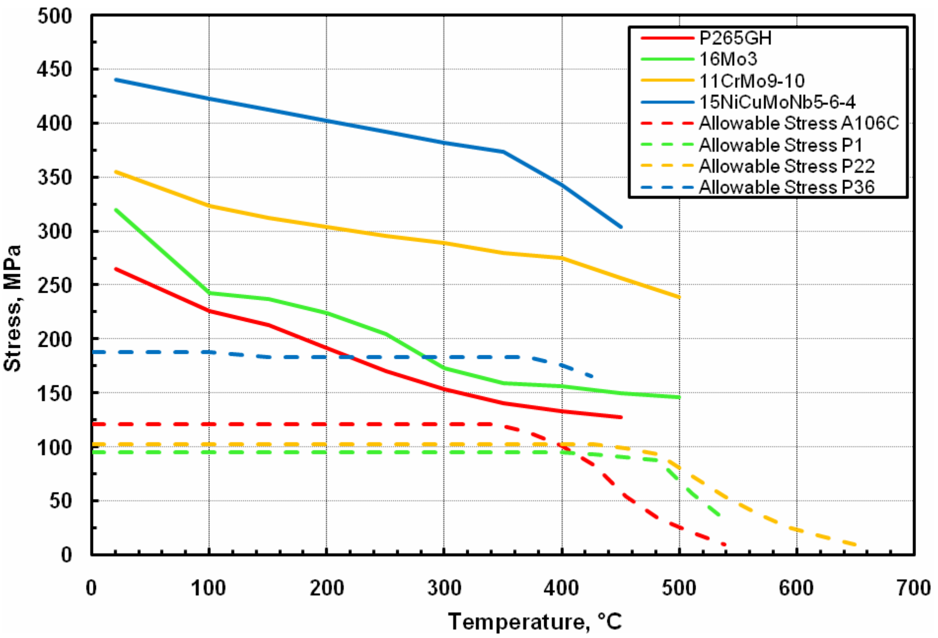


Figure 3 Plot demonstrating the advantage of P36/15NiCuMoNb5-6-4 based on both the minimum 0.2% proof stress in BS EN 10216-2 and ASME maximum allowable stresses.

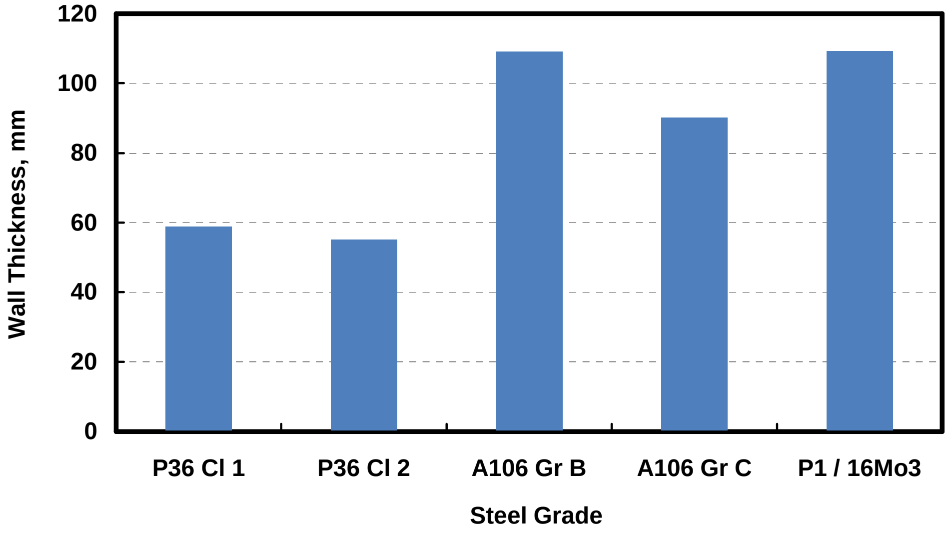


Figure 4 Minimum wall thickness pipe that could be used for an application at 320°C (610°F) and 370bar with an internal diameter of 480mm.

