Tensile Properties and Corrosion Susceptibility of Alloy C–276 in S–I Environment

A.K.Roy[a], *J.Pal*[b]

[a]*Associate Professor, Mechanical Engineering, University of Nevada, Las Vegas, 4505 Maryland Parkway, Las Vegas, NV 89154, USA*
[b]*Graduate Student, Mechanical Engineering, University of Nevada, Las Vegas, 4505 Maryland Parkway, Las Vegas, NV 89154, USA*

Abstract

The tensile properties of Alloy C-276, a leading candidate structural material for heat exchanger applications, have been determined at temperatures ranging from ambient to 600°C at a strain rate of 10^{-3}/sec. The results indicate that both the yield strength and ultimate tensile strength of this alloy were gradually reduced with increasing temperature, as expected. However, the ductility in terms of percentage elongation was reduced at 200 and 450°C. The results of stress corrosion cracking (SCC) tests involving this alloy in a simulated acidic solution containing sulfuric acid and sodium iodide (S-I) revealed no failure at a constant load. SCC testing under a slow-strain-rate condition showed reduced failure stress at an elevated temperature, with insignificant variation in the ductility parameters. As to the general corrosion behavior, this alloy showed very little weight-loss in a similar environment. The fractographic evaluation of the primary fracture surface of the tensile specimens revealed dimpled microstructures, indicating ductile failure.

Keywords: Alloy C-276, Tensile Properties, Stress Corrosion Cracking, Corrosion Rate, Fractography

Work Description

Fossil fuels have been extensively used throughout the world for quite sometime. Since the cost of fossil fuels is escalating at an alarming rate, substantial efforts are currently being made to identify and develop an alternate source of energy. Hydrogen is one such energy, which is known to be available from many sources using techniques such as electrolysis of water at elevated temperatures. However, the cost of hydrogen generation using the conventional electrolysis technique is unusually high. In view of this rationale, the United States Department of Energy (USDOE) has initiated a bold step in generating hydrogen using thermochemical processes involving chemical reactions at elevated temperatures. The elevated temperatures needed for hydrogen generations are proposed to be developed from nuclear power.

The sulfur–iodine(S–I) cycle is a leading process of generating hydrogen using nuclear power. The heat generated from the nuclear power plant will be transmitted to the hydrogen generation plant by use of an intermediate heat–exchanger. The hydrogen generating plant itself will also have its own heat–exchanger, as illustrated in figure 1. The structural materials to be used in this heat–exchanger will be subjected to the presence of aggressive chemical species at temperatures approaching 800°C. Thus, these materials have to possess significant corrosion resistance and resistance to plastic deformation at elevated temperatures.

