Steel TIPS

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Compatibility of Mixed Weld Metal

By

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Acknowledgments

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Index of Steel TIPS Publications

The following is a list of available Steel TIPS. Copies will be sent upon request. Some are in very limited quantity.

- Seismic Design of Special Concentrically Braced Frames
- Seismic Design of Eccentrically Braced Frames
- Seismic Design of Column Tree Moment Resisting Frames
- Dynamic Tension Tests of Simulated Moment Resisting Frame Welded Joints
- Reference Guide for Structural Steel Welding Practices
- Seismic Strengthening with Steel Slotted Bolt Connections
- Slotted Bolted Connection Energy Dissipaters
- Heavy Structural Shapes in Tension Applications

INTRODUCTION

PURPOSE

The purpose of this *Steel TIPS* is to provide structural designers, fabricators, and erectors with the history, use, and compatibility of mixed weld metals for structural steel applications.

ORGANIZATION AND CONTENT

To accomplish the purpose, the authors have organized this *Steel TIPS* into the following categories:

- Historical background.
- AWS and AISC requirements.
- Effect of the Northridge Earthquake.
- Combinations of mixed weld metal.

The authors do not recommend or approve any particular combination of mixed weld metal Instead, they set forth combinations used and possible combinations. Please remember, the Engineer has the right to approve any combination of mixed weld metal.

CONTENTS

1. HISTORICAL BACKGROUND

For many years fabricators and erectors have used, as common practice, electrodes with different specifications and classifications in the same weld (mixed weld metals). Mixed weld metal results from:

- Different root pass and fill-in pass electrodes.
- Weld repair work to both shop and field welds.
- The more recent practice of making field welds over shop welds.

Compatibility is a basic requirement of mixed weld metals. The different electrodes and the mixed weld metal must have, as a minimum, matching yield strength, tensile strength, and impact properties—if impact properties are specified.

In this *SteelTIPS*, the authors will limit their discussion to two welding processes:

- Shielded Metal Arc Welding (SMAW).
- Flux Cored Arc Welding (FCAW).

MIXING ELECTRODES.

In the Same Weld Process. First, fabricators and erectors commonly used different manual coated "stick" electrodes (SMAW) in the same weld. Then, when flux cored electrodes (FCAW) came on the market in the mid 1950's, they started using different FCAW electrodes in the same weld. They used the different electrodes:

- To take advantage of one electrode's penetration capabilities for root passes and the other electrode's capabilities for fill-in passes.
- For weld repair work.

In Different Weld Processes. With the availability of self shielding flux cored electrodes, fabricators and erectors began using electrodes from the two different welding processes in the same weld. They used:

- SMAW electrodes in the root passes for good penetration and low hydrogen properties, and FCAW electrodes in the fill-in passes for high deposition rates.
- SMAW over FCAW for weld repair work.

FCAW With Outside Gas Shielding. With the availability of flux cored electrodes with outside gas shielding in the mid 1960's, fabricators and erectors started using two FCAW processes in the same weld:

- Self-shielding from the flux in the core of the wire (FCAW-ss).
- Gas shielding from an outside source (FCAW-g).

Fabricators generally used:

- FCAW-g in the root passes for good welding characteristics.
- FCAW-ss electrodes in fill-in passes for good deposition rates.

Outside gas shielding was generally limited to shop fabrication because erectors had difficulty protecting the gas from winds encountered in field erection.

Interestingly, fabricators and erectors used Gas Metal Arc Welding (GMAW) equipment to make the first Flux Cored Arc Welds. GMAW equipment used solid wire electrodes with inert gas shielding. Users called this GMAW welding process "Dual Shielding." Now common practice is to call flux cored electrodes with outside gas shielding (FCAW-g) as "Dual Shielding."

Since Northridge. Then the 1994 Northridge Earthquake occurred. Since the Earthquake, the volume of mixed weld metal has proliferated greatly, and with just about any combination of SMAW and FCAW electrodes. Combinations resulted from both damage repair work and from new welds. Damage repair work involved welding one classification or process over another classification or process. New design details set up the situation where erectors used one process to weld over a different shop process.

IMPACT REQUIREMENTS.

At first, the construction industry paid little regard to impact requirements of the electrodes. Later, various Advisory Task Groups formed to investigate the Earthquake damage (e.g., AISC, AWS, SAC Joint Venture, SEAOC, LA City and County, and other Code Agencies) called for impact requirements in electrodes used in seismic designs. The various code agencies are putting these impact requirements into their codes.

