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Long-Term Embrittlement of Cast Duplex Stainless Steels in LWR Systems

Semiannual Report
October 1991–March 1992

Prepared by O. K. Chopra

Argonne National Laboratory

Prepared for
U.S. Nuclear Regulatory Commission

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Long-Term Embrittlement of Cast Duplex Stainless Steels in LWR Systems

by

O. K. Chopra

Abstract

This progress report summarizes work performed by Argonne National Laboratory on long-term thermal embrittlement of cast duplex stainless steels in LWR systems during the six months from October 1991 to March 1992. Charpy-impact, tensile, and fracture toughness J-R curve data are presented for several heats of cast stainless steel that were aged 10,000–58,000 h at 290, 320, and 350°C. The results indicate that thermal aging decreases the fracture toughness of cast stainless steels. In general, CF-3 steels are the least sensitive to thermal aging and CF-8M steels are the most sensitive. The values of fracture toughness J_{IC} and tearing modulus for CF-8M steels can be as low as ≈ 90 kJ/m² and ≈ 60 , respectively. The fracture toughness data are consistent with the Charpy-impact results, i.e., unaged and aged steels that show low impact energy also exhibit lower fracture toughness. All steels reach a minimum saturation fracture toughness after thermal aging; the time to reach saturation depends on the aging temperature. The results also indicate that low-strength cast stainless steels are generally insensitive to thermal aging.

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Executive Summary

Cast stainless steels used in pump casings, valve bodies, piping, and other components in coolant systems of light water nuclear reactors (LWRs) suffer a loss in toughness after many years of service at temperatures in the range of 280–320°C (≈536–608°F). A program is being conducted at Argonne National Laboratory to investigate the low-temperature thermal embrittlement of cast duplex stainless steels under LWR operating conditions and to evaluate possible remedies for the thermal embrittlement problem in existing and future plants. The scope of the investigation includes the following goals: (1) characterize and correlate the microstructure of in-service reactor components and laboratory-aged material with loss of fracture toughness to establish the mechanism of aging and validate the simulation of in-reactor degradation by accelerated aging, (2) establish the effects of key compositional and metallurgical variables on the kinetics and extent of thermal embrittlement, and (3) develop the methodology and correlations necessary for predicting the toughness loss suffered by cast stainless steel components during the normal and extended life of LWRs.

Microstructural and mechanical-property data have been obtained on 25 experimental heats (static-cast keel blocks and slabs) and 6 commercial heats (centrifugally cast pipes, a static-cast pump impeller, and a static-cast pump casing ring), as well as on reactor-aged material of CF-3, CF-8, and CF-8M grades of cast stainless steel. The ferrite content of the cast materials ranges from 3 to 30%. Ferrite morphology for the castings containing >5% ferrite is either lacy or acicular.

Charpy-impact, tensile, and J-R curve tests have been conducted on several experimental and commercial heats of cast stainless steel that were aged up to 58,000 h at temperatures of 290–400°C (554–752°F). Results indicate that thermal aging at these temperatures increases the tensile strength and decreases the impact energy and fracture toughness of the steels. The Charpy transition curve shifts to higher temperatures. Different heats exhibit different degrees of thermal embrittlement: in general, the low-carbon CF-3 steels are the most resistant, and the molybdenum-bearing, high-carbon CF-8M steels are the least resistant to thermal embrittlement. Embrittlement of cast stainless steels results in brittle fracture associated with either cleavage of the ferrite or separation of the ferrite/austenite phase boundary. A predominantly brittle failure occurs when either the ferrite phase is continuous, e.g., in cast material with a high ferrite content, or the ferrite/austenite phase boundary provides an easy path for crack propagation, e.g., in high-carbon grades of cast steels with phase-boundary carbides. Consequently, the amount, size, and distribution of the ferrite phase in the duplex structure and the presence of phase-boundary carbides are important parameters in controlling the degree or extent of thermal embrittlement.

Thermal aging of cast stainless steels at temperatures <500°C (<932°F) leads to precipitation of additional phases in the ferrite matrix, e.g., formation of a chromium-rich α' phase by spinodal decomposition; nucleation and growth of α' ; precipitation of a nickel- and silicon-rich G phase, $M_{23}C_6$ carbide, and γ_2 (austenite); and additional precipitation and/or growth of existing carbides at the ferrite/austenite phase boundaries. The additional phases provide the strengthening mechanisms that increase strain hardening and the local tensile stress. Consequently, the critical stress level for brittle fracture is achieved at higher tem-

peratures. The effects of material variables on the thermal embrittlement of cast stainless steels have been evaluated.

Fracture toughness J-R curve data are presented for several experimental and commercial heats of cast stainless steel that were aged 10,000–58,000 h at 290, 320, and 350°C (554, 608, and 662°F). Thermal aging decreases the fracture toughness of cast stainless steels. The values of fracture toughness J_{IC} and average tearing modulus for heats that are sensitive to thermal aging (e.g., CF-8M steels) are as low as $\approx 90 \text{ kJ/m}^2$ and ≈ 60 , respectively. The results also indicate that the fracture toughness of cast stainless steels can be lower than that of the wrought stainless steels. The low-strength cast stainless steels are generally insensitive to thermal aging.

1 Introduction

Cast duplex stainless steels used in light water reactor (LWR) systems for primary pressure-boundary components such as valve bodies, pump casings, and primary coolant piping are susceptible to thermal embrittlement at reactor operating temperatures, i.e., 280–320°C (536–608°F). Aging of cast stainless steels at these temperatures causes an increase in hardness and tensile strength and a decrease in ductility, impact strength, and fracture toughness of the material. Most studies on thermal embrittlement of cast stainless steels involve simulation of end-of-life reactor conditions by accelerated aging at higher temperatures, viz., 400°C (752°F), because the time period for operation of power plants (≈ 40 y) is far longer than can generally be considered for laboratory studies. Thus, estimates of the loss of fracture toughness suffered by cast stainless steel components are based on an Arrhenius extrapolation of high-temperature data to reactor operating conditions.

A program is being conducted at Argonne National Laboratory to investigate the significance of low-temperature embrittlement of cast duplex stainless steels under LWR operating conditions and to evaluate possible remedies for thermal embrittlement problems in existing and future plants. The scope of the program includes the following goals: (1) characterize and correlate the microstructure of in-service reactor components and laboratory-aged material with loss of fracture toughness to establish the mechanism of aging and validate the simulation of in-reactor degradation by accelerated aging, (2) establish the effects of key compositional and metallurgical variables on the kinetics and extent of thermal embrittlement, and (3) develop the methodology and correlations for predicting the toughness loss suffered by cast stainless steel components during normal and extended life of LWRs.

Microstructural and mechanical-property data have been obtained on 25 experimental heats (19 in the form of static-cast keel blocks and 6 in the form of 76-mm slabs) and 6 commercial heats (centrifugally cast pipes and a static-cast pump impeller and pump casing ring), as well as on reactor-aged material of grades CF-3, CF-8, and CF-8M cast stainless steel. Specimen blanks for Charpy-impact, tensile, and fracture toughness J-R curve tests were aged at 290, 320, 350, and 400°C (554, 608, 662, and 752°F) for times up to 58,000 h. The reactor-aged material is from the recirculating-pump cover plate assembly of the KRB reactor, which was in service in Gundremmingen, Germany, for ≈ 8 yr at 284°C (543°F). Data on chemical composition, ferrite content, hardness, ferrite morphology, and grain structure of the experimental and commercial heats have been reported earlier.¹ The chemical composition, hardness, and ferrite content and distribution of the cast materials are given in Table 1. Results of microstructural characterization and mechanical-property data from Charpy-impact, tensile, and J-R curve tests on 16 heats of cast stainless steel aged up to 30,000 h at temperatures between 290 and 450°C have also been presented earlier.¹⁻¹²

Mechanical-property results from the present study and data from other investigations have been analyzed to develop the procedure and correlations for estimating thermal embrittlement of cast stainless steel components from known material parameters.¹³⁻¹⁵ This report presents fracture toughness data on several heats of cast stainless steel aged for 10,000–58,000 h at 290, 320, and 350°C (554, 608, and 662°F).

Table 1. Product form, chemical composition, hardness, and ferrite morphology of various heats of cast stainless steel

Heat	Grade	Chemical Composition (wt.%)									Ferrite ^a (%)		Hard- ness R _B	Ferrite Spacing (μm)
		Mn	Si	P	S	Mo	Cr	Ni	N	C	Calc.	Meas.		
Keel Blocks ^b														
50	CF-3	0.60	1.10	0.016	0.007	0.33	17.89	9.14	0.079	0.034	3.0	4.4	80.1	194
49	CF-3	0.60	0.95	0.010	0.007	0.32	19.41	10.69	0.065	0.010	4.4	7.2	76.6	185
48	CF-3	0.60	1.08	0.009	0.006	0.30	19.55	10.46	0.072	0.011	5.1	8.7	78.1	127
47	CF-3	0.60	1.06	0.007	0.006	0.59	19.81	10.63	0.028	0.018	8.4	16.3	79.7	68
52	CF-3	0.57	0.92	0.012	0.005	0.35	19.49	9.40	0.052	0.009	10.3	13.5	81.6	69
51	CF-3	0.63	0.86	0.014	0.005	0.32	20.13	9.06	0.058	0.010	14.3	18.0	83.8	52
58	CF-8	0.62	1.12	0.010	0.005	0.33	19.53	10.89	0.040	0.056	3.2	2.9	77.1	303
54	CF-8	0.55	1.03	0.011	0.005	0.35	19.31	9.17	0.084	0.063	4.1	1.8	83.3	317
57	CF-8	0.62	1.08	0.009	0.004	0.34	18.68	9.27	0.047	0.056	4.4	4.0	80.2	138
53	CF-8	0.64	1.16	0.012	0.009	0.39	19.53	9.23	0.049	0.065	6.3	8.7	83.1	92
56	CF-8	0.57	1.05	0.007	0.007	0.34	19.65	9.28	0.030	0.066	7.3	10.1	82.5	84
59	CF-8	0.60	1.08	0.008	0.007	0.32	20.33	9.34	0.045	0.062	8.8	3.5	83.2	75
61	CF-8	0.65	1.01	0.007	0.007	0.32	20.65	8.86	0.080	0.054	10.0	13.1	85.3	82
60	CF-8	0.67	0.95	0.008	0.006	0.31	21.05	8.34	0.058	0.064	15.4	21.1	86.7	63
62	CF-8M	0.72	0.56	0.007	0.005	2.57	18.29	12.39	0.030	0.063	2.8	4.5	78.1	140
63	CF-8M	0.61	0.58	0.007	0.006	2.57	19.37	11.85	0.031	0.055	6.4	10.4	81.6	81
66	CF-8M	0.60	0.49	0.012	0.007	2.39	19.45	9.28	0.029	0.047	19.6	19.8	85.3	41
65	CF-8M	0.50	0.48	0.012	0.007	2.57	20.78	9.63	0.064	0.049	20.9	23.4	89.0	43
64	CF-8M	0.60	0.63	0.006	0.005	2.46	20.76	9.40	0.038	0.038	29.0	28.4	89.7	41
76-mm Slabs ^c														
69	CF-3	0.63	1.13	0.015	0.005	0.34	20.18	8.59	0.028	0.023	21.0	23.6	83.7	35
73	CF-8	0.72	1.09	0.028	0.016	0.25	19.43	8.54	0.053	0.070	7.0	7.7	78.8	253
68	CF-8	0.64	1.07	0.021	0.014	0.31	20.64	8.08	0.062	0.063	14.9	23.4	84.6	87
70	CF-8M	0.55	0.72	0.021	0.016	2.30	19.17	9.01	0.049	0.066	14.2	18.9	86.5	96
74	CF-8M	0.54	0.73	0.022	0.016	2.51	19.11	9.03	0.048	0.064	15.5	18.4	85.8	90
75	CF-8M	0.53	0.67	0.022	0.012	2.58	20.86	9.12	0.052	0.065	24.8	27.8	89.5	69
Reactor Components ^d														
P3	CF-3	1.06	0.88	0.017	0.014	0.01	18.89	8.45	0.168	0.021	2.8	1.9	82.2	-
P2	CF-3	0.74	0.94	0.019	0.006	0.16	20.20	9.38	0.040	0.019	12.5	15.6	83.8	69
I	CF-3	0.47	0.83	0.030	0.011	0.45	20.20	8.70	0.032	0.019	20.4	17.1	81.0	65
C1	CF-8	1.22	1.18	0.033	0.008	0.65	19.00	9.37	0.040	0.039	7.8	2.2	79.5	-
P1	CF-8	0.59	1.12	0.026	0.013	0.04	20.49	8.10	0.056	0.036	17.7	24.1	84.9	90
P4	CF-8M	1.07	1.02	0.019	0.015	2.05	19.64	10.00	0.151	0.040	5.9	10.0	83.1	182
205	CF-8M	0.93	0.63	0.019	-	3.37	17.88	8.80	-	0.040	21.0	15.9	-	79
758	CF-8M	0.91	0.62	0.018	-	3.36	17.91	8.70	-	0.030	24.2	19.2	-	62
Reactor-Aged ^e														
KRB	CF-8	0.31	1.17	-	-	0.17	21.99	8.03	0.038	0.062	27.7	34.0	-	-

^a Calculated from the composition with Hull's equivalent factor.

Measured by ferrite scope AUTO Test FE, Probe Type FSP-1.

^b Static Cast Keel Blocks: Foundry ESCO; Size 180 x 120 x 90-30 mm.

^c Static Cast Slabs: Foundry ESCO; Size 610 x 610 x 76 mm.

^d Centrifugally Cast Pipes:

P3 Foundry SANDUSKY; Size 580 mm O.D., 76 mm wall.

P2 Foundry FAM, France; Size 930 mm O.D., 73 mm wall.

P1 Foundry ESCO; Size 890 mm O.D., 63 mm wall.

P4 Foundry SANDUSKY; Size 580 mm O.D., 32 mm wall.

205 Size 305 mm O.D., 25 mm wall.

Static Cast:

Elbow 758: Size 305 mm O.D., 30 mm wall.

Pump Impeller I: Foundry ESCO; Size 660 mm diameter.

Pump Casing C1: Foundry ESCO; Size 600 mm O.D., 57 mm wall.

^e KRB Reactor Pump Cover Plate: Foundry GF; Size 890 mm diameter.

2 Fracture Toughness

The J-R curve tests were conducted at room temperature and at 290°C (554°F) according to ASTM Specifications E 813-85 and E 1152-87. Compact-tension (CT) specimens, 25.4 mm thick (i.e., 1T size), were used for the tests. The fracture toughness results for 10 laboratory-aged heats of cast stainless steel and service-aged material from the KRB reactor pump cover plate are listed in Table A-1 of the Appendix. The J-R curve test data, as well as an analysis and qualification of the data for tests conducted on long-term aged specimens, are also given in the Appendix; details of the tests on specimens aged up to 30,000 h have been presented earlier.^{5,12}

2.1 Unaged Cast Stainless Steels

The fracture toughness J-R curves of unaged cast stainless steels vary significantly for the various heats. Figure 1 shows fracture toughness J-R curves for centrifugally and static-cast steels at room temperature and 290°C (554°F). The centrifugally cast steels exhibit higher fracture toughness than static-cast steels. The static-cast pump casing ring (Heat C1 with $\delta_c = 8\%$) shows the lowest fracture toughness and the centrifugally cast pipe (Heat P2 with $\delta_c = 12\%$) shows the highest. The room-temperature J-R curves for unaged Heat C1 are marginally higher than those at 290°C. At temperatures up to 320°C (608°F), a minimum J-R curve for unaged static-cast stainless steels can be expressed as

$$J_d = 400[\Delta a]^{0.40} \quad (1)$$

and for centrifugally cast stainless steels as

$$J_d = 650[\Delta a]^{0.43}, \quad (2)$$

where crack extension Δa is in mm and deformation J integral J_d is in kJ/m².

Fracture toughness data for unaged cast stainless steels also indicate that J-R curves for structurally "weak" heats may be lower than those for wrought stainless steel. J-R curves for wrought stainless steels¹⁶⁻²¹ at temperatures $\geq 290^\circ\text{C}$ are shown with the minimum J-R curve for unaged cast stainless steels, in Fig. 2. The fracture toughness J-R curve of wrought stainless steels is higher than the minimum J-R curve for static-cast stainless steels.

2.2 Influence of Thermal Aging

The effects of aging time and temperature on the fracture toughness J-R curves of the various heats of cast stainless steel are shown in Figs. 3-9. Thermal aging of cast stainless steels decreases their fracture toughness at both room temperature and 290°C. The values of J_{IC} and average tearing modulus for heats that are sensitive to thermal aging are as low as ≈ 90 kJ/m² and ≈ 60 , respectively. The J-R curve data are consistent with the Charpy-impact results, i.e., unaged and aged materials that show low impact energy also exhibit lower fracture toughness. All materials reach a minimum saturation fracture toughness after thermal aging. The time to reach saturation depends on the aging temperature, e.g.,

Figure 1. Fracture toughness J - R curves for centrifugally and static-cast stainless steels at room temperature and at 290°C

Figure 2. Fracture toughness J - R curves for wrought stainless steels at temperatures $\geq 290^\circ\text{C}$ and lower-bound J - R curve for static-cast stainless steel

Figure 3. Effect of aging time and temperature on the fracture toughness J - R curves at room temperature and at 290°C for static-cast Heat 68

Figure 4. Effect of aging time and temperature on the fracture toughness J - R curves at room temperature and at 290°C for static-cast Heat 69

Figure 5. Effect of aging time and temperature on the fracture toughness J-R curves at room temperature and at 290°C for static-cast Heat 75

Figure 6. Effect of aging time and temperature on the fracture toughness J-R curves at room temperature and at 290°C for static-cast Heat 74

Figure 7. Effect of aging time and temperature on the fracture toughness J-R curves at room temperature and at 290°C for static-cast Heat C1

Figure 8. Effect of aging time and temperature on the fracture toughness J-R curves at room temperature and at 290°C for centrifugally cast Heat P1

Figure 9. Effect of aging time and temperature on the fracture toughness J-R curves at room temperature and at 290°C for centrifugally cast Heat P2

10,000 h at 400°C or 30,000 h at 350°C. The kinetics for the decrease in fracture toughness are identical to those observed for the change in Charpy-impact energy. In general, loss in toughness increases with an increase in ferrite content. The CF-3 steels show the smallest and CF-8M steels the largest loss in fracture toughness. Also, for a specific steel, the decrease in toughness is larger at room temperature than at 290°C (554°F).

The static-cast slabs (e.g., Heats 68, 69, and 75) exhibit an unusual aging behavior, viz., the room-temperature J-R curves for the static-cast slabs in the unaged condition are exceptionally low, although their Charpy-impact energies are comparable with those for other heats. Also, the room-temperature fracture toughness increased initially after aging, e.g., J-R curves for Heats 68, 69, and 75 aged for 2,570 h at 400°C (752°F), up to 10,000 h at 350°C (662°F), or up to 30,000 h at 320 and 290°C (608 and 554°F) are generally higher than those for the unaged materials. An initial increase in fracture toughness was not observed at 290°C for these heats or for any other product form.

The poor room-temperature fracture toughness of the cast slabs is most likely due to residual stresses introduced in the material either during casting or the production heat treatment. The initial increase in fracture toughness of the aged material is most likely due to relaxation of the residual stresses during aging. Fracture toughness results for recovery-annealed materials support this argument. Annealing studies indicate that thermal embrittlement of cast stainless steels can be reversed by annealing the embrittled material for 1 h at 550°C and then water quenching.^{1-3,7,12} The Charpy-transition curves of recovery-annealed CF-3, CF-8, and CF-8M steels agree very well with those of unaged materials.^{7,12} However, fracture toughness J-R curves of recovery-annealed Heats 68 and 75 are significantly higher than those of the unaged materials and are comparable to those of materials that were aged for relatively short times, Figs. 3 and 5. These results suggest that the mechanical test data obtained on unaged static-cast slabs do not represent baseline properties. For the static-cast slabs, fracture toughness should initially increase during reactor service before it decreases because of thermal embrittlement. Fracture toughness J-R curves for the recovery-annealed material most likely represent the baseline properties without the effect of residual stresses.

2.3 Low-Strength Cast Stainless Steels

Mechanical-property data on thermally-aged cast stainless steels indicate that cast stainless steels with low impact strength and poor fracture toughness are generally insensitive to thermal aging, e.g., Heat C1, a static-cast CF-8 steel with 7.8% ferrite. Static-cast CF-8 steels with 5-10% ferrite typically have a room-temperature Charpy-impact energy >150 J/cm². The room-temperature Charpy-impact energy for unaged Heat C1 is ≈60 J/cm² and does not change even after aging up to 30,000 h at 320-400°C.^{1,12} The impact strength of Heat C1 is, in fact, lower than the saturation impact energy of thermally aged cast stainless steels with equivalent ferrite content. The fracture toughness data also show no degradation in properties; J-R curves for aged and unaged Heat C1 are comparable, Fig 7.

Thermal aging of cast stainless steels at temperatures <500°C (932°F) affects the fracture processes normally associated with thermal embrittlement of cast stainless steel, viz., cleavage of ferrite and separation of austenite/ferrite phase boundary. The formation of ad-

ditional phases, such as the chromium-rich α' phase, promotes cleavage of the ferrite, and precipitation and/or growth of carbides/nitrides at the phase boundaries causes phase-boundary separation. The extent of thermal embrittlement is controlled by the amount of brittle fracture. A predominantly brittle failure occurs when either the ferrite phase is continuous, e.g., in cast material with a large ferrite content, or the ferrite/austenite phase boundary provides an easy path for crack propagation, e.g., in high-carbon or high-nitrogen steels that contain phase-boundary carbides or nitrides.

Low-strength cast stainless steels are generally insensitive to thermal aging because failure of these steels is controlled by oxide inclusions or other flaws in the casting, i.e., by fracture processes other than cleavage of ferrite and phase-boundary separation. Failure processes associated with inclusions or flaws are relatively insensitive to thermal aging. Consequently, cast stainless steels with low impact strength and poor fracture toughness show little or no degradation of mechanical properties.

2.4 Recovery--Annealed Material

The influence of annealing on 12 laboratory-aged heats of CF-3, CF-8, and CF-8M steels and service-aged material from the KRB reactor pump cover plate indicate that the mechanical properties of aged cast stainless steels can be restored by annealing the embrittled material for 1 h at 550°C and water-quenching.^{7,12} The α' phase, which is the primary cause for thermal embrittlement, is not stable at temperatures >550°C and therefore dissolves during the annealing treatment. The material is water-quenched to avoid formation of σ and other intermetallic phases that may also degrade mechanical properties. In all cases, the Charpy-transition curves for the annealed materials agree very well with those for the unaged steel.¹²

Charpy data for laboratory-aged materials also indicate that the kinetics of embrittlement can be obtained from the reembrittlement of recovery-annealed material.¹² The Charpy-transition curve for recovery-annealed CF-3, CF-8, and CF-8M steels aged for 10,000 h at 400°C is virtually identical to that of the as-received material aged for 10,000 h at 400°C. The kinetics of thermal embrittlement for the as-received material and recovery-annealed material are also identical. The activation energies for thermal embrittlement of Heats 68, 69, and 75 are 168 ± 37 , 167 ± 48 , and 146 ± 21 kJ/mole, respectively, for the as-received material, and 122 ± 41 , 176 ± 49 , and 130 ± 28 kJ/mole, respectively, for recovery-annealed and aged material.¹² Fracture toughness data also show similar behavior; J-R curves for recovery-annealed Heats 68 and 75 aged for 10,000 h at 400°C are identical to those of the as-received steels aged for 10,000 h at 400°C, Fig. 10.

The results indicate that baseline mechanical properties, as well as the kinetics of embrittlement, of aged cast stainless steels can be determined from the recovery-annealed material. This may be very useful for evaluating degradation of mechanical properties of service-aged components, where the baseline mechanical properties of archive material are generally not available.

Figure 10. Reembrittlement of static-cast Heats 68 and 75.

3 Conclusions

Charpy-impact, tensile, and fracture toughness J-R curve data are presented for several experimental and commercial heats of cast stainless steel that were aged 10,000–58,000 h at 290, 320, and 350°C. Thermal aging decreases the fracture toughness of cast stainless steels. The values of fracture toughness J_{IC} and average tearing modulus for heats that are sensitive to thermal aging (e.g., CF-8M steels) are as low as ≈ 90 kJ/m² and ≈ 60 , respectively. In general, CF-3 steels are the least sensitive to thermal aging and CF-8M steels are the most sensitive. The fracture toughness data are consistent with the Charpy-impact results, i.e., unaged and aged steels that show low impact energy also exhibit lower fracture toughness. All steels reach a minimum saturation fracture toughness after thermal aging. The time to reach saturation depends on the aging temperature. Mechanical-property data also indicate that the fracture toughness of cast stainless steels can be lower than that of the wrought stainless steels. The low-strength cast stainless steels are generally insensitive to thermal aging.

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Appendix

J-R Curve Characterization

The J-R curve tests were performed according to ASTM Specifications E 813-85 (Standard Test Method for J_{IC} , a Measure of Fracture Toughness) and E 1152-87 (Standard Test Method for Determining J-R Curve). Compact-tension (CT) specimens, 25.4 mm (1 in.) thick with 10% side grooves, were used for the tests. The CT specimen design, shown in Fig. A-1, is similar to the specimen of ASTM Specification E 399, the notch region is modified in accordance with E 813 and E 5112, to permit measurement of load-line displacement by axial extensometer. The extensometer was mounted on razor blades that were screwed onto the specimen along the load line.

Prior to testing, the specimens were fatigue-precracked at room temperature and at load levels within the linear elastic range. The final ratio of crack length to width (a/W) after precracking was ≈ 0.55 . The final 1-mm (≈ 0.04 -in.) crack extension was carried out at a load range of 13 kN (2.92 kip)-1.3 kN (0.292 kip), i.e., during precracking, K_{max} was $< 25 \text{ MPa}\cdot\text{m}^{1/2}$ ($22.6 \text{ ksi}\cdot\text{in.}^{1/2}$). After precracking, all specimens were side-grooved by 20% of the total specimen thickness, i.e., 10% per side, to ensure uniform crack growth during testing.

The J-R curve tests were performed on an Instron testing machine with 90 kN (20 kip) maximum load capacity. The load and load-line displacement data were digitized with digital voltmeters and stored on a disk for post test analysis and correction of the test data. The single-specimen compliance procedure was used to estimate the crack extension. Rotation and modulus corrections were applied to the compliance data. Both deformation theory and modified forms of the J integral were evaluated for each test.

