ORNL/LTR-2018/499

Tensile Testing of Irradiated Grade 92 Ferritic-Martensitic Steels at the IMET Hot Cell Facility

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April 2018

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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Fusion & Materials for Nuclear Systems Division

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Date Published: April 2018

NSUF Work Package #: UF-18OR021003
Work Package Manager: Kory Linton
Milestone #: M3UF-18OR0210032

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UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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ACKNOWLEDGMENTS

This research used resources at the LAMDA laboratory operated by the Oak Ridge National Laboratory. Funding for this research was provided by the US Department of Energy, Office of Nuclear Energy Nuclear Science User Facility. This report was authored by UT-Battelle, LLC under Contract No. DE-AC05-00OR22725 with the US Department of Energy.

ACRONYMS

FM	Ferritic-martensitic
IMET	Irradiated Materials Examination and Testing
ORNL	Oak Ridge National Laboratory
PIE	Post-Irradiation Examination
NSUF	Nuclear Science User Facilities
HFIR	High Flux Isotope Reactor
CINR	Consolidated Innovative Nuclear Research
LAMDA	Low Activation Materials Development and Analysis
SEM	Scanning Electron Microscopy
TEM	Transmission Electron Microscopy

EXECUTIVE SUMMARY

This report summarizes the completed post-irradiation tensile testing of five ferritic-martensitic (FM) steel SS-J2 specimens at the Irradiated Materials Examination and Testing (IMET) hot cell facility at Oak Ridge National Laboratory (ORNL). A brief description of the motivation for the study, the properties and irradiation conditions of the samples, and the tensile testing conditions are provided. The results will be used to compare the mechanical properties of the irradiated specimens to un-irradiated conditions to determine how irradiation affects the steel alloy material behavior.

1. INTRODUCTION

Stainless steels are used for a number of structural components in nuclear reactors, including pressure tubes, which are used in-core and exposed directly to radiation. Steels used for nuclear applications must be able to retain mechanical properties during irradiation to ensure the safe performance of reactors. The recent development of a number of high-performance stainless steels has provided the prospect of materials that may surpass the irradiation performance of currently used steels. Specifically, modern ferritic-martensitic (FM) steels have an improved thermal conductivity, high-temperature stability, and void swelling compared to currently used steels [1, 2]. In addition, innovative steels may have the potential to be used in next generation nuclear systems, which have higher operating temperatures and more severe neutron flux conditions [3]. Compared to the classic FM steel Grade 91 that has been used in varied types of reactors, Grade 92 generally has greater tensile and creep strengths, which provides better safety margins and economics. Irradiation testing of new steel alloys is necessary to evaluate the materials for future reactor applications. Post-irradiation examination (PIE) of irradiated steels can determine the effects of irradiation on mechanical properties and microstructural evolution, thereby providing insight into the development of advanced alloys.

Oak Ridge National Laboratory (ORNL) has a number of PIE capabilities under the Nuclear Science User Facility (NSUF) program to test mechanical properties, including in-cell tensile testing of sub-sized (SS-J2) tensile specimens. This report summarizes the tensile testing of five irradiated ferritic-martensitic steel specimens that were previously irradiated in the High Flux Isotope Reactor (HFIR). The purpose of the tensile testing is to investigate the post-irradiation mechanical behavior of FM steel Grade 92 and provide data to evaluate the performance of this material for potential use in current and advanced nuclear reactor applications. Radiation resistance of three heats of Grade 92 are to be examined in this CINR NSUF FY2017 project. One of the heats is optimized Grade 92, developed under the Advanced Reactor Concept program. Its tensile test results are reported here. The other two heats are commercial Grade 92, which will be examined and reported separately in near future.