2. AMERICAN WELDING SOCIETY (AWS) REQUIREMENTS

The AWS *Structural Welding Code—Steel* (AWS Code) covers the welding requirements for welded steel structures. [1] This Code does not **directly** address the use of mixed weld metals or impact requirements for welds. However, the AWS Code:

- **Implies** the use of mixed weld metals in Section 3.3.
- Sets forth impact testing requirements in Annex III **if** the contract drawings or specifications require impact testing.

MIXING WELD METALS

Base Metal/Filler Metal Combinations. Although the AWS Code does not directly address the use of mixed weld metals, it does imply their use. Close attention to the untitled table in Section 3.3, "Base Metal/Filler Metal Combinations," page 41, shows:

- "Any steel to itself or any steel to another in the same group" can be welded by "Any filler metal listed in the same group."
- "Any steel in one group to any steel in another" can be welded by "Any filler metal listed for a lower strength group. [SMAW electrodes shall be the low hydrogen classification]" (E7015, E7016, and E7018). [2]

Implications. Section 3.3 and Table 3.1 on page 42 show that many base metals in a steel group can be welded to each other by different electrodes; therefore, the AWS Code allows mixed weld metal in the same weld based on strength relationships.

Additional Requirements by Advisory Task Groups. Besides compatible yield strength and tensile strength requirements required by the AWS Code, the Advisory Task Groups recommended that electrodes involved in mixed weld metal welds must have compatible impact requirements Further, the Advisory Task Groups recommended testing and evaluation of the mixed weld metal combinations.

IMPACT

Not Addressed in AWS Code. The AWS Code does not address impact requirements; that is the Engineer's responsibility. However, the AWS Code does address impact **testing** requirements in Annex III.

IMPACT TESTING

Application of Annex III of the AWS Code. Annex III of the AWS Code addresses impact testing. The title of Annex III is "Requirements for Impact Testing" with a subtitle "Mandatory Information." A further comment under the subtitle states:

> (This Annex is a part of ANSI/AWS D1.1-96, *Structural Welding Code—Steel* and includes mandatory requirements for use in this standard.) [3]

However, Section III1.1 states:

> The impact test requirements and test procedures in this Annex shall apply only when specified in the contract drawings or specifications in accordance with 5.26.5(3)[d] and 4.1.1.3, and Table 3.1 of this code. [4]

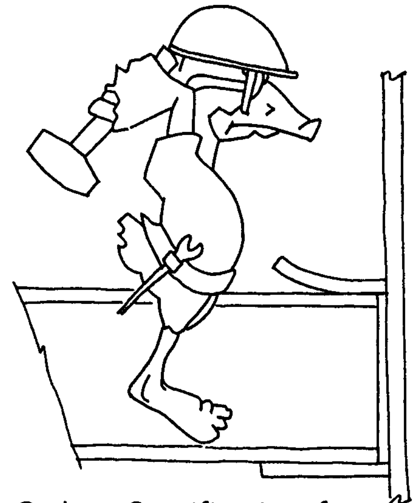
Thus, the decision to call for impact testing requirements is left to the discretion of the designer or engineer responsible for the contract drawings or specifications.

Use of Test Results. Annex Section III1.2 states in part:

> . . . The energy values determined are qualitative comparisons on a selected specimen and although frequently specified as an acceptance criterion, they cannot be used directly as energy figures that would serve for engineering calculations [e.g., failure analysis calculations]. [5]

Scatter. A great scatter is normal in Charpy V-Notch test results. The AWS Code provides a limited discussion of scatter in Annex III; however, it references other publications that thoroughly discuss fracture toughness—including scatter. Annex III, Table III-1, calls for three specimens for each test location, with an optional five specimens per test location. When using five specimens, Note 2 in the Table applies and states in part, "The highest and lowest values are then discarded **to minimize some of the scatter normally associated with Charpy testing of welds and HAZ.** [Emphasis added.]" [6] HAZ denotes the portion of the base metal whose mechanical properties or microstructure has been altered by the heat of welding and quenching effect of the base metal. See Article 7, "Commentary on Impact Requirements and Testing," for comments on impact testing and scatter.

