RESULTS OF FRACTURE TOUGHNESS TESTS OF SEVERAL RAFM STEELS IRRADIATED IN JP-27 CAPSULE IN HFIR — M. A. Sokolov (Oak Ridge National Laboratory)

OBJECTIVE

The objective of this present work is to perform fracture toughness evaluation of several heats of F82H RAFM steel irradiated in JP-27 capsule in the High-Flux Isotope Reactor (HFIR).

SUMMARY

Large number of 3-point bend multi-notch specimens of several RAFM steels was irradiated at 300°C and 400°C in capsule JP-27 up to ~22 dpa. These specimens were tested in the hot cell and results are reported here.

TEST RESULTS

Three-notch bend bar specimen was used in this irradiation experiment for fracture toughness studies. The specimens were 1.65-mm thick and 3.3-mm wide. Specimens were tested in general accordance with ASTM E1921 standard. Test temperatures were coordinated between JAEA, UCSB and ORNL based on available tensile data and direct hardness measurements on bend bars prior to the fracture toughness tests. Table 1 provides fracture toughness test results of all specimens tested. The main goal of this study was to measure the reference fracture toughness transition temperature, T_o. Thus, the test temperatures were selected such that tests would be performed in the transition region where specimens would break by cleavage. Despite these efforts several specimens did not cleave. This highlights one more time the very narrow temperature window that is available to generate meaningful results from very small specimens like those used in this experiment. Some of these specimens developed J-R curve from which J-integral at the onset of stable crack growth, J_Q, was determined and reported in Table 1. The other specimens run out of measuring capacity without stable growth or cleavage. For those specimens, the final J-integral value at the end of the test, J_{final}, is reported in the Table 1.

Several heats of F82H steel were irradiated in this experiment. The IEA and Mod. 3 heats are designated as F82H-IEA and F82H-MOD3, respectfully. Mod.1 heat was studied with various heat treatments that had additional designations F82H-MOD1E, F82H-MOD1F, F82H-MOD1G, and F82H-MOD1H. Also, two heats of F82H steel alloyed with 1.4% of Ni^{58} and Ni^{60} are designated as F82H-58Ni and F82H-60Ni, respectfully. In addition to fracture toughness data, target irradiation temperature, dose, and average hardness are also reported in Table 1.

Table1. Fracture toughness results

Material	Irr. T °C	Dose dpa	ID	Test T °C	J_c kJ/m^2	K_{Jc} MPam$^{1/2}$	H_v	Remarks
F82H-IEA	300	18	034M	26	16.08	61.21	N/A	
			037D	50	84.24	139.51	364	J_{final}
			037M	50	37.88	93.55		
			037U	50	39.41	95.42		
			035D	75	50.41	107.43	360	J_Q
			035M	50	12.24	53.18		
			035U	65	21.82	70.81		
			036D	26	5.77	36.67	353	
			036M	50	11.31	51.12		
			036U	75	39.44	95.03		
	400	22	044D	-80	92.89	149.91	338	J_{final}
			044M	-100	14.09	58.59		
			045D	-100	17.32	64.96	298	
			045U	-100	94.62	151.83		
			046D	-40	84.17	141.71	310	J_{final}

