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Effect of Trace Element Addition on Mechanical Properties and Corrosion Resistance in Ni-based Alloys for Molten Salt Reactor

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1. Introduction

The development of Molten Salt Reactor (MSR) technology is actively underway over the world. As a variety of MSR design concepts are considered depending on the situation of each country, Korea is developing MSRs that use a liquid fuel in the form of chloride salt and fast neutron spectrum. The MSR attracts interest because it provides a number of benefits, including passive safety, atmospheric pressure operation, high thermal efficiency, *etc*. However, the corrosion of structural materials in molten chloride is recognized as a critical concern about the success of MSRs. The mechanical stability and corrosion resistance of structural alloy materials used in molten salt reactors under extreme high-temperature corrosion environments are very important.

During the MSRE (Molten Salt Reactor Experiment) program, which was operated by Oak Ridge National Laboratory in 1962, Hastelloy N (Ni-based alloy) and its variants were tested in the fluoride salts, which was found that there was significant surface cracking [1,2]. In order to overcome material problems in the MSR environments, we are developing a series of new Ni-alloys, which are being tested in chloride salts. In this study, 1.2 kg ingots of Ni-based alloys were prepared by adding trace elements such as Cu, Zr and La to improve mechanical tensile properties, atmospheric oxidation and corrosion resistance, and compared with the Hastelloy N standard specimen.

2. Methods and Results

The effect of tensile and corrosion properties according to the addition of trace elements of Cu, Zr, and La in the Ni alloy whose composition is slightly changed in the Hastelloy N base was evaluated. By weighing metals for each Ni-based composition, eleven 1.2 kg Ni alloy ingots were manufactured, and hot rolling was performed at 1100°C. Thereafter, the heat treatment was performed at 1100°C for 1 hour and quenched. According to the type and content of trace elements, the tensile strength and elongation were measured at room temperature and 700°C, and atmospheric oxidation and high-temperature molten salt (57 mol% NaCl – 43 mol% $MgCl_2$) corrosion experiments were performed at 700°C for 200 hours.

2.1 Mechanical Properties

For room temperature tensile test, the specimen No. 5 containing 4.19 wt% Cu had an yield strength (YS) of 455 MPa and an ultimate tensile strength (UTS) of 932 MPa, which was higher than specimen No. 4 without trace elements, and showed an elongation of 42% (Fig. 1(a)). The specimen No. 8 containing 0.014 wt% Zr had a high YS of 444 MPa and an UTS of 920 MPa and showed an elongation of 40% (Fig. 1(b)). For reference, in the case of Hastelloy N, the room temperature YS of 314 MPa, an UTS of 794 MPa, and an elongation of 50% were shown. Meanwhile, Fig. 1(c) shows an YS of 342 MPa, an UTS of 560 MPa, and an elongation of 18% as a result of a 700°C high-temperature tensile test for specimen No. 8 containing 0.014 wt% Zr, and showed superior characteristics compared to specimen 4 [3]. In the case of Hastelloy N, the YS is 218 MPa, the UTS is 480 MPa, and the elongation is 30% at 704°C. In other words, almost all specimens containing trace elements, including specimen No. 4, showed higher YS and UTS than Hastelloy N, but the elongation characteristics were relatively low. This is judged that when the heat treatment condition is changed from the existing quenching to the furnace cooling, the elongation characteristics can be improved while maintaining the existing tensile strength characteristics, and from this change, the simultaneous improvement of tensile strength and elongation characteristics can be expected compared to Hastelloy N.

2.2 Atmosphere & Salt Corrosion Properties

It was confirmed that an oxide film was formed after atmospheric oxidation at 700°C for 200 hours, and the oxidation of Ni-Cr-Mo-O proceeded with a non-uniform thickness of 2 to 20 μm, and Fig. 2(a) shows the weight increase after oxidation for each specimen. In addition, a corrosion experiment was conducted at 700°C for 200 hours using 57 mol% NaCl - 43% $MgCl_2$ molten salt, and Fig. 2(b) shows the weight loss for each specimen compared to Hastelloy N. As a result of observing the corroded cross-section SEM and EDS, there was a carbide secondary phase of Mo-Si-C, and the salt corrosion depth of Hastelloy N with Cr and Fe depletion

