QW-253
WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
Shielded Metal-Arc (SMAW)

Paragraph		Brief of Variables	Essential	Supplementary Essential	Nonessential
QW-402 Joints	.1	ϕ Groove design			X
	.4	− Backing			X
	.10	ϕ Root Spacing			X
	.11	± Retainers			X
QW-403 Base Metals	.5	ϕ Group Number		X	
	.6	*T* Limits impact		X	
	.7	*T/t* Limits > 8 in.	X		
	.8	ϕ *T* Qualified	X		
	.9	*t* Pass > ½ in.	X		
	.11	ϕ P-No. qualified	X		
	.13	ϕ P-No. 5/9/10	X		
QW-404 Filler Metals	.4	ϕ F-Number	X		
	.5	ϕ A-Number	X		
	.6	ϕ Diameter			X
	.7	ϕ Diam. > ¼ in.		X	
	.12	ϕ AWS class.		X	
	.30	ϕ *t*	X		
	.33	ϕ AWS class.			X
QW-405 Positions	.1	+ Position			X
	.2	ϕ Position		X	
	.3	ϕ ↑↓ Vertical welding			X
QW-406 Preheat	.1	Decrease > 100°F	X		
	.2	ϕ Preheat maint.			X
	.3	Increase > 100°F (IP)		X	
QW-407 PWHT	.1	ϕ PWHT	X		
	.2	ϕ PWHT (T & T range)		X	
	.4	*T* Limits	X		
QW-409 Electrical Characteristics	.1	> heat input		X	
	.4	ϕ Current or polarity		X	X
	.8	ϕ I & E range			X
QW-410 Technique	.1	ϕ String/weave			X
	.5	ϕ Method cleaning			X
	.6	ϕ Method back gouge			X
	.25	ϕ Manual or automatic			X
	.26	± Peening			X

Legend:
+ Addition
− Deletion
> Increase/greater than
< Decrease/less than
↑ Uphill
↓ Downhill
← Forehand
→ Backhand
ϕ Change

QW-253.1
WELDING VARIABLES PROCEDURE SPECIFICATIONS (WPS)
Shielded Metal-Arc (SMAW)

Paragraph		Special Process Essential Variables: Hardfacing Overlay (QW-216)	Special Process Essential Variables: Corrosion-Resistant Overlay (QW-214)
QW-402 Joints	.16	< finished *t*	< finished *t*
QW-403 Base Metals	.20	ϕ P-Number	ϕ P-Number
	.23	ϕ T Qualified	ϕ T Qualified
QW-404 Filler Metals	.12	ϕ AWS class.	
	.37		ϕ A-Number
	.38	ϕ Dia. (1st layer)	ϕ Dia. (1st layer)
QW-405 Positions	.4	+ Position	+ Position
QW-406 Preheat	.4	Dec. > 100°F preheat > Interpass	Dec. > 100°F preheat > Interpass
QW-407 PWHT	.6	ϕ PWHT	ϕ PWHT
QW-409 Electrical Characteristics	.4	ϕ Current or polarity	ϕ Current or polarity
	.22	Inc. > 10% 1st layer	Inc. > 10% 1st layer
QW-410 Technique	.38	ϕ Multi- to single-layer	ϕ Multi- to single-layer

Legend:
+ Addition   > Increase/greater than   ↑ Uphill   ← Forehand   ϕ Change
− Deletion   < Decrease/less than   ↓ Downhill   → Backhand

ARTICLE IV
WELDING DATA

QW-400 VARIABLES

QW-401 General

Each welding variable described in this Article is applicable as an essential, supplemental essential, or nonessential variable for procedure qualification when referenced in QW-250 for each specific welding process. Essential variables for performance qualification are referenced in QW-350 for each specific welding process. A change from one welding process to another welding process is an essential variable and requires requalification.

QW-401.1 Essential Variable (Procedure). A change in a welding condition which will affect the mechanical properties (other than notch toughness) of the weldment (for example, change in P-Number, welding process, filler metal, electrode, preheat or postweld heat treatment, etc.).

QW-401.2 Essential Variable (Performance). A change in a welding condition which will affect the ability of a welder to deposit sound weld metal (such as a change in welding process, deletion of backing, electrode, F-Number, technique, etc.).

QW-401.3 Supplemental Essential Variable (Procedure). A change in a welding condition which will affect the notch-toughness properties of a weldment (for example, change in welding process, uphill or down vertical welding, heat input, preheat or PWHT, etc.).

When a procedure has been previously qualified to satisfy all requirements other than notch toughness, it is then necessary only to prepare an additional test coupon using the same procedure with the same essential variables, but additionally with all of the required supplementary essential variables, with the coupon long enough to provide the necessary notch-toughness specimens.

When a procedure has been previously qualified to satisfy all requirements including notch toughness, but one or more supplementary essential variable is changed, then it is only necessary to prepare an additional test coupon using the same welding procedure and the new supplementary essential variable(s), with the coupon long enough to provide the necessary notch-toughness specimens. If a previously qualified weld procedure has satisfactory notch-toughness values in the weld metal, then it is necessary only to test notch-toughness specimens from the heat affected zone when such are required.

QW-401.4 Nonessential Variable (Procedure). A change in a welding condition which will *not* affect the mechanical properties of a weldment (such as joint design, method of back gouging or cleaning, etc.)

QW-401.5 The welding data includes the welding variables grouped as joints, base metals, filler metals, position, preheat, postweld heat treatment, gas, electrical characteristics, and technique. For convenience, variables for each welding process are summarized in QW-415 for procedure qualification and QW-416 for performance qualification.

QW-402 Joints

QW-402.1 A change in the type of groove (Vee-groove, U-groove, single-bevel, double-bevel, etc.).

QW-402.2 The addition or deletion of a backing.

QW-402.3 A change in the nominal composition of the backing.

QW-402.4 The deletion of the backing in single-welded groove welds. Double-welded groove welds are considered welding with backing.

QW-402.5 The addition of a backing or a change in its nominal composition.

QW-402.6 An increase in the fit-up gap, beyond that initially qualified.

QW-402.7 The addition of backing.

QW-402.8 A change in nominal size or shape of the stud at the section to be welded.

QW-402.9 In stud welding, a change in shielding as a result of ferrule or flux type.

QW-402.10 A change in the specified root spacing.

QW-402.11 The addition or deletion of nonmetallic retainers or nonfusing metal retainers.

QW-402.12 The welding procedure qualification test shall duplicate the joint configuration to be used in production within the limits listed, except that pipe or tube to pipe or tube may be used for qualification of a pipe or tube to other shapes, and solid round to solid round may be used for qualification of a solid round to other shapes:

(a) any change exceeding ±10 deg. in the angle measured for the plane of either face to be joined, to the axis of rotation;

(b) a change in cross-sectional area of the weld joint greater than 10%;

(c) a change in the outside diameter of the cylindrical weld interface of the assembly greater than ±10%;

(d) a change from solid to tubular cross section at the joint or vice versa regardless of (b) above.

QW-402.13 A change in the joint from spot to projection to seam or vice versa.

QW-402.14 A decrease in the center-to-center distance when the welds overlap. An increase or decrease of more than 10% in the spacing of the welds when they are within two diameters of each other.

QW-402.15 A change in the size or shape of the projection in projection welding.

QW-402.16 A decrease in the distance between the weld fusion line and the final surface of the production corrosion-resistant or hard-facing weld metal overlay below the minimum thickness qualified as shown in QW-462.5. There is no limit on the maximum thickness for corrosion-resistant or hard-facing weld metal overlay that may be used in production.

QW-402.17 An increase in the thickness of the production spray fuse hard-facing deposit above the thickness deposited on the procedure qualification test coupon.

QW-403 Base Metals

QW-403.1 A change from a base metal listed under one P-Number in QW-422 to a metal listed under another P-Number or to any other base metal. When joints are made between two base metals that have different P-Numbers, a procedure qualification shall be made for the applicable combination of P-Numbers, even though qualification tests have been made for each of the two base metals welded to itself.

QW-403.2 The maximum thickness qualified is the thickness of the test coupon.

QW-403.3 Where the measurement of penetration can be made by visual or mechanical means, requalification is required where the base metal thickness differs by 20% from that of the test coupon thickness when the test coupon thickness is 1 in. and under, and 10% when the test coupon thickness is over 1 in. Where the measurement of penetration cannot be made, requalification is required where the base metal thickness differs by 10% from that of the test coupon when the test coupon thickness is 1 in. and under, and 5% when the test coupon thickness is over 1 in.

QW-403.4 Welding procedure qualifications shall be made using a base metal of the same type or grade or another base metal listed in the same group (see QW-422) as the base metal to be used in production welding. When joints are to be made between base metals from two different groups, a procedure qualification must be made for the applicable combination of base metals, even though procedure qualification tests have been made for each of the two base metals welded to itself.

