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Filler Metal Selection for Welding a High Nitrogen Stainless Steel

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Cromanite is a high-strength austenitic stainless steel that contains approximately 19% chromium, 10% manganese, and 0.5% nitrogen. It can be welded successfully, but due to the high nitrogen content of the base metal, precautions have to be taken to ensure sound welds with the desired combination of properties. Although no matching filler metals are currently available, Cromanite can be welded using a range of commercially available stainless steel welding consumables. E307 stainless steel, the filler metal currently recommended for joining Cromanite, produces welds with mechanical properties that are generally inferior to those of the base metal. In wear applications, these lower strength welds would probably be acceptable, but in applications where full use is made of the high strength of Cromanite, welds with matching strength levels would be required. In this investigation, two welding consumables, ER2209 (a duplex austenitic-ferritic stainless steel) and 15CrMn (an austenitic-manganese hardfacing wire), were evaluated as substitutes for E307. When used to join Cromanite, 15CrMn produced welds displaying severe nitrogen-induced porosity, and this consumable is therefore not recommended. ER2209, however, outperformed E307, producing sound porosity-free welds with excellent mechanical properties, including high ductility and strength levels exceeding the minimum limits specified for Cromanite.

Keywords austenitic stainless steel, Cromanite, E307 stainless steel

1. Introduction

The family of high-manganese, high-nitrogen, austenitic stainless steels currently includes alloys that exhibit the best combination of strength and toughness of any material known to man.[1] This has led to increased interest in these materials and, as a result, Columbus Stainless, a primary stainless steel producer in South Africa, recently introduced a new austenitic stainless steel, known as Cromanite, into the market. It is a high-manganese, high-nitrogen stainless steel with a chemical composition, as shown in Table 1.

Nitrogen is a very effective austenite-forming element in iron alloys[2]; that is, it enlarges the austenite phase field on a phase diagram at the expense of ferrite. By stabilizing the austenitic microstructure down to room temperature, the nitrogen alloying additions in Cromanite replace most of the nickel usually added to austenitic stainless steels. This translates into a substantial reduction in alloying element costs. Nitrogen also increases the strength of stainless steels, without a significant loss in toughness,[3] and has a beneficial effect on certain corrosion properties.

In order for the beneficial effects of high nitrogen contents in stainless steel to be realized, the nitrogen has to be retained in solid solution in the austenite. The precipitation of nitrides or carbonitrides can result in a decrease in ductility, lower resistance to stress-corrosion cracking, and changes in the phase balance.[4] The nitrogen added to Cromanite is retained in solid solution by ensuring a high nitrogen solubility limit in the steel. Chromium and manganese are particularly effective in increasing the solubility of nitrogen in stainless steel.

Historically, high-manganese, high-nitrogen stainless steels have been produced in pressurized furnaces, where a high nitrogen partial pressure is maintained above the melt to force the nitrogen into solution in the steel. In the case of Cromanite, the high manganese and chromium levels increase the nitrogen solubility in the steel to such an extent that it can be produced under atmospheric pressure using conventional steel-making processes. This significantly reduces production costs. The production route currently used to produce Cromanite at Columbus Stainless is[5]:

Electric arc furnace
↓
Decarburizing vessel
↓
Continuous slab caster

As a result of its high nitrogen content, Cromanite displays an excellent combination of mechanical properties (Table 2), including high strength, ductility, and toughness. Cromanite has a high capacity to work-harden under deformation, as evidenced by the appreciable increase in strength during cold rolling, which is shown in Table 2. The high rate of work hardening can be attributed to a low stacking fault energy due

Table 1 Typical Chemical Composition of Cromanite (Percentage by Mass)

Cr	Mn	N	Ni	C	Fe
19.0	10.0	0.5	0.9	0.03	Balance

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Table 2 Published Mechanical Properties of Cromanite[5]

Thermo-Mechanical History	0.2% Proof Stress (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Charpy Impact Toughness (25 °C)
As hot rolled	750	950	40	150 J
As hot rolled and annealed	550	850	50	250 J
As hot rolled, annealed and cold worked (50%)	1700	1720	10	Not available

to the low nickel and high manganese contents. The work-hardening properties of Cromanite under impact loading are similar to those of Hadfield manganese steel.[5]

The high strength and toughness of Cromanite, combined with good corrosion resistance, render the steel an excellent candidate for materials-handling applications involving wet sliding abrasion and high-impact abrasion. It is expected to have a major advantage over conventional wear-plate materials in materials handling applications in which moisture plays a role. This is mainly due to its excellent combination of wear resistance and corrosion resistance. It also has the potential for a variety of high-strength applications.[5]

Cromanite is currently finding successful application in a wide range of areas, such as[5]:

- Liner plates protecting chutes and conveyors in gold mines;
- Launders in coal wash plants;
- Shredders, cane knives, and hammers in sugar mills;
- Railcar bumper plates; and
- Bottom plates for electromagnets.

