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Changes in Mechanical Properties of Candidate Structural Materials by Corrosion in High Temperature Molten Salt

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1. Introduction

There has recently been an effort to develop small modular reactors (MSRs) that use molten salt as a coolant and fuel especially in centuries with advanced nuclear technologies [1]. MSR is a novel reactor concept that, when compared to conventional large reactors, can significantly improve safety and economics.

Coolant system materials are required to maintain excellent mechanical properties even under operating conditions because they use a corrosive and high-temperature salt [2].. Because some candidate materials are not covered by the ASME high-temperature reactor design codes, a procedure for obtaining properties and selecting various candidate materials is required [3].

Furthermore, extensive research on the effects of material degradation on deterioration due to the special environment of molten salt is essential.

2. Experimental

The mechanical properties of Hastelloy N, Incoloy 800H, Inconel 617, and Type 316H stainless steel, which are candidate materials for molten salt reactors, were determined in this study by performing tensile tests at room and 650ºC after 1,000 hours of exposure to 650ºC molten salt with a composition similar to that used as a coolant in molten salt reactors.

The chemistries of candidate alloys are listed in Table 1. The specimens shown in Fig. 1 immersed in molten salt mixture of $MgCl_2$ and NaCl at 650ºC using the reactor shown in Fig. 2, pulled out after 1,000 hours, and then subjected to a tensile tests. Tensile tests were performed on which are candidate materials for MSR structures, using small specimens at room temperature and operating temperature (650ºC) in accordance with the ASTM A370-21 standard test. The specimens were subsidized with a reduced section of 15 mm, a thickness of 1mm and a width of 3 mm.

Table 1. Chemistries of candidate alloys for MSR.

Element / Alloy	C	Si	Mn	Cr	Ni	Mo	Co	Fe
Type 316H	0.049	0.57	0.59	16.82	10.29	2.12		bal.
Alloy 800H	0.07	0.42	0.98	20.43	30.18			bal.
Alloy 617	0.090	0.14	0.08	22.20	52.61	9.52	12.3	1.26
Aloy N	0.072	0.273	0.414	7.66	69.33	16.0	0.253	3.66

The test was conducted using MTS Landmark hydraulic material test system with a strain rate of 6.9 x 10^{-4}/s.

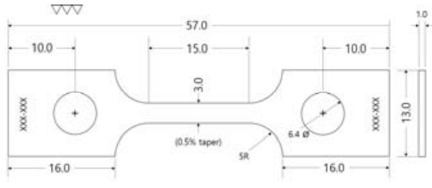

Fig. 1. Drawing of subsize tensile specimen.

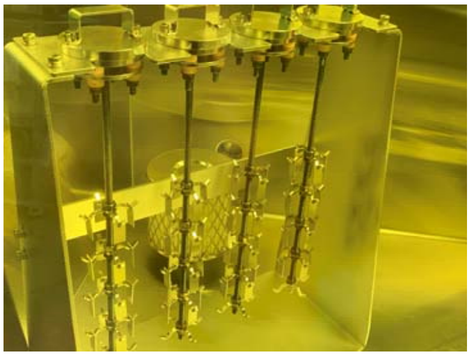

Fig. 2. High temperature molten salt corrosion test rig for candidate material

3. Results and Discussion

The strength of the four candidate materials at room temperature and 650ºC after corrosion in $MgCl_2$-NaCl molten salt at 650ºC are shown in Fig. 3 and Fig. 4, respectively.

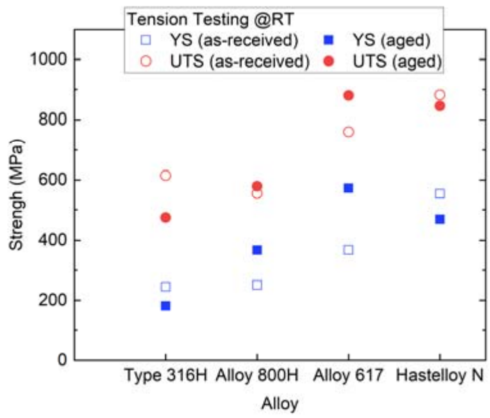

Fig. 3. Comparison of strength at room temperature before and after corrosion of candidate materials.

The strength was high in the order of Hastelloy N, Alloy 617, Type 316H, Alloy 800H but all alloys showed values above the adequate level as shown in Fig. 3 in the initial condition.

The room temperature yield strength and ultimate tensile strength of Type 316H stainless steel after corrosion were decreased by 26% and 23%, respectively, whereas, those of Hastelloy N decreased to a small extent of 16% and 4%, respectively. In contrast, the yield strength of Alloy 800H and Alloy 617 increased by 46% and 56%, respectively, while the ultimate tensile strength increased by 4% and 16%.

The change in strength at 650°C after corrosion tests also showed a tendency generally similar to the results at room temperature.