QW-403.5 Welding procedure qualifications shall be made using a base metal of the same type or grade or another base metal listed in the same P-Number and Group Number (see QW-422) as the base metal to be used in production welding. A procedure qualification shall be made for each P-Number and Group Number combination of base metals, even though procedure qualification tests have been made for each of the two base metals welded to itself. If, however, the procedure specification for welding the combination of base metals specifies the same essential variables, including electrode or filler metal, as both specifications for welding each base metal to itself, such that base metals is the only change, then the procedure specification for welding the combination of base metals is also qualified. In addition, when base metals of two different P-Number Group Number combinations are qualified using a single test coupon, that coupon qualifies the welding of those two P-Number Group Numbers to themselves as well as to each other using the variables qualified.

QW-403.6 The minimum base metal thickness qualified is the thickness of the test coupon T or $\frac{5}{8}$ in., whichever is less. However, where T is less than $\frac{1}{4}$ in., the minimum thickness qualified is $\frac{1}{2}T$. This limitation does not apply when a WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic material is solution annealed after welding.

QW-403.7 For the multipass processes of shielded metal-arc, submerged-arc, gas tungsten-arc, and gas metal-arc, the maximum thickness qualified for $1\frac{1}{2}$ in. and over thickness T of the test coupon of QW-451.1 shall be 8 in. for the conditions shown in QW-451.1. For thicknesses greater than 8 in., the procedure test coupon thickness of the joint to be welded in production divided by 1.33, and the maximum thickness of base metal and deposited weld metal qualified is $1.33T$ or $1.33t$, as applicable.

QW-403.8 A change in base metal thickness beyond the range qualified in QW-451, except as otherwise permitted by QW-202.4(b).

QW-403.9 For single-pass or multipass welding in which any pass is greater than $\frac{1}{2}$ in. thick, an increase in base metal thickness beyond 1.1 times that of the qualification test coupon.

QW-403.10 For the short-circuiting transfer mode of the gas metal-arc process, when the qualification test coupon thickness is less than $\frac{1}{2}$ in., an increase in thickness beyond 1.1 times that of the qualification test coupon. For thicknesses of $\frac{1}{2}$ in. and greater, use QW-451.1 or QW-451.2, as applicable.

QW-403.11 Base metals specified in the WPS shall be qualified by a procedure qualification test which was made using base metals in accordance with QW-424.

QW-403.12 A change from a base metal listed under one P-Number of QW-422 to a base metal listed under another P-Number. When joints are made between two base metals that have different P-Numbers, requalification is required even though the two base metals have been independently qualified using the same procedure. When the melt-in technique is used for joining P-No. 1, P-No. 3, P-No. 4, and P-No. 5A, a procedure qualification test with one P-Number metal shall also qualify for that P-Number metal welded to each of the lower P-Number metals, but not vice versa.

QW-403.13 A change from one P-No. 5 to any other P-No. 5 (viz P-No. 5A to P-No. 5B or P-No. 5C or vice versa). A change from P-No. 9A to P-No. 9B but not vice versa. A change from one P-No. 10 to any other P-No. 10 (viz P-No. 10A to P-No. 10B or P-No. 10C, etc., or vice versa).

QW-403.15 Welding procedure qualifications for laser beam welding and electron beam welding shall be made using a base metal of the same type or grade or another base metal listed in the same P-Number (and the same group where given — see QW-422) as the base metal to be used in production welding. When joints are to be made between base metals from two different P-Numbers (or two different groups), a procedure qualification must be made for the applicable combination of base metals even though procedure qualification tests have been made for each of the two base metals welded to itself.

QW-403.16 A change in the pipe diameter beyond the range qualified in QW-452, except as otherwise permitted in QW-303.1, QW-303.2, or when welding corrosion-resistant weld metal overlay is performed parallel to the axis of the pipe.

QW-403.17 In stud welding, a change in combination of base metal listed under one P-Number in QW-422 and stud metal P-Number (as defined in Note below), or to any other base metal/stud metal combination.

NOTE: Stud metal shall be classified by nominal chemical composition and can be assigned a P-Number when it meets the nominal composition of any one of the P-Number metals.

QW-403.18 A change from one P-Number to any other P-Number or to a base metal not listed in QW-422, except as permitted in QW-423, and in QW-420.2.

QW-403.19 A change to another base material type or grade (type or grade are materials of the same nominal chemical analysis and mechanical property range, even though of different product form), or to any other base material type or grade. When joints are made between two different types or grades of base material, a procedure qualification must be made for the applicable combinations of materials, even though procedure qualification tests have been made for each of the two base materials welded to itself.

QW-403.20 A change from a base metal, listed under one P-Number in QW-422, to a metal listed under another P-Number or to any other base metal; from a base metal of one subgroup to any other grouping in P-No. 10 or 11.

QW-403.21 The addition or deletion of a coating, plating or cladding, or a change in the nominal chemical analysis or thickness range of the plating or cladding, or a change in type of coating as specified in the WPS.

QW-403.22 A change in the nominal base metal thickness exceeding 5% of any outer sheet thickness or 10% of the nominal thickness of the total joint from that qualified.

QW-403.23 A change in base metal thickness beyond the range qualified in QW-453.

QW-404 Filler Metals

QW-404.1 A change in the cross-sectional area of the filler metal added (excluding buttering) or in the wire-feed speed greater than ±10% beyond that qualified.

QW-404.2 A decrease in the thickness or change in nominal specified chemical analysis of weld metal buttering beyond that qualified. (Buttering or surfacing is the deposition of weld metal on one or both faces of the joint prior to preparation of the joint for final electron beam welding.)

QW-404.3 A change in the size of the filler metal.

QW-404.4 A change from one F-Number in QW-432 to any other F-Number or to any other filler metal not listed in QW-432.

QW-404.5 (Applicable only to ferrous metals.) A change in the chemical composition of the weld deposit from one A-Number to any other A-Number in QW-442. Qualification with A-No. 1 shall qualify for A-No. 2 and vice versa.

The weld metal chemical composition may be determined by any of the following.

(a) For all welding processes — from the chemical analysis of the weld deposit taken from the procedure qualification test coupon.

(b) For SMAW, GTAW, and PAW — from the chemical analysis of the weld deposit prepared according to the filler metal specification, or from the chemical composition as reported either in the filler metal specification or the manufacturer's or supplier's certificate of compliance.

(c) For GMAW and EGW — from the chemical analysis of the weld deposit prepared according to the filler metal specification or the manufacturer's or supplier's certificate of compliance when the shielding gas used was the same as that used to weld the procedure qualification test coupon.

(d) For SAW — from the chemical analysis of the weld deposit prepared according to the filler metal specification or the manufacturer's or supplier's certificate of compliance when the flux used was the same as that used to weld the procedure qualification test coupon.

In lieu of an A-Number designation, the nominal chemical composition of the weld deposit shall be indicated on the WPS and on the PQR. Designation of nominal chemical composition may also be by reference to the AWS classification (where such exists), the manufacturer's trade designation, or other established procurement documents.

QW-404.6 A change in the nominal size of the electrode or electrodes specified in the WPS.

QW-404.7 A change in the nominal diameter of the electrode to over ¼ in. This limitation does not apply when a WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic material is solution annealed after welding.

QW-404.8 Addition or deletion, or a change in nominal amount or composition of supplementary deoxidation material (in addition to filler metal) beyond that qualified. (Such supplementary metal may be required for weld metal deoxidation for some metals being welded.)

QW-404.9

(a) A change in the indicator for minimum tensile strength (e.g., the 7 in F7A2-EM12K) when the flux wire combination is classified in Section II, Part C.

(b) A change in either the flux trade name or wire trade name when neither the flux nor the wire is classified in Section II, Part C.

(c) A change in the flux trade name when the wire is classified in Section II, Part C but the flux is not classified. A change in the wire classification within the requirements of QW-404.5 does not require requalification.

(d) A change in the flux trade name for A-No. 8 deposits.

QW-404.10 Where the alloy content of the weld metal is largely dependent upon the composition of the flux used, any change in any part of the welding procedure which would result in the important alloying elements in the weld metal being outside of the specification range of chemistry given in the Welding Procedure Specification. If there is evidence that the production welds are not being made in accordance with the procedure specification, the authorized inspector may require that a check be made on the chemical composition of the weld metal. Such a check shall preferably be made on a production weld.

QW-404.12 A change in the SFA specification filler metal classification or to a filler metal not covered by an SFA specification, or from one filler metal not covered by an SFA specification to another which is not covered by an SFA specification.

