

ANSI/AWS D10.8-96
An American National Standard

**Recommended
Practices for Welding of
Chromium-Molybdenum
Steel Piping and
Tubing**



American Welding Society

Key Words — Chromium-molybdenum steel pipe,
chromium-molybdenum steel tubing

ANSI/AWS D10.8-96
An American National Standard

Approved by
American National Standards Institute
July 17, 1996

Recommended Practices for Welding of Chromium-Molybdenum Steel Piping and Tubing

Supersedes AWS D10.8-86

Prepared by
AWS Committee on Piping and Tubing

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

This document presents recommendations for welding chromium-molybdenum steel pipe and tubing to itself and to various other materials. Subjects covered in detail are filler metal selection, joint design, preheating, and postheating. Particular emphasis is placed on the importance of maintaining interpass temperature and dangers inherent in interrupted heating cycles.



American Welding Society

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International Standard Book Number: 0-87171-500-7

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Foreword

(This Foreword is not a part of ANSI/AWS D10.8-96, *Recommended Practices for Welding of Chromium-Molybdenum Steel Piping and Tubing*, but is included for information purposes only).

The chromium-molybdenum (Cr-Mo) steels considered in this document contain from one-half to nine percent chromium and some molybdenum. These elements increase the corrosion and oxidation resistance of steel and impart greater strength and microstructural stability at elevated temperatures.

Since such alloy additions also increase hardenability, steps must be taken to prevent cracking during and after solidification by reducing stresses, limiting hydrogen content, and assuring adequate ductility. These steps include limiting the addition of those elements which increase hardenability, preheating, using filler metals and processes which minimize the addition of hydrogen to the weld, and postweld heat treatment (PWHT).

When these alloys are used in a corrosive environment, care should be taken to eliminate crevices and reduce hardness. When the service conditions include exposure to high temperatures, consideration must also be given to the need for increased creep strength and possible problems due to temper embrittlement and stresses resulting from differential thermal expansion. In addition, when joining different chromium-molybdenum steels to each other or to austenitic chromium-nickel stainless steels, consideration must be given to dilution during welding, diffusion of elements during service, and differences in thermal expansion and corrosion resistance.

The selection of base metals is beyond the scope of this document; however, the selection of filler metals for various base metal combinations and suggested preheating and postweld heat treating temperatures are included. This recommended practice discusses the special considerations which are advisable when preheating and post heating. A more complete treatment of this subject is to be found in ANSI/AWS D10.10, *Recommended Practices for Local Heating of Welds in Piping and Tubing*. Also not discussed in detail are the methods of root-pass welding. These are treated fully in ANSI/AWS D10.11, *Recommended Practices for Root Pass Welding of Pipe Without Backing*.

Comments and suggestions are welcome. They should be addressed to the Secretary, Committee on Piping and Tubing, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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Recommended Practices for Welding of Chromium-Molybdenum Steel Piping and Tubing

1. Scope

These recommended practices apply to the arc welding of the following base-metal combinations:

- (1) Similar chromium-molybdenum steels
- (2) Dissimilar chromium-molybdenum steels
- (3) Chromium-molybdenum to austenitic chromium-nickel stainless steels

- (4) Chromium-molybdenum to either carbon or carbon-molybdenum steels

In this document, the chromium-molybdenum steel alloys are referred to as Cr-Mo steels.

Cr-Mo steels are used extensively in the power, chemical, and petroleum industries. The properties of such piping and tubing materials and the applicable fabrication and inspection requirements are addressed in a wide range of documents, including:

- (1) ASTM Material Specifications
- (2) ASME Codes for Pressure Piping, B31
 - (a) Power Piping (ANSI/ASME B31.1)
 - (b) Chemical Plant and Petroleum Refinery Piping (ANSI/ASME B31.3)
- (3) ASME Boiler and Pressure Vessel Codes (Sections I, IIA, IIC, VIII, and IX)
- (4) NBIC National Board Inspection Code for Boilers and Pressure Vessels (ANSI/NB-23)
- (5) API Piping Inspection Code (Inspection, Repair, Alteration and Rerating of In-Service Piping Systems), (API 570).

2. Base Metals

2.1 General. Table 1 lists the types of steel considered and the nominal chemical compositions and abbreviations by which they will be identified in this document. If materials not listed in Table 1 are used, the contents of

Table 1
Base Metal Abbreviations

Types of Steel		
Nominal Composition	ASME/ ASTM Grade*	Abbreviation
Carbon Steel (less than 0.35% C)	A, B, or C	C-steel
Carbon—1/2% Mo	P1 or T1	C-Mo
1/2% Cr—1/2% Mo	P2 or T2	1/2 Cr-Mo
1% Cr—1/2% Mo	P12 or T12	1 Cr-Mo
1-1/4% Cr—1/2% Mo	P11 or T11	1-1/4 Cr-Mo
2% Cr—1/2% Mo	T3b	2 Cr-Mo
2-1/4% Cr—1% Mo	P22 or T22	2-1/4 Cr-Mo
3% Cr—1% Mo	P21 or T21	3 Cr-Mo
5% Cr—1/2% Mo	P5 or T5	5 Cr-Mo
7% Cr—1/2% Mo	P7 or T7	7 Cr-Mo
9% Cr—1% Mo	P9 or T9	9 Cr-Mo
9% Cr—1% Mo-V, Nb, and N	P91 or T91	9Cr-Mo-V
18% Cr—8% Ni	TP-304	304 S. S.
18% Cr—12% Ni-Mo	TP-316	316 S. S.
18% Cr—10% Ni-Nb (Cb)	TP-347	347 S. S.
18% Cr—10% Ni-Ti	TP-321	321 S. S.
25% Cr—20% Ni	TP-310	310 S. S.

