LA-UR-14-20263

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Intended for: Report

Issued: 2014-01-15

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Development of improved ATF engineering alloy - Mechanical testing of initial alloy

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Abstract

In this report we present the results on the tensile testing of two FeCrAl alloys developed at Oak Ridge National Laboratory.

1. Introduction

After the events took place in Fukushima in 2011, improved accident tolerant fuel became a major research area worldwide. The improved accident tolerant fuel systems require enhanced durability under the loss of active cooling for a considerably longer period compared to standard system (UO₂-Zircaloy) while maintaining (or improving) normal fuel performance. One class of the candidate cladding material is FeCrAl alloys.

FeCrAl ferritic alloys are highly resistant to oxidation due to formation of a protective oxide scale at high temperatures [1]. Therefore they are considered as alternative cladding materials for current fleet of light water reactors [2].

The purpose of this report is to present results of mechanical testing performed on the initial FeCrAl ferritic alloys that will perform better under accident scenarios mentioned above. Testing includes room temperature and elevated temperature testing at ~300°C and 600°C.

2. Experimental

2.1. Materials

The ORNL improved accident tolerant FeCrAl alloys (ORNL-A and ORNL-B) were cast by arc-melting in a back-filled argon gas atmosphere, pre-alloyed with Y, Cr and Al and cast. The nominal chemical compositions are given in Table 1. Figure 1 shows the optical microscopy images of the two alloys. The details of the production steps can be found elsewhere [3].

Table 1 Nominal and analyzed alloy compositions of ORNL nuclear-grade FeCrAl alloys

ID	Status	Composition, wt%							
		Fe	Cr	Al	Y	C	S	O	N
ORNL-A	Aim	79.85	15	5	0.15	0	0	0	0
	Analyzed	79.87	14.98	5.02	0.033	0.0040	0.0012	0.0013	0.0005
ORNL-B	Aim	79.35	17.5	3	0.15	0	0	0	0
	Analyzed	79.54	17.51	2.93	0.017	0.0050	0.0006	0.0015	0.0011

Figure 1 Optical microscopy images of (a) ORNL A (b) ORNL B

2.2. Tensile tests

Tensile samples were cut using EDM. The tests were performed at a strain rate of 0.0005 s^{-1} on an Instron 1125. Compliance was corrected using loading slope. Machine was calibrated using HT-9 samples previously tested. Figure 2 shows the miniature tensile test sample schematic. A minimum of two samples of each alloy were tested.

Figure 2. Schematic of miniature tension test samples with dimensions. The samples were cut using EDM.

3. Results

Engineering stress-strain curves obtained at room temperature are shown in Figure 3. SEM images of the fracture surfaces are also shown. Both images show typical ductile fracture surfaces that contain dimples. Yield strength values were measured at 0.2% offset. The fitting

parameters were also shown on the graph inlets. ORNL A shows a higher yield strength compared to ORNL B. Both show similar total elongation values ~20%.

Figure 3. Engineering stress-strain curves of ORNL A (top) and B (bottom) samples are shown. Corresponding SEM images show dimples, typical of ductile fracture surface.

High temperature testing

Engineering stress-strain curves obtained at 300 and 600°C are shown in Figures 4 and 5. Yield strength values were measured at 0.2% offset. The fitting parameters to the linear portion

of the stress-strain curves were also shown on the graph inlets. ORNL A shows higher yield strength compared to ORNL B.

Figure 4. Engineering stress-strain curves of ORNL A&B alloy tested at 300°C.

Figure 5. Engineering stress-strain curves of ORNL A and B alloys tested at 600°C.

Summary

Two FeCrAl based alloys were tested in tension at room temperature and elevated temperatures (300 and 600°C). Typical tensile behavior is observed for this class of alloys. The results are summarized in Table 2.

Table 2. Summary of the tensile tests on ORNL A & B at 23, 300, and 600C.

23°C	σ_Y (MPa)	σ_{UTS} (MPa)	$\epsilon_{uniform}$ (%)	ϵ_{total} (%)
ORNL A	581	587	3.3	21
ORNL B	539	547	2.8	19.8
300°C				
ORNL A	485	493	1.9	17.5
ORNL B	453	470	1.7	15.9
600°C				
ORNL A	188	207	9	32.1
ORNL B	200	209	1.9	28.6

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