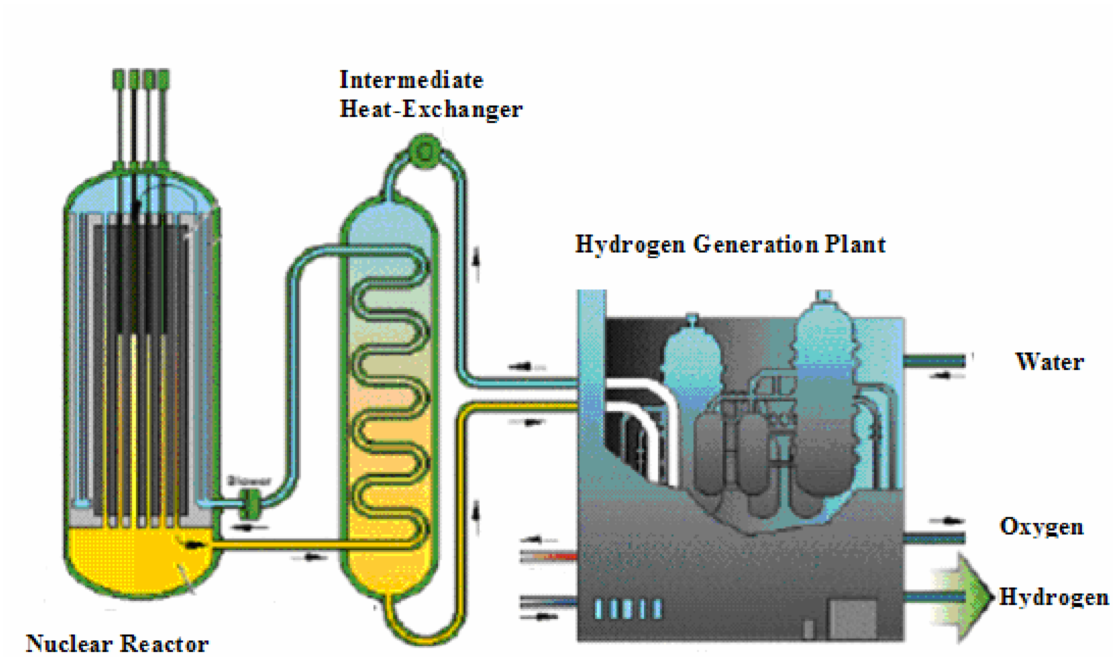

Figure 1

While many candidate structural materials in this investigation have been identified by The USDOE for such application, austenitic Alloy C–276 has been tested in a solution-annealed condition for evaluation of its metallurgical and corrosion properties under conditions relevant to the S–I cycle. The chemical composition of Alloy C-276 tested in this investigation is shown in Table 1.The tensile properties of Alloy C-276 have been determined at temperatures ranging from ambient to 600°C using a commercially available testing machine. For elevated temperature tensile testing, nitrogen was used in the testing chamber to prevent the contamination/oxidation of the gage section of the cylindrical specimen. Parameters such as the yield strength (YS), ultimate tensile Strength (UTS), percent elongation (%El) and percent reduction in area (%RA) were determined from these tests.

Table 1. Chemical composition of Alloy C-276(wt %)

Heat No.	C	Co	Cr	Fe	Mn	Mo	Ni	P	S	Si	V	W
2760 1 3939	0.005	1.42	15.87	5.43	0.52	15.62	BAL	0.007	0.003	0.02	0.15	3.56

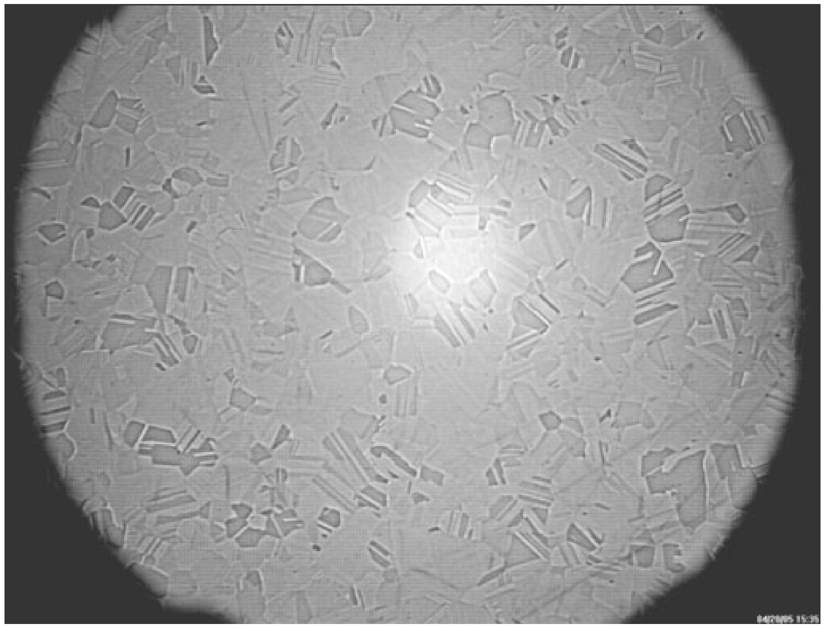

Figure 2. Optical Micrograph of Sectioned Bar Material at 50X

The susceptibility of Alloy C–276 to stress corrosion cracking (SCC) was determined using cylindrical specimens in a simulated acidic solution (pH~1) containing sulfuric acid and sodium iodide at ambient and elevated temperatures using constant load (CL) and slow–strain–rate (SSR) testing techniques. A strain rate of 3.3 X 10^{-6} sec^{-1} was used in the SSR testing. The cracking susceptibility at CL was determined by the time–to–failure (TTF) for a maximum testing duration of 30 days. The SCC behavior under the SSR condition was expressed in terms of TTF, the true failure stress (σ_f) and ductility parameters including %El and %RA. The corrosion rate of Alloy C–276 was determined by immersing coupons in a similar (S–I) environment contained in an autoclave at 150°C for a variable time period. The metallurgical microstructure of Alloy C–276, evaluated by optical microscopy, is shown in figure 2. The fractographic evaluation of all cylindrical specimens at the primary fracture face was determined by scanning electron microscopy (SEM). The comprehensive test results are summarized below:

Results

- The results of tensile testing using smooth cylindrical specimens indicate that both YS and UTS were gradually reduced with increasing temperature. However, the failure strain (e_f) was reduced at temperatures upto 200°C followed by an enhancement upto 400°C. Subsequently, some irregular pattern was observed at temperatures beyond this level. The comparisons of engineering stress vs. strain (s-e) diagrams at different temperatures are shown in figure 3. The magnitudes of all tensile parameters determined from these tests are shown in Table 2. Also, the variations of all four parameters with temperature are illustrated in figures 4-7.

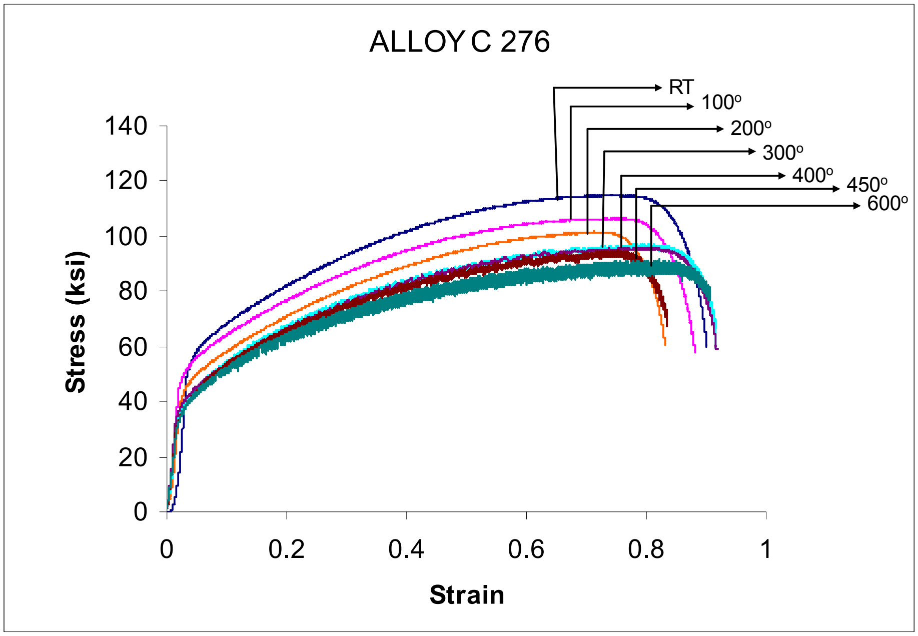

Figure 3. Comparison of s-e Diagram vs. Temperature

Table 2. Results of Tensile Testing

Temp (° C)	YS, ksi (Mpa)	UTS, ksi (Mpa)	%El	%RA
RT	51.8 (357.2)	115.6 (797.0)	86.8	81.6
100	47.0 (324.1)	107.2 (739.1)	86.1	81.7
200	42.1 (290.3)	102.9 (709.5)	81.3	77.9
300	40.0 (275.8)	98.2 (677.1)	88.9	75.8
400	34.9 (240.6)	96.9 (668.1)	85.6	71.0
450	32.2 (222.0)	95.0 (655.0)	81.1	74.9
600	31.0 (213.7)	91.2 (628.8)	86.8	64.3