After each test, the specimen was heated to 350°C to heat-tint the exposed fracture surface. The specimen was then fractured at liquid nitrogen temperature. The initial (i.e., fatigue precrack) and final (test) crack lengths were measured optically for both halves of the fractured specimen. The crack lengths were determined by the 9/8 averaging technique, i.e., the two near-surface measurements were averaged and the resultant value averaged with the remaining seven measurements.

The fracture toughness J_{IC} values were determined in accordance with ASTM Specifications E 813-81 and E 813-85. For the former, J_{IC} is defined as the intersection of the blunting line given by $J = 2\sigma_f \Delta a$, and the linear fit of the J-vs- Δa test data between the 0.15-mm and 1.5-mm exclusion lines. The flow stress, σ_f , is the average of the 0.2% yield stress and the ultimate stress. The ASTM Specification E 813-85 procedure defines J_{IC} as the intersection of the 0.2-mm offset line with the power-law fit (of the form $J = C\Delta a^n$) of the test data between the exclusion lines. J-R curve tests on cast stainless steels indicate that a slope of four times the flow stress ($4\sigma_f$) for the blunting line expresses the J-vs.- Δa data better than the slope of $2\sigma_f$ that is defined in E 813-81 or E 813-85. The fracture toughness J_{IC} values were determined with the $4\sigma_f$ slope for the blunting line or 0.2-mm offset line.

The tearing modulus was also evaluated for each test. The tearing modulus is given by $T = E(dJ/da)/\sigma_f^2$, where E is the Young's modulus and σ_f is the flow stress. The ASTM

E 813-81 value of tearing modulus is determined from the slope dJ/da of the linear fit to the J-vs.- Δa data. For the power law curve fits, an average value of dJ/da was calculated^{A-1} to obtain average tearing modulus.

The fracture toughness results for four commercial and four experimental heats of cast stainless steel aged up to 58,000 h at 290, 320, 350, 400, and 450°C, (554, 608, 662, 752, and 842°F) and for the service-aged KBR pump cover plate material, are given in Table A-1. The test data, as well as an analysis and qualification of the data for 71 J-R curve tests, have been presented earlier.^{A-2,A-3} Data analysis and qualification for tests conducted on long-term low-temperature aged materials are presented in this Appendix.

Data Analysis Procedures

The compliance method was used to determine crack length during the tests. The Hudak-Saxena calibration equation^{A-4} was used to relate the specimen load line elastic compliance C_l on an unloading/loading sequence with the crack length a_l . The compliance, i.e., slope ($\Delta\delta/\Delta P$) of the load line displacement vs. load record obtained during the unloading/loading sequence, is given by

$$U_{LL} = \frac{1}{(B_e E_e C_l)^{1/2} + 1} \quad (A-1)$$

and

$$a_l/W = 1.000196 - 4.06319(U_{LL}) + 11.242(U_{LL})^2 - 106.043(U_{LL})^3 + 464.335(U_{LL})^4 - 650.677(U_{LL})^5, \quad (A-2)$$

where E_e is the effective elastic modulus, B_e is the effective specimen thickness expressed as $B - (B - B_N)^2/B$, and W is specimen width.

Both rotation and modulus corrections are applied to the compliance data. The modulus correction^{A-4} is used to account for the uncertainties in testing, i.e., in the values of initial crack length determined by compliance and measured optically. The effective modulus E_M is determined from

$$E_e = \frac{1}{C_0 B_e} \left(\frac{W + a_0}{W - a_0} \right)^{1/2} f(a_0/W) \quad (A-3)$$

and

$$f(a_0/W) = 2.163 + 12.219(a_0/W) - 20.065(a_0/W)^2 - 0.9925(a_0/W)^3 + 20.609(a_0/W)^4 - 9.9314(a_0/W)^5 \quad (A-4)$$

where C_0 is initial compliance, B_e is effective specimen thickness, and a_0 is the initial physical crack size measured optically.

To account for crack opening displacement in CT specimens, the crack size should be corrected for rotation.^{A-5} The corrected compliance is calculated from

$$\theta = \sin^{-1} \left[\left(\frac{d_m}{2} + D \right) / (D^2 + R^2)^{1/2} \right] - \tan^{-1} \left(\frac{D}{R} \right) \quad (A-5)$$

and

$$C_c = C_m / \left[\left(\frac{H^*}{R} \sin \theta - \cos \theta \right) \left(\frac{D}{R} \sin \theta - \cos \theta \right) \right], \quad (A-6)$$

where C_c and C_m are, respectively, the corrected and measured elastic compliance at the load line, H^* represents the initial half-span of load points (i.e., center of pinholes), R is the radius of rotation of the crack centerline ($= (W+a)/2$), a is the updated crack length, D is one-half of the initial distance between the displacement points (i.e., half gauge length), d_m is the total measured load line displacement, and θ is the angle of rotation of a rigid body element about the unbroken midsection line.

The J value is calculated at any point on the load-vs.-load line displacement record using the relationship

$$J = J_{el} + J_{pl}, \quad (A-7)$$

where J_{el} is the elastic component of J and J_{pl} is the plastic component of J . For a CT specimen, at a point corresponding to the coordinates P_i and δ_i on the specimen load-vs.-load line displacement record and a_i is $(a_0 + \Delta a_i)$, the deformation J is given by

$$J_{D(i)} = (K_i)^2 (1-\nu^2)/E_e + J_{pl(i)}, \quad (A-8)$$

where from ASTM method E 399,

$$K_i = [P_i / (B B_N W_e)^{1/2}] f(a_i/W), \quad (A-9)$$

with

$$f(a_i/W) = [2 + (a_i/W)] [0.886 + 4.64(a_i/W) - 13.32(a_i/W)^2 + 14.72(a_i/W)^3 - 5.6(a_i/W)^4] / [1 - (a_i/W)]^{3/2} \quad (A-10)$$

and

$$J_{pl(i)} = [J_{pl(i-1)} + \left(\frac{\eta_i}{b_i} \right) \frac{A_{pl(i)} - A_{pl(i-1)}}{B_N}] \left[1 - \left(\frac{\gamma_i}{b_i} \right) (a_i - a_{i-1}) \right] \quad (A-11)$$

where ν is Poisson's ratio, b is the uncracked ligament, A_{pl} is the plastic component of the area under the load-vs.-load line displacement record, and η is a factor that accounts for the tensile component of the load as given by

$$\eta_i = 2 + 0.522 b_i/W, \quad (A-12)$$

and γ is a factor that accounts for limited crack growth as given by

$$\gamma_i = 1 + 0.76 b_i/W. \quad (A-13)$$

The modified J values (J_M) are calculated from the relationship (from Ref. A-6)

$$J_{M(i)} = J_{D(i)} + \Delta J_1, \quad (A-14)$$

where

$$\Delta J_1 = \Delta J_{i-1} + \left(\frac{Y_1}{b}\right) J_{D(i)} (a_i - a_{i-1}). \quad (A-15)$$

According to ASTM Specification E 1152-87, the J_D -R curves are valid only for crack growth up to 10% of the initial uncracked ligament. Also, they show a dependence on specimen size. The J_M -R curves have been demonstrated to be independent of specimen size and yield valid results for larger crack growth.

Data Qualification

The various validity criteria specified in ASTM Specification E 813-85 for J_{IC} and in ASTM Specification E 1152-87 for the J-R curve were used to qualify the results from each test. The various criteria include maximum values of crack extension and J-integral; limits for initial uncracked ligament, effective elastic modulus, optically measured physical crack length, and spacing of J- Δa data points. The ω criteria (from Ref. A-7) was also used to ensure that a region of J dominance exists.

For the present investigation, most of the unaged or short-term-aged specimens yielded invalid J_{IC} values because of the relatively high toughness of the material. The reasons for the discrepancies are data point spacing, shape of the final crack front, or size of the uncracked ligament. In general, the size of the uncracked ligament or the specimen thickness was inadequate for the unaged or short-term-aged specimens because of the relatively high toughness of the material. The J_{max} limit for the J-vs.- Δa data was ignored in most tests to obtain a good power-law fit of the test data.

The shape of the crack front was also very irregular for most cast stainless steels. This may be attributed to the coarse grain structure of the casting and differences in ferrite morphology. Cast stainless steels with large columnar grains, in particular, showed significant variation in crack length along the width of a specimen. Furthermore, the crack front always had a leading crack near the edges of the specimen. The near-surface measurements of the final physical crack length were often $>\pm 1.02$ mm, the maximum value allowed for data qualification.

The fracture surfaces often showed uncracked ridges or ligaments along the direction of crack extension. The uncracked ligaments add significant error to the estimation of crack length by compliance. Therefore, the difference between the crack extension predicted from elastic compliance and the average measured physical crack extension is more than the maximum value allowed by ASTM E 1152.

All tests showed significant load relaxation during the unloading/reloading cycle for estimating crack length by elastic compliance. All unloadings were 25% of the load. The load at the end of the unloading/reloading cycle is always lower than it was at the start of the unloading cycle. The difference is appreciable for the room-temperature test.

Therefore, the initial 20–30% of the unloading curve was ignored in estimating crack length.

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Figure A-1. Configuration of compact-tension test specimen

Table A-1. Results from fracture toughness tests conducted at ANL and MEA on nine heats of cast stainless steel

Specimen Number	Heat	Orientation	Test Temp. a	Δa Final ^b		Deformation J ^c			Modified J ^c			Flow		Impact Energy (J/cm ²)	Condition		
				Comp. (mm)	Opt. (mm)	J _{IC} (kJ/m ²)	T _{av}	C	n	J _{IC} (kJ/m ²)	T _{av}	C	n		Stress (MPa)	Time (h)	Temp. Ref. (°C)
CF-3																	
IIS-03	I	C-L	25	0.530	13.50	12.90	475.9	604	0.694	435.2	712	796.0	0.788	411.2	179.7	Unaged	2
IIS-01	I	L-C	25	0.538	15.20	13.77	623.9	541	0.591	639.2	610	896.5	0.638	411.2	179.7	Unaged	2
I2S-01	I	L-C	25	0.534	12.18	13.66	478.2	675	0.743	483.6	741	840.7	0.784	411.2	179.7	Unaged	2
IIS-07	I	L-C	25	0.561	6.44	6.75	453.5	353	0.560	473.3	380	739.7	0.580	450.6	214.4	30000	320
IIS-06	I	C-L	25	0.527	12.69	14.72	497.8	336	0.522	506.7	373	771.1	0.558	466.8	141.2	10000	350
IIS-04	I	L-C	25	0.535	12.86	14.04	455.9	334	0.539	462.9	369	733.9	0.574	466.8	141.2	10000	350
I2S-03	I	L-C	25	0.544	12.93	14.17	330.2	463	0.747	333.6	501	710.1	0.778	466.8	141.2	10000	350
IIS-02	I	L-C	290	0.525	13.18	14.83	386.1	491	0.459	393.4	563	534.3	0.506	284.2	140.7	Unaged	2
I2S-02	I	L-C	290	0.532	6.21	7.23	376.7	633	0.561	393.0	670	557.0	0.576	284.2	140.7	Unaged	2
IIS-08	I	L-C	290	0.566	10.51	11.43	251.8	344	0.494	252.1	400	414.8	0.549	309.5	194.1	30000	320
IIS-05	I	L-C	290	0.541	12.45	13.62	249.9	367	0.480	252.9	411	402.2	0.518	303.7	130.1	10000	350
I2S-04	I	L-C	290	0.538	12.65	13.91	274.5	425	0.512	277.5	476	443.2	0.552	303.7	130.1	10000	350
P2B-03	P2	C-L	25	0.538	6.92	7.95	1271.7	1194	0.817	1301.3	1393	1256.5	0.898	381.0	385.8	Unaged	2
P2B-01	P2	L-C	25	0.541	6.25	7.18	1300.1	1400	0.890	1245.6	1592	1225.2	0.961	381.0	385.8	Unaged	2
P2T-01	P2	L-C	25	0.539	3.18	2.92	1365.3	1104	0.754	1480.4	1113	1315.3	0.747	381.0	385.8	Unaged	2
P2T-19	P2	L-C	25	0.585	2.17	2.10	2272.4	1471	0.897	3031.9	1771	1547.2	0.978	423.7	489.0	58000	290
P2B-16	P2	L-C	25	0.572	4.05	4.24	1284.5	801	0.654	1429.2	877	1395.2	0.683	427.5	248.7	55000	320
P2T-06	P2	L-C	25	0.719	3.31	4.17	935.4	988	0.820	1025.5	1140	1236.9	0.879	421.7	360.4	3000	350
P2T-08	P2	L-C	25	0.531	9.52	10.76	913.3	1091	0.897	989.9	1154	1261.8	0.913	436.8	286.7	10000	350
P2T-10	P2	L-C	25	0.531	8.53	8.39	1468.0	903	0.728	1647.8	1000	1487.1	0.767	436.8	286.7	10000	350
P2B-11	P2	C-L	25	0.556	2.58	4.00	688.4	575	0.643	710.3	639	998.1	0.686	434.7	224.2	30000	350
P2B-06	P2	L-C	25	0.527	11.83	13.04	747.1	808	0.765	787.2	893	1097.5	0.804	426.4	159.5	10000	400
P2T-04	P2	L-C	25	0.528	11.26	12.18	820.2	681	0.666	849.6	758	1096.7	0.711	426.4	159.5	10000	400
P2B-02	P2	L-C	290	0.531	6.51	8.03	1483.5	1435	0.691	1749.4	1682	1102.3	0.765	268.5	300.5	Unaged	2
P2T-02	P2	L-C	290	0.534	3.62	3.98	892.3	1272	0.694	949.6	1524	891.5	0.782	268.5	300.5	Unaged	2
P2T-20	P2	L-C	290	0.568	1.89	2.28	1314.8	892	0.554	1371.3	1228	1097.2	0.714	293.8	-	58000	290
P2B-17	P2	L-C	290	0.572	3.72	4.61	1192.3	822	0.525	1344.7	947	1134.2	0.575	293.7	-	55000	320
P2T-07	P2	L-C	290	0.525	8.36	9.50	1060.3	1208	0.689	1154.4	1397	1004.8	0.756	288.2	347.5	3000	350
P2T-09	P2	L-C	290	0.529	8.44	10.47	1033.8	1272	0.717	1182.9	1382	1013.5	0.743	286.8	321.5	10000	350
P2B-12	P2	L-C	290	0.568	4.84	5.58	650.7	1078	0.726	686.7	1192	824.8	0.768	292.1	334.5	30000	350
P2T-05	P2	L-C	290	0.515	11.85	13.63	874.6	732	0.484	917.2	866	920.0	0.548	288.6	159.5	10000	400
692-08B	69	H-H	25	0.530	13.72	16.07	204.4	263	0.597	205.3	287	421.6	0.628	435.5	207.1	Unaged	2
692-08T	69	H-H	25	0.537	13.34	14.60	267.0	408	0.700	268.8	438	571.9	0.728	435.5	207.1	Unaged	2
691-06T	69	H-H	25	0.552	9.18	10.02	567.2	434	0.586	574.9	486	866.5	0.631	446.4	187.0	30000	320
691-03B	69	H-H	25	0.562	9.92	10.78	486.0	274	0.466	493.6	309	731.5	0.506	475.5	184.4	50000	320
692-05V	69	V-H	25	0.560	8.48	9.62	557.9	410	0.603	580.0	435	885.6	0.619	475.5	184.4	50000	320
691-04B	69	H-H	25	0.519	12.47	13.61	702.9	307	0.888	720.9	350	925.5	0.466	467.7	154.1	2570	350
691-01T	69	H-H	25	0.552	10.97	10.33	514.0	385	0.559	520.4	431	801.4	0.601	452.1	188.6	10000	350
691-04T	69	H-H	25	0.548	11.30	12.07	406.7	277	0.497	412.1	309	652.7	0.534	463.2	120.1	30000	350

Table A-1. (Contd.)

Specimen Number	Heat Treatment	Orientation	Test Temp. a	Δa Final b		Deformation J c			Modified J c			Flow		Impact Energy (J/cm ²)	Condition				
				Comp. (mm)	Opt. (mm)	J _{IC} (kJ/m ²)	T _{av}	C	n	J _{IC} (kJ/m ²)	T _{av}	C	n		Stress (MPa)	Time (h)	Temp. Ref. d (°C)		
691-03B	69	H-H	25	0.514	12.86	13.65	454.9	200	614.2	0.368	459.3	229	639.4	0.408	469.1	141.6	2570	400	2
696-01T	69	H-H	25	0.566	5.11	5.90	223.1	244	548.3	0.527	328.9	268	573.1	0.558	484.0	96.9	10000	400	1
691-05B	69	H-H	25	0.517	12.85	14.04	495.1	212	661.4	0.375	503.7	243	690.3	0.413	472.7	121.1	2570	450	2
693-07T	69	H-H	290	0.532	12.87	14.50	700.1	378	756.3	0.312	723.6	467	785.8	0.370	301.4	257.6	Unaged		2
693-01V	69	V-H	290	0.582	12.53	13.56	266.3	423	424.8	0.540	252.3	504	439.5	0.621	301.4	257.6	Unaged		1
691-07T	69	H-H	290	0.571	10.30	11.33	376.5	375	492.9	0.410	376.5	453	514.4	0.475	295.4	213.0	30000	320	1
691-03T	69	H-H	290	0.580	9.02	9.84	210.8	304	364.9	0.530	211.3	339	381.0	0.570	339.8	176.0	50000	320	1
691-06T	69	H-H	290	0.530	12.97	14.17	450.9	231	523.7	0.259	465.1	280	550.0	0.301	312.2	261.1	2570	350	2
691-02T	69	H-H	290	0.562	10.16	11.07	158.4	562	362.6	0.756	158.8	609	376.8	0.789	294.8	169.3	10000	350	1
691-03T	69	H-H	290	0.560	10.38	11.03	210.3	339	365.5	0.545	212.5	375	381.7	0.580	323.3	159.8	30000	350	1
691-05T	69	H-H	290	0.526	12.47	13.42	255.0	301	368.5	0.412	256.5	345	384.7	0.456	304.4	140.6	2570	400	2
697-01T	69	H-H	290	0.564	9.91	10.16	166.8	243	296.4	0.510	168.7	268	309.9	0.541	336.6	135.0	10000	400	1
691-05T	69	H-H	290	0.519	12.77	13.75	261.9	256	376.0	0.395	264.3	291	392.3	0.433	327.6	123.8	2570	450	2
CF-8																			
C1B-03	C1	C-L	25	0.531	13.47	15.20	306.3	557	549.0	0.664	310.3	606	569.8	0.696	356.2	59.7	Unaged		2
C1B-01	C1	L-C	25	0.526	12.87	14.45	291.9	230	404.6	0.361	295.2	264	422.5	0.399	356.2	59.7	Unaged		2
C1B-02	C1	L-C	25	0.537	11.60	12.65	185.3	455	416.5	0.724	186.1	489	431.3	0.752	356.2	59.7	Unaged		2
C1B-18	C1	L-C	25	0.550	10.04	10.93	270.9	343	447.5	0.530	275.1	379	467.1	0.564	360.0	50.5	30000	320	1
C1B-08	C1	L-C	25	0.560	10.19	11.27	265.9	228	390.3	0.402	270.1	258	409.1	0.438	360.0	63.8	10000	350	1
C1B-11	C1	L-C	25	0.558	10.51	12.03	241.9	386	451.3	0.620	244.7	424	470.4	0.653	365.0	44.6	30000	350	1
C1B-04	C1	L-C	290	0.529	12.89	14.44	-	-	-	-	254.0	625	384.5	0.539	241.1	-	Unaged		2
C1B-05	C1	L-C	290	0.529	13.21	14.95	236.4	583	362.4	0.527	254.3	600	380.3	0.523	241.4	-	Unaged		2
C1B-19	C1	L-C	290	0.566	10.11	10.86	184.8	546	323.1	0.591	184.7	603	335.2	0.630	245.0	-	30000	320	1
C1B-09	C1	L-C	290	0.570	9.69	10.46	205.9	590	357.4	0.619	205.7	657	371.6	0.663	245.0	-	10000	350	1
C1B-12	C1	L-C	290	0.564	9.62	10.84	273.0	399	373.8	0.420	276.2	465	391.2	0.469	250.0	-	30000	350	1
KRB-06	KRB	C-R	25	0.617	5.63	7.51	263.4	564	639.4	0.853	264.5	616	666.1	0.890	428.4	131.1	68000	284	1
KRB-01	KRB	R-C	25	0.553	6.58	6.49	396.2	403	657.1	0.602	400.4	447	684.6	0.642	428.4	131.1	68000	284	1
KRB-04	KRB	R-C	25	0.576	6.69	7.29	531.6	626	843.9	0.687	536.9	698	875.9	0.734	428.0	232.0	Annealed		1
KRB-05	KRB	C-R	290	0.609	9.10	10.58	681.1	337	764.3	0.346	707.5	420	802.1	0.411	329.0	321.2	68000	284	1
P1B-03	P1	C-L	25	0.526	10.27	12.53	592.2	603	866.5	0.652	602.6	670	898.0	0.697	413.8	228.3	Unaged		2
P1B-01	P1	L-C	25	0.524	8.42	9.07	413.3	678	776.1	0.785	419.8	733	803.4	0.818	416.5	228.3	Unaged		2
P1T-01	P1	L-C	25	0.537	9.25	10.42	560.3	1124	1017.4	0.958	610.7	1132	1045.3	0.946	416.5	228.3	Unaged		2
P1T-17	P1	L-C	25	0.574	4.45	5.11	784.2	907	1058.9	0.784	807.8	1006	1091.2	0.831	406.9	356.4	58000	290	1
P1B-11	P1	L-C	25	0.551	-	8.28	1002.3	407	1105.6	0.429	1069.2	465	1163.1	0.468	420.7	207.3	30000	320	1
P1B-14	P1	L-C	25	0.553	8.29	9.32	723.6	363	957.9	0.510	744.4	404	995.5	0.546	480.4	144.7	55000	320	1
P1T-08	P1	C-L	25	0.519	13.90	13.07	209.1	445	526.3	0.808	202.0	422	546.4	0.861	439.8	156.4	10000	350	2

Table A-1. (Contd.)

Specimen Number	Orientation	Test	Aa Final ^b			Deformation J ^c			Modified J ^c			Flow		Condition					
			Comp. (mm)	Opt. (mm)	J _{IC} (kJ/m ²)	T _{av}	C	n	J _{IC} (kJ/m ²)	T _{av}	C	σ _i	Stress (MPa)	Impact Energy (J/cm ²)	Time (h)	Temp. Ref. (°C)			
P1B-06	P1	L-C	25	0.523	3.88	3.07	707.3	437	945.8	0.544	720.2	497	982.0	0.594	458.1	156.4	10000	350	2
P1T-06	P1	L-C	25	0.525	12.58	13.79	468.0	565	837.6	0.740	468.4	622	866.5	0.783	458.1	156.4	10000	350	2
P1B-09	P1	L-C	25	0.562	7.70	9.78	409.0	420	708.2	0.644	414.7	460	735.7	0.679	451.4	87.7	30000	350	1
P1B-05	P1	L-C	25	0.535	12.35	14.13	228.7	231	445.0	0.582	230.8	249	462.2	0.609	481.8	51.7	10000	400	2
P1T-04	P1	L-C	25	0.558	11.75	12.22	186.8	187	368.0	0.558	188.1	203	382.7	0.586	481.8	51.7	10000	400	2
P1B-02	P1	L-C	290	0.522	12.79	14.84	554.7	534	664.1	0.448	571.2	624	691.7	0.501	295.8	255.8	Unaged		2
P1T-02	P1	L-C	290	0.533	12.38	14.46	630.9	630	733.8	0.488	674.5	688	771.2	0.512	295.8	255.8	Unaged		2
P1T-18	P1	L-C	290	0.563	6.58	7.46	332.6	846	579.3	0.760	348.5	885	599.1	0.771	295.1	-	58000	290	1
P1B-12	P1	L-C	290	0.571	9.05	10.43	456.3	366	571.2	0.403	467.6	429	597.6	0.453	306.1	-	30000	320	1
P1B-15	P1	L-C	290	0.572	8.76	9.79	451.9	493	618.4	0.527	461.3	561	644.8	0.576	321.4	-	55000	320	1
P1B-07	P1	L-C	290	0.527	7.19	9.63	400.7	384	529.9	0.424	428.2	410	559.7	0.434	315.8	244.7	10000	350	2
P1T-07	P1	L-C	290	0.526	12.36	14.10	542.1	469	663.3	0.435	558.4	537	691.7	0.484	315.8	244.7	10000	350	2
P1B-10	P1	L-C	290	0.551	10.11	11.17	294.0	440	491.5	0.595	299.2	488	513.9	0.633	331.6	-	30000	350	1
P1T-05	P1	L-C	290	0.513	12.48	13.47	293.7	391	451.7	0.505	298.7	431	470.0	0.538	324.2	133.5	10000	400	2
683-05B	68	H-H	25	0.527	13.04	14.68	324.4	396	552.8	0.586	327.0	432	572.9	0.619	400.2	245.4	Unaged		2
683-05T	68	H-H	25	0.519	13.88	16.29	282.3	335	485.5	0.554	284.0	369	504.1	0.590	400.2	245.4	Unaged		2
683-03V	68	V-H	25	0.528	12.81	15.00	311.8	364	526.0	0.562	315.5	398	546.3	0.594	400.2	245.4	Unaged		2
683-06T	68	H-H	25	0.572	4.76	5.83	1097.4	567	1170.2	0.529	1157.0	667	1213.5	0.593	400.2	237.4	Annealed		1
682-06T	68	H-H	25	0.578	8.62	9.69	647.3	328	864.1	0.484	657.1	380	901.3	0.539	461.4	135.1	30000	320	1
683-02B	68	H-H	25	0.564	9.16	10.28	596.3	407	860.1	0.568	611.0	456	897.3	0.611	458.8	96.0	53000	320	1
682-05V	68	V-H	25	0.577	9.31	10.37	492.3	287	679.5	0.442	502.9	325	709.7	0.481	435.5	96.0	53000	320	1
681-04B	68	H-H	25	0.543	10.22	11.65	798.0	560	1037.7	0.608	832.0	607	1075.5	0.636	444.3	192.9	2570	350	2
682-02T	68	H-H	25	0.560	8.08	8.35	475.2	367	719.1	0.546	488.3	397	746.2	0.571	442.5	100.0	10000	350	1
682-04T	68	H-H	25	0.562	8.18	8.63	205.1	244	430.4	0.634	204.7	265	446.3	0.666	464.6	80.6	30000	350	1
681-06V	68	V-H	25	0.575	9.03	10.20	206.0	159	357.5	0.472	207.4	175	372.3	0.502	464.6	80.6	30000	350	1
681-03B	68	H-H	25	0.548	10.73	12.13	408.4	307	648.6	0.531	412.6	338	673.6	0.566	467.8	74.1	2570	400	2
681-01T	68	H-H	25	0.553	7.08	6.85	260.5	253	487.6	0.578	266.1	265	502.6	0.590	472.5	46.4	10000	400	1
681-03V	68	V-H	25	0.548	10.96	11.66	214.0	244	443.4	0.626	216.2	258	456.9	0.645	476.1	46.4	10000	400	1
682-08B	68	H-H	25	0.567	9.98	10.98	412.7	255	627.4	0.481	421.1	283	655.5	0.514	472.5	74.7	10000 ^e	400	1
681-04T	68	H-H	25	0.531	12.92	14.52	294.7	193	467.7	0.448	296.6	214	486.1	0.480	471.7	54.2	2570	450	2
681-05B	68	H-H	25	0.540	-	-	252.6	330	532.9	0.680	253.2	356	551.9	0.711	471.7	54.2	2570	450	2
683-07T	68	H-H	290	0.536	12.59	14.50	753.1	368	783.0	0.271	752.5	545	795.3	0.384	282.2	287.1	Unaged		2
683-06B	68	H-H	290	0.564	7.05	8.22	413.0	550	553.1	0.513	425.8	631	579.9	0.562	282.2	220.5	Annealed		1
682-07T	68	H-H	290	0.570	10.35	11.48	225.3	432	401.9	0.601	225.9	477	418.1	0.640	309.9	221.2	30000	320	1
683-02T	68	H-H	290	0.564	10.01	11.16	274.0	266	410.8	0.443	274.2	306	429.2	0.490	341.6	202.4	53000	320	1
681-06T	68	H-H	290	0.544	13.40	15.28	406.3	573	592.8	0.575	413.7	642	617.0	0.619	318.8	147.5	2570	350	2
682-03T	68	H-H	290	0.563	10.13	10.69	281.6	423	451.5	0.544	283.0	472	469.5	0.585	320.2	207.6	10000	350	1
682-05T	68	H-H	290	0.572	10.27	11.24	303.8	291	438.6	0.437	311.8	322	458.3	0.466	328.1	187.7	30000	350	1
681-05T	68	H-H	290	0.550	12.69	14.66	335.4	362	464.9	0.431	343.1	414	487.9	0.473	312.2	139.6	2570	400	2
681-02T	68	H-H	290	0.569	10.55	11.38	242.5	312	396.2	0.510	245.7	347	413.7	0.546	332.7	144.0	10000	400	1

Table A-1. (Contd.)