*Table uses Symbols P (pipe), T (tube), and TP (tube or pipe). Other product forms with same nominal chemistry for which this document applies are CP (cast pipe), F (forging), FP (forged pipe), and WP (welded pipe).

this document may not apply. This will be especially true if the hardenability is increased by the presence of a higher carbon content. The carbon content of the materials listed is usually below 0.15 percent.

The primary factors governing the choice of filler metals are the composition of the base metals to be joined and the service conditions of the system. Generally, the filler metal composition and the mechanical properties of the deposited weld metal should match

those of the base metals as closely as possible. Where service includes corrosion or oxidation, the corrosion and oxidation characteristics of the base metals and the weld deposit should be either matched as closely as possible or selected to minimize galvanic reaction.

2.2 Base-Metal Addition. Since the last edition of this recommended practice, one new Cr-Mo alloy has been added. It has a nominal composition of 9% Cr and 1% Mo, but vanadium, niobium (columbium), and nitrogen have been added to improve mechanical properties and corrosion resistance at elevated temperatures. This new material has been assigned the grade designation of P91 and T91. Its weldability is similar to that of conventional 9 Cr-Mo materials. Special filler metals have been developed for some welding processes.

3. Filler Metals

3.1 General. Suggested filler metals for various base-metal combinations are shown in Table 2. The filler metals in this table are listed in accordance with the AWS classifications for electrodes and rods for the shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), and flux cored arc welding (FCAW) processes. The classifications of filler metals for other processes will be in accordance with the specifications for those specific processes.

Until recently the 5, 7, and 9 Cr-Mo electrodes and filler metals had been included in the same AWS filler metal specifications as austenitic stainless steels and had been assigned classifications such as E502. Recognizing that these filler metals are basically low-alloy steels, their classifications have been transferred to AWS's low-alloy filler metal specifications and have been assigned classifications such as E8018-B6. During these transition years, welding procedures and filler metal inventories can be expected to use both classifications. For the convenience of the user, Table 2 of this document lists these electrodes with their respective old and new classifications.

Cr-Mo piping systems are usually selected for corrosion resistance, high-temperature creep strength, or both. Since corrosion resistance is often associated with maximum hardness, low-carbon electrodes (e.g., E8018-B3L), which are less air hardenable, are frequently selected for such applications. However, if high-temperature creep resistance is a major design consideration, minimum carbon levels may be required, and a minimum percent carbon (such as 0.05%) may be specified by the user.

3.2 Low Hydrogen. To reduce the probability of cracking, low-hydrogen practices should be followed. Poten-

tial sources of hydrogen should be minimized or eliminated. This means both removing moisture and other hydrogen-containing materials (such as cutting oils) from the surfaces of the base metals and using clean and dry filler metals and shielding gases. The moisture content of filler materials must be kept low by proper manufacturing, packaging, storage, and usage procedures, or by redrying and cleaning.

All low-hydrogen electrodes exposed to the atmosphere for times in excess of the recommended time period should be reconditioned according to the manufacturer's recommendations.

Moisture control is of special concern when joining two different base metals. While it is common practice for the electrode to match the chemical composition of the lower alloyed material, the moisture limits should be based upon the higher alloyed ferritic base metal. This is because higher alloyed and higher strength ferritic steels are more susceptible to hydrogen-induced cracking. Since most austenitic stainless steel and nickel alloy electrodes are likely to contain more moisture than many Cr-Mo steel electrodes, it is advisable to carefully rebake such electrodes before they are used for welding Cr-Mo steels.

The time during which low-hydrogen electrodes may safely be exposed to the atmosphere (and thereby absorb some moisture) can be extended by the use of electrodes whose coverings have been specially designed and processed to reduce the rate of moisture absorption. For electrodes meeting such requirements, AWS provides an "R" designator (e.g., E7018R and E8018-B2-R).

If contamination is observed or suspected the following actions are suggested:

3.2.1 Atmospheric moisture absorption by shielded metal arc welding (SMAW) electrodes or submerged arc welding (SAW) fluxes may be corrected by rebaking the material in accordance with the manufacturer's recommendations. Should this information not be available, the user should determine an appropriate rebaking procedure. As a starting point, rebake a small quantity of SMAW electrodes at 700°F (370°C) for one hour. Since rebaking may reduce the bond between the covering and the core wire, the user should determine if adhesion of the coating to the core wire has been damaged or if welding operability has been adversely affected. If so, the rebake temperature will need to be reduced. SAW fluxes should be rebaked for 1 hour at about 600°F (315°C). For electrodes and fluxes, rebake temperatures below 500°F (260°C) are not recommended.

3.2.2 SMAW electrodes or SAW fluxes should be discarded if contaminated with materials such as hydrocarbons or exposed to water (such as left in the rain).