2.2 P36: Specifications and product forms

ASTM/ASME and EN specified composition ranges are given in Tables 1 & 2, and the various product forms, required properties and heat treatments are given in Table 3. The commonly used descriptors are given below and for the remainder of this document the material will be referred to as P36.

ASTM A182	Forgings	Grade F36
ASTM A213	Tubes	Grade T36
ASTM A335	Seamless pipe	Grade P36
BS EN 10216-2	Seamless tube	Grade 15NiCuMoNb5-6-4 / 1.6368

Table 1 Specified composition for F36/T36/P36 steel in A182/A213/A335

	C	Mn	Si	S	P	Cr	Ni	Mo	Cu	Nb	V	N	Al
Min	0.10	0.80	0.25	-	-	-	1.00	0.25	0.50	0.015	-	-	-
Max	0.17	1.20	0.50	0.025	0.030	0.30	1.30	0.50	0.80	0.045	0.02	0.02	0.050

Table 2 Specified composition for 15NiCuMoNb5-6-4 / 1.6368 steel in EN 10216-2

	C	Mn	Si	S	P	Cr	Ni	Mo	Cu	Nb	V	N	Al
Min	-	0.80	0.25	-	-	-	1.00	0.25	0.50	0.015	-	-	-
Max	0.17	1.20	0.50	0.020	0.025	0.30	1.30	0.50	0.80	0.045	-	-	0.050

Table 3 Heat treatment and mechanical property requirements for P36 steels

Standard	Alloy	Heat treatment *		Tensile strength MPa (ksi)	0.2% proof stress MPa (ksi)	Longitudinal elongation %	Max hardness HB/HV/HRC
		Normalising temp, °C (°F)	Tempering temp, °C (°F)				
A182	F36 Cl 1	≥900 (1650)	≥595 (1100)	≥620 (90)	≥440 (64)	≥15	252/-/-
	F36 Cl 2	≥900 (1650)	≥595 (1100)	≥660 (95.5)	≥460 (66.5)	≥15	252/-/-
A213	T36 Cl 1	≥900 (1650)	≥595 (1100)	≥620 (90)	≥440 (64)	≥15	250/265/25
	T36 Cl 2	≥900 (1650)	≥595 (1100)	≥660 (95.5)	≥460 (66.5)	≥15	250/265/25
A335	P36 Cl 1	≥900 (1650)	≥595 (1100)	≥620 (90)	≥440 (64)	≥15	250/265/-
	P36 Cl 2	≥900 (1650)	≥595 (1100)	≥660 (95.5)	≥460 (66.5)	≥15	250/265/-
EN 10216-2	1.6368	880-980 (1620-1800)	580-680 (1080-1260)	610-780 (88.5-113)	≥440 (64)	≥19	-

* ASTM A182/A213/A335 Class 2 is subject to accelerated cooling in air or liquid quenching.

3 Preheat, interpass temperature and PWHT

3 .1 Preheat and interpass

P36 material is often used in thick sections so there is inevitably going to be some risk of hydrogen cracking after welding. ASTM A182 and ASME B31.1 both recommend a preheat-interpass temperature range of 205-370°C (400-700°F). These values appear quite high and are certainly higher than the recommendations of V+M, a major manufacturer of this alloy, who suggest:

≤15mm thick	80–150°C (175-300°F)
15-30mm thick	100–180°C (210-355°F)
30-50mm thick	120–220°C (250-425°F)
>50mm thick	120–250°C (250-480°F)

BS 2633 has preheat recommendations that are similar to the V+M recommendations, 100°C (210°F) for TIG roots and 150°C (300°F) for MMA/SAW. With lower preheat levels of 50°C (120°F) for TIG and 100°C (210°F) for MMA/SAW being acceptable for thicknesses ≤12.5mm.