Specimen Number	Heat	Orientation	Test Temp. a	Δa Final b		Deformation J c				Modified J c				Flow		Impact	Condition		
				Comp. (mm)	Opt. (mm)	J _{IC} (kJ/m ²)	T _{av}	C	n	J _{IC} (kJ/m ²)	T _{av}	C	n	Stress (MPa)	Energy (J/cm ²)		Time (h)	Temp. Ref. (°C)	
681-03T	68	H-H	290	0.529	12.69	13.77	312.2	319	454.9	0.446	316.5	361	475.1	0.486	338.5	124.8	2570	450	2
205-23C	205	L-C	290	0.511	15.71	16.36	185.0	149	328.1	0.482	186.7	161	339.7	0.506	440.2 ^e	123.5	18000	400	1
205-25C	205	L-C	25	0.569	10.45	11.65	275.8	248	493.9	0.555	274.9	274	513.4	0.593	461.1	113.8	18000	400	1
207-10C	207	L-C	290	0.573	9.47	10.78	473.9	508	637.0	0.526	484.5	578	663.9	0.574	320.5	271.6	Unaged		1
207-09C	207	L-C	290	0.564	10.76	11.09	615.1	409	718.8	0.405	642.9	483	755.8	0.456	320.5	271.6	Unaged		1
205-24C	205	L-C	290	0.581	9.93	11.14	207.2	256	340.0	0.475	208.1	285	354.3	0.512	339.0	116.3	18000	400	1
743-05B	74	H-H	25	0.528	12.61	14.71	610.3	415	795.4	0.481	633.5	451	826.1	0.505	405.1	210.1	Unaged		2
743-05T	74	H-H	25	0.523	12.44	14.04	577.1	276	710.6	0.355	595.4	323	746.0	0.398	405.1	210.1	Unaged		2
743-03V	74	V-H	25	0.601	7.56	8.28	418.5	326	599.0	0.460	426.7	371	627.7	0.502	405.1	210.1	Unaged		1
745-03V	74	V-H	25	0.589	10.42	12.13	464.2	323	667.9	0.505	472.8	365	697.7	0.548	405.1	210.1	Unaged		1
743-03B	74	H-H	25	0.576	9.69	10.62	344.8	199	532.2	0.452	350.3	222	556.4	0.485	472.7	82.4	50000	320	1
744-02V	74	V-H	25	0.592	9.57	10.63	207.8	125	335.9	0.410	211.0	137	350.4	0.435	472.7	82.4	50000	320	1
741-06T	74	H-H	25	0.532	12.55	14.31	692.1	385	852.6	0.439	724.7	437	895.6	0.476	410.5	159.1	2570	350	2
742-05T	74	H-H	25	0.570	11.41	12.00	208.6	220	391.6	0.548	209.8	241	407.9	0.579	447.3	63.0	30000	350	1
741-03B	74	H-H	25	0.514	12.35	15.18	389.0	248	556.5	0.420	394.0	277	578.7	0.455	429.6	128.9	2570	400	2
741-01T	74	H-H	25	0.564	10.93	11.53	218.7	233	409.0	0.555	219.9	255	425.0	0.585	442.5	76.5	10000	400	1
741-03T	74	H-H	25	0.522	13.08	14.57	238.8	210	404.0	0.483	241.7	226	418.0	0.505	438.5	84.6	2570	450	2
741-05B	74	H-H	25	0.533	12.91	13.74	289.4	288	502.9	0.548	296.2	297	514.8	0.554	438.5	84.6	2570	450	2
743-07T	74	H-H	290	0.581	8.21	9.34	285.1	437	452.9	0.562	289.4	490	473.5	0.604	297.9	181.9	Unaged		1
743-03T	74	H-H	290	0.558	10.22	10.99	233.2	208	363.0	0.439	235.8	232	378.8	0.473	353.3	147.4	50000	320	1
741-05T	74	H-H	290	0.577	10.18	10.89	309.3	285	438.2	0.421	314.5	325	459.1	0.462	325.7	135.2	2570	400	1
741-02T	74	H-H	290	0.560	10.37	10.92	195.3	303	348.9	0.546	196.5	334	363.5	0.580	335.5	142.9	10000	400	1
741-04T	74	H-H	290	0.577	10.45	11.31	100.7	239	232.9	0.651	101.3	257	242.2	0.678	332.1	94.4	3000	450	1
752-08T	75	H-H	25	0.584	10.80	11.92	463.2	226	639.4	0.405	471.9	259	670.1	0.447	461.0	236.9	Unaged		1
753-05T	75	H-H	25	0.552	11.12	12.63	537.4	416	817.6	0.591	541.3	467	849.1	0.638	461.0	228.3	Annealed		1
751-07T	75	H-H	25	0.563	10.20	11.27	515.2	305	749.3	0.501	441.6	342	782.1	0.541	470.5	266.0	30000	290	1
752-06T	75	H-H	25	0.557	10.61	12.00	281.2	173	493.4	0.509	282.8	190	514.1	0.542	536.1	64.3	30000	320	1
753-02B	75	H-H	25	0.530	10.50	10.67	167.7	76	295.3	0.440	167.7	84	306.1	0.468	547.7	37.3	50000	320	1
752-05V	75	V-H	25	0.561	10.69	11.56	214.0	106	355.8	0.420	215.1	117	370.1	0.449	547.7	37.3	50000	320	1
752-02T	75	H-H	25	0.548	11.92	12.16	274.2	164	478.0	0.496	276.6	178	495.9	0.523	542.8	46.0	10000	350	1
752-04T	75	H-H	25	0.571	11.05	12.35	104.3	63	189.4	0.429	104.2	69	196.5	0.456	531.2	30.5	30000	350	1
751-06V	75	V-H	25	0.553	11.50	12.29	90.9	60	172.2	0.451	91.3	65	177.8	0.471	531.2	30.5	30000	350	1
751-03B	75	H-H	25	0.563	11.55	12.31	238.4	136	407.3	0.461	241.1	149	424.1	0.488	528.7	46.3	2570	400	1
751-01B	75	H-H	25	0.547	11.23	11.66	123.8	109	281.2	0.599	123.6	117	290.3	0.624	569.6	35.8	10000	400	1
751-01T	75	H-H	25	0.565	11.39	13.13	88.9	105	231.4	0.670	88.2	112	238.8	0.696	569.6	35.8	10000	400	1
751-03V	75	V-H	25	0.557	11.03	11.98	149.6	114	309.2	0.548	123.6	124	320.3	0.575	569.6	35.8	10000	400	1

Table A-1. (Contd.)

Specimen Number	Heat Treatment	Orientation	Test Temp.	Δa Final ^b		Deformation J ^c			Modified J ^c			Flow		Impact Energy (J/cm ²)	Condition				
				Comp. (mm)	Opt. (mm)	J _{IC} (kJ/m ²)	T _{av} (°C)	C	n	J _{IC} (kJ/m ²)	T _{av} (°C)	C	n		Stress (MPa)	Time (h)	Temp. (°C)	Ref.	
753-06B	75	H-H	25	0.569	10.10	10.65	181.5	63	277.8	0.334	182.4	71	289.7	0.363	569.6	40.5	10000 ^e	400	1
751-04T	75	H-H	25	0.567	10.85	11.19	170.4	151	348.1	0.563	171.7	162	360.6	0.586	523.5	51.1	2570	450	1
752-08B	75	H-H	290	0.579	7.83	8.49	436.8	386	583.3	0.453	448.2	444	611.6	0.498	333.5	164.8	Unaged		1
752-03V	75	V-V	290	0.565	8.32	9.21	493.4	289	600.0	0.347	500.4	365	630.5	0.418	333.5	164.8	Unaged		1
753-05B	75	H-H	290	0.568	10.29	11.30	329.8	452	518.5	0.562	335.0	500	539.8	0.599	333.5	201.5	Annealed		1
752-07T	75	H-H	290	0.565	10.53	11.08	210.0	212	358.0	0.488	213.2	232	373.1	0.515	389.0	160.0	30000	320	1
753-02T	75	H-H	290	0.573	10.00	10.87	234.4	142	354.5	0.385	236.3	160	370.2	0.419	415.0	124.7	50000	320	1
752-03T	75	H-H	290	0.551	10.12	10.68	129.5	206	288.2	0.627	129.7	221	298.7	0.654	409.9	151.5	10000	350	1
752-05T	75	H-H	290	0.574	10.09	10.49	108.4	202	262.6	0.669	108.3	217	272.3	0.697	408.7	111.9	30000	350	1
751-05T	75	H-H	290	0.563	10.23	10.56	150.2	206	301.9	0.571	151.4	223	313.7	0.597	397.2	115.5	2570	400	1
751-02T	75	H-H	290	0.568	10.40	10.53	156.1	145	274.2	0.462	154.8	161	284.4	0.497	409.6	135.8	10000	400	1
751-02V	75	V-V	290	0.569	10.33	11.14	262.0	121	363.6	0.320	266.6	140	382.5	0.356	409.6	135.8	10000	400	1
751-03T	75	H-H	290	0.559	10.06	10.36	107.1	151	230.1	0.577	107.2	165	240.0	0.609	405.2	82.0	2570	450	1
758-02C	758	L-C	25	0.582	10.84	10.39	91.2	101	209.0	0.591	91.5	108	216.6	0.613	501.0 ^e	69.6	18000	400	1
758-03C	758	L-C	25	0.568	11.57	13.56	103.4	116	239.1	0.607	103.4	124	247.3	0.632	501.0 ^e	69.6	18000	400	1
758-01C	758	L-C	290	0.567	11.90	12.37	167.2	128	268.8	0.400	167.8	142	279.8	0.432	397.1 ^e	118.1	18000	400	1

^a The first digit represents the direction normal to the plane of the crack and second digit is the direction of crack propagation. For pipe and pump cover plate materials L = longitudinal or axial, C = circumferential, and R = radial directions. For slabs H = horizontal direction in the plane of the slab and V = vertical direction transverse to the plane of the crack.

^b Final crack extension: Comp. = determined from compliance and Opt. = measured optically.

^c According to ASTM E-813 but with a slope of four times the flow stress for the blunting line.

^d Tests conducted at 1 ANL and 2 MEA.

^e Samples aged for 10,000 h at 400°C, annealed for 1 h at 550°C and water quenched, and then aged again for 10,000 h at 400°C.

Table A-2. Test data for specimen P2T-19

Test Number	: 0087	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.78 mm	Flow Stress	: 423.70 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	30.19	30.24	0.0459	21.250	0.407
2	91.85	92.33	0.1390	25.434	0.907
3	162.09	162.56	0.1382	27.817	1.409
4	237.45	238.47	0.1781	29.592	1.909
5	316.63	318.53	0.2264	31.005	2.409
6	398.94	403.01	0.3193	32.215	2.911
7	485.94	489.02	0.2847	33.459	3.409
8	558.51	560.97	0.2662	34.138	3.810
9	631.19	634.80	0.2968	35.031	4.210
10	702.68	710.41	0.3942	35.701	4.610
11	774.39	787.64	0.5121	36.429	5.011
12	852.64	865.03	0.4956	37.296	5.410
13	928.30	946.08	0.5907	37.809	5.810
14	1012.12	1027.21	0.5472	38.445	6.213
15	1094.79	1111.40	0.5700	39.099	6.616
16	1172.16	1194.96	0.6558	39.223	7.010
17	1243.84	1281.10	0.8435	39.871	7.408
18	1346.67	1364.08	0.6041	40.501	7.811
19	1417.16	1456.81	0.8567	41.007	8.210
20	1506.81	1542.45	0.8138	41.548	8.609
21	1591.19	1634.66	0.8928	42.024	9.010
22	1663.02	1727.32	1.0922	42.215	9.409
23	1770.40	1841.52	1.1532	42.627	9.906
24	1888.24	1960.22	1.1605	43.263	10.411
25	1997.54	2081.01	1.2512	43.651	10.912
26	2116.74	2200.42	1.2528	44.051	11.411
27	2218.30	2325.89	1.4214	44.197	11.914
28	2314.24	2449.44	1.6066	44.580	12.412
29	2430.70	2573.03	1.6521	45.191	12.912
30	2538.97	2700.96	1.7714	45.332	13.410
31	2660.74	2828.82	1.8066	45.837	13.912
32	2779.87	2960.88	1.8779	46.098	14.417
33	2889.82	3091.41	1.9865	46.248	14.912
34	3013.95	3251.42	2.1668	46.596	15.510

Table A-3. Deformation J_{IC} and J-R curve results for specimen P2T-19

Test Number	: 0087	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 290°C	Aging Time	: 59,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.78 mm	Flow Stress	: 423.70 MPa
Modulus E	: 218.45 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.7063 mm	Init. a/w	: 0.5850 (Measured)
Final Crack	: 31.8094 mm	Final a/w	: 0.6264 (Measured)
Final Crack	: 31.8731 mm	Final a/w	: 0.6277 (Compliance)
Linear Fit $J = B + M(\Delta a)$			
Intercept B	: 327.810 kJ/m ²	Slope M	: 1269.33 kJ/m ² mm
Fit Coeff. R	: 0.9783	(7 Data Points)	
J_{IC}	: 1305.8 kJ/m ²	(7456.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.770 mm	(0.0303 in.)	
T Average	: 1544.6	(J_{IC} at 0.15)	
Power-Law Fit $J = C(\Delta a)^n$			
Coeff. C	: 1542.22 kJ/m ²	Exponent N	: 0.8966
Fit Coeff. R	: 0.9803	(7 Data Points)	
J_{IC} (0.20)	: 2272.4 kJ/m ²	(12975.6 in.-lb/in. ²)	
Δa (J_{IC})	: 1.541 mm	(0.0607 in.)	
T Average	: 1471.2	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 1959.7 kJ/m ²	(11190.5 in.-lb/in. ²)	
Δa (J_{IC})	: 1.306 mm	(0.0514 in.)	
T Average	: 1477.2	(J_{IC} at 0.15)	
K _{Jc}	: 1306.9 MPa-m ^{0.5}		
J_{IC} Validity & Data Qualification (E 813-85)			
J_{max} Allowed	: 595.26 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)	
Data Limit	: J_{max} Ignored		
Δa (max) Allowed	: 6.113 mm	(at 1.5 Exclusion Line)	
Data Limit	: 1.5 Exclusion line		
Data Point Spacing	: Inadequate		
b_{net} or b_0 Size	: Inadequate		
dJ/da at J_{IC}	: Inadequate		
a_0 Measurement	: 5 Outside Limit		
Final Crack Shape	: OK		
Crack Size Estimate	: OK	(by Compliance)	
E Effective	: Inadequate		
J_{IC} Estimate	: INVALID		
J-R Curve Validity & Data Qualification (E 1152-86)			
J_{max} Allowed	: 429.50 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)	
Δa (max) Allowed	: 2.107 mm	($\Delta a = 0.1 b_0$)	
Δa (max) Allowed	: 7.721 mm	($\omega = 5$)	
Data Points	: Zone A = 34	Zone B = 0	
Data Point Spacing	: Inadequate		
J-R Curve Data	: INVALID		

Table A-4. Modified J_{IC} and J - R curve results for specimen P2T-19

Test Number	: 0087	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.78 mm	Flow Stress	: 423.70 MPa
Modulus E	: 218.45 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.7063 mm	Init. a/w	: 0.5850 (Measured)
Final Crack	: 31.8094 mm	Final a/w	: 0.6264 (Measured)
Final Crack	: 31.8731 mm	Final a/w	: 0.6277 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 89.649 kJ/m ²	Slope M	: 1478.44 kJ/m ² mm
Fit Coeff. R	: 0.9922	(4 Data Points)	
J_{IC}	: 702.2 kJ/m ²	(4009.9 in.-lb/in. ²)	
Δa (J_{IC})	: 0.414 mm	(0.0163 in.)	
T Average	: 1799.0	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 1547.19 kJ/m ²	Exponent N	: 0.9784
Fit Coeff. R	: 0.9935	(4 Data Points)	
J_{IC} (0.20)	: 3031.9 kJ/m ²	(17313.0 in.-lb/in. ²)	
Δa (J_{IC})	: 1.989 mm	(0.0783 in.)	
T Average	: 1770.5	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 2397.3 kJ/m ²	(13688.9 in.-lb/in. ²)	
Δa (J_{IC})	: 1.564 mm	(0.0616 in.)	
T Average	: 1772.2	(J_{IC} at 0.15)	
K _{Jc}	: 1898.0 MPa-m ^{0.5}

Figure A-2. Deformation and modified J - R curves at room temp. for Heat P2 aged 58,000 h at 290°C

Figure A-3. Deformation J_{IC} at room temp. for Heat P2 aged 58,000 h at 290°C

Figure A-4. Modified J_{IC} at room temp. for Heat P2 aged 58,000 h at 290°C

Table A-5. Test data for specimen P2B-16

Test Number	: 0086	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.38 mm
Spec. Width	: 50.81 mm	Flow Stress	: 427.45 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	31.00	30.97	-0.0293	23.209	0.405
2	82.91	83.43	0.1119	27.610	0.806
3	141.08	142.13	0.1846	30.137	1.208
4	204.14	204.63	0.1334	31.893	1.607
5	270.49	272.03	0.2043	33.362	2.009
6	339.47	342.09	0.2610	34.511	2.412
7	409.66	413.25	0.3031	35.753	2.808
8	485.14	487.05	0.2422	36.675	3.210
9	558.55	565.30	0.3922	37.521	3.612
10	634.06	642.84	0.4472	38.316	4.011
11	712.46	722.96	0.4887	39.271	4.411
12	792.96	804.19	0.5042	39.934	4.809
13	868.15	889.22	0.6955	40.584	5.210
14	952.26	972.55	0.6817	41.443	5.610
15	1035.22	1060.22	0.7579	41.947	6.010
16	1119.78	1148.34	0.8110	42.435	6.411
17	1202.77	1237.47	0.8959	43.010	6.808
18	1291.52	1327.24	0.9088	43.405	7.208
19	1377.42	1427.86	1.0845	43.788	7.638
20	1457.83	1512.50	1.1321	44.130	8.007
21	1552.32	1606.48	1.1267	44.529	8.408
22	1636.73	1702.99	1.2470	44.731	8.807
23	1710.14	1800.36	1.4731	45.102	9.209
24	1790.25	1896.66	1.6181	44.820	9.613
25	1875.23	1993.14	1.7160	45.084	10.011
26	1963.94	2091.74	1.7960	45.215	10.412
27	2040.58	2191.95	1.9783	45.366	10.812
28	2123.08	2290.50	2.0971	45.775	11.210
29	2222.88	2391.10	2.1027	45.690	11.616
30	2309.58	2492.56	2.2024	45.777	12.010
31	2382.43	2623.32	2.5764	45.682	12.510
32	2493.94	2746.24	2.6465	44.864	13.010
33	2579.96	2877.36	2.9111	44.528	13.515
34	2656.38	3003.69	3.1923	44.222	14.012
35	2748.47	3129.67	3.3753	43.979	14.512
36	2820.47	3259.26	3.6743	42.725	15.013
37	2870.23	3384.43	4.0524	41.476	15.512

Table A-6. Deformation J_{IC} and J-R curve results for specimen P2B-16

Test Number	: 0086	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.38 mm
Spec. Width	: 50.81 mm	Flow Stress	: 427.45 MPa
Modulus E	: 213.07 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.0719 mm	Init. a/w	: 0.5721 (Measured)
Final Crack	: 33.3156 mm	Final a/w	: 0.6557 (Measured)
Final Crack	: 33.1243 mm	Final a/w	: 0.6519 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 636.934 kJ/m ²	Slope M	: 709.87 kJ/m ² mm
Fit Coeff. R	: 0.9868	(19 Data Points)	
J_{IC}	: 1089.1 kJ/m ²	(6219.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.637 mm	(0.0251 in.)	
T Average	: 827.8	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 1327.18 kJ/m ²	Exponent N	: 0.6538
Fit Coeff. R	: 0.9914	(19 Data Points)	
J_{IC} (0.20)	: 1284.5 kJ/m ²	(7335.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.951 mm	(0.0375 in.)	
T Average	: 801.4	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 1189.4 kJ/m ²	(6791.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.846 mm	(0.0333 in.)	
T Average	: 810.7	(J_{IC} at 0.15)	
K _{Jc}	: 773.0 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 619.55 kJ/m ²	($J_{max} = b_o \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 3.140 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion line	
Data Points	: Zone A = 9	Zone B = 3
Data Point Spacing	: OK	
b_{net} or b_o Size	: Inadequate	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: OK	(by Compliance)
E Effective	: Inadequate	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 435.49 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.174 mm	($\Delta a = 0.1 b_o$)
Δa (max) Allowed	: 5.876 mm	($\omega = 5$)
Data Points	: Zone A = 36	Zone B = 0
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-7. Modified J_{IC} and J - R curve results for specimen P2B-16

Test Number	: 0086	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.38 mm
Spec. Width	: 50.81 mm	Flow Stress	: 427.45 MPa
Modulus E	: 213.07 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.0719 mm	Init. a/w	: 0.5721 (Measured)
Final Crack	: 33.3156 mm	Final a/w	: 0.6557 (Measured)
Final Crack	: 33.1243 mm	Final a/w	: 0.6519 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 674.943 kJ/m ²	Slope M	: 767.76 kJ/m ² mm
Fit Coeff. R	: 0.9911	(17 Data Points)	
J_{IC}	: 1225.0 kJ/m ²	(6995.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.716 mm	(0.0282 in.)	
T Average	: 895.3	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 1395.18 kJ/m ²	Exponent N	: 0.6832
Fit Coeff. R	: 0.9936	(17 Data Points)	
J_{IC} (0.20)	: 1429.2 kJ/m ²	(8160.9 in.-lb/in. ²)	
Δa (J_{IC})	: 1.036 mm	(0.0408 in.)	
T Average	: 876.5	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 1319.7 kJ/m ²	(7536.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.922 mm	(0.0363 in.)	
T Average	: 885.7	(J_{IC} at 0.15)	
K _{Jc}	: 825.9 MPa-m ^{0.5}

Figure A-5. Deformation and modified J - R curves at room temp. for Heat P2 aged 55,000 h at 320°C

Figure A-6. Deformation J_{IC} at room temp. for Heat P2 aged 55,000 h at 320°C

Figure A-7. Modified J_{IC} at room temp. for Heat P2 aged 55,000 h at 320°C

Table A-8. Test data for specimen P2T-20

Test Number	: 0101	Test Temp.	: 290°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.84 mm	Flow Stress	: 293.78 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	13.99	14.01	0.0380	13.711	0.307
2	36.72	36.69	0.0100	15.998	0.608
3	62.43	62.34	-0.0087	17.457	0.912
4	89.11	89.70	0.1317	18.532	1.209
5	118.84	117.21	-0.2078	19.470	1.508
6	147.44	148.69	0.1423	20.381	1.807
7	180.36	178.63	-0.1535	21.046	2.111
8	209.95	212.45	0.2009	21.774	2.408
9	244.50	244.40	0.0145	22.421	2.708
10	280.21	279.46	-0.0258	23.055	3.010
11	312.65	315.56	0.1772	23.665	3.310
12	350.14	350.83	0.0672	24.182	3.610
13	381.49	389.56	0.3988	24.726	3.910
14	425.39	424.99	0.0553	25.231	4.210
15	457.05	466.35	0.4173	25.724	4.509
16	500.77	503.75	0.2010	26.215	4.810
17	535.62	545.99	0.4354	26.680	5.109
18	576.53	586.10	0.4119	27.100	5.409
19	615.35	628.58	0.5124	27.507	5.708
20	661.50	670.76	0.4109	27.920	6.012
21	711.02	713.13	0.2402	28.295	6.308
22	741.50	759.54	0.6007	28.672	6.611
23	785.30	801.80	0.5678	29.032	6.910
24	826.70	847.57	0.6562	29.296	7.209
25	876.49	892.72	0.5676	29.691	7.511
26	910.16	940.56	0.8259	30.032	7.809
27	964.11	985.56	0.6714	30.275	8.112
28	1011.94	1033.74	0.6772	30.469	8.410
29	1047.78	1082.58	0.8822	30.884	8.709
30	1105.37	1128.31	0.7040	31.129	9.009
31	1134.16	1181.52	1.0575	31.461	9.317
32	1189.43	1226.32	0.9124	31.562	9.610
33	1216.81	1279.28	1.2547	31.798	9.911
34	1278.10	1325.69	1.0642	31.988	10.211
35	1317.75	1378.87	1.2312	32.045	10.510
36	1365.55	1428.93	1.2582	32.166	10.810
37	1420.60	1479.74	1.2096	32.431	11.110
38	1456.56	1533.49	1.4069	32.517	11.412
39	1487.32	1585.23	1.6328	32.718	11.710
40	1529.18	1637.17	1.7380	32.877	12.010
41	1574.63	1690.50	1.8176	33.002	12.311
42	1570.12	1693.54	1.8939	33.438	12.330