As several of the applications envisaged for Cromanite require welding during the fabrication process, it is important that the weldability of Cromanite be evaluated, suitable filler metals be selected, and potential problems be identified. Due to the high nitrogen content, welding requires special care to ensure that the nitrogen remains in the metal during welding, and that the excellent mechanical properties are maintained.

There are currently no matching filler metals commercially available for welding Cromanite. Cromanite can be joined successfully using a range of commercially available stainless steel electrodes, but the weld metal mechanical properties are generally inferior to those of the base metal. The aim of this investigation was to identify a commercially available welding consumable that provides weld metal mechanical properties comparable to those of the Cromanite parent plate.

In order to evaluate each of the filler metals selected for this investigation, three important requirements were identified that have to be satisfied when Cromanite is welded to itself or to any other material. These following three requirements were used as the criteria against which each of the welds was measured.

1.1 Resistance to Hot Cracking During Welding

Hot cracking is believed to occur when phases with low melting points form at the grain boundaries of the solid during solidification. These phases are usually enriched in elements such as sulfur and phosphorus, which tend to segregate to the grain boundary regions. The low-melting phases can persist as liquid films at the grain boundaries of the solid at much lower temperatures than the solidus of the bulk material. When the material is subjected to shrinkage-induced strains during cooling, the low strength and ductility of the liquid grain boundary films can result in the formation of cracks.[6]

Fully austenitic stainless steel welds can be very susceptible to hot cracking.[7] In order to guarantee adequate resistance to hot cracking during the welding of austenitic stainless steels, it is generally recognized that the weld metal has to solidify as primary δ-ferrite, rather than as austenite,[8-10] as evidenced by the presence of at least 5% δ-ferrite in the room-temperature microstructure of the weld.[6,11]

The compositions of austenitic stainless steel welding consumables are usually adjusted to meet these requirements, but when Cromanite is welded, an increase in weld metal nitrogen content due to dilution may result in a shift to primary austenitic solidification and fully austenitic weld metal. For this reason, it is important to evaluate Cromanite welds produced using different filler metals to ensure adequate resistance to hot cracking.

1.2 Mechanical Properties of the Weld Metal

The second important requirement that has to be met when Cromanite is welded is the presence of adequate weld metal mechanical properties. Cromanite is a relatively high-strength material. While lower strength welds are viable in wear environments, applications in which Cromanite is used primarily for its high strength, such as structural fabrications, would require conformance to stricter acceptance standards. These standards are usually specified by applicable codes, such as BS EN 288 (1992 Specification and Approval of Welding Procedures for Metallic Materials). The codes generally specify that the transverse tensile strength of the welded specimen should not be less than the corresponding specified minimum value for the parent metal.

1.3 Nitrogen Solubility in the Weld Metal

The third important requirement concerns the solubility of nitrogen in the weld metal. It is likely that the nitrogen content of the weld metal will increase during welding as a result of dilution with the high nitrogen parent plate. At the elevated temperatures encountered during the weld thermal cycle, nitrogen diffusion into the weld metal from the parent plate (adjacent to the fusion line) could also play a role. If the nitrogen level in the weld exceeds the solubility limit at any time prior to or during solidification, nitrogen bubbles can form in the liquid, thereby increasing the likelihood for nitrogen porosity. In order to reduce the risk of nitrogen-induced porosity, the solubility of nitrogen in the weld metal has to be high enough to accommodate any increase in nitrogen concentration. As chromium and manganese are known to increase the solubility limit of nitrogen in austenitic stainless steel, high levels of these elements are desired in the weld metal when filler metals for welding Cromanite are selected.

Table 3 Chemical Compositions of the Commercially Available Welding Consumables Evaluated in This Investigation (Percentage by Mass, Balance Iron)

Consumable	Cr	Mn	Ni	C	Si	Mo	N
E307	18.8	6.10	8.8	0.10	0.60	0.1	…(a)
ER2209	22.7	1.50	8.1	0.018	0.48	3.0	0.16
15CrMn	16.0	15.0	…(a)	0.4	0.25	…(a)	0.10

(a) No deliberate addition.