When a filler metal conforms to an SFA specification classification, requalification is not required if a change is made in any of the following:

(a) from a filler metal which is designated as moisture-resistant to one which is not designated as moisture-resistant and vice-versa (i.e., from E7018R to E7018);

(b) from one diffusible hydrogen level to another (i.e., from E7018-H8 to E7018-H16);

(c) for carbon, low alloy, and stainless steel filler metals having the same minimum tensile strength and the same nominal chemical composition, a change from one low hydrogen coating type to another low hydrogen coating type (i.e., a change among EXX15, 16, or 18 or EXXX15, 16, or 17 classifications);

(d) from one position-usability designation to another for flux cored electrodes (i.e., a change from E70T-1 to E71T-1 or vice versa);

(e) from a classification which requires impact testing to the same classification which has a suffix which indicates that impact testing was performed at a lower temperature or exhibited greater toughness at the required temperature or both, as compared to the classification which was used during procedure qualification (i.e., a change from E7018 to E7018-1).

QW-404.14 The deletion or addition of filler metal.

QW-404.15 A change from one F-Number in QW-432 to any other F-Number or to any other filler metal, except as permitted in QW-433.

QW-404.17 A change in the type of flux or composition of the flux.

QW-404.18 A change from wire to plate electrodes, and vice versa.

QW-404.19 A change from consumable guide to nonconsumable guide, and vice versa.

QW-404.20 Any change in the method by which filler metal is added, such as preplaced shim, top strip, wire, wire feed, or prior weld metal buttering of one or both joint faces.

QW-404.21 For filler metal additions, any change from the nominal specified analysis of the filler metal qualified.

QW-404.22 The omission or addition of consumable inserts. Qualification in a single-welded butt joint, with or without consumable inserts, qualifies for fillet welds and single-welded butt joints with backing or double-welded butt joints. Consumable inserts that conform to SFA-5.30, except that the chemical analysis of the insert conforms to an analysis for any bare wire given in any SFA specification or AWS Classification, shall be considered as having the same F-Number as that bare wire as given in QW-432.

QW-404.23 A change in the filler metal from bare (solid) or metal cored to flux cored, or vice versa.

QW-404.24 The addition or deletion of supplementary filler metal.

QW-404.25 The addition or deletion of supplementary powdered filler metal.

QW-404.26 An increase in the amount of supplementary powdered filler metal.

QW-404.27 Where the alloy content of the weld metal is largely dependent upon the composition of the supplementary powdered filler metal, any change in any part of the welding procedure which would result in the important alloying elements in the weld metal being outside of the specification range of chemistry given in the Welding Procedure Specification.

QW-404.29 A change in the flux trade name and designation.

QW-404.30 A change in deposited weld metal thickness beyond the range qualified in QW-451 for procedure qualification or QW-452 for performance qualification, except as otherwise permitted in QW-303.1 and QW-303.2. When a welder is qualified using radiography, the thickness ranges of QW-452.1 apply.

QW-404.31 The maximum thickness qualified is the thickness of the test coupon.

QW-404.32 For the low voltage short-circuiting type of gas metal-arc process when the deposited weld metal thickness is less than ½ in., an increase in deposited weld metal thickness beyond 1.1 times that of the qualification test deposited weld metal thickness. For weld metal thicknesses of ½ in. and greater, use QW-451.1 or QW-451.2, or QW-452.1 or QW-452.2, as applicable.

QW-404.33 A change in the SFA specification filler metal classification, or, if not conforming to an AWS filler metal classification, a change in the manufacturer's trade name for the electrode or filler metal. When optional supplemental designators, such as those which indicate moisture resistance (i.e., XXXXR), diffusible hydrogen (i.e., XXXX H16, H8, etc.), and supplemental impact testing (i.e., XXXX-1 or EXXXXM), are specified on the WPS, only filler metals which conform to the classification with the optional supplemental designator(s) specified on the WPS shall be used.

QW-404.34 A change in flux type (i.e., neutral to active or vice versa) for multilayer deposits in P-No. 1 materials.

QW-404.35 A change in the flux/wire classification or a change in either the electrode or flux trade name when not classified in an SFA specification. Requalification is not required when a wire/flux combination conforms to an SFA specification and a change is made from one diffusible hydrogen level to another (i.e., a change from F7A2-EA1-A1H4 to F7A2-EA1-A1H16).

QW-404.36 Where flux from recrushed slag is used, it shall be tested in accordance with Section II, Part C by either the manufacturer or user, or qualified as an unclassified flux in accordance with QW-404.9.

QW-404.37 A change in the composition of the deposited weld metal from one A-Number in QW-442 to any other A-Number, or to an analysis not listed in the table. Each AWS classification of A-No. 8 or A-No. 9 analysis of QW-442, or each nonferrous alloy in QW-432, shall require separate WPS qualification. A-Numbers may be determined in accordance with QW-404.5.

QW-404.38 A change in the nominal electrode diameter used for the first layer of deposit.

QW-404.39 For submerged-arc welding and electroslag welding, a change in the nominal composition or type of flux used. Requalification is not required for a change in flux particle size.

QW-404.40 A change in the nominal cross-sectional area of the electrodes or supplementary filler metal of more than 10%.

QW-404.41 A change of more than 10% in the powdered metal feed rate recorded on the PQR.

QW-404.42 A change of more than 5% in the particle size range of the powder.

QW-404.43 A change in the powdered metal particle size range recorded on the PQR.

QW-404.44 A change from a homogeneous powdered metal to a mechanical mixed powdered metal or vice versa.

QW-404.45 A change in the form of filler metal from solid to fabricated wire, flux-cored wire, powdered metal, or vice versa.

QW-404.46 A change in the powder feed rate range qualified.

QW-405 Positions

QW-405.1 The addition of other welding positions than those already qualified. See QW-120, QW-130, and QW-303.

QW-405.2 A change from any position to the vertical position uphill progression. Vertical-uphill progression (e.g., 3G, 5G, or 6G position) qualifies for all positions. In uphill progression, a change from stringer bead to weave bead. This limitation does not apply when a WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic material is solution annealed after welding.

QW-405.3 A change from upward to downward, or from downward to upward, in the progression specified for any pass of a vertical weld, except that the cover or wash pass may be up or down. The root pass may also be run either up or down when the root pass is removed to sound weld metal in the preparation for welding the second side.

QW-405.4 Except as specified below, the addition of other welding positions than already qualified.

(a) Qualification in the horizontal, vertical, or overhead position shall also qualify for the flat position. Qualification in the horizontal fixed position, 5G, shall qualify for the flat, vertical, and overhead positions. Qualification in the horizontal, vertical, and overhead positions shall qualify for all positions. Qualification in the inclined fixed position, 6G, shall qualify for all positions.

(b) A fabricator who does production welding in a particular orientation may make the tests for procedure qualification in this particular orientation. Such qualifications are valid only for the positions actually tested, except that an angular deviation of ±-15 deg. is permitted in the inclination of the weld axis and the rotation of the weld face as defined in QW-461.1. A test specimen shall be taken from the test coupon in each special orientation.

(c) In the vertical position, a change in the progression of travel from uphill to downhill, or vice versa.

QW-406 Preheat

QW-406.1 A decrease of more than 100°F in the preheat temperature qualified. The minimum temperature for welding shall be specified in the WPS.

QW-406.2 A change in the maintenance or reduction of preheat upon completion of welding prior to any required postweld heat treatment.

QW-406.3 An increase of more than 100°F in the maximum interpass temperature recorded on the PQR. This limitation does not apply when a WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic material is solution annealed after welding.

QW-406.4 A decrease of more than 100°F in the preheat temperature qualified or an increase in the maximum interpass temperature recorded on the PQR. The minimum temperature for welding shall be specifed in the WPS.

QW-406.5 A change in the maintenance or reduction of preheat upon completion of spraying and prior to fusing.

QW-406.6 A change of more than 10% in the amplitude or number of preheating cycles from that qualified.

QW-407 Postweld Heat Treatment

QW-407.1 A separate PQR is required for each of the following conditions.

(a) For P-No. 1, P-No. 3, P-No. 4, P-No. 5, P-No. 6, P-No. 9, P-No. 10, and P-No. 11 materials, the following postweld heat treatment conditions apply:

(1) No PWHT;

(2) PWHT below the lower transformation temperature;

(3) PWHT above the upper transformation temperature (e.g., normalizing);

(4) PWHT above the upper transformation temperature followed by heat treatment below the lower transformation temperature (e.g., normalizing or quenching followed by tempering);

(5) PWHT between the upper and lower transformation temperatures.

(b) For all other materials, the following postweld heat treatment conditions apply:

(1) No PWHT;

(2) PWHT within a specified temperature range.

QW-407.2 A change in the postweld heat treatment (see QW-407.1) temperature and time range requires a PQR.

The procedure qualification test shall be subjected to PWHT essentially equivalent to that encountered in the fabrication of production welds, including at least 80% of the aggregate times at temperature(s). The PWHT total time(s) at temperature(s) may be applied in one heating cycle.

