



ArcelorMittal

How to Weld “T-1”[®] Constructional Alloy Steels



**Based upon the U.S. Steel Brochure of the same name, January 1995.
The registered trademark “T-1”[®] is specifically licensed to ArcelorMittal USA by U. S.
Steel for use on steel plate**

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Foreword

This brochure contains suggestions gathered from research studies and fabrication experiences of our own and of our customers. The suggestions are presented as an aid to design, materials, and welding engineers. The suggestions should not be used for any specific application without examination and verification of their suitability for the application. Procedures suggested in this book should be thoroughly tested to determine that they meet established goals before acceptance. Unless otherwise indicated, the terminology used in this book is that established by the American Welding Society, ANSI/AWS A3.0-80, Welding Terms and Definitions.

The values stated in U.S. customary units are to be regarded as standard. For use of metric units as a replacement for U.S. customary units, refer to AWS A2.3-80, Metric Practice Guide for the Welding Industry.

“T-1”[®] steels were originally developed by the U.S. Steel Corporation. This brochure is based upon a document of the same name authored by U.S. Steel in January 1995. ArcelorMittal USA facilities has been a licensee of “T-1” steels from USS since 1959. In 2003, the International Steel Group Inc. (now ArcelorMittal USA) purchased the plate assets of USS, which included the “T-1” trademark.

ArcelorMittal USA assumes no responsibility for, and makes no representations or warranties as to, the applicability or suitability of the information in this book for any specific application.

How to Weld “T-1” Constructional Alloy Steels

Introduction

Strength, toughness, ductility, weldability, atmospheric corrosion resistance, economy – these make up the attractive combination of properties and characteristics offered to designers and fabricators by ArcelorMittal USA “T-1”, “T-1” Type A, “T-1” Type B and “T-1” Type C constructional alloy steels. ⁽¹⁾ The high yield strength steels, as a group, have a lower tolerance than lower-strength structural steels for zones of high stress concentration at design details and weld imperfections. Therefore, to obtain maximum advantage of the above-mentioned characteristics of the “T-1” Steels, it is necessary in their application that their higher yield strength be accompanied by refinements in design, workmanship and inspection.

Codes and Specifications

Codes and Specifications recognize the “T-1” Steels as ASTM A514 and A517 Grades B, F, H, and Q; and ASME SA517 Grades B and F. Designers, fabricators, and users of the “T-1” Steels should consider:

- a.) For general structural applications, the provisions in the current edition of the American Welding Society (AWS) D1.1 Structural Welding Code – Steel;
- b.) For bridge applications, the provisions in the current edition of the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Welding Structural Steel Highway Bridges; and the AASHTO/AWS D1.5 Bridge Welding Code.
- c.) For pressure-retaining applications, the provisions in the current edition of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, Division 1 (Part UHT) and Division 2 (Part AF, Article F-6).

All of the above-mentioned Codes and Specifications include provisions for welding procedure qualification and welder performance qualification, as well as inspection requirements.

(1) For chemical and mechanical properties of “T-1” Steels, refer to the ArcelorMittal USA brochure [“A514 and “T-1” Steels”](#) or the [“Plate Steel Specification Guide”](#).

Welding Processes and Procedures

Because the ArcelorMittal USA “T-1” Steels are different from ordinary carbon steels, welding practices, while simple are different also. These practices are similar to welding any high yield strength quenched and tempered alloy steel. “T-1” Steels can be welded satisfactorily by all major welding processes when proper procedures are used. The most widely used welding processes are the arc welding processes – shielded metal arc welding, submerged arc welding, gas metal arc welding, flux cored arc welding and gas tungsten arc welding. In welds made by these processes, the cooling from welding is usually so rapid that the mechanical properties of the weld approach those of the steel in the mill heat treated condition. Thus, reheat treatment (quenching and tempering) of the steel after welding is not necessary.

Other welding processes, such as oxyacetylene welding, electroslag welding, or any process employing multiple arcs, which subject the steels to excessive heat input and resultant slow cooling from welding, significantly degrade the mechanical properties of the steels. Reheat treatment of steels welded by these processes is necessary.

The suitability of the specific welding processes and welding procedure used should be established by the user based on the design application. As with other steels, no welding of “T-1” Steels should be done when temperature in the work place is below 0°F to minimize the possibility of poor workmanship.

CAUTION: If reheat treatment after welding is contemplated, contact the ArcelorMittal USA Plate Customer Technical Service Department at 610-383-3105 for important information on the effect of such a treatment. It is important to note that this grade of steel may be susceptible to cracking in the heat-affected zone of welds during postweld heat treatment (stress relief). Therefore, ArcelorMittal USA recommends that careful consideration be given to this phenomenon by competent welding engineers before stress relieving is applied to weldments of this grade. See Rule 4 on page 20 of this document. Also, it is not recommended for service at temperatures lower than -50°F or higher than 800°F.

Cutting and Joint Preparation

Cutting and joint preparation of “T-1” Steels can be suitably done by oxygen or arc cutting, either manual or mechanized, by practices in accordance with those suggested in the AWS handbook, latest edition. Such cutting does not require preheating in thicknesses up to and including 3 inches, but the steel temperature should not be lower than 50°F during cutting. For thicknesses over 3 inches, a preheat temperature of 300°F minimum is suggested to minimize the possibility of edge cracking. Preheat temperatures above 450°F may result in an excessively wide heat-affected zone from the thermal cutting and significant degradation of mechanical properties in this zone. When severe forming is to be done on a plate with a thermal cut edge, removal of the heat-affected zone by grinding or machining is desirable to minimize the possibility of edge cracking from straining of an unremoved heat-affected zone. Refer to the [Guidelines for Fabricating and Processing Plate Steel](#) for additional information on thermal cutting and forming.