2. Experimental Procedure

2.1 Commercially Available Stainless Steel Filler Metals

During the course of this investigation, the properties of welds produced using three different commercially available stainless steel filler metals were compared. Each of the welds was evaluated against the requirements considered earlier. Typical compositions of the three consumables selected for this investigation are shown in Table 3.

E307 is an austenitic stainless steel wire and is the filler metal currently recommended by Columbus Stainless for joining Cromanite. Its high chromium and manganese levels increase the nitrogen solubility limit in order to accommodate any nitrogen picked up by the weld metal due to dilution with the Cromanite parent plate. It also displays a high rate of work hardening. ER2209 is a duplex austenitic-ferritic stainless steel wire and was selected on the basis of its all-weld metal mechanical properties, which are similar to those of Cromanite in the annealed condition. The filler metal designated 15CrMn is an austenitic-manganese, self-shielded, flux-cored hardfacing wire. The weld deposit work-hardens rapidly under impact, making it suitable for wear applications under severe impact conditions. It is also used for joining manganese steel to itself or to carbon steel.

2.2 Test Procedure

A series of Cromanite-to-Cromanite welds were produced by joining 10 mm thick annealed Cromanite plates using the filler metals shown in Table 3. The gas metal arc-welding and flux-cored arc-welding processes and single-V weld preparations were used. A shielding gas containing 98% argon and 2% oxygen was used for E307 and ER2209. The hardfacing electrode, as a self-shielded flux-cored wire, required no additional shielding gas. Welding was performed semi-automatically, and at least two passes were required to complete each weld.

After a visual and nondestructive examination, the welded samples were sectioned, and the weld metal microstructures, mechanical properties, and nitrogen levels were evaluated. A diagram demonstrating the location of the different test specimens is shown in Fig. 1. All tests were performed according to the requirements described in BS EN 288 (Part 3. Welding Procedure Tests for the Arc Welding of Steels) and related standards.

2.2.1 Visual and Nondestructive Evaluation. In accordance with BS EN 288, all the welds were examined visually and nondestructively using dye-penetrant testing and radiographic techniques.

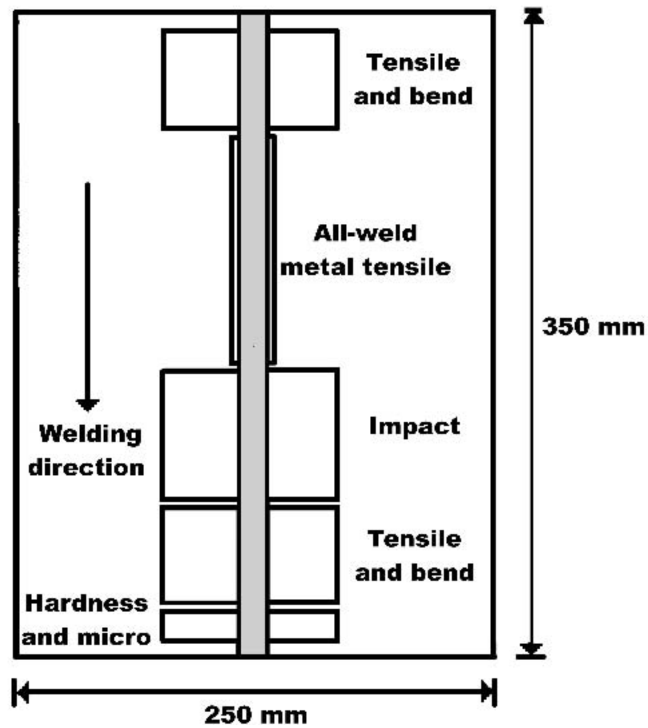

Fig. 1 Location of test specimens

2.2.2 Microstructure and Macroetch. Although not required by BS EN 288, the microstructure of each weld was examined in order to determine whether the requirements for hot-cracking resistance were met. The welds were sectioned, and the samples mounted and polished. The polished samples were etched using Beraha's etchant for stainless steel, and photomicrographs of the resulting weld microstructures were taken. The ferrite number (FN), which defines the ferrite content of the weld by its magnetic response, was measured for each weld using a calibrated Fischer Ferritscope (Fischer Instrumentation, UK). The etched welds were also examined and photographed at a low magnification to demonstrate the macrostructure of each joint.

