Recommended Welding Guidelines

API-582

a practical approach for industrial welding practices

By The PetroStreet Team

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P-NUMBERS

Grouping of Base Metals:

Guess !!!

What are the P Numbers for:

- Ferritic Stainless Steels
- Austenitic Stainless Steels
- Martensitic Stainless Steels
- Duplex Stainless Steels

Table 3.1 Applicable P-Numbers

Base Metal	P number
Carbon Steel	P1
C- ½%Mo	P3
1-1.25%Cr – 0.5% Mo	P4
2.25- 9% Cr – 0.5%-1% Mo	P5A, P5B, P5C
12% Cr	P6
Aluminium and Aluminium base alloys	P21 – P25
Copper and Coper base alloys	P31 – P35
Nickel and Nickel base alloys	P41 – P47
Titanium and Titanium base alloys	P51 – P53
Zirconium and zirconium alloys	P61 – P62

WELDING CONSUMABLES

For Carbon & Low Alloy Steels:

Base Material	Carbon Steel	Carbon-Molybdenum Steel	1 & 1 1/4 Cr - 1/2 Mo Steel	2 1/4 Cr - 1 Mo Steel	5 Cr - 1/2 Mo Steel	9 Cr - 1 Mo Steel	2 1/4 Nickel Steel	3 1/2 Nickel Steel	9% Nickel Steel
Carbon Steel	AB (3)	AC	AD	A,D,E	ADEF	ADEFH	AJ	AK	*
Carbon-Molybdenum Steel		C	CD	CDE	CDE	CDEFH	*	*	*
1 & 1 1/4 Cr - 1/2 Mo Steel			D	DE	DEF	DEFH	*	*	*
2 1/4 Cr - 1 Mo Steel				E	EF	EFH	*	*	*
5 Cr - 1/2 Mo Steel					F	FH	*	*	*
9 Cr - 1 Mo Steel						H (4)	*	*	*
2 1/4 Nickel Steel							J	JK	LM
3 1/2 Nickel Steel								K	LM
9% Nickel Steel									LM

Legend

A	ASME SFA 5.1 classification E70XX low hydrogen (5)
B	ASME SFA 5.1 classification E6010 for root pass (5)
C	ASME SFA 5.5 classification E70XX-A1, low hydrogen
D	ASME SFA 5.5 classification E70XX-B2L (6) or E80XX-B2, low hydrogen
E	ASME SFA 5.5 classification E80XX-B3L (6) or E90XX-B3, low hydrogen
F	ASME SFA 5.5 classification E80XX-B6 or E80XX-B6L (6), low hydrogen
H	ASME SFA 5.5 classification E80XX-B8 or E80XX-B8L (6), low hydrogen
J	ASME SFA 5.5 classification E80XX-C1 or E70XX-C1L, low hydrogen
K	ASME SFA 5.5 classification E80XX-C2 or E70XXC2L, low hydrogen
L	ASME SFA 5.11 classification ENiCrMo-3
M	ASME SFA 5.11 classification ENiCrMo-6
-	An unlikely or unsuitable combination. Consult the Owner's Engineer if this combination is needed.

Notes

(1) Appendix A-1 refers to coated electrodes. For bare wire welding (SAW, GMAW, GTAW), use equivalent electrode classifications (ASME SFA A5.14, A5.17, A5.18, A5.20, A5.23, A5.28). Refer to the text for information on other processes.

(2) Higher alloy electrode specified in the table should normally be used to meet the required tensile strength or toughness after post weld heat treatment. The lower alloy electrode specified may be required in some applications to meet weld metal hardness requirements.

(3) Other E60XX and E70XX welding electrodes may be used if approved by the purchaser.

(4) This table does not cover modified versions of Cr-Mo alloys

(5) Refer para. 6.1.4

(6) PWHT can cause the strength of theswe filler metals to drop below minimum requirements.