Table A-9. Deformation J_{IC} and J-R curve results for specimen P2T-20

Test Number	: 0101	Test Temp.	: 290°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.84 mm	Flow Stress	: 293.78 MPa
Modulus E	: 178.18 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.8656 mm	Init. a/w	: 0.5677 (Measured)
Final Crack	: 31.1469 mm	Final a/w	: 0.6126 (Measured)
Final Crack	: 30.7595 mm	Final a/w	: 0.6050 (Compliance)
Linear Fit $J = B + M(\Delta a)$			
Intercept B	: 675.623 kJ/m ²	Slope M	: 490.66 kJ/m ² mm
Fit Coeff. R	: 0.9110	(6 Data Points)	
J_{IC}	: 1159.9 kJ/m ²	(6623.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.987 mm	(0.0389 in.)	
T Average	: 1012.9	(J_{IC} at 0.15)	
Power-Law Fit $J = C(\Delta a)^n$			
Coeff. C	: 1128.02 kJ/m ²	Exponent N	: 0.5536
Fit Coeff. R	: 0.9161	(6 Data Points)	
J_{IC} (0.20)	: 1314.8 kJ/m ²	(7507.8 in.-lb/in. ²)	
Δa (J_{IC})	: 1.319 mm	(0.0519 in.)	
T Average	: 891.7	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 1261.1 kJ/m ²	(7201.2 in.-lb/in. ²)	
Δa (J_{IC})	: 1.223 mm	(0.0482 in.)	
T Average	: 901.7	(J_{IC} at 0.15)	
K_{Jc}	: 628.3 MPa-m ^{0.5}		
J_{IC} Validity & Data Qualification (E 813-85)			
J_{max} Allowed	: 430.43 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)	
Data Limit	: J_{max} Ignored		
Δa (max) Allowed	: 3.386 mm	(at 1.5 Exclusion Line)	
Data Limit	: 1.5 Exclusion Line		
Data Point Spacing	: Inadequate		
b_{net} or b_0 Size	: Inadequate		
dJ/da at J_{IC}	: OK		
Initial Crack Shape	: OK		
Final Crack shape	: OK		
Crack Size Estimate	: OK	(by Compliance)	
E Effective	: OK		
J_{IC} Estimate	: INVALID		
J-R Curve Validity & Data Qualification (E 1152-86)			
J_{max} Allowed	: 297.92 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)	
Δa (max) Allowed	: 2.198 mm	($\Delta a = 0.1 b_0$)	
Δa (max) Allowed	: 5.068 mm	($\omega = 5$)	
Data Points	: Zone A = 37	Zone B = 1	
Data Point Spacing	: Inadequate		
J-R Curve Data	: INVALID		

Table A-10. Modified J_{IC} and J-R curve results for specimen P2T-20

Test Number	: 0101	Test Temp.	: 290°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.84 mm	Flow Stress	: 293.78 MPa
Modulus E	: 178.18 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.8656 mm	Init. a/w	: 0.5677 (Measured)
Final Crack	: 31.1469 mm	Final a/w	: 0.6126 (Measured)
Final Crack	: 30.7595 mm	Final a/w	: 0.6050 (Compliance)
Linear Fit			
$J = B + M(\Delta a)$			
Intercept B	: 443.098 kJ/m ²	Slope M	: 680.13 kJ/m ² mm
Fit Coeff. R	: 0.9874	(5 Data Points)	
J_{IC}	: 1051.9 kJ/m ²	(6006.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.895 mm	(0.0352 in.)	
T Average	: 1404.1	(J_{IC} at 0.15)	
Power-Law Fit			
$J = C(\Delta a)^N$			
Coeff. C	: 1097.19 kJ/m ²	Exponent N	: 0.7135
Fit Coeff. R	: 0.9914	(5 Data Points)	
J_{IC} (0.20)	: 1371.3 kJ/m ²	(7830.7 in.-lb/in. ²)	
Δa (J_{IC})	: 1.367 mm	(0.0538 in.)	
T Average	: 1228.4	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 1276.4 kJ/m ²	(7288.3 in.-lb/in. ²)	
Δa (J_{IC})	: 1.236 mm	(0.0487 in.)	
T Average	: 1239.1	(J_{IC} at 0.15)	
K_{Jc}	: 726.3 MPa-m ^{0.5}

Figure A-8. Deformation and modified J-R curves at 290°C for Heat P2 at 58,000 h at 290°C

Figure A-9. Deformation J_{IC} at 290°C for Heat P2 aged 58,000 h at 290°C

Figure A-10. Modified J_{IC} at 290°C for Heat P2 aged 58,000 h at 290°C

Table A-11. Test data for specimen P2B-17

Test Number	: 0098	Test Temp.	: 290°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.35 mm
Spec. Width	: 50.81 mm	Flow Stress	: 293.65 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	14.53	14.45	-0.1546	14.688	0.305
2	39.37	39.51	-0.0353	17.549	0.607
3	67.25	66.63	-0.2563	19.166	0.903
4	97.63	97.84	-0.0968	20.384	1.214
5	128.40	128.13	-0.1660	21.438	1.508
6	160.41	161.93	0.0353	22.337	1.808
7	194.47	195.45	-0.0151	23.130	2.107
8	229.53	232.68	0.1527	23.834	2.414
9	272.40	273.98	0.0512	24.485	2.758
10	315.60	319.43	0.1751	25.296	3.110
11	360.58	364.48	0.1788	26.076	3.458
12	406.21	411.63	0.2430	26.732	3.807
13	455.48	459.49	0.1899	27.120	4.159
14	502.28	509.27	0.2910	27.799	4.508
15	555.09	558.93	0.1944	28.475	4.861
16	593.96	612.54	0.6116	28.835	5.210
17	649.00	661.54	0.4548	29.418	5.558
18	700.87	716.41	0.5265	29.642	5.909
19	756.02	770.01	0.4923	30.193	6.259
20	794.59	827.62	0.8890	30.631	6.611
21	857.64	879.27	0.6678	30.864	6.958
22	907.67	938.87	0.8422	31.328	7.308
23	965.00	995.72	0.8339	31.656	7.661
24	1011.74	1055.12	1.0389	31.965	8.008
25	1070.20	1113.46	1.0371	32.323	8.361
26	1122.04	1174.45	1.1699	32.531	8.711
27	1179.87	1233.96	1.1929	32.761	9.059
28	1244.17	1294.92	1.1492	32.997	9.411
29	1301.78	1357.46	1.2108	33.198	9.761
30	1339.19	1420.65	1.5192	33.382	10.109
31	1395.16	1481.13	1.5709	33.448	10.459
32	1446.48	1544.95	1.7083	33.560	10.808
33	1499.46	1609.01	1.8251	33.441	11.162
34	1549.44	1673.62	1.9735	33.431	11.514
35	1613.34	1744.45	2.0408	33.240	11.904
36	1656.12	1821.05	2.3567	33.250	12.310
37	1737.21	1912.10	2.4450	32.818	12.816
38	1790.58	2005.65	2.7858	32.474	13.312
39	1861.41	2096.02	2.9440	32.371	13.811
40	1943.33	2188.27	3.0238	32.335	14.312
41	1989.39	2283.58	3.3899	31.888	14.811
42	2036.22	2376.62	3.7209	31.550	15.317

Table A-12. Deformation J_{IC} and J-R curve results for specimen P2B-17

Test Number	: 0098	Test Temp.	: 290°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.35 mm
Spec. Width	: 50.81 mm	Flow Stress	: 293.65 MPa
Modulus E	: 179.79 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 29.0344 mm	Init. a/w	: 0.5715 (Measured)
Final Crack	: 33.6406 mm	Final a/w	: 0.6621 (Measured)
Final Crack	: 32.7553 mm	Final a/w	: 0.6447 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 741.071 kJ/m ²	Slope M	: 395.38 kJ/m ² mm
Fit Coeff. R	: 0.9855	(13 Data Points)	
J_{IC}	: 1117.1 kJ/m ²	(6378.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.951 mm	(0.0374 in.)	
T Average	: 824.4	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 1076.41 kJ/m ²	Exponent N	: 0.5248
Fit Coeff. R	: 0.9921	(13 Data Points)	
J_{IC} (0.20)	: 1192.3 kJ/m ²	(6808.1 in.-lb/in. ²)	
Δa (J_{IC})	: 1.215 mm	(0.0478 in.)	
T Average	: 822.2	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 1144.9 kJ/m ²	(6537.6 in.-lb/in. ²)	
Δa (J_{IC})	: 1.125 mm	(0.0443 in.)	
T Average	: 832.2	(J_{IC} at 0.15)	
K_{Jc}	: 596.1 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 426.24 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 3.183 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 5	Zone B = 3
Data Point Spacing	: OK	
b_{net} or b_0 Size	: Inadequate	
dJ/da at J_{IC}	: OK	
Initial Crack Shape	: OK	
Final Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 298.80 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.177 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 4.827 mm	($\omega = 5$)
Data Points	: Zone A = 36	Zone B = 0
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-13. Modified J_{IC} and J - R curve results for specimen P2B-17

Test Number	: 0098	Test Temp.	: 290°C
Material Type	: CF-3	Heat Number	: P2
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.35 mm
Spec. Width	: 50.81 mm	Flow Stress	: 293.65 MPa
Modulus E	: 179.79 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 29.0344 mm	Init. a/w	: 0.5715 (Measured)
Final Crack	: 33.6406 mm	Final a/w	: 0.6621 (Measured)
Final Crack	: 32.7553 mm	Final a/w	: 0.6447 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 771.288 kJ/m ²	Slope M	: 454.08 kJ/m ² mm
Fit Coeff. R	: 0.9949	(12 Data Points)	
J_{IC}	: 1257.4 kJ/m ²	(7179.8 in.-lb/in. ²)	
Δa (J_{IC})	: 1.070 mm	(0.0421 in.)	
T Average	: 946.8	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 1134.21 kJ/m ²	Exponent N	: 0.5747
Fit Coeff. R	: 0.9963	(12 Data Points)	
J_{IC} (0.20)	: 1344.7 kJ/m ²	(7678.7 in.-lb/in. ²)	
Δa (J_{IC})	: 1.345 mm	(0.0529 in.)	
T Average	: 946.6	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 1286.7 kJ/m ²	(7347.1 in.-lb/in. ²)	
Δa (J_{IC})	: 1.245 mm	(0.0490 in.)	
T Average	: 956.8	(J_{IC} at 0.15)	
K_{Jc}	: 645.9 MPa-m ^{0.5}

Figure A-11. Deformation and modified J - R curves at 290°C for Heat P2 aged 55,000 h at 320°C

Figure A-12. Deformation J_{IC} at 290°C for Heat P2 aged 55,000 h at 320°C

Figure A-13. Modified J_{IC} at 290°C for Heat P2 aged 55,000 h at 320°C

Table A-14. Test data for specimen 691-03B

Test Number	: 0093	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: 69
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.30 mm
Spec. Width	: 50.83 mm	Flow Stress	: 475.52 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	20.96	20.96	0.0001	23.745	0.304
2	61.36	61.34	-0.0080	30.200	0.605
3	108.69	109.29	0.1193	33.540	0.905
4	159.49	159.83	0.0849	35.742	1.205
5	215.02	215.89	0.1338	37.483	1.510
6	270.34	272.43	0.2206	38.672	1.808
7	328.56	331.13	0.2481	39.700	2.109
8	388.46	391.70	0.2801	40.652	2.410
9	447.51	453.60	0.3963	41.341	2.708
10	506.84	516.54	0.5241	41.768	3.008
11	566.74	581.16	0.6724	42.099	3.312
12	626.50	644.55	0.7745	42.106	3.608
13	689.82	709.85	0.8246	42.524	3.912
14	725.62	754.09	1.0261	42.410	4.109
15	773.22	808.60	1.1793	42.348	4.361
16	814.86	864.65	1.4793	42.456	4.611
17	856.02	905.77	1.4786	42.186	4.811
18	889.58	952.32	1.7230	41.780	5.010
19	923.02	996.05	1.9078	41.474	5.212
20	954.74	1039.82	2.1154	41.256	5.411
21	988.32	1083.25	2.2782	41.098	5.610
22	1029.60	1126.71	2.3125	41.047	5.813
23	1069.55	1184.40	2.5795	40.668	6.060
24	1111.67	1238.76	2.7550	40.142	6.311
25	1159.16	1305.45	3.0159	39.452	6.609
26	1208.16	1376.22	3.2961	38.875	6.930
27	1258.29	1447.75	3.5574	38.266	7.258
28	1303.37	1525.33	3.9341	37.468	7.609
29	1355.66	1611.64	4.3065	36.286	8.009
30	1392.90	1697.66	4.8140	34.778	8.409
31	1446.22	1779.34	5.0942	33.931	8.815
32	1480.62	1867.79	5.6030	32.545	9.231
33	1520.76	1942.06	5.9107	31.337	9.612
34	1558.73	2021.59	6.2694	30.332	10.009
35	1586.98	2101.87	6.7010	29.433	10.415
36	1628.79	2197.67	7.1272	28.128	10.909
37	1663.07	2293.41	7.5903	26.894	11.412
38	1692.28	2385.09	8.0404	25.396	11.910
39	1713.64	2475.50	8.5183	24.227	12.411
40	1728.92	2563.28	9.0012	23.142	12.911
41	1768.53	2666.77	9.4062	21.997	13.508
42	1789.40	2771.62	9.9150	20.826	14.113

Table A-15. Deformation J_{IC} and J-R curve results for specimen 691-03B

Test Number	: 0093	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: 69
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.30 mm
Spec. Width	: 50.83 mm	Flow Stress	: 475.52 MPa
Modulus E	: 204.49 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.5531 mm	Init. a/w	: 0.5617 (Measured)
Final Crack	: 39.3375 mm	Final a/w	: 0.7739 (Measured)
Final Crack	: 38.4682 mm	Final a/w	: 0.7568 (Compliance)
Linear Fit $J = B + M(\Delta a)$			
Intercept B	: 375.502 kJ/m ²	Slope M	: 307.79 kJ/m ² mm
Fit Coeff. R	: 0.9747	(11 Data Points)	
J_{IC}	: 448.0 kJ/m ²	(2558.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.236 mm	(0.0093 in.)	
T Average	: 278.3	(J_{IC} at 0.15)	
Power-Law Fit $J = C(\Delta a)^n$			
Coeff. C	: 701.01 kJ/m ²	Exponent N	: 0.4658
Fit Coeff. R	: 0.9909	(11 Data Points)	
J_{IC} (0.20)	: 486.0 kJ/m ²	(2775.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.456 mm	(0.0179 in.)	
T Average	: 274.0	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 450.3 kJ/m ²	(2571.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.387 mm	(0.0152 in.)	
T Average	: 280.1	(J_{IC} at 0.15)	
K _{Jc}	: 445.5 MPa-m ^{0.5}		
J_{IC} Validity & Data Qualification (E 813-85)			
J_{max} Allowed	: 706.21 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)	
Data Limit	: J_{max} Ignored		
Δa (max) Allowed	: 2.010 mm	(at 1.5 Exclusion Line)	
Data Limit	: 1.5 Exclusion line		
Data Points	: Zone A = 5	Zone B = 4	
Data Point Spacing	: OK		
b_{net} or b_0 Size	: Inadequate		
dJ/da at J_{IC}	: OK		
a_f Measurement	: Near-Surface	Outside Limit	
Initial Crack Shape	: OK		
Crack Size Estimate	: Inadequate	(by Compliance)	
E Effective	: OK		
J_{IC} Estimate	: INVALID		
J-R Curve Validity & Data Qualification (E 1152-86)			
J_{max} Allowed	: 482.70 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)	
Δa (max) Allowed	: 2.228 mm	($\Delta a = 0.1 b_0$)	
Δa (max) Allowed	: 4.332 mm	($\omega = 5$)	
Data Points	: Zone A = 14	Zone B = 5	
Data Point Spacing	: Inadequate		
J-R Curve Data	: INVALID		

Table A-16. Modified J_{IC} and J-R curve results for specimen 691-03B

Test Number	: 0093	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: 69
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.30 mm
Spec. Width	: 50.83 mm	Flow Stress	: 475.52 MPa
Modulus E	: 204.49 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.5531 mm	Init. a/w	: 0.5617 (Measured)
Final Crack	: 39.3375 mm	Final a/w	: 0.7739 (Measured)
Final Crack	: 38.4682 mm	Final a/w	: 0.7568 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 360.289 kJ/m ²	Slope M	: 352.41 kJ/m ² mm
Fit Coeff. R	: 0.9824	(11 Data Points)	
J_{IC}	: 442.2 kJ/m ²	(2525.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.232 mm	(0.0092 in.)	
T Average	: 318.7	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 731.49 kJ/m ²	Exponent N	: 0.5058
Fit Coeff. R	: 0.9938	(11 Data Points)	
J_{IC} (0.20)	: 493.6 kJ/m ²	(2818.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.460 mm	(0.0181 in.)	
T Average	: 309.2	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 453.3 kJ/m ²	(2588.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.388 mm	(0.0153 in.)	
T Average	: 315.5	(J_{IC} at 0.15)	
K _{Jc}	: 463.9 MPa-m ^{0.5}

Figure A-14. Deformation and modified J-R curves at room temp. for Heat 69 aged 50,000 h at 320°C

Figure A-15. Deformation J_{IC} at room temp. for Heat 69 aged 50,000 h at 320°C

Figure A-16. Modified J_{IC} at room temp. for Heat 69 aged 50,000 h at 320°C

Table A-17. Test data for specimen 692-05V

Test Number	: 0094	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: 69
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.34 mm
Spec. Width	: 50.81 mm	Flow Stress	: 475.52 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	20.07	20.08	0.0027	22.571	0.304
2	58.15	58.03	-0.0495	28.498	0.607
3	102.61	103.08	0.0751	31.578	0.907
4	150.51	151.45	0.1395	33.573	1.209
5	201.58	202.26	0.1145	35.307	1.510
6	254.03	256.52	0.2499	36.363	1.809
7	308.93	311.61	0.2621	37.516	2.112
8	364.56	369.44	0.3730	38.574	2.412
9	423.76	427.42	0.3208	39.401	2.716
10	481.36	486.91	0.3915	40.013	3.010
11	540.05	548.09	0.4744	40.758	3.312
12	601.85	608.86	0.4438	41.152	3.611
13	658.77	673.26	0.6438	41.532	3.910
14	714.44	736.94	0.8395	42.154	4.212
15	777.40	799.74	0.8358	42.195	4.513
16	836.54	865.86	0.9797	42.581	4.811
17	899.53	931.10	1.0223	42.743	5.113
18	958.90	998.53	1.1654	42.985	5.413
19	1019.05	1065.76	1.2828	43.023	5.716
20	1076.78	1131.83	1.4130	43.126	6.012
21	1119.41	1188.36	1.6201	42.995	6.260
22	1167.17	1244.50	1.7389	42.797	6.514
23	1215.89	1299.62	1.8255	42.489	6.761
24	1248.63	1358.09	2.1608	42.205	7.010
25	1306.06	1422.62	2.2488	41.787	7.310
26	1358.87	1490.89	2.4313	41.506	7.607
27	1401.95	1561.69	2.7448	41.182	7.916
28	1455.54	1625.76	2.8583	40.642	8.213
29	1504.42	1693.52	3.0541	40.189	8.509
30	1552.46	1784.36	3.4772	39.375	8.906
31	1605.32	1871.38	3.7985	37.921	9.307
32	1651.91	1964.62	4.2173	37.007	9.733
33	1698.19	2044.54	4.5073	36.236	10.114
34	1745.65	2130.19	4.8229	35.671	10.511
35	1812.71	2238.90	5.1491	34.850	11.016
36	1864.42	2344.92	5.5546	33.647	11.511
37	1912.18	2449.03	5.9567	32.481	12.010
38	1958.09	2574.90	6.4991	31.310	12.613
39	2012.97	2699.64	6.9494	30.269	13.232
40	2058.33	2816.54	7.3898	29.185	13.814
41	2096.83	2956.34	7.9815	27.420	14.511
42	2140.66	3088.26	8.4709	25.831	15.205

Table A-18. Deformation J_{IC} and J-R curve results for specimen 692-05V

Test Number	: 0094	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: 69
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.34 mm
Spec. Width	: 50.81 mm	Flow Stress	: 475.52 MPa
Modulus E	: 198.45 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.4719 mm	Init. a/w	: 0.5603 (Measured)
Final Crack	: 38.0906 mm	Final a/w	: 0.7496 (Measured)
Final Crack	: 36.9428 mm	Final a/w	: 0.7270 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 380.631 kJ/m ²	Slope M	: 468.10 kJ/m ² mm
Fit Coeff. R	: 0.9844	(11 Data Points)	
J_{IC}	: 504.9 kJ/m ²	(2883.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.265 mm	(0.0105 in.)	
T Average	: 410.8	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 854.04 kJ/m ²	Exponent N	: 0.6026
Fit Coeff. R	: 0.9882	(11 Data Points)	
J_{IC} (0.20)	: 557.9 kJ/m ²	(3185.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.493 mm	(0.0194 in.)	
T Average	: 410.0	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 501.8 kJ/m ²	(2865.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.414 mm	(0.0163 in.)	
T Average	: 416.9	(J_{IC} at 0.15)	
K _{Jc}	: 524.0 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 708.24 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 2.228 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion line	
Data Points	: Zone A = 3	Zone B = 3
Data Point Spacing	: OK	
b_{net} or b_0 Size	: Inadequate	
dJ/da at J_{IC}	: OK	
a_0 Measurement	: 1 Outside Limit	
a_f Measurement	: Near-Surface	Outside Limit
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 483.68 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.234 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 5.466 mm	($\omega = 5$)
Data Points	: Zone A = 22	Zone B = 1
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-19. Modified J_{IC} and J-R curve results for specimen 692-05V

Test Number	: 0094	Test Temp.	: 25°C
Material Type	: CF-3	Heat Number	: 69
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.34 mm
Spec. Width	: 50.81 mm	Flow Stress	: 475.52 MPa
Modulus E	: 198.45 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.4719 mm	Init. a/w	: 0.5603 (Measured)
Final Crack	: 38.0906 mm	Final a/w	: 0.7496 (Measured)
Final Crack	: 36.9428 mm	Final a/w	: 0.7270 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 405.072 kJ/m ²	Slope M	: 478.68 kJ/m ² mm
Fit Coeff. R	: 0.9812	(12 Data Points)	
J_{IC}	: 541.3 kJ/m ²	(3090.9 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.285 mm	(0.0112 in.)	
T Average	: 420.1	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 885.61 kJ/m ²	Exponent N	: 0.6194
Fit Coeff. R	: 0.9894	(12 Data Points)	
$J_{IC} (0.20)$	: 580.0 kJ/m ²	(3311.8 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.505 mm	(0.0199 in.)	
T Average	: 435.1	(J_{IC} at 0.20)	
$J_{IC} (0.15)$	: 520.1 kJ/m ²	(2969.6 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.423 mm	(0.0167 in.)	
T Average	: 442.1	(J_{IC} at 0.15)	
K _{Jc}	: 540.7 MPa-m ^{0.5}

Figure A-17. Deformation and modified J-R curves at room temp. for Heat 69 aged 50,000 h at 320°C

Figure A-18. Deformation J_{IC} at room temp. for Heat 69 aged 50,000 h at 320°C

Figure A-19. Modified J_{IC} at room temp. for Heat 69 aged 50,000 h at 320°C

Table A-20. Test data for specimen 691-03T

Test Number	: 0105	Test Temp.	: 290°C
Material Type	: CF-3	Heat Number	: 69
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.32 mm
Spec. Width	: 50.83 mm	Flow Stress	: 339.84 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	15.55	15.56	0.0102	16.217	0.304
2	43.62	43.52	-0.0453	19.779	0.606
3	75.73	76.12	0.0846	21.804	0.907
4	110.16	110.43	0.0641	23.093	1.207
5	146.07	147.78	0.2459	24.230	1.506
6	184.77	185.51	0.1503	25.146	1.809
7	221.17	227.01	0.5570	25.731	2.107
8	261.37	265.63	0.4516	26.180	2.407
9	298.18	310.70	0.9245	26.811	2.710
10	332.13	343.49	0.8658	26.884	2.959
11	370.71	379.18	0.7338	27.055	3.208
12	400.57	418.37	1.1214	27.279	3.460
13	434.34	452.59	1.1386	27.246	3.708
14	459.67	492.05	1.6373	27.056	3.959
15	490.28	526.62	1.7677	27.040	4.207
16	515.46	565.79	2.1974	26.901	4.458
17	550.16	600.82	2.2070	26.571	4.710
18	593.38	646.24	2.2650	26.255	5.009
19	613.81	693.87	2.8142	25.975	5.310
20	656.74	735.34	2.8958	25.487	5.610
21	691.90	797.51	3.4744	24.946	6.007
22	731.76	854.71	3.8189	24.013	6.409
23	756.23	914.02	4.1690	22.935	6.810
24	781.51	968.75	4.9868	21.848	7.211
25	816.91	1037.17	5.5267	20.854	7.707
26	840.02	1105.60	6.2213	19.607	8.209
27	874.06	1169.54	6.6508	18.710	8.708
28	896.09	1235.17	7.2406	17.454	9.208
29	930.77	1309.70	7.7431	16.308	9.809
30	947.15	1382.63	8.4151	15.196	10.410
31	962.55	1451.58	9.0167	14.180	11.009