QW-407.4 For test coupon (PQR) receiving a postweld heat treatment in which the upper transformation temperature is exceeded, the maximum qualified thickness for production welds is 1.1 times the thickness of the test coupon.

QW-407.5 A separate PQR is required for each of the following conditions:

(a) No PWHT;

(b) A change of more than 10% in the number of post heating cycles following the welding interval;

(c) PWHT within a specified temperature and time range if heat treatment is performed separately from the welding operation.

QW-407.6 A change in postweld heat treatment condition in QW-407.1 or an increase of 25% or more in total time at postweld heat treating temperature.

QW-407.7 A change in the heat treatment temperature range qualified if heat treatment is applied after fusing.

QW-408 Gas

QW-408.1 The addition or deletion of trailing shielding gas and/or a change in its composition.

QW-408.2 A change from a single shielding gas to any other single shielding gas or to a mixture of shielding gases, or a change in specified percentage composition of shielding gas mixture, or omission of shielding gas.

QW-408.3 A change in the specified flow rate range of the shielding gas or mixture of gases.

QW-408.4 A change in composition and flow rates of orifice gas and shielding gas.

QW-408.5 The addition or deletion of gas backing, a change in backing gas composition, or a change in the specified flow rate range of the backing gas.

QW-408.6 Any change of environment shielding such as from vacuum to an inert gas, or vice versa.

QW-408.7 A change in the type of fuel gas.

QW-408.8 The omission of inert gas backing except that requalification is not required when welding a single-welded butt joint with a backing strip or a double-welded butt joint or a fillet weld. This exception does not apply to P-No. 5X, P-No. 6X, and P-No. 10I metals.

QW-408.9 For groove welds in P-No. 4X and all welds of P-No. 5X, P-No. 6X, P-No. 10I, P-No. 10J, and P-No. 10K metals, the deletion of backing gas or a change in the nominal composition of the backing gas from an inert to a mixture including non-inert gas(es).

QW-408.10 For P-No. 10I, P-No. 5X, and P-No. 6X metals, the deletion of trailing shielding gas, a change in the trailing gas composition, or a decrease of 10% or more in the trailing gas flow rate.

QW-408.11 The addition or deletion of one or more of the following: shielding gas, trailing shielding gas, backing gas, or plasma-removing gas.

QW-408.12 A change of more than 5% in the flow rate of one or more of the following: shielding gas, trailer shielding gas, backing gas, and plasma-removing gas.

QW-408.13 A change in the position or orientation of plasma-removing gas jet relative to the workpiece (e.g., coaxial transverse to beam).

QW-408.14 A change in the oxygen or fuel gas pressure beyond the range qualified.

QW-408.15 In gas metal-arc welding and gas tungsten-arc welding: a change from a single gas to any other single gas or to a mixture of gases, or vice versa; a change in specified percentage composition of gas mixture or omission of shielding gas; a decrease of 10% or more in the rate of flow of shielding gas or mixture.

QW-408.16 A change of more than 5% in the flow rate of the plasma-arc gas or powdered metal feed gas recorded on the PQR.

QW-408.17 A change in the plasma-arc gas, shielding gas, or powdered metal feed gas from a single gas to any other single gas, or to a mixture of gases, or vice versa.

QW-408.18 A change of more than 10% in the gas mixture composition of the plasma-arc gas, shielding gas, or powdered metal feed gas recorded on the PQR.

QW-408.19 A change in the nominal composition of the powder feed gas or (plasma-arc spray) plasma gas qualified.

QW-408.20 A change of more than 5% in the plasma gas flow rate range qualified.

QW-409 Electrical Characteristics

QW-409.1 An increase in heat input, or an increase in volume of weld metal deposited per unit length of weld, over that qualified. The increase may be measured by either of the following:

(a) Heat input (J/in.)

$$= \frac{\text{Voltage} \times \text{Amperage} \times 60}{\text{Travel Speed (in./min)}}$$

(b) Volume of Weld Metal = an increase in bead size or a decrease in length of weld bead per unit length of electrode.

The requirement for measuring the heat input or volume of deposited weld metal does not apply when the WPS is qualified with a PWHT above the upper transformation temperature or a solution anneal after welding austenitic materials.

QW-409.2 A change from spray arc, globular arc, or pulsating arc to short circuiting arc, or vice versa.

QW-409.3 The addition or deletion of pulsing current to dc power source.

QW-409.4 A change from ac to dc, or vice versa; and in dc welding, a change from straight polarity to reverse polarity, or vice versa.

QW-409.5 A change of ±15% from the amperage or voltage ranges in the qualified WPS.

QW-409.6 A change in the beam current of more than ±5%, voltage of more than ±2%, welding speed of more than ±2%, beam focus current of more than ±5%, gun-to-work distance of more than ±5%, or a change in oscillation length or width of more than ±20% from those previously qualified.

QW-409.7 Any change in the beam pulsing frequency duration from that qualified.

QW-409.8 A change in the range of amperage, or except for SMAW and GTAW welding, a change in the range of voltage. A change in the range of electrode wire feed speed may be used as an alternative to amperage.

QW-409.9 A change in the arc timing of more than $\pm \frac{1}{10}$ sec.

QW-409.10 A change in amperage of more than ±10%.

QW-409.11 A change in the power source from one model to another.

QW-409.12 A change in type or size of tungsten electrode.

QW-409.13 A change in the shape or dimensions of the welding electrode; a change from one RWMA (Resistance Welding Manufacturer's Association) class electrode material to another.

QW-409.14 Addition or deletion of upslope or downslope current control, or a change of more than 10% in the slope current time or amplitude.

QW-409.15 A change of more than 5% in the electrode pressure, the welding current, or the welding time cycle from that qualified, except that requalification is not required if there is a change of not more than 10% in either the electrode pressure or the welding current or the welding time cycle, provided the remaining two variables remain at the values qualified. A change from ac to dc or vice versa. The addition or deletion of pulsing current to a dc power source. When using pulsing dc current, a change of more than 5% in the pulse amplitude, width, or number of pulses per cycle from that qualified.

QW-409.16 A change from synchronous to asynchronous timing.

QW-409.17 A change in the power supply primary voltage or frequency, or in the transformer turns ratio, tap setting, choke position, secondary open circuit voltage or phase control setting.

QW-409.18 A change in the procedure or frequency of tip cleaning.

QW-409.19 Any change in the beam pulsing frequency and pulse duration from that qualified.

QW-409.20 Any change in the following variables: mode of operation (from pulsed to continuous or vice versa), energy distribution across the beam (i.e., multimode or gaussian), lens focal length, and lens focal distance.

QW-409.21 Any change in the following variables: wattage of more than 2%, welding speed of more than 2%, spot size of more than 2%, and lens to work distance of more than 5%.

QW-409.22 An increase of more than 10% in the amperage used in application for the first layer.

QW-409.23 A change of more than 10% in the ranges of amperage or voltage qualified.

QW-409.24 A change of more than 10% in the filler wire wattage recorded on the PQR. Wattage is a function of current voltage, and stickout dimension.

QW-409.25 A change of more than 10% in the plasma-arc current or voltage recorded on the PQR.

QW-409.26 For the first layer only, an increase in heat input of more than 10% or an increase in volume of weld metal deposited per unit length of weld of more than 10% over that qualified. The increase may be measured by either of the following:

(a) Heat input (J/in.)

$$= \frac{\text{Voltage} \times \text{Amperage} \times 60}{\text{Travel Speed (in./min)}}$$

(b) Volume of Weld Metal = an increase in bead size or a decrease in length of weld bead per unit length of electrode.

QW-410 Technique

QW-410.1 A change from the stringer bead technique to the weave bead technique, or vice versa.

QW-410.2 A change in the nature of the flame, oxidizing to reducing, or vice versa.

QW-410.3 A change in the orifice, cup, or nozzle size.

QW-410.4 A change in the welding technique, forehand to backhand, or vice versa.

QW-410.5 A change in the method of initial and interpass cleaning (brushing, grinding, etc.)

QW-410.6 A change in the method of back gouging.

QW-410.7 A change in width, frequency, or dwell time of oscillation, for machine or automatic welding only.

QW-410.8 A change in the contact tube to work distance.

QW-410.9 A change from multipass per side to single pass per side. This limitation does not apply when a WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic material is solution annealed after welding.

QW-410.10 A change from single electrode to multiple electrode, or vice versa, for machine or automatic welding only. This limitation does not apply when a WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic material is solution annealed after welding.

QW-410.11 A change from closed chamber to out-of-chamber conventional torch welding in P-No. 5X metals, but not vice versa.

QW-410.12 A change from the melt-in technique to the keyhole technique of welding, or vice versa, or the inclusion of both techniques though each has been individually qualified.