3.2 Post weld heat treatment (PWHT)

PWHT will need to be applied to all welds. Based on the base material specifications tempering of the original base material needs to be carried out ≥595°C (1100°F). Recommendations for PWHT in ASTM A182/ASME B31.1 are 595-650°C (1100-1200°F) for Class 1 material and 540-620°C (1005-1150°F) for Class 2 material.

In practice fabricators tend to use a PWHT temperature in line with the requirements specified for Class 2 material; typically 590°C (1095°F).

The holding time for PWHT given in ASTM A182 is 1 hour per 25mm (1in), 15 minute minimum, for Class 1 material up to 50mm (2in) and 15 minutes for each additional 25mm (inch) of thickness >50mm (>2in). For Class 2 materials the holding time is 1 hour per 25mm (1in), half hour minimum.

In BS 2633 the recommendation is for a PWHT temperature of 550-590°C (1020-1095°F) but with the temperature being 30°C (55°F) below the original base material tempering temperature. The hold time is recommended to be 2.5 minutes/mm (1 hour/inch), minimum one hour.

PWHT can be applied directly from the welding/preheat temperature without any need for cooling to room temperature.

4 Welding consumables

Welding of P36 has been carried out by three main arc welding processes: TIG/GTAW, MMA/SMAW and submerged arc welding. The TIG process is used predominantly for single sided root runs, with filling and capping runs being completed with either MMA or MMA and submerged arc depending on the location (shop or site) and welding position.

The welding consumables that are used for welding P36 are generally not an exact match for the base material composition, the weld metals tend to be either Mn-Mo or Ni-Mo alloyed. The relevant Metrode consumables are discussed in greater detail in the following sections.

4.1 Metrode range of P36 welding consumables

Table 4 gives a summary of the Metrode welding consumables used for welding P36. A brief description of each of the consumables is given in this section along with representative welding parameters, where appropriate. Typical weld deposit compositions for each consumable type are given in Table 5.

Table 4 Metrode P92 welding consumables

Metrode brand name	*Welding process*	*Specification*
MnMo	TIG/GTAW	*AWS A5.28:* ER80S-D2/ER90S-D2
1NiMo.B	MMA/SMAW	*AWS A5.5:* E9018-G
1NiMo	Submerged Arc Wire (SAW)	*AWS A5.23:* EF3 *BS EN 756:* S3Ni1Mo
LA436	Submerged Arc Flux	*BS EN 760:* SA FB 2 55 AC
1NiMo + LA436	SAW + Flux	*AWS A5.23:* F9P2F3-EF3

Table 5 Typical analysis of consumables used for welding P36

Element, wt%	*C*	*Mn*	*Si*	*S*	*P*	*Cr*	*Ni*	*Mo*	*Cu*
MnMo *TIG wire [1]*	0.10	1.9	0.6	0.005	0.010	-	0.05	0.5	0.1
1NiMo.B *MMA deposit*	0.06	1.2	0.4	0.008	0.008	0.05	0.95	0.4	0.05
1NiMo *SAW wire [1]*	0.10	1.75	0.2	0.005	0.010	0.05	0.9	0.55	0.1
1NiMo+LA436 *SAW deposit*	0.09	1.6	0.3	0.005	0.010	-	0.9	0.5	0.1

Notes:
[1] Solid TIG/SAW wire composition

4.2 TIG (GTAW) – MnMo wire

There is a need for a solid welding wire suitable for TIG (GTAW) welding. This process is predominantly used for root welding.

TIG welding of P36 using MnMo is carried out using pure argon shielding gas with electrode DC- polarity. The P36 alloy and MnMo filler are low alloyed and it is not necessary to use a purge gas. The most commonly used size for manual TIG root welding is 2.4mm (3/32in) diameter used in conjunction with a similar diameter 2% thoriated tungsten electrode. Using DC-, typical parameters would be about 90A, 12V; with a gas flow rate of about 10 l/min (20cu.ft/hr).

