

# The Effects of Intermixed Weld Metal on Mechanical Properties — Part I

## *Dilution from FCAW-S weld metals influences SMAW mechanical properties*

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**ABSTRACT.** It is common for individual weld joints to be fabricated using a combination of electrode types and welding processes. While this situation arises most often as a result of repair welding, it also can arise due to scheduled fabrication sequencing, which requires a change from one electrode and/or process to another within the same weld joint. When weld metals deriving their properties from different metallurgical mechanisms are intermixed in the same joint, the resulting properties of the combination have caused some concern. This work is the first in a series that examines the intermixing of conventional carbon-manganese weld metals with various self-shielded flux cored arc weld metals. In this case, two different shielded metal arc weld metals are combined with various self-shielded flux cored arc weld metals. The effects of dilution from the underlying self-shielded flux cored root layers on the mechanical properties of shielded metal arc weld metal are examined. Variations in both tensile and Charpy V-notch impact properties have been documented. The effect on tensile results is limited to relatively minor changes in ductility. Reductions in Charpy V-notch impact energies were noted in all cases. The results are evaluated in terms of the chemical composition gradients and weld microstructure variations that result from dilution. Possible mechanisms are discussed.

### Introduction

Welding is an integral part of most modern construction and manufacturing operations. On any given project, welding operations frequently involve a range of welding consumables and processes. It is often necessary to repair flaws that form as a result of service or defects created dur-

ing manufacture. Repair welds are often made with welding consumables and processes different from those used in the original joint construction. For example, shielded metal arc welding (SMAW) repairs in submerged arc welding (SAW) deposits, gas metal arc welding (GMAW) deposits, gas-shielded flux cored arc welding (FCAW-G) deposits or self-shielded flux cored arc welding (FCAW-S) deposits are common. For many applications, the use of different welding consumables and processes in a single weld joint is planned in the normal fabrication sequence. Often, it is not practical or cost-effective to fabricate a welded joint using a single consumable and process. For example, many line pipe welds are produced using SMAW for the root pass and FCAW-S for the fill passes. Fabrication of large components or structures often involves shop welding using GMAW and FCAW-G, followed by FCAW-S or SMAW in the field. The process of fitting and tack welding is often accomplished using SMAW, with the remainder of the structure welded using processes that achieve higher deposition rates.

These are examples of applications in which intermixing of different weld metals can occur in a single weld joint. These examples indicate that, while not occurring in every case, intermixing does occur rather frequently as a normal part of the fabrication process. By contrast, most welding consumables are opti-

mized without considering dilution effects from either the underlying base metal or a weld metal of different chemical composition. Welding consumable specifications standardize on the type of base material to be used for certification and conformance testing. Accordingly, electrodes are designed to produce weld metal mechanical properties through optimization of the alloy design and the use of slag/metal reactions to create the proper composition and microstructure. Depending on the anticipated service requirements and the operating characteristics desired, the alloy levels and slag systems are optimized in different ways. The introduction of elements through dilution/intermixing at levels not originally intended can alter the weld metal properties and resulting weld performance. For example, when welding high carbon or microalloyed base metal, high concentrations of carbon or microalloying elements in the weld metal can occur through dilution. Similar dilution effects occur when one welding consumable is deposited over another of significantly different composition. Further dilution may also result in a loss of alloy elements in the weld, if the base material or underlying weld metal possesses a "leaner" composition than the welding consumable used to fabricate the balance of the weld joint. In either case, a shift in chemical composition away from optimum can occur.

The effect of such unexpected variations in chemical composition can be undesirable changes in the mechanical properties of the weld metal. While a great deal of study has been devoted to dilution effects from base metals, only limited study has been conducted on the effects of intermixing weld metals deposited by different processes/electrode types. Most arc welding processes rely on a protective slag and/or a shielding gas to protect the weld metal from the atmosphere during welding. In this respect, the FCAW-S process is unique. FCAW-S consumables produce very little shielding gas and rely on the addition of large