QW-410.14 A change in the angle of the axis of the beam relative to the workpiece.

QW-410.15 A change in the spacing of multiple electrodes for machine or automatic welding.

QW-410.17 A change in the type or model of the welding equipment.

QW-410.18 An increase in the absolute pressure of the vacuum welding environment beyond that qualified.

QW-410.19 Any change in filament type, size, or shape.

QW-410.20 The addition of a wash pass.

QW-410.21 A change of welding from one side to welding from both sides, or vice versa.

QW-410.22 A change in either of the following stud welding parameters: a change of stud gun model; a change in the lift more than $\pm^1/_{32}$ in.

QW-410.25 A change from manual or semiautomatic to machine or automatic welding and vice versa.

QW-410.26 The addition or deletion of peening.

QW-410.27 A change in the rotational speed producing a change in the outside surface velocity (ft/min) greater than ± 10% of the outside surface velocity qualified.

QW-410.28 A change in the thrust load (lb) greater than ±10% of the thrust load qualified.

QW-410.29 A change in the rotational energy (lb-ft^2) greater than ±10% of the rotational energy qualified.

QW-410.30 Any change in upset dimension (overall loss in length of parts being joined) greater than ±10% of the upset qualified.

QW-410.31 A change in the method of preparing the base metal prior to welding (e.g., changing from mechanical cleaning to chemical cleaning or to abrasive cleaning, or vice versa).

QW-410.32 A change of more than 10% in the holding pressure prior to or after welding. A change of more than 10% in the electrode holding time.

QW-410.33 A change from one welding type to another, or modification of equipment, including Manufacturer, control panel, model number, electrical rating or capacity, type of electrical energy source, or method of applying pressure.

QW-410.34 Addition or deletion of an electrode cooling medium and where it is used.

QW-410.35 A change in the distance between arms or a change in the throat depth.

QW-410.37 A change from single to multiple pass or vice versa.

QW-410.38 A change from multiple-layer to single layer cladding/hardsurfacing, or vice versa.

QW-410.39 A change in the torch type or tip size.

QW-410.40 For submerged-arc welding and electroslag welding, the deletion of a supplementary device for controlling the magnetic field acting on the weld puddle.

QW-410.41 A change of more than 15% in the travel speed range recorded on the PQR.

QW-410.42 The addition or elimination of oscillation of the plasma torch or filler wires; a change from simple harmonic to constant velocity oscillating motion or vice versa; a change of more than 10% in oscillation displacement recorded on the PQR; however, a procedure qualified using a minimum oscillation displacement and a procedure qualified using a maximum oscillation displacement shall qualify for all weld bead oscillations in between, with all other essential variables remaining the same.

QW-410.43 For the torch or workpiece, a change of more than 10% in the travel speed range qualified.

QW-410.44 A change of more than 15% in the spray-torch to workpiece distance qualified.

QW-410.45 A change in the method of surface preparation of the base metal to be hard-faced (example: sandblasting versus chemical cleaning).

QW-410.46 A change in the spray-torch model or tip orifice size.

QW-410.47 A change of more than 10% in the fusing temperature range qualified. A change in the rate of cooling from the fusing temperature of more than 50°F/hr, a change in the fusing method (example: torch, furnace, induction).

QW-410.48 A change in the constricted arc from transferable to nontransferable or vice versa.

QW-410.49 A change in the diameter of the plasma torch-arc constricting orifice.

QW-410.50 A change in the number of electrodes acting on the same welding puddle.

QW-410.51 The addition or elimination of oscillation of the electrode or electrodes.

QW-410.52 A change in the method of delivering the filler metal to the molten pool, such as from the leading or trailing edge of the torch, the sides of the torch, or through the torch.

QW-416
WELDING VARIABLES
Welder Performance

Paragraph[1]		Brief of Variables	Essential					
			OFW QW-352	SMAW QW-353	SAW QW-354	GMAW[2] QW-355	GTAW QW-356	PAW QW-357
Joints QW-402	.4	− Backing		X		X	X	X
	.7	+ Backing	X					
Base Metal QW-403	.2	Maximum qualified	X					
	.16	ϕ Pipe diameter		X	X	X	X	X
	.18	ϕ P-Number	X	X	X	X	X	X
Filler Metals QW-404	.14	± Filler	X				X	X
	.15	ϕ F-Number	X	X	X	X	X	X
	.22	± Inserts					X	X
	30	ϕ *t* Weld deposit		X	X	X	X	X
	.31	ϕ *t* Weld deposit	X					
	.32	*t* Limit (s. cir. arc)				X		
Positions QW-405	.1	+ Position	X	X	X	X	X	X
	.3	ϕ ↑↓ Vert. welding		X		X	X	X
Gas QW-408	.7	ϕ Type fuel gas	X					
	.8	− Inert backing				X	X	X
Electrical QW-409	.2	ϕ Transfer mode				X		
	.4	ϕ Current or polarity					X	

Welding Processes:

FGW	Gas welding (fuel gas welding)
SMAW	Shielded metal-arc welding
SAW	Submerged-arc welding
GMAW	Gas metal-arc welding
GTAW	Gas tungsten-arc welding
PAW	Plasma-arc welding

Legend:

ϕ Change	*t* Thickness
+ Addition	↑ Uphill
− Deletion	↓ Downhill

NOTES:

(1) For description, see Section IV.

(2) Flux-cored arc welding as shown in QW-355, with or without additional shielding from an externally supplied gas or gas mixture, is included.

QW-451 Procedure Qualification Thickness Limits and Test Specimens (Cont'd)

QW-451.2
GROOVE-WELD TENSION TESTS AND LONGITUDINAL-BEND TESTS

Thickness T of Test Coupon Welded, in.	Range of Thickness T of Base Metal Qualified, in. [Note (1)] Min.	Max.	Thickness t of Deposited Weld Metal Qualified, in. [Note (1)] Max.	Type and Number of Tests Required (Tension and Guided-Bend Tests) [Note (2)] Tension QW-150	Face Bend QW-160	Root Bend QW-160
Less than 1/16	T	$2T$	$2t$	2	2	2
1/16 to 3/8, incl.	1/16	$2T$	$2t$	2	2	2
Over 3/8	3/16	$2T$	$2t$	2	2	2

NOTES:

(1) See QW-403 (.2, .3, .6, .7, .9, .10) QW-404.32, and QW-407.4 for further limits on range of thicknesses qualified. These are also applicable to deposited weld metal thicknesses. Also see QW-202 (.2, .3, .4 for allowable exceptions.

(2) For combination of welding procedures, see QW-200.4.

QW-451 Procedure Qualification Thickness Limits and Test Specimens (Cont'd)

QW-451.3
FILLET-WELD TESTS[1]

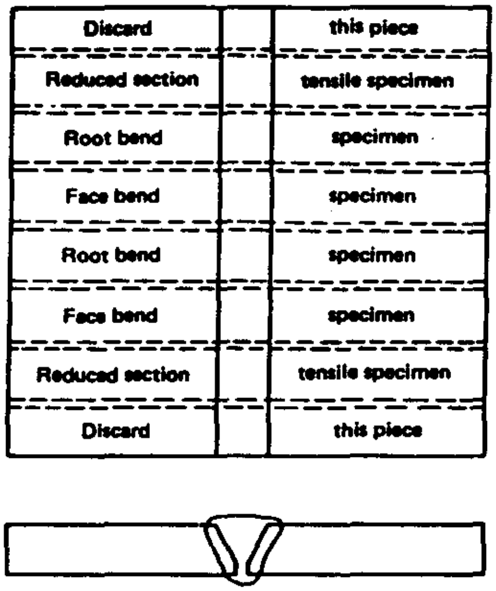
Type of Joint	Thickness of Test Coupons as Welded, in.	Range Qualified	Type and Number of Tests Required [QW-462.4(a) or QW-462.4(d)] Macro
Fillet	Per QW-462.4(a)	All fillet sizes on all base metal thicknesses and all diameters	5
Fillet	Per QW-462.4(d)		4

NOTE:
(1) Production assembly mockups may be substituted in accordance with QW-181.1.1. When production assembly mockups are used, range qualified shall be limited to the fillet sizes, base metal thicknesses, and configuration of the mockup.