4.3 MMA (SMAW) – 1NiMo.B electrodes

MMA (SMAW) welding is still the most adaptable of the arc welding processes and therefore is still widely used for construction and fabrication work, particularly for on-site erection and repair work. Typical deposit analysis is given in Table 5 and mechanical properties are covered in Section 5.

P36 steels are ferritic/bainitic in microstructure and normally used in thick sections where hydrogen cracking could occur. This means that precautionary measures to avoid hydrogen cracking are particularly important. Preheat requirements have been covered in Section 3.1, but in relation to MMA electrodes, coating moisture and hence potential diffusible hydrogen are also critical. To ensure low coating moisture content, as supplied, and after some atmospheric exposure, the electrodes are manufactured using a specially designed flux binder system.

1NiMo.B electrodes are supplied in hermetically sealed metal cans as defined by AWS A5.5 Paragraph 22.2. The as-packed moisture content of the electrodes is ≤0.15%, and the exposed moisture content is ≤0.40%, as per A5.5 (27°C/80°F-85%RH). In AWS terminology, these electrodes are classified with the H4R suffix.

1NiMo.B is a basic low hydrogen electrode with a moisture resistant coating designed to give low weld metal diffusible hydrogen levels. The electrode operates on DC+ and on AC (70V min OCV) but DC+ is preferred for most applications. The electrode is all-positional, except vertical down, and is suitable for welding fixed pipework in the ASME 5G/6G positions.

4.4 Submerged arc - 1NiMo + LA436 wire/flux combination

For components where mechanised welding is practical and joints can be manipulated into the flat position (or rotated), SAW is the preferred and most productive welding process. The 1NiMo wire is available in 2.4mm (3/32in), 3.2mm (1/8in) or 4.0mm (5/32in) diameter and should be used in combination with Metrode LA436 flux. LA436 is an agglomerated aluminate basic flux with a basicity of ~1.6.

The typical sub arc weld metal composition is given in Table 5. There is a modest influence of the flux but the chemical analysis is very close to that of the 1NiMo wire. It can be seen that there is slight reduction in carbon content and a little silicon pick up from the flux.

4.4.1 Procedural aspects

1NiMo submerged arc wire is supplied in 2.4mm (3/32inch), 3.2mm (1/8inch) and 4.0mm (5/32inch) diameters as standard. Typical welding parameters using DC+ polarity and LA436 flux are given in Table 6.

Table 6 Welding parameters for P36 submerged arc

Flux	*Wire dia, mm (in)*	*Electrode extension, mm (in)*	*Current, A*	*Voltage, V*	*Travel speed mm/min (in/min)*
LA436	2.4 (3/32)	20–25 (0.8-1.0)	350–500 (DC+)	28-32	400–500 (15-20)
	3.2 (1/8)	20–25 (0.8-1.0)	400–600 (DC+)	28-32	400–500 (15-20)
	4.0 (5/32)	20–25 (0.8-1.0)	500–700 (DC+)	28-32	400–500 (15-20)

The LA436 flux produces excellent slag release and cosmetic bead appearance**.** As in the submerged arc welding of any low alloy steel, hydrogen control is important (see section 4.3 on MMA). Correct storage, handling and recycling of the flux is essential. If flux recycling is carried out, the machine hopper should be regularly topped up with fresh flux to prevent the accumulation of fines. LA436 flux that has become damp or has been exposed to the atmosphere for 8 hours or more should be re-dried at 300-350°C (575-650°F) for 2 hours, see Figure 5.