WELDING CONSUMABLES

For Stainless Steels:

Type 410 Stainless Steel			ABC	AB	AB	AB	AB	AB	AB	AB	AB	AB
Type 304 Stainless Steel				D	DH	DJ	A	DF	DGH	DI	DE	DE
Type 304L Stainless Steel					H	DHJ	A	DF	GH	HI	DE	DE
Type 304H Stainless Steel						J	A	DFJ	DGHJ	DIJ	DEJ	EJ
Type 310 Stainless Steel							K	AK	A	A	A	A
Type 316 Stainless Steel								F	FG	FI	EF	EF
Type 316L Stainless Steel									G	GI	EG	EG
Type 317L Stainless Steel										I	EI	EI
Type 321 Stainless Steel											E	E
Type 347 Stainless Steel												E

Legend

A	ASME SFA 5.4 classification E309-XX
B	ASME SFA 5.11classification ENiCrFe-2 or -3 (Note (4))
C	ASME SFA 5.4 Classification E410-XX (0.05% C max.) (Heat Treatment @1400 F requi
D	ASME SFA 5.4 classification E308-XX
E	ASME SFA 5.4 classification E347-XX
F	ASME SFA 5.4 classification E316-XX
G	ASME SFA 5.4 classification E316L-XX
H	ASME SFA 5.4 classification E308L-XX
I	ASME SFA 5.4 classification E317L-XX
J	ASME SFA 5.4 classification E308H-XX
K	ASME SFA 5.4 classification E310-XX

Note (1) Appendix A-2 refers to coated electrodes. For bare wire welding (SAW, GMAW, GTAW), use equivalent electrode classifications (ASME SFA A5.9, A5.14) Refer to the text for information on other processes.

(2) The higher alloy electrode specified in the table is normally preferred.

(3) See Section 6.3 of this document for weld metal Delta Ferrite requirements.

(4) Refer to para. 6.2.2 for the temperature limitation for Nickel base filler metals.

WELDING CONSUMABLES

For Duplex Stainless Steels:

Base Material	2205 (S31803 and S32205)	25Cr	Super Duplex	P1-P5	P8 type 304	P8 type 316	P8 type 31254	P43 type 600,625	P45 type Alloy 825
2205	A	B,C	C	A,D	A	A,E	G	G,H	F,G,H
25Cr		B,C	C	B,C,D	A,B,E	A,B,E	G	G,H	F,G,H
Super Duplex			C	C,D	A,C,E	A,C,E	G	G	G

Legend

A	ASME SFA 5.4, classification E(R) 2209
B	ASME SFA 5.4, Classification E (R)2553
C	ASME SFA 5.4, Classification E(R) 2594
D	ASME SFA 5.4, ClassificationE(R) 309L
E	ASME SFA 5.4, Classification E(R) 309LMo
F	ASME SFA 5.4, Classification E(R) 383
G	ASME SFA 5.11, Classification ENiCrMo-3
H	ASME SFA 5.11, Classification ENiCr-3

*An unlikely or unsuitable combination. Consult the Purchaser's engineer if this combination is needed.

Note: Appendix A.3 refers to coated electrodes. For bare wire welding (SAW, GMAW, GTAW), use equivalent electrode classification (ASME SFA A 5.9 and 5.14).

WELDING CONSUMABLES

For Copper and Nickel Based Alloys:

Base Material	70-30 & 90-10 Cu-Ni	Alloy 400 (N04400)	Nickel 200 (N02200)	Alloy 800 (N08800), 800H (N08810), 800HT (N08811)	Alloy 600 (N06600)	Alloy 625 (N06625)	Alloy 825 (N08825)	Alloy C-22 (N06022)	Alloy C-276 (N10276)	Alloy B-2 (N10665)	Alloy G-3 (N06985)	Alloy G-30 (N06030)
Carbon and Low Alloy Steel	BC	BC	C	A	A	A	A	D	E	F	G	H
300-Series Stainless Steel	BC	AC	AC	A	A	A	A	D	E	F	G	H
400-Series Stainless Steel	B	B	AC	A	A	A	A	D	E	F	G	H
70-30 & 90-10 Cu-Ni	B	B	C	C	C	C	C	*	*	*	*	*
Alloy 400 (N04400)		B	BC	A	A	A	A	A	A	F	A	A
Nickel 200 (N02200)			C	AC	AC	AC	AC	CD	CE	CF	CG	CH
Alloy 800 (N08800), 800H (N08810), 800HT (N08811)				K	A	A	A	DJ	EJ	FJ	GJ	HJ
Alloy 600 (N06600)					A	AJ	A	DJ	EJ	FJ	GJ	HJ
Alloy 625 (N06625)						J	J	DJ	EJ	FJ	GJ	HJ
Alloy 825 (N08825)							J	DJ	EJ	FJ	GJ	HJ
Alloy C-22 (N06022)								D	EJ	FJ	GJ	HJ
Alloy C-276 (N10276)									E	FJ	GJ	HJ
Alloy B-2 (N10665)										F	GJ	HJ
Alloy G-3 (N06985)											G	HJ
Alloy G-30 (N06030)												H

Legend

A	ASME SFA 5.11, classification ENiCrFe-2 or -3
B	ASME SFA 5.11, Classification ENiCu-7
C	ASME SFA 5.11, Classification ENi-1
D	ASME SFA 5.11, Classification ENiCrMo-10
E	ASME SFA 5.11, Classification ENiCrMo-4
F	ASME SFA 5.11, Classification ENiMo-7
G	ASME SFA 5.11, Classification ENiCrMo-9
H	ASME SFA 5.11, Classification ENiCrMo-11
J	ASME SFA 5.11, Classification ENiCrMo-3
K	ASME SFA 5.11, Classification ENiCrCoMo-1 or matching filler

WELDING CONSUMABLES

For Weld Overlay:

Overlay Material	Weld Overlay Materials (1) (2)			
	Equipment Requiring PWHT		Equipment Not Requiring PWHT	
	First Layer	Top Layer(s)	First Layer	Top Layer(s)
405 / 410S	EniCrFe-2 or -3 or ERNiCr-3		EniCrFe-2 or -3 or ERNiCr-3	
304 SS	(3)	(3)	E / ER309	E / ER308
304L SS	E / ER309L	E / ER308L	E / ER309L	E / ER308L
316 SS	(3)	(3)	E / ER309Mo	E / ER316
316L SS	E / ER309LMo	E / ER316L	E / ER309LMo	E / ER316L
317L SS	E / ER309LMo	E / ER317L	E / ER309LMo	E / ER317L
321 / 347 SS	E / ER309	E / ER347	E / ER309Nb	E / ER347
Alloy 20-Cb3	E / ER320LR	E / ER320LR	E / ER320LR	E / ER320LR
Alloy 400	E / ERNiCu-7 (4)	E / ERNiCu-7	E / ERNiCu-7 (4)	E / ERNiCu-7

Electrode nominal diameter and AWS classification shall be considered essential variables.

(1) Use of this table is limited to carbon and low-alloy steel backing materials.

(2) For overlay not involving clad restoration, use the combination of consumables that results in the desired weld metal chemical composition in the top layer(s).

(3) E/ER308 and E/ER316 are not normally used in the post-weld heat-treated condition. The Purchaser shall approve the use of non-low-carbon E/ER308 and E/ER316 in the post-weld heat-treated condition.

(4) ENi-1 or ERNi-1 may be used as an alternate.