2.2.3 Mechanical Properties. In order to characterize the mechanical properties of the welded joints, a series of mechanical tests was performed according to the specifications contained in BS EN 288. Transverse tensile tests (with the weld located perpendicular to the direction of applied stress during the tensile test) were performed in order to locate the preferential fracture site in each specimen. Although not required by BS EN 288, all-weld metal tensile tests were also performed to measure the strength and ductility of the weld metal. All-weld metal tensile specimens with gauge length-to-diameter ratios of 5:1 were used. The toughness of the welds was measured by performing room-temperature weld metal Charpy impact tests on subsize specimens. In addition, root and face bend tests were performed, and the hardness of each weld was measured using a calibrated Vickers hardness tester with a load of 30 kg. The mechanical properties of the welds were compared to the properties of annealed Cromanite that were measured in an earlier investigation.[12]

2.2.4 Nitrogen Solubility. In order to ascertain whether nitrogen was picked up by the weld metal during welding due

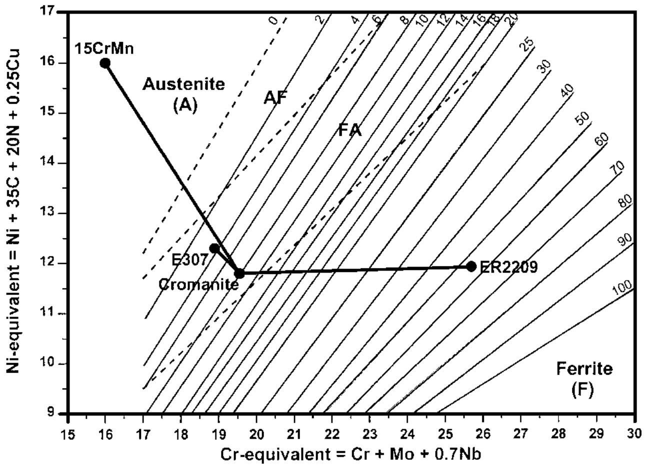

Fig. 2 WRC-1992 constitution diagram for predicting weld metal microstructures[13]

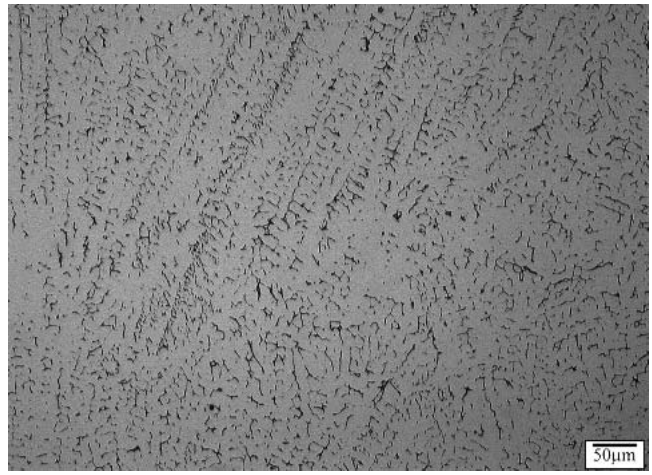

Fig. 3 Weld metal microstructure of a Cromanite-to-Cromanite weld using E307 filler wire (FN 6.6)

to dilution with the Cromanite parent metal, the nitrogen content of each weld was measured using inert gas fusion analysis and was compared to the nitrogen content of the filler wire prior to welding. The initial nitrogen levels of the welding consumables were obtained through analysis of the wire or from the manufacturers' chemical test certificates.

3. Results and Discussion

3.1 Visual and Nondestructive Evaluation

Visual examination and penetrant testing of the welds revealed no visible surface defects, but x-ray examination exposed a number of defects of varying significance in each of the welds. X-ray examination of the weld produced using the E307 filler wire revealed a small number of minute gas pores. The weld produced using the ER2209 filler wire contained more porosity in the form of blowhole and wormhole porosity, but the defects were isolated and relatively small. These defects are not expected to influence the mechanical properties of the welds to any appreciable extent. The 15CrMn weld, however, contained a significant number of large gas pores, with some blowholes as large as 3 mm in diameter. The presence of these blowholes is expected to have a detrimental effect on the properties of the 15CrMn welds.