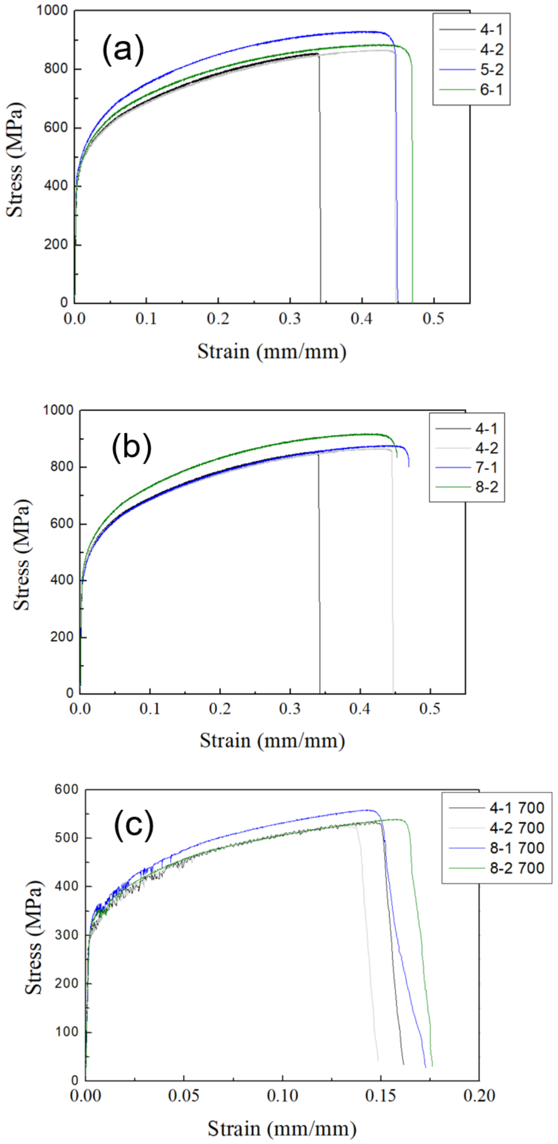

Fig. 1. Change in tensile stress/elongation at room temperature due to the addition of trace elements of (a) Cu, (b) Zr, and (c) change in tensile stress/elongation at 700°C due to the addition of trace element of Zr.

was 60 μm or more, while those of specimens containing trace elements were as small as 10 to 30 μm. It was found that specimens 4 or 7 were excellent in resistance to atmospheric oxidation and salt corrosion, and most of the specimens showed superior oxidation/salt corrosion characteristics than the reference Hastelloy N. In particular, in the case of salt corrosion, all specimens with trace elements were superior to Hastelloy N.

3. Conclusions

As a result of the tensile tests at room temperature and 700°C, the YS and UTS in most specimens were

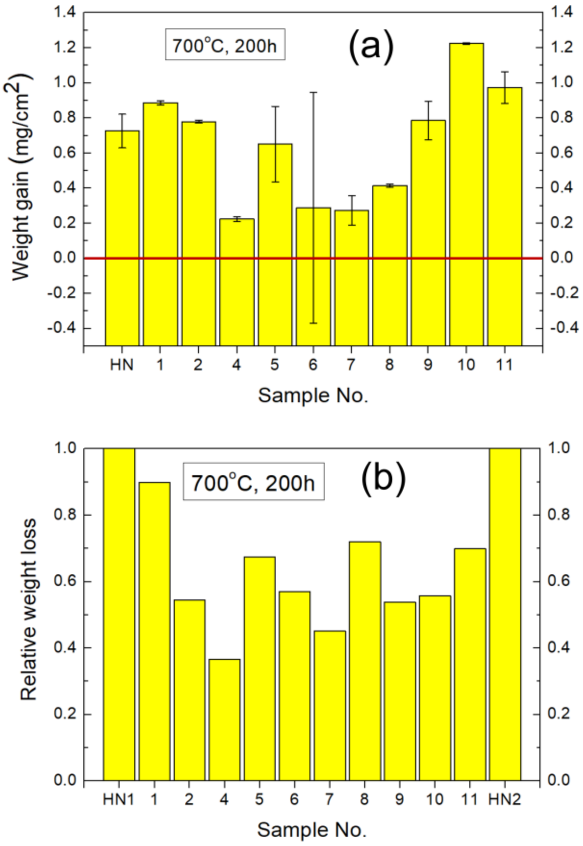

Fig. 2. (a) weight gain after atmospheric oxidation and (b) relative weight loss after salt corrosion at 700°C, 200 h.

higher than those of Hastelloy N, but the elongation characteristics were lower than those of Hastelloy N in both room temperature and high temperature. This can be solved by changing the heat treatment process. At 700°C for 200 hours, the thickness of oxidation corrosion at the atmosphere was relatively smaller than that of salt corrosion, but it was corroded to a significant level (1/2~1/3), and in the case of salt corrosion, less corrosion occurred in all specimens than Hastelloy N. Specimens 4 and 7 showed superior characteristics compared to Hastelloy N in tensile properties, atmospheric and salt corrosion resistance.

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