Table A-21. Deformation J_{IC} and J-R curve results for specimen 691-03T

Test Number	: 0105	Test Temp.	: 290°C
Material Type	: CF-3	Heat Number	: 69
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.32 mm
Spec. Width	: 50.83 mm	Flow Stress	: 339.84 MPa
Modulus E	: 183.79 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 29.4656 mm	Init. a/w	: 0.5797 (Measured)
Final Crack	: 39.3031 mm	Final a/w	: 0.7733 (Measured)
Final Crack	: 38.4823 mm	Final a/w	: 0.7571 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 173.968 kJ/m ²	Slope M	: 185.12 kJ/m ² mm
Fit Coeff. R	: 0.9046	(9 Data Points)	
J_{IC}	: 201.4 kJ/m ²	(1150.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.148 mm	(0.0058 in.)	
T Average	: 294.6	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 364.89 kJ/m ²	Exponent N	: 0.5299
Fit Coeff. R	: 0.8949	(9 Data Points)	
J_{IC} (0.20)	: 210.8 kJ/m ²	(1203.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.355 mm	(0.0140 in.)	
T Average	: 303.5	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 189.0 kJ/m ²	(1079.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.289 mm	(0.0114 in.)	
T Average	: 310.0	(J_{IC} at 0.15)	
K_{Jc}	: 305.9 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 483.99 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.874 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 3	Zone B = 2
Data Point Spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
Initial Crack Shape	: OK	
Final Crack shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 345.31 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.136 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 4.871 mm	($\omega = 5$)
Data Points	: Zone A = 7	Zone B = 7
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-22. Modified J_{IC} and J-R curve results for specimen 691-03T

Test Number	: 0105	Test Temp.	: 290°C
Material Type	: CF-3	Heat Number	: 69
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.32 mm
Spec. Width	: 50.83 mm	Flow Stress	: 339.84 MPa
Modulus E	: 183.79 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 29.4656 mm	Init. a/w	: 0.5797 (Measured)
Final Crack	: 39.3031 mm	Final a/w	: 0.7733 (Measured)
Final Crack	: 38.4823 mm	Final a/w	: 0.7571 (Compliance)

Linear Fit	$J = B + M(\Delta a)$
Intercept B	: 164.824 kJ/m ²
Fit Coeff. R	: 0.9248
J_{IC}	: 195.0 kJ/m ²
Δa (J_{IC})	: 0.143 mm
T Average	: 334.3

Slope M	: 210.08 kJ/m ² mm
(9 Data Points)	
(1113.2 in.-lb/in. ²)	
(0.0056 in.)	
(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$
Coeff. C	: 380.96 kJ/m ²
Fit Coeff. R	: 0.9118
J_{IC} (0.20)	: 211.3 kJ/m ²
Δa (J_{IC})	: 0.355 mm
T Average	: 338.9
J_{IC} (0.15)	: 187.4 kJ/m ²
Δa (J_{IC})	: 0.288 mm
T Average	: 345.6
K_{Jc}	: 317.9 MPa-m ^{0.5}

Exponent N	: 0.5698
(9 Data Points)	
(1206.6 in.-lb/in. ²)	
(0.0140 in.)	
(J_{IC} at 0.20)	
(1070.0 in.-lb/in. ²)	
(0.0113 in.)	
(J_{IC} at 0.15)

Figure A-20. Deformation and modified J-R curves at 290°C for Heat 69 aged 50,000 h at 320°C

Figure A-21. Deformation J_{IC} at 290°C for Heat 69 aged 50,000 h at 320°C

Figure A-22. Modified J_{IC} at 290°C for Heat 69 aged 50,000 h at 320°C

Table A-23. Test data for specimen P1T-17

Test Number	: 0085	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.37 mm
Spec. Width	: 50.81 mm	Flow Stress	: 406.90 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	31.50	31.54	0.0360	24.008	0.405
2	85.53	85.58	0.0395	29.018	0.806
3	146.94	147.73	0.1393	31.437	1.208
4	196.38	196.71	0.0948	32.689	1.513
5	247.04	247.06	0.0716	33.898	1.809
6	299.19	300.41	0.1441	34.702	2.111
7	350.19	354.40	0.2977	35.560	2.409
8	405.07	408.73	0.2735	36.288	2.710
9	458.99	466.11	0.4060	37.098	3.008
10	518.49	522.91	0.3151	37.520	3.312
11	575.71	583.67	0.4215	38.246	3.614
12	630.50	643.68	0.5636	38.694	3.914
13	688.23	703.50	0.6157	39.253	4.213
14	750.21	764.10	0.5843	39.939	4.510
15	811.30	828.29	0.6491	40.406	4.814
16	868.59	892.55	0.7841	40.686	5.115
17	923.92	954.92	0.9115	40.810	5.407
18	986.27	1019.63	0.9516	41.553	5.709
19	1053.70	1084.20	0.9063	41.736	6.007
20	1126.30	1163.62	1.0066	41.901	6.358
21	1191.51	1242.89	1.2003	42.343	6.709
22	1264.63	1320.71	1.2611	42.605	7.059
23	1348.38	1400.64	1.2148	42.936	7.413
24	1412.88	1483.36	1.4237	43.004	7.760
25	1474.04	1564.95	1.6466	43.254	8.111
26	1552.60	1644.39	1.6556	43.317	8.461
27	1640.31	1728.59	1.6214	43.421	8.819
28	1711.07	1811.85	1.7378	43.536	9.161
29	1768.71	1896.61	1.9801	43.722	9.511
30	1858.81	1990.02	2.0081	43.621	9.911
31	1930.83	2089.85	2.2327	43.538	10.312
32	2029.29	2209.85	2.3971	43.506	10.810
33	2158.48	2355.81	2.5167	43.023	11.410
34	2250.06	2507.82	2.9231	42.706	12.017
35	2359.52	2676.32	3.2953	41.805	12.710
36	2507.01	2871.36	3.5739	41.459	13.511
37	2679.09	3122.19	3.9976	41.112	14.514
38	2836.29	3370.34	4.4500	40.193	15.511

Table A-24. Deformation J_{IC} and J-R curve results for specimen P1B-17

Test Number	: 0085	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.37 mm
Spec. Width	: 50.81 mm	Flow Stress	: 406.90 MPa
Modulus E	: 204.67 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.1594 mm	Init. a/w	: 0.5739 (Measured)
Final Crack	: 34.2656 mm	Final a/w	: 0.6744 (Measured)
Final Crack	: 33.6094 mm	Final a/w	: 0.6615 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 304.413 kJ/m ²	Slope M	: 752.53 kJ/m ² mm
Fit Coeff. R	: 0.9889	(21 Data Points)	
J_{IC}	: 566.2 kJ/m ²	(3233.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.348 mm	(0.0137 in.)	
T Average	: 930.2	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 1058.89 kJ/m ²	Exponent N	: 0.7841
Fit Coeff. R	: 0.9908	(21 Data Points)	
J_{IC} (0.20)	: 784.2 kJ/m ²	(4478.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.682 mm	(0.0268 in.)	
T Average	: 906.8	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 678.6 kJ/m ²	(3874.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.567 mm	(0.0223 in.)	
T Average	: 915.1	(J_{IC} at 0.15)	
K _{Jc}	: 722.3 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 587.26 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 3.066 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 11	Zone B = 3
Data Point Spacing	: OK	
b_{net} or b_0 Size	: Inadequate	
dJ/da at J_{IC}	: OK	
Initial Crack Shape	: OK	
Final Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 414.45 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.165 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 6.887 mm	($\omega = 5$)
Data Points	: Zone A = 38	Zone B = 0
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-25. Modified J_{IC} and J - R curve results for specimen P1B-17

Test Number	: 0085	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.37 mm
Spec. Width	: 50.81 mm	Flow Stress	: 406.90 MPa
Modulus E	: 204.67 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.1594 mm	Init. a/w	: 0.5739 (Measured)
Final Crack	: 34.2656 mm	Final a/w	: 0.6744 (Measured)
Final Crack	: 33.6094 mm	Final a/w	: 0.6615 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 288.610 kJ/m ²	Slope M	: 812.73 kJ/m ² mm
Fit Coeff. R	: 0.9903	(21 Data Points)	
J_{IC}	: 576.5 kJ/m ²	(3291.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.354 mm	(0.0139 in.)	
T Average	: 1004.7	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 1091.18 kJ/m ²	Exponent N	: 0.8307
Fit Coeff. R	: 0.9935	(21 Data Points)	
J_{IC} (0.20)	: 807.8 kJ/m ²	(4612.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.696 mm	(0.0274 in.)	
T Average	: 1005.5	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 684.8 kJ/m ²	(3910.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.571 mm	(0.0225 in.)	
T Average	: 1012.9	(J_{IC} at 0.15)	
K_{Jc}	: 777.3 MPa-m ^{0.5}

Figure A-23. Deformation and modified J - R curves at room temp. for Heat P1 aged 58,000 h at 290°C

Figure A-24. Deformation J_{IC} at room temp. for Heat P1 aged 58,000 h at 290°C

Figure A-25. Modified J_{IC} at room temp. for Heat P1 aged 58,000 h at 290°C

Table A-26. Test data for specimen P1B-14

Test Number	: 0084	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.37 mm
Spec. Width	: 50.84 mm	Flow Stress	: 480.43 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	10.37	10.38	0.0479	19.497	0.203
2	33.14	33.09	-0.0146	27.195	0.405
3	61.66	61.76	0.0498	30.745	0.607
4	92.24	92.05	-0.0217	32.942	0.807
5	125.45	125.81	0.0742	34.456	1.009
6	159.27	159.85	0.1021	35.771	1.210
7	194.43	194.88	0.0892	36.951	1.409
8	231.14	230.90	0.0293	37.706	1.609
9	267.45	269.63	0.2058	38.788	1.809
10	305.38	305.71	0.0894	39.324	2.010
11	344.38	345.55	0.1355	39.997	2.210
12	381.91	385.15	0.2369	40.575	2.410
13	421.86	423.70	0.1755	40.985	2.610
14	462.07	465.24	0.2286	41.258	2.811
15	502.17	505.38	0.2299	41.773	3.009
16	540.98	548.23	0.3660	42.239	3.212
17	578.78	589.70	0.4806	42.689	3.412
18	618.70	631.68	0.5405	43.181	3.613
19	662.22	673.93	0.5064	43.517	3.814
20	702.12	717.79	0.6068	43.824	4.011
21	742.36	760.88	0.6750	43.911	4.211
22	787.91	803.97	0.6197	44.102	4.412
23	831.05	850.65	0.6946	44.392	4.618
24	864.52	895.60	0.9272	44.592	4.815
25	903.72	937.14	0.9722	44.744	5.010
26	951.77	983.91	0.9486	44.982	5.220
27	995.42	1028.77	0.9698	44.848	5.415
28	1033.67	1074.93	1.1017	44.935	5.614
29	1074.27	1118.97	1.1569	44.882	5.811
30	1118.23	1166.22	1.2072	44.958	6.018
31	1156.26	1214.09	1.3518	44.637	6.224
32	1191.66	1257.83	1.4702	44.145	6.418
33	1220.48	1302.69	1.6906	43.995	6.613
34	1257.66	1346.48	1.7784	43.791	6.813
35	1294.59	1393.05	1.9022	43.687	7.016
36	1337.83	1449.30	2.0626	43.573	7.261
37	1379.53	1506.80	2.2503	43.369	7.512
38	1418.61	1564.53	2.4637	42.961	7.763
39	1464.78	1620.26	2.5691	42.217	8.013
40	1498.98	1690.52	2.9520	41.801	8.311
41	1549.38	1757.10	3.1168	41.163	8.618
42	1611.08	1848.04	3.4001	40.923	9.012
43	1661.60	1938.55	3.7694	39.414	9.411
44	1693.40	2027.72	4.2784	38.134	9.813
45	1741.87	2140.52	4.8199	36.496	10.336
46	1800.77	2261.83	5.3165	35.167	10.910
47	1903.96	2410.76	5.6552	34.692	11.613
48	2020.11	2583.79	6.0447	34.255	12.410
49	2117.35	2756.90	6.5280	32.634	13.211
50	2184.77	2925.03	7.1303	30.834	14.013
51	2235.82	3085.45	7.7481	28.657	14.817
52	2285.95	3237.50	8.2939	27.015	15.613

Table A-27. Deformation J_{IC} and J-R curve results for specimen P1B-14

Test Number	: 0084	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.37 mm
Spec. Width	: 50.84 mm	Flow Stress	: 480.43 MPa
Modulus E	: 193.05 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.1250 mm	Init. a/w	: 0.5532 (Measured)
Final Crack	: 37.4469 mm	Final a/w	: 0.7366 (Measured)
Final Crack	: 36.4189 mm	Final a/w	: 0.7164 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 508.011 kJ/m ²	Slope M	: 435.11 kJ/m ² mm
Fit Coeff. R	: 0.9685	(18 Data Points)	
J_{IC}	: 656.7 kJ/m ²	(3749.9 in.-lb/in. ²)	
Δa (J_{IC})	: 0.342 mm	(0.0135 in.)	
T Average	: 373.4	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 957.93 kJ/m ²	Exponent N	: 0.5095
Fit Coeff. R	: 0.9810	(18 Data Points)	
J_{IC} (0.20)	: 723.6 kJ/m ²	(4131.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.577 mm	(0.0227 in.)	
T Average	: 363.4	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 673.1 kJ/m ²	(3843.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.500 mm	(0.0197 in.)	
T Average	: 370.2	(J_{IC} at 0.15)	
K _{Jc}	: 535.8 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 727.40 kJ/m ²	($J_{max} = b_o \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 2.254 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 8	Zone B = 4
Data Point Spacing	: OK	
b_{net} or b_o Size	: Inadequate	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 489.39 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.271 mm	($\Delta a = 0.1 b_o$)
Δa (max) Allowed	: 4.701 mm	($\omega = 5$)
Data Points	: Zone A = 33	Zone B = 2
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-28. Modified J_{IC} and J-R curve results for specimen P1B-14

Test Number	: 0084	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.37 mm
Spec. Width	: 50.84 mm	Flow Stress	: 480.43 MPa
Modulus E	: 198.05 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.1250 mm	Init. a/w	: 0.5532 (Measured)
Final Crack	: 37.4469 mm	Final a/w	: 0.7366 (Measured)
Final Crack	: 36.4189 mm	Final a/w	: 0.7164 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 501.345 kJ/m ²	Slope M	: 478.66 kJ/m ² mm
Fit Coeff. R	: 0.9784	(19 Data Points)	
J_{IC}	: 667.6 kJ/m ²	(3812.4 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.347 mm	(0.0137 in.)	
T Average	: 410.7	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 995.50 kJ/m ²	Exponent N	: 0.5462
Fit Coeff. R	: 0.9872	(19 Data Points)	
$J_{IC} (0.20)$	: 744.4 kJ/m ²	(4250.7 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.587 mm	(0.0231 in.)	
T Average	: 404.1	(J_{IC} at 0.20)	
$J_{IC} (0.15)$	: 687.4 kJ/m ²	(3925.5 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.508 mm	(0.0200 in.)	
T Average	: 411.2	(J_{IC} at 0.15)	
K _{Jc}	: 558.8 MPa-m ^{0.5}

Figure A-26. Deformation and modified J-R curves at room temp. for Heat P1 aged 55,000 h at 320°C

Figure A-27. Deformation J_{IC} at room temp. for Heat P1 aged 55,000 h at 320°C

Figure A-28. Modified J_{IC} at room temp. for Heat P1 aged 55,000 h at 320°C

Table A-29. Test data for specimen PIT-18

Test Number	: 0100	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.82 mm	Flow Stress	: 295.08 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	14.82	14.88	0.1173	15.075	0.305
2	40.01	40.58	0.3916	18.246	0.606
3	68.61	68.08	0.0779	19.871	0.907
4	99.56	100.04	0.2681	21.060	1.207
5	132.41	131.49	0.0724	21.969	1.509
6	165.94	166.12	0.1929	22.746	1.809
7	200.19	200.89	0.2388	23.570	2.109
8	238.80	235.53	-0.0581	24.245	2.408
9	265.24	268.66	0.3869	24.849	2.659
10	295.54	298.34	0.3496	25.250	2.908
11	323.42	331.87	0.6538	25.810	3.158
12	360.61	362.53	0.3379	26.134	3.409
13	390.08	398.51	0.6257	26.534	3.659
14	426.25	430.64	0.4620	27.046	3.909
15	464.73	465.55	0.3291	27.245	4.161
16	487.52	502.69	0.8304	27.667	4.410
17	519.30	536.48	0.8962	27.983	4.661
18	550.17	573.49	1.0843	28.308	4.912
19	593.92	607.34	0.8021	28.464	5.159
20	625.47	647.13	1.0232	28.822	5.410
21	661.50	683.42	1.0299	29.024	5.661
22	701.57	720.13	0.9497	29.004	5.907
23	731.62	760.13	1.1760	29.289	6.160
24	763.47	797.72	1.3004	29.419	6.410
25	788.55	837.11	1.5977	29.329	6.660
26	825.81	874.45	1.5993	29.448	6.911
27	863.57	913.98	1.6328	29.609	7.161
28	889.15	954.42	1.9027	29.486	7.410
29	920.10	992.95	2.0351	29.458	7.660
30	952.36	1032.83	2.1630	29.440	7.910
31	981.32	1073.00	2.3444	29.200	8.160
32	1015.58	1112.70	2.4287	29.087	8.413
33	1050.61	1161.32	2.6314	29.004	8.711
34	1092.94	1208.55	2.7014	28.781	9.011
35	1128.47	1257.17	2.8810	28.737	9.308
36	1181.54	1312.67	2.9127	28.657	9.659
37	1208.65	1371.11	3.3070	28.349	10.008
38	1261.08	1434.14	3.4340	28.284	10.409
39	1305.15	1500.52	3.6897	28.150	10.810
40	1362.54	1582.49	3.9564	28.024	11.310
41	1425.72	1664.13	4.1459	27.525	11.811
42	1458.89	1746.95	4.6336	26.740	12.310
43	1500.78	1826.41	4.9866	26.073	12.811
44	1539.65	1905.58	5.3493	25.291	13.310
45	1575.42	1984.82	5.7246	24.642	13.812
46	1618.50	2063.06	6.0160	24.302	14.313
47	1661.00	2142.26	6.3080	23.897	14.815
48	1703.15	2219.81	6.5786	23.076	15.311

Table A-30. Deformation J_{IC} and J-R curve results for specimen PIT-18

Test Number	: 0100	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.82 mm	Flow Stress	: 295.08 MPa
Modulus E	: 180.90 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.5844 mm	Init. a/w	: 0.5625 (Measured)
Final Crack	: 36.0438 mm	Final a/w	: 0.7092 (Measured)
Final Crack	: 35.1630 mm	Final a/w	: 0.6919 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 204.637 kJ/m ²	Slope M	: 376.66 kJ/m ² mm
Fit Coeff. R	: 0.9375	(18 Data Points)	
J_{IC}	: 300.5 kJ/m ²	(1716.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.255 mm	(0.0100 in.)	
T Average	: 782.6	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 579.31 kJ/m ²	Exponent N	: 0.7600
Fit Coeff. R	: 0.9477	(18 Data Points)	
J_{IC} (0.20)	: 332.6 kJ/m ²	(1899.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.482 mm	(0.0190 in.)	
T Average	: 845.5	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 283.2 kJ/m ²	(1617.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.390 mm	(0.0154 in.)	
T Average	: 854.5	(J_{IC} at 0.15)	
K_{Jc}	: 457.0 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 437.42 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 2.478 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 9	Zone B = 3
Data Point Spacing	: OK	
b_{net} or b_0 Size	: Inadequate	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 299.24 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.224 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 6.705 mm	($\omega = 5$)
Data Points	: Zone A = 31	Zone B = 3
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-31. Modified J_{IC} and J - R curve results for specimen P1T-18

Test Number	: 0100	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 290°C	Aging Time	: 58,000 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.82 mm	Flow Stress	: 295.08 MPa
Modulus E	: 180.90 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.5844 mm	Init. a/w	: 0.5625 (Measured)
Final Crack	: 36.0438 mm	Final a/w	: 0.7092 (Measured)
Final Crack	: 35.1630 mm	Final a/w	: 0.6919 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 211.629 kJ/m ²	Slope M	: 392.50 kJ/m ² mm
Fit Coeff. R	: 0.9592	(20 Data Points)	
J_{IC}	: 317.1 kJ/m ²	(1810.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.269 mm	(0.0106 in.)	
T Average	: 815.5	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 599.13 kJ/m ²	Exponent N	: 0.7710
Fit Coeff. R	: 0.9612	(20 Data Points)	
J_{IC} (0.20)	: 348.5 kJ/m ²	(1990.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.495 mm	(0.0195 in.)	
T Average	: 884.9	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 296.1 kJ/m ²	(1690.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.401 mm	(0.0158 in.)	
T Average	: 893.9	(J_{IC} at 0.15)	
K_{Jc}	: 471.7 MPa-m ^{0.5}

Figure A-29. Deformation and modified J - R curves at 290°C for Heat P1 aged 58,000 h at 290°C

Figure A-30. Deformation J_{IC} at 290°C for Heat P1 aged 58,000 h at 290°C

Figure A-31. Modified J_{IC} at 290°C for Heat P1 aged 58,000 h at 290°C

Table A-32. Test data for specimen P1B-15

Test Number	: 0099	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.37 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.80 mm	Flow Stress	: 321.35 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	15.13	15.19	0.1330	15.586	0.305
2	41.40	40.97	-0.1305	18.870	0.606
3	72.19	72.59	0.0999	20.873	0.907
4	104.84	104.51	-0.0323	22.125	1.209
5	138.70	139.87	0.1676	23.181	1.507
6	175.97	174.56	-0.0996	24.024	1.810
7	212.12	213.67	0.1497	24.701	2.110
8	250.14	250.77	0.0846	25.241	2.409
9	280.17	285.00	0.3466	25.900	2.661
10	314.78	316.96	0.2002	26.350	2.912
11	341.03	353.89	0.7372	26.757	3.161
12	371.45	376.91	0.3945	26.983	3.357
13	403.41	406.75	0.3039	27.210	3.559
14	426.54	436.88	0.5835	27.494	3.760
15	454.98	463.68	0.5219	27.770	3.959
16	474.28	495.05	0.9498	27.988	4.159
17	507.00	521.16	0.7299	28.217	4.360
18	545.05	550.77	0.4677	28.490	4.560
19	564.98	584.03	0.8621	28.580	4.761
20	594.70	611.08	0.7869	28.762	4.959
21	615.76	643.67	1.0968	28.942	5.161
22	651.12	671.03	0.8927	28.940	5.360
23	682.65	707.11	1.0031	28.998	5.582
24	698.82	734.81	1.2730	29.172	5.758
25	731.00	764.17	1.2101	29.157	5.960
26	755.91	796.85	1.3772	29.307	6.159
27	782.26	828.09	1.4785	29.198	6.362
28	805.72	859.39	1.6350	28.945	6.559
29	830.33	890.69	1.7637	28.697	6.760
30	865.52	920.25	1.6596	28.637	6.959
31	871.54	954.87	2.1755	28.338	7.160
32	899.32	982.17	2.1672	28.159	7.360
33	914.97	1015.64	2.4696	28.039	7.562
34	931.24	1045.92	2.7010	27.726	7.760
35	970.89	1083.10	2.6620	27.670	8.009
36	997.28	1124.42	2.8898	27.390	8.259
37	1026.44	1163.12	3.0304	26.872	8.512
38	1052.12	1209.74	3.3273	26.439	8.808
39	1091.19	1255.87	3.4233	26.213	9.117
41	1154.13	1362.24	3.9870	25.139	9.814
42	1182.24	1423.84	4.3895	24.602	10.211
43	1218.07	1498.55	4.8333	23.692	10.710
44	1251.27	1574.08	5.2930	22.634	11.224
45	1267.53	1645.71	5.8698	21.552	11.726
46	1288.47	1710.78	6.3113	20.407	12.203
47	1315.93	1779.78	6.7097	19.805	12.708
48	1331.29	1860.00	7.3050	18.903	13.290
49	1364.32	1911.95	7.4725	18.380	13.708
50	1369.59	1981.54	8.0226	17.576	14.213
51	1394.84	2044.37	8.3318	16.755	14.714
52	1406.40	2109.55	8.7577	16.030	15.220

Table A-33. Deformation J_{IC} and J-R curve results for specimen P1B-15

Test Number	: 0099	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.37 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.80 mm	Φλω Στρεσς	: 321.35 MPa
Modulus E	: 177.54 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 29.0656 mm	Init. a/w	: 0.5722 (Measured)
Final Crack	: 38.8563 mm	Final a/w	: 0.7650 (Measured)
Final Crack	: 37.8233 mm	Final a/w	: 0.7446 (Compliance)

Linear Fit	J = B+M(Δa)		
Intercept B	: 331.357 kJ/m ²	Slope M	: 281.87 kJ/m ² mm
Fit Coeff. R	: 0.9317	(18 Data Points)	
J_{IC}	: 424.4 kJ/m ²	(2423.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.330 mm	(0.0130 in.)	
T Average	: 484.6	(J_{IC} at 0.15)	

Power-Law Fit	J = C(Δa)ⁿ		
Coeff. C	: 618.44 kJ/m ²	Exponent N	: 0.5273
Fit Coeff. R	: 0.9369	(18 Data Points)	
J_{IC} (0.20)	: 451.9 kJ/m ²	(2580.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.552 mm	(0.0217 in.)	
T Average	: 493.2	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 417.6 kJ/m ²	(2384.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.475 mm	(0.0187 in.)	
T Average	: 502.3	(J_{IC} at 0.15)	
K_{Jc}	: 409.6 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 465.52 kJ/m ²	($J_{max}=b_o\sigma_f/15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 2.235 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 7	Zone B = 4
Data Point Spacing	: OK	
b_{net} or b_o Size	: Inadequate	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 325.67 kJ/m ²	($J_{max}=b_{net}\sigma_f/20$)
Δa (max) Allowed	: 2.173 mm	(Δa=0.1 b_o)
Δa (max) Allowed	: 4.846 mm	(ω=5)
Data Points	: Zone A = 26	Zone B = 2
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-34. Modified J_{IC} and J - R curve results for specimen P1B-15

Test Number	: 0099	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: P1
Aging Temp.	: 320°C	Aging Time	: 55,000 h
Spec. Thickness	: 25.37 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.80 mm	Φλω Στρεσσ	: 321.35 MPa
Modulus E	: 177.54 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 29.0656 mm	Init. a/w	: 0.5722 (Measured)
Final Crack	: 38.8563 mm	Final a/w	: 0.7650 (Measured)
Final Crack	: 37.8233 mm	Final a/w	: 0.7446 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 311.091 kJ/m ²	Slope M	: 327.76 kJ/m ² mm
Fit Coeff. R	: 0.9498	(18 Data Points)	
J_{IC}	: 417.6 kJ/m ²	(2384.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.325 mm	(0.0128 in.)	
T Average	: 563.5	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 644.82 kJ/m ²	Exponent N	: 0.5756
Fit Coeff. R	: 0.9502	(18 Data Points)	
J_{IC} (0.20)	: 461.3 kJ/m ²	(2634.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.559 mm	(0.0220 in.)	
T Average	: 561.3	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 421.6 kJ/m ²	(2407.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.478 mm	(0.0188 in.)	
T Average	: 570.8	(J_{IC} at 0.15)	
K_{Jc}	: 430.7 MPa-m ^{0.5}