Strong reliable welded joints can be readily made in the ArcelorMittal USA “T-1” Steels by following a welding procedure that includes these four rules:

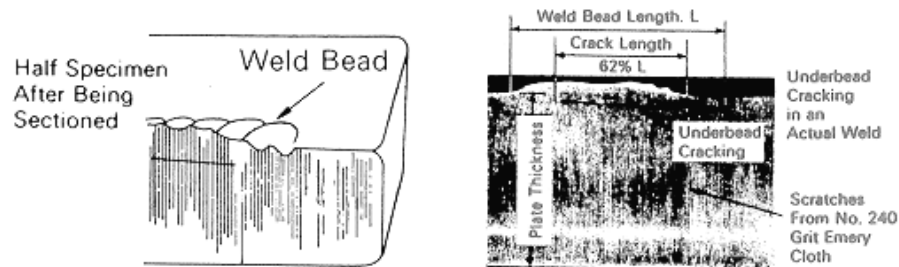
- 1 Use the correct electrode, electrode flux combination or electrode gas combination;
- 2 Use the correct welding heat;
- 3 Use the correct welding techniques and fabrication practices
- 4 Use care in applying postweld heat treatment (see page 19)

Rule 1

Use the Correct Electrode, Electrode Flux Combination or Electrode Gas Combination

Use only welding processes that are suitably controlled to ensure that they are “low hydrogen”.

Hydrogen is the No. 1 enemy of sound welds in alloy steels – and ArcelorMittal USA “T-1” Steels are alloy steels. In the extremely high heat of welding, any hydrogen introduced into the welding arc atmosphere can be absorbed by the molten weld metal. As the metal in the joint solidifies, its capacity to hold the hydrogen in solution is greatly reduced and much of the hydrogen is given off into the air from the surface of the weld. However, small, but measurable, amounts are retained and can cause hydrogen-induced heat-affected zone cracking or hydrogen-induced weld-metal cracking when the weld cools. Hydrogen-induced cracking – which is not usually visible on the surface of the weld – is the most frequent cause of unsound welds in alloy steels.



depositing a weld bead on ArcelorMittal USA “T-1” Steel with a Type E6010 electrode whose coating inherently has a high hydrogen content. Note the plainly visible crack running almost the entire length of the heat-affected zone under the bead.

A weld in which hydrogen-induced cracking occurs is not as strong as a sound weld – the work pieces are not evenly joined in some places because of the cracking. For example, many welds are subject to forces that tend to pull them apart. This means that a weld with hydrogen-induced cracks could fail under a lower force than expected depending on the extent of cracking.

How to Select the Correct Low Hydrogen Covered Electrodes for Shielded Metal Arc Welding

Low hydrogen covered electrodes for shielded metal arc welding are produced to meet requirements of AWS A5.1⁽¹⁾ (latest edition) or A5.5⁽²⁾ (latest edition). Electrode classifications are marked on electrode containers as well as on individual electrodes. The electrode classification system is described in AWS A5.1 and A5.5 and designates the weld strength, electrode type and weld metal composition and toughness. The first two or three digits in the classification indicate the minimum tensile strength of the deposited metal in ksi. The next two digits designate the type of electrode coating and the applicable welding current and welding position. A letter or letter digit suffix, when used, following the digits discussed above indicate a specific chemical composition. Some electrode classifications are also required to meet specific toughness criteria.

For low hydrogen electrodes, the last digit designating the type of coating should be 5, 6, or 8. E8015, E9016, E11018 and E7028 are examples of low hydrogen electrodes that may be used to weld ArcelorMittal USA “T-1” Steels.

For applications where the weld must be as strong as the “T-1” Steels and have similar toughness, use E11018-M electrodes per AWS A5.5 (latest edition) capable (depending on welding procedure) of depositing weld metal having a minimum tensile strength of 110 ksi and a Charpy V-notch toughness of 20-ft-lbs. at -60°F. In some cases, such as for “T-1” Type A Steel in thin sections, it may be necessary to use a higher strength electrode such as E12018-M in order to meet guided bend test requirements for welding procedure qualification or welder performance qualification. The AWS specification limit on maximum moisture content for E100, E110, and E120 classes of electrodes, as well as the E9018 electrodes, is 5 ml/100gm weld metal diffusible hydrogen, which is suitable for welding the “T-1” Steels.

Other electrodes classified by AWS A5.1 or A5.5 depositing weld metal different in strength and toughness may be either necessary or sufficient depending on design stress and application⁽³⁾. For example, electrodes that deposit weld metal lower in strength (E100, E90, E80 and E70 classes) than that of the “T-1” Steels are often adequate, depending on design stress such as for fillet welds in longitudinal shear; furthermore, lower strength weld metal is frequently desirable to reduce the chance of cracking in highly restrained fillet welds or groove welds in tee or corner joints. When welding a “T-1” Steel to a steel grade of lower strength, the electrode strength steel may be as low as that suitable for the lower strength steel. When electrodes lower in strength than E100, E110 or E120 classes are used to weld a “T-1” Steel, such lower strength electrodes should be baked as discussed in the following section. This is necessary to assure that the diffusible hydrogen does not exceed 5 ml/100 gm since the AWS specification limits on maximum moisture content for E70, E80 and some E90 class electrodes exceed 5 ml/100 gm.

