FERRITE IN LEAN AUSTENITIC TYPE 16.8.2
STAINLESS STEEL WELD METAL

BY

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1. INTRODUCTION

This technical note was prompted by a recent observation that heat treatment had an unexpected effect on the microstructure of 16.8.2 weld metal. It also provides an opportunity to outline briefly some of this alloy's characteristics and virtues, which to a surprising extent appear to be overlooked or neglected. No reference to 16.8.2 appears in Folkard's standard text on welding metallurgy [1], and yet this weld metal displays an unusual combination of properties, including excellent high temperature microstructural stability, resistance to hot cracking at the lowest FN, and good cryogenic toughness.

Table 1: Welding consumable specifications

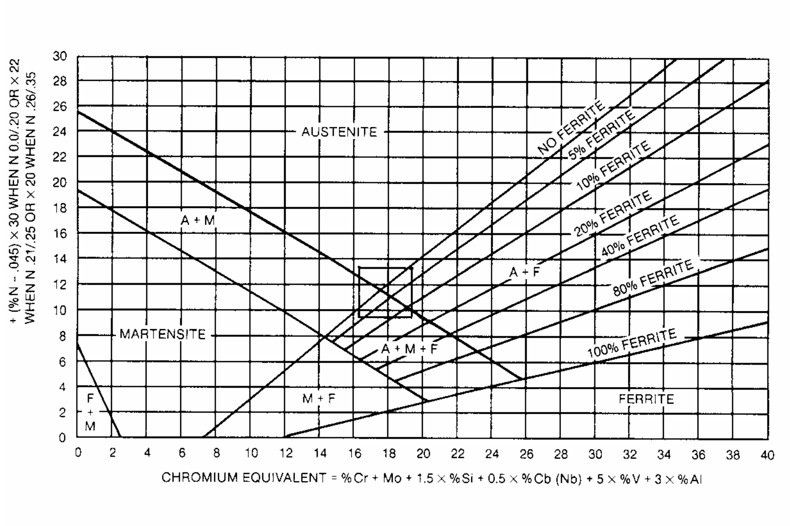
	MMA EN 1600	Wire EN12072	MMA AWS A5.4	Wire AWS A5.9	MMA 17.8.2 BS 2926
C	< 0.08	< 0.10	< 0.10	< 0.10	0.06 – 0.10
Mn	< 2.5	1.0 – 2.5	0.5 – 2.5	1.0 – 2.0	0.5 – 2.5
Si	< 1.0	< 1.0	< 0.60	0.30 – 0.65	< 0.8
S	< 0.025	< 0.02	< 0.03	< 0.03	< 0.030
P	< 0.030	< 0.03	< 0.03	< 0.03	< 0.040
Cr	14.5 – 16.5	14.5 – 16.5	14.5 – 16.5	14.5 – 16.5	16.5 – 18.5
Ni	7.5 – 9.5	7.5 – 9.5	7.5 – 9.5	7.5 – 9.5	8.0 – 9.5
Mo	1.5 – 2.5	1.0 – 2.5	1.0 – 2.0	1.0 – 2.0	1.5 – 2.5
Cu	–	–	< 0.75	< 0.75	–

Table 1 gives AWS and recently introduced EN specification limits for SMAW weld metal and the wire composition for GTAW/GMAW/SAW processes. These are almost equivalent except for an inexplicably higher minimum Mo in EN1600. For historical completeness, the specification limits are also included for the related type 17.8.2 in BS 2926, although its alloy level is higher than 16.8.2.

2. MICROSTRUCTURE

The first published reference to 16.8.2 in 1956 describes the development by The Babcock and Wilcox Company of an electrode depositing weld metal with about 0.07C-15.6Cr-8.2Ni-1.5Mo[2]. On the Schaeffler diagram this composition was shown to be centred around the austenite 'nose' at the confluence of the A+M and A+F boundaries. This area is shown on the Espy modified diagram, Figure 1, assuming 0.04-0.1%C and constant values of 0.5%Si-1.5%Mn-0.05%N. In addition to austenite, with perhaps up to 10% ferrite, a significant region is predicted to show martensite in the as-deposited weld metal.