3.2 Microstructure and Resistance to Hot Cracking

The room-temperature microstructure and solidification mode of austenitic stainless steel welds is determined principally by the chemical composition and, in particular, by the balance between austenite- and ferrite-forming elements.[11] Weld parameters only have a secondary influence on the microstructure.[7] By depicting the relationship between austenite- and ferrite-forming elements in the form of Ni- and Cr-equivalents, diagrams such as the WRC-1992 constitution diagram[13] (Welding Research Council) can be used to predict the microstructure and solidification mode of stainless steel welds. Such a diagram, with the positions of Cromanite, E307, ER2209, and 15CrMn indicated, is shown in Fig. 2. The influence of dilution on the weld microstructure and solidification mode can be predicted using tie-lines connecting the different filler metal positions with the position of the base metal (Cromanite). Increasing levels of dilution shift the weld metal composition toward the position of the base metal along the tie-line. The diagram predicts that Cromanite welds produced using E307 and ER2209 filler metal solidify with δ-ferrite as the leading phase (the "Ferrite" and "FA" fields on the diagram), regardless of the amount of dilution with the Cromanite base metal, while retaining varying amounts of δ-ferrite in the microstructure down to room temperature. 15CrMn is predicted to solidify as primary austenite (the "A" field on the diagram) and is expected to remain fully austenitic down to room temperature at normal levels of dilution.

Typical weld metal microstructures of Cromanite welds joined using E307, ER2209, and 15CrMn are shown in Fig. 3-5, respectively. The measured FN of each weld is shown in brackets in the figure caption. The FNs are in good agreement with the predicted ferrite contents, as is shown in the WRC-1992 diagram in Fig. 2, generally corresponding to levels of dilution of approximately 30-40%.

The Fe-Cr-Ni ternary system provides the basis for describing phase equilibria in austenitic stainless steels. By selecting a vertical section at 70% iron, shown in Fig. 6, the possible phase transformations during solidification can be approximated.[9] Depending on the chemical composition, and in particular the balance between austenite- and ferrite-formers (as represented by the Cr- and Ni-equivalents, rather than the actual chromium and nickel contents), an austenitic stainless steel can solidify by primary separation of austenite (on the nickel-rich side of the diagram to the right of the eutectic liquid (L) + ferrite (F) + austenite (A) triangle) or δ-ferrite (on the chromium-rich side of the diagram to the left of the eutectic triangle) from the melt. The initial solidification product is dependent only on the composition of the melt at the liquidus temperature.[7]

The weld metal microstructure of the weld produced using E307 filler wire (Fig. 3) consists of an austenite matrix (light-colored phase) and vermicular (feathery) δ-ferrite (dark-colored phase). The predominantly vermicular morphology and the presence of δ-ferrite at the original dendrite cores in the

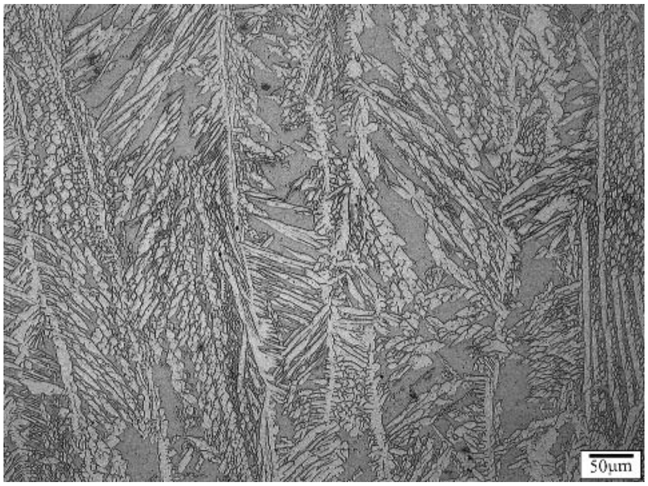

Fig. 4 Weld metal microstructure of a Cromanite-to-Cromanite weld using ER2209 filler wire (FN 37.0)