(1) Specification for Carbon Steel electrodes for Shielded Metal Arc Welding

(2) Specification for Low Alloy Steel Covered Arc Welding Electrodes

(3) For unpainted structures boldly exposed to the atmosphere, contact the nearest ArcelorMittal USA plate office at 610-383-2589 or email jerry.shick@arcelormittal.com for information on selection of welding electrodes

How to Control Moisture in Low Hydrogen Covered Electrodes and Hydrogen in Weld Metal

When exposed to air, low hydrogen electrodes may pick up excessive moisture. Such moisture-contaminated electrodes are sources of hydrogen that can generate heat-affected zone or weld metal cracking even though the electrodes are classified as low hydrogen. Once the electrode container has been opened, it is essential that the following precautions be taken to keep the electrodes suitably dry:

1. If the electrodes are in a hermetically sealed container, immediately upon opening the container, put the electrodes into a ventilated holding oven at 250-300°F.
2. If the electrode container has been damaged so as to allow entry of air or if it is a type of container that is not hermetically sealed (such as cardboard box), the electrodes must be properly dried to reduce the moisture to less than 0.2 percent. Check with the electrode manufacturer for the correct temperature and time to use. One, to one-and-a-quarter, hours at 800°F is common. Be sure the oven is vented for air circulation. Dried electrodes should be placed – while still warm – in a holding oven at 250-300°F. This procedure is required to conform with the AWS specification which limits weld metal diffusible hydrogen to 5 ml/100 gm.
3. Never remove more than a half-hour's supply of electrodes from the holding oven at one time. If electrodes are out of the holding oven longer than one-half hour, repeat Step 2, unless the electrode manufacturer guarantees that a specific longer exposure time will not result in weld metal with diffusible hydrogen exceeding 5 ml/100 gm.
4. If there is any doubt about the effectiveness of the drying procedure being followed, take electrodes that are ready for use, put them in a glass tube, and stopper the tube tightly at both ends. Have the coating analyzed for moisture by your plant chemist or a commercial laboratory. Testing should be in accordance with AWS A5.5. Weld metal diffusible hydrogen should not exceed 5 ml/100 gm.
5. ***Electrodes that have been wet or contaminated by other foreign substances, such as oil, grease or paint, should be discarded.***

How to Select the Correct Electrode Flux Combination for Submerged arc Welding

For applications where the weld must be as strong as the “T-1” Steels, submerged arc welding may be done with an Mn-Ni-Cr-Mo electrode and a neutral flux designated F114-EF5-F5 per AWS A5.23 (latest edition). ⁽¹⁾ The electrode flux classification system is described in AWS A5.23 and designates the weld metal strength and toughness, electrode type and composition and the weld metal composition. For the above-suggested electrode flux combination, the F114 indicates an electrode and flux capable (depending on welding procedure) of depositing weld metal having a minimum tensile strength of 110 ksi and a Charpy V-notch toughness of 20 ft-lbs. minimum at -40°F. The EF5 indicates an electrode with a specific Mn-Ni-Cr-Mo composition. The F5 indicates a specific weld metal composition.

Other electrode flux combinations depositing weld metal different from F114-EF5-F5 in strength or toughness may be either necessary or sufficient depending on design stress and application.

How to Control Hydrogen in Electrodes and Fluxes

As with low hydrogen covered electrodes, excessive hydrogen from electrodes or fluxes used for submerged arc welding can cause heat-affected zone or weld metal cracking. Hydrogen from electrodes comes from contaminants, such as drawing compounds or grease, trapped on the electrode surface. When such electrodes deposit weld metal containing greater than 5 ml/100 gm diffusible hydrogen, there is a possibility of cracking in welds of many alloy steels including the “T-1” Steels. To avoid this possibility, the electrodes should be procured with the electrode manufacturer’s guarantee that the total diffusible hydrogen content of the deposit is not more than 5 ml/100 gm.

To control hydrogen in fluxes, it is essential that the following precautions be taken:

1. Buy fluxes in moisture-resistant packages. Do not open the packages until ready to weld. Flux should be placed in the dispensing system immediately upon opening the package, and any remaining flux should be stored in a holding oven at 250-300°F or as recommended by the flux manufacturer.
2. Flux from damaged packages should be discarded or should be dried at 500°F (throughout the flux mass) for one hour, minimum or as recommended by the flux manufacturer. After drying, either use the flux immediately or store it in a holding oven.
3. Discard any flux that has been contaminated by foreign materials, such as oil or dirt, or that has become fused during welding.

(1) Specification for Low Alloy Steel Electrodes and Fluxes for Submerged arc Welding

How to Select the Correct Electrode Gas Combination for Gas Metal Arc and Flux Cored Arc Welding

Gas metal arc welding may be done with an Mn-Ni-Cr-Mo electrode, designated ER110S-1 and argon-2% oxygen shielding gas, per AWS A5.28 (latest edition). ⁽¹⁾ The electrode classification system is described in AWS A5.28 and designates the weld metal strength, toughness and composition. For the above-suggested electrode, the ER110S-1 designates a bare solid electrode capable (depending on welding procedure) of depositing weld metal having a minimum tensile strength of 110 ksi, a Charpy V-notch toughness of 50 ft-lbs. minimum at -60°F, and a specific Mn-Ni-Cr-Mo composition.

Flux cored arc welding may be done with an Mn-Ni-Mo electrode, designated E110T5-K3, or an Mn-Ni-Cr-Mo electrode designated E110T5-K4, and with appropriate shielding gas, per AWS A5.29 (latest edition). ⁽²⁾ The electrode classification system is described in AWS A5.29 and designates the weld metal strength, toughness and composition. For example, the above-suggested electrode E110T5-K3 designates a flux cored electrode capable (depending on welding procedure) of depositing weld metal having a minimum tensile strength of 110 ksi, a Charpy V-notch toughness of 20 ft-lbs. at -60°F, and a specific Mn-Ni-Mo composition.