3. AISC REQUIREMENTS



The AISC *Manual of Steel Construction: Allowable Stress Design* (AISC Manual) addresses mixing weld metals and impact requirements for both the base metal and weld metals as follows:

- Mixed Weld Metal. PART 5-Specifications and Codes, *Specification for Structural Steel Buildings—Allowable Stress Design and Plastic Design* (AISC Specifications), discusses mixing weld metals.
- Impact. PART 1-Dimensions and Properties, briefly discusses impact. PART 5 -Specifications and Codes, addresses limited impact requirements. [7]

MIXING WELD METALS

AISC Specifications. Refer to Chapter J-Connections, Joints and Fasteners. Section J2.6., Mixed Weld Metal, states:

> **6. Mixed Weld Metal**
>
> When notch-toughness is specified, the process consumables for all weld metal, tack welds, root pass and subsequent passes, deposited in a joint shall be compatible to assure notch-tough composite weld metal. [8]

The following AISC Specification Commentary illustrates a lack of compatibility between process consumables (electrodes), and reinforces the Advisory Task Groups' recommendation that users evaluate mixed weld metals by testing.

AISC Specifications Commentary. Section C-J2.6., Mixed Weld Metal, states:

> **6. Mixed Weld Metal**
>
> Instances have been reported in which tack welds deposited using a self-shielded process with aluminum deoxidizers (which by itself provided notch-tough weld metal) were subsequently covered by weld passes using a submerged arc process (which by itself provided notch-tough weld metal) resulted in composite weld metal with low notch-toughness (Terashima and Hart, 1984; Kotecki and Moll, 1970; and Kotecki and Moll, 1972). [9]

IMPACT

PART 1 Dimensions and Properties. Pages 1-4, 1-5, and 1-6 have very good, concise write-ups on Brittle Fracture, Lamellar Tearing, and Jumbo Shapes and Heavy Welded Built-up Sections. However, PART 1 barely touches on notch-toughness (impact). The last paragraph under the subtopic "Selecting a Steel" does mention notch toughness.

PART 5 Specifications and Codes. The Specifications and corresponding Commentary address impact in Sections A3.1.c. Heavy Shapes, A4.2. Impact, and A.4.5. Other Forces. Engineers seldom request impact requirements for base metal, except for heavy shapes. See below.

Section A3.1.c. Heavy Shapes specifies impact requirements for the following members when subject to primary tensile stresses due to tension or flexure if spliced using full penetration welds:

- ASTM A6 Groups 4 and 5 rolled shapes.
- Built-up members with plates exceeding 2 in. thick

For this use the contract documents shall specify, ". . . the steel shall be specified in the contract documents to be supplied with Charpy V-Notch testing in accordance with ASTM A6, Supplementary Requirement S5. The impact test shall meet a minimum average value of 20 ft-lbs. absorbed energy at +70°F . . . ." [10]

When using mixed weld metal in Groups 4 and 5 rolled heavy shapes, the designer or engineer, fabricator, and erector, should be familiar with impact requirements and precautions addressed in:

- Section A3.1.c.
- The Section's Commentary.
- All sections listed in Section A3 1 c on page 5-126, including corresponding commentary sections

The Section also states in part:

> The above supplementary toughness requirements shall also be considered for welded full-penetration joints other than splices in heavy rolled and built-up members subject to primary tensile stresses. [11]

The Specification Commentary discusses "considered."

Section A4.2. Impact, does not call for Charpy V-Notch toughness testing. The Section states:

> **2. Impact**
>
> For structures carrying live loads* which induce impact, the assumed live load shall be increased sufficiently to provide for same.
> If not otherwise specified, the increase shall be not less than:

[See pages 5-29 for listings ranging from 10% - 100%]
[The * footnote is not included in the above quote] [12]

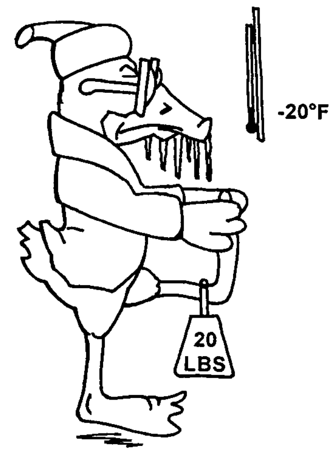
Note: The listed percentages increase the live loads to compensate for loads that induce impact.

Section A4.5. Other Forces, states:

5. Other Forces

Structures in localities subject to earthquakes, hurricanes and other extraordinary conditions shall be designed with due regard for such conditions. [13]

4. EFFECT OF 1994 NORTHRIDGE EARTHQUAKE



As Mentioned in Article 1, "Historical Background," fabricators and erectors had used electrodes with different specifications and classifications for many years before the Northridge Earthquake.