DISSIMILAR WELDING

When Joining:

Ferritic Steels (P1 through P5) to: (a) Martensitic Stainless Steels (P6) or
(b) Ferritic Stainless Steels (P7) or
(c) Austenitic Stainless Steels (P8)

Filler metal shall be selected based on the following criteria:

- ✓ Type 309 or 309L for design temperatures not exceeding 600F (315C)
- ✓ Nickel-based alloy filler metal based on design conditions listed in Table

AWS Filler Material Designation	Max. Design Temperature (non-sulfur environment)	Max. Design Temperature (sulfur environment)
ENiCrFe-3	1000 °F (540 °C)	700 °F (370 °C)
ERNiCr-3, ENiCrFe-2	1400 °F (760 °C)	750 °F (400 °C)
ERNiCrMo-3	1100°F (590 °C)	900°F (482 °C)
ER NiCr-4	1100°F (590 °C)	1100°F (590 °C)*

*Note: In some condition, ERNiCrCoMo-1 should also be considered.

- ✓ For service conditions exceeding the limits stated in above table, consult the vendor
- ✓ ER310 (E310-XX) and ERNiCrFe-6 shall NOT be used

SPECIAL WELDING CONSIDERATIONS

Low Alloy Steels Welding (P3-P5):

For welding of low alloy steels which are to be used:

- With heavy wall thickness (above 1 inch)
- With high temperature (825F to 1100F)
- With high pressure hydrogen service

Special considerations must be checked out from **API-934** to ensure all requirements of welding filler metal, pre & post heat treatment and additive precautions.

SPECIAL WELDING CONSIDERATIONS

Austenitic Stainless Steel Welding (P8 Group 1):

For welding of austenitic stainless steels, following guidelines and restrictions apply:

- Materials requiring PWHT or materials in high temperature service), the Ferrite Number (FN) for the deposited weld metal should not exceed **10 FN** measured prior to PWHT. (Ferrite number (FN) shall always be measured prior to PWHT).

- Minimum Ferrite Number for filler metal should be **4 FN** except for the following:
  - The minimum FN for type 347 shall be **5 FN**
  - When joining stainless steels for cryogenic service, non-magnetic applications, or special corrosive service, consumables with a lower FN may be required. The maximum ferrite number for E16-8-2 weld deposits shall be **5 FN**

- When austenitic stainless steel weld materials are used at service temperatures above 550 C:
  - Materials shall have a formulation that does not intentionally add bismuth, and bismuth in the deposited weld metal shall not exceed **0.002%**
  - Materials shall have a maximum FN of 9 FN.

SPECIAL WELDING CONSIDERATIONS

Duplex Stainless Steel Welding (P10H):

Special considerations must be checked out from **API-938C** to ensure all requirements of welding filler metal, pre & post heat treatment and additive precautions.

- Ferrite content shall be measured on base metal, HAZ and weld metal.
- Ferrite content in these locations shall be **30% - 65%. Ferrite**
- If the deposited weld metal ferrite content is greater than 60%, the moisture content of duplex electrodes shall be controlled to **0.2%** max.

SHIELDING AND PURGING GASES

Guidelines:

- Shielding gases shall meet the purity requirements of AWS 5.32/A5.32M.
- Back purging is required for the GTAW and GMAW processes for welding materials having a nominal chromium content greater than 2 ¼ % unless the joint is ground or back gouged to sound metal.
- Whenever a back purging gas is selected to prevent oxidation or scale formation on the underside of the weld, the purge shall be maintained until at least 1/4 in. (6.5 mm) depth of weld metal has been deposited.
- For socket, seal, and any other attachment welds on base materials less than 1/4" thick, the back purging shall be maintained throughout the welding operation.