### KEY WORDS

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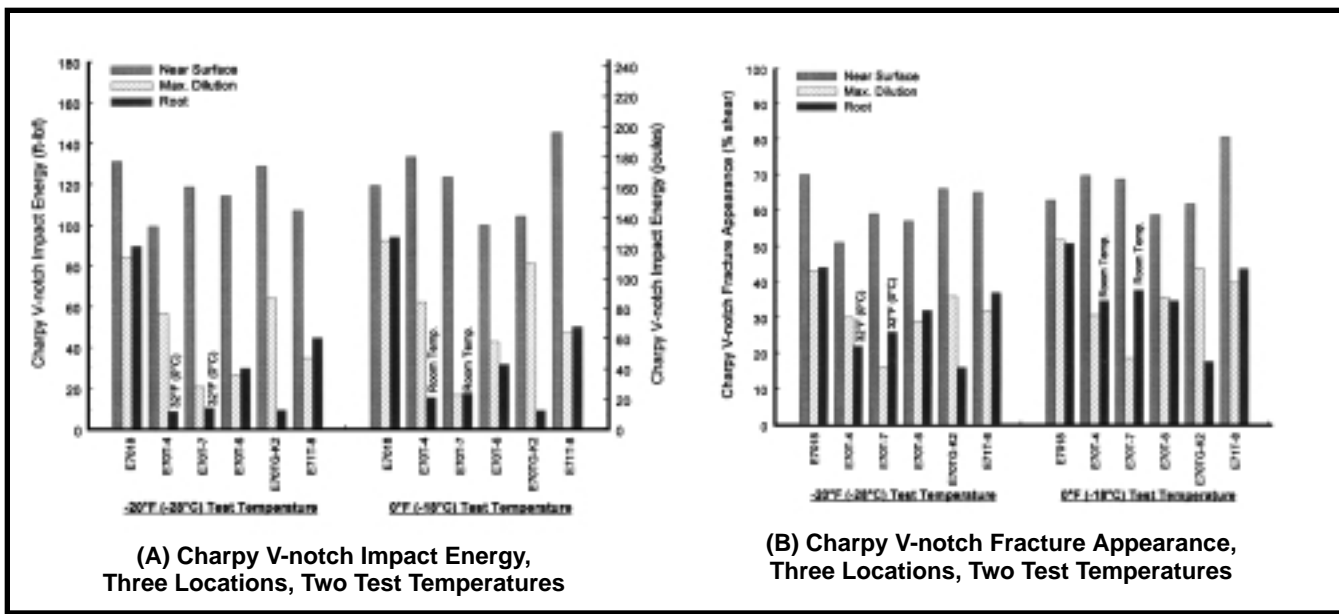


Fig. 4 — Charpy impact toughness, E7018 over various FCAW-S.