Other gas metal arc or flux cored arc welding electrodes depositing weld metal different in strength and toughness from those weld metals described above may be either necessary or sufficient depending on design stress and application.

How to Control Hydrogen in Electrodes and Gases

As with low hydrogen covered electrodes, excessive hydrogen from electrodes or gases used for gas metal arc or flux cored arc welding can cause heat-affected-zone or weld-metal cracking. Hydrogen from electrodes comes from contaminants, such as drawing compounds or grease, trapped on the electrode surface. In addition, for flux cored electrodes, hydrogen can come from any moisture retained or absorbed by the core materials. When gas metal arc or flux cored arc welding electrodes deposit weld metal containing greater than 5 ml/100 gm diffusible hydrogen, there is a possibility of cracking in welds of many alloy steels including the "T-1" steels. To avoid this possibility, the electrodes should be procured with the electrode manufacturer's guarantee that the total diffusible hydrogen content of the deposit is not more than 5 ml/100 gm.

Shielding gases for gas metal arc or flux cored arc welding of the "T-1" Steels should be welding quality low-moisture-content gases {dew point: -40°F or lower} to minimize the possibility of heat-affected-zone and weld-metal cracking.

Summary of Rule 1

- 1. For shielded metal arc welding, use only low hydrogen electrodes that provide weld metal of suitable strength and toughness – and keep them dry.**
- 2. For submerged arc welding, use only hydrogen-controlled electrodes and fluxes that provide weld metal of suitable strength and toughness.**
- 3. For gas metal arc and flux cored arc welding, use only hydrogen-controlled electrodes and gases that provide weld metal of suitable strength and toughness.**

(1) Specification for Low-Alloy Steel Filler Metals for Gas Shielded Arc Welding

(2) Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding

Rule 2

Use the Correct Welding Heat

Welding heat is the result of the preheat temperature, the interpass temperature and the heat input obtained from the amperage, voltage and travel speed of the welding arc. Welding is a process that heats metal – and heats it fast. The temperature in the welding arc is one of the highest that can be generated – up to 40,000°F. All of this heat is concentrated in a small area.

Welded joints in many steels are improved by preheating the base metal and by using a relatively high welding heat input, because the high heat input prolongs the time it takes for the joint to cool after welding. Thus, slow cooling is desirable for such steels. However, for the “T-1” Steels, as with many modern low-carbon alloy steels, just the opposite is true.

The most desirable welds in “T-1” Steels are those in which the amounts of preheat and welding heat input are held within specified limits so that the weld area cools rather quickly. Although the weld area is hardened somewhat by this rapid cooling, it does not become brittle.

Preheat and Interpass Temperatures

When a hot weld bead cools, it shrinks more than the surrounding cooler metal and thus is strained severely – sometimes so severely that the weld cracks. The more massive the joint, the more strain that occurs in the weld bead. If the base metal around the joint is preheated, however, the base metal and the weld metal shrink more uniformly as the joint cools. This is usually helpful because less strain occurs in the weld bead and weld cracking is less likely to occur.

However, **preheating can be overdone**. In welding the “T-1” Steels, if the preheat and interpass temperatures are too high and the welding heat input is excessive, undesirable changes occur in the metallurgical structure of the heat-affected base metal to make it brittle. Therefore, the proper combination of heats must be used. Preheat and interpass temperatures may be measured by various methods, the most common being the use of temperature-indicating crayons. To select the minimum preheat and interpass temperatures of the “T-1” Steels, use the following Table 1.

Table 1		
Suggested Minimum Preheat or Interpass Temperature, °F ^{(a)(b)}		
Plate Thickness, Inches	Produced to Published Tensile Properties	Produced to Minimum BHN Hardness Requirements ^(c)
Up to 1/2, incl.	50 ^(d)	100
Over 1/2 to 1, incl.	50 ^(d)	150
Over 1 to 2, incl.	150	200
Over 2	200	250

- (a) Applicable to shielded metal arc, submerged arc, gas metal arc, flux cored arc and gas tungsten arc welding processes.
- (b) A preheat or interpass temperature above the minimum shown may be required for highly restrained welds; however, preheat or interpass temperature should not exceed 400°F for thickness up to and including 1-1/2 in. or 450°F for thicknesses over 1-1/2 in.
- (c) Minimum BHN of 321, 340 or 360
- (d) Welding a steel which is at an initial temperature below 100°F may require localized preheating to remove moisture from the surface of the steel.

How to Control Heat Input in Welding the “T-1” Steels

Controlling the heat input for welds in the “T-1” Steels depends upon the following factors:

1. *Amperage, voltage and arc travel speed.* The welding heat input depends principally on amperage and the speed at which the arc travels along the joint. For a given welding process, changes in arc voltage have a relatively small effect on heat input. A higher amperage produces a higher heat input. A slow arc travel speed produces a higher heat input than a fast speed because each increment along the weld joint is exposed to the high temperature of the arc for a longer time.
2. *Thickness of the pieces to be welded.* A thick piece of steel can absorb more heat than a thin piece. Therefore, a thick piece of the “T-1” Steel can tolerate a higher heat input than a thin piece.
3. *Temperature (preheat or interpass) of the piece to be welded.* A piece of steel which is already warm will extract heat more slowly from an area locally heated to a still higher temperature, as in welding, than a cooler piece. Therefore, a piece of the “T-1” Steels which is warm as a result of either preheating or previous passes of a welding arc will not tolerate as high a heat input as a cooler piece. In some cases, it may be necessary to either reduce the heat input or wait until the piece cools to a lower temperature.