MIXED WELD METALS

Northridge Damage Repairs. The use of mixed weld metals increased following the Earthquake, mainly because damage repairs involved gouging out for weld cracks, and rewelding with an electrode other than the electrode used in the original weld. Erectors most commonly used—and continue to use—SMAW E7018 low hydrogen, manual electrodes and certain FCAW electrodes to repair damaged weld joints made with FCAW, E70T-4 flux cored electrodes.

New Welds. Engineers started following the Advisory Task Group's recommendation of requiring impact tests for mixed weld metals in new welds.

IMPACT REQUIREMENTS

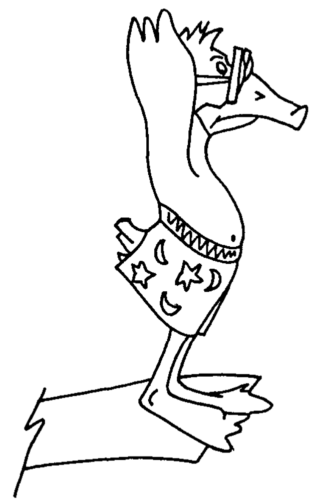
Northridge Damage Repairs. During initial damage repairs, engineers paid little attention to the impact requirements of the original weld metal and the repair electrode because:

- Expediency of the repairs precluded investigative testing.
- AWS Code and the AISC Specifications did not have any impact requirements for base metals—except for limited requirements by AISC for Steel Groups 4 and 5 jumbo shapes and certain built-up members. (See Specification A3.1.C reviewed in Article 3, "AISC Requirements").
- SMAW and FCAW repair electrodes had good impact requirements—usually 20 ft. lbs. at -20°F.

As repair work progressed, the Investigating Advisory Task Groups made their recommendations available. Engineers expressed concern about the recommendations regarding impact requirements of the original weld metal and the repair weld metal. However, engineers apparently took no action regarding recommendations on the original weld metal, but did follow recommendations on repair weld metal.

New Welds. Later, the Advisory Task Groups recommended that if engineers wanted impact requirements for mixed weld metal, each electrode used to make the weld had to meet those impact requirements. As a result, engineers now frequently request impact requirements for both SMAW and FCAW electrodes.

5. IMPACT REQUIREMENTS AND IMPACT TESTING BEFORE NORTHRIDGE



Most of the structural steel construction before the 1994 Northridge Earthquake had very little impact requirements because:

- Applicable editions of the AWS Code had no impact requirements.
- Applicable editions of the AISC Manual had limited or no impact requirements.

AWS IMPACT REQUIREMENTS

In AWS Code. Various AWS Codes governed the construction of structures subjected to the Northridge Earthquake. The 1988, 1990, and 1994 AWS Codes included Appendix IIIs that are almost identical to Annex III in the 1996 AWS Code. Therefore, the present AWS impact requirements limited to impact testing—reviewed in Article 2, "AWS Requirements"—applied to structures built under the earlier named codes. Before 1988 the AWS Code lacked even those impact testing requirements.

AISC IMPACT REQUIREMENTS

In AISC Manual. Various AISC Manuals governed construction of structures subjected to the Northridge Earthquake. The 1980 AISC Manual included 1978 Specifications similar to the 1989 AISC Manual Therefore, the present AISC impact requirements—reviewed in Article 2, "AISC Requirements"—applied to structures built from 1978 to 1994. Before 1978, the AISC Manual did not address impact requirements.

6. MIXED WELD METAL COMBINATIONS

The use of mixed weld metal combinations can be divided into the following three main periods based on the different conditions for the combinations during the periods:

1. Pre-Northridge Earthquake Practice.
2. Urgent Northridge Earthquake Damage Repairs.
3. Post-Northridge Earthquake Practice.

The following "General Criteria," "Conditions" listed under a Period, and criteria within the tables, decided the electrode combinations used for each period.

GENERAL CRITERIA

The following criteria pertain to electrodes listed in Period 1, 2, and 3 tables:

- Root weld passes require good penetration and good fusion to base metals.
- Fill-in weld passes require good fusion to base metals and to other passes.
- The AWS *Welding Handbook* and electrode manufacturers' bulletins contain electrode information and specifications. [14]
- FCAW-ss and FCAW-g electrodes make good fill-in passes because of their higher deposition rates. However, outside gas shielded electrodes create problems in field welding because the shielding gas must be protected from the wind.
- The Engineer may require approval of mixed weld metal including electrode combinations previously qualified by test.