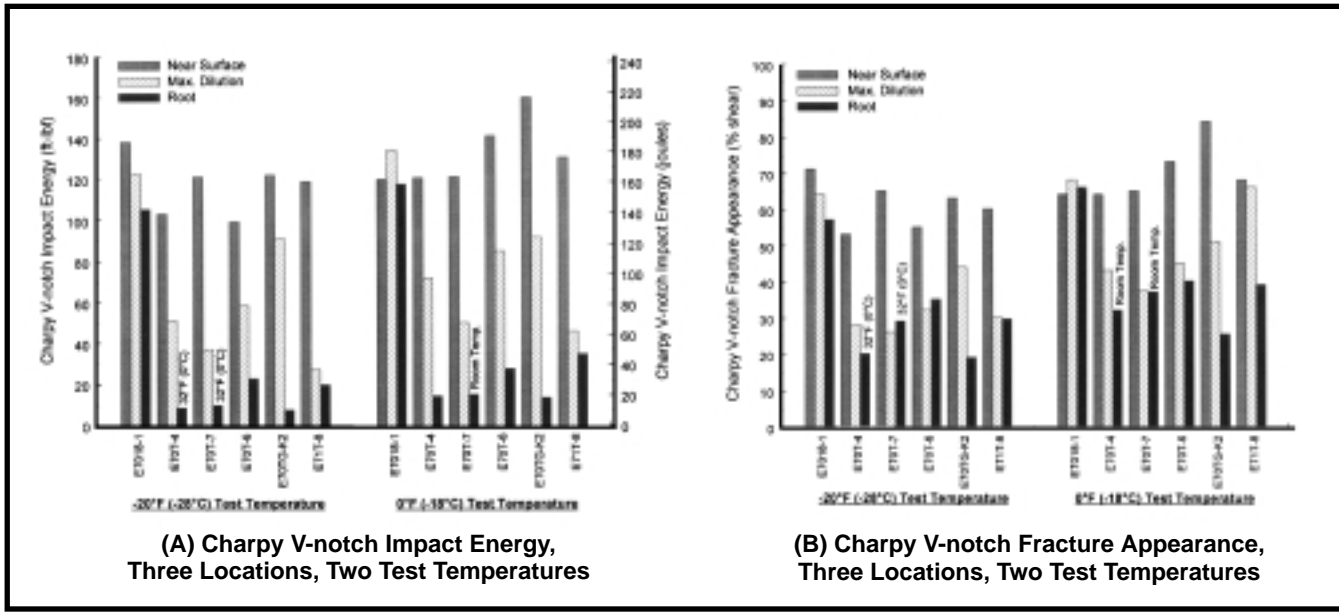


Fig. 5 — Charpy impact toughness, E7018-1 over various FCAW-S.

FCAW-S root passes. The specimen locations were recorded to facilitate removal of comparable specimens from the E7018 and E7018-1 baseline welds. Five CVN impact tests were conducted at each of two temperatures, -18°C and -29°C (0°F and -20°F) for all combinations at the near surface and maximum dilution locations. Most root specimens were tested at these same test temperatures. The exception is for the E70T-4 root, which was tested at room temperature and 0°C (32°F).

Chemical analysis was conducted at both the near surface and maximum dilu-

tion locations in a transverse macrosection that was removed from each groove weld. Bulk chemical composition of the experimental weld metals was determined using a BAIRD Model DV 4 emission spectrometer and LECO analysis equipment. Samples for carbon, sulfur and aluminum analyses were taken by collecting chips after drilling at the same locations. Total aluminum content was determined by atomic absorption spectroscopy following dissolution in Aqua Regia/hydrogen fluoride and fuming in perchloric acid.

To develop a more detailed understanding of the specific effects of inter-

mixing weld metals, additional tests were conducted for both E7018 and E7018-1 welded over E70T-4 and E70T-6. Full transition CVN curves for the maximum dilution location were developed to assess changes in transition temperature and upper shelf energies. Comparison was made with CVN transition curves developed for the E7018 and E7018-1 baseline welds. Selected fracture surfaces representing lower shelf, transition region and upper shelf were examined for any changes in the nature of fracture that might be attributed to dilution effects.

Due to dilution with the FCAW-S root













ble weld metal deposited over E70T-4 or undiluted weld metal. However, examination of the CVN fracture surfaces did not reveal inclusions or second-phase particles at cleavage initiation sites just ahead of the notches. This would suggest that the lower toughness in the intermixed regions was not due to increased fractions of AlN or deoxidization products.

Examination of the primary SMA weld metals in the region of maximum dilution was difficult because of the small bead size and extensive reheating that occurred during weld deposition. As a result, the bead-on-plate welds were used to characterize the primary weld metal microstructures. The microstructural changes induced in the E7018 bead-on-plate weld metals as a result of intermixing are shown in Fig. 16. The relative proportions of the various microconstituents in the E7018 welds were quantified according to the IIW classification scheme, as shown graphically in Fig. 17. Comparison of the undiluted weld metal microstructures (Fig. 16A) with those deposited over the FCAW-S base shows that dilution from the FCAW-S promoted microstructural refinement in both SMA weld metals. Acicular ferrite increased at the expense of both grain boundary ferrite and aligned ferrite. The increased acicular ferrite was particularly apparent in the E7018 weld metal, which had only 20–30 vol-% acicular ferrite in the undiluted condition. In addition to microstructural quantification, prior austenite grain size was measured in the diluted weld metals. Both the SMA weld metals deposited over the E70T-4 had finer prior austenite grain sizes than those that were deposited over the E70T-6.

As with the trends in retransformed weld metal microstructures in the regions of maximum dilution, the refinement of the primary weld metals and increase in acicular ferrite suggests that toughness of this region should improve relative to undiluted weld metal. Comparison of the E7018 and E7018-1 weld metals shows that less grain boundary ferrite, less aligned ferrite and more acicular ferrite are associated with the E7018-1 than the E7018. Consequently, the E7018-1 weld metals are expected to exhibit higher toughness based on as-welded microstructure alone. The CVN results presented here are not consistent with this expectation because the notched samples contained retransformed weld metal almost exclusively.