Table 2
Suggested Filler Metals for Various Base Metal Combinations

Base Metals	C-Steel	C-Mo	1/2-1-1/4 Cr-Mo	2 & 2-1/4 Cr-Mo	3 & 5 Cr-Mo	7 Cr-Mo	9 Cr-Mo	9 Cr-Mo-V	3XX-SS
C-Steel	¹	A	A	A	A	A	A	A	I ³
C-Mo	A	B	B	B	B	B	B	B	I ³
1/2-1-1/4 Cr-Mo	A	B	C ²	C	C	C	C	C	I ³
2 & 2-1/4 Cr-Mo	A	B	C	D	D	D	D	D	I ³
3 & 5 Cr-Mo	A	B	C	D	E	E	E	E	I ³
7 Cr-Mo	A	B	C	D	E	F	F	F	I ³
9 Cr-Mo	A	B	C	D	E	F	G	G	I ³
9 Cr-Mo-V	A	B	C	D	E	F	G	H	I ³
3XX-SS	I ³	I ³	I ³	I ³	I ³	I ³	I ³	I ³	⁴

Letter	Composition	SMAW ⁶	GTAW/GMAW	FCAW
A	C-Steel	E7108	ER70S-2 or 3	E7X-T5M, -T9M, or -T12M
B	C-Mo	E7018-A1	ER70S-B2L or ER80S-B2 (7)	E7XT5-A1M or E8XT1-A1M
C	1-1/4 Cr-Mo	E7018-B2L or E8018-B2	ER70S-B2L or ER80S-B2	E8XTX-B2LM or E8XTX-B2M
D	2-1/4 Cr-Mo	E8018-B3L or E9018-B3	ER80S-B3L or ER90S-B3	E9XTX-B3LM or E9XTX-B3M
E	5 Cr-Mo	E8018-B6 or B6L E502-15 ⁸	ER80S-B6 ER502 ⁹	Note 7
F	7 Cr-Mo	E8018-B7 or B7L E7 Cr-15 ⁸	Note 7	Note 7
G	9 Cr-Mo	E8018-B8 or B8L E505-15 ⁸	ER80S-B8 ER505 ⁹	Note 7
H	9 Cr-Mo-V	E9018-B9	ER90S-B9	Note 7
I	Ni-Cr-Fe	ENiCrFe-2 or -3	ERNiCr-3	Note 7

Notes:

1. See AWS D10.12, *Recommended Practice and Procedures for Welding Plain Carbon Steel Pipe*.
2. For 1/2 Cr-Mo base metals, E8018-B1 and E8XT1-B1M or -B1/LM may be used for SMAW and FCAW respectively.
3. For non-cyclic thermal service up to about 600°F (315°C), type E309 or E309Mo stainless steel filler metal is frequently used.
4. See AWS D10.4, *Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing*.
5. These classifications are shown in the following AWS filler metal specifications for the applicable welding processes:

Material	SMAW	GTAW/GMAW	FCAW
C-Steel	A5.1	A5.18	A5.20
Low-Alloy Steel	A5.5	A5.28	A5.29
Nickel Alloys	A5.11	A5.14	—
300 Series SS	A5.4	A5.9	A5.22

See appropriate AWS filler metal specifications for other welding processes.

6. While electrode with type 18 coverings or coatings are shown on this table, electrodes with type 15 and 16 coatings are equally acceptable.
7. Filler metals with matching chemical compositions have not been classified by AWS and may not be commercially available.
8. Newer E8018-BX are classified in AWS specification A5.5 Older E50X-XX and E7Cr are classified in AWS specification A5.4.
9. Newer ER80S-BX are classified in AWS specification A5.28 Older ER50X are classified in AWS specification A5.9.

3.2.3 Moisture on bare, solid wires may be removed by heat or clean, dry air.

3.2.4 Hydrocarbons on bare, solid wires may be removed by degreasing, rinsing, and thoroughly drying. (Spools and coils may require rewinding.)

3.3 Backing Rings and Consumable Inserts. The chemical composition of backing rings and consumable inserts usually is similar to that of the filler metal, although lower alloy compositions have been used successfully. Since a lower alloy composition of the backing ring or consumable insert may reduce the corrosion and creep resistance of the weld, it should not be employed without first reviewing the service requirements of the fabricated part. Such a review is also necessary when temporary backing rings are used, because the dilution of the weld metal by the backing material affects the chemical composition of the final weld.

3.4 Applications. Applications for the filler metals shown in Table 2 are the following:

3.4.1 Joining Similar Steels. In addition to matching the composition and mechanical properties of the base metal as closely as practical, the chromium and molybdenum content and the tensile strength of the weld metal should not be lower than the minimum values specified for the base metal.

3.4.2 Joining Dissimilar Ferritic Steels. Where dissimilar metals are being welded, the only four possible filler metal compositions are (1) the lower alloy base metal composition, (2) the higher alloy base metal composition, (3) an intermediate composition, or (4) a composition different from any of the first three. Where both base metals are ferritic, the fourth possibility mentioned above (that of an entirely different alloy) is of special concern for service at elevated temperatures or in corrosive environments. Consistent with the factors listed above, this fourth possibility should normally be considered only where one of the base metals is stainless steel or a nickel or copper alloy.

Where only ferritic metals are being joined, good service results have been achieved with all of the first three possible ferritic filler metal compositions. However, the majority of users select either a lower or an intermediate composition of filler metal for butt joints because the weld metal does not need to be stronger or more resistant to corrosion or creep than the lower alloyed base metal.

Table 2 follows the aforementioned concepts. Exceptions are advisable in the case of supports, hanger lugs, and similar parts attached to a piping or tubing system. Filler metal should then be selected to match the mechanical and chemical properties of the pressure-retaining part in order to compensate for dilution during welding.