Table 2 lists the suggested maximum heat input for “T-1”, “T-1” type A, “T-1” type B and “T-1” type C steels in various thicknesses at different preheat and interpass temperatures. The word “any” in the tables indicate that the heat input is not critical for the heat-affected zone of the base metal for the respective steel thickness and temperature shown and denotes any heat input attainable by normal practice of the chosen welding process. However, heat input in excess of 80 kJ/in., regardless of section thickness or preheat and interpass temperature, may reduce weld metal toughness.

Table 2											
Suggested Maximum Heat Input, KJ/in.*											
“T-1” and “T-1” Type C Steels						“T-1” Type A and “T-1” Type B Steels					
Preheat and Interpass Temp. °F						Preheat and Interpass Temp. °F					
Thickness						Thickness					
In.	70	150	200	300	400	In.	70	150	200	300	400
3/16	27	23	21	17	13	3/16	18	15	14	12	9
1/4	36	32	29	24	19	1/4	24	21	19	16	12
1/2	70	62	56	47	40	1/2	35	31	28	24	18
3/4	121	107	99	82	65	3/4	47	42	38	32	26
1	Any	188	173	126	93	1	64	57	53	42	34
1-1/4	Any	Any	Any	175	127	1-1/4	89	77	70	56	42
1-1/2	Any	Any	Any	Any	165	1-1/2	Any	120	110	86	66
2	Any	Any	Any	Any	Any	2	Any	Any	154	120	94

* Tables for single-arc applications of the shielded metal arc, submerged arc, gas tungsten arc, flux cored arc and gas metal arc processes; not applicable to multiple-arc and to electro-slag welding and other high-heat-input vertical-welding processes, since welds are made by these processes in the “T-1” Steels should be reheat treated by quenching and tempering after welding.

The maximum heat input for “T-1” and “T-1” type C steels are based on a minimum Charpy V-notch impact value of 10 ft-lbs. at –50F in the heat-affected zone, simulated by in a “Gleeble” treated specimen. The maximum heat input for “T-1” type A and “T-1” type B steels is based on a minimum Charpy V-notch impact value of 10 ft-lbs. at 0F in the heat-affected zone, simulated in a “Gleeble” treated specimen.

For thicknesses greater than those shown on the table, the heat input should not exceed the values in the last line of the table for the steel to be welded – “T-1”, “T-1” type A, “T-1” type B, or “T-1” type C. When welding “T-1” or “T-1” type C steels to “T-1” type A or “T-1” type B steels, the values in the table for the “T-1” type A and the “T-1” type B steels should not be exceeded. When welding different thicknesses of the “T-1” Steels, the lower of the heat-input limits should not be exceeded.

The heat-input table is to be used only for the single arc applications of the shielded metal arc, submerged arc, gas tungsten arc, gas metal arc and flux cored arc processes. The heat input, as shown in the table, is directly applicable for groove welds in butt joints or corner joints and fillet welds in corner joints. However, because the geometrical configurations of tee joints and lap joints provides, in general, more rapid cooling from welding, the maximum heat input, as shown in the table, may be increased by about 25 percent for fillet welds or groove welds in tee joints and lap joints.

Calculating Welding Heat Input for “T-1” Steels

Heat input may be determined by using the following formula:

$$\text{Heat Input, Kilojoules per inch} = \frac{\text{Amperes} \times \text{volts} \times 60}{1000 \times (\text{Speed, Inches per minute})}$$

To determine welding heat input using the shielded metal arc welding process to butt weld two 1/2” “T-1” steel plates that are already at a temperature of 300F.

Step 1 – Select volts, amps and speed for the welding process to be used.

1. Assume an arc voltage of 25 volts. Such a value is typical of that for a low hydrogen covered electrode.
2. Next, assume a current of 200 amps. Such a value is within the operating range for a 3/16 inch size low hydrogen covered electrode.
3. Now, assume an arc travel speed of 5 inches per minute. Arc travel speed is easily determined by having a welder deposit a weld bead on a piece of scrap while another person times the operation for 1 minute. The length of the weld bead in inches is the arc travel speed in inches per minute.

We now have: Volts = 25
Amps = 200
Speed = 5 inches per minute

Step 2 – Determine the heat input that will result from the selected welding variables of 25 volts, 200 Amps and 5 inches per minute of travel speed.

Using the formula we get:

$$\begin{aligned} \text{KJ /in.} &= \text{Heat Input} = \frac{25 \times 200 \times 60}{1000 \times 5} \\ &= 60 \text{ kJ/in.} \end{aligned}$$

Step 3 – Find the suggested maximum heat input for ½-inch “T-1” Steel plate at 300F.

Using Table 3 “T-1” and “T-1” type C steels, locate the plate thickness (½ inch) in the first column. Next, follow that row to the right, stopping at the column for the known plate temperature (300°F) under Preheat and Interpass Temperature. The box where the row and column meet shows the suggested maximum heat input to be 47 kJ/in. [or heat input]. See illustration below.

