IMPROVING THE WELDABILITY OF FeCrAl ALLOYS THROUGH TiC ADDITIONS

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ABSTRACT

FeCrAl alloys were prepared with TiC additions to act as hydrogen traps and improve resistance to hydrogen cracking. Weldability results showed that alloys with up to 20 wt% Al and 11 wt% Cr could be prepared crack-free with relatively small TiC additions of ~ 4 wt%. Thermogravimetric analysis of Fe-10Al-5Cr corrosion coupons with and without TiC has shown that the corrosion resistance is not significantly affected by the presence of the second phase. These results suggest that TiC can be used to decrease the hydrogen cracking susceptibility of FeAlCr based alloys, which are candidates for use in weld overlay applications in coal-fired boiler tube fabrication. A solidification model was developed as an aid to control the TiC content in FeCrAl alloys.

INTRODUCTION

FeCrAl coatings can provide excellent corrosion protection of waterwalls in coal fired power plants operating under low NOx firing conditions. These coatings provide several advantages over currently used Ni base alloys. First, they provide significantly better corrosion resistance. Second, they are Fe based (instead of Ni based) and rely primarily on Al (rather than Cr) as a preferential oxidizing element. As a result, they are significantly cheaper. Lastly, the Al and Cr are uniformly distributed on a microscopic scale throughout the coating. In contrast, commercial Ni base overlays exhibit microsegregation that causes preferential corrosion and corrosion-fatigue cracking. The FeCrAl alloys should be immune to this problem since they do not exhibit microsegregation. However, use of FeCrAl weld overlay coatings is currently limited due to their susceptibility to hydrogen cracking during welding. The addition of carbides is often made to Fe based alloys to act as hydrogen trap sites as a means to mitigate hydrogen cracking, and TiC is one of the most effective carbides for this purpose. In this work, the influence of TiC additions on the weldability and corrosion resistance of FeCrAl alloys is evaluated.

EXPERIMENTAL PROCEDURE

Alloys were prepared in an arc-button melting furnace with a combination of virgin elements and high-purity alloys. Alloys were prepared with various Al, Cr, Ti, and C concentrations. Weldability coupons (3.2 cm long x 2.5 cm wide x 0.6 cm thick) were machined from the arc button melts. Autogenous GTA welds were placed on the top face of the samples in the long direction. The GTAW process was used with an argon shielding gas to simulate standard welding conditions. A mixture of argon with 5% hydrogen was also used as a shielding gas to simulate hydrogen incorporation into the weld pool to produce conditions that would promote hydrogen cracking. The process parameters used were 200 amps, 11.5-14.0 volts, an arc gap of 2.5-3.0 mm, and a travel speed of 5 mm/s. A dye penetrant technique was used to observe cracks in the samples. Corrosion coupons (approximately 10 mm x 10 mm x 2 mm) were machined from the buttons and metallographically ground and polished to a 0.3 μm Al_2O_3 finish. A Netzsch Instruments STA 409 thermal analyzer was used to measure the weight gain of the corrosion coupons at 500°C in a simulated coal combustion environment (10%CO – 5%CO_2 – 2% H_2O – 0.12% H_2S – N_2) gas. Light optical microscopy (LOM), scanning electron microscopy (SEM), and electron backscattered diffraction (EBSD) were used to characterize the microstructure of the alloys.

RESULTS AND DISCUSSION

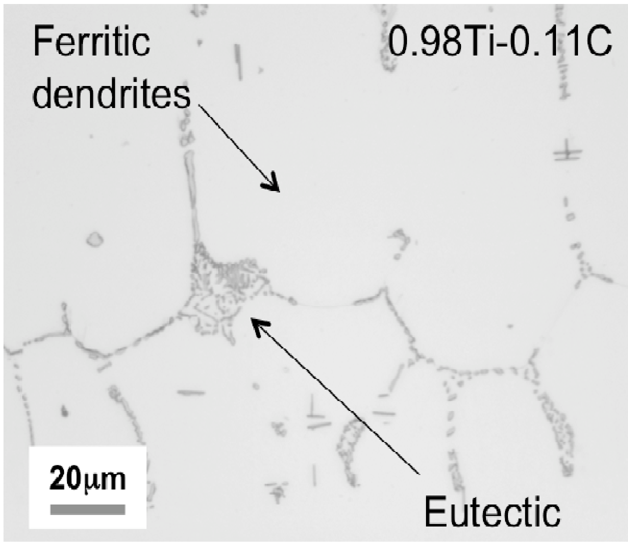

Figure 1. Light optical photomicrograph of Fe-10Al-5Cr-0.98Ti-0.11C alloy.