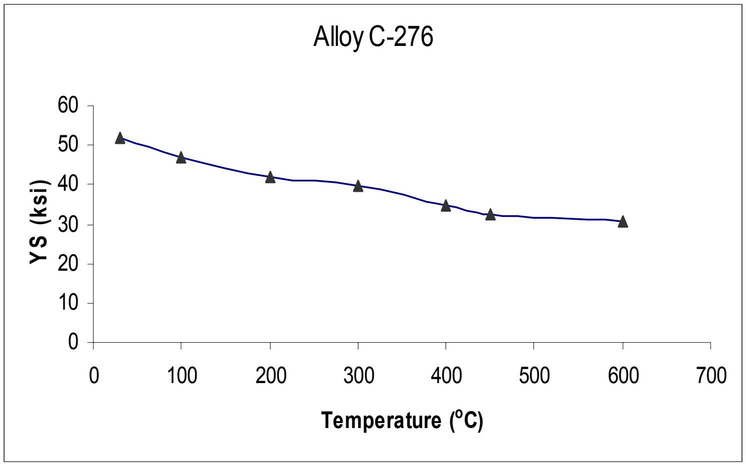

Figure 4. YS vs. Temperature

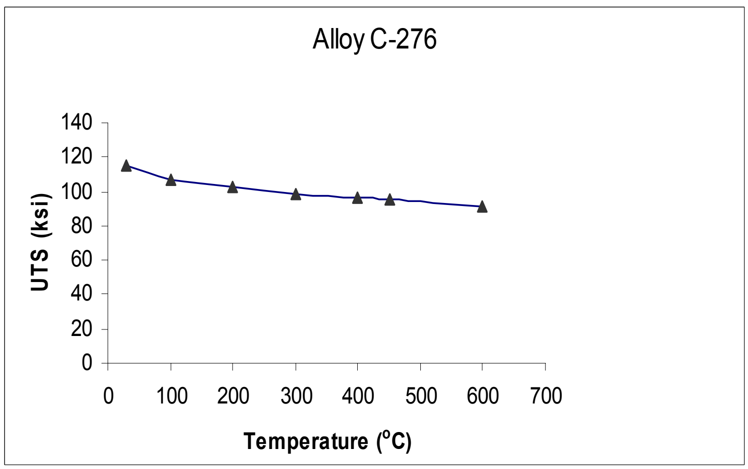

Figure 5. UTS vs. Temperature

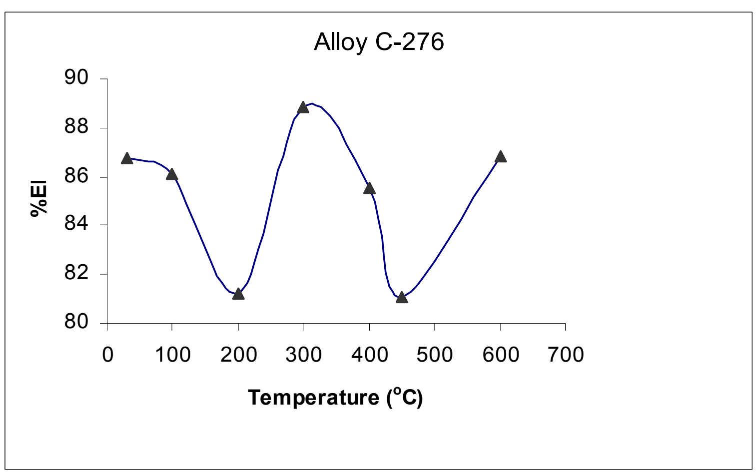

Figure 6. %El vs. Temperature

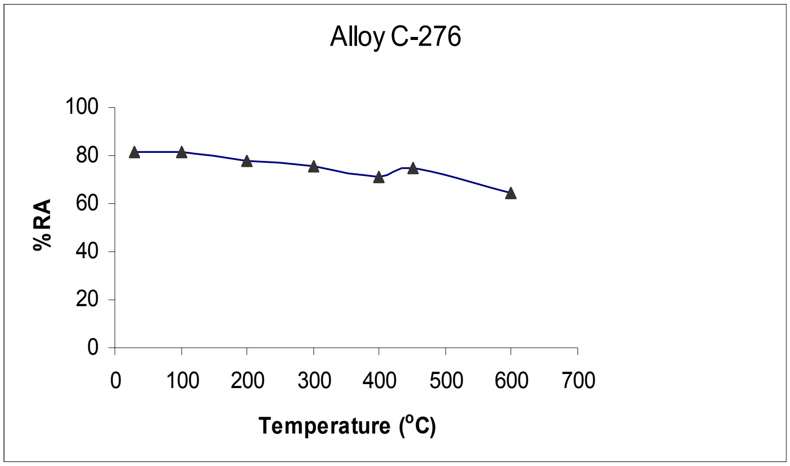

Figure 7. %RA vs. Temperature

- The susceptibility of Alloy C-276 to SCC in the S-I solution at CL was determined by using both smooth and notched specimens. The results indicate that the smooth specimens did not undergo failure at an applied stress equivalent to 95% of the material's YS value. As to the notched specimens, no failures were observed at an applied load of 70% of the yielding load of Alloy C-276.