3.4.3 Joining Ferritic to Austenitic Chromium-Nickel Steels. When joining ferritic steels to austenitic chromium-nickel steels, the composition and properties of the weld metal represent a mixture of the two base metals and the filler metal. A consideration of the resultant mechanical, metallurgical, and corrosion-resistance properties eliminates the use of the following:

(1) Ferritic filler metal, or austenitic steel filler metal of approximately 18% Cr-8% Ni composition, since the resultant diluted weld metal will be martensitic, with lower ductility and increased cracking susceptibility.

(2) Fully austenitic stainless steel filler metal (such as type E310), since these may produce weld metal with microcracks which can propagate into serious cracking.

(3) High-nickel alloy electrodes with titanium additions (such as ERNiCrFe-6) which will produce weld metal deposits with over 0.75% Ti, since these may age-harden during subsequent heating operations.

Successful welds have been made with Type E309 stainless steel filler metal, which are slightly ferritic (Ferrite Numbers 2-10) and contain sufficient chromium and nickel to compensate for dilution. However, weld deposits may contribute to thermal stress or fatigue problems if the weld is exposed to thermal cyclic service or to temperatures above 600°F (315°C). This is due to the pronounced difference in thermal coefficient of expansion between the ferritic base metals and the austenitic stainless steels. The thermal stresses which are produced may exceed the yield point and can initiate and then propagate cracking at or near the fusion line. In addition, at elevated temperatures, carbon migrates from the chromium-molybdenum base metal to the 300-series stainless weld metal, producing a decarburized zone that has weakened and can shorten the life of the joint.

Thermal stresses between ferritic and austenitic base metals cannot be eliminated or even reduced. However, they can be distributed over a wider area with a weld metal whose coefficient of expansion is intermediate between the two base metals. Nickel-base filler metals containing about 65% Ni, 15% Cr, and 12% Fe meet this requirement and are capable of producing weld metal that is metallurgically and mechanically sound. Furthermore, they reduce carbon migration from the chromium-molybdenum base metal. Typical AWS classifications for this type of filler metal are ENiCrFe-2, -3, or -4 and ERNiCr-3. However, high-nickel alloys are less resistant to high-temperature sulphur corrosion than the higher alloyed Cr-Mo steels and all austenitic stainless steels. Furthermore, high-nickel alloys often call for different welding techniques and joint designs, since these filler metals have less fluidity than austenitic chromium-nickel stainless steels.

3.4.4 Use of Transition Sections and Buttering. Where dissimilar metals are to be joined, it is sometimes

better to avoid a butt joint between the two base metals. This can be accomplished either by interposing a short transition section, sometimes called a *safe end*, or by buttering one of the metals with the filler metal before proceeding to weld the butt joint. These procedures are commonly used when postweld heat treatment is required on one of the base metals and not the other, or to avoid a field heat-treating operation. For example, when a ferritic base metal is to be joined to an austenitic base metal, the heat treatment can be detrimental to the austenitic base metal due to embrittlement by sigma phase. This can be overcome by buttering the ferritic side of the joint with a nickel-base alloy; this would be followed by heat treatment. The weld between the buttered end and the austenitic stainless steel will not require heat treatment. The same reasoning applies to two ferritic metals when only one of them requires heat treatment. In this case, however, the transition section or filler metal should be an iron-based alloy rather than a nickel-based alloy.

3.5 Other Filler Metals. The filler metals listed in Table 2 are not necessarily the only ones suitable for such welds. Other filler metals may well be proven acceptable by procedure qualification and service tests. The table lists electrodes and rods for the SMAW, GTAW, GMAW and FCAW processes. Where other welding processes are used, filler metal of equivalent compositions and properties should be selected, provided that the dilution with these processes produces equivalent weld-metal compositions.

4. Joint Design and Preparation

4.1 Standard Joint Preparations. Standard joint preparations, such as those established in ANSI B16.25, are suitable for the base metals covered by this document. The geometry of the joint should minimize any notch conditions that might lead to stress concentration. Sharp corners or sudden changes in section thickness or shape should be avoided.

Preheating practices for tack welding are generally the same as those used in the welding of the joint. Striking the arc on the pipe or tube in areas where the welding or heat-treating will not remove the effects of the arc strike should be avoided.

4.2 Root-Pass Considerations. Weld bevel and fit-up should assure complete joint penetration without excessive melt-through. If a backing ring is used, the weld bevel and fit-up must permit complete fusion of the weld to both the ring and the pipe bevels. Backing rings should not be used when service requires extreme cleanliness or involves a corrosive environment. In such service, crevices between the ring and the inner surface of

the pipe or tube must be avoided. There are other applications, such as those involving high-velocity fluids or internal cleaning devices (e.g., scraping pigs) where backing rings are likely to cause operational difficulties. In such cases, the root pass is made using GTAW or GMAW without a backing ring. Recommended procedures for such welds are given in ANSI/AWS D10.11, *Recommended Practices for Root Pass Welding of Pipe without Backing*.

Two practices which apply to the root pass welding of Cr-Mo steels should be considered:

(1) Back purging of Cr-Mo joints is often required to prevent oxidation on the ID of the pipe. While there is not a fixed rule, the following common practices, which are based upon the chemical composition of the filler metal, are often selected:

- Under 4% Cr: No back-purge
- 4–6% Cr: Sometimes back-purge (based on service requirements)
- Over 6% Cr: Always back-purge

(2) For up to 2-1/4% Cr-Mo joints, some European fabricators use rutile coated SMAW electrodes successfully for the root passes when welding butt joints for standard wall piping. Since these are not low-hydrogen systems, adequate preheating becomes very important. Such electrodes had been commercially available in the U.S. through the 1950s and had been classified by AWS as E8013-B2 and E9013-B3.