The following AWS Specifications give root pass, fill-in pass, and impact requirements for electrodes listed in Period 1, 2, and 3 tables:

- AWS A5.1 *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding.* [15]
- AWS A5.5 *Specification for Low Alloy Steel Electrodes for Shielded Metal Arc Welding.* [16]
- AWS A5.20 *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding.* [17]
- AWS A5.29 *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding.* [18]

PERIOD 1. PRE-NORTHRIDGE EARTHQUAKE PRACTICE

Conditions. Based on the type of weld, Pre-Northridge Earthquake Practice can be divided into two categories; 1) Original Weld, and 2) Weld Repair. Weld Repair Combinations probably made up a much larger volume of mixed weld metal than Original Weld Combinations.

Original Welds. Combinations in Table 1 show SMAW and FCAW fill-in pass electrodes welded over SMAW root pass electrodes. Typically the root pass electrodes were selected for good penetration and good fusion. The fill-in pass electrodes were selected for good fusion to base metals and to other passes. Engineers, fabricators, and erectors paid very little attention to electrode impact requirements; however, they reported no problems with the mixed weld combinations.

TABLE 1 ORIGINAL WELD COMBINATIONS

ROOT PASS ELECTRODES	FILL-IN PASS ELECTRODES
AWS CLASSIFICATION	**AWS CLASSIFICATION**
GROUP 1 - KNOWN COMBINATIONS	
Impact Requirements = 20 ft. lbs. at -20°F. **SMAW Electrodes** E7015 E7016 E7018	Impact requirements = 20 ft. lbs. at -20°F, unless noted. **SMAW Electrode** E7028 **FCAW Electrodes** E70T-4 (No Impact) E7XT-7 (No Impact) E71T-8 E70TG-K2
GROUP 2 - POSSIBLE COMBINATIONS	
Impact requirements = 20 ft. lbs. at -20°F to -150°F. **SMAW Electrodes** E7015 E7016 E7018 E7048 E8015 E8016 E8018	Impact requirements = 20 ft. lbs. at -20°F to -100°F. **FCAW Electrodes** E7XT-1 E70T4-K2 E7XT-5 E70T5-A1 E70T-6 E71T8-Ni1 E71T-8 E71T8-Ni2 E7XT-9 E71T8-K6 E7XT-12 E8XT-Ni1, Ni2 E61T8-K6 E80T-Ni1, Ni2, K2

Notes: 1. Erectors and fabricators could have welded any Fill-in pass electrode over any root pass electrode.

Weld Repairs. Combinations in Table 2 show SMAW and FCAW weld repair electrodes welded over SMAW and FCAW original weld electrodes. Fabricators and erectors used a multitude of electrode combinations to make weld repairs to shop and field welds. Repair items included·

- Undercut.
- Cracks, porosity, incomplete fusion, and slag inclusion.
- Undersized welds.
- Lamellar tearing (gouging into adjacent weld metal required).

Fabricators and erectors could have made the original weld with SMAW, FCAW, GMAW, or SAW electrodes. SMAW and FCAW electrodes usually made up the repair electrodes.

TABLE 2 WELD REPAIR COMBINATIONS

ORIGINAL WELD ELECTRODES	WELD REPAIR ELECTRODES
AWS CLASSIFICATION	**AWS CLASSIFICATION**
Impact requirements = 20 ft. lbs. at -20°F, unless noted. **SMAW Electrodes** E7015 E7016 E7018 E7028 **FCAW Electrodes** E70T-4 (No Impact) E7XT-7 (No Impact) E7XT-8 E70TG-K2	Impact requirements = 20 ft. lbs. at -20°F, unless noted. **SMAW Electrodes** E7015 E7016 E7018 **FCAW Electrodes** E70T-4 (No Impact) E7XT-7 (No Impact) E7XT-8 E70TG-K2

Notes:
1. Electrodes listed under "Original Electrodes" are taken from "Group 1-Known Combinations" in Table 1.
2. Erectors and fabricators could have welded any repair electrode over any existing weld electrode.

PERIOD 2. URGENT NORTHRIDGE EARTHQUAKE DAMAGE REPAIRS

Conditions. Combinations in Table 3 show SMAW repair weld electrodes welded over SMAW and FCAW electrodes in the existing weld. FCAW electrodes were readily available for damage repairs. They were very popular, high deposit electrodes. However, for the emergency damage repairs immediately following the earthquake, erectors commonly used SMAW low hydrogen electrodes welded over a gouged out joint made with SMAW or FCAW electrodes.

Most of the weld joint damage consisted of a lack of fusion of the weld metal to the base metal. Erectors repaired this type of damage by:

- Back-gouging the joint to clean base metal and clean weld metal.
- Grinding to clean up.
- Rewelding fill-in and build-up with E70XX electrodes.