- The results of SCC testing under the SSR condition showed a gradual reduction in σ_f value with increasing temperature. However, the TTF and the ductility parameters were not significantly influenced by the variation in temperature. A comparison of the s-e diagrams at different temperatures is shown in Figs. 8-1 & 8-2. The magnitudes of TTF, $\sigma_{f,}$ %El and %RA using both smooth and notched specimens are given in Table 3.

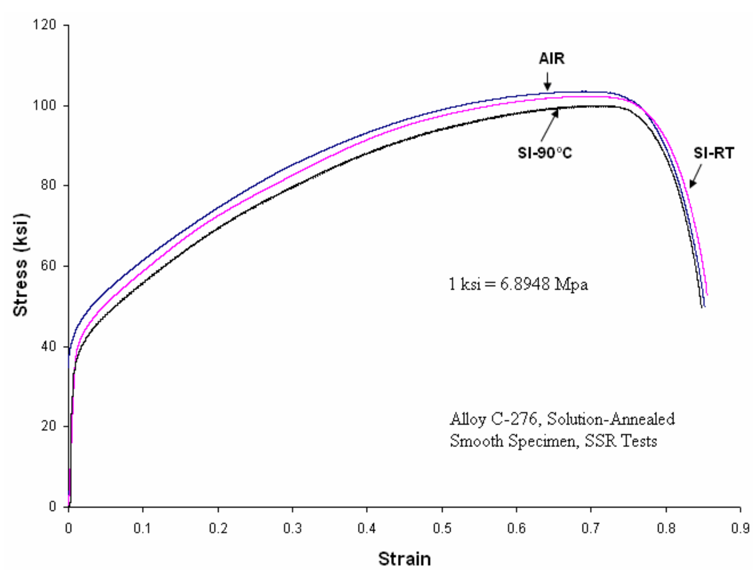

Figure 8-1. Comparison of s-e Diagrams in Air and S-I Solution

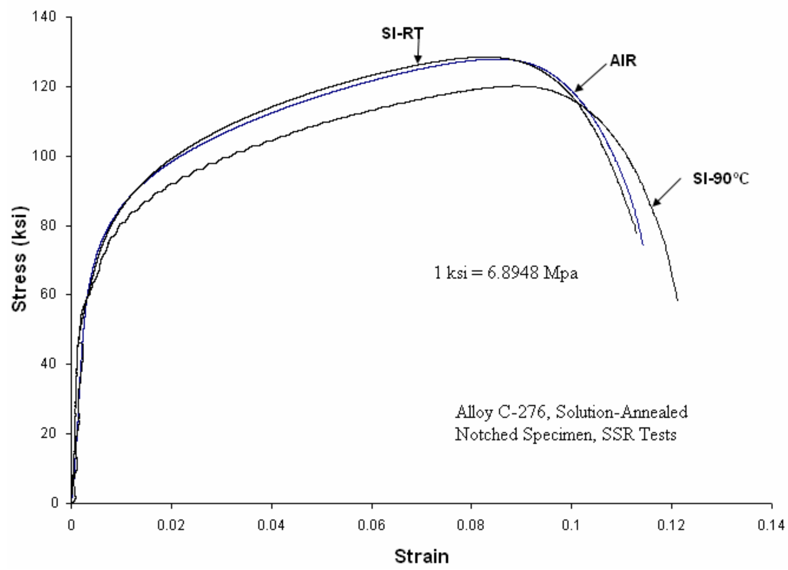

Figure 8-2. Comparison of s-e Diagrams in Air and S-I Solution

Table 3. SSR Test Results (smooth & notched specimen)

Environment/ Specimen Type	Temperature (^oC)	%El	%RA	σ_f (ksi)	TTF (hours)
Air/ ST	RT	20.6	81.6	274	72.1
S-I / ST	RT	21.1	80.8	265	73.1
S-I/ ST	90	20.5	79.0	247	71.6
Air/ NT	RT	2.9	58.0	174	10.6
S-I/ NT	RT	2.7	54.5	162	10.5
S-I/ NT	90	2.9	55.9	146	11.1

ST: Smooth Tensile
NT: Notched Tensile
RT: Room Temperature

- The results of corrosion testing performed in an autoclave in a 150°C acidic solution indicate that the resultant weight-loss after exposures of 7, 14 and 28 days were nominal. The calculated corrosion rates in terms of mpy are given in Table 4. None of the tested coupons showed any signs of localized attack. Variation of weight-loss as a function of test duration is shown in Fig. 9.