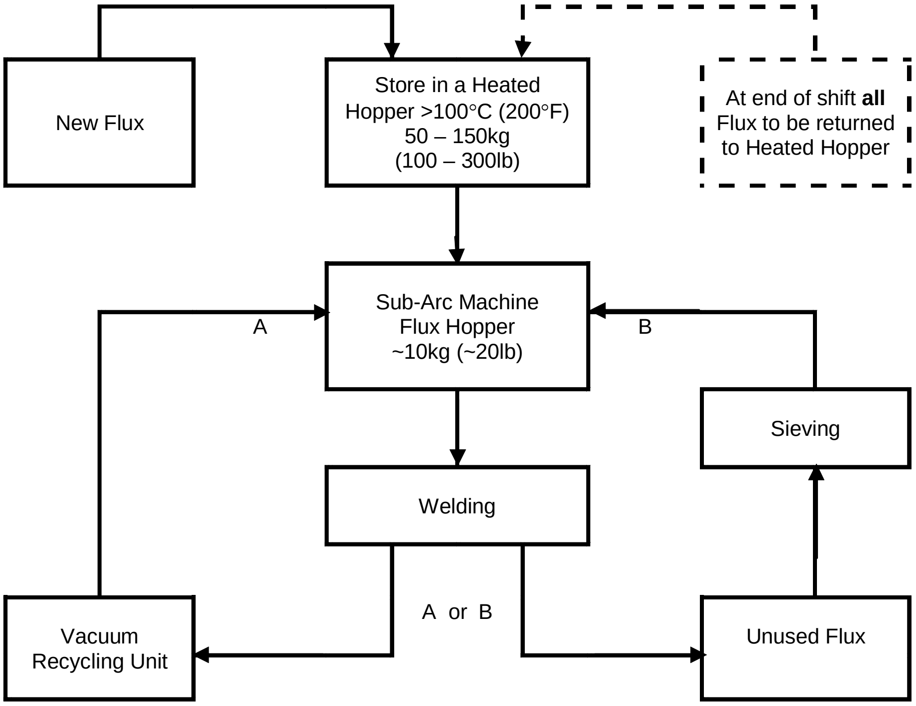


Figure 5 Control and storage of LA436 submerged arc flux

5 Weld metal mechanical properties

5.1 Ambient temperature tensile properties

In Table 7, typical tensile data for TIG, MMA and sub-arc weld metals is given after various PWHTs. It can be seen that all three processes provide adequate strength and ductility for the welding of P36 base material. In addition to the as-welded data and 590/620°C (1095/1150°F) PWHT data there is also data presented after a PWHT at 645/650°C (1195/1200°F) even though this is a higher temperature than would normally be applied to P36 joints. The effect of PWHT on the tensile properties of the weld metals is shown graphically in Figure 6 and it can be seen that all weld deposits comfortably exceed the minimum base material requirement of 460MPa 0.2% proof stress.

Table 7 Ambient temperature tensile and hardness properties of Metrode P36 welding consumables

Consumable Type	*PWHT temp/time °C (°F)/hr*	*Test temperature °C (°F)*	*Tensile strength MPa (ksi)*	*0.2% proof strength MPa (ksi)*	*Elong. 4d%*	*R of A %*	*Mid-section hardness HV*
MnMo *TIG/GTAW*	AW	20 (68)	730 (105)	620 (90)	28	70	245
	620 (1150)/1	20 (68)	644 (93)	543 (79)	31	78	210
	645 (1195)/4	20 (68)	621 (90)	536 (78)	30	76	210
1NiMo.B *MMA/SMAW*	590 (1095)/2	20 (68)	679 (98)	605 (88)	28	69	225
	650 (1200)/5	20 (68)	662 (96)	596 (86)	30	69	225
1NiMo + LA436 Sub Arc	590 (1095)/2	20 (68)	683 (99)	561 (81)	30	71	245