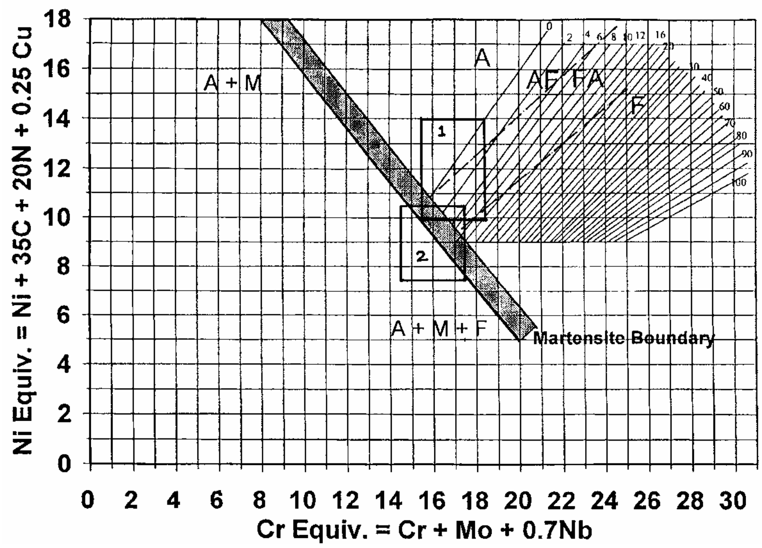
Figure 1: Espy diagram showing location of 16.8.2 with partially constrained composition limits (see text)



However, the appendices to AWS A5.4 and A5.9 state that 16.8.2 weld metal will typically show below 5FN. There seems to be no evidence that commercial weld metals contain martensite, although it is recognised that lean austenite compositions will be susceptible to strain-induced martensite. Recently, these leaner compositions have been studied thoroughly by Kotecki [3] , using plain Cr-Ni alloys. Kotecki's work explains the observed microstructure of 16.8.2 and corrects the misleading predictions of previous constitution diagrams.

Figure 2 places the Figure 1 composition area for 16.8.2 (box 1) on the modified WRC diagram with Kotecki's martensite boundary zone. The lower boundary to this zone, corresponding closely to the appearance of as-deposited martensite, is touched by the leanest corner of 16.8.2, beyond which all 2T bend tests fail. Within the zone, bend test failures may occur owing to strain-induced martensite.

Figure 2: WRC diagram showing location of 16.8.2 weld metal (box 1) and the same with carbon and chromium removed from the matrix as $M_{23}C_6$ (box 2)



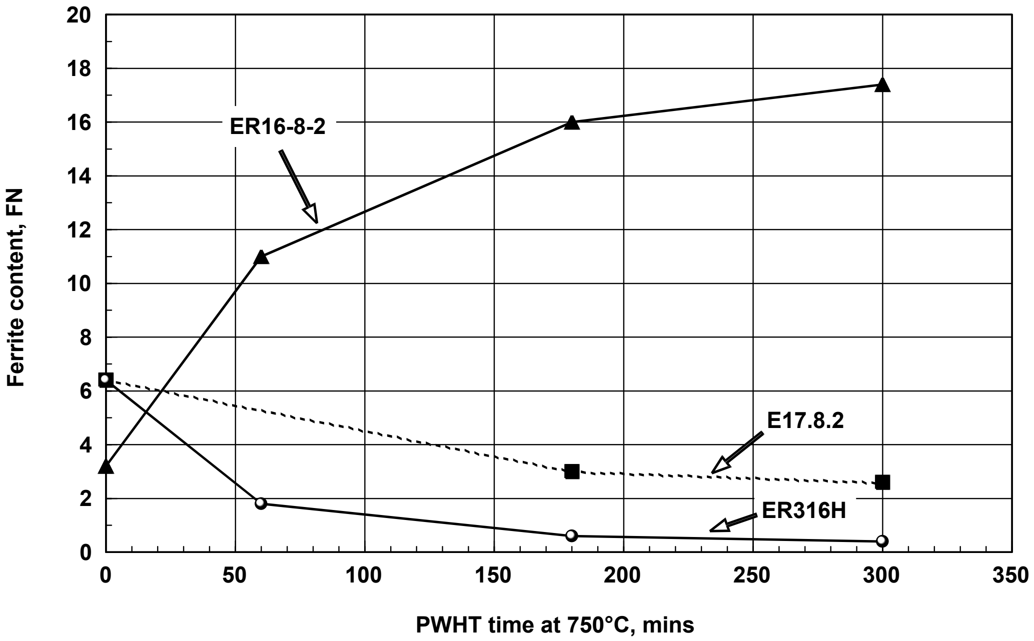
Weld metals of 16.8.2 type were not included in the WRC ferrite database and consequently the current WRC-1992 diagram cuts off at 17Cr eq. Fortunately, extension of the WRC iso-ferrite lines provides very satisfactory agreement between prediction and measurement. The ferrite lines are extended to Kotecki's martensite boundary in Figure 2.

