WELD OVERLAY CLADDING WITH IRON ALUMINIDES

G.M. GOODWIN

Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, Tennessee 37831-6096

ABSTRACT

The hot and cold cracking tendencies of some early iron aluminide alloy compositions limited their use to applications where good weldability was not required. Considerable progress has been made toward improving this situation. Using hot crack testing techniques developed at ORNL and a systematic study of alloy compositional effects, we have established a range of compositions within which hot cracking resistance is very good, essentially equivalent to stainless steel. Cold cracking, however, remains an issue, and extensive efforts are continuing to optimize composition and welding parameters, especially preheat and postweld heat treatment, to minimize its occurrence.

In terms of filler metal and process development, we have progressed from sheared strip through aspiration cast rod and shielded metal arc electrodes to the point where we can now produce composite wire with a steel sheath and aluminum core in coil form, which permits the use of both the gas tungsten arc and gas metal arc processes. This is a significant advancement in that the gas metal arc process lends itself well to automated welding, and is the process of choice for commercial weld overlay applications.

Using the newly developed filler metals, we have prepared clad specimens for testing in a variety of environments both in-house and outside ORNL, including laboratory and commercial organizations.

As a means of assessing the field performance of this new type of material, we have modified several non-pressure boundary boiler components, including fuel nozzles and port shrouds, by introducing areas of weld overlay in strategic locations, and have placed these components in service in operating boilers for a side-by-side comparison with conventional corrosion-resistant materials.

INTRODUCTION

Alloys based on the intermetallic compound Fe_3Al exhibit many attractive properties, particularly excellent resistance to high temperature oxidation. Their use in commercial applications has been limited, however, by the limited workability of wrought material and the susceptibility of weldments to both hot and cold cracking. Prior efforts [1-5] have systematically evaluated the effect of alloy composition on hot cracking.

By the use of the Sigmajig test [6], we have found that hot cracking can essentially be eliminated by the addition of carbon and the control of maximum levels of niobium, zirconium, and other alloying elements. Cold cracking, however, remains an issue, and recent efforts have been aimed at minimizing its occurrence, concurrent with development of welding filler metals, processes, and procedures aimed at commercial applications.

FILLER METAL DEVELOPMENT

Due to the difficulty in fabricating wrought solid wire of these compositions, the welding development efforts have utilized several alternate forms of filler metal. Early work [1-2] used strip sheared from sheet, which, although useful to investigate compositional effects, could not be considered for commercial applications. Subsequently, aspiration casting, where liquid metal is drawn into a quartz tube producing solid rod, was used as a means for evaluating a number of experimental compositions.[3-5] This technique proved successful, but can only produce rods of limited length (about 12-in. maximum) and diameter (about 1/8-in. minimum), thus restricting its use to the manual gas tungsten arc (GTA) process with relatively high heat input. It was realized from the onset that what was needed was a filler metal of small diameter, (approximately 1/16-in.) available in coil form, which could be used with both the GTA and gas metal arc (GMA) processes, permitting better control of dilution and semi-automatic welding. A novel technique for meeting these needs was found in the form of a composite filler wire, shown in cross-section in Figure 1.

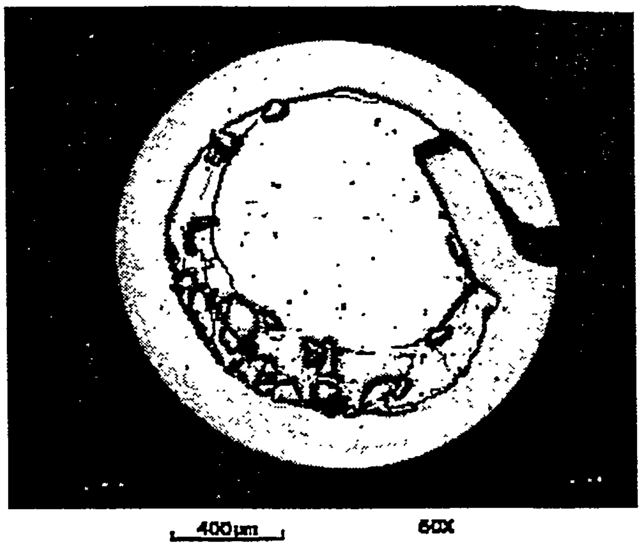

Figure 1. Composite filler wire for producing iron aluminide deposits, consisting of an iron sheath, aluminum core, and other alloying elements in granular form.

