



Original Article

Corrosion and Wear Properties of Cold Rolled 0.087% Gd Lean Duplex Stainless Steels for Neutron Absorbing Material

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ABSTRACT

Lean duplex stainless steels with 0.087 wt.% gadolinium (Gd) were inert arc-melted and cast in molds of size 10 mm × 10 mm × 20 mm. The micro-hardnesses of the rolling direction (RD), transverse direction (TD) and short transverse (ST) direction were 258.5 H_V, 292.3 H_V, and 314.7 H_V, respectively. A 33% cold rolled specimen had the crystallographic texture that (100) pole was mainly concentrated to the normal direction (ND) and (110) pole was concentrated in the center of ND and RD. The corrosion potential and corrosion rate in artificial seawater and 0.1M H₂SO₄ solution were in the range of 105.6–221.6 mV_{SHE}, 0.59–1.06 mA/cm², and 4.75–8.25 mV_{SHE}, 0.69–1.68 mA/cm², respectively. The friction coefficient and wear loss of the 0.087 w/o Gd-lean duplex stainless steels in artificial seawater were about 67% and 65% lower than in air, whereas the wear efficiency was 22% higher. The corrosion and wear behaviors of the 0.087 w/o Gd-lean duplex stainless steels significantly depended on the Gd phases.

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1. Introduction

More efficient storage of spent nuclear fuel is one of the most important issues in current Korean nuclear industry, since the amount of stored fuel will soon approach the full storage capacity. Most spent fuel storage racks use boron as the neutron absorber material, in forms of Boral, Metamic, or borated stainless steel, because of the high thermal neutron absorption cross section and ease of fabrication [1,2]. However, boron has been found to produce helium gas as it absorbs neutrons,

which leads to the formation of He gas bubbles during its use in the spent fuel racks. This harms the integrity of the rack [3,4]. Recently, duplex stainless steel containing gadolinium (Gd) has been under development as a neutron-absorbing structural material for spent fuel racks [5]. Gd isotopes have a much higher thermal neutron absorption cross section (>60 times higher for Gd-157 than for B-10) and a higher isotopic abundance of the strong neutron absorber: 30.45% for thermal neutron absorption cross section > 60,000 barn (Gd-155, Gd-157) versus 19.9% for thermal neutron absorption cross

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section = 3,840 barn (B-10). Therefore, it has a good potential for use as an absorber in the structural material, if dissolved in stainless steel.

Austenitic stainless steels have been used as the structural alloys for the transportation and storage of spent nuclear fuel. Recently, duplex stainless steels with austenitic and ferritic phases have been favorably considered as the structural material in various applications because of their higher strength and better corrosion resistance than a single phase of austenitic stainless steels. Various duplex stainless steels with different alloying elements, such as chromium, nickel, and molybdenum, have been developed [6]. Among these alloys, lean duplex stainless steels, which have little alloying elements, have been tried as the neutron-absorbing material, as they may cause less precipitation by neutron-induced phase transformation during usage [7].

Although duplex stainless steels have been widely studied, little information is available on the effects of neutron-absorbing elements on the microstructure development and the characteristics of lean duplex stainless steels. Hence, the objective of this study is to fabricate a lean duplex stainless steel with Gd and to characterize its mechanical and corrosion behaviors.

2. Materials and methods

The lean duplex stainless steels with Gd were fabricated by using plasma arc melting (PAM-Plasma, Japan), mother alloys of Fe–Mo, Fe–Gd, and Fe–Cr–Ni alloys, and alloy elements such as manganese (Mn > 99.99, Samchang, Korea) and silicon (Si > 99.99, Samchang). The mother alloys were prepared by vacuum induction melting (Inductotherm, USA) with metallic slots of iron (Fe > 99.99, Samchang), chromium (Cr > 99.99, Samchang), nickel (Ni > 99.99, Samchang) and Gd (Gd > 99.9%, Samchang).

The melt was poured at 1,640°C into an alumina mold coated with yttria (Y₂O₃). The cast block, with dimensions of 150 mm × 75 mm × 15 mm, was cut and hot rolling was carried out three times at 950°C, solution treatment at 1,070°C for 1 hour, and water-quenching; finally, cold rolling was carried out to a thickness of 3.0 mm.

Table 1 is the final composition of the final product, as determined by inductively coupled plasma mass spectrometry (Agilent-8800, Agilent Technology, USA).

The microstructure of the specimen was observed by optical microscopy (AT Microscope, MX-3000, Korea) after etching with Carpenter's etchant. The crystallographic texture was determined by electron backscattered diffractometry (Jeol, JSM-7100F, Japan).

Microhardness was determined with a micro-Vickers hardness tester (HuaTec, DHV-1000, China) at a load of 98 N for rolling directions, like rolling direction (RD), transverse direction (TD), and short transverse (ST) direction. Mechanical properties such as ultimate tensile strength, yield strength, and elongation were determined with a universal test machine (Shimadzu, AG-300kNX, Japan). The specimen was

Table 1 – Chemical composition of cast lean duplex stainless steel (wt.%).

Fe	Cr	Ni	Mo	Si	Mn	Gd
Balance	22.25	5.33	2.90	0.45	0.85	0.087

prepared by ASTM A370. Wear resistance was measured with a pin on disk type wear tester (R&B, Triboss PD-102, Korea) and the wear surface and wear debris were observed and analyzed by scanning electron microscopy (Coxem, CX200-TA, Korea) and energy dispersive spectroscopy (Hitachi, S-4300, Japan). Corrosion behavior in an artificial seawater (ASTM D1141-98) and 0.1M H₂SO₄ solution was measured by the potentiodynamic method (Potentiostat, Gamry 100, USA) using reference and counter electrodes of saturated calomel electrode (Princeton, USA) and platinum rod.

3. Results and discussion

3.1. Microstructure observation and crystallographic texture analysis

Fig. 1 is the microstructure of the 0.087% Gd lean duplex stainless steel in which the elongated austenitic and ferritic phases were well observed. Average sizes of the grains on the surface normal to the ST, TD, and RD directions were \perp ST = 6.58, \perp TD = 6.55, and \perp RD = 10.66 μ m.

Fig. 2 is the typical crystallographic texture of the 33% cold rolled 0.087% Gd lean duplex stainless steel. As shown in Fig. 2, mainly (100) pole was concentrated to sample the normal direction (ND) which was parallel to the ST direction (ND// \perp ST) and (110) pole was concentrated in the middle of the ND and the RD.

3.2. Mechanical properties and corrosion behavior

The micro-Vickers hardnesses of the RD, TD, and ST direction were 258.5 H_V, 292.3 H_V, and 314.7 H_V, respectively. Ultimate tensile strength, yield strength, and elongation were 694 MPa, 538 MPa, and 37.1%, respectively. This data means that mechanical properties of the 0.087% lean duplex stainless steels are much higher than those of the commercial neutron absorber materials such as boron stainless steels (ASTM-A887-89 Grades A and B).

Fig. 3 shows the polarization curves of the 0.087% Gd lean duplex stainless steels in an artificial seawater and 0.1M H₂SO₄ solution at 25°C. As shown in Fig. 3, passivity was not present in both solutions. Table 2 shows the corrosion potential and corrosion rate in the artificial seawater and 0.1M H₂SO₄ solution. The corrosion rates of the 0.087% Gd lean duplex stainless steels were much higher in 0.1M H₂SO₄ solution than in artificial seawater. The corrosion potential and corrosion rate in artificial seawater and 0.1M H₂SO₄ solution

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