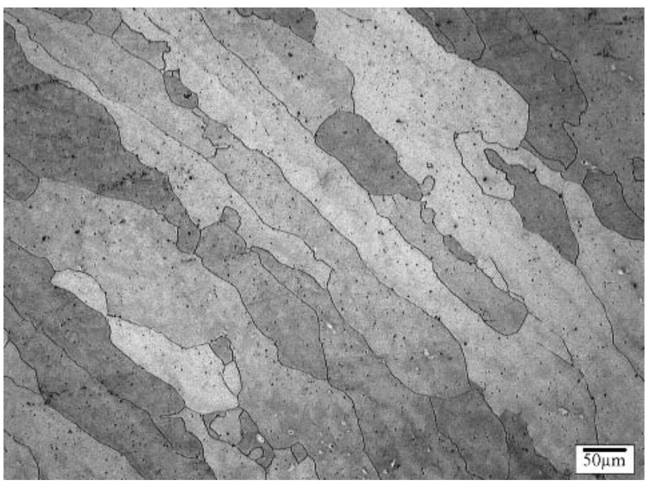

Fig. 5 Weld metal microstructure of a Cromanite-to-Cromanite weld using 15CrMn filler wire (FN 0)

microstructure confirm the prediction of the WRC-1992 diagram that this weld solidified as δ-ferrite. The weld metal composition is probably situated on the chromium-rich side of the Fe-Cr-Ni phase diagram in Fig. 6, most likely near the eutectic triangle. The first δ-ferrite to form at the original dendrite cores in this weld is highly enriched in ferrite-forming elements, such as chromium, and is depleted in austenite-formers, and therefore it remains stable down to room temperature as the predominantly vermicular δ-ferrite network. The remainder of the δ-ferrite transforms to austenite in the solid state on cooling.

The higher Cr-equivalent-to-Ni-equivalent ratio of ER2209 results in a high level of retained δ-ferrite (FN 37.0) in the weld metal microstructure (Fig. 4), although dilution with the high nitrogen parent metal causes a significant decrease in δ-ferrite content compared to the undiluted filler metal composition (along the tie-line in Fig. 2). The high δ-ferrite content causes a change in δ-ferrite morphology from a vermicular morphology to a coarser microstructure, with austenite (light phase) outlining the columnar primary δ-ferrite grain boundaries, and Widmanstätten austenite needles growing from the grain boundaries into the grain interiors. The high levels of retained δ-ferrite in the room-temperature microstructure and the morphology of the δ-ferrite provide additional evidence that the ER2209 weld solidified as primary δ-ferrite. The weld metal composition is probably situated more toward the chromium-rich side of the phase diagram in Fig. 6, further to the left of the eutectic triangle than E307.

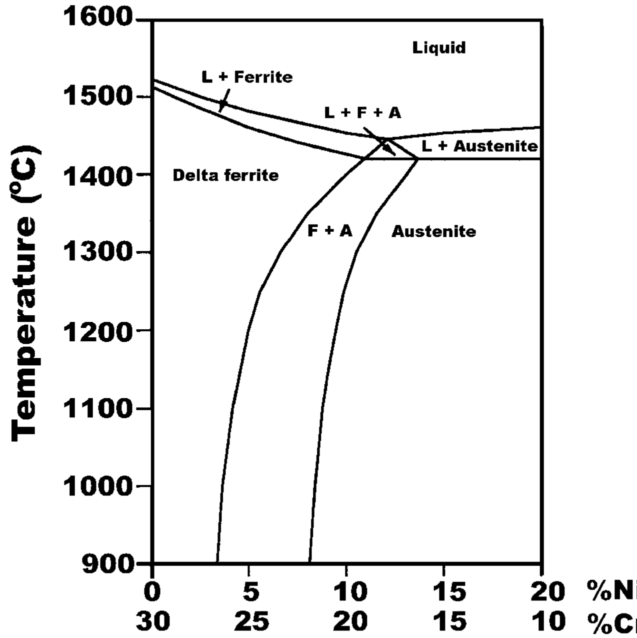

Fig. 6 Vertical section at 70% Fe (percentage by mass) of the Fe-Cr-Ni ternary system.[10] L, liquid; A, austenite; F, ferrite

The weld metal microstructure of the 15CrMn weld is fully austenitic and consists of coarse columnar austenite grains growing from the fusion boundary toward the weld centerline. The morphology of the austenite and the absence of any δ-ferrite in the microstructure confirm the prediction of the WRC-1992 diagram that the weld solidified as primary austenite and remained fully austenitic down to room temperature.