4.3 Fit-Up. In addition to tack welds, joint alignment can be maintained by internal or external supports, jigs, or fixtures. They should be adequate for holding the joint in place and minimizing tensile and bending or transverse stresses during welding. However, they should be flexible enough or should be removed during the course of welding in order to permit normal weld shrinkage and thereby reduce stresses that might cause cracking. External supports should also be designed so that they do not interfere with adequate access to the joint during welding.

The following are two common types of external supports for pipe and tube:

- (1) Pipe clamps bolted together around each pipe and joined by bars with turnbuckles to adjust the load and to maintain a specified root opening
- (2) U-shaped bridges that are welded to each pipe and cross above the joint with adequate space beneath them for welding

5. Preheating

5.1 General. Preheating is recommended for all Cr-Mo steels and should be maintained throughout the entire

welding operation. This includes prior to any thermal cutting, prior to striking an arc for tack welding and after weld interruptions. In some cases, the preheat is maintained during interruptions, until some type of post-heating is started, or both. The area to be welded or thermally cut should be heated to the minimum temperatures suggested in Table 3, unless the applicable governing document requires a higher temperature. Where dissimilar alloys are involved that require different minimum preheating temperatures, the higher temperature should be used and maintained during welding.

For some materials, maximum preheat or interpass temperature limits, or both, have also been established. Such limits apply primarily to materials heat treated to achieve specific properties, such as low-temperature notch toughness, and for materials not suitable for high-temperature service. Since the Cr-Mo steels discussed in this document are usually selected for elevated temperature service conditions, maximum preheat and interpass temperatures are usually not required by metallurgical considerations but may be imposed because of welder comfort. However, for dissimilar metal joints involving austenitic stainless steels and nickel alloys, a maximum interpass temperature should be specified.

Temperatures lower than those given in Table 3 are recommended for the welding of the root pass with GTAW on low-chromium alloys. Lower temperatures permit better control of the shape of the root bead, with less likelihood of excessive reinforcement or melt-through. The slower travel speed and the lower hydrogen and moisture levels associated with the GTAW process

justify some reduction in preheat temperature. Lower preheat temperatures are sometimes also used for tack welding, but this requires careful inspection to be sure that the welds and the heat-affected zones (HAZs) are free of cracks. When welding must be performed in confined areas, it may be necessary to use low preheat temperatures for the safety of the welder. However, any deviations from the temperatures in Table 3 should be made in accordance with the applicable code, and they should be verified by both procedure qualification tests and service experience.

Heating should not be limited to the metal surface. Sufficient time and energy should be provided to permit uniform soaking of the entire weld area. Heat should be applied by a method that will produce a uniform temperature around the joint. The width of the heated band should be sufficient so that the required temperature is achieved throughout the thickness.

Oxyfuel gas torch heating may produce excessive temperature gradients not only through a thick wall but also around the circumference, unless heating is done slowly and uniformly around the joint. Special care is required when the same surface is used for heating and for measuring the temperature. To be sure that through-heating and not just surface heating has been achieved, it is advisable to wait about one minute between removal of the heating torch(es) and the measurement of the temperature. This is not a problem when heating from one side and measuring the temperature from the other. Thus, when access and safety considerations permit, effective preheating can be achieved by placing the heating torch inside the pipe while welding from the outside.

Another preheating method involves the use of wrap-around electric resistance heaters. These heaters are typically used in conjunction with thermocouples attached to the pipe to monitor and control temperatures. Such preheating provides uniform, continuous heat before welding, while welding is in progress, and during interruptions. Use of thermocouples to monitor and control temperature also permits a permanent record of the preheat temperature to be produced for quality assurance purposes. However, the magnetic field produced by the flow of electricity through some configuration of resistance elements may produce arc blow while depositing the root pass.

5.2 Interruption of Heating Cycle. Preheat is normally maintained until the welding has been completed. However, an interruption of the preheat may be acceptable after evaluating the situation. The effects of interrupting the heating cycle are primarily mechanical in nature. A combination of residual stresses, low ductility, and the presence of hydrogen may promote cracking at ambient temperatures. Thus, when welding thicker sections or higher alloyed Cr-Mo steels (greater than three percent

Table 3
Suggested Minimum Preheat
Temperatures for Various Base Metals

Base Metal	°F	°C
C-Steel	50	10
C-Mo and 1/2 Cr-Mo	175	80
1-1/4 Cr-Mo	250	120
2-3 Cr-Mo	300	150
5-9 Cr-Mo	400	200
9 Cr-Mo-V	400	200
300-SS	50	0

Notes:

1. Some codes require slightly higher preheat temperatures.
2. For wall thickness exceeding 1 in. (25 mm), for conditions of high restraint and when PWHT is not employed, higher preheat temperatures are beneficial.
3. When the GTAW process is used for root passes, lower preheat temperatures are sometimes desirable for the root pass only.
4. When joining two different Cr-Mo steels, the minimum preheat temperature should be based upon the higher alloyed Cr-Mo steel.
5. When joining Cr-Mo steels to C, C-Mo or 3XX stainless steels, the minimum preheat temperature should be based upon the Cr-Mo steel.

chromium), it is often advisable to retain the preheat without interruption until postheating or postweld heat treatment is started.