The wire consists of an iron sheath of approximately 0.009-in. thickness surrounding a core wire of commercially pure aluminum. Other alloying elements (C, Cr, Mo, Zr, B) are added as granular ferroalloys. After forming and crimping, the composite wire is drawn to eliminate void space and to arrive at precise final diameter, in this case 0.0625-in. The resulting product is readily produced in coil form and can thus be used with automatic wire feeders for a number of welding processes.

Figure 2 shows a cross-section of a multi-pass weld pad produced using the automatic GMA process on 1-in. thick 2-1/4Cr-1 Mo steel plate.

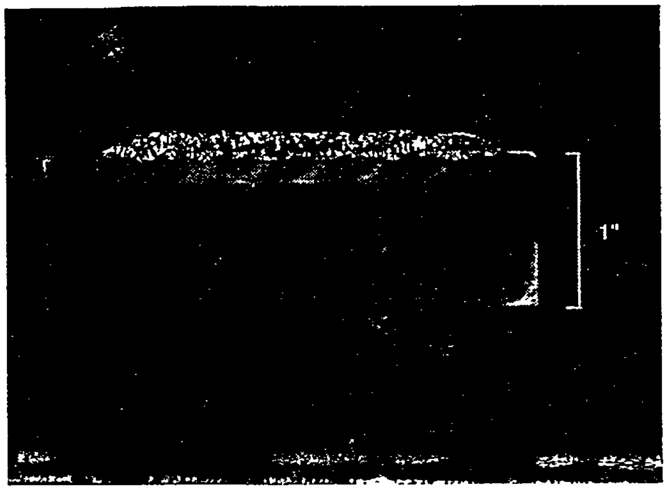

Figure 2. Multipass weld pad produced with composite filler metal using the automatic gas metal arc process on 2 1/4 Cr-1 Mo base plate.

The welding parameters used are summarized in Table 1.

Table I. Welding Parameters for Gas Metal Arc Weld Overlay Using 1/16-in. Diameter Composite Iron Aluminide Wire

Current:	245 Amperes, Reverse Polarity (DCEN)
Voltage:	27 volts
Wire Feed:	190 inches/minute
Travel:	13.1 inches/minute
Shield Gas:	Argon, 45 cubic feet/hour
Bead offset:	3/8-in.
Electrode Stickout:	3/4-in.
Preheat:	350° C
Postweld Heat Treatment:	750° C, 1 hour

The weld deposit had approximately 30% dilution and was free of cracks, voids, and porosity. Usability of the wire was found to be excellent and arc spatter was minimal. It was concluded that this form of wire could readily be used in commercial applications with the automatic GMA or GTA processes.

COMPOSITIONAL EFFECTS

As noted earlier, control of composition of the weld deposit was accomplished to essentially eliminate hot cracking in these alloys.[4] Control of cold cracking, however, has proven to be more elusive, showing a rough correlation with aluminum content[5], and a clear dependence on geometry, weld preheat, and postweld heat treatment conditions. The dependence on aluminum level is known to be complex, based on the observations of cracking in high and very low aluminum level alloys[7]. In order to clarify this relationship, we are preparing wire compositions which will bracket the range of aluminum levels which can be produced using the composite wire technique with dilution levels consistent with commercial practice. The desired chromium level in the alloy is also debatable, depending on the service conditions to be encountered, so heats of the composite wire have been produced with and without chromium. Table II summarizes the alloy compositions currently under study, and notes two additional heats which have been ordered. The latter heats represent the highest and lowest aluminum levels which can be produced with the composite wire approach, based on the thickness of the iron sheath and the diameter of the aluminum core wire.