The presence of significant amounts of δ-ferrite in the microstructure of the E307 and ER2209 welds at elevated temperatures during solidification (as predicted by the WRC-1992 diagram), and retained in the weld microstructure down to room temperature, suggests that these welds fulfill the requirements for hot cracking resistance. The conclusion can be drawn that welds produced using these filler metals will not be susceptible to hot cracking during welding. The absence of δ-ferrite during solidification and in the room temperature microstructure of the 15CrMn weld suggests that this weld may be susceptible to hot cracking. The high manganese level of this filler metal (as shown in Table 3) may, however, alleviate the cracking tendency of the weld metal by combining with harmful elements, such as sulfur, to form inclusions.[14] No cracks were observed in any of the welds, but it must be taken into account that welding was performed under low-restraint conditions.

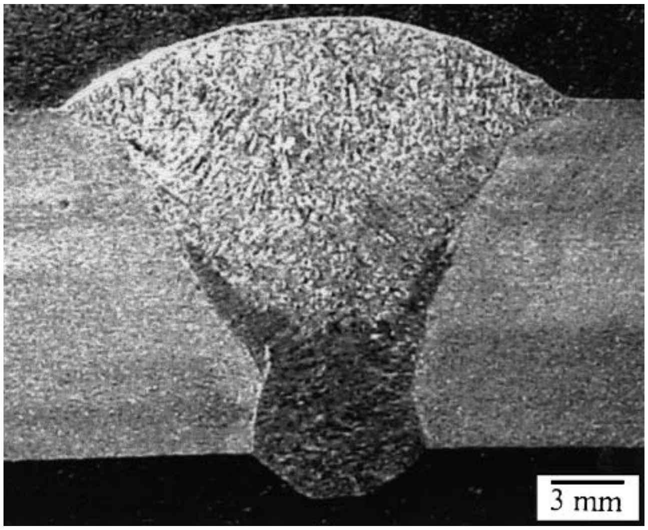

Fig. 7 Macrostructure of a Cromanite-to-Cromanite weld using ER2209 filler wire

Macroetch examination of the welds revealed full-penetration joints and sound weld profiles. An example of the macrostructure of a typical weld is shown in Fig. 7, and it demonstrates the joint geometry and the three passes used to complete this particular weld.

Table 4 Tensile and Yield Strength of Welds Produced Using E307, ER2209, and 15CrMn Filler Wire, Compared to That of Annealed Cromanite

	All-Weld Metal (MPa)		Transverse (MPa)		
Material	0.2% Proof Stress	Ultimate Tensile Strength	0.2% Proof Stress	Ultimate Tensile Strength	Hardness (Vickers Scale)
Cromanite (annealed)	…	…	587	916	267
Weld E307	428	680	496	745	181
Weld ER2209	655	837	631	848	253
Weld 15CrMn	639	780	580	621	270

Table 5 Ductility and Toughness of Welds Produced Using E307, ER2209, and 15CrMn Filler Wire, Compared to the Corresponding Properties of Annealed Cromanite Base Metal

	All-Weld Metal (%)		
Material	Elongation at Fracture	Reduction in Area	Charpy Impact Toughness (25 °C)
Cromanite (annealed)	75	60	298 (full-size)
Weld E307	41	34	109
Weld ER2209	37	58	137
Weld 15CrMn	14	32	81

3.3 Mechanical Properties

The mechanical properties of Cromanite-to-Cromanite welds joined using E307, ER2209, and 15CrMn filler metal are shown in Tables 4 and 5. The values shown in these tables are the average values of two all-weld metal tensile tests, two transverse tensile tests, three impact tests, and at least five hardness measurements. The values generally showed good repeatability during testing.

The all-weld metal tensile test results shown in Tables 4 and 5 demonstrate that the strength of all the welds tested, with the exception of the E307 weld, exceeds the minimum tensile and yield stress requirements of 450 and 800 MPa, respectively, that are specified for Cromanite. The tensile strength of the 15CrMn weld is slightly lower than the specified value, but this can probably be attributed to the presence of large defects in the weld metal. The E307 and ER2209 welds display excellent ductility. The lower ductility of the 15CrMn weld can also be attributed in part to the large blowholes present in the weld metal. (The percentage elongation shown in Table 5 for annealed Cromanite is higher than the published value shown in Table 2. This can be explained by a difference in specimen dimensions, as the percentage elongation measured during a tensile test depends on the gauge length of the samples.)