Figure A-32. Deformation and modified J - R curves at 290°C for Heat P1 aged 55,000 h at 320°C

Figure A-33. Deformation J_{IC} at 290°C for Heat P1 aged 55,000 h at 320°C

Figure A-34. Modified J_{IC} at 290°C for Heat P1 aged 55,000 h at 320°C

Table A-35. Test data for specimen C1B-18

Test Number	: 0110	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 320°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.25 mm
Spec. Width	: 50.79 mm	σ_f	: 360.00 MPa

Unload Number	J_d (kJ/m ²)	J_m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	19.52	19.50	-0.0391	21.239	0.304
2	53.78	53.82	-0.0120	25.337	0.605
3	92.22	92.43	0.0247	27.115	0.907
4	132.53	134.30	0.2593	28.540	1.208
5	174.86	176.66	0.2625	29.758	1.510
6	218.95	221.43	0.3204	30.665	1.808
7	264.71	267.82	0.3648	31.493	2.111
8	310.56	314.88	0.4363	32.204	2.409
9	356.64	363.60	0.5699	32.718	2.710
10	400.93	413.35	0.8131	33.249	3.010
11	445.73	463.31	1.0173	33.104	3.312
12	482.44	505.13	1.2015	32.946	3.562
13	521.38	546.50	1.2823	33.081	3.811
14	556.89	589.86	1.5239	32.922	4.062
15	589.26	632.33	1.8142	32.772	4.312
16	629.08	673.19	1.8421	32.482	4.562
17	658.00	717.48	2.2298	32.042	4.810
18	699.52	767.56	2.4307	31.841	5.113
19	739.02	818.72	2.6875	31.685	5.410
20	771.84	870.18	3.0729	30.467	5.711
21	798.10	920.77	3.5507	29.879	6.015
22	829.53	967.86	3.8431	29.451	6.309
23	866.93	1026.25	4.2115	28.764	6.600
24	901.26	1084.18	4.6034	28.245	7.011
25	944.43	1149.51	4.9482	26.943	7.411
26	970.11	1213.88	5.5187	25.594	7.811
27	988.22	1274.55	6.1172	24.001	8.212
28	1006.79	1332.51	6.6468	22.961	8.611
29	1041.02	1405.57	7.1390	21.969	9.109
30	1046.95	1476.96	7.9279	19.456	9.612
31	1056.47	1539.83	8.5433	18.202	10.110
32	1075.98	1603.77	9.0323	17.363	10.611
33	1091.49	1666.64	9.5301	16.233	11.110
34	1101.76	1727.06	10.0357	15.284	11.609

Table A-36. Deformation J_{IC} and J-R curve results for specimen C1B-18

Test Number	: 0110	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 320°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.25 mm
Spec. Width	: 50.79 mm	σ_f	: 360.00 MPa
Modulus E	: 194.43 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 27.9156 mm	Init. a/w	: 0.5496 (Measured)
Final Crack	: 38.8469 mm	Final a/w	: 0.7648 (Measured)
Final Crack	: 37.9513 mm	Final a/w	: 0.7472 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 192.649 kJ/m ²	Slope M	: 237.57 kJ/m ² mm
Fit Coeff. R	: 0.9840	(11 Data Points)	
J_{IC}	: 230.7 kJ/m ²	(1317.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.160 mm	(0.0063 in.)	
T Average	: 356.4	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 447.54 kJ/m ²	Exponent N	: 0.5303
Fit Coeff. R	: 0.9889	(11 Data Points)	
J_{IC} (0.20)	: 270.9 kJ/m ²	(1547.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.388 mm	(0.0153 in.)	
T Average	: 343.3	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 244.5 kJ/m ²	(1396.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.320 mm	(0.0126 in.)	
T Average	: 350.5	(J_{IC} at 0.15)	
K _{Jc}	: 351.7 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 549.03 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.942 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 4	Zone B = 3
Data Point Spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
Initial Crack Shape	: OK	
Final crack shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 364.43 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.288 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 4.870 mm	($\omega = 5$)
Data Points	: Zone A = 8	Zone B = 7
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-37. Modified J_{IC} and J - R curve results for specimen C1B-18

Test Number	: 0110	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 320°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.25 mm
Spec. Width	: 50.79 mm	σ_f	: 360.00 MPa
Modulus E	: 194.43 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 27.9156 mm	Init. a/w	: 0.5496 (Measured)
Final Crack	: 38.8469 mm	Final a/w	: 0.7648 (Measured)
Final Crack	: 37.9513 mm	Final a/w	: 0.7472 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 184.433 kJ/m ²	Slope M	: 264.86 kJ/m ² mm
Fit Coeff. R	: 0.9882	(11 Data Points)	
J_{IC}	: 226.0 kJ/m ²	(1290.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.157 mm	(0.0062 in.)	
T Average	: 397.3	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 467.09 kJ/m ²	Exponent N	: 0.5639
Fit Coeff. R	: 0.9910	(11 Data Points)	
J_{IC} (0.20)	: 275.1 kJ/m ²	(1570.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.391 mm	(0.0154 in.)	
T Average	: 379.2	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 246.0 kJ/m ²	(1405.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.321 mm	(0.0126 in.)	
T Average	: 386.6	(J_{IC} at 0.15)	
K_{Jc}	: 365.2 MPa-m ^{0.5}

Figure A-35. Deformation and modified J - R curves at room temp. for Heat C1 aged 30,000 h at 320°C

Figure A-36. Deformation J_{IC} at room temp. for Heat C1 aged 30,000 h at 320°C

Figure A-37. Modified J_{IC} at room temp. for Heat C1 aged 30,000 h at 320°C

Table A-38. Test data for specimen C1B-08

Test Number	: 0112	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.29 mm
Spec. Width	: 50.82 mm	Flow Stress	: 360.00 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	18.65	18.67	0.0273	20.167	0.303
2	51.80	51.65	-0.0436	23.879	0.606
3	88.88	89.08	0.0367	25.638	0.907
4	128.62	129.33	0.1125	26.999	1.214
5	168.77	169.27	0.0900	27.971	1.509
6	210.35	212.26	0.2142	28.781	1.808
7	252.46	256.03	0.3341	29.492	2.109
8	294.96	301.56	0.5184	29.865	2.411
9	337.06	346.48	0.6662	29.747	2.709
10	377.48	392.95	0.9458	30.170	3.010
11	417.96	439.14	1.1798	29.573	3.311
12	456.66	485.28	1.4551	29.164	3.610
13	493.49	532.51	1.8062	28.988	3.917
14	528.02	577.29	2.1253	28.739	4.210
15	561.53	623.35	2.4860	28.301	4.508
16	606.50	677.11	2.7176	28.087	4.860
17	650.04	732.09	2.9951	27.979	5.210
18	698.09	795.24	3.3310	27.681	5.610
19	744.22	857.69	3.6662	27.236	6.008
20	788.62	921.00	4.0269	26.859	6.411
21	825.77	983.89	4.4858	26.046	6.810
22	860.56	1047.28	4.9634	24.774	7.225
23	878.42	1132.35	6.0040	20.777	7.788
24	885.31	1197.54	6.8632	19.794	8.310
25	922.02	1260.33	7.2257	19.842	8.807
26	990.01	1342.58	7.4083	19.804	9.408
27	1036.26	1428.47	7.8803	19.035	10.009
28	1079.36	1509.42	8.3018	18.123	10.610
29	1117.43	1589.06	8.7375	17.494	11.207
30	1138.43	1667.63	9.3077	16.006	11.808
31	1114.03	1736.04	10.1919	13.759	12.408

Table A-39. Deformation J_{IC} and J-R curve results for specimen C1B-08

Test Number	: 0112	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.29 mm
Spec. Width	: 50.82 mm	Flow Stress	: 360.00 MPa
Modulus E	: 191.61 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.4531 mm	Init. a/w	: 0.5599 (Measured)
Final Crack	: 39.7188 mm	Final a/w	: 0.7815 (Measured)
Final Crack	: 38.6451 mm	Final a/w	: 0.7604 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 215.126 kJ/m ²	Slope M	: 162.80 kJ/m ² mm
Fit Coeff. R	: 0.9895	(7 Data Points)	
J_{IC}	: 242.5 kJ/m ²	(1385.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.168 mm	(0.0066 in.)	
T Average	: 240.7	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 390.29 kJ/m ²	Exponent N	: 0.4018
Fit Coeff. R	: 0.9990	(7 Data Points)	
J_{IC} (0.20)	: 265.9 kJ/m ²	(1518.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.385 mm	(0.0151 in.)	
T Average	: 227.7	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 247.5 kJ/m ²	(1413.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.322 mm	(0.0127 in.)	
T Average	: 233.6	(J_{IC} at 0.15)	
K_{Jc}	: 309.3 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 536.85 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.847 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 3	Zone B = 2
Data Point Spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 365.17 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.237 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 3.780 mm	($\omega = 5$)
Data Points	: Zone A = 8	Zone B = 5
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-40. Modified J_{IC} and J-R curve results for specimen C1B-08

Test Number	: 0112	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.29 mm
Spec. Width	: 50.82 mm	Flow Stress	: 360.00 MPa
Modulus E	: 191.61 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.4531 mm	Init. a/w	: 0.5599 (Measured)
Final Crack	: 39.7188 mm	Final a/w	: 0.7815 (Measured)
Final Crack	: 38.6451 mm	Final a/w	: 0.7604 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 209.057 kJ/m ²	Slope M	: 186.89 kJ/m ² mm
Fit Coeff. R	: 0.9934	(7 Data Points)	
J_{IC}	: 240.2 kJ/m ²	(1371.8 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.167 mm	(0.0066 in.)	
T Average	: 276.3	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 409.08 kJ/m ²	Exponent N	: 0.4378
Fit Coeff. R	: 0.9989	(7 Data Points)	
$J_{IC} (0.20)$	: 270.1 kJ/m ²	(1542.5 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.388 mm	(0.0153 in.)	
T Average	: 258.2	(J_{IC} at 0.20)	
$J_{IC} (0.15)$	: 249.5 kJ/m ²	(1424.7 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.323 mm	(0.0127 in.)	
T Average	: 264.5	(J_{IC} at 0.15)	
K_{Jc}	: 321.2 MPa-m ^{0.5}

Figure A-38. Deformation and modified J-R curves at room temp. for Heat C1 aged 10,000 h at 350°C

Figure A-39. Deformation J_{IC} at room temp. for Heat C1 aged 10,000 h at 350°C

Figure A-40. Modified J_{IC} at room temp. for Heat C1 aged 10,000 h at 350°C

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Table A-41. Test data for specimen C1B-11

Test Number	: 0111	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.29 mm
Spec. Width	: 50.81 mm	Flow Stress	: 365.00 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	18.56	18.54	-0.0421	20.286	0.302
2	52.08	52.11	-0.0177	24.232	0.606
3	89.10	89.69	0.1113	25.831	0.906
4	128.18	128.76	0.1102	27.351	1.205
5	169.77	170.43	0.1188	28.458	1.507
6	211.69	214.17	0.2788	29.002	1.808
7	254.22	258.01	0.3724	29.790	2.109
8	297.41	303.24	0.4963	30.281	2.408
9	340.34	349.98	0.6955	30.699	2.710
10	383.72	396.41	0.8346	31.086	3.008
11	429.48	444.24	0.9188	31.428	3.310
12	472.38	494.03	1.1697	31.456	3.612
13	518.69	541.68	1.2139	31.624	3.910
14	566.22	591.43	1.2806	31.729	4.211
15	603.07	642.71	1.6812	31.695	4.510
16	649.07	689.99	1.7139	31.686	4.808
17	691.05	742.03	1.9538	31.579	5.111
18	729.10	792.36	2.2281	31.243	5.409
19	768.58	842.03	2.4416	30.630	5.709
20	786.50	892.80	3.0952	28.399	6.011
21	808.60	938.11	3.5361	27.613	6.312
22	837.77	983.37	3.8274	27.281	6.609
23	878.48	1046.39	4.2061	26.489	7.009
24	915.36	1108.57	4.6105	25.810	7.411
25	961.58	1185.96	5.0752	25.477	7.908
26	1024.79	1262.36	5.2578	25.431	8.408
27	1086.55	1359.19	5.7060	24.763	9.009
28	1146.60	1452.51	6.1007	24.077	9.609
29	1207.23	1544.83	6.4514	23.519	10.207
30	1263.90	1638.14	6.8306	22.719	10.809
31	1302.96	1735.86	7.4009	21.091	11.453
32	1323.89	1812.71	7.9196	19.230	12.008
33	1318.53	1891.99	8.6742	17.834	12.608
34	1346.45	1968.01	9.0838	17.081	13.209
35	1368.74	2046.80	9.5433	16.330	13.811
36	1382.71	2123.14	10.0297	15.481	14.408
37	1392.33	2197.19	10.5117	14.301	15.015

Table A-42. Deformation J_{IC} and J-R curve results for specimen C1B-11

Test Number	: 0111	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.29 mm
Spec. Width	: 50.81 mm	Flow Stress	: 365.00 MPa
Modulus E	: 190.23 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.3563 mm	Init. a/w	: 0.5581 (Measured)
Final Crack	: 40.3813 mm	Final a/w	: 0.7947 (Measured)
Final Crack	: 38.8679 mm	Final a/w	: 0.7649 (Compliance)
Linear Fit			
$J = B + M(\Delta a)$			
Intercept B	: 159.262 kJ/m ²	Slope M	: 280.10 kJ/m ² mm
Fit Coeff. R	: 0.9893	(11 Data Points)	
J_{IC}	: 197.1 kJ/m ²	(1125.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.135 mm	(0.0053 in.)	
T Average	: 400.0	(J_{IC} at 0.15)	
Power-Law Fit			
$J = C(\Delta a)^n$			
Coeff. C	: 451.32 kJ/m ²	Exponent N	: 0.6198
Fit Coeff. R	: 0.9917	(11 Data Points)	
J_{IC} (0.20)	: 241.9 kJ/m ²	(1381.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.366 mm	(0.0144 in.)	
T Average	: 387.5	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 211.8 kJ/m ²	(1209.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.295 mm	(0.0116 in.)	
T Average	: 394.2	(J_{IC} at 0.15)	
K_{Jc}	: 361.6 MPa-m ^{0.5}		
J_{IC} Validity & Data Qualification (E 813-85)			
J_{max} Allowed	: 546.45 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)	
Data Limit	: J_{max} Ignored		
Δa (max) Allowed	: 1.971 mm	(at 1.5 Exclusion Line)	
Data Limit	: 1.5 Exclusion Line		
Data Points	: Zone A = 3	Zone B = 3	
Data Point Spacing	: OK		
b_{net} and b_0 Size	: OK		
dJ/da at J_{IC}	: OK		
a_f Measurement	: Near-Surface	Outside Limit	
Initial Crack Shape	: OK		
Crack Size Estimate	: Inadequate	(by Compliance)	
E Effective	: OK		
J_{IC} Estimate	: INVALID		
J-R Curve Validity & Data Qualification (E 1152-86)			
J_{max} Allowed	: 370.24 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)	
Δa (max) Allowed	: 2.246 mm	($\Delta a = 0.1 b_0$)	
Δa (max) Allowed	: 5.604 mm	($\omega = 5$)	
Data Points	: Zone A = 7	Zone B = 9	
Data Point Spacing	: OK		
J-R Curve Data	: INVALID		

Table A-43. Modified J_{IC} and J - R curve results for specimen C1B-11

Test Number	: 0111	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.29 mm
Spec. Width	: 50.81 mm	Flow Stress	: 365.00 MPa
Modulus E	: 190.23 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.3563 mm	Init. a/w	: 0.5581 (Measured)
Final Crack	: 40.3813 mm	Final a/w	: 0.7947 (Measured)
Final Crack	: 38.8679 mm	Final a/w	: 0.7649 (Compliance)

Linear Fit $J = B + M(\Delta a)$
 Intercept B : 148.422 kJ/m²
 Fit Coeff. R : 0.9920
 J_{IC} : 188.4 kJ/m²
 Δa (J_{IC}) : 0.129 mm
 T Average : 442.5

Slope M : 309.89 kJ/m²mm
 (11 Data Points)
 (1075.9 in.-lb/in.²)
 (0.0051 in.)
 (J_{IC} at 0.15)

Power-Law Fit $J = C(\Delta a)^N$
 Coeff. C : 470.42 kJ/m²
 Fit Coeff. R : 0.9924
 J_{IC} (0.20) : 244.7 kJ/m²
 Δa (J_{IC}) : 0.368 mm
 T Average : 424.1
 J_{IC} (0.15) : 212.0 kJ/m²
 Δa (J_{IC}) : 0.295 mm
 T Average : 430.8
 K_{Jc} : 375.6 MPa-m^{0.5}

Exponent N : 0.6532
 (11 Data Points)
 (1397.1 in.-lb/in.²)
 (0.0145 in.)
 (J_{IC} at 0.20)
 (1210.7 in.-lb/in.²)
 (0.0116 in.)
 (J_{IC} at 0.15)

Figure A-41. Deformation and modified J - R curves at room temp. for Heat C1 aged 30,000 h at 350°C

Figure A-42. Deformation J_{IC} at room temp. for Heat C1 aged 30,000 h at 350°C

Figure A-43. Modified J_{IC} at room temp. for Heat C1 aged 30,000 h at 350°C

Table A-44. Test data for specimen C1B-19

Test Number	: 0113	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 320°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.25 mm
Spec. Width	: 50.82 mm	σ_f	: 245.00 MPa

Unload Number	J_d (kJ/m ²)	J_m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	14.88	14.96	0.1278	13.872	0.306
2	37.39	37.75	0.2832	15.887	0.606
3	62.49	62.62	0.2165	17.268	0.906
4	89.77	89.79	0.1907	18.145	1.207
5	117.92	117.88	0.1815	19.047	1.505
6	145.99	148.28	0.4655	19.724	1.807
7	177.30	177.76	0.2839	20.215	2.108
8	205.42	210.73	0.6921	20.671	2.407
9	239.10	241.13	0.4554	21.121	2.707
10	268.05	275.88	0.8242	21.513	3.007
11	299.93	308.77	0.8811	21.738	3.306
12	332.49	343.58	0.9951	22.185	3.608
13	362.96	378.79	1.2121	22.258	3.906
14	397.81	413.88	1.2222	22.428	4.209
15	423.83	451.35	1.6632	22.427	4.511
16	458.37	485.90	1.6633	22.403	4.811
17	483.08	523.32	2.0847	22.375	5.107
18	518.26	558.33	2.0793	22.335	5.407
19	543.78	597.06	2.4619	22.333	5.710
20	576.25	632.98	2.5556	22.116	6.010
21	607.31	670.89	2.7306	21.994	6.312
22	632.15	714.60	3.1851	21.717	6.657
23	663.69	757.07	3.4333	21.346	7.007
24	688.35	801.17	3.8509	20.956	7.358
25	720.56	843.20	4.0503	20.433	7.708
26	739.27	893.43	4.6583	20.082	8.107
27	783.18	939.88	4.7045	19.763	8.509
28	819.02	1003.14	5.1695	19.338	9.006
29	850.82	1063.52	5.6255	18.437	9.509
30	875.76	1122.19	6.1346	17.555	10.008
31	905.25	1178.81	6.5226	16.746	10.506
32	917.63	1234.82	7.1185	15.727	11.005
33	927.12	1287.93	7.6887	14.433	11.509
34	924.03	1337.67	8.3551	13.417	12.006
35	948.74	1386.79	8.6494	12.901	12.517
36	951.03	1436.03	9.1949	12.244	13.010
37	963.48	1482.72	9.5776	11.512	13.509
38	960.67	1529.57	10.1143	10.912	14.010

Table A-45. Deformation J_{IC} and J-R curve results for specimen C1B-19

Test Number	: 0113	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 320°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.25 mm
Spec. Width	: 50.82 mm	σ_f	: 245.00 MPa
Modulus E	: 178.97 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.7594 mm	Init. a/w	: 0.5660 (Measured)
Final Crack	: 39.6219 mm	Final a/w	: 0.7797 (Measured)
Final Crack	: 38.8737 mm	Final a/w	: 0.7650 (Compliance)

Linear Fit

$$J = B + M(\Delta a)$$

Intercept B	: 121.090 kJ/m ²	Slope M	: 197.54 kJ/m ² mm
Fit Coeff. R	: 0.9480	(9 Data Points)	
J_{IC}	: 151.7 kJ/m ²	(866.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.155 mm	(0.0061 in.)	
T Average	: 589.0	(J_{IC} at 0.15)	

Power-Law Fit

$$J = C(\Delta a)^n$$

Coeff. C	: 323.09 kJ/m ²	Exponent N	: 0.5910
Fit Coeff. R	: 0.9114	(9 Data Points)	
J_{IC} (0.20)	: 184.8 kJ/m ²	(1055.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.389 mm	(0.0153 in.)	
T Average	: 546.1	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 163.9 kJ/m ²	(936.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.317 mm	(0.0125 in.)	
T Average	: 556.1	(J_{IC} at 0.15)	
K _{Jc}	: 295.0 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 360.24 kJ/m ²	($J_{max} = b_o \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.996 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 2	Zone B = 2
Data Point Spacing	: OK	
b_{net} and b_o Size	: OK	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 248.07 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.206 mm	($\Delta a = 0.1 b_o$)
Δa (max) Allowed	: 5.372 mm	($\omega = 5$)
Data Points	: Zone A = 6	Zone B = 12
Data Point Spacing	: OK	
J-R Curve Data	: INVALID	

Table A-46. Modified J_{IC} and J - R curve results for specimen C1B-19

Test Number	: 0113	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 320°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.25 mm
Spec. Width	: 50.82 mm	σ_f	: 245.00 MPa
Modulus E	: 178.97 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.7594 mm	Init. a/w	: 0.5660 (Measured)
Final Crack	: 39.6219 mm	Final a/w	: 0.7797 (Measured)
Final Crack	: 38.8737 mm	Final a/w	: 0.7650 (Compliance)

Linear Fit
 $J = B + M(\Delta a)$
 Intercept B : 111.293 kJ/m²
 Fit Coeff. R : 0.9573
 J_{IC} : 143.4 kJ/m²
 $\Delta a (J_{IC})$: 0.146 mm
 T Average : 654.2

Slope M : 219.42 kJ/m²mm
 (9 Data Points)
 (818.8 in.-lb/in.²)
 (0.0058 in.)
 (J_{IC} at 0.15)

Power-Law Fit
 $J = C(\Delta a)^n$
 Coeff. C : 335.18 kJ/m²
 Fit Coeff. R : 0.9222
 $J_{IC} (0.20)$: 184.7 kJ/m²
 $\Delta a (J_{IC})$: 0.388 mm
 T Average : 602.6
 $J_{IC} (0.15)$: 161.9 kJ/m²
 $\Delta a (J_{IC})$: 0.315 mm
 T Average : 612.7
 K_{Jc} : 306.4 MPa-m^{0.5}

Exponent N : 0.6302
 (9 Data Points)
 (1054.8 in.-lb/in.²)
 (0.0153 in.)
 (J_{IC} at 0.20)
 (924.7 in.-lb/in.²)
 (0.0124 in.)
 (J_{IC} at 0.15)

Figure A-44. Deformation and modified J - R curves at 290°C for Heat C1 aged 30,000 h at 320°C

Figure A-45. Deformation J_{IC} at 290°C for Heat C1 aged 30,000 h at 320°C

Figure A-46. Modified J_{IC} at 290°C for Heat C1 aged 30,000 h at 320°C

Table A-47. Test data for specimen C1B-09

Test Number	: 0114	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.32 mm
Spec. Width	: 50.79 mm	σ_f	: 245.00 MPa

Unload Number	J_d (kJ/m ²)	J_m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	13.73	13.75	0.0474	13.000	0.304
2	34.98	34.98	0.0346	14.931	0.605
3	58.57	58.50	0.0108	16.062	0.907
4	82.83	83.99	0.2824	17.047	1.205
5	109.16	110.02	0.2340	17.799	1.506
6	136.28	137.86	0.3279	18.456	1.805
7	165.83	166.71	0.2539	19.010	2.110
8	194.72	196.33	0.3188	19.517	2.408
9	222.02	227.14	0.5904	20.008	2.706
10	252.38	257.69	0.6033	20.422	3.006
11	281.13	290.50	0.8484	20.893	3.307
12	314.55	322.47	0.7706	21.193	3.608
13	348.51	356.07	0.7530	21.495	3.908
14	378.30	390.49	0.9574	21.658	4.207
15	412.01	424.05	0.9512	21.782	4.509
16	434.41	459.98	1.4599	21.602	4.810
17	460.74	493.38	1.7080	21.493	5.110
18	482.29	528.47	2.1537	21.178	5.409
19	512.34	561.88	2.2572	20.970	5.709
20	545.20	609.87	2.6877	20.959	6.109
21	585.54	655.83	2.8356	20.784	6.508
22	620.27	703.84	3.1601	20.539	6.908
23	655.09	751.05	3.4433	20.257	7.310
24	686.18	811.02	4.0574	19.804	7.810
25	724.93	868.23	4.4220	19.128	8.309
26	751.99	926.37	4.9981	18.214	8.808
27	789.19	982.62	5.3290	17.899	9.311
28	816.15	1039.47	5.8189	17.080	9.808
29	842.88	1094.70	6.2609	16.618	10.307
30	870.51	1150.47	6.6747	16.292	10.809
31	901.43	1205.50	7.0106	15.781	11.308
32	931.44	1260.66	7.3432	15.295	11.809
33	959.50	1315.18	7.6765	14.801	12.308
34	971.79	1368.99	8.1778	14.105	12.808
35	982.90	1420.65	8.6480	13.413	13.309
36	1007.70	1471.08	8.9324	12.854	13.811
37	1018.59	1523.43	9.3747	12.292	14.323
38	1035.23	1570.64	9.6885	11.724	14.812