As is noted in the table, the weld process, substrate, and dilution substantially affect the composition of the overlay clad deposit, particularly the aluminum level. Note that with an aim of 20 weight % Al for an all weld metal (undiluted) deposit, we actually achieved 21.8 weight % using the GTA process; when this same wire was used on dissimilar substrates (2 1/4 Cr-1 Mo steel and 310 stainless steel) with two weld processes, GMA and GTA, the aluminum levels were 12.6 and 15.3 weight % respectively. The higher aluminum loss with the GMA process is undoubtedly due to higher dilution and vaporization in the arc.

HEAT TREATMENT EFFECTS

It was established earlier [4,5] that weld preheat and postweld heat treatment were often effective at avoiding cold cracking during welding or upon subsequent cooling from completion of the weld. Optimization of these heat treatment conditions is important for economic and environmental considerations, as heat treatments are expensive, time consuming, and can cause hardship to the operator.

TABLE II: COMPOSITION OF EXPERIMENTAL HEATS OF IRON ALUMINIDE ALLOYS

HEAT	WEIGHT %	Al	Cr	C	Zr	Mo
Stoody I	Aim, All weld metal	20	7	0.1	0.25	0.25
	Actual, All weld metal	21.8	7.3	0.06	0.40	NA[c]
	Actual, Clad Deposit [a]	12.6	6.0	0.08	0.20	0.44
	Actual, Clad Deposit [b]	15.3	12.7	0.05	0.22	0.04
Stoody II	Aim, All weld metal	20	--	0.1	0.25	0.25
	Actual, All weld metal	21.5	--	0.08	0.25	NA
Stoody III	Aim, All weld metal	12	--	0.1	0.25	0.25
Stoody IV	Aim, All weld metal	26	--	0.1	0.25	0.25

a Single layer automatic gas metal arc on 1-in. thick type 2 1/4 Cr-1Mo steel
b Single layer manual gas tungsten arc on 1/2-in. thick type 310 stainless steel
c NA - Not Analyzed

A series of welds was produced with preheat and postweld heat treatment reduced in 50° C steps starting at 350° C and 750° C respectively. It was found that preheat temperatures as low as 250° C would sometimes yield crack free deposits, but that 350° C was required to completely avoid cracking for a standard test geometry (4x6x1-in. block of 2 1/4 Cr-1 Mo steel). Similarly, reduced postweld heat treatment temperatures would often produce sound deposits which would subsequently crack during liquid penetrant examination. It appears that 350° C and 750° C are minimum temperatures required for the standard geometry with this range of compositions.

ENVIRONMENTAL TESTING

To establish the corrosion resistance of weld overlay clads in a variety of environments, we have prepared specimens of differing geometries and substrates for testing by several organizations.

In house testing at ORNL (Peter Tortorelli) utilizes strips of overlay deposit removed from different substrates, and tested independent of the substrate. This program has evaluated numerous aluminide filler metals. For gas corrosion tests at Babcock & Wilcox (Steven Kung), we clad twenty plate specimens of Type 310 stainless steel with the Stoody I filler metal using the manual GTA process, and for molten salt characterization at Lawrence Livermore National Laboratory (Donald Stevens), we used the same filler metal to overlay rod and plate specimens of Inconel 600. Results from all the tests will help determine the optimized alloy composition.

INDUSTRIAL SERVICE TESTING

In order to demonstrate the performance of the iron aluminide compositions in a commercial environment, we have modified several non-pressure boundary components of a paper mill recovery boiler. These components will be placed in service along with others of conventional materials, and will thus give a side-by-side comparison of performance. Figure 3 shows black liquor nozzles of the splash plate type, used to fire the fuel slurry into the boiler. Each is approximately 6-in. long. Figure 3(a) is a new part made of wrought type 316 stainless steel, and Figure 3(b) shows a similar part which has been removed from service and weld repaired using the Stoody I filler metal.