When interrupting or after completing the welding of a Cr-Mo steel joint, and prior to dropping the preheat, it is advisable to increase the temperature by about 100°F (50°C) for at least 15 minutes and sometimes up to 4 hours to permit hydrogen to diffuse out and decrease the risk of hydrogen-induced cracking. The need for such a heating procedure increases as the alloy content, and thereby the hardenability increases, or the joint is subject to high restraint. Extended time, higher temperatures, or both should be considered whenever thicker materials or low-preheat temperatures are involved. Such treatment is often called *postheating*.

5.3 Moisture and Other Materials Containing Hydrogen. Hydrogen can be introduced into the arc from both water vapor and hydrogen-containing compounds. If hydrogen is absorbed in the metal, it may interact with residual stresses and cause cracking when the weldment is cooled. Therefore, interrupting the preheating cycle is safer when dry and clean base metals, welding consumables, and shielding gases have been used. When using the SMAW or FCAW processes or when there is some concern about hydrogen pick-up, hydrogen can be reduced by postheating as described in 5.2.

5.4 Joint Restraint. Interruptions of the heating cycle are more risky if a partially completed weld is subject to bending moments or high axial loading.

(1) Such bending moments may be encountered while transporting inadequately supported, partially welded piping assemblies such as moving them to a heat treating or inspection area.

(2) High axial loading is encountered during pretensioning operations called *cold-springing*. This is used for closure welds of pipe intended for elevated temperature service. The pipe is deliberately installed too short in order to compensate for thermal expansion. The tensioning device used to position the joint for welding should not be removed until all welding and all postheating has been completed.

5.5 Mass of the Base Metal. An increase in pipe wall thickness increases both the restraint on the weld and the cooling rate from welding temperatures. Thus the weld area is subjected to high residual stresses at a time when it may be less ductile.

For a given joint, the greater the percentage of the weld that has been completed, the more nearly the strength and rigidity of the joint approach those of a completed weld. Therefore, any interruption of the welding is generally not permitted until some minimum amount of weld metal has been deposited. Wherever interruptions are permitted, the weldment must be cooled

slowly and uniformly. Welding should not proceed until the preheat temperature has been reestablished in the weld area.

Based on industrial experience, the following is suggested regarding interrupted heating cycles in the welding of the Cr-Mo steels included in this document. However, it must be emphasized that such general suggestions should be interpreted in the light of the factors mentioned above and the specific job conditions. They should not be applied indiscriminately.

5.5.1 For Cr-Mo steels containing less than 4 percent chromium, the heating cycle may be interrupted provided the greater of two layers has been deposited or 1/3 of the groove has been filled with weld metal. In addition, the welding procedure should employ adequate preheating, dry low-hydrogen filler metals, post-heating and slow cooling to ambient temperatures.

5.5.2 For Cr-Mo grades containing 4 percent or more chromium, the heating cycle should not be interrupted until the weld has been completed.

6. Postweld Heat Treatment (PWHT)

6.1 General. The three primary benefits derived from PWHT are the following:

- (1) Stress relieving
- (2) Tempering (softening) and restoring ductility
- (3) Diffusing hydrogen

A combination of these can reduce the risk of cracking, improve mechanical properties and provide better corrosion resistance. Suggested PWHT temperatures for various base metals are listed in Table 4. For joints involving several materials, the temperatures for the highest alloyed Cr-Mo steel are usually selected.

6.2 PWHT Temperatures. The temperature ranges listed in Table 4 are broad in order to accommodate different needs for different industries. Other, and at times more restrictive, PWHT temperatures have been accepted on the basis of code requirements, welding procedure qualifications, and service experience. For instance, when normalized and tempered steels are used, the PWHT temperature should be lower than the tempering temperature. When high creep and rupture strength are the primary concerns (as in the power industry), the temperatures selected are often at the lower end of the range. However, when resistance to corrosion and hydrogen embrittlement are the primary concerns (as in the petroleum and chemical industry), temperatures at the higher end of the range are often used.

6.3 PWHT Holding Time. Most codes require a holding time at the specified temperature of 1 hour per inch of

Table 4
Suggested PWHT Temperature Ranges

Materials	Thickness		Temperature Ranges ³	
	Inch	mm	°F	°C
C-Steel	≤3/4	≤19	none ¹	
	>3/4	>19	1100–1200	590–675
C-Mo and 1/2 Cr-Mo	≤5/8	≤16	none ¹	
	>5/8	>16	1150–1300	620–700
1–1-1/4 Cr-Mo	≤1/2	≤13	none ^{1,2}	
	>1/2	>13	1250–1375	675–750
2–3 Cr-Mo	≤8	≤10	none ^{1,2}	
	>3/8	>10	1300–1400	700–760
5–9 Cr-Mo	all		1300–1400	700–760
9 Cr-Mo-V	all		1350–1400	730–760
300-Series SS	all		none	

Notes:

1. For certain corrosive environments, PWHT is required for all thicknesses.

2. Maximum pipe diameters and maximum of 0.15% C are sometimes applied.

3. To achieve special hardness limits or other mechanical properties, holding time and/or temperature may have to be modified.

thickness (25 mm), but they differ considerably regarding the minimum time at temperature for Cr-Mo steels: ASME B31.1 requires only 15 minutes and ASME B31.3 requires 120 minutes.