PREHEATING AND INTERPASS TEMPERATURE

Guidelines:

- ✓ Preheating, where required, applies to all welding, tack welding, and thermal cutting.
- ✓ Minimum preheat requirements shall follow the applicable code such as Appendix R of ASME Section VIII, Table 330.1.1 of B31.3, and Annex XI of AWS D1.1.
- ✓ The preheat temperature shall be applied throughout the entire thickness of the weld and at least 4 in. (100 mm) on each side of the weld.
- ✓ The preheat and interpass temperature shall be checked by use of thermocouples, temperature indicating crayons, pyrometers or other suitable methods.
- ✓ The maximum interpass temperature shall be specified in the WPS and PQR for austenitic stainless steels, duplex stainless steels, and non-ferrous alloys and, when impact testing is required for carbon and low-alloy steels.
- ✓ When welding high carbon equivalent forgings and fittings, special welding procedures including preheat and cooling rate control for hardness management needs to be developed to reduce risk of Hydrogen Assisted Cracking.

PREHEATING AND INTERPASS TEMPERATURE

Recommended Maximum Interpass Temperatures:

Material Group	Maximum. Interpass Temperature
P1(Carbon steels)	600 °F (315 °C)
P3-P5A-P5C (Low alloy steels)	500 °F (250 °C)
P5B (Alloy steel)	600 °F (315 °C)
P6 (410/410S)	600 °F (315°C)
P6 (type 405)	500 °F (250°C)
P6 (CA6NM)	650 °F (345°C)
P8 (Austenitic stainless steel)	300 °F (175°C)
P 10H (Duplex stainless)	300 °F (150°C)*
P41, P42	300 °F (150°C)
P43, 44 and 45	350 °F (175°C)

* Note: interpass temperature may vary depending on material grades.

POSTWELD HEAT TREATMENT (PWHT)

Guidelines:

- ✓ All WPS's specifying PWHT should indicate the following:
  - a. Maximum Heating rate
  - b. Holding temperature range
  - c. Holding time
  - d. Maximum Cooling rate
- ✓ Production hardness testing may be required to verify adequacy of heat treatments.
- ✓ PWHT of Austenitic stainless steel, Duplex stainless steel or non-ferrous alloys requires approval by the Purchaser.
- ✓ Except for weld overlays, welding procedure qualification tests for austenitic stainless steel to Ferritic steel welds shall employ the maximum PWHT temperature limit specified in the welding procedure whenever the stainless steel is heated above 705C.
- ✓ Repairing a post-weld heat-treated component, without PWHT requires that the repair meet all applicable construction code requirements, or follow NB-23 or API 510.

POSTWELD HEAT TREATMENT (PWHT)

Guidelines:

- ✓ *Commentary: If postweld heat treatment was originally conducted due to service requirements (specifically environmental cracking prevention), postweld heat treatment of the repair should be considered.*
- ✓ When repairs are made to cladding or overlay welds on low alloy steels without subsequent PWHT, a minimum remaining clad or overlay thickness of 3/16 in. (5 mm) is required unless it can be demonstrated that no new HAZ is formed in the base metal with thinner overlay.
- ✓ Exemption of code required PWHT for Ferritic materials based on the use of Austenitic or nickel-based filler materials is not permitted.
- ✓ Code exemption of PWHT for P4 and P5 materials (low alloy steels) is Not permitted for applications in sour or hydrogen service or where the nominal chromium content of the material exceeds 1.25%.

POSTWELD HEAT TREATMENT (PWHT)

Recommended Criteria:

P-No.	Material Type	Nominal Thickness at Weld (in.)	Service Environment	Holding Temperature (deg F) See Note 1	Time at Holding Temperature (hr.)
1	Carbon steel	According to code	Code	1100-1200	1hr/in. (1 minimum) or per the code
1	Carbon steel	All	Wet H2S	1150 minimum	1hr/in. (1 minimum)
1	Carbon steel	All	Caustic	1150 minimum	1hr/in. (1 minimum)
1	Carbon steel	All	Amine	1150 minimum	1hr/in. (1 minimum)
1	Carbon steel	All	Carbonates	1200 minimum	1hr/in. (1 minimum)
1	Carbon steel	All	HF Acid	1150 minimum	1hr/in. (1 minimum)
1	Carbon steel	All	Deaerator	1150 minimum	1hr/in. (1 minimum)
3	C-1/2Mo	According to Code	Code	1150-1200	1hr/in. (1 minimum)
3	Mn-Mo	All	All	1150-1200	1hr/in. (1 minimum)
4	1Cr-1/2Mo, 1-1/4Cr-1/2Mo	All	For maximum tempering (Creep)	1275-1325	1hr/in. (2 minimum)
4	1Cr-1/2Mo, 1-1/4Cr-1/2Mo	All	For optimum high temperature properties (Toughness)	1250-1300	1hr/in. (2 minimum)
5A	2-1/4Cr-1Mo	All	For maximum tempering (Creep)	1300-1350	1hr/in. (2 minimum)