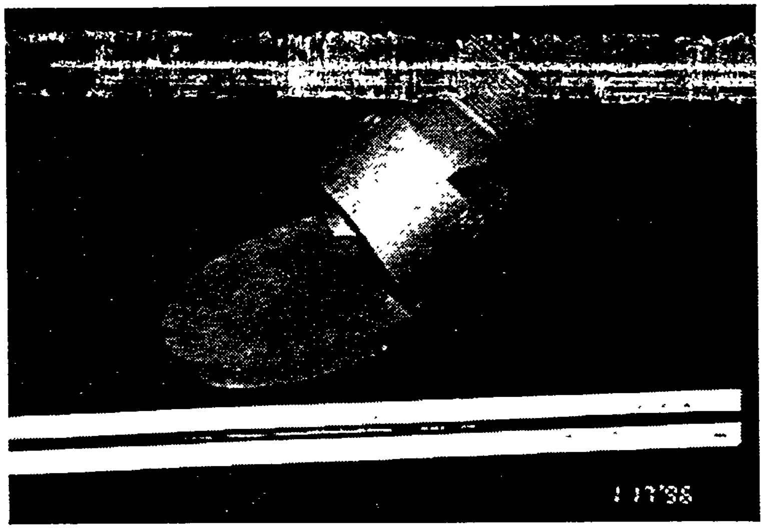

Figure 3. Splash plate type black liquor nozzles:
(a) new

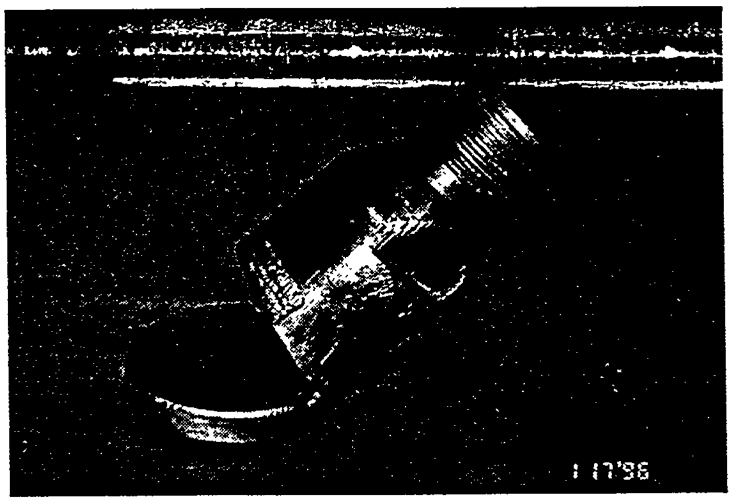

Figure 3. Splash plate type black liquor nozzles:
b) weld repaired after service by overlay cladding of splash plate (circular plate) and top of nozzle barrel. Each is approximately 6-in. long.

The splash plate (circular plate) has two layers of weld overlay which has subsequently been surface ground, and the leading edge of the nozzle barrel has a patch of overlay in a region where erosion commonly occurs.

Figure 4 shows a swirl cone type black liquor nozzle, after service, (a), and after weld overlay repair, (b). Major erosion/corrosion areas which have been clad are the outlet orifice (top), and the leading edge of the swirl cone [(b), left].

