Sensitization and Aging Effects on Environmental Fatigue of Stainless Steel

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1. Introduction

Among published environmental fatigue test data of stainless steels, Type 304 SS, Type 316 SS, Type 316N SS, Type 316 Weld SS, and cast stainless steel CF8M in Japan and U.S., useful data were quoted for analyzing the effect of sensitizing stainless steels in LWR environments[1~7].

Temperature of the test data are 288~325℃ which is operating temperature range of LWR plants. Data were classified in terms of dissolved oxygen levels (low as 3~20ppb, high as 0.2~8ppm), strain rates in tension stroke (order of E-01 to E-03%/s), and sensitization (aging). Then the sensitized or aged data were compared with un-sensitized ones on logarithmic graph of vertical strain rate and horizontal fatigue life. Trend of sensitization was investigated for each heat of stainless steels.

2. Test conditions

Table. 1 showed test conditions

(Unit: %)

Heats	Authors	Products	C Ni	Si Co	Mn Cu	P V	S Pb	Ni O(ppm)	Cr H(ppm)	Mo Ferrite	Solution Annealing	Aging/Sensitization	Remarks
304-09T	T. Endo	Bar/Rod	0.070	0.270	1.690	0.033	0.009	8.150	18.160		1050degCx1hr, WQ	650degCx10hrs	JNUPAD
304-21T	Tstsumi	Plate	0.060 0.040	0.590 0.070	0.830	0.023	0.002	9.170	18.890		1050degCx10min, WQ		
304-22T	Tstsumi	Pipe	0.061	0.580	1.740	0.026	0.003	9.600	18.350		1060degCx30min, WQ		
304-23T	Tstsumi	Sntzd Plate	0.060 0.0035	0.550 0.028	0.900	0.026	0.004	8.870	18.380		1040degCx5min, WQ	650degCx20hrs	
316-12T	Tstsumi	Pipe	0.060	0.610	1.690	0.025	0.010	13.060	16.550	2.080	1060degCx30min, WQ		
316-13T	Tstsumi	Frgd Pipe	0.070	0.500	1.480	0.031	0.006	11.060	17.600	2.300	1050degCx40min, WQ		
316-14T	Tstsumi	Sntzd Pipe	0.057	0.640	1.640	0.026	0.006	13.020	16.480	2.070	1055degCx30min, WQ	700degCx100hrs	
316N-Argn	Chopra	Pipe	0.013 0.105	0.490	1.69 0.100	0.020	0.002	13.690	17.540	2.450	1038-1093degCx30min, WQ		
316N-1	Nakao	Tube	0.010 0.106	0.510	1.670	0.027	0.001	13.250	17.500	2.500	1058degCx30m, WQ	650degCx2hrs	JNUPAD
316N-4	Higuchi	Plate	0.008 0.090	0.560	1.460	0.028	0.001	12.110	17.730	2.600	Solution Heat Annealed		
316TW	Tstsumi	Weld mtrl	0.040	0.390	1.310	0.011	0.005	11.600	19.600	2.200		?	
CF8M-20T	Tstsumi	Cast Pipe	0.053 0.045	0.950 0.060	0.800 0.130	0.030 0.060	0.005 0.020	9.520 78.000	20.520 5.200	2.200 19.700	1100degCx5hrs, WQ	465degCx25200hrs	SCS14A
CF8M-74	Chopra		0.064 0.048	0.730	0.540			9.030	19.110	2.510 18.000	1065-1120degCx30min,	400degCx10000hrs	
CF8M-75	Chopra		0.065 0.052	0.690	0.530			9.120	20.860	2.580 28.000	1065-1120degCx30min,	400degCx10000hrs	

3. Sensitization Data

3.1 Type 304 SS(Figure 1)

In LWR environments of low DO(Dissolved Oxygen) and tension strain rates order of E-01 and E-02, fatigue life of Type 304 SS tends to increase a bit with sensitizing when testing at the strain rate of tension stroke, order of E-01 and E-02. There were not sensitized data in the strain range order of E-03 and E-04 in low DO condition. However, fatigue life in high DO environment, the strain rate order of E-01 decreases with sensitization. There was no sufficient data in other strain range orders except order of E-01 in high DO water environments