2. TENSILE TESTING EXPERIMENTAL PROCEDURE

Five irradiated SS-J2 tensile specimens were tested in air at room temperature in an Instron ElectroPuls E1000 test system, which is located in Cell 2 at the Irradiated Materials Examination and Testing (IMET) hot cell facility. Table 1 shows a list of the specimens and their associated irradiation conditions. The specimens were irradiated with different conditions in order to isolate the effect of dose and temperature on the mechanical properties. The geometry for the SS-J2 specimen is 4.0 x 16.0 x 0.5 mm with a gauge section of 1.2 x 5.0 x 0.5 mm (Figure 1). The samples were loaded in the Instron machine (Figure 2) and tested under a fixed crosshead speed, which causes a fixed strain rate. The crosshead speed during the tensile test was 0.012 in/min and the corresponding strain rate was 0.001 s^{-1}. The elongation response of the material is recorded throughout the test in order to produce tensile curves until the point at which the strain causes rupturing of the specimen.

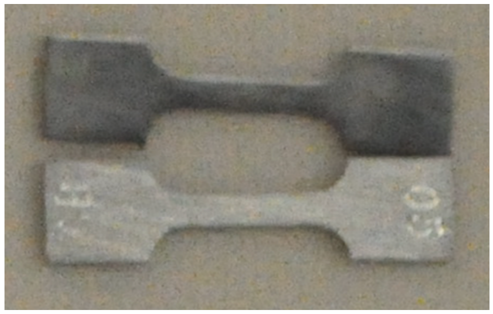

Figure 1. SS-J2 Specimen GB05 pictured before irradiation.

Table 1. List of irradiation conditions for tensile tested specimens.

Sample ID	Material Alloy	Dose [dpa]	Temperature [°C]
GB04	FM (9Cr-2WVNb)	7	300
GB05	FM (9Cr-2WVNb	14	300
GB11	FM (9Cr-2WVNb)	7	650
GB12	FM (9Cr-2WVNb	14	650
TA04	FM (9Cr-1WVTa)	7.4	300

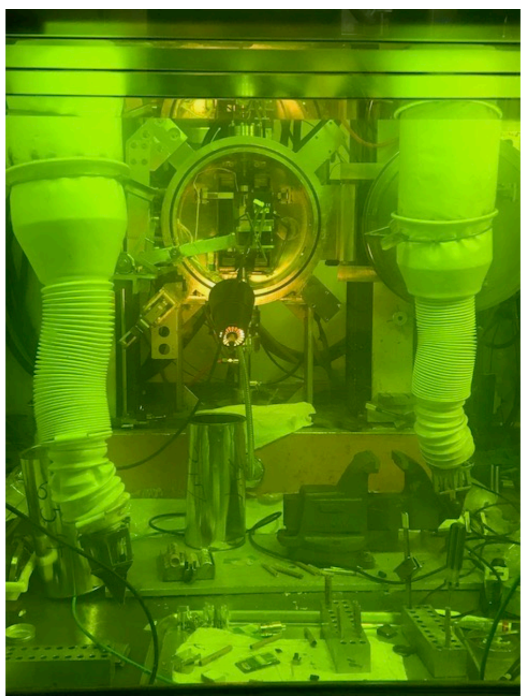

Figure 2. Instron machine used for tensile testing, which is located in Cell 2 at the IMET facility.

3. RESULTS

The resulting tensile curves for each tested specimen are shown in Figure 3. The data that will be extracted from these tensile curves during the analysis include material properties such as yield strength, uniform elongation, and ultimate strength. These curves will be compared to the reference un-irradiated tensile curve for these alloys in order to determine the evolution of the mechanical behavior as a function of temperature and accumulated dose.