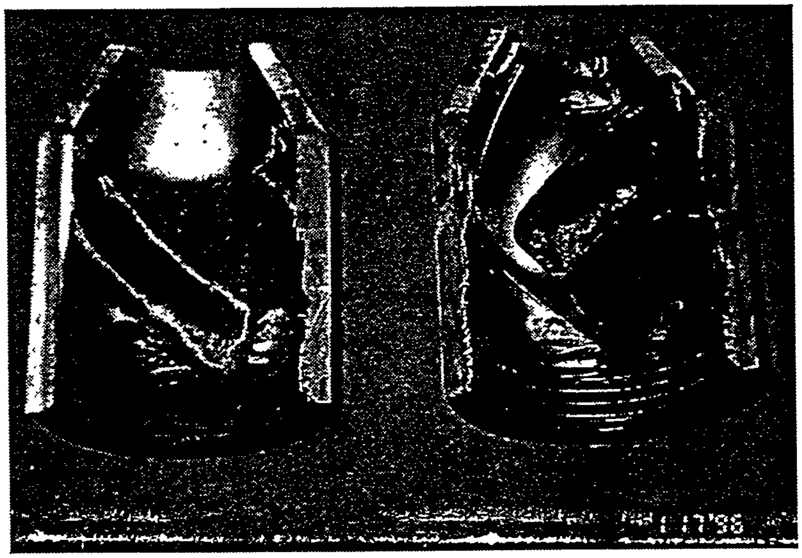

Figure 4. Swirl cone type black liquor nozzles:

(a) After service

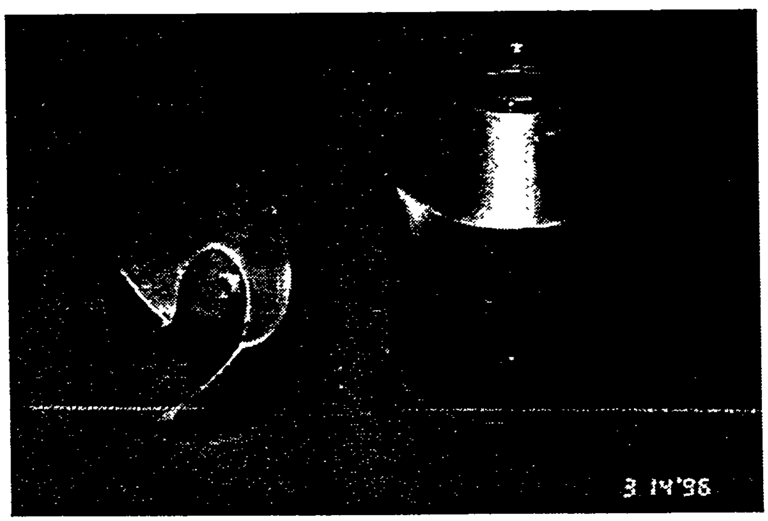

Figure 4. Swirl cone type black liquor nozzles:

(b) Weld overlay repaired at outlet orifice (right, top) and swirl cone leading edge (left, top). Approximately 4-in. long.

Figure 5 shows four sections of a liquor gun port shroud fabricated from 1/2-in. thick type 410 stainless steel plate. These plates are welded into the gun port openings in a hexagonal array (two long plates on the sides, short plates on tops and bottoms) to protect the water wall tubes, and often experience severe erosion/corrosion. The pads of aluminide overlay will give a direct comparison of their performance with that of the standard type 410 plate.

Industrial service testing is seen as an excellent way to rate these new alloys versus conventional alloys, and to guide our development toward additional commercial applications.