Table 3											
Suggested Maximum Heat Input, KJ/in.*											
“T-1” and “T-1” Type C Steels						“T-1” Type A and “T-1” Type B Steels					
Preheat and Interpass Temp. °F						Preheat and Interpass Temp. °F					
Thickness						Thickness					
In.	70	150	200	300	400	In.	70	150	200	300	400
3/16	27	23	21	17	13	3/16	18	15	14	12	9
1/4	36	32	29	24	19	1/4	24	21	19	16	12
1/2	70	62	56	47	40	1/2	35	31	28	24	18
3/4	121	107	99	82	65	3/4	47	42	38	32	26
1	Any	188	173	126	93	1	64	57	53	42	34
1-1/4	Any	Any	Any	175	127	1-1/4	89	77	70	56	42
1-1/2	Any	Any	Any	Any	165	1-1/2	Any	120	110	86	66
2	Any	Any	Any	Any	Any	2	Any	Any	154	120	94

* Tables for single-arc applications of the shielded metal arc, submerged arc, gas tungsten arc, flux cored arc and gas metal arc processes; not applicable to multiple arc and to electro-slag welding and other high heat input vertical welding processes, since welds are made by these processes in the “T-1” Steels should be reheat treated by quenching and tempering after welding.

Because the 60 KJ/in. determined in Step 2 exceed the maximum suggested limit of 47 KJ/in., an adjustment in welding variables is needed. If the heat input is more than 47 KJ/in. undesirable changes occur in the metallurgical structure of the heat-affected base metal to reduce its toughness.

Step 4 – Adjust the welding variables to avoid excessive heat input when welding.

There are several ways to make the adjustment:

A. Lower the current [leave the arc voltage and arc travel speed the same].

$$\text{KJ/in.} = \text{Heat Input} = 47 \text{ [max.]} = \frac{25 \times \text{amps} \times 60}{5 \times 1000}$$

$$47 \text{ [max.]} = \frac{1500 \times \text{amps}}{5000}$$

$$\text{amps} = \frac{47 \times 5000}{1500}$$

$$\text{amps} = 156$$

This illustration shows that a welding current of 156 amps in combination with 25 volts and 5 inches per minute will produce a heat input of 47 KJ/in., a value that does not exceed the suggested maximum in Step 3.

Note: For optimum operating and usability characteristics for a particular size electrode, the current should be within the range recommended by the electrode manufacturer. In the example above, the welding current of 156 amps may be below the operating range for a particular brand of 3/16-inch size electrode, in which case a smaller diameter electrode should be used.

B. Increase the arc travel speed [leaving the arc current and arc voltage the same].

$$\text{KJ/in.} = \text{Heat Input} = 47 \text{ [max.]} = \frac{25 \times 200 \times 60}{1000 \times \text{in./min.}}$$

$$\text{in./min.} = \frac{300000}{1000 \times 47}$$

$$\text{in./min.} = 6.38$$

Again, this illustration shows that 200 amps, 25 volts and 6-3/8 inches per minute arc travel speed will produce a heat input of 47 KJ/in., a value that does not exceed the suggested maximum determined in Step 3.

Note: Welding speed should not be too high or too low for optimum weld soundness and contour.

- C. Allow the plates to cool [leaving the arc current, arc voltage and arc travel speed the same].** For any given thickness of steel, as the preheat or interpass temperature is lowered, the suggested maximum heat input increases as may be seen from the heat input tables. Using the Heat Input Table for “T-1” and “T-1” type C steels follow the line for 1/2 inch plate to the right, stopping at the column showing 62 KJ/in. This suggested maximum Heat Input Value for ½-inch thick steel at a preheat or interpass temperature of 150F is slightly higher than the 60 KJ/in. determined in Step 2, indicating that a welding heat input of 60 KJ/in. could be used for welding 1/2 inch plate at 150F. By interpolation of preheat and interpass temperatures in the Heat Input Table, 60 KJ/in. could be used for welding ½-inch plate at a temperature as high as about 170°F.

Caution: Selection of preheat and interpass temperature should be consistent with the table discussed under Preheating.

Is there a best way to make the adjustment? Each fabricator must develop his own answer to such a question, since the optimum welding practice may vary among fabricators depending on many conditions, such as the welding site, location and design of the weld joint, the welding process and equipment and the service application of the welded joint.

Caution: Heat input calculations will not be correct unless the voltage and amperage are accurate. Amperage and voltage should be measured as close as practical to the welding arc.

Summary of Rule 2

Use the correct welding heat for the “T-1” Steels:

1. Select preheat and interpass temperature for the thickness of the steel to be welded (see table) for the welding process to be used.
2. Select voltage, amperage and arc travel speed and determine the Heat Input (welding heat input) that will result from this selection.
3. Compare the determined Heat Input with the maximum Heat Input that is the suggested limit (see table) and revise selected voltage, amperage and arc travel speed, if necessary.

Rule 3

Use the Correct Welding Techniques and Fabrication Practices

Stringer Bead Technique

The stringer bead technique is suggested for both single and multiple-pass welds in the “T-1” Steels. In multiple-pass welding, before a bead is deposited over a previous bead, flux, scale or oxide must be removed by one of the usual cleaning methods (powered or manual hammer and brush).

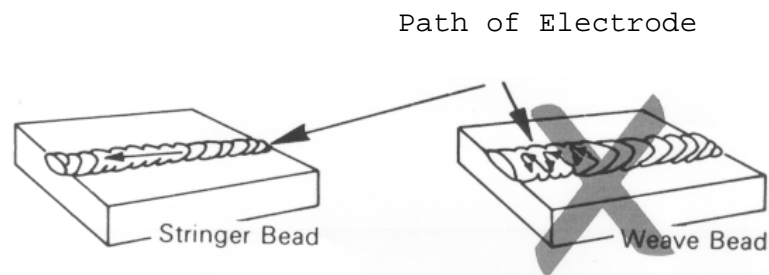
To minimize porosity at locations where the arc is started when low hydrogen covered electrodes are used, a back-step technique should be used. Start the arc about one inch forward of the intended beginning of the weld bead increment, back step the arc about one inch and then begin the forward progression of the arc such that the weld bead covers the start location. This back-step technique will aid in obtaining radiographically acceptable welds.