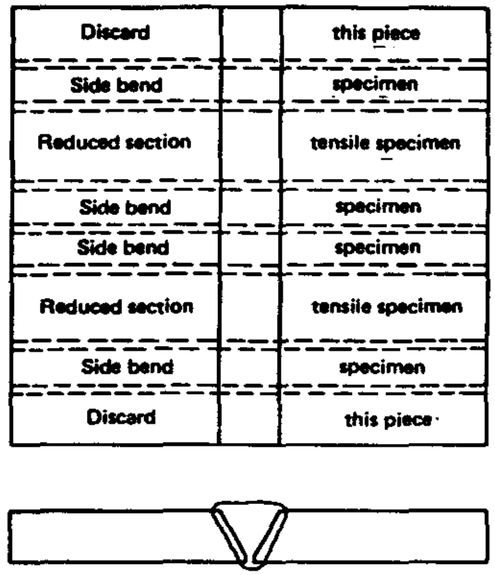
QW-451.4
FILLET WELDS QUALIFIED BY GROOVE-WELD TESTS

Thickness T of Test Coupon (Plate or Pipe) as Welded	Range Qualified	Type and Number of Tests Required
All groove tests	All fillet sizes on all base metal thicknesses and all diameters	Fillet welds are qualified when the groove weld is qualified in accordance with either QW-451.1 or QW-451.2 (see QW-202.2)

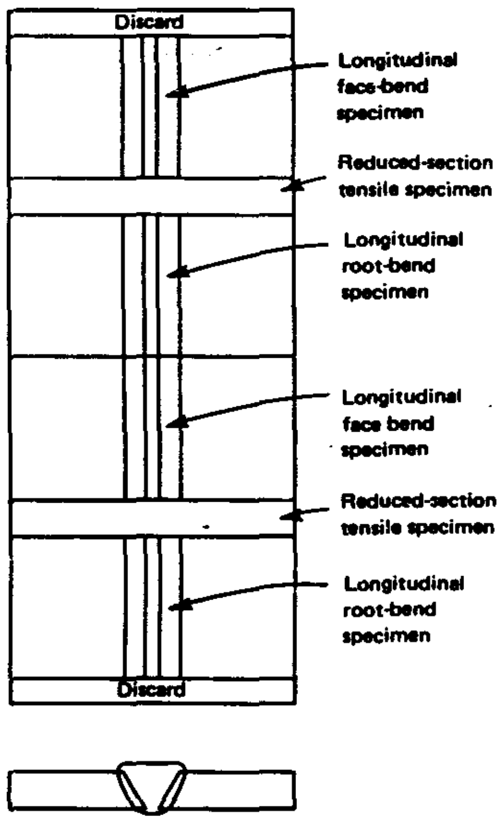
QW-463 Order of Removal



QW-463.1(a) PLATES — LESS THAN ¾ IN. THICKNESS PROCEDURE QUALIFICATION

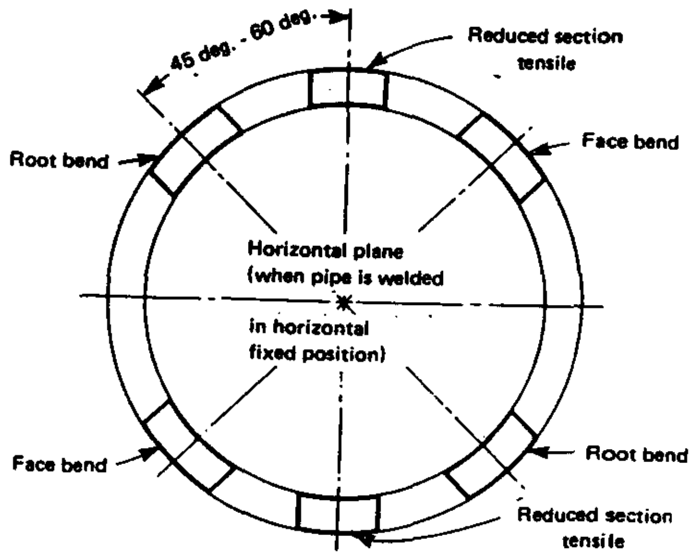


QW-463.1(b) PLATES — ¾ IN. AND OVER THICKNESS AND ALTERNATE FROM ⅜ IN. BUT LESS THAN ¾ IN. THICKNESS PROCEDURE QUALIFICATION

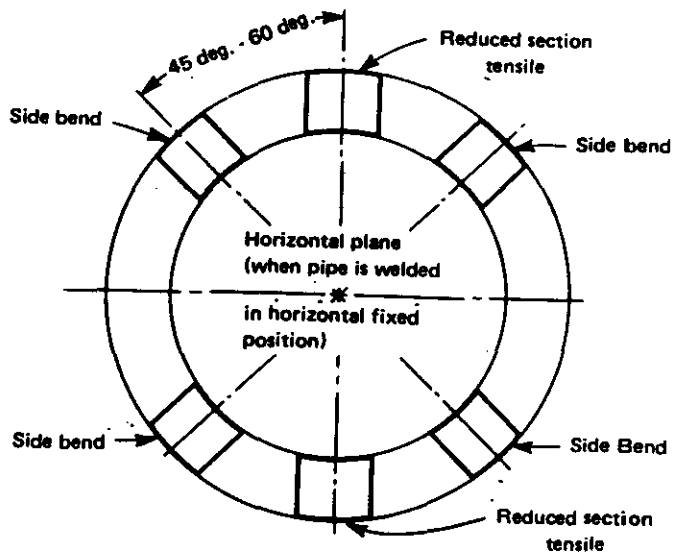


QW-463.1(c) PLATES — LONGITUDINAL PROCEDURE QUALIFICATION

QW-463 Order of Removal (Cont'd)



QW-463.1(d) PROCEDURE QUALIFICATION



QW-463.1(e) PROCEDURE QUALIFICATION

Lecture ~~13~~ 14.

Controlling Weld Variables from Design to Deposition

Understanding weld metal properties and the influence of welding parameters can help you achieve higher quality, cost-effective welds

BY DUANE K. MILLER

Many variables can affect the properties of weld deposits made in the shop or field and cause these properties to vary from the results reported for the tightly controlled standard filler metal qualification tests developed by AWS. Understanding these variables and how they can be controlled through proper welding procedures will help achieve higher weld quality and greater consistency of weld characteristics from design to deposition.

Commonly used welds include fillet welds, complete joint penetration (CJP) groove welds, and partial joint penetration (PJP) groove welds. The strength of each weld type depends on the strength of the deposited weld metal and on specific dimensional characteristics of the weld. For a fillet weld, these factors include the leg size; for a CJP weld, the thickness of the plate joined; and for a partial penetration weld, the depth of penetration. The length of any of these weld types will obviously affect the connection strength as well.

In each case, however, the strength of the deposited weld metal is critical to the performance of the joint. Weld strength traditionally has been based on the tensile (vs. yield) strength of the deposited metal. Engineers rely on electrode classifications to determine the strength of the deposited weld metal. These classifications provide some basic information on properties such as yield strength and tensile strength. For example, the "70" in E7018, a typical low-hydrogen electrode, indicates a minimum tensile strength of 70,000 lb/in.[2] Although this value is used for design purposes, the strength levels of the deposited metal may vary considerably. A review of filler metal specifications and qualification tests will help to understand why.

Specifications of Filler Metals

Among the mechanical properties described in the AWS filler metal specifications for a given electrode classification are specific yield and tensile strength and elongation values. Minimum Charpy values for impact toughness may or may not be included, depending on the electrode classification. Other properties specified include limits on significant alloy levels, welding performance criteria, and other process-specific issues such as the percentage of moisture in the coatings of low-hydrogen electrodes for SMAW.

Most strength-related properties are specified as minimum values, and electrodes certified to a specification typically exceed these values. A caution on the use of this information appears in the appendix to the filler metal specification, stating that actual weld metal properties may vary widely in relation to joint design, penetration, procedures and other factors. Because it would be impossible to duplicate all possible conditions that might be encountered in actual use, the purpose of the filler metal qualification test plate is only for classification of a particular product to a specific filler metal type. However, it is useful in making comparisons of electrodes within a specification.

Knowing the weld and how its actual characteristics may dif-

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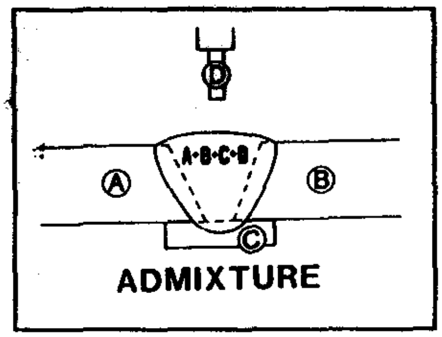

Fig. 1 — Schematic illustration of admixture.

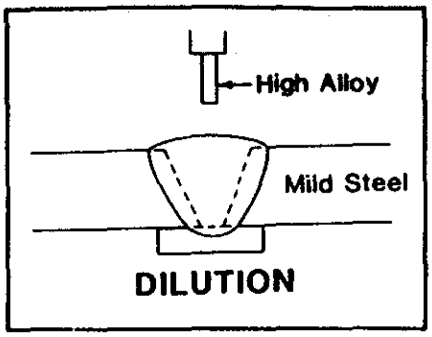

Fig. 2 — Schematic illustration of dilution.

