33. Cladding Materials for SNAP-8

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The SNAP-8 is an electrical generating system being developed for use in future space vehicles. The reactor is NaK cooled, fueled and moderated with zirconium hydride containing ^{235}U , and reflected with beryllium. The fuel element is clad with Hastelloy N. We have found that this alloy is subject to a type of thermal neutron damage that results in reduced strength and ductility at high temperatures. We were asked to determine (1) the magnitude of the property changes in Hastelloy N due to irradiation, (2) whether the properties could be improved significantly by thermal-mechanical treatments or by changes in alloy composition, and (3) the property changes in several other candidate cladding materials.

During the first year of this study,¹ we found that irradiation in the range of 650 to 760°C to thermal fluences of 2 to 3×10^{20} neutrons/cm² reduced the postirradiation fracture ductility of standard Hastelloy N. Under certain conditions of test temperature and strain rate, the fracture strain was only a few tenths of a percent in wrought materials² and in tubes.³ We also found that small changes in alloy composition were very effective in improving the properties and that various thermal-mechanical treatments did not affect the postirradiation properties significantly.¹

During the past year, we compared the postirradiation properties of several candidate cladding materials. These materials included Hastelloy X, Incoloy 800 with various titanium levels, type 304 stainless steel, a modified type 304L stainless steel containing 0.2% Ti, and several heats of modified Hastelloy N containing additions of titanium, zirconium, and niobium. The

work on the modified Hastelloy N is also of interest to the Molten Salt Reactor Program and is discussed further in Chapter 34 of this report.

The designers felt that failure would result from the inability of the material to deform plastically rather than from overstressing. Hence, the strain at fracture is the most important parameter in this study and our results are presented on this basis in Figs. 33.1 and 33.2. The nickel-base alloys (Fig. 33.1) are characterized by a very distinct ductility minimum as a function of strain rate. The titanium-modified Hastelloy N exhibits some improvement over standard Hastelloy N, but Hastelloy X is significantly better than both standard and modified Hastelloy N. The iron-base alloys (Fig. 33.2) were generally more ductile than the nickel-base alloys. The fracture strain of type 304 stainless steel decreased with decreasing strain rate (or decreasing stress), whereas the fracture strain of the titanium-modified type 304L stainless steel and Incoloy 800 increased with decreasing strain rate. The one heat of Incoloy 800 containing 0.10% Ti and 0.12% C had markedly higher ductility at low strain rates than any of the other alloys. Since Incoloy 800 is a candidate LMFBR alloy, its postirradiation properties are also discussed in Part III, Chapter 22 of this report.

Several laboratory melts of modified Hastelloy N containing various concentrations of titanium were irradiated and then creep tested in an effort to determine the titanium concentration required to give optimum resistance to irradiation damage. The results of tests at 650 and 760°C are summarized in Fig. 33.3. The general trend at both temperatures is that the properties continue to improve with increasing titanium level. The minimum level required for significant improvement seems to be slightly higher at 760 than at 650°C (0.5 compared with 0.3%). At both temperatures there seems to be little additional improvement over the range of 0.5 to 0.8% Ti.

Other modified alloys of the Hastelloy N type had very good postirradiation properties. For an alloy with 1% Zr, at 760°C the rupture life was 100 times that of standard Hastelloy N and the fracture strain was 12%

¹ H. E. McCoy, Jr., and J. R. Weir, Jr., *Metals and Ceramics Div. Ann. Progr. Rept. June 30, 1967*, ORNL-4170, pp. 160-61.

² H. E. McCoy, *Effects of Irradiation on the Mechanical Properties of Two Vacuum-Melted Heats of Hastelloy N*, ORNL-TM-2043 (January 1968).

³ H. E. McCoy, Jr., and J. R. Weir, "Stress-Rupture Properties of Irradiated and Unirradiated Hastelloy N Tubes," *Nucl. Appl.* 4, 96-104 (1968).

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Fig. 33.1. The Effect of Strain Rate on the Postirradiation Ductility of Three Nickel-Base Alloys. The titanium-modified Hastelloy N had the nominal percentage composition of Ni-12 Mo-7 Cr-0.2 Mn-0.5 Ti-0.05 C.

Fig. 33.2. The Effect of Strain Rate on the Postirradiation Ductility of Incoloy 800 and Stainless Steel. The modified type 304L stainless steel had the percentage composition of Fe-19.5 Cr-11 Ni-1 Mn-0.05 Si-0.2 Ti-0.012 C.

compared with 1% for standard Hastelloy N under comparable conditions. An alloy containing 2% Nb and 0.5% Ti showed an 80-fold improvement in rupture life and a fracture strain of 20%.

Although our program disclosed that several improved alloys could probably be developed, a project decision was made that the properties of standard Hastelloy N were adequate for satisfactory operation of the reactor. The latter part of this fiscal year was spent in testing specimens that were already irradiated, and our program will terminate July 1, 1968.

Fig. 33.3. Variation of Postirradiation Creep Properties of Modified Hastelloy N with Titanium Content.