The yield strength and ultimate tensile strength of Type 316H stainless steel after corrosion were decreased by 36% and 23%, respectively, whereas, the yield strength of Hastelloy N increased by 3% and the ultimate tensile strength decreased by 13%, respectively.

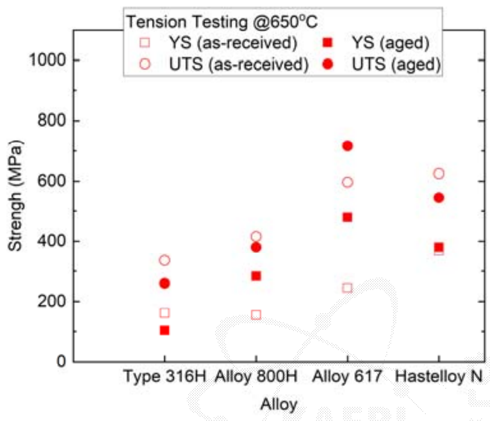

Fig. 4. Comparison of strength at 650°C before and after corrosion of candidate materials.

In terms of elongation, Type 316H stainless steel, Alloy 800H, and Alloy 617 all experienced a similar decrease about 50%, while Hastelloy N experienced a little change at room temperature as shown in Fig. 5.

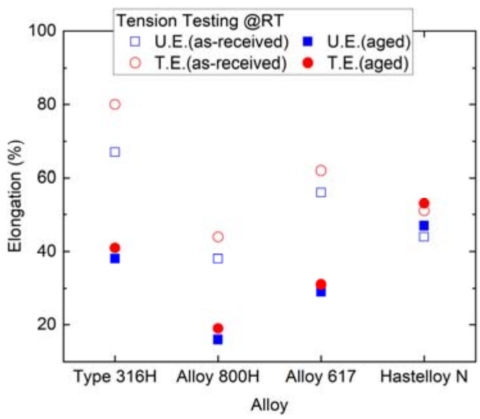

Fig. 5. Comparison of ductility at room temperature before and after corrosion of candidate materials.

This largely due to the depth of grain boundary damage caused by Cr depletion, the distribution of void formation, and the fact that the depth of grain boundary damage in Alloy 617 was more than twice as deep as that in Hastelloy N as shown in Fig. 6. As a result, it is thought that significant embrittlement occurred as a result of Cr depletion via grain boundary damage, decomposition of Cr-rich carbides, and the formation of voids. For A 800H and Alloy 617, the formation of gamma-prime could cause hardening and loss of ductility at 650°C.

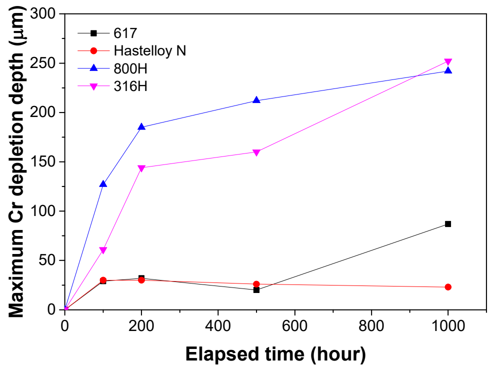

Fig. 6. Comparison of Cr depletion depth of candidate materials by corrosion in molten salt at 650°C.

At 650°C, all except for the total elongation of Hastelloy N showed a reduction in elongation of more than 50% as shown in Fig. 7. It is noteworthy that even in case of Hastelloy N the reduction in elongation due to corrosion is quite large at 650°C.

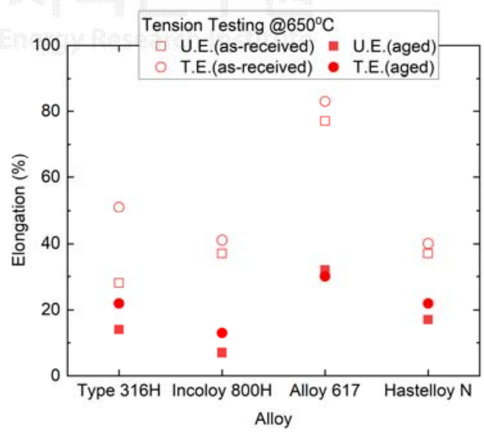

Fig. 7. Comparison of ductility at 650°C before and after corrosion of candidate materials.

REFERENCES

[1] R. N. Wright and T. –L. Sham, "Status of Metallic Structural Materials for Molten Salt Reactors", INL/EXT-18-45171, Idaho National Laboratory, Idaho Falls, Idaho, May 2018.

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[3] J. Busby et al., "Technical Gap Assessment for Materials and Component Integrity Issues for Molten Salt Reactors", ORNL/SPR-2019/1089, Oak Ridge National Laboratory, Oak Ridge, TN, March 2019.