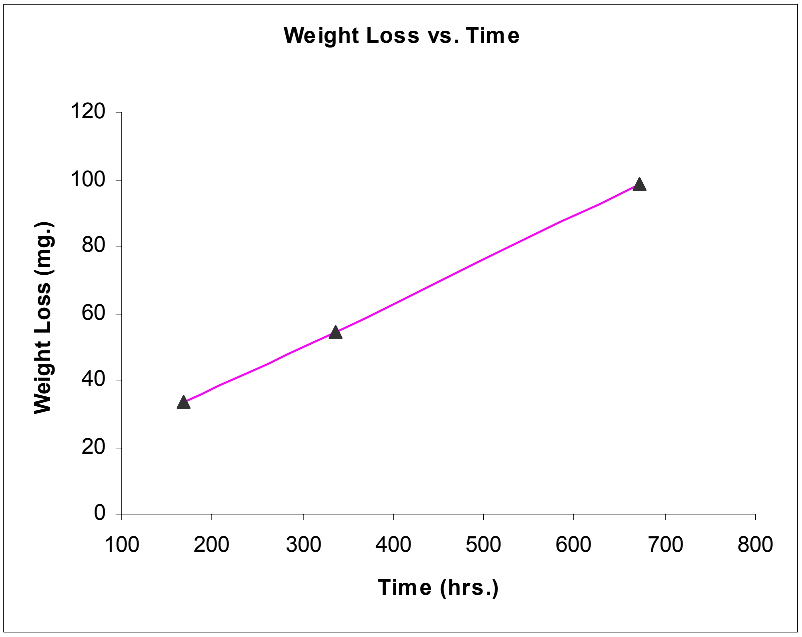

Figure 9. Weight-loss vs. Test Duration, Coupons, 150°C

Table 4.Corrosion Rates (mpy)

Days / hrs	mpy (= 534W/D.A.T.)
7 / 168	5.21
14 / 336	4.26
28 / 672	3.85

- The SEM study of the primary fracture surface of all tested cylindrical specimens revealed dimpled microstructure, indicating ductile failure. The SEM micrographs of Alloy C-276 of specimens used in tensile and SSR testing are shown in figures 10 and 11.

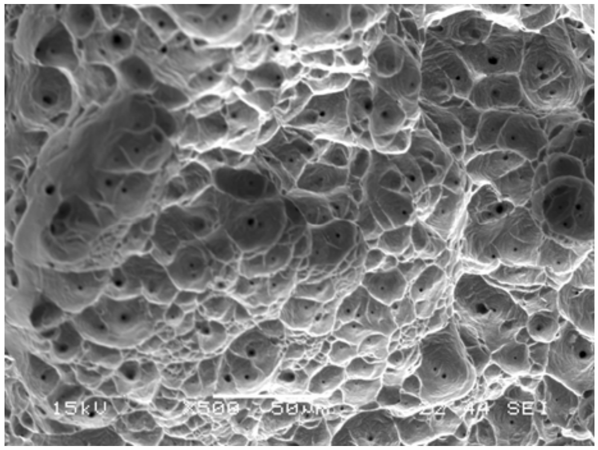

Figure 10. SEM Micrograph (Smooth Specimen-Tensile Testing at 100°C), 500X

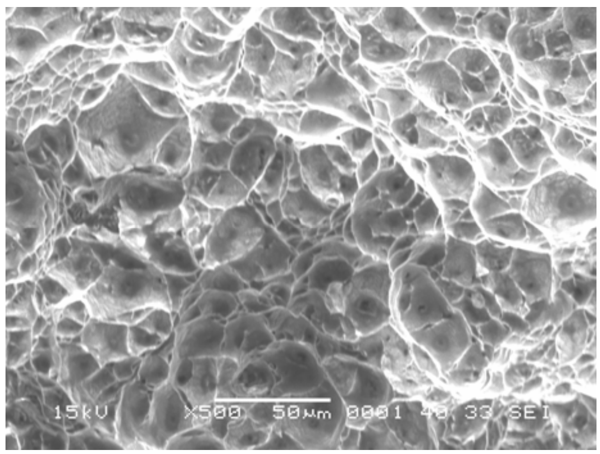

Figure 11. SEM Micrograph (Smooth Specimen-SSR Testing at 90°C), 500X

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