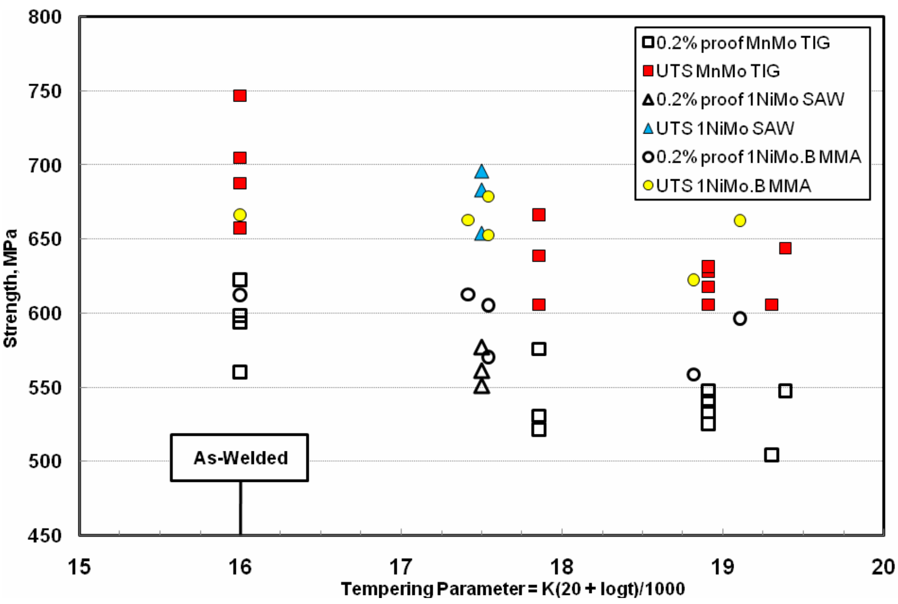


Figure 6 Effect of PWHT on ambient temperature tensile properties of P36 welding consumables.

5.2 Elevated temperature tensile properties

For an alloy designed to be used at 200-450°C (390-840°F), the high temperature properties of P36 weld metal are of considerable importance. The hot tensile properties of the weld metals are shown in Table 8 and are plotted against base material requirements in Figure 7.

The hot tensile properties of the weld metal do not necessarily provide information on the joint properties but they are important because design is based on proof stress and not creep properties.

The all-weld metal hot tensile tests reported were carried out on specimens with a gauge diameter of only 5mm. There is some evidence that strength values on small gauge size specimens may be conservative when compared to results from specimens with larger gauge diameter. The results reported are from longitudinal all-weld metal tests.

Table 8 Elevated temperature tensile properties of Metrode P36 welding consumables

Consumable Type	*PWHT temp/time °C (°F)/hr*	*Test temperature °C (°F)*	*Tensile strength MPa (ksi)*	*0.2% proof strength MPa (ksi)*	*Elong. 4d %*	*R of A %*
MnMo TIG/GTAW	590 (1095)/2	250 (482) 350 (662) 450 (842)	650 (94) 665 (96) 585 (85)	525 (76) 490 (71) 460 (67)	24 27 25	71 65 79
1NiMo.B MMA/SMAW	590 (1095)/2	250 (482) 350 (662) 450 (842)	635 (92) 625 (91) 564 (82)	490 (71) 455 (66) 469 (68)	21 25 29	64 58 65