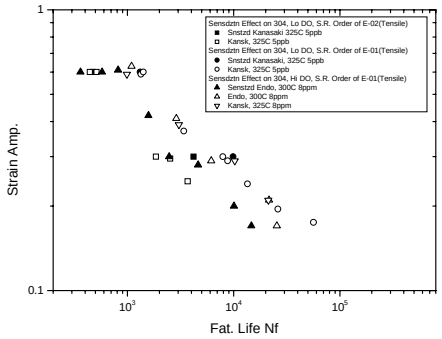

Figure 1. Sensdztn Effect on 304

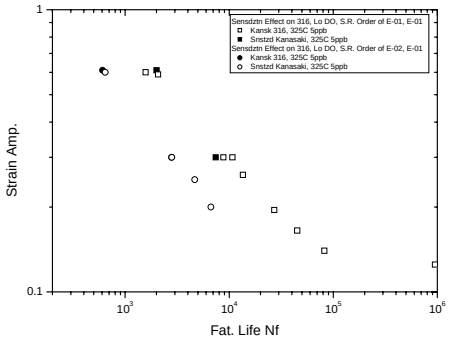

Figure 2. Sensdztn Effect on 316

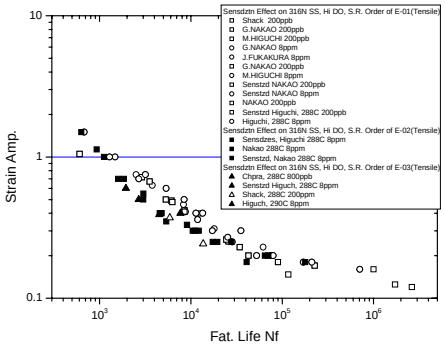

Figure 3. Sensdztn Effect on 316N SS

3.2 Type 316 SS(Figure 2)

Because no sensitized fatigue test data in high DO LWR environment was published, sensitization effect of Type 316 SS was only analyzed for the test results of low DO environment and strain range of E-01 and E-02 of tension fatigue load stroke. In low DO environment, sensitization does not affect fatigue life of Type 316 stainless steel.

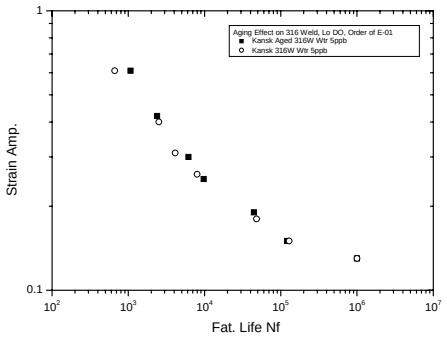

Figure 4. Aging Effect on 316 Weld

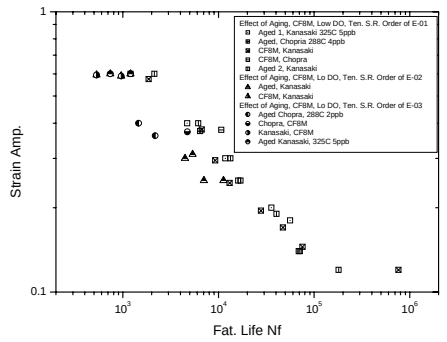

Figure 5. Aging Effect on CF8M

3.3 Type 316N SS(Figure 3)

In case of the Type 316 SS, published sensitization data were available only for the high DO environment test data. Low DO condition could not be analyzed for the sensitization effect. Strain rate spectrum of the high DO data was well organized but the fatigue life of Type 316N SS is not affected by sensitization beside of slow tensile strain rate range of E-03. Fatigue life at the slow strain rate range of E-03 tends to increase with sensitization. In order to avoid data intricacy in a graph, data drawn individually in accordance to the data authors but no change was observed in the fatigue life of this condition.

4. Aging Data

4.1 Type 316W SS(Figure 4)

Available data to see the effect of sensitization of Type 316W SS was ones for low DO and strain rate order of E-01. Fatigue life of aged Type 316W SS shows a trend to increase a bit at the strain rate order of E-01. Considering strain rate effect on environmental fatigue, test data at slower strain rate are required to see the effect clearly.

4.2 Type CF8M SS(Figure 5)

Environmental fatigue test data in low DO and variable range of strain rate are available for Type CF8M SS. Test temperature of Japanese data and ANL ones are different as of 325℃ and 288℃. Japanese data shows that fatigue life increases with aging Type CF8M in all strain rate range. However, fatigue life of ANL ones decreases in 288 ℃ test temperature. This is probably caused for the sensitivity of cast stainless steel Type CF8M to the aging temperature. Further tests and metallurgical investigation is needed for addressing this phenomenon clearly.

5. Conclusion

In LWR environments of low DO fatigue life of Type 304 SS tends to increase a bit with sensitizing but in high DO environment it decreases.

Sensitization does not affect fatigue life of Type 316 stainless steel in low DO environment.

Strain rate spectrum of Type 316N SS in high DO environment was well organized but the fatigue life is not affected by sensitization beside of slow tensile strain rate range of E-03. Fatigue life at the slow strain rate range of E-03 tends to increase with sensitization.

Fatigue life of sensitized Type 316W SS shows a trend to increase a bit at the strain rate order of E-01.

Japanese data shows that fatigue life increases with aging Type CF8M in all strain rate ranges and test temperature 325℃. However, fatigue life of ANL ones decreases in 288℃ test temperature. This is probably caused for the sensitivity of cast stainless steel Type CF8M to the aging conditions. Further tests and metallurgical investigation is needed to address this phenomenon clearly. Analyzing results above being just based on published data to date, additional experimental data production and research on root causers of sensitization effects in metallurgy is encouraged in the future, especially for cast stainless steels and missed test boron acid environments of each type of stainless steels.

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