All the alloys exhibited a microstructure consisting of a ferrite matrix with an interdendritic eutectic constituent. Figure 1 shows an example of this microstructure for an Fe-10Al-5Cr-0.98Ti-0.11C (weight percent) alloy. Backscattered diffraction results confirmed that the matrix is ferritic and the eutectic is comprised of ferrite and TiC. In general, increasing the amount of carbon and titanium increases the amount of the ferrite/TiC eutectic that forms. However, the amount of eutectic that forms is not solely related to the nominal solute concentrations but also depends on the thermodynamics of the alloy system and the kinetics of solute redistribution during solidification. Therefore, a solidification model was developed to understand the solidification behavior of these alloys. The modeling approach is described in detail elsewhere and is only briefly explained here [1]. A liquidus projection for the Fe-10Al-5Cr-Ti-C system was calculated using thermodynamic software [2] and databases to compute the primary phases that are in equilibrium with the liquid for a range of Ti and C concentrations (Figure 2). Solute redistribution models based on previous results [3,4] were used to make primary solidification path calculations, and the calculated solidification paths are also shown directly in Figure 2. These primary solidification paths, in conjunction with the liquidus projection, were adapted for use in calculating the amount of eutectic that is expected to form for a given nominal composition. This is done by noting that the liquid remaining when the primary solidification path intersects the eutectic line will transform to the ferrite/TiC eutectic as solidification goes to completion. Thus, the amount of

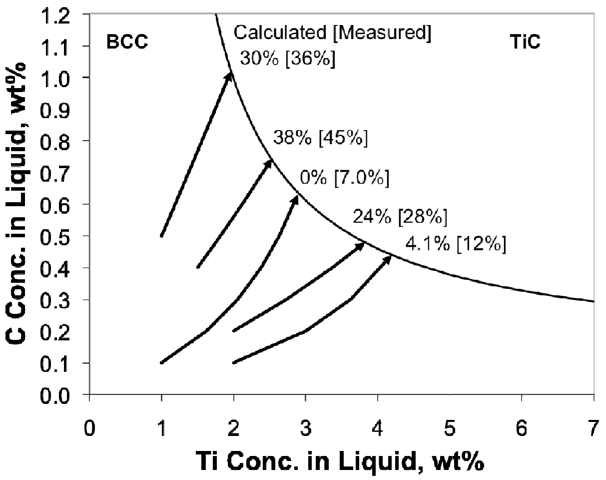

Figure 2. Calculated liquidus projection for the Fe-10Al-5Cr-Ti-C (wt%) alloy system, primary solidification paths, and calculated and measured (in brackets) percent eutectic for several nominal compositions.

liquid present at this point represents the amount of eutectic that will form in the final microstructure. The measured and calculated eutectic fractions are also shown in Figure 2, and reasonable agreement is observed between the measured and calculated values. These calculations are useful for controlling the amount of TiC-containing eutectic that will form in the alloys during solidification.

Figure 3 shows initial weldability results used to assess the effectiveness of the test for inducing hydrogen cracks. In this test, Fe-10Al-5Cr-0.05C alloys were welded in argon gas mixtures that were free of hydrogen (Figure 3a) and contained 5% hydrogen (Figure 3b). When an argon shielding gas was used, the test button did not crack. However, when an Ar/H shielding gas was used, the test button cracked, indicating the test was useful for simulating the cracking mechanism. Metallographic analysis of the weldability coupon showed that the cracks propagated both along grain boundaries and within the grains, which is consistent with hydrogen cracking in these alloys.

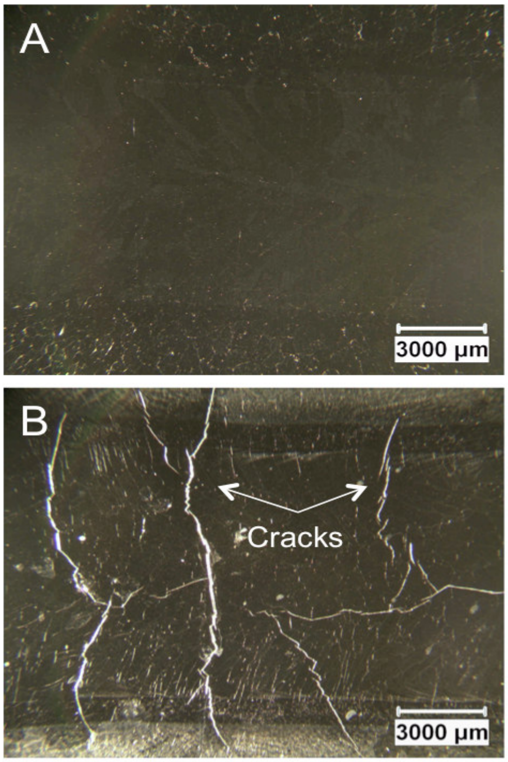

Figure 3. Stereophotomicrographs of Fe-10Al-5Cr alloys welded with pure Ar (A) and Ar/5H (B). Note the alloy welded with Ar/5H exhibits extensive cracking.

Figure 4 shows weldability results conducted on a series of alloys with increasing amounts of Al and Cr. Previous results have shown that increases in the amounts of Al and Cr lead to an increase in cracking susceptibility. In general, alloys with Al and Cr additions above approximately 12 and 5 weight percent, respectively, can not be welded without cracking. The results shown in Figure 4 indicates that the addition of TiC extends the weldable composition range significantly beyond these values to the point where alloys with Al and Cr level as high as 20 and 11 weight percent, respectively, can be welded without cracking.

