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Proceedings of the 72nd World Foundry Congress
21-25th May 2016, Nagoya, Japan

Characterization of duplex stainless steel casting with gadolinium as neutron absorbers for spent fuel storage applications

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The aim of this study is to investigate the effects of gadolinium addition on the microstructure and mechanical properties of duplex stainless steel (DSS) fabricated using a normal casting method. The oxygen content in the cast DSS alloy with gadolinium decreased because of the high reactivity of gadolinium with oxygen. Notably, the ultimate tensile strength and strain at break of the cast alloy significantly increased with the addition of gadolinium from 919 ± 25 to 969 ± 8 MPa and from 24.8% ± 1.9% to 28.4% ± 1.1%, respectively.

Keywords: *Duplex stainless steel; gadolinium; casting; microanalysis; inclusions; mechanical characterization*

1. Introduction

Gadolinium (Gd) is one of more abundant rare earth metals and has special characteristics such as a high neutron cross-section [1]. The Gd has been used in neutron therapy applications for targeting tumor; and recently, it has been introduced as a neutron absorber material which can be used to shield nuclear reactors such as nuclear fuels [2]. The successful fabrication of DSS with Gd addition can take advantage of the rare earth metal characteristics to enhance corrosion resistance and mechanical properties of DSS for a variety of applications in the nuclear industry.

2. Method

The present study is focused on studying the Gd influence on the microstructure and mechanical properties of DSS. DSS with a pitting resistance equivalent number (PREN = wt.% Cr + 3.3 wt.% Mo + 30 wt.% N) 50 was used and 0.1 wt% of Gd was added and alloyed through casting [25]. The microstructure and inclusions of alloys were investigated, while the mechanical properties were examined by Charpy impact, hardness and tensile strength tests..

3. Results and Discussion

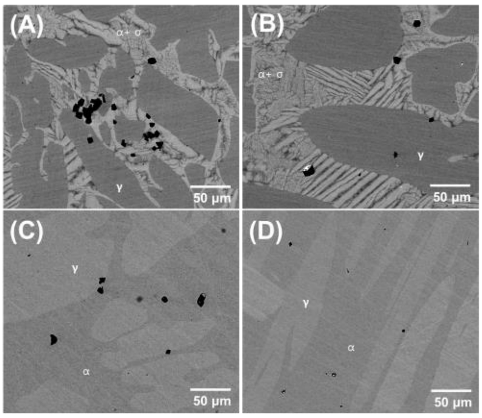

Fig. 1 Back scattered electron (BSE) images of (A), (C) Alloy I and (B), (D) Alloy II as casting (Left side is as cast and right side is after solution treatment

Figure 1 shows the BSE images of Alloy I and Alloy II before and after heat-treatment. The σ and χ phases in the ferrite matrix were observed before heat-treatment due to the slow cooling rate (Figure 1 (A) and (B)). The clusters of irregular-shaped inclusions (black particles) were found in Alloy I, whereas isolated globular inclusions (black and black-white particles) were detected in Alloy II, as shown in Figure 1 (A) and (B). Alloy I and Alloy II were heat-treated at 1130℃ which is the predicted temperature for adjusting ferrite-austenite ratio (45:55) and dissolving the σ and χ phases. After water quenching, typical duplex structures were obtained from Alloy I and Alloy II as shown in Figure 1 (C) and (D). The austenite phase was evenly distributed as islands in the ferrite matrix, and no intermetallic phases were observed following double-solution annealing. The inclusions in Alloy I and Alloy II, however, were still detected which indicated that the remaining inclusions are in non-intermetallic forms such as oxides or nitrides which have high melting temperatures.

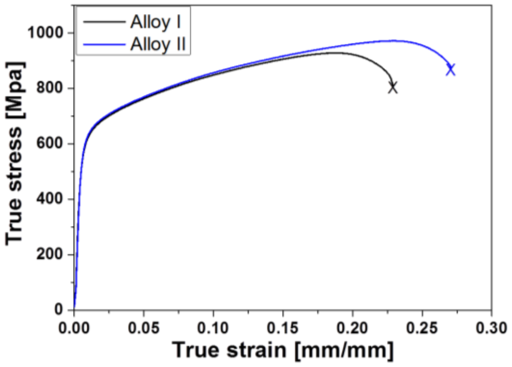

Fig. 2 Tensile stress versus strain curves of Alloy I and Alloy II

The typical stress versus strain curves of the fabricated duplex stainless steels by uniaxial tensile test is shown in Figure 2. For all cast alloys, the specimens possessed ductile fracture behaviors; the early stage elastic deformation region was followed by a plastic elongation prior to failure. The curves of Alloy I and Alloy II have no difference in elastic region with a yield strength of approximately 550 MPa and an elastic modulus of approximately 145 GPa which are reasonable values of cast duplex stainless steel alloys, whereas the mechanical properties of Alloy II in the plastic region seem to be improved greatly with higher ultimate tensile strength and strain at break [3].

The yield strength and elastic modulus of cast duplex stainless steel alloy slightly increased with the addition of gadolinium from 537±5 MPa to 557±12 MPa and from 143±16 GPa to 149±5 GPa, respectively. However, the ultimate tensile strength and strain at break of Alloy II (969±8 MPa and 28.4±1.1%) were significantly higher than those of Alloy I (919±25 MPa and 24.8±1.9%) by 5.4% and 14.5%, respectively ($p<0.05$).

4. Conclusions

Duplex stainless steel with stable microstructure and excellent mechanical properties was successfully fabricated by the addition of gadolinium. The oxygen content in cast duplex stainless steel alloy with gadolinium decreased by 16% due to the high reactivity of gadolinium with oxygen. The ultimate tensile strength and strain at break of cast alloy significantly increased with the addition of gadolinium from 919±25 MPa to 969±8 MPa and from 24.8±1.9% to 28.4±1.1%, respectively. This simple, but effective fabrication process of duplex stainless steel has great potential as a method to answer limitations of neutron absorbing structural materials as well as other various industry applications.

Acknowledgements

This work was supported by Ministry of Trade, Industry & Energy of the republic of Korea. (No. NS140028 and No. NS130039).

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