Table A-48. Deformation J_{IC} and J-R curve results for specimen C1B-09

Test Number	: 0114	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.32 mm
Spec. Width	: 50.79 mm	σ_f	: 245.00 MPa
Modulus E	: 169.37 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.9406 mm	Init. a/w	: 0.5698 (Measured)
Final Crack	: 39.3969 mm	Final a/w	: 0.7757 (Measured)
Final Crack	: 38.6292 mm	Final a/w	: 0.7606 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 162.460 kJ/m ²	Slope M	: 189.99 kJ/m ² mm
Fit Coeff. R	: 0.8686	(9 Data Points)	
J_{IC}	: 201.5 kJ/m ²	(1150.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.206 mm	(0.0081 in.)	
T Average	: 536.1	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 357.44 kJ/m ²	Exponent N	: 0.6186
Fit Coeff. R	: 0.8850	(9 Data Points)	
J_{IC} (0.20)	: 205.9 kJ/m ²	(1176.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.410 mm	(0.0161 in.)	
T Average	: 590.3	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 181.9 kJ/m ²	(1038.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.336 mm	(0.0132 in.)	
T Average	: 600.3	(J_{IC} at 0.15)	
K _{Jc}	: 308.3 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)		
J_{max} Allowed	: 356.87 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 2.072 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 4	Zone B = 2
Data Point Spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)		
J_{max} Allowed	: 248.86 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.185 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 5.592 mm	($\omega = 5$)
Data Points	: Zone A = 13	Zone B = 5
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-49. Modified J_{IC} and J-R curve results for specimen C1B-09

Test Number	: 0114	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.32 mm
Spec. Width	: 50.79 mm	σ_f	: 245.00 MPa
Modulus E	: 169.37 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.9406 mm	Init. a/w	: 0.5698 (Measured)
Final Crack	: 39.3969 mm	Final a/w	: 0.7757 (Measured)
Final Crack	: 38.6292 mm	Final a/w	: 0.7606 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 151.518 kJ/m ²	Slope M	: 215.01 kJ/m ² mm
Fit Coeff. R	: 0.8954	(9 Data Points)	
J_{IC}	: 194.1 kJ/m ²	(1108.4 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.198 mm	(0.0078 in.)	
T Average	: 606.7	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 371.61 kJ/m ²	Exponent N	: 0.6631
Fit Coeff. R	: 0.9047	(9 Data Points)	
$J_{IC} (0.20)$	: 205.7 kJ/m ²	(1174.7 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.410 mm	(0.0161 in.)	
T Average	: 657.2	(J_{IC} at 0.20)	
$J_{IC} (0.15)$	: 179.2 kJ/m ²	(1023.2 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.333 mm	(0.0131 in.)	
T Average	: 667.2	(J_{IC} at 0.15)	
K _{Jc}	: 322.1 MPa-m ^{0.5}

Figure A-47. Deformation and modified J-R curves at 290°C for Heat C1 aged 10,000 h at 350°C

Figure A-48. Deformation J_{IC} at 290°C for Heat C1 aged 10,000 h at 350°C

Figure A-49. Modified J_{IC} at 290°C for Heat C1 aged 10,000 h at 350°C

Table A-50. Test data for specimen C1B-12

Test Number	: 0115	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.81 mm	σ_f	: 250.00 MPa

Unload Number	J_d (kJ/m ²)	J_m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	21.42	21.31	-0.1193	14.295	0.407
2	43.94	44.45	0.1647	15.921	0.706
3	68.48	68.59	0.0517	16.929	1.007
4	94.10	95.59	0.3201	17.866	1.307
5	122.53	122.06	0.0312	18.554	1.609
6	150.52	151.12	0.1579	19.137	1.906
7	180.12	180.21	0.1080	19.730	2.208
8	216.05	215.28	0.0379	20.208	2.558
9	249.64	251.96	0.2534	20.780	2.907
10	283.57	288.82	0.4314	21.006	3.257
11	316.40	327.06	0.7223	21.331	3.607
12	351.75	365.52	0.8713	21.662	3.958
13	387.56	404.98	1.0292	21.709	4.308
14	422.15	444.95	1.2399	21.801	4.658
15	438.09	474.68	1.7527	21.782	4.910
16	480.59	512.68	1.6001	21.892	5.256
17	506.26	556.64	2.1775	21.804	5.609
18	545.13	595.88	2.1880	21.762	5.958
19	572.14	639.52	2.6434	21.644	6.309
20	611.43	686.55	2.8396	21.482	6.707
21	643.99	736.13	3.2425	21.337	7.109
22	678.44	783.91	3.5381	20.801	7.508
23	712.27	844.95	4.0991	20.415	8.006
24	757.39	903.98	4.3651	19.854	8.507
25	791.82	965.22	4.8452	19.526	9.010
26	834.12	1023.84	5.1186	18.955	9.508
27	860.83	1095.88	5.8303	18.225	10.107
28	892.48	1164.36	6.3723	17.164	10.709
29	922.57	1231.75	6.8890	16.433	11.308
30	949.61	1298.72	7.4110	15.684	11.908
31	979.97	1363.84	7.8405	14.972	12.508
32	1000.80	1416.73	8.2198	14.327	13.004
33	1029.02	1480.85	8.6225	13.596	13.609
34	1048.07	1553.63	9.1935	12.951	14.308
35	1075.36	1623.58	9.6229	12.287	15.007

Table A-51. Deformation J_{IC} and J-R curve results for specimen C1B-12

Test Number	: 0115	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.81 mm	σ_f	: 250.00 MPa
Modulus E	: 172.84 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.6469 mm	Init. a/w	: 0.5638 (Measured)
Final Crack	: 39.4844 mm	Final a/w	: 0.7771 (Measured)
Final Crack	: 38.2698 mm	Final a/w	: 0.7532 (Compliance)
Linear Fit $J = B + M(\Delta a)$			
Intercept B	: 237.476 kJ/m ²	Slope M	: 134.67 kJ/m ² mm
Fit Coeff. R	: 0.9182	(6 Data Points)	
J_{IC}	: 274.4 kJ/m ²	(1567.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.274 mm	(0.0108 in.)	
T Average	: 372.4	(J_{IC} at 0.15)	
Power-Law Fit $J = C(\Delta a)^n$			
Coeff. C	: 373.77 kJ/m ²	Exponent N	: 0.4197
Fit Coeff. R	: 0.9503	(6 Data Points)	
J_{IC} (0.20)	: 273.0 kJ/m ²	(1558.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.473 mm	(0.0186 in.)	
T Average	: 399.1	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 256.0 kJ/m ²	(1462.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.406 mm	(0.0160 in.)	
T Average	: 408.3	(J_{IC} at 0.15)	
K_{Jc}	: 294.0 MPa-m ^{0.5}		
J_{IC} Validity & Data Qualification (E 813-85)			
J_{max} Allowed	: 369.39 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)	
Data Limit	: J_{max} Ignored		
Δa (max) Allowed	: 2.000 mm	(at 1.5 Exclusion Line)	
Data Limit	: 1.5 Exclusion Line		
Data Points	: Zone A = 1	Zone B = 2	
Data Point Spacing	: OK		
b_{net} or b_0 Size	: Inadequate		
dJ/da at J_{IC}	: OK		
a_f Measurement	: Near-Surface	Outside Limit	
Initial Crack Shape	: OK		
Crack Size Estimate	: Inadequate	(by Compliance)	
E Effective	: OK		
J_{IC} Estimate	: INVALID		
J-R Curve Validity & Data Qualification (E 1152-86)			
J_{max} Allowed	: 253.40 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)	
Δa (max) Allowed	: 2.216 mm	($\Delta a = 0.1 b_0$)	
Δa (max) Allowed	: 3.935 mm	($\omega = 5$)	
Data Points	: Zone A = 11	Zone B = 6	
Data Point Spacing	: Inadequate		
J-R Curve Data	: INVALID		

Table A-52. Modified J_{IC} and J - R curve results for specimen C1B-12

Test Number	: 0115	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: C1
Aging Temp.	: 350°C	Aging Time	: 30,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.81 mm	σ_f	: 250.00 MPa
Modulus E	: 172.84 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.6469 mm	Init. a/w	: 0.5638 (Measured)
Final Crack	: 39.4844 mm	Final a/w	: 0.7771 (Measured)
Final Crack	: 38.2698 mm	Final a/w	: 0.7532 (Compliance)
Linear Fit			
$J = B + M(\Delta a)$			
Intercept B	: 229.314 kJ/m ²	Slope M	: 159.93 kJ/m ² mm
Fit Coeff. R	: 0.9416	(6 Data Points)	
J_{IC}	: 273.0 kJ/m ²	(1558.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.273 mm	(0.0107 in.)	
T Average	: 442.3	(J_{IC} at 0.15)	
Power-Law Fit			
$J = C(\Delta a)^N$			
Coeff. C	: 391.16 kJ/m ²	Exponent N	: 0.4692
Fit Coeff. R	: 0.9664	(6 Data Points)	
J_{IC} (0.20)	: 276.2 kJ/m ²	(1576.9 in.-lb/in. ²)	
Δa (J_{IC})	: 0.476 mm	(0.0187 in.)	
T Average	: 464.9	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 256.4 kJ/m ²	(1463.9 in.-lb/in. ²)	
Δa (J_{IC})	: 0.406 mm	(0.0160 in.)	
T Average	: 474.9	(J_{IC} at 0.15)	
K _{Jc}	: 307.6 MPa-m ^{0.5}

Figure A-50. Deformation and modified J - R curves at 290°C for Heat C1 aged 30,000 h at 350°C

Figure A-51. Deformation J_{IC} at 290°C for Heat C1 aged 30,000 h at 350°C

Figure A-52. Modified J_{IC} at 290°C for Heat C1 aged 30,000 h at 350°C

Table A-53. Test data for specimen 683-02B

Test Number	: 0089	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.82 mm	Flow Stress	: 458.80 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	32.47	32.48	0.0076	26.797	0.405
2	92.54	92.48	-0.0087	32.788	0.806
3	161.57	162.19	0.0779	36.013	1.208
4	215.93	217.16	0.1348	37.372	1.508
5	272.93	274.08	0.1287	38.723	1.808
6	332.28	333.12	0.1117	39.890	2.109
7	391.39	394.52	0.2202	40.589	2.409
8	454.05	455.07	0.1349	41.368	2.711
9	514.06	520.12	0.3123	41.939	3.011
10	571.95	584.61	0.5190	42.417	3.313
11	632.26	647.96	0.6043	42.946	3.612
12	695.70	713.82	0.6657	43.276	3.913
13	758.05	781.64	0.7913	43.157	4.216
14	816.45	847.39	0.9466	43.393	4.510
15	879.57	913.73	1.0096	43.459	4.810
16	944.67	982.42	1.0744	43.657	5.113
17	1004.41	1050.57	1.2162	43.789	5.410
18	1059.50	1119.82	1.4406	43.392	5.710
19	1114.68	1188.16	1.6368	43.337	6.010
20	1171.11	1256.08	1.7980	41.849	6.312
21	1239.70	1331.21	1.8843	41.794	6.651
22	1281.11	1389.81	2.1016	41.220	6.907
23	1325.13	1459.48	2.4113	40.647	7.217
24	1375.07	1522.58	2.5630	39.894	7.512
25	1414.02	1589.77	2.8758	39.353	7.810
26	1474.46	1677.81	3.1653	38.806	8.213
27	1542.38	1763.83	3.3451	38.143	8.612
28	1597.09	1875.47	3.8787	36.777	9.110
29	1665.22	1981.02	4.2103	36.481	9.615
30	1740.29	2087.17	4.4704	35.702	10.111
31	1790.61	2219.01	5.1141	34.040	10.711
32	1842.65	2340.33	5.6325	32.611	11.311
33	1888.23	2459.60	6.1550	29.760	11.911
34	1905.78	2592.45	6.9323	27.264	12.611
35	1933.26	2716.07	7.5501	25.762	13.311
36	1943.92	2839.40	8.2427	24.225	14.010
37	1976.07	2959.61	8.7593	23.317	14.711
38	2023.84	3079.90	9.1641	22.305	15.404

Table A-54. Deformation J_{IC} and J-R curve results for specimen 683-02B

Test Number	: 0089	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.82 mm	Flow Stress	: 458.80 MPa
Modulus E	: 196.30 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.6375 mm	Init. a/w	: 0.5635 (Measured)
Final Crack	: 38.9156 mm	Final a/w	: 0.7658 (Measured)
Final Crack	: 37.8016 mm	Final ϵ/w	: 0.7438 (Compliance)
Linear Fit $J = B + M(\Delta a)$			
Intercept B	: 405.985 kJ/m ²	Slope M	: 439.26 kJ/m ² mm
Fit Coeff. R	: 0.9857	(13 Data Points)	
J_{IC}	: 533.7 kJ/m ²	(3047.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.291 mm	(0.0115 in.)	
T Average	: 409.6	(J_{IC} at 0.15)	
Power-Law Fit $J = C(\Delta a)^n$			
Coeff. C	: 860.06 kJ/m ²	Exponent N	: 0.5683
Fit Coeff. R	: 0.9944	(13 Data Points)	
J_{IC} (0.20)	: 596.3 kJ/m ²	(3405.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.525 mm	(0.0207 in.)	
T Average	: 407.0	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 543.8 kJ/m ²	(3105.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.446 mm	(0.0176 in.)	
T Average	: 414.1	(J_{IC} at 0.15)	
K _{Jc}	: 516.8 MPa-m ^{0.5}		
J_{IC} Validity & Data Qualification (E 813-85)			
J_{max} Allowed	: 678.49 kJ/m ²	($J_{max}=b_o\sigma_f/15$)	
Data Limit	: J_{max} Ignored		
Δa (max) Allowed	: 2.241 mm	(at 1.5 Exclusion Line)	
Data Limit	: 1.5 Exclusion line		
Data Points	: Zone A = 4	Zone B = 4	
Data Point Spacing	: OK		
b_{net} or b_o Size	: Inadequate		
dJ/da at J_{IC}	: OK		
a_f Measurement	: Near-Surface	Outside Limit	
Initial Crack Shape	: OK		
Crack Size Estimate	: Inadequate	(by Compliance)	
E Effective	: OK		
J_{IC} Estimate	: INVALID		
J-R Curve Validity & Data Qualification (E 1152-86)			
J_{max} Allowed	: 465.27 kJ/m ²	($J_{max}=b_{net}\sigma_f/20$)	
Δa (max) Allowed	: 2.218 mm	($\Delta a=0.1b_o$)	
Δa (max) Allowed	: 5.187 mm	($\omega=5$)	
Data Points	: Zone A = 20	Zone B = 1	
Data Point Spacing	: Inadequate		
J-R Curve Data	: INVALID		

Table A-55. Modified J_{IC} and J - R curve results for specimen 683-02B

Test Number	: 0089	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.82 mm	Flow Stress	: 458.80 MPa
Modulus E	: 196.30 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.6375 mm	Init. a/w	: 0.5635 (Measured)
Final Crack	: 38.9156 mm	Final a/w	: 0.7658 (Measured)
Final Crack	: 37.8016 mm	Final a/w	: 0.7438 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 382.067 kJ/m ²	Slope M	: 499.75 kJ/m ² mm
Fit Coeff. R	: 0.9904	(13 Data Points)	
J_{IC}	: 525.0 kJ/m ²	(2998.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.286 mm	(0.0113 in.)	
T Average	: 466.0	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 897.33 kJ/m ²	Exponent N	: 0.6107
Fit Coeff. R	: 0.9962	(13 Data Points)	
J_{IC} (0.20)	: 611.0 kJ/m ²	(3488.9 in.-lb/in. ²)	
Δa (J_{IC})	: 0.533 mm	(0.0210 in.)	
T Average	: 455.9	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 551.4 kJ/m ²	(3148.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.450 mm	(0.0177 in.)	
T Average	: 463.3	(J_{IC} at 0.15)	
K_{Jc}	: 542.4 MPa-m ^{0.5}

Figure A-53. Deformation and modified J - R curves at room temp. for Heat 68 aged 52,600 h at 320°C

Figure A-54. Deformation J_{IC} at room temp. for Heat 68 aged 52,600 h at 320°C

Figure A-55. Modified J_{IC} at room temp. for Heat 68 aged 52,600 h at 320°C

Table A-56. Test data for specimen 682-05V

Test Number	: 0088	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.30 mm
Spec. Width	: 50.83 mm	Flow Stress	: 435.48 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	31.80	31.78	-0.0270	25.250	0.405
2	89.50	89.50	-0.0224	30.714	0.806
3	155.19	155.97	0.0811	33.393	1.208
4	206.40	208.16	0.1717	34.523	1.508
5	260.66	261.38	0.0975	35.799	1.809
6	316.10	318.53	0.1964	36.496	2.109
7	370.89	376.45	0.3485	37.241	2.411
8	427.08	433.49	0.3838	37.855	2.709
9	485.09	494.11	0.4783	38.081	3.013
10	541.86	554.06	0.5797	38.201	3.312
11	596.70	614.65	0.7450	38.209	3.611
12	652.14	674.67	0.8644	38.271	3.910
13	701.41	737.34	1.1838	38.091	4.211
14	753.75	796.37	1.3307	38.106	4.509
15	809.34	858.46	1.4627	37.938	4.812
16	863.92	920.45	1.6023	37.769	5.112
17	901.02	984.64	2.0806	35.740	5.416
18	942.56	1040.86	2.3255	35.123	5.714
19	986.14	1099.63	2.5652	35.049	6.012
20	1049.49	1179.07	2.8008	34.620	6.410
21	1107.72	1259.67	3.1063	33.586	6.812
22	1151.42	1337.90	3.5512	32.916	7.208
23	1215.69	1435.09	3.9457	32.325	7.710
24	1288.92	1531.34	4.2022	31.714	8.210
25	1343.84	1630.83	4.6679	30.661	8.713
26	1362.39	1722.78	5.3949	27.261	9.217
27	1385.51	1806.54	5.9698	26.745	9.711
28	1437.06	1911.57	6.4464	25.950	10.307
29	1509.38	2016.92	6.7222	25.451	10.907
30	1552.05	2127.77	7.2584	23.838	11.518
31	1563.69	2243.96	8.0343	20.633	12.216
32	1558.02	2345.68	8.7978	19.333	12.909
33	1583.92	2447.37	9.3096	18.245	13.609

Table A-57. Deformation J_{IC} and J-R curve results for specimen 682-05V

Test Number	: 0088	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.30 mm
Spec. Width	: 50.83 mm	Flow Stress	: 435.48 MPa
Modulus E	: 198.55 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.3031 mm	Init. a/w	: 0.5765 (Measured)
Final Crack	: 39.6719 mm	Final a/w	: 0.7805 (Measured)
Final Crack	: 38.6128 mm	Final a/w	: 0.7597 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 356.795 kJ/m ²	Slope M	: 309.19 kJ/m ² mm
Fit Coeff. R	: 0.9913	(8 Data Points)	
J_{IC}	: 433.8 kJ/m ²	(2477.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.249 mm	(0.0098 in.)	
T Average	: 323.7	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 679.53 kJ/m ²	Exponent N	: 0.4424
Fit Coeff. R	: 0.9923	(8 Data Points)	
J_{IC} (0.20)	: 492.3 kJ/m ²	(2811.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.483 mm	(0.0190 in.)	
T Average	: 287.4	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 460.1 kJ/m ²	(2627.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.414 mm	(0.0163 in.)	
T Average	: 293.8	(J_{IC} at 0.15)	
K _{Jc}	: 429.8 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 624.91 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 2.034 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion line	
Data Points	: Zone A = 4	Zone B = 1
Data Point Spacing	: OK	
b_{net} or b_0 Size	: Inadequate	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 441.95 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.152 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 4.132 mm	($\omega = 5$)
Data Points	: Zone A = 11	Zone B = 4
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-58. Modified J_{IC} and J - R curve results for specimen 682-05V

Test Number	: 0088	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.30 mm
Spec. Width	: 50.83 mm	Flow Stress	: 435.48 MPa
Modulus E	: 198.55 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.3031 mm	Init. a/w	: 0.5765 (Measured)
Final Crack	: 39.6719 mm	Final a/w	: 0.7805 (Measured)
Final Crack	: 38.6128 mm	Final a/w	: 0.7597 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 344.115 kJ/m ²	Slope M	: 351.31 kJ/m ² mm
Fit Coeff. R	: 0.9933	(8 Data Points)	
J_{IC}	: 431.0 kJ/m ²	(2461.4 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.247 mm	(0.0097 in.)	
T Average	: 367.8	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 709.72 kJ/m ²	Exponent N	: 0.4811
Fit Coeff. R	: 0.9937	(8 Data Points)	
$J_{IC} (0.20)$	: 502.9 kJ/m ²	(2871.7 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.489 mm	(0.0192 in.)	
T Average	: 324.9	(J_{IC} at 0.20)	
$J_{IC} (0.15)$	: 466.3 kJ/m ²	(2662.8 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.418 mm	(0.0164 in.)	
T Average	: 331.7	(J_{IC} at 0.15)	
K _{Jc}	: 447.7 MPa-m ^{0.5}

Figure A-56. Deformation and modified J - R curves at room temp. for Heat 68 aged 52,600 h at 320°C

Figure A-57. Deformation J_{IC} at room temp. for Heat 68 aged 52,600 h at 320°C

Figure A-58. Modified J_{IC} at room temp. for Heat 68 aged 52,600 h at 320°C

Table A-59. Test data for specimen 682-08B

Test Number	: 0109	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 400°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.19 mm
Spec. Width	: 50.81 mm	Flow Stress	: 472.50 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	20.88	20.86	-0.0537	23.728	0.302
2	62.85	62.88	-0.0347	30.934	0.605
3	112.17	112.19	-0.0343	34.471	0.906
4	166.21	166.32	-0.0242	36.817	1.207
5	222.41	224.22	0.1287	38.471	1.507
6	280.77	282.13	0.0979	39.398	1.808
7	340.26	344.47	0.2552	40.468	2.108
8	400.09	407.13	0.3858	40.945	2.411
9	459.72	470.47	0.5322	41.541	2.711
10	509.82	523.82	0.6463	41.604	2.962
11	559.53	577.18	0.7617	41.671	3.210
12	606.50	632.67	1.0070	41.532	3.462
13	645.57	674.97	1.0931	40.905	3.665
14	684.52	716.95	1.1692	40.725	3.861
15	722.86	761.96	1.3263	40.829	4.067
16	768.11	814.68	1.4900	40.591	4.310
17	813.25	870.19	1.7023	39.883	4.565
18	850.51	924.72	2.0359	39.619	4.815
19	889.03	976.36	2.2749	38.293	5.064
20	921.00	1029.56	2.6423	37.416	5.315
21	962.75	1090.25	2.9515	36.777	5.611
22	1002.70	1152.97	3.3014	34.714	5.914
23	1032.45	1212.62	3.7389	33.644	6.214
24	1054.78	1272.52	4.2626	31.160	6.525
25	1072.99	1324.03	4.7100	30.357	6.812
26	1099.97	1378.10	5.0594	29.747	7.112
27	1132.26	1443.10	5.4611	28.867	7.461
28	1149.92	1509.81	6.0342	25.740	7.828
29	1147.77	1571.25	6.7501	23.350	8.217
30	1157.90	1629.79	7.2756	22.467	8.611
31	1177.94	1690.73	7.7019	21.781	9.009
32	1216.80	1769.62	8.0971	21.428	9.509
33	1260.83	1848.38	8.4209	20.607	10.009
34	1304.64	1927.06	8.7291	20.117	10.509
35	1338.93	2005.91	9.1037	19.401	11.007
36	1353.07	2081.54	9.5968	17.428	11.510
37	1371.69	2150.07	9.9810	16.622	12.008

Table A-6C. Deformation J_{IC} and J-R curve results for specimen 682-08B

Test Number	: 0109	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 400°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.19 mm
Spec. Width	: 50.81 mm	Flow Stress	: 472.50 MPa
Modulus E	: 198.51 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.8031 mm	Init. a/w	: 0.5668 (Measured)
Final Crack	: 39.7875 mm	Final a/w	: 0.7830 (Measured)
Final Crack	: 38.7841 mm	Final a/w	: 0.7633 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 299.712 kJ/m ²	Slope M	: 313.72 kJ/m ² mm
Fit Coeff. R	: 0.9944	(10 Data Points)	
J_{IC}	: 359.4 kJ/m ²	(2052.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.190 mm	(0.0075 in.)	
T Average	: 278.9	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 627.39 kJ/m ²	Exponent N	: 0.4807
Fit Coeff. R	: 0.9976	(10 Data Points)	
J_{IC} (0.20)	: 412.7 kJ/m ²	(2356.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.418 mm	(0.0165 in.)	
T Average	: 254.7	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 379.0 kJ/m ²	(2164.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.351 mm	(0.0138 in.)	
T Average	: 260.3	(J_{IC} at 0.15)	
K_{Jc}	: 414.8 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 693.31 kJ/in ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.959 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 4	Zone B = 2
Data point spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial crack shape	: CX	
Crack Size estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 477.06 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.201 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 4.457 mm	($\omega = 5$)
Data Points	: Zone A = 7	Zone B = 7
Data point spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-61. Modified J_{IC} and J - R curve results for specimen 682-08B

Test Number	: 0109	Test Temp.	: 25°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 400°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.19 mm
Spec. Width	: 50.81 mm	Flow Stress	: 472.50 MPa
Modulus E	: 198.51 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.8031 mm	Init. a/w	: 0.5668 (Measured)
Final Crack	: 39.7875 mm	Final a/w	: 0.7830 (Measured)
Final Crack	: 38.7841 mm	Final a/w	: 0.7633 (Compliance)
Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 289.634 kJ/m ²	Slope M	: 351.37 kJ/m ² mm
Fit Coeff. R	: 0.9962	(10 Data Points)	
J_{IC}	: 355.8 kJ/m ²	(2031.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.188 mm	(0.0074 in.)	
T Average	: 312.4	(J_{IC} at 0.15)	
Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 655.51 kJ/m ²	Exponent N	: 0.5140
Fit Coeff. R	: 0.9977	(10 Data Points)	
J_{IC} (0.20)	: 421.1 kJ/m ²	(2404.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.423 mm	(0.0166 in.)	
T Average	: 282.9	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 383.9 kJ/m ²	(2192.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.353 mm	(0.0139 in.)	
T Average	: 288.8	(J_{IC} at 0.15)	
K _{Jc}	: 430.8 MPa-m ^{0.5}

Figure A-59. Deformation and modified J - R curves at room temp. for Heat 68 aged 10,000 h at 400°C, then recovery-annealed and aged again for 10,000 h at 400°C

Figure A-60. Deformation J_{IC} at room temp. for Heat 68 aged 10,000 h at 400°C, then recovery-annealed and aged again for 10,000 h at 400°C

Figure A-61. Modified J_{IC} at room temp. for Heat 68 aged 10,000 h at 400°C, then recovery-annealed and aged again for 10,000 h at 400°C