The results of the transverse tensile tests indicate that the tensile and yield strengths of the ER2209 welded samples correspond well with those of annealed Cromanite, with the measured values exceeding the minimum requirements specified for Cromanite. The tensile and yield strengths of the E307 and 15CrMn welds, however, are significantly lower than those of Cromanite. Fracture occurred in the weld metal of all the samples tested, with most of the deformation during the tensile test occurring in the weld metal. Except in the case of the 15CrMn welds, the strength in the transverse direction is generally higher than that measured during the corresponding all-weld metal tensile test. This can be attributed to the influence of the Cromanite base metal surrounding the weld in the tensile samples. The transverse strength of the 15CrMn weld is probably low as a result of the presence of defects (gas porosity) in the weld metal. These defects were evident on the fracture surfaces of the failed 15CrMn tensile samples.

Due to plate thickness limitations, subsize Charpy impact specimens were used to determine the toughness of the welds. Final specimen dimensions were 8 × 10 × 55 mm. As a result, the impact toughness values shown in Table 5 for welded specimens cannot be compared to the toughness quoted in the same table for annealed Cromanite, since this value relates to full-size (or 10 × 10 × 55 mm) specimens. The impact toughness values of the different welds, however, can be compared. The weld produced using ER2209 filler metal displays excellent toughness, especially considering the size of the specimens tested. E307 also provides welds with excellent impact toughness. The 15CrMn weld displayed low toughness, attributable in part to the presence of large blowholes in the weld metal. These defects were visible on the fracture surfaces of the Charpy specimens.

The average hardness of the weld metal of each weld is shown in Table 4. The results demonstrate that the ER2209 and 15CrMn welds are very similar in hardness to annealed Cromanite. The hardness of the E307 weld is significantly lower, although in-service work-hardening under conditions of impact or high-stress abrasion will raise the hardness to a limited ex-

Table 6 The Measured Nitrogen Content of Welds Produced Using E307, ER2209, and 15CrMn Filler Wire Compared to the Original Nitrogen Content of the Filler Wire (Percentage by Mass)

Material	Original N Content (%)	Weld Metal N Content (%)
Weld metal E307	0.051	0.111
Weld metal ER2209	0.160	0.169
Weld metal 15CrMn	0.100	0.242

tent. The 15CrMn welds are also likely to work-harden significantly under impact due to the low nickel and high manganese contents. The ER2209 weld work-hardens less than the E307 and 15CrMn welds (due to its higher nickel content) and displays less uniform elongation during tensile testing. As a result, it will probably be less suitable for wear applications than E307 or 15CrMn.

The E307 and ER2209 welds passed the transverse root and face bend test requirements set by the code, bending through 180° with no visible defects. The 15CrMn welds, however, did not perform well, failing at bend angles well below 180°. The presence of gas porosity in the 15CrMn welds probably played a significant role in this respect.

3.4 Nitrogen Solubility in the Weld Metal

The weld metal nitrogen content of each weld, measured by an inert gas fusion analysis technique, is shown in Table 6, compared to the original nitrogen content of the filler wire. If these values are compared, it is evident that significant amounts of nitrogen were picked up by the E307 and 15CrMn welds as a result of dilution with the high nitrogen Cromanite parent plate. The ER2209 weld absorbed less nitrogen from the base metal, probably due to its higher initial nitrogen level.

The high level of nitrogen absorbed from the base metal by the 15CrMn weld probably resulted in the formation of porosity in the weld metal as the nitrogen solubility limit was exceeded during solidification. The presence of a large number of blowholes in the 15CrMn weld metal severely limits its application for joining Cromanite. The absence of significant amounts of porosity in the E307 and ER2209 welds demonstrates that the solubility limit was not exceeded during welding.

4. Summary and Conclusions

Cromanite is a new high-strength austenitic stainless steel produced by Columbus Stainless. Its combination of wear resistance and corrosion resistance renders it an excellent candidate for materials-handling applications involving wet-sliding abrasion and high-impact abrasion. It has already been used successfully in a number of prototype applications.

There are currently no matching filler metals commercially available for joining Cromanite. In applications in which Cromanite is used mainly for its high strength, welds with matching mechanical properties are required. During the course of this project, two commercially available welding consumables, ER2209 (a duplex austenitic-ferritic stainless steel filler metal) and 15CrMn (a hardfacing wire) were tested concurrently and compared to welds produced using E307, the filler metal currently recommended for joining Cromanite.

The duplex ER2209 weld outperformed the E307 weld, demonstrating excellent mechanical properties, including high ductility and strength levels exceeding the minimum limits specified for Cromanite. These welds were resistant to hot cracking and showed little, if any, nitrogen-induced porosity. High levels of porosity make the 15CrMn wire unsuitable for joining Cromanite.

Acknowledgments

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