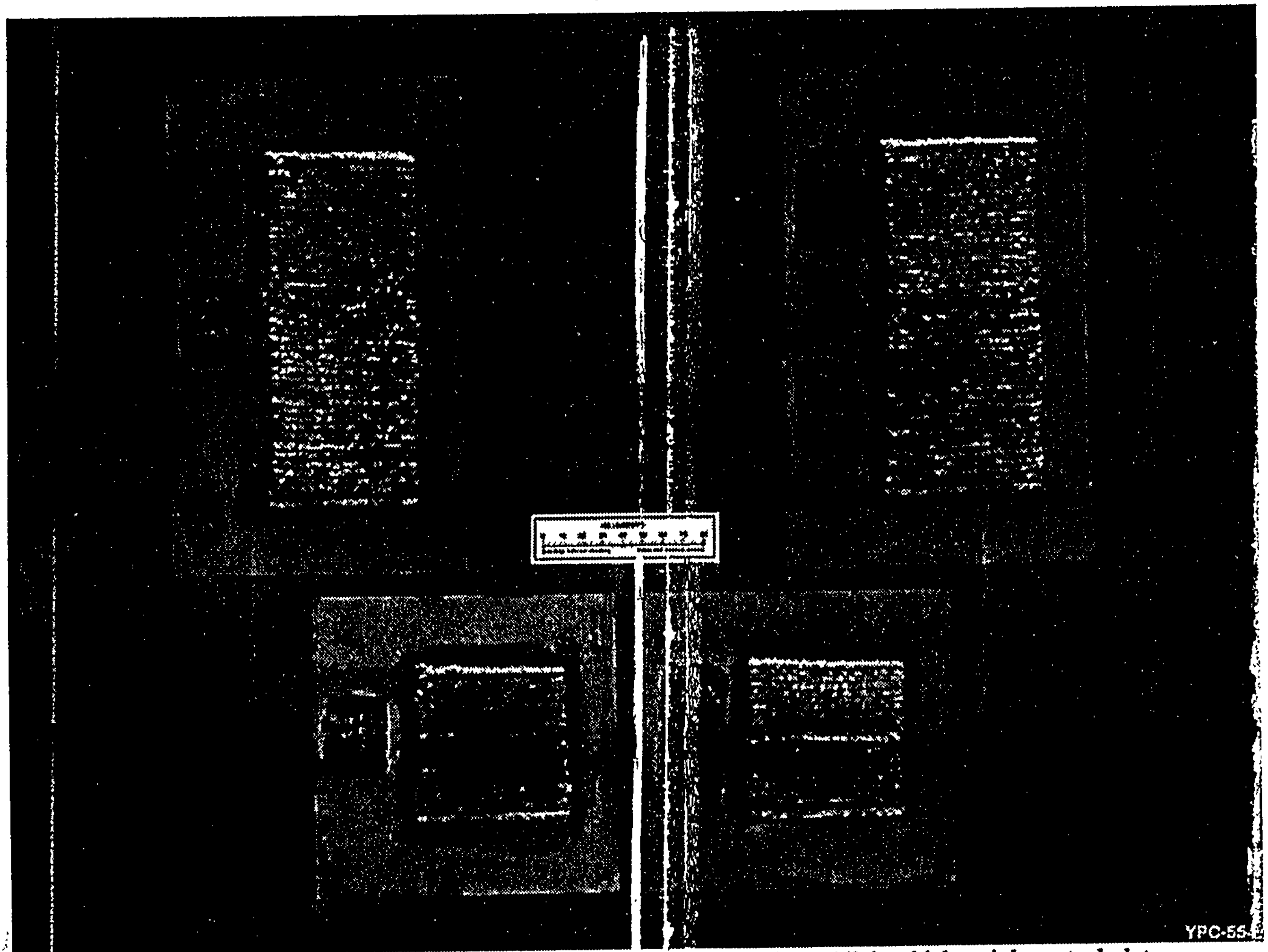

Figure 5. Liquor gun port shroud assembly. We d overlay pads on 1/2-in. thick stainless steel plate will show comparative erosion/corrosion performance.

SUMMARY

Considerable progress has been made in the development of iron aluminide alloys for weld overlay cladding applications. Filler metals were produced in coil form using a composite approach with an iron sheath and aluminum core wire, permitting the use of automated gas metal arc and gas tungsten arc welding. Compositional modifications were made to essentially eliminate hot cracking, and efforts continue to reduce or eliminate cold cracking by optimizing composition and welding parameters, especially preheat and postweld heat treatment.

Clad specimens were prepared for testing in-house and elsewhere to confirm corrosion performance, and overlay welded components were placed in service in commercial boilers for a side-by-side comparison with currently used materials.

REFERENCES

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