2.1 Effect of heat treatment

The lean composition and low ferrite typically found in 16.8.2 weld metal provides excellent microstructural stability and ductility retention for service at elevated temperature[4], or for stress relief PWHT. In a recent case, ferrite stability was assessed for TIG ER16.8.2, ER316H and SMAW E17.8.2 weld metal pads by exposure at 750°C for up to 5h. Decline of initial ferrite under these conditions is at least partly associated with transformation to (non-magnetic) intermetallics such as sigma or chi-phase.

The results of these tests are shown in Figure 3. As expected, ferrite in ER316H declined significantly and quite rapidly, followed by the leaner E17.8.2 with a smaller shift. In contrast, the magnetic response FN (Magnegage) for ER16.8.2 progressively increased with exposure time at 750°C, reaching a plateau of around 17FN after 5h at temperature.

Figure 3: Effect of PWHT at 750°C on weld metal ferrite (magnetic response) in GTAW ER16-8-2 compared with ER316H and SMAW 17.8.2



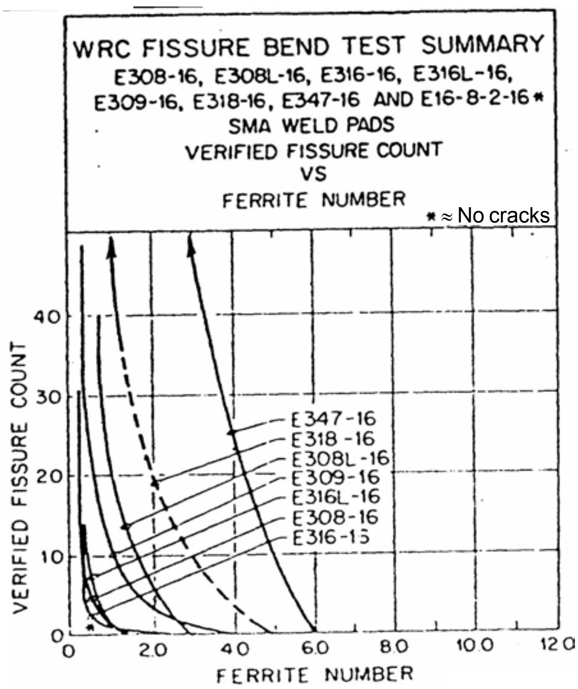
The explanation for this unexpected behaviour is that carbide precipitation during PWHT has destabilised a proportion of the prior austenite, raising its Ms temperature and leading to some martensite transformation on cool-out to ambient. This is illustrated schematically on Figure 2 where the area marked 2 is "carbon-free" 16.8.2, shifted down towards the martensitic zone and to the left as a result of $M_{23}C_6$ removing Cr from the matrix. A few subsequent experiments have shown that this behaviour is quite sensitive to relatively small differences in composition, and that further transformation can be obtained by cooling in a domestic refrigerator. Others who have worked with 16.8.2 may be familiar with the effect of PWHT or high temperature service, but no published report could be found.

2.2 Ferrite and hot cracking

The presence of ferrite, determined at room temperature, is conventionally considered to be desirable or necessary for maximum resistance to hot cracking in nominally austenitic weld metals. Type 16.8.2 is unusual in that hot cracking is not generally reported in typical commercial compositions with little or no measured ferrite.