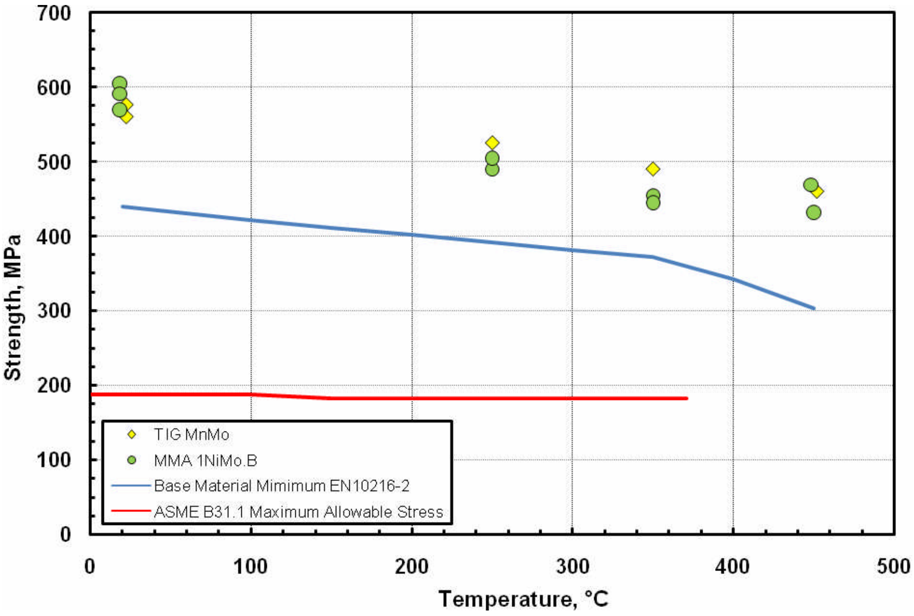


Figure 7 Elevated temperature 0.2% proof strength data for Metrode P36 consumables compared with base material. Based on all-weld metal tests carried out after a PWHT of 590°C (1095°F)/2 hours.

5.3 Weld metal toughness

Toughness is not the most important consideration for power generation applications, where service is at elevated temperature, but weld metals still need to have adequate toughness. The ASTM base material standards do not impose any requirement on the P36 base material but the EN standard does require a minimum of 27J at room temperature. Table 9 summarises the impact data for the three processes and clearly shows all weld metals comfortably meet 27J at ambient temperature.

Table 9 Typical all-weld metal toughness values for Metrode P36 welding consumables

Consumable Type	*Gas or Flux*	*PWHT °C (°F)/hr*	*Test temperature °C (°F)*	*Toughness [1]*	
				J (ft-lb)	*mm (inch)*
MnMo TIG/GTAW	Pure Argon	AW	-45 (-49)	100 (75)	1.20 (0.047)
		620 (1150)/1	-30 (-22)	170 (125)	2.28 (0.090)
		645 (1195)/4	-45 (-49)	150 (110)	2.15 (0.085)
1NiMo.B MMA/SMAW	N/A	AW	-50 (-58)	75 (55)	1.10 (0.043)
		590 (1095)/2	+20 (68)	120 (90)	1.22 (0.048)
			-50 (-58)	70 (52)	1.10 (0.043)
1NiMo Sub Arc	LA436 Flux	590 (1095)/2	+20 (68)	150 (110)	2.17 (0.085)

Note:

[1] There will inevitably be a certain degree of batch to batch variation in impact properties, but the values quoted above are representative of recent tests.

Sub-zero toughness is not critical but Figure 8 provides transition curves for all processes showing that they all comfortably exceed the base material requirement. Figure 9 shows the effect of tempering on TIG and MMA weld metals; the TIG process generally shows an improvement following PWHT but the MMA process does not vary significantly.

