IRRADIATION CREEP AND SWELLING FROM 400°C TO 600°C OF THE OXIDE DISPERSION STRENGTHENED FERRITIC ALLOY MA957—M. B. Toloczko, D. S. Gelles, F. A. Garner, and R. J. Kurtz (Pacific Northwest National Laboratory),* and K. Abe (Dept. of Quantum Sci. and Energy Eng., Tohoku University, Sendai, Japan)

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EXTENDED ABSTRACT

Recently, there has been a growing interest in the use of oxide dispersion strengthened (ODS) ferritic steels for fusion reactor applications. As part of an extensive study performed at PNNL on the ODS steel MA957 [1], irradiation creep tests were performed on pressurized tubes made from MA957 by two different methods. The tubes were made either by gun drilling alone or by a combination of rod drawing and gun drilling. The different fabrication methods were explored because ODS steels have been difficult to form. The pressurized tubes were irradiated in the Fast Flux Test Facility (FFTF) to doses ranging from 40 dpa to 110 dpa at temperatures ranging from 400°C to 600°C. The effective stresses resulting from the pressurization of the tubes ranged from 0 MPa to 175 MPa.

Swelling was estimated from diameter changes of the stress free tubes, and none of the stress-free tubes exhibited any evidence of swelling by this measurement. The observed irradiation creep behavior as a function of dose was similar to previously observed irradiation creep behavior in conventional ferritic-martensitic steels except that at 400°C, there appears to be a slight reduction in irradiation creep rate of MA957 after 80 dpa. The creep behavior below 80 dpa may perhaps represent a creep transient, or the reduction in creep rate above 80 dpa may be due in-part to the method used to manufacture this steel. In comparing the creep behavior of the gun-drilled tubing to the drawn tubing, the creep rates and transients were similar in magnitude, but the gun-drilled tubing was more prone to failure. Most all the gun drilled tubes failed before the last irradiation, but nearly all the drawn tubes survived all the irradiation cycles. An example of this can be seen in Figure 1.

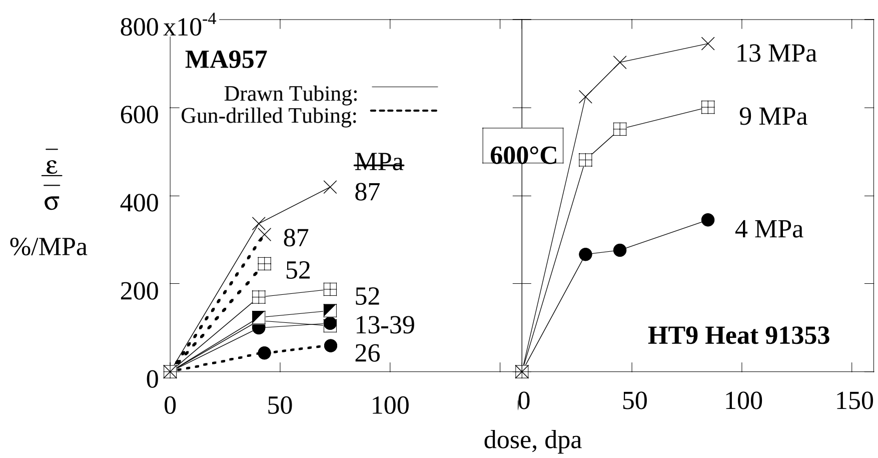

Figure 1. Irradiation creep behavior of MA957 and HT9 at 600°C showing that the drawn MA957 tubes failed less frequently than the gun-drilled MA957 tubes and also showing at this temperature in an irradiation environment that transient creep strain in MA957 is much lower than that for HT9.

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The physical mechanisms which contribute to creep in an irradiation environment can be considered to be due to both irradiation and thermal effects on point defect and extended defect populations and dynamics. The progression of irradiation creep as a function of time is similar to that of thermal creep; there is a creep transient which appears to occur within the first 40 dpa, and then this is followed by steady state creep. The similarity is likely due to the fact that in the temperature range studied here, creep in a thermal environment is a large fraction of the amount of creep which occurs in an irradiation environment [2]. For temperatures from 400°C to 550°C, the observed steady state irradiation creep rates of MA957 were similar to that of HT9. At 600°C, the steady state creep rate of MA957 was unchanged, but the value for HT9 had doubled. The creep rates are shown in Figure 2. At 600°C, it is likely that thermal creep is beginning to strongly dominate the total creep signal, and it is known that ODS steels are more resistant to thermal creep than conventional ferritic-martensitic steels at this temperature [3]. Transient creep strain contributed increasingly to the total irradiation creep strain as the temperature increased from 400°C to 600°C for both MA957 and HT9, and by about 75 dpa at 600°C, the transient creep strain contributed to about one-half the total creep strain in MA957. This can be seen in Figure 1. The total creep strain in MA957 after 40 dpa at 600°C is due almost entirely to transient creep and is about 0.25% strain at 26 MPa, and about 0.9% strain at 52 MPa. The transient values for MA957 were much smaller than that for HT9 as can also be seen in Figure 1.

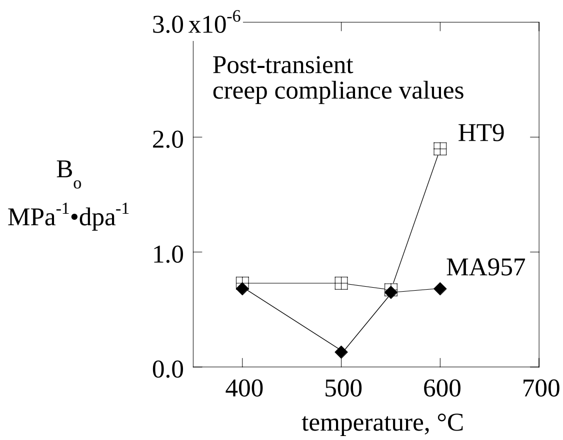

Figure 2. Creep compliance of MA957 (and HT9) as a function of temperature.

MA957 offers no clear advantage over HT9 at temperatures below 600°C. However, from the experimental results, it is clear that MA957 has better creep resistance than HT9 in an irradiation environment for temperatures of 600°C and probably higher. At 600°C, the large contribution of transient creep to the total amount of creep in MA957 is noteworthy, and for doses up to 40 dpa, it makes up essentially all of the total creep strain. The total creep strains at an effective stress of about 52 MPa after 40 dpa at about 600°C are about 0.9%. If better irradiation creep resistance is required, it appears that the next step in improving the irradiation creep resistance of MA957 at 600°C (and probably above) should be aimed at understanding and controlling the creep transient. The reduced failure rate of the drawn tubing also suggests that some effort should be aimed towards defining the processing conditions which provide the best failure resistance.

References

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[3] D. K. Mukhopadhyay, F. H. Froes, D. S. Gelles, Development of oxide dispersion strengthened ferritic steels for fusion, J. Nucl. Mater. 258-263 (1998) 1209-1215.