Partial Weave Technique

Because vertical position welding with upward arc progression usually necessitates the use of some weaving, a partial weave technique may be used in welding the “T-1” Steels, provided the weave is limited to two electrode diameters.

Do Not Use the Full-Weave Technique

The full-weave technique is not considered suitable for welding the “T-1” Steels. Weaving results in a reduction of the forward travel speed of the arc. The full-weave technique (more than two electrode diameters) generally results in excessive heat input, poor weld soundness, and a weld with reduced strength and toughness.



Metal Removal Technique

Any of several methods may be used if it is necessary to remove welds, or portions of welds or base metal, such as in back gouging, correction of errors and removal of defects. Arc-air gouging followed by clean-up grinding is suggested. Proper air pressures and currents generally minimize carbon deposits which may occur in arc-air gouging. Grinding to 1/32 inch below the exposed surface will normally remove any carbon deposits. If arc-air gouging and clean-up grinding is not done properly, carbon deposits on the exposed surface may subsequently cause cracking. Chipping, grinding or machining are other suitable methods for metal removal.

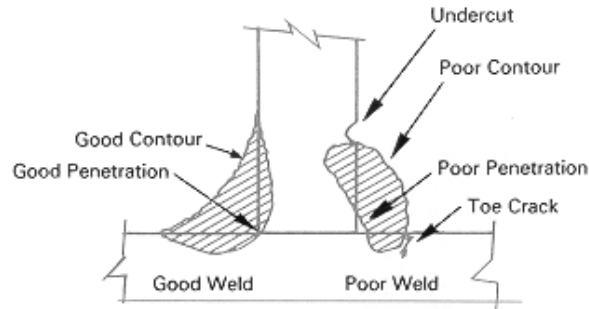
Caution: Do not use an oxyacetylene torch for gouging since the heat input by this method is difficult to control and excessive heat input may result in a detrimental reduction of mechanical properties for the base metal or the weld joint.

Weld Finish

Refinements in design, workmanship and inspection are necessary because welded joints in the “T-1” Steels are usually loaded to higher stresses than are joints in steels of lower strength. Abrupt changes in section should be avoided. Offset in alignment of sections to be butt welded should be minimized. Any such offset should be faired at a three-to-one taper over the width of the finished weld. The maximum weld reinforcement should not exceed 10 percent of the material thickness or 1/8 inch, whichever is less.

The junction between the face of a weld and the base metal should merge smoothly into the base metal with minimum undercutting for fillet welds and groove welds, as well as for butt welds. The face of such welds should be free of coarse ripples, grooves, overlaps, abrupt ridges or valleys. Welding techniques used must be such as to provide adequate weld penetration, particularly at the root.

The following illustration of two fillet welds shows desirable features of a good weld on the left and undesirable features of a poor weld on the right.



Weld Restraint

In the section of *Preheating* under *Rule 2*, the effects on weld metal of shrinkage during cooling of a hot weld head were discussed. Further, the table on *Suggested Minimum Preheat or Interpass Temperature* includes a cautionary note that a preheat or interpass temperature above the minimum shown may be required for highly restrained welds. In all welds, some restraint is always provided by the joint members themselves. This restraint may be high depending on the thickness and the arrangement of the members. Additional restraint may be introduced by external devices such as jigs or presses or by welding sequence.

In some joint designs, the restraint produced by the members in resisting shrinkage during cooling from welding is such that high tensile stresses are imposed in the through-thickness direction of the steel being joined. Eventually, these stresses may cause planar separation or lamellar tearing that may or may not occur in plates and structural shapes produced by conventional steelmaking processes and are independent of steel strength. Some of the ways to minimize the occurrence of lamellar tearing are by changing the location and design of the joint, by using surface or butter welding to locally improve the through-thickness properties of the joint or by using steel specially processed to have improved through-thickness ductility.

With high restraint and weld metal as strong as or stronger than the "T-1" Steels, the weld shrinkage may sometimes overstrain the heat-affected zone of the base metal causing cracking at the toes or roots of fillet or groove welds in tee or corner joints. Such cracking is more likely to occur when any one of the following conditions exists:

1. the pieces joined are thicker than about 1-1/2 inch,
2. the weld does not merge smoothly into the base metal,
3. there is excessive hydrogen during welding,
4. the preheat or interpass temperature is too low,
5. the weld shrinkage excessively strains the base metal in its through-thickness direction.

Previously discussed suggestions concerning hydrogen control, preheat and interpass temperature, and weld finish will assist in minimizing such cracking. Some additional procedures and techniques that have been used individually or in combination to minimize such cracking are as follows:

1. Choose weld joint design, weld location and the sequence of assembly of members by welding that will minimize weld restraint.
2. Use a lower-strength weld metal for tee or corner joints than would normally be used for butt joints, provided design stress requirements are met, since many tee or corner joints do not require weld metal as high in strength as that for butt welds.
3. Air hammer peen the welds. Peening is a technique for locally redistributing welding stresses by mechanical means. Proper peening plastically deforms the weld metal so that final shrinkage forces are greatly reduced in the joint. Peening is most effective when done while the weld metal is still hot, immediately after removal of its protective slag. Sometimes it may be necessary to peen after each weld pass (except root and final passes); at other times peening only the toe passes (except final) is sufficient.
4. Surface or butter in the toe area of fillet welds. One or more adjacent stringer beads are deposited in the anticipated toe area for the desired fillet weld. These surfacing or buttering welds should be made with low-strength weld metal. The desired fillet weld should then be made such that at least half a bead width of the surfacing or buttering welds remains exposed; otherwise, the benefits from using the low-strength weld metal will be reduced or lost.
5. Use low-carbon soft steel wire spacers for fillet welds. The soft wires provide a cushion that reduces the restraint when the two members being welded move together under the effect of weld shrinkage.