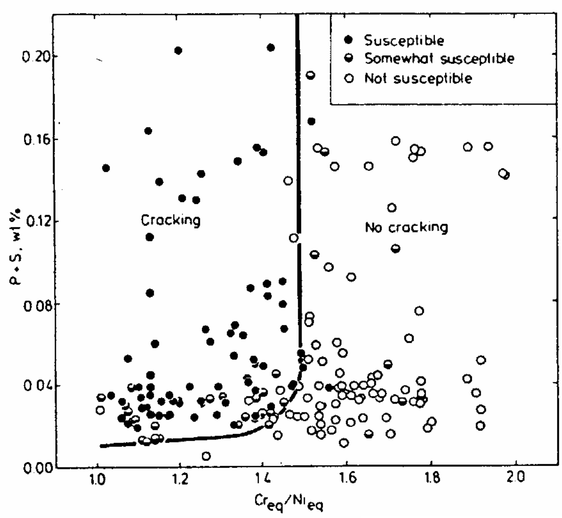
Using the fissure bend test, Lundin et al [5, 6]found trivial microfissuring in two batches of E16-8-2-16 with 0.7 and 1.2FN, and the onset and extent of hot cracking could not be plotted against FN, unlike the other standard austenitic types investigated, see Figure 4. The accepted explanation for this is evident with reference to the WRC diagram FA solidification mode boundary which intersects low FN levels in compositions with low Cr_{eq} values.

Figure 4: Comparison of the fissuring relationship for eight different austenitic stainless steel weld metals [5,6]



The hot cracking resistance of 16.8.2 may be even more robust than is apparent from the WRC diagram. The Suutala diagram[7], Figure 5, shows a dramatic improvement in resistance to hot cracking at a Cr_{eq}:Ni_{eq} ratio of about 1.5, based on coefficients derived by Hammer and Svensson[8]. The 16.8.2 compositions evaluated by Lundin et al have Cr_{eq}:Ni_{eq} ratios of 1.73 and 1.64 (assuming 0.05%N), which places them well into the 'safe' region. If these compositions were pushed to the Cr_{eq}:Ni_{eq}=1.5 limit (eg by raising Ni), the equivalent WRC Ni_{eq} values would be about 0.5Ni_{eq} above the austenite boundary. Clearly, further work to explore the hot cracking behaviour of these lean austenitics would be fruitful.

Figure 5: Suutala diagram [7]