Again, engineers and erectors paid little attention to electrode impact requirements of the resulting mixed weld metal joint, although they suspected most original welds were made with FCAW E70T-4 electrodes that had no impact requirements. Engineers accepted most of the combinations in Table 3, with acceptance based on normal welding procedures.

TABLE 3
URGENT EARTHQUAKE DAMAGE REPAIR COMBINATIONS

EXISTING WELD ELECTRODES	REPAIR WELD ELECTRODES
AWS CLASSIFICATION	**AWS CLASSIFICATION**
Impact requirements = 20 ft. lbs. at -20°F, unless noted.	Impact requirements = 20 ft. lbs. at -20°F.
SMAW Electrodes	**SMAW Electrodes**
E7015	E7015
E7016	E7016
E7018	E7018
E7028	
FCAW Electrodes	
E70T-4 (No Impact)	
E7XT-7 (No Impact)	
E7XT-8	
E70TG-K2	

Notes: 1. Erectors could have welded any repair electrode over any existing weld electrode.

PERIOD 3. POST-NORTHRIDGE EARTHQUAKE PRACTICE

Conditions. Based on the type of welding, Post-Northridge Earthquake Practice can be subdivided into two categories:

- Later Northridge Earthquake damage repairs.
- New welds.

Later Northridge Earthquake Damage Repairs. After completing the urgent Northridge Earthquake damage repairs, erectors started making "later" damage repairs. Erectors made these later damage repairs under criteria based on reports by the Advisory Task Groups. The Advisory Task Groups unanimously recommended that all electrodes in a weld metal combination shall have matching physical properties (e.g., yield strength, tensile strength, and elongation) and compatible impact Requirements—usually 20 ft. lbs. at -20°F. Combinations in Table 4 show SMAW or FCAW repair electrodes welded over SMAW or FCAW electrodes in the existing weld.

TABLE 4 LATER DAMAGE REPAIR WELD COMBINATIONS

EXISTING WELD ELECTRODES	REPAIR WELD ELECTRODES
AWS CLASSIFICATION	**AWS CLASSIFICATION**
Impact requirements = 20 ft. lbs at -20°F, unless noted.	Impact requirements = 20 ft. lbs. at -20°F.
SMAW Electrodes	**SMAW Electrodes**
E7015	E7015
E7016	E7016
E7018	E7018
E7028	
FCAW Electrodes	**FCAW Electrodes**
E70T-4 (No Impact)	E71T-8
E70T-7 (No Impact)	E70TG -K2
E71T-8	
E70TG-K2	

Notes: 1. Erectors could have welded any repair electrode over any existing weld electrode.

New Welds. Criteria developed by the Advisory Task Groups and new joint designs developed by engineers have increased the use of mixed weld combinations. The following situations may require mixed weld metal:

1. Back-up bar removal with subsequent fill-in and build-up.
2. Beam flange weld to column flange with a shop welded cover plate acting as a back-up bar.
3. Beam web weld to column flange with a shop welded shear plate acting as a back-up bar.
4. Column splice weld over box column shop weld.

Test Program Combinations. The James F. Lincoln Arc Welding Foundation is conducting tests on compatibility of various electrode combinations. See the Foundation's publication "*Fabricators' and Erectors' Guide to Welded Steel Construction*" for a discussion of mixing weld metal and for test results. [19] Table 5.3 in the Guide gives intermixing recommendations. Most combinations listed in the Table meet the Advisory Task Groups' impact requirements, although some individual electrodes have no specified impact requirements.

Currently Used Combinations. The authors have helped develop or have learned of various combinations of mixed weld metal. Table 5 shows some currently used combinations of FCAW electrodes welded over SMAW electrodes or other FCAW electrodes.