The microstructural trends observed in the retransformed weld metals and the primary bead-on-plate weld metals were consistent with those reported by other re-

searchers. Several other researchers have reported improvements in the primary weld metal microstructures and refinement of the retransformed weld metal microstructures with carbon increases up to 0.12 wt-% in SMA welds. (Refs. 19–21). Evans (Ref. 19) reported only a minor influence of carbon on toughness of weld metals containing an intermediate range of manganese concentrations. When manganese concentrations were optimal, there was little effect of carbon on microstructure or toughness, provided that carbon concentration remained less than 0.12 wt-%. Increasing carbon concentration at higher manganese concentrations (1.8 wt-%) resulted in an increased grain boundary carbide thickness and slightly lower toughness. Similarly, Svensson and Grøtoft (Ref. 20) concluded that increased carbon concentrations at higher manganese concentrations (~2.2 wt-% Mn) promoted the formation of segregated microphases that, along with slightly higher nitrogen concentrations, were believed to decrease weld metal toughness. Further, several researchers (Refs. 20, 21) report that austenite grain size decreased with increased carbon concentration. In the present experiment, similar trends were observed in the intermixed weld metals deposited over the higher carbon FCAW-S root electrodes. Given the fact that there was very little difference in the volume fraction of cementite film and M-A constituent among the various multipass welds, and that microstructure improved in the bead-on-plate welds when diluted with self-shielded flux cored arc weld metal, it is most likely that transfer of carbon from the various root weld metals to the SMA fill passes played only a minor role in controlling the toughness measured in the intermixed weld metals.

## Summary and Conclusions

1) There was no measurable effect of dilution from the FCAW-S root layers on ultimate tensile strength, yield point or yield strength of the E7018 and E7018-1 weld metals. There was a relatively small reduction in tensile ductility, as measured by reduction in area for the E7018 deposits only.

2) Reduction of toughness relative to typical E7018 and E7018-1 performance was measured in both the maximum dilution and root location Charpy V-notch tests for all combinations. This study suggests that the toughness measured in the maximum dilution and root weld metals was controlled by fracture initiation in the lowest toughness region.

3) While a significant reduction in

CVN impact toughness was measured as a result of dilution from FCAW-S root passes, both E7018 and E7018-1 electrodes are expected to produce impact energies exceeding 27 J (20 ft-lb) at temperatures as low as  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ) when intermixed with FCAW-S.

4) The major microstructural and compositional changes occurring as a result of using E7018 and E7018-1 electrodes to weld over E70T-4 and E70T-6 self-shielded flux cored arc weld metals were limited only to a small region of weld metal, typically the first layer deposited. Toughness of the near surface weld metals was essentially identical to that found in undiluted weld metals, although there was evidence of grain refinement in the E7018 weld metal deposited over E70T-4 and E70T-6 roots.

5) Microstructural examination of these intermixed weld metals did not provide any clear indication of possible mechanisms causing the reduced toughness. While a slight increase in second-phase carbide content (grain boundary carbide films, M-A constituent and pearlite) was measured in the intermixed weld metals relative to the undiluted weld metal, the second-phase volume was not extensive enough to cause the observed decrease in toughness.

6) Refinement of the reheated weld metal and increased fractions of acicular ferrite in primary weld metal were documented in the weld metals diluted with E70T-4 and E70T-6. Considering that the fracture stress and yield stress both increase with decreasing grain size, increased toughness was expected. It is apparent that the toughness increase normally experienced with grain refinement was offset in the intermixed weld metals by some other factor.

7) It is proposed that the observed toughness decrease with dilution may result from the presence of excess free aluminum and/or free nitrogen, which these SMAW deposits are not designed to accommodate. Speculations regarding the influence of free aluminum and/or free nitrogen on fracture stress require additional research for resolution.

8) The conclusions and observations presented here should be considered to be product specific. There are numerous electrodes classified under any single classification that do not result in the same weld metal compositions employed in this study. Consequently, other E7018 and E7018-1 electrodes may not exhibit the same response to intermixing with the FCAW-S presented here. The specific nature of various FCAW-S electrodes within a given classification can also be expected to produce different results in the E7018 and E7018-1 deposits.