P-No.	Material Type	Nominal Thickness at Weld (in.)	Service Environment	Holding Temperature (deg F) See Note 1	Time at Holding Temperature (hr.)
5A	2-1/4Cr-1Mo	All	For maximum high temperature properties (Toughness)	1275-1325	1hr/in. (2 minimum)
5B	5Cr-1/2Mo	All	All	1325-1375	1hr/in. (2 minimum)
5B	9Cr-1Mo	All	All	1350-1400	1hr/in. (2 minimum)
5B	9Cr-1Mo-V	All	All	1375-1425	1hr/in. (2 minimum)
5C	2-1/4Cr-1Mo-V	All	All	1300-1350	8 minimum ref: 934A
6	Martensitic Stainless Steels	According to Code	All	According to Code See Note 2	1hr/in. (2 minimum)
7	Ferritic Stainless Steels	According to Code	All	According to Code	1hr/in. (1 minimum) as needed
8	Austenitic Stainless Steels	According to Code	All	According to Code See Note 3	According to Code
9A	1-1/2 to 2-1/2 Ni	According to Code	All	1100F-1150	1hr/in. (1 minimum)
9B	3-1/2 Ni				
10H	Duplex Stainless Steels	According to Code	All	According to Code	1hr/in. (1 minimum)
11A	8 Ni, 9 Ni	According to Code	All	According to Code	1hr/in. (1 minimum)

POSTWELD HEAT TREATMENT (PWHT)

Special Notes for PWHT Table:

- ✓ **Note 1** - For Q&T or N&T materials, the PWHT holding temperature shall be at least 25F below the original tempering temperature of the base metal.
- ✓ **Note 2** - For Types CA-15 and CA-15M materials, a double tempering heat treatment is required. Initial heat treatment at 1150F minimum, followed by air cooling to ambient temperature, and second heat treatment at 1150F minimum (but lower than initial temperature) and air cooling to ambient temperature.
- ✓ **Note 3** - For Type CA6NM material, a double tempering heat treatment is required. Initial heat treatment at 1225F-1275F, followed by air cooling to ambient temperature, and second heat treatment at 1100F-1150F and air cooling to ambient temperature.
- ✓ **Note 4** - For Types 321 and 347 materials, post weld thermal stabilization may be specified at 1600F-1650F for 2-4 hours.

POSTWELD HEAT TREATMENT (PWHT)

Local PWHT:

- ✓ Local PWHT involving circumferential bands around piping or vessels shall be performed as follows in order to control harmful thermal gradients:

    a. The holding temperature (soak) band width shall be the greater of **W+4t** or the governing code requirement, where W is the width of the weld cap and t is the thickness of the component.

    b. Beyond the edges of the holding temperature band, a gradient band shall be applied so that the temperature at its outer edges is **Not less than 1/2 the holding temperature**. The width of this gradient shall be **2.5 times the square root of rt**, where r is the component radius and t is the component thickness.

    c. Beyond the edges of the gradient band, a decay band shall be applied to allow the temperature to gradually approach ambient. The width of this decay band shall be **2.5 times the square root of rt**, where r is the component radius and t is the component thickness.

- ✓ Local Spot PWHT (called **Bull's Eye**) on vessels or piping shall require approval of the purchaser.

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