For thin materials, it takes only 15 minutes to relieve an adequate amount of residual stresses which is a primary concern of ASME B31.1. However, it takes longer to temper the material and provide satisfactory corrosion resistance which is usually a primary consideration for ASME B31.3 fabrication. The latter is of special interest for Cr-Mo steels exceeding 4% Cr.

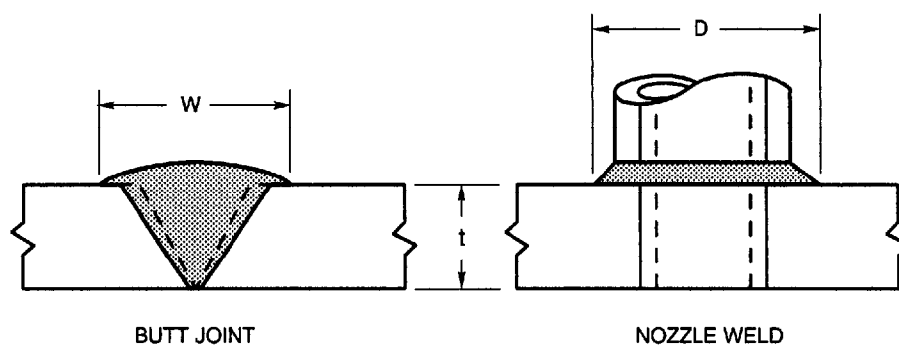
6.4 Heating and Cooling. Heating requirements also differ considerably. While there is general agreement that heating should be uniform, only ASME B31.1 specifies a maximum heating rate of 600°F per hour for up to 2 in. (50 mm) thick pipe. However, piping built to ASME B31.3 has performed successfully when heated from ambient to PWHT temperature in a few minutes.

Cooling requirements also differ considerably, but there is general agreement that the cooling should be uniform to minimize the reestablishment of residual stresses. While ASME B31.3 does not list or spell out any numerical requirement, ASME B31.1 specifies a maximum cooling rate of 600°F per hour for thicknesses up to 2 in. (50 mm) pipe. This has been an accepted rate for up to 3% Cr-Mo steels. However, for higher alloyed

Cr-Mo steels, an extended holding time, a slower cooling rate, or both, may be needed to meet specific hardness requirements. It is advisable to use the Welding Procedure Qualification to determine the adequacy at the specific holding time and cooling rate.

6.5 Local PWHT. The above requirements can easily be met when the entire piping or tubing assembly is postweld heat treated in a furnace. Since this often is not possible, local PWHT represents an acceptable alternative. The method and the equipment for heating should provide uniform heating around the circumference. If branch connections are postweld heat treated, care should be taken to heat a wide band of metal all around the pipe or tube into which the branch is welded. Otherwise, local expansion and permanent upsetting may leave the heated area with higher and more extensive stresses than those present in the as-welded structure.

For local heat treatment, a circumferential band around the pipe should be heated to the specified temperature range. The heating band shall straddle the centerlines of the butt, nozzle, or attachment joints. Figure 1 illustrates the minimum width of the band which according to the two most frequently specified American piping codes must be heated to the PWHT temperature. While they did not have identical requirements, both appear to provide satisfactory results and either can be followed



Code	pARA.	Minimum band width for local PWHT	
		Pipe or tube butt joint	Attachment or nozzle weld
ASME B31.1	132.7	3t	D + 4t
ASME B31.3	331.2.6	W + 2 in.	D + 2 in.

Note: 2 in. equals approximately 50 mm.

Figure 1—ASME B31.1 and B31.3 Bandwidth Requirement for Local PWHT

for non-code applications. To produce satisfactory results, the temperatures should gradually diminish outside the heated band. This is usually achieved by extending heating elements and the insulation beyond this band. For a detailed discussion of local PWHT, please refer to ANSI/AWS D10.10, *Recommended Practices for Local Heating of Welds in Piping and Tubing*.

6.6 Quality Control of PWHT. Adequacy of any production PWHT operation involving Cr-Mo steels can be established by carefully monitoring properly installed thermocouples. The postweld heat treated weldments can also be inspected by hardness testing; a wide range of portable instruments is available. When using such instruments, it is important to inspect not only the weld deposit, but also the HAZs.

For the materials covered by this document, the hardness numbers drop after PWHT. The specific change in hardness depends upon the individual alloy and the applied PWHT cycle. Some codes (e.g., ASME B31.3) and some job specifications dealing with corrosive service specify maximum hardness limits. For other applications, the ability to pass the bend test, associated with procedure qualifications, demonstrates adequate ductility.

7. Repair and Maintenance Welding of Service Exposed Cr-Mo Piping and Tubing

While this section is not intended to review all possible repair and maintenance options, three subjects re-

lated primarily to Cr-Mo piping and tubing should be considered.

7.1 Base-Metal Contamination. Cleaning metal surfaces prior to welding on any new or used materials applies to all metals. However, Cr-Mo steel which has been in high-temperature hydrogen service, may have absorbed some hydrogen. When welding over such contaminated steels, the heat associated with any welding process can diffuse some of the hydrogen. If this hydrogen enters the newly deposited weld metal, it is likely to cause porosity and even cracking. Often, the welder, especially when using the GTAW process, can see these gas bubbles in the weld puddle. This problem can be overcome by heating the steel for about 15 to 30 minutes prior to welding. While optimum holding times and temperatures have not been established, present recommendations range from 400 to 1200°F (200–650°C). A test weld or a bead on the bevel face using the GTAW process may demonstrate the weldability of service exposed steels.