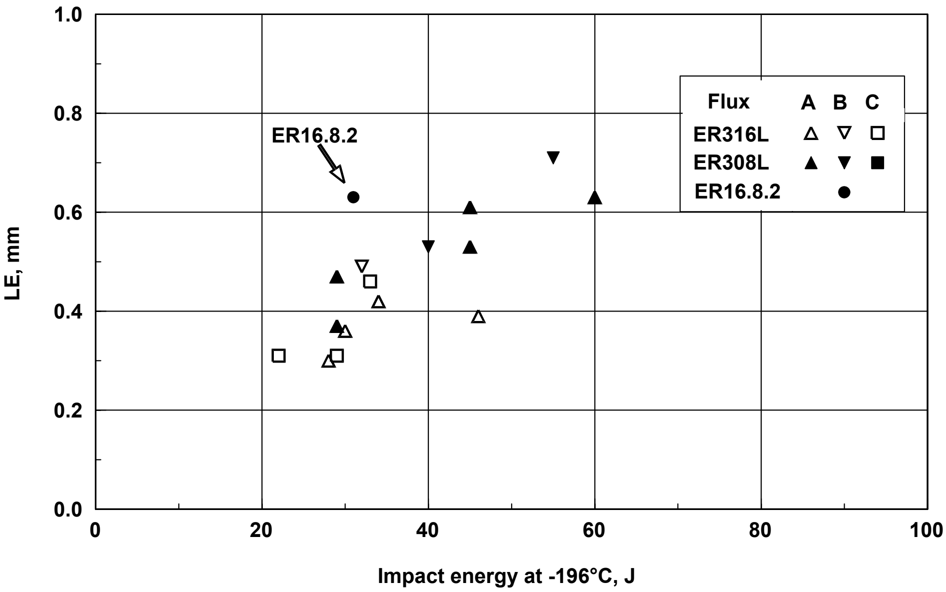
3. OTHER USEFUL PROPERTIES

3.1 Cryogenic temperatures

The cryogenic properties of austenitic SMAW weld metals in relation to ferrite content were reported in detail by Szumachowski and Reid about 20 years ago[9]. These tests were interesting in that E16-8-2 types were included, and the performance of the leaner weld metals appeared superior to many others, especially when considering the requirement to meet a minimum charpy lateral expansion of 0.38mm (15mils in customary US units). In particular, 16.8.2 types were less sensitive to the generally detrimental effect of ferrite on toughness. At the same time, all the 16.8.2 welds had 0.04-0.055%C, as for commercial products designed for high temperature applications, whereas <0.04C was found necessary in conventional austenitics containing ferrite. It is known, but not reported by these authors, that 16.8.2 charpy specimens when fractured at –196°C become quite strongly magnetic as a consequence of strain-induced (or low temperature transformed) martensite being present.

For information, the divergent impact properties at –196°C of SAW ER16.8.2 are shown – for a single batch – compared with various batches of SAW ER308L and ER316L in Figure 6. Based on analysis, the WRC-predicted ferrite was 1FN and measured 1.1FN (mid-section of weld) and 1.6FN (final bead). After PWHT at 750°C/5h, the same weld gave 26J and 0.52mm lateral expansion at –101°C, which confirms a high resistance to thermal embrittlement.

Figure 6: Relationship between impact energy and lateral expansion of ER316L, ER308L and ER16.8.2 SAW weld metals at –196°C



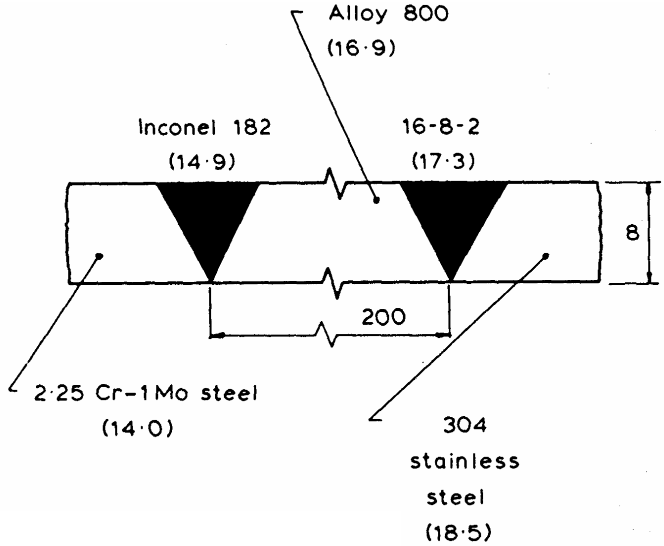
In view of the useful cryogenic properties of 16.8.2, which arise from its relative safety at low FN levels coupled with low microsegregation and embrittlement tendency, it is surprising that no reference to cryogenic applications is given in a recent review[10] or in the appendix to AWS A5.4.

3.2 Elevated temperature dissimilar welds

The customary applications of 16.8.2 are for elevated temperature service, especially for thick section 347H where the low stress-rupture ductility, hot cracking and in-service HAZ relaxation cracking susceptibility are aggravated by the use of matching weld metal [2,11,12]. It may also be specified for welding 304H, in preference to 308H weld metal [13].

Strictly, these are dissimilar metal welds (equivalent base material, ASTM 16-8-2, exists but does not seem to be encountered). However a more radical use of 16.8.2 for welding dissimilar materials has been presented [14]. Type 16.8.2 was chosen and successfully evaluated for welding 304(H) to an alloy 800 transition piece between stainless type 304(H) and P22 (2Cr-1Mo), see Figure 7. This was chosen on the basis of its intermediate coefficient of thermal expansion, although the presumed value is a little difficult to reconcile with the data presented by Elmer et al [15]. In Y-groove tests, and in spite of dilution effects, the microfissuring resistance of 16.8.2 was found to be slightly superior to 182 weld metal, although both were satisfactory.

Figure 7: Use of 16.8.2 weld metal for transition joint in protoype fast breeder reactor. Thermal expansion coefficients are shown in brackets [13]



4. ACKNOWLEDGEMENT

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