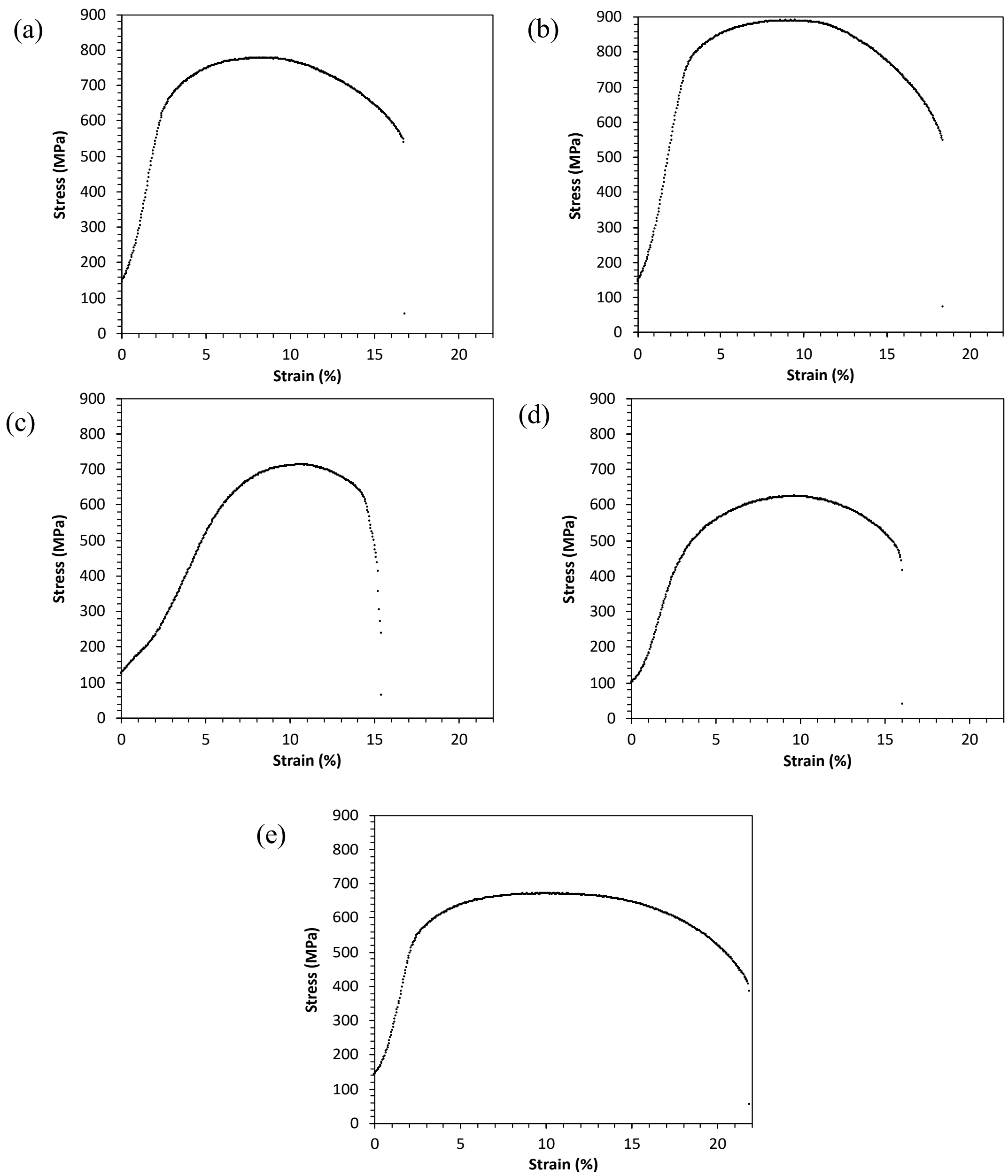

Figure 3. Results from tensile testing of (a) GB04, (b) GB05, (c) GB11, (d) GB12, and (e) TA04.

4. CONCLUSION AND PATH FORWARD

The successful completion of the 2018 NSUF Milestone "Tensile testing of GB specimens currently located at ORNL" consisted of tensile testing five neutron irradiated ferritic-martensitic steel specimens. The tensile tests were done at the IMET hot cell facility at ORNL. The next step in this research is to investigate the resulting microstructures of these specimens. Therefore, one-half of each ruptured specimen has been shipped to the Low Activation Materials Development and Analysis (LAMDA) laboratory, where further characterization will take place. Characterization techniques that will be utilized at LAMDA include Scanning Electron Microscopy (SEM), nano-indentation, and Transmission Electron Microscopy (TEM). These results will provide an in-depth understanding of the evolution of the FM Grade 92 alloy microstructure and mechanical properties during irradiation and will help evaluate whether this steel is suitable for use in a nuclear reactor.

5. REFERENCES

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