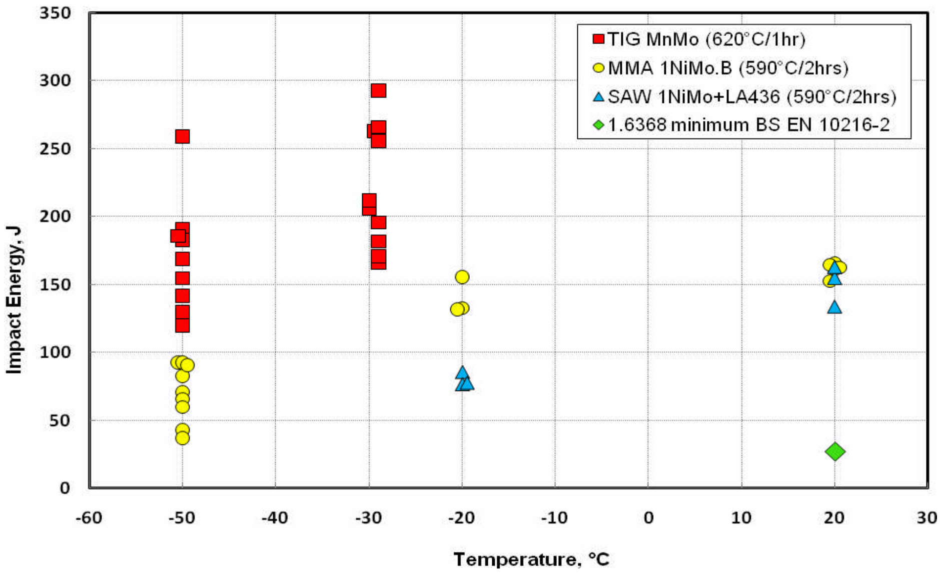


Figure 8 Impact energy transition for consumables used for welding P36. Based on all-weld metal data PWHT at either 590°C (1095°F)/2hr or 620°C (1150°F)/1hr.

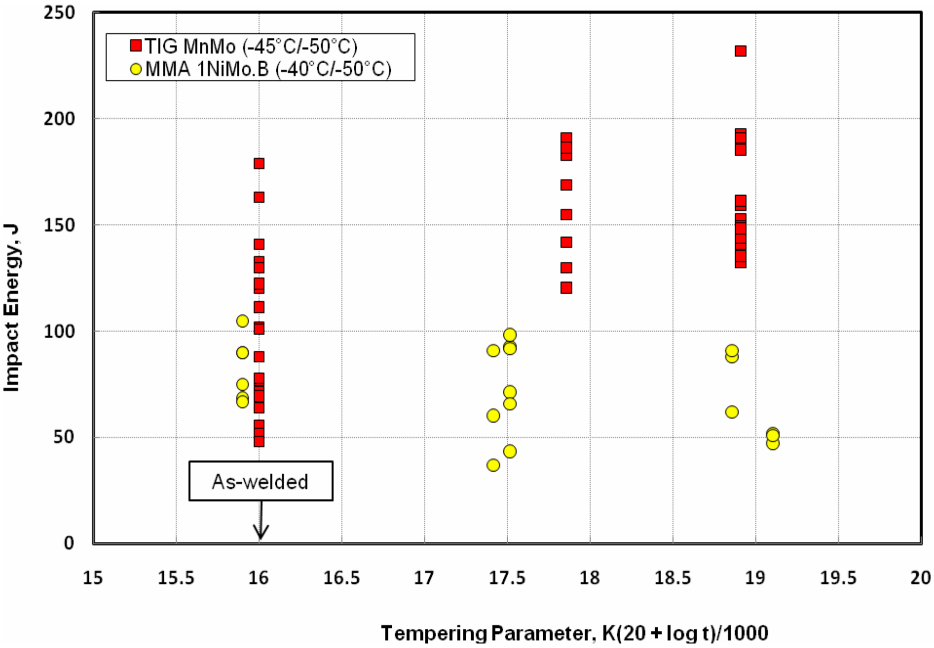


Figure 9 ***Variation in impact energy with PWHT for TIG and MMA. All-weld metal data tested at -40 to -50°C (-40 to -58°F).***

6 Further reading

Vallourec & Mannesmann Tubes "*The WB36 Book (15NiCuMo)*", 2002.

ASTM A182/A182M-08 "Standard specification for forged or rolled alloy and stainless steel pipe flanges, forged fittings, and valves and parts for high temperature service."

ASTM A335/A335M-06 "Standard specification for seamless ferritic alloy-steel pipe for high-temperature service."

Cases of the code for pressure piping; B31 Case 182. Use of 1.15Ni-0.65Cu-Mo-Cb in ASME B31.1 Construction. November 10, 2006.

BS EN 10216-2:2002 "Seamless tubes for pressure purposes – Technical delivery conditions Part 2. Non-alloy and alloy steel tubes with specified elevated temperature properties."