Figure 5 shows corrosion results for Fe-10Al-5Cr alloys with and without TiC additions. Results for alloy 622 are shown for comparison, since this is the current industry standard weld overlay alloy. Although the weight gain is slightly higher with the addition of TiC, the corrosion resistance of the Fe-

10Al-5Cr alloy with TiC is still significantly better than alloy 622. Thus, the presence of TiC additions should not have any significant effect on the corrosion performance of these alloys. Additional tests are needed under various conditions and exposure times to confirm this for a wider range of potential service conditions.

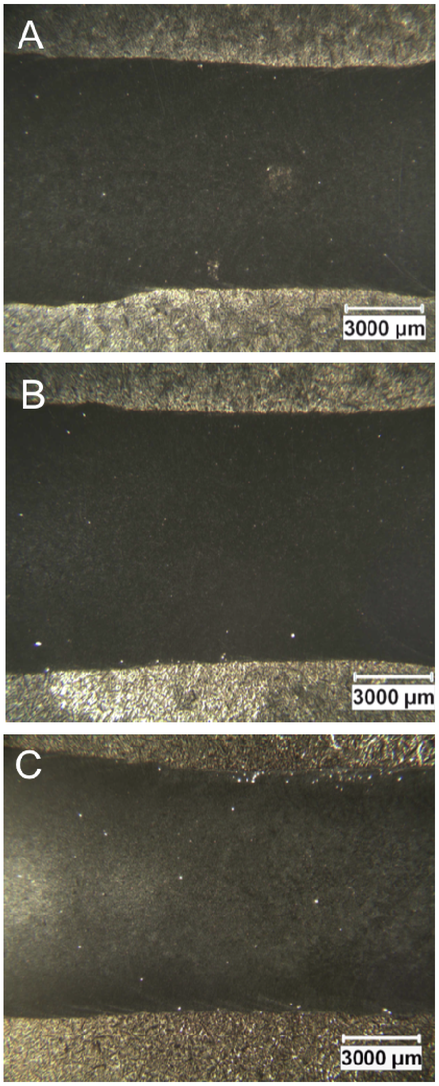

Figure 4. Stereophotomicrographs showing crack-free welds prepared with the Ar/5H shielding gas. A) Fe-5Al-2Cr with 8 wt% TiC. B) Fe-10Al-5Cr with 5 wt% TiC. C) Fe-20Al-11Cr with 4 wt% TiC.

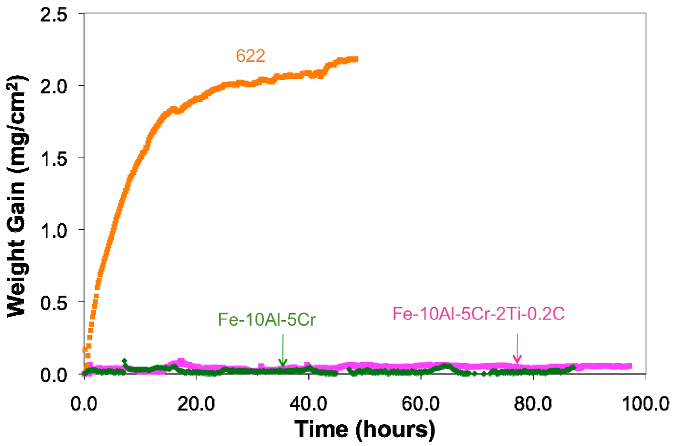

Figure 5. Thermogravimetric analysis of corrosion coupons of Fe-10Al-5Cr with and without TiC compared to Inconel 622 overlay coupon using a gaseous environment of 10%CO – 5%CO_2 – 2% H_2O – 0.12% H_2S – N_2 at 500°C.

CONCLUSIONS

The effect of Ti and C on the weldability and corrosion resistance of Fe-10Al-5Cr alloys has been studied. The addition of Ti and C to Fe-10Al-5Cr based alloys produces a microstructure consisting of ferrite with an interdendritic eutectic comprised of ferrite and TiC. TiC decreases the severity of hydrogen assisted cracking to the point where alloys with 20 wt% Al and 11 wt% Cr can be welded without cracking. The corrosion resistance of TiC containing Fe-10Al-5Cr based weld metal is comparable to TiC-free overlays for short term testing. A solidification model has been developed and validated as a means for controlling the TiC content in FeCrAl alloys.

REFERENCES

1. K.D. Adams, The Influence of Ti and C on the Solidification Microstructure of Fe-10Al-5Cr Alloys, PhD Thesis, Lehigh University, Bethlehem, PA, May, 2009.
2. Thermo-Calc, Inc., Thermo-Calc, TCFE5 Iron and Steel Database, Stockholm, Sweden.
3. S. Kobayashi, Mathematical Analysis of Solute Redistribution During Solidification Based on a Columnar Dendrite Model. Transactions ISIJ, 28 (1988) 728-735.
4. J.N. DuPont, Mathematical modeling of solidification paths in ternary alloys: limiting cases of solute redistribution. Metallurgical and Materials Transactions A, 37A [6] (2006) 1937-1947.