7.2 Temper Embrittlement. Some Cr-Mo steels can embrittle when exposed to elevated temperatures for an extended time. This loss of ductility at ambient temperature, which is known as *temper embrittlement*, has been experienced primarily in 2-1/4% Cr-Mo steels which had operated for many months at about 850°F (450°C). Since these embrittled steels have an acceptable ductility at a typical preheat temperature of 300°F (150°C), temper embrittlement does not normally present a welding problem. However, this low ductility can be a problem when

pressure testing or pressurizing the piping system at lower temperatures.

7.3 Relaxation of PWHT Requirements. While new Cr-Mo steel fabrication and construction often requires full furnace or full encirclement PWHT (as described in 6.4), several inspection-type codes have provided some relaxations when repairing or modifying Cr-Mo piping and tubing systems. The following documents provide some relaxations and at the same time impose several controls and limitations for which the specific document should be consulted:

(1) API-570 permits spot heating of the weld area in place of heating a circumferential band around the pipe and the nozzle.

(2) ANSI/NB-23 permits the substitution of higher preheat temperatures, postheating and temper bead welding as an alternative to PWHT of carbon and low-alloyed steels. However, due to lack of experimental data, care should be exercised when applying the alternative method to Cr-Mo steels with more than 2-1/2% Cr.

Spot PWHT can achieve the same reduction in hardness as conventional PWHT. Temper beading can also

soften the weldment, but the adequacy of the procedure must be demonstrated. However, neither system can be expected to appreciably lower any welding-related residual stresses. There is some concern that the API method may increase distortion and residual stresses in the longitudinal direction.

8. Safe Practices

These recommended practices may involve hazardous materials, operations, and equipment. Reference to ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, along with applicable Material Safety Data Sheets*, is strongly recommended so as to be aware of health and safety precautions associated with the materials and processes discussed in this document.

*Material Safety Data Sheets (MSDS) are available through the material suppliers. Additional sources of safety related information are listed in Annex A.

Annex A

List of Safety Related References

1. American Welding Society (AWS). *Arc Welding and Cutting Noise*. Miami, FL: American Welding Society, 1979.
 2. ———. *Effects of Welding on Health I, II, III, and IV*. Miami, FL: American Welding Society, 1979, 1981, 1983.
 3. ———. *Fumes and Gases in the Welding Environment*. Miami, FL: American Welding Society, 1979.
 4. ———. *The Welding Environment*. Miami, FL: American Welding Society, 1973.
 5. ———. *Ultraviolet Reflectance of Paint*, Miami: American Welding Society, 1976
 6. Balchin, N. C. *Health and Safety in Welding and Allied Processes*, 3rd Ed. England: The Welding Institute, 1983.
 7. Compressed Gas Association, Inc. *Handbook of Compressed Gases*, 2nd Ed., New York: Van Nostrand Reinhold Co., 1981.
 8. ———. *Safe Handling of Compressed Gases in Containers*, P-1, New York: Compressed Gas Association, 1974.
 9. Dalziel, C. F. "Effects of electric current on man." *ASEE Journal* (6): 18-23, 1973.
 10. Fireman's Fund Insurance Companies. *Welding Fume Control with Mechanical Ventilation*, 2nd Ed. San Francisco, CA: Fireman's Fund Insurance Companies, 1981.
 11. National Fire Protection Association (NFPA). ANSI/NFPA 51B-1977, *Cutting and Welding Processes*, Quincy, MA: National Fire Protection Association, 1977.
 12. The Welding Institute. *The Facts About Fume*. England: The Welding Institute, 1976.
- Further detailed information may be found in the publications of the following organizations.
1. American Welding Society (AWS)
550 N.W. LeJeune Road
Miami, FL 33126
 2. Occupational Safety and Health Administration (OSHA), all publications available from:
Superintendent of Documents
U.S. Printing Office
Washington, DC 20402
 3. American Conference of Governmental Industrial Hygienists (ACGIH)
1330 Kemper Meadows Drive, Suite 600
Cincinnati, OH 45240-1634
 4. National Institute for Occupational Safety and Health (NIOSH)
4676 Columbia Parkway
Cincinnati, OH 45226
 5. National Fire Protection Association (NFPA)
P.O. Box 9101
1 Batterymarch Park
Quincy, MA 02269-9101

Document List

The following is a complete list of the standards prepared by the AWS Committee on Piping and Tubing

Document Code	Document Title
D10.4	Austenitic Chromium Nickel Stainless Steel Piping and Tubing, Recommended Practices for Welding
D10.6	Titanium Piping and Tubing, Recommended Practices for Gas Tungsten Arc Welding
D10.7	Aluminum and Aluminum Alloy Pipe, Recommended Practices for Gas Shielded Arc Welding
D10.8	Chromium-Molybdenum Steel Piping and Tubing, Recommended Practices for Welding
D10.10	Local Heating of Welds in Piping and Tubing, Recommended Practices for
D10.11	Root Pass Welding, Recommended Practices for
D10.12	Plain Carbon Steel Pipe, Recommended Practices and Procedures for Welding
D10.13	Brazing of Copper Pipe and Tubing for Medical Gas Systems, Recommended Practices for

For ordering information, contact the Order Department, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126. Phone 1-800-334-9353.