Summary of Rule 3

Use the correct welding techniques and practices:

1. **Use the stringer bead technique for welding the “T-1” Steels, back-stepping the weld start to minimize porosity at the weld start.**
2. **Use the partial weave technique to make vertical welds in the “T-1” Steels, but restrict the weave to no more than two electrode diameters.**
3. **Grind welds after arc-air gouging to minimize carbon deposits.**
4. **Contour the welds properly.**
5. **Minimize cracking at the toes and roots of highly restrained welds by:**
 - a. **Using joint design, location and sequence of assembly to minimize weld restraint,**
 - b. **Using lowest strength weld metals meeting design requirements.**
 - c. **Air-hammer peening the welds,**
 - d. **Surface or butter welding in the toe area of fillet welds,**
 - e. **Using low-carbon soft steel wire spacers for fillet welds.**

Rule 4

Use Caution in Applying Postweld Heat Treatment

Postweld heat treatment as used in this book means any heat treatment subsequent to welding provided the heat treatment temperature exceeds 700°F but does not exceed that used by the steel manufacturer to temper the steel. Generally, welded structures of ArcelorMittal USA “T-1” Steels should not be given a postweld heat treatment. Loss of weld-metal and heat-affected-zone toughness and stress-rupture cracking may occur as a result of such a treatment. Many modern steels for welded construction, such as the “T-1” Steels, are designed to be used in the as-welded condition. Unlike some carbon steels, the postweld heat treatment process can have an adverse effect on such alloy steels. Those alloying elements that contribute most significantly to the attainment of high strength and notch toughness in alloy steels and in weld metal joining these steels are usually the alloy elements that have an adverse effect when weldments of such steels are postweld heat treated.

The decision to use a postweld heat treatment with the “T-1” Steels, as for other steels, should only be made when the user of the steel can be sure that the anticipated benefits from the heat treatment are needed and will be realized and that possible harmful effects can be tolerated. Postweld heat treatment is necessary for some applications in which the steel used has inadequate notch toughness after cold forming or welding, for some applications in which the steel after cold forming or welding must retain close dimensional stability during machining, or for some applications in which high residual stresses from cold forming or welding might lead to stress corrosion cracking. When the application is one of these, careful consideration should be given to whether or not the “T-1” Steels are appropriate steels to use, and whether the possible harmful effects of postweld heat treatment can be tolerated. Furthermore, careful consideration should be given to whether or not the particular design, fabrication and inspection should be proven by testing one or more prototypes in the as-welded and postweld heat treated conditions.

The results of notch-toughness tests have shown that postweld heat treatment in the temperature range 950 to 1200°F may impair weld metal and heat-affected-zone toughness; the extent of impairment depends on chemical composition, treatment temperature and time at temperature, and is greater with slow cooling as in stress relieving. Furthermore, when welds in the “T-1” Steels, as with many other alloy steels, are given a postweld heat treatment above about 950°F, intergranular cracking may occur in the grain-coarsened region of the heat-affected zone of the base metal. The intergranular cracking occurs by stress rupture, usually in the early stage of the postweld heat treatment. Susceptibility to this cracking increases with increasing weld restraint and with increasing severity of zones of stress concentration. In addition, chromium, molybdenum and vanadium are major contributors to this crack susceptibility, but other carbide-forming elements assist. The precipitation of carbides during the elevated-temperature stress relaxation alters the delicate balance between resistance to grain boundary sliding and resistance to deformation within the coarsened grains of the heat-affected zone. The cracking is variously known as “stress-rupture cracking”, “stress-relief cracking,” and “reheat cracking.”

Some procedures and techniques that have been used individually or in combination to minimize such cracking are as follows:

1. Choose weld joint design, weld location and the sequence of assembly of members by welding that will minimize weld restraint.
2. Choose the weld joint design and contour the weld finish to minimize zones of stress concentration. Butt welds are preferable to fillet welds. Remove backing strips if used, and then back weld.
3. Use weld metal having elevated-temperature strength significantly lower than that of the heat-affected zone of the steel during the postweld heat treatment.
4. Surface or butter in the toe area of fillet welds. One or more adjacent stringer beads are deposited in the anticipated toe area for the desired fillet weld. These surfacing or buttering welds should be made with low-strength weld metal. The desired fillet weld should then be made such that at least half a bead width of the surfacing welds remains exposed as described in the discussion on *Weld Restraint*.
5. Air hammer peen the welds as previously described in the discussion on *Weld Restraint*.

CAUTION: None of these procedures or techniques can be guaranteed either individually or in combination to eliminate the possibility of stress-relief cracking in any particular application.

If postweld heat treatment must be performed, the temperature should not exceed that used by the steel manufacturer for tempering the steel. A postweld heat treatment at about 50°F lower than the tempering temperature is desirable to avoid lowering the strength of the steel.

It is also recommended that the weldments be non-destructive tested (NDT) both prior to and after the postweld heat treatment to establish if any cracking is present. The NDT may include liquid penetrant, magnetic particle, x-ray and ultrasonic testing.

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