			046M	-60	81.55	139.98		J_{final}
			046U	-100	13.4	57.14		
			047D	-80	124.68	173.68	315	
			047U	-80	19.95	69.48		
F82H-58Ni	300	16	534D	65	47.15	104.09	436	
			534M	75	68.52	125.25		
			534U	75	16.56	61.57		
			535D	75	31.59	85.04	437	
			535M	75	28.61	80.93		
			535U	75	67.62	124.43		
			536D	75	26.46	77.79	433	
			536M	75	29.77	82.56		
			536U	75	65.03	122.02		
	400	21	544D	-80	110.31	163.37	346	
			544M	-90	97.45	153.82		
			544U	-90	353.18	292.82		
			545D	-60	98.27	153.66	N/A	
			545M	-80	81.05	140.04		
			545U	-110	120.6	171.70		
			546D	-90	94.84	151.74	365	
			546M	-100	79.97	139.58		
			546U	-100	98.44	154.86		
			547D	23	106.79	157.85	392	
			547M	-20	90.76	146.64		
			547U	-60	69.12	128.87		
F82H-60Ni	300	16	634D	75	39.33	94.89	436	
			634M	75	44.8	101.28		
			634U	75	32.12	85.76		
			635D	65	39.12	94.81	429	
			635M	65	30.67	83.95		
			635U	65	36.28	91.31		
			636D	65	29.9	82.89	430	
			636M	65	58.64	116.08		
			636U	65	40.64	96.64		
	400	21	644D	26	77.85	134.70	N/A	
			644M	26	10.69	49.91		
			644U	26	364.12	291.31		J_{final}
			645D	-40	109.12	161.35	345	J_{final}
			645M	-80	117.58	168.67		J_{final}
			645U	-122	87.95	146.93		
			646D	-120	115.56	168.37	N/A	
			646M	-136	30.75	87.09		
			646U	-147	144.21	188.95		
			647D	-120	86.12	145.35	324	
			647M	-120	109.18	163.65		
			647U	-120	108.99	163.51		
F82H-MOD3	300	18	H34D	50	73.08	129.94	354	J_{final}
			H34M	29	51.72	109.74		J_Q
			H34U	-20	35.08	91.16		
			H35D	0	36.21	92.29	364	
			H35M	0	34.16	89.64		J_Q
			H35U	-20	72.79	131.32		J_{final}
			H36D	-20	52.92	111.97	364	J_Q

			H36D	-40	33.99	90.05		
	400	22	H44D	-140	23.86	76.77	292	
			H44M	-140	33.62	91.12		
			H44U	-140	58.34	120.03		
			H45D	-140	33.15	90.48	290	
			H45M	-140	6.63	40.47		
			H45U	-140	69.54	131.05		
			H46D	-140	56.63	118.26	301	
			H46M	-140	68.94	130.49		
			H46U	-140	68.73	130.29		
			H47D	-140	49.74	110.83	310	
			H47M	-140	56.07	117.68		
			H47U	-140	42.72	102.71		
F82H-MOD1E	300	13	XE34D	-40	14.42	58.66	325	
			XE34M	-20	78.33	136.23		J_{final}
			XE34U	-40	9.31	47.13		
			XE35D	26	89.79	144.66	325	J_{final}
			XE35M	-20	9.64	47.79		
			XE35U	0	21.67	71.40		
			XE36D	26	35.19	90.56	323	
			XE36M	26	61.70	133.15		
			XE36U	26	85.41	141.09		
F82H-MOD1F	300	14	XF34D	26	89.57	144.48	312	J_Q
			XF34M	26	31.68	85.93		
			XF34U	26	89.21	144.19		J_{final}
			XF35D	26	95.98	149.56	332	J_{final}
			XF36D	-20	24.79	76.63	337	
			XF36M	-10	25.22	77.16		
			XF36U	-10	18.13	65.42		
F82H-MOD1G	300	13	XG34D	-40	5.35	35.72	298	
			XG34M	-20	34.74	90.72		
			XG34U	-20	52.67	111.71		
			XG35D	-20	13.15	55.82	329	
			XG35M	-20	14.52	58.65		
			XG35U	0	7	40.58		
			XG36D	-10	100.57	154.09	315	J_{final}
			XG36M	-40	6.38	39.02		
			XG36U	-20	30.13	84.49		
F82H-MOD1H	300	17	XH34D	-20	9.44	47.29	347	
			XH34M	0	8.66	45.13		
			XH34U	0	92.87	147.9		J_Q
			XH35D	23	89.49	144.50	354	J_{final}
			XH35M	-20	21.24	70.94		
			XH35U	-20	22.27	72.64		