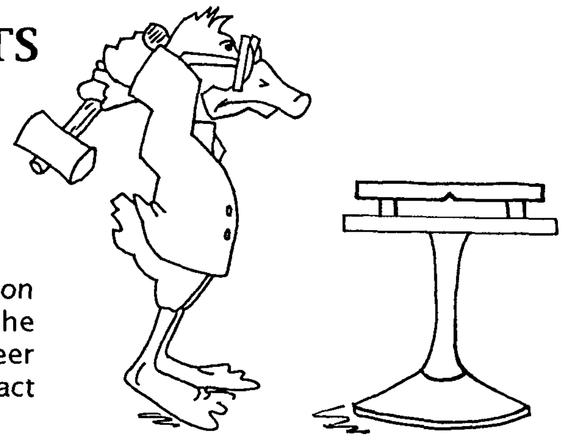
TABLE 5 NEW WELD COMBINATIONS

ROOT PASS OR BASE WELD ELECTRODES	FILL-IN PASS ELECTRODES	APPLICATIONS OF WELD COMBINATIONS
AWS CLASSIFICATION		
E7018	E71T-8	Beam flange to column flange
E70T-6	E71T-8	Make column splice smooth
E70T-6	E71T-8	Overlay from back-up bar removal
E70T-7 (No impact)	E71T-8	Make column splice smooth
E70T-1	E71T-8	Column splice weld over shop weld on box column
E70T-1	E71T-8	Beam flange to column flange weld over shop weld on cover plate
E70T-1	E71T-8	Beam web to column flange weld over shop weld on shear plate
E70T-1	E70T-6	Column splice weld over shop weld on box column
E70T-1	E70T-6	Beam flange to column flange weld over shop weld on cover plate
E70T-1	E70TG-K2	Column splice weld over shop weld on box column
E70TG-K2	E70T-6	Beam bottom flange to column flange
E70TG-K2	E71T-8	Beam bottom flange to column flange
E70T-1	E70TG-K2 over E71T8-Ni1	Test, Joint B-U4a-GF
E71T-8	E70T-6	Test, Joint B-U2a-F

Notes:

1. The fill-in pass electrodes are welded over root pass electrodes or base weld electrodes.
2. Each row shows a specific weld combination.
3. Electrode impact requirements vary from 20 ft. lbs. to 45 ft. lbs. at -20°F, unless noted.
4. New weld repairs also use the combinations shown in Table 5.
5. Fabricating shops use the E70T-1 classification (FCAW-g) electrode.
6. The Engineer may require approval of any mixed weld metal combination.

7. COMMENTARY ON IMPACT REQUIREMENTS AND IMPACT TESTING



This Article gives the authors' personal views on impact requirements and impact testing. The text in this Article 7 assumes the Engineer specifies impact requirements and impact testing requirements.

IMPACT REQUIREMENTS

Welding Electrodes. AWS Specifications AWS A5.1, A5.5, A5.20, and A5.29 give impact requirements for commonly used welding electrodes. See "General Criteria" in Article 6, "Mixed Weld Combinations," for complete Specification titles. Approximately 60 to 75 percent of the specified electrodes have impact requirements of 20 ft. lbs. at -20°F. So specifying SMAW and FCAW welding electrodes with proper impact requirements is not a problem. We recommend the Engineer specify the electrode impact requirements in the project Specifications, just like the Engineer specifies the grade of steel for the project.

Base Metal. Most structural steels in the AISC Specifications have no impact requirements. An exception is ASTM A6 Steel Groups 4 and 5 hot-rolled shapes and welded sections made of plate with a minimum thickness of 2 in. These shapes and sections need impact requirements of 20 ft. lbs. at 70°F, under certain tension stresses and with complete joint penetration welded splices (See Article 3, "AISC Requirements"). These are not strict impact requirements, especially when most SMAW and FCAW electrodes have impact properties of 20 ft lbs at -20°F.

AWS *Welding Handbook*, Figure 12.18 on page 400, "Typical Transition Curve for Mild Steel Plate," shows absorbed energy values. [14] For temperate zones, especially if the structural steel frame is enclosed, mild steel and low alloy high strength steels have absorbed energy values of 20 ft. lbs. to 40 ft. lbs. at 25°F to 75°F.

However, for very low temperature zones, (e.g., the North Slope in Alaska, Parts of Canada, and the Rocky Mountains), the Handbook recommends the Engineer specify a minimum impact requirement. We will always be indebted to the Charpy V-Notch impact test for pointing out in World War II how cold water temperatures caused brittle fracture on ships. Recent discoveries and a review of eyewitness accounts now confirm the passenger ship TITANIC experienced brittle fracture failure when colliding with the iceberg and when sinking.

IMPACT TESTING

Charpy V-Notch Test. The Steel Industry extensively uses the Charpy V-Notch

Impact Test on its steel products—including weld metal. Test specimens are small bars—machined, ground, and notched, usually 10mm x 10mm x 55mm in length (0.394 in. x 0.394 in. x 2.165 in.). A specially designed testing machine supports the specimens in the horizontal position. A pendulum force strikes and breaks the specimen with a single blow, with the pendulum force striking on the side opposite the notch. The testing machine measures and records the energy absorbed in breaking the test specimen.