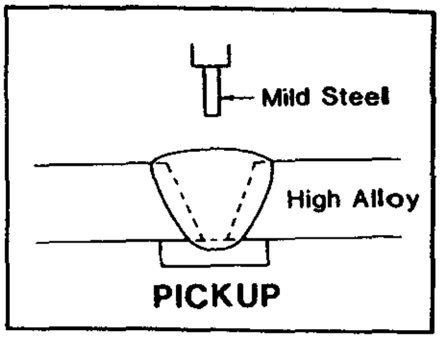

Fig. 3 — Schematic illustration of pickup.

fer from the specification requires understanding the effects of deviations from classification test conditions and actual welding parameters. These can be classified into two broad categories: chemical and thermal changes.

Chemical Effects

Two key influences that may cause chemical changes in the weld are the plate chemistry and the amount of admixture. Defining admixture, dilution and pickup will help clarify their effects on weld chemistry.

Admixture is illustrated in Fig. 1. Here, the weld is joining plate A to plate B, and a backing strip labeled C is included. The joint is to be filled with filler metal D. The force and energy of the arc will melt some of plate A, some of plate B and some of plate C. The final composition of the weld metal will include A, B, C and D. This conglomeration of material is known as admixture. The base metals and the filler metal may have significantly different chemistries. As material from the base plate is introduced into the admixture, it can be seen that weld chemistry changes. Plate chemistry that differs from that used for filler metal qualification may cause the weld chemistry to differ as well.

Figure 2 illustrates dilution, which occurs when an electrode that has more of an alloy is used to weld on a lower alloy plate. As the high alloy is mixed with the lower alloy, creating an admixture, the high alloy is diluted. For example, using a stainless steel electrode to weld on mild steel will result in a lower chrome and nickel content in the weld than in the electrode.

Alloy pickup, shown in Fig. 3, is the opposite of dilution. If a mild steel electrode is used to weld on high-alloy plate that contains, for example, nickel, the weld deposit will contain nickel, which was not present in the mild steel filler. When the deposit contains a greater amount of an alloy than the electrode, the situation is known as alloy pickup.

The extent of admixture is a function of the joint geometry, the process used and the procedures employed. To understand the effects of joint geometry, consider the two different butt joints shown in Fig. 4. The plate thickness is the same for both joints. The first joint, a square-edged butt, required welding from two sides. The bottom side was welded first, then the plate was turned, and the top side was welded to achieve full joint strength. The area contained within the dotted lines shows the extensive influence of base material on the weld, which would contain a high percentage of the base metal. This admixture would be composed primarily of base material.

The second butt joint, a single-V butt with a backup, comes close to approaching the joint prescribed in the filler metal specifications. Here, minimum amounts of base material are melted, so the admixture is composed primarily of filler metal. Despite their general similarities, production joints typically use smaller root openings than the AWS test plate joint and have higher levels of admixture.

The welding process used will affect the degree of penetration that is achieved. Penetration has a direct effect on admixture. This can be seen in Fig. 5. The deepest penetrating process, in which the base material has the most significant effect, is submerged arc welding (SAW). Near the other extreme, shielded metal arc welding gives relatively shallow penetration, so the base material has a lesser effect. Gas tungsten arc welding is a bit of an anomaly. The degree of penetration is relatively shallow but if an autogenous weld is made (one that does not employ filler metal but relies only on melting of the base metal),

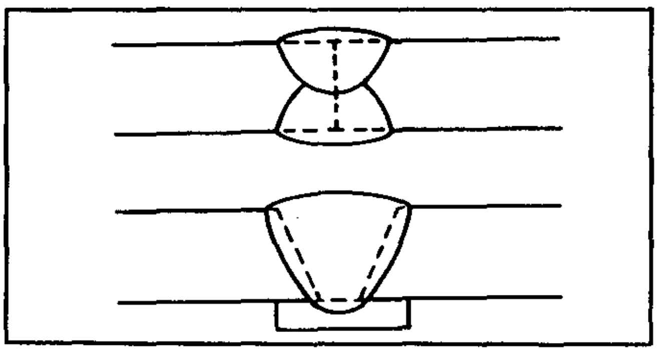

Fig. 4 — The effect of joint geometry on admixture. Top — a square-edged butt joint that required welding from two sides; Bottom — a single-V butt joint with a backup.

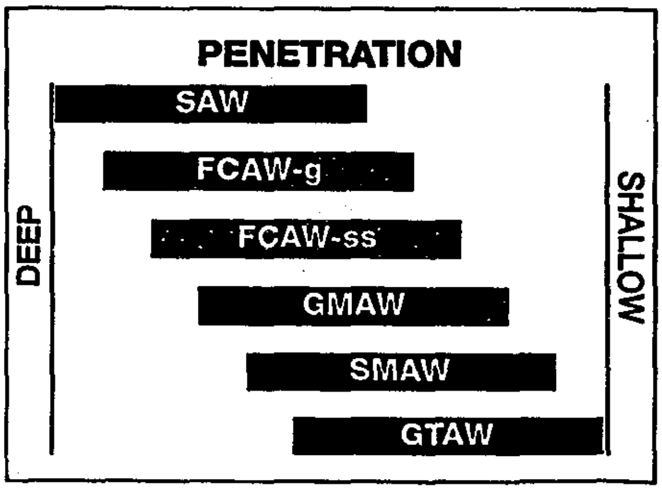

Fig. 5 — Illustration of the levels of penetration for various welding processes.

the admixture is 100% base metal. Processes between these extremes produce a range of results. The gas-shielded flux cored processes give relatively deep penetration. Self-shielded flux cored processes can have a range in penetration. The gas metal arc process features deep penetration in the spray mode and relatively shallow penetration in the short arc mode.

Within a given process, the degree of penetration is mainly a function of amperage and electrode size. Penetration is generally proportional to current density. Current density is the amperage divided by the cross-sectional area of the electrode, or I/A. Since the area, A, is proportional to the diameter squared (d^2), current density is proportional to I/d^2. Thus, for a given amperage, a smaller electrode will give a deeper penetrating weld, along with an increase in admixture. Although penetration is most closely related to current density, travel speed, polarity, electrode extension and welding position also affect penetration.

ALLOY EFFECTS
—STRENGTH—

SIGNIFICANT ——————→ MOST SIGNIFICANT

Nickel	Chromium Silicon Manganese	Molybdenum Copper	Carbon Vanadium Columbium

Fig. 6 — The effects of various alloying elements on strength.

ALLOY EFFECTS
—TOUGHNESS—

DECREASES	INACTIVE (LITTLE EFFECT)	IMPROVES
Vanadium Carbon Columbium	Copper Silicon Chromium Molybdenum	Nickel Manganese

Fig. 7 — The effects of various alloying elements on toughness.

Effects of Alloys on Mechanical Properties

The amount of plate that ends up in the admixture may change the deposit analysis from that of filler metal qualification deposits, and correspondingly affect mechanical properties. While the significance of individual alloys introduced into the admixture may be evaluated on a weight percentage basis, combinations of elements may produce a synergetic effect, with complicated reactions that are beyond the scope of this article. The following general trends apply to carbon-manganese-silicon steels typically welded with carbon and low-alloy steel electrodes.

Figure 6 shows the general effect of various alloying elements on strength. In small percentages, those elements in the "Most Significant" column greatly increase the strength of an alloy. The other elements listed also contribute to increased strength but in proportionally lesser degrees the further to the left they are listed on the chart. For example, although nickel will contribute to the strength of the admixture, it would require a much greater weight percentage of nickel to provide the same degree of added strength as would be provided by a far smaller percentage of vanadium. Although the A36 plate used for qualification of many products does not require the inclusion of vanadium and/or columbium, welds made in plate bearing these elements (such as A572) will become higher in strength if there is a high degree of admixture and alloy pickup (because the vanadium and columbium are in the base material rather than the welding material).

Alloying elements may also affect toughness properties. To predict toughness changes, alloys can be categorized in three groups, as shown in Fig. 7. Vanadium, carbon and columbium typically lower the impact energy. Copper, silicon, chromium and molybdenum have very little effect either way. Nickel and manganese increase the impact energy and nickel is a key ingredient for gaining better impact properties without significantly increasing the strength of the metal.

Effects of Procedures on Chemistry

In some cases, changes in the welding procedure may produce significant chemical deviations in the weld. For example, consider the submerged arc welding process, where the deposit chemistry is dependent, among other things, on the effect of the flux. If an active flux is used, manganese and silicon levels in the deposit will be dependent on the arc voltage used. Because voltage is not considered as a variable in filler metal classification test plates, any variation from the standard 28 V on which they are based may cause a change in the level of manganese and/or silicon.