Other Standard Methods. Besides Charpy V-Notch testing, ASTM A370-92 *Standard Test Methods and Definitions for Mechanical Testing of Steel Products* and ASTM E23-88 *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials* address the following other methods of impact testing:

- The Izod V-Notch Test (broken in vertical cantilever action).
- The Drop Weight Test—developed by the U.S. Navy National Research Laboratory.
- The Crack Tip Opening Displacement Test (CTOD). [20,21]

AWS Requirements. Annex III of the AWS Code sets forth the following impact testing requirements:

- ***Three Specimens.*** Table III-1 calls for a set of three test specimens for each test location. The Engineer has the responsibility to specify the following items on the contract drawings or specifications:
    - Test temperature.
    - Minimum average energy value per set of three (location).
    - Minimum energy value per specimen from any set.
- ***Five Specimens.*** An optional test—probably used in 75 to 80 percent of tests—allows a set of five test specimens for each location with the highest and lowest values discarded. The result is the average value for the three middle specimens. Discarding the highest and lowest values minimizes the variations (scatter) normally associated with Charpy V-Notch test results of welds and Heat Affected Zone (HAZ). See Table III-1, Note No. 2.
- ***Specimen Location.*** Figure III-1 notes the locations of the test specimens from the weld centerline, the Heat Affected Zone, and the weld face.

Scatter. Charpy V-Notch test results have large variations (great scatter) because of many potential differences in testing procedures This scatter of test results sets up a difficult situation to make a judgment when only a single specimen is tested at each location. Unfortunately the evidence—or lack of evidence—indicates the single test is generally the procedure followed. Differences in testing procedures contributing to scatter include:

- Material strength and thickness.
- Heat input of the weld specimen.
- Rolling direction of grain orientation.
- Variations in testing procedures.
- Small specimens.

- Locations of tests.
- Personnel making the tests.

ASTM Codes. ASTM A370-92 and ASTM E23-88 give impact requirement testing procedures for the various impact testing methods. The Codes also alert the Engineer to be careful in comparing the results of impact tests, including steel test specimens machined from the same heat number lot. See:

- Annex A5, "Notes on Significance of Notch-Bar Impact Testing" in ASTM A370-96.
- Appendix XI, "Notes on Significance of Notched-Bar Impact Testing" in ASTM E23-88. (Applies to all steel products.)

Notes Relating to the ASTM Codes.

1. The Charpy V-Notch (CVN) impact test is especially appropriate for minimum operating temperatures and maximum in service rates of loading.

2. The notch behavior of face-centered cubic metals does show a broad relationship of tensile test results. In contrast, body-centered cubic ferrite steel test results show very little relationship between tensile test and CVN impact test results.

   The property that keeps a notched-bar from cleaving (holds together under load), is its "cohesive strength." The bar fractures when the normal stress exceeds the cohesive strength. Fracture without the bar deforming is the condition for brittle fracture.

   Usually plastic deformation precedes failure. Besides the normal stress, the applied load also sets up shear stresses that are about 45 degrees to the normal stress. Elastic behavior ends when the shear stress exceeds the shear strength of the material and when deformation or plastic yielding sets in. Fracture with the bar deforming is the condition for ductile failure.

3. Size effect of the test specimens is another source of differences that cause variations in test results. The larger the specimen, the higher value the test results; however, an increase in width will also increase the restraint of the notch action tending to reduce the absorbed energy

4. The temperature effect has great influence on the notched specimen behavior. Steel temperature at the time of the test must be known, and the absorbed energy test results must be recorded and compared to requirements— _ ft. lbs. at _°F. Temperature influence is especially true for body centered cubic ferrite steels.

5. The testing machine also contributes to variations in test result values through items like:

   - Machine rigidity.
   - Support anvil detail.

- Pendulum striking of the specimen (not squarely).
- Details of the machine anchor bolts.

6. While Charpy or Izod tests may not directly predict the ductile or brittle behavior of the steel specimens or of large masses (large structures), the test results can serve as acceptance criteria.

7. The Engineer must recognize that the project Specifications in the Bid Documents should specify:

   - The dimensional detail of the specimens.
   - Base metal material.
   - Weld deposit material.
   - The testing procedure.

8. The Engineer must know a structure's operating conditions, and set the test results the Engineer is trying to achieve The engineer should also be thoroughly familiar with typical absorbed energy transition curves (ft. lbs. at °F) for the types of steel to be use on the project.

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18. AWS A5.29 *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*, AWS, Miami, 1995.
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