To determine when voltage may affect weld strength, it is necessary to understand the Wall neutrality number, often designated as "W." Identical tests are run at two voltages, the standard 28 V and 36 V. The absolute difference in the weight percentage of silicon is added to the absolute difference in the weight percentage of manganese. These figures, when added together and multiplied by 100, equal the Wall neutrality number. The American Welding Society has designated fluxes having a Wall number of 40 or less as neutral and those with a Wall number of more than 40 as active. If the Wall number is less than 40, the effect of voltage is considered insignificant. However, if it is above 40, the silicon and manganese contents of the weld may be increased with higher voltage, thereby increasing the weld strength and, typically, reducing elongation. While silicon will have little effect on the weld deposit in terms of toughness, manganese tends to improve it slightly. Active fluxes are typically used to make single- or limited-pass welds. The increase in silicon and manganese that is possible with these fluxes can offset the dilution that typically occurs when deep-penetrating SAW is used, resulting in higher-quality, better-appearing, crack-free welds. However, when used for multipass welds (with less admixture), the voltage must be carefully controlled to ensure that alloy buildup does not occur because this could lead to weld cracking.

Shielding gas also may affect weld properties. When CO_2 gas is used in flux cored welding, alloys may oxidize and not be transferred to the weld deposit. Less alloy is oxidized if inert gases are used for shielding. Therefore, the deposit will have a higher alloy content, which generally results in higher strength levels and lower impact energy. An increase of 5000–10,000 lb/in.^{2} (34.47–68.94 MPa) in tensile strength is common, while Charpy impact properties may drop by as much as 50% when inert gas shielding is used with electrodes designed for CO_2 operation.

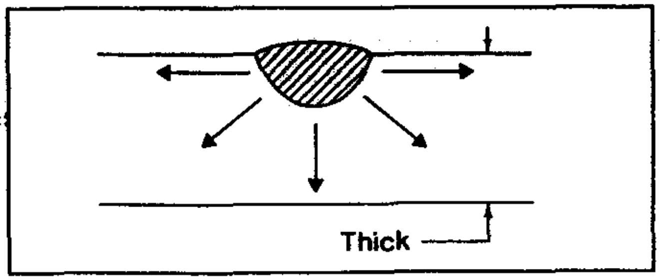

Fig. 8 — Heat conduction in three directions on thick plate, which produces a rapid cooling rate.

Thermal Effects

There are several ways in which thermal effects can change the properties of actual welds in comparison to test plates. For instance, differences in the level of preheat between the classification test and that required for the actual weld may result in changes in strength and toughness. Higher preheat and interpass temperatures generally reduce weld yield and tensile strength and typically improve Charpy impact toughness, unless that temperature exceeds 500°F (260°C) where a decrease usually begins.

Heat input also may be different. Variables covered by the classification tests include electrode size, voltage, amperage, polarity, travel speed and welding position. All of these affect the heat input, which is calculated by multiplying the welding amperage times the voltage times 60 and dividing the product by the travel speed. Some heat input calculations will incorporate a thermal efficiency factor.

The voltage and amperage are dictated by the welding procedure, as is the travel speed. Efficiency is related to the process. SAW causes most of the heat of the arc to be retained by the base material. Other processes may allow more of the energy to escape through radiation, smoke, spatter and other means, rather than entering the plate. However, many heat input equations do not consider the effect of efficiency. Comparison of the numerical values obtained from heat input calculations is best limited to comparing results from the same process unless some efficiency factor is applied.

The higher the amperage, for instance, the more heat will be put into the joint, presuming the same travel speed and voltage are being used. With increased travel speed, however, high amperage welding procedures can be adjusted so as to maintain the same heat input. If the weld nugget size is kept the same, heat input is very often nearly constant.

Cooling rate should also be considered. Cooling rate depends upon the temperature of the steel being welded, the heat input, the thickness of the part, the geometry of the part and the ambient temperature. Figure 8 shows heat conduction in three directions on thick plate, which produces a rapid cooling rate. Conversely, a slower cooling rate is associated with thin plate, as shown in Fig. 9, where heat is transferred in only two directions. In general, with carbon steel materials, the faster the material is cooled, the higher its strength but the lower its Charpy impact properties will be.

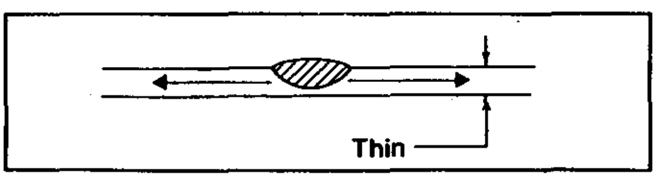

Fig. 9 — Thin plate showing a slower cooling rate. The heat is transferred in two directions.

Multiple-pass welding creates a thermal effect on previous beads as subsequent passes are made. The resultant reheating of previously deposited beads improves Charpy impact properties, making multiple passes highly desirable if the goal is to achieve the ultimate in impact properties.

Postweld heat treatments are another factor. Stress relief at 1100°–1200°F (593°–649°C) typically causes the tensile strength to drop 5000 lb/in.^{2} and the yield strength to drop 10,000 lb/in.^{2} Longer-term stress relief or different temperatures from the standard 1100°F for 1 h used for AWS specimens will also affect the results. Normalizing, or thermal treatment at temperatures approaching 1600° or 1700°F (827° or 927°C), will have a very significant effect, typically lowering yield and tensile properties.

The various thermal effects can interact with each other. For example, a weld may be made with an interpass temperature of 300°F (149°C). Stress relieving it at 1150°F (621°C) for 1 h would produce a given set of results. Welding the same plate using the same welding procedure but using an interpass temperature of 200°F (93°C) and stress relieving at 1150°F for 8 h might produce the same yield and tensile strengths for both welds.

Procedures Control Weld Quality

Controlling all the variables outlined above to achieve consistent weld quality is made easier by the use of the "welding procedure specification" (WPS), which signifies the combination of variables used to make a certain weld. Often referred to as the "welding procedure" or simply "procedure," the WPS consists of, as a minimum, the process; electrode specification, classification, and diameter; electrical characteristics; base metal specification; minimum preheat and interpass temperatures; welding current (amperage)/wire feed speed; arc voltage; travel speed; position of welding; postweld heat treatment; shielding gas type and flow rate; and joint design details. It can be seen that this comprehensive information, when followed carefully, provides substantial control over welding variables.

Many issues must be evaluated when selecting welding procedure values. A brief look at some of the considerations will show how these procedures provide the guidance needed to achieve consistent weld quality.

The requirements of each weld are determined by the interaction of many factors. The required level of penetration is a function of the joint design and the weld type, but all welds must achieve fusion to ensure their strength. Each weld must achieve a specified yield and/or tensile strength value, although the connection design will largely determine the exact level. Acceptable levels of undercut and porosity are a function of the type of loading to which the weld is subjected.

Welders cannot be expected to determine the most efficient means of meeting these conditions. Since neither the welder nor the inspector develops these procedures, neither may know why each variable was selected. Instead, knowledgeable welding technicians and engineers create the written welding procedure specifications with which to convey these requirements to welders. In fact, the suitability of a weld made by a skilled welder in conformance with the requirements of a WPS can only be as good as the WPS itself.

Some things outlined in the WPS are obviously necessary to ensure quality. The limits of suitable operation for the welding process and electrode must be understood as they apply to the specific steel grade, joint design, and welding position. The specified electrode must be operated on the proper polarity, with amperage levels suitable for both electrode diameter and base material thickness. Proper shielding gases must be employed as well. Other not so obvious factors can also be communicated through a written WPS. For example, the preheat required for a given application is a function of steel grades, material thickness, and type of electrode employed (low hydrogen or otherwise). The required preheat, once determined, can be easily communicated through the WPS.

If the parameters outlined in the WPS are not conformed to, the deposited weld metal may not meet the quality requirements imposed by the code or the job specifications. Correcting the problem may involve removing and replacing the unacceptable weld. Other economic considerations result from not following the procedures designed to produce the best combination of weld quality and cost-effectiveness. For example, the cost of welding is approximately inversely proportional to the deposition rate. In the semiautomatic welding processes, the deposition rate is tied to wire feed speed. If an acceptable weld can be made with a wire feed speed of 200 in./min (508 cm/min), a weld made at 160 in./min (406.4 cm/min) will cost about 25% more than the weld that conforms to the WPS. Since penetration is related to current density, and current density is a function of the amperage, the 160 in./min procedure may not achieve the required level of penetration because the amperage is a function of the wire feed speed. Welds made in conformance with WPS values are likely to be performed at rates that are conducive to achieving the desired weld quality and yet are economical.

Many variables may affect the properties of the completed weld, and it is important that everyone in the design-fabrication-inspection sequence understand these influences. It is essential that welding variables be controlled to achieve the goals of quality welds at an economical rate. Welding Procedure Specifications are the key tool used to communicate these requirements so that the mutually compatible goals of quality and economy can be achieved. ◆