Table A-62. Test data for specimen 683-02T

Test Number	: 0095	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.30 mm
Spec. Width	: 50.79 mm	Flow Stress	: 341.62 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	16.15	16.34	0.4039	16.910	0.305
2	44.63	43.98	-0.0232	20.742	0.613
3	77.17	78.08	0.3890	22.637	0.906
4	112.34	111.09	0.0152	24.063	1.208
5	148.94	150.98	0.4306	25.225	1.508
6	192.19	192.05	0.2221	26.129	1.844
7	239.91	243.44	0.4973	27.000	2.210
8	280.74	283.34	0.4381	27.576	2.509
9	329.66	323.16	-0.0542	27.836	2.808
10	356.03	362.84	0.5997	28.176	3.054
11	387.75	395.93	0.6612	28.379	3.306
12	421.39	433.42	0.8183	28.469	3.560
13	449.90	470.68	1.1486	28.393	3.809
14	477.18	507.73	1.4920	28.316	4.060
15	496.62	537.29	1.8294	28.123	4.261
16	532.89	572.97	1.8110	27.896	4.513
17	554.23	603.99	2.0955	27.689	4.709
18	577.72	633.23	2.2566	27.394	4.910
19	609.06	662.02	2.1889	27.105	5.112
20	630.01	701.88	2.6647	26.817	5.361
21	649.53	737.60	3.0539	26.334	5.610
22	684.58	780.25	3.2252	25.577	5.910
23	709.19	825.10	3.6572	24.921	6.211
24	734.79	866.92	3.9864	24.282	6.509
25	765.09	916.67	4.3589	23.502	6.859
26	791.34	965.50	4.7681	22.445	7.210
27	818.51	1018.78	5.2160	21.617	7.602
28	843.18	1072.57	5.6897	20.655	8.006
29	866.78	1124.47	6.1274	20.083	8.406
30	885.33	1176.77	6.6259	19.195	8.807
31	912.33	1226.67	6.9479	18.394	9.208
32	923.83	1277.35	7.4762	17.372	9.608
33	947.04	1323.80	7.7764	16.648	10.007
34	953.02	1372.67	8.3105	16.023	10.408
35	985.90	1416.98	8.4467	15.575	10.809
36	990.13	1466.22	8.9644	14.821	11.210
37	1000.05	1510.00	9.3406	14.180	11.610
38	1014.85	1554.37	9.6573	13.450	12.012
39	1024.11	1597.74	10.0105	12.829	12.411

Table A-63. Deformation J_{IC} and J-R curve results for specimen 683-02T

Test Number	: 0095	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.30 mm
Spec. Width	: 50.79 mm	Flow Stress	: 341.62 MPa
Modulus E	: 176.93 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.6250 mm	Init. a/w	: 0.5636 (Measured)
Final Crack	: 39.7875 mm	Final a/w	: 0.7834 (Measured)
Final Crack	: 38.6355 mm	Final a/w	: 0.7607 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 239.035 kJ/m ²	Slope M	: 160.41 kJ/m ² mm
Fit Coeff. R	: 0.9060	(9 Data Points)	
J_{IC}	: 270.8 kJ/m ²	(1546.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.198 mm	(0.0078 in.)	
T Average	: 243.2	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 410.83 kJ/m ²	Exponent N	: 0.4426
Fit Coeff. R	: 0.9128	(9 Data Points)	
J_{IC} (0.20)	: 274.0 kJ/m ²	(1564.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.401 mm	(0.0158 in.)	
T Average	: 266.0	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 253.3 kJ/m ²	(1446.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.335 mm	(0.0132 in.)	
T Average	: 272.5	(J_{IC} at 0.15)	
K _{Jc}	: 310.7 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)		
J_{max} Allowed	: 504.73 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.899 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion line	
Data Points	: Zone A = 4	Zone B = 3
Data Point Spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)		
J_{max} Allowed	: 346.66 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.216 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 4.130 mm	($\omega = 5$)
Data Points	: Zone A = 7	Zone B = 9
Data Point Spacing	: OK	
J-R Curve Data	: INVALID	

Table A-64. Modified J_{IC} and J - R curve results for specimen 683-02T

Test Number	: 0095	Test Temp.	: 290°C
Material Type	: CF-8	Heat Number	: 68
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.36 mm	Net Thickness	: 20.30 mm
Spec. Width	: 50.79 mm	Flow Stress	: 341.62 MPa
Modulus E	: 176.93 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.6250 mm	Init. a/w	: 0.5636 (Measured)
Final Crack	: 39.7875 mm	Final a/w	: 0.7834 (Measured)
Final Crack	: 38.6355 mm	Final a/w	: 0.7607 (Compliance)
Linear Fit $J = B + M(\Delta a)$			
Intercept B	: 229.031 kJ/m ²	Slope M	: 187.87 kJ/m ² mm
Fit Coeff. R	: 0.9293	(9 Data Points)	
J_{IC}	: 265.5 kJ/m ²	(1516.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.194 mm	(0.0077 in.)	
T Average	: 284.8	(J_{IC} at 0.15)	
Power-Law Fit $J = C(\Delta a)^N$			
Coeff. C	: 429.19 kJ/m ²	Exponent N	: 0.4898
Fit Coeff. R	: 0.9308	(9 Data Points)	
J_{IC} (0.20)	: 274.2 kJ/m ²	(1565.9 in.-lb/in. ²)	
Δa (J_{IC})	: 0.401 mm	(0.0158 in.)	
T Average	: 306.0	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 250.6 kJ/m ²	(1431.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.333 mm	(0.0131 in.)	
T Average	: 312.8	(J_{IC} at 0.15)	
K_{Jc}	: 323.9 MPa-m ^{0.5}

Figure A-62. Deformation and modified J - R curves at 290°C for Heat 68 aged 52,600 h at 320°C

Figure A-63. Deformation J_{IC} at 290°C for Heat 68 aged 52,600 h at 320°C

Figure A-64. Modified J_{IC} at 290°C for Heat 68 aged 52,600 h at 320°C

Table A-65. Test data for specimen 745-03V

Test Number	: 0108	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 25°C	Aging Time	: 0 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.35 mm
Spec. Width	: 50.82 mm	σ_f	: 405.00 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	16.35	16.31	-0.1431	19.135	0.303
2	51.75	51.74	-0.1285	25.293	0.604
3	86.16	86.44	-0.0537	27.385	0.855
4	122.60	123.68	0.0811	28.772	1.107
5	152.39	153.33	0.0638	29.570	1.308
6	191.71	193.36	0.1344	30.232	1.559
7	230.27	233.67	0.2741	31.634	1.807
8	270.14	274.44	0.3348	31.354	2.059
9	320.06	321.19	0.1599	30.713	2.350
10	367.34	372.24	0.3400	32.240	2.636
11	403.66	409.30	0.3715	32.544	2.859
12	444.55	453.85	0.5122	32.639	3.111
13	485.90	496.61	0.5616	32.618	3.361
14	518.60	531.70	0.6392	32.469	3.560
15	553.36	565.94	0.6235	32.421	3.761
16	586.59	601.90	0.7010	32.452	3.963
17	625.29	645.54	0.8312	32.255	4.211
18	664.35	688.62	0.9305	32.291	4.459
19	709.45	742.20	1.1240	32.007	4.759
20	756.05	794.59	1.2470	31.958	5.061
21	799.37	847.68	1.4416	31.602	5.358
22	842.55	900.64	1.6247	31.552	5.660
23	890.24	963.00	1.8810	30.954	6.010
24	933.42	1024.29	2.1785	30.027	6.362
25	970.17	1084.35	2.5407	29.254	6.711
26	1004.39	1152.14	3.0329	28.066	7.111
27	1038.74	1216.65	3.4518	26.766	7.510
28	1078.40	1301.91	4.0447	25.643	8.031
29	1107.00	1376.42	4.6101	24.389	8.511
30	1142.30	1451.18	5.0697	23.336	9.002
31	1175.46	1528.23	5.5536	22.206	9.510
32	1204.59	1600.82	6.0090	21.026	10.007
33	1228.34	1673.18	6.4949	20.000	10.509
34	1251.02	1758.56	7.0887	18.630	11.112
35	1253.46	1836.90	7.7753	16.899	11.708
36	1259.69	1910.33	8.3570	15.532	12.308
37	1270.74	1982.10	8.8598	14.410	12.909
38	1276.93	2052.03	9.3658	13.358	13.511
39	1274.97	2119.18	9.8938	12.448	14.108
40	1267.61	2183.93	10.4250	11.546	14.709

Table A-66. Deformation J_{IC} and J-R curve results for specimen 745-03V

Test Number	: 0108	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 25°C	Aging Time	: 0 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.35 mm
Spec. Width	: 50.82 mm	σ_f	: 405.00 MPa
Modulus E	: 172.58 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.9438 mm	Init. a/w	: 0.5893 (Measured)
Final Crack	: 42.0688 mm	Final a/w	: 0.8279 (Measured)
Final Crack	: 40.3687 mm	Final a/w	: 0.7944 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 339.858 kJ/m ²	Slope M	: 313.43 kJ/m ² mm
Fit Coeff. R	: 0.9786	(12 Data Points)	
J_{IC}	: 421.4 kJ/m ²	(2406.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.260 mm	(0.0102 in.)	
T Average	: 329.8	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 667.89 kJ/m ²	Exponent N	: 0.5050
Fit Coeff. R	: 0.9870	(12 Data Points)	
J_{IC} (0.20)	: 464.2 kJ/m ²	(2650.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.487 mm	(0.0192 in.)	
T Average	: 322.8	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 427.9 kJ/m ²	(2443.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.414 mm	(0.0163 in.)	
T Average	: 329.3	(J_{IC} at 0.15)	
K _{Jc}	: 409.4 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 563.52 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 2.100 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 6	Zone B = 2
Data Point Spacing	: OK	
b_{net} or b_0 Size	: Inadequate	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: Inadequate	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 412.09 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.087 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 4.661 mm	($\omega = 5$)
Data Points	: Zone A = 18	Zone B = 2
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-67. Modified J_{IC} and J - R curve results for specimen 745-03V

Test Number	: 0108	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 25°C	Aging Time	: 0 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.35 mm
Spec. Width	: 50.82 mm	σ_f	: 405.00 MPa
Modulus E	: 172.58 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.9438 mm	Init. a/w	: 0.5893 (Measured)
Final Crack	: 42.0688 mm	Final a/w	: 0.8279 (Measured)
Final Crack	: 40.3687 mm	Final a/w	: 0.7944 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 323.332 kJ/m ²	Slope M	: 359.17 kJ/m ² mm
Fit Coeff. R	: 0.9852	(12 Data Points)	
J_{IC}	: 415.4 kJ/m ²	(2372.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.256 mm	(0.0101 in.)	
T Average	: 377.9	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 697.69 kJ/m ²	Exponent N	: 0.5484
Fit Coeff. R	: 0.9907	(12 Data Points)	
J_{IC} (0.20)	: 472.8 kJ/m ²	(2699.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.492 mm	(0.0194 in.)	
T Average	: 365.2	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 431.5 kJ/m ²	(2463.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.416 mm	(0.0164 in.)	
T Average	: 372.0	(J_{IC} at 0.15)	
K _{Jc}	: 428.4 MPa-m ^{0.5}

Figure A-65. Deformation and modified J - R curves at room temp. for unaged Heat 74

Figure A-66. Deformation J_{IC} at room temp. for unaged Heat 74

Figure A-67. Modified J_{IC} at room temp. for unaged Heat 74

Table A-68. Test data for specimen 743-03B

Test Number	: 0092	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.26 mm
Spec. Width	: 50.81 mm	Flow Stress	: 472.73 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	19.24	19.22	-0.0434	21.880	0.303
2	58.74	58.81	-0.0021	28.826	0.606
3	88.89	88.82	-0.0400	31.310	0.806
4	121.87	121.91	-0.0202	33.022	1.007
5	156.15	156.57	0.0307	34.392	1.208
6	191.08	191.68	0.0489	35.462	1.407
7	227.04	228.47	0.1213	36.274	1.606
8	264.12	265.54	0.1198	36.825	1.807
9	301.57	304.21	0.1956	37.346	2.006
10	337.77	343.50	0.3648	37.904	2.206
11	364.76	372.32	0.4566	38.342	2.357
12	392.44	402.08	0.5524	38.478	2.507
13	422.08	430.85	0.5155	38.648	2.657
14	450.43	463.28	0.6763	38.679	2.809
15	476.80	492.92	0.7971	38.752	2.958
16	504.94	523.03	0.8655	38.803	3.109
17	530.77	554.86	1.0612	38.673	3.260
18	556.63	585.04	1.1947	38.662	3.412
19	584.94	614.77	1.2360	38.389	3.561
20	612.89	645.95	1.3252	38.201	3.711
21	639.35	676.85	1.4422	38.018	3.861
22	662.43	707.74	1.6387	37.932	4.010
23	688.89	737.20	1.7108	37.591	4.161
24	710.57	769.58	1.9577	37.421	4.311
25	739.50	797.36	1.9324	37.362	4.462
26	765.98	829.79	2.0586	37.284	4.610
27	798.99	871.51	2.2344	37.116	4.810
28	832.56	912.13	2.3694	36.512	5.010
29	862.35	956.30	2.6323	35.822	5.221
30	886.66	994.53	2.8766	34.980	5.414
31	911.93	1033.84	3.1133	34.114	5.614
32	930.65	1074.26	3.4653	32.598	5.818
33	950.05	1109.22	3.7100	32.117	6.011
34	978.73	1168.28	4.1632	30.883	6.312
35	1011.61	1220.78	4.4424	30.282	6.607
36	1051.38	1275.89	4.6501	29.675	6.908
37	1087.76	1332.70	4.9137	29.044	7.211
38	1118.61	1407.84	5.4544	27.753	7.609
39	1163.74	1475.89	5.7195	27.355	8.008
40	1202.31	1549.92	6.1079	26.207	8.412
41	1228.02	1636.81	6.7399	23.904	8.909
42	1250.48	1717.18	7.3079	22.249	9.413
43	1256.55	1793.71	7.9690	20.619	9.910
44	1266.06	1867.01	8.5420	19.300	10.411
45	1289.55	1954.22	9.0840	18.112	11.009
46	1303.10	2042.55	9.6872	16.656	11.625

Table A-69. Deformation J_{IC} and J-R curve results for specimen 743-03B

Test Number	: 0092	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.26 mm
Spec. Width	: 50.81 mm	Flow Stress	: 472.73 MPa
Modulus E	: 188.92 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.2469 mm	Init. a/w	: 0.5756 (Measured)
Final Crack	: 39.8656 mm	Final a/w	: 0.7846 (Measured)
Final Crack	: 38.9341 mm	Final a/w	: 0.7662 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 268.043 kJ/m ²	Slope M	: 250.96 kJ/m ² mm
Fit Coeff. R	: 0.9910	(14 Data Points)	
J_{IC}	: 309.1 kJ/m ²	(1764.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.163 mm	(0.0064 in.)	
T Average	: 212.2	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 532.20 kJ/m ²	Exponent N	: 0.4515
Fit Coeff. R	: 0.9928	(14 Data Points)	
J_{IC} (0.20)	: 344.8 kJ/m ²	(1968.9 in.-lb/in. ²)	
Δa (J_{IC})	: 0.382 mm	(0.0151 in.)	
T Average	: 198.5	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 317.1 kJ/m ²	(1811.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.318 mm	(0.0125 in.)	
T Average	: 203.3	(J_{IC} at 0.15)	
K _{Jc}	: 365.4 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 679.66 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.874 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion line	
Data Points	: Zone A = 5	Zone B = 4
Data Point Spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 478.88 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.157 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 4.208 mm	($\omega = 5$)
Data Points	: Zone A = 10	Zone B = 12
Data Point Spacing	: OK	
J-R Curve Data	: INVALID	

Table A-70. Modified J_{IC} and J - R curve results for specimen 743-03B

Test Number	: 0092	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.26 mm
Spec. Width	: 50.81 mm	Flow Stress	: 472.73 MPa
Modulus E	: 188.92 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 29.2469 mm	Init. a/w	: 0.5756 (Measured)
Final Crack	: 39.8656 mm	Final a/w	: 0.7846 (Measured)
Final Crack	: 38.9341 mm	Final a/w	: 0.7662 (Compliance)
Linear Fit			
$J = B + M(\Delta a)$			
Intercept B	: 260.096 kJ/m ²	Slope M	: 282.51 kJ/m ² mm
Fit Coeff. R	: 0.9935	(14 Data Points)	
J_{IC}	: 305.8 kJ/m ²	(1746.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.162 mm	(0.0064 in.)	
T Average	: 238.8	(J_{IC} at 0.15)	
Power-Law Fit			
$J = C(\Delta a)^n$			
Coeff. C	: 556.40 kJ/m ²	Exponent N	: 0.4851
Fit Coeff. R	: 0.9938	(14 Data Points)	
J_{IC} (0.20)	: 350.3 kJ/m ²	(2000.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.385 mm	(0.0152 in.)	
T Average	: 221.6	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 319.7 kJ/m ²	(1825.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.319 mm	(0.0126 in.)	
T Average	: 226.6	(J_{IC} at 0.15)	
K _{Jc}	: 378.9 MPa-m ^{0.5}

Figure A-68. Deformation and modified J - R curves at room temp. for Heat 74 aged 50,000 h at 320°C

Figure A-69. Deformation J_{IC} at room temp. for Heat 74 aged 50,000 h at 320°C

Figure A-70. Modified J_{IC} at room temp. for Heat 74 aged 50,000 h at 320°C

Table A-71. Test data for specimen 744-02V

Test Number	: 0090	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.36 mm
Spec. Width	: 50.85 mm	Flow Stress	: 472.73 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	18.39	18.34	-0.1568	20.953	0.302
2	50.58	50.82	0.0038	26.695	0.554
3	86.31	86.55	0.0059	29.721	0.803
4	126.91	127.17	0.0084	31.663	1.057
5	169.31	170.47	0.1129	32.928	1.309
6	211.58	215.14	0.3286	33.535	1.559
7	253.47	259.65	0.5182	33.904	1.809
8	296.77	305.62	0.6787	33.860	2.062
9	336.36	352.37	1.0470	33.184	2.310
10	366.40	398.81	1.7874	30.694	2.564
11	392.55	439.45	2.3776	28.954	2.815
12	419.44	477.92	2.8090	28.217	3.058
13	447.10	519.18	3.2724	27.388	3.308
14	475.86	559.38	3.6301	26.429	3.562
15	500.34	599.19	4.0750	25.374	3.808
16	528.58	637.73	4.3533	24.914	4.062
17	557.96	676.70	4.5942	24.064	4.311
18	591.13	723.65	4.9151	23.479	4.609
19	622.46	770.52	5.2521	23.094	4.912
20	666.05	832.38	5.6142	22.475	5.308
21	711.55	893.23	5.8932	21.684	5.711
22	753.34	953.32	6.2008	20.848	6.107
23	788.53	1012.93	6.5834	19.882	6.507
24	808.01	1069.04	7.1230	18.118	6.904
25	824.12	1121.16	7.6246	16.367	7.308
26	810.35	1167.98	8.4359	14.162	7.706
27	815.13	1209.16	8.9050	13.447	8.106
28	830.50	1252.94	9.2555	12.963	8.505
29	848.14	1297.50	9.5729	12.553	8.904

Table A-72. Deformation J_{IC} and J-R curve results for specimen 744-02V

Test Number	: 0090	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.36 mm
Spec. Width	: 50.85 mm	Flow Stress	: 472.73 MPa
Modulus E	: 193.98 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 30.0875 mm	Init. a/w	: 0.5917 (Measured)
Final Crack	: 40.7219 mm	Final a/w	: 0.8008 (Measured)
Final Crack	: 39.6604 mm	Final a/w	: 0.7799 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 163.426 kJ/m ²	Slope M	: 172.78 kJ/m ² mm
Fit Coeff. R	: 0.9770	(4 Data Points)	
J_{IC}	: 179.9 kJ/m ²	(1027.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.095 mm	(0.0037 in.)	
T Average	: 150.0	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 335.85 kJ/m ²	Exponent N	: 0.4099
Fit Coeff. R	: 0.9929	(4 Data Points)	
J_{IC} (0.20)	: 207.8 kJ/m ²	(1186.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.310 mm	(0.0122 in.)	
T Average	: 124.9	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 190.5 kJ/m ²	(1087.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.251 mm	(0.0099 in.)	
T Average	: 128.4	(J_{IC} at 0.15)	
K _{Jc}	: 285.3 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 654.37 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.722 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion line	
Data Point Spacing	: Inadequate	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 481.31 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.076 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 3.853 mm	($\omega = 5$)
Data Points	: Zone A = 5	Zone B = 4
Data Point Spacing	: Inadequate	
J-R Curve Data	: INVALID	

Table A-73. Modified J_{IC} and J - R curve results for specimen 744-02V

Test Number	: 0090	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.39 mm	Net Thickness	: 20.36 mm
Spec. Width	: 50.85 mm	Flow Stress	: 472.73 MPa
Modulus E	: 193.98 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 30.0875 mm	Init. a/w	: 0.5917 (Measured)
Final Crack	: 40.7219 mm	Final a/w	: 0.8008 (Measured)
Final Crack	: 39.6604 mm	Final a/w	: 0.7799 (Compliance)
Linear Fit			
$J = B + M(\Delta a)$			
Intercept B	: 160.803 kJ/m ²	Slope M	: 190.31 kJ/m ² mm
Fit Coeff. R	: 0.9821	(4 Data Points)	
J_{IC}	: 178.8 kJ/m ²	(1021.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.095 mm	(0.0037 in.)	
T Average	: 165.2	(J_{IC} at 0.15)	
Power-Law Fit			
$J = C(\Delta a)^n$			
Coeff. C	: 350.44 kJ/m ²	Exponent N	: 0.4352
Fit Coeff. R	: 0.9947	(4 Data Points)	
J_{IC} (0.20)	: 211.0 kJ/m ²	(1204.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.312 mm	(0.0123 in.)	
T Average	: 137.4	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 192.2 kJ/m ²	(1097.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.252 mm	(0.0099 in.)	
T Average	: 141.1	(J_{IC} at 0.15)	
K_{Jc}	: 294.0 MPa-m ^{0.5}

Figure A-71. Deformation and modified J - R curves at room temp. for Heat 74 aged 50,000 h at 320°C

Figure A-72. Deformation J_{IC} at room temp. for Heat 74 aged 50,000 h at 320°C

Figure A-73. Modified J_{IC} at room temp. for Heat 74 aged 50,000 h at 320°C

Table A-74. Test data for specimen 743-07T

Test Number	: 0106	Test Temp.	: 290°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 25°C	Aging Time	: 0 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.81 mm	Flow Stress	: 297.90 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	13.96	13.93	-0.0853	14.768	0.303
2	39.99	40.05	-0.0312	18.202	0.605
3	59.47	59.97	0.1191	19.339	0.808
4	79.52	79.74	0.0505	20.146	1.007
5	100.75	101.54	0.1589	20.810	1.207
6	122.53	122.73	0.0699	21.360	1.406
7	144.62	146.89	0.3291	21.802	1.611
8	167.24	168.28	0.1973	22.314	1.808
9	191.03	192.32	0.2202	22.679	2.007
10	214.53	216.50	0.2751	23.056	2.208
11	239.89	240.00	0.1400	23.378	2.408
12	261.47	266.22	0.4463	23.652	2.607
13	285.44	289.80	0.4223	23.841	2.807
14	309.42	315.76	0.5313	24.066	3.008
15	334.04	341.00	0.5628	24.319	3.207
16	363.94	366.06	0.3375	24.519	3.409
17	384.23	394.38	0.6878	24.735	3.607
18	408.40	419.32	0.7191	24.733	3.810
19	428.34	446.94	1.0148	24.876	4.009
20	452.68	472.56	1.0612	24.942	4.210
21	480.10	499.10	1.0310	25.084	4.409
22	504.35	527.02	1.1496	25.023	4.608
23	529.53	554.52	1.2206	25.071	4.811
24	546.54	582.47	1.5414	25.044	5.007
25	570.23	609.30	1.6296	25.072	5.213
26	594.72	636.82	1.7103	25.043	5.411
27	619.09	664.48	1.7944	25.136	5.608
28	650.91	691.76	1.6839	25.289	5.810
29	669.22	722.45	1.9736	25.342	6.010
30	696.96	756.58	2.1163	25.259	6.257
31	719.31	793.15	2.4201	25.007	6.508
32	750.45	827.48	2.4851	24.765	6.760
33	771.41	864.36	2.7969	24.568	7.008
34	805.57	906.08	2.9374	24.159	7.309
35	835.43	949.08	3.1703	23.926	7.608
36	877.31	1006.17	3.4239	23.542	8.009
37	913.52	1063.01	3.7494	23.139	8.408
38	951.65	1118.57	4.0094	22.267	8.809
39	976.70	1173.96	4.4418	21.579	9.207
40	1004.26	1227.46	4.7948	20.928	9.610
41	1035.55	1294.58	5.2568	20.147	10.108
42	1072.96	1374.23	5.7691	19.691	10.708
43	1122.94	1452.51	6.0909	18.960	11.310
44	1155.88	1532.14	6.5926	18.119	11.914
45	1204.42	1620.13	6.9898	17.436	12.609
46	1244.59	1709.44	7.4556	16.697	13.311
47	1287.40	1795.77	7.8449	16.123	14.009
48	1331.36	1882.55	8.2067	15.620	14.710

Table A-75. Deformation J_{IC} and J-R curve results for specimen 743-07T

Test Number	: 0106	Test Temp.	: 290°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 25°C	Aging Time	: 0 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.81 mm	σ_f	: 297.90 MPa
Modulus E	: 163.31 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 29.5313 mm	Init. a/w	: 0.5812 (Measured)
Final Crack	: 38.8688 mm	Final a/w	: 0.7649 (Measured)
Final Crack	: 37.7380 mm	Final a/w	: 0.7427 (Compliance)
Linear Fit $J = B + M(\Delta a)$			
Intercept B	: 196.593 kJ/m ²	Slope M	: 244.35 kJ/m ² mm
Fit Coeff. R	: 0.9787	(17 Data Points)	
J_{IC}	: 247.3 kJ/m ²	(1412.2 in.-lb/in. ²)	
Δa (J_{IC})	: 0.208 mm	(0.0082 in.)	
T Average	: 449.7	(J_{IC} at 0.15)	
Power-Law Fit $J = C(\Delta a)^n$			
Coeff. C	: 452.86 kJ/m ²	Exponent N	: 0.5624
Fit Coeff. R	: 0.9852	(17 Data Points)	
J_{IC} (0.20)	: 285.1 kJ/m ²	(1628.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.439 mm	(0.0173 in.)	
T Average	: 437.3	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 257.3 kJ/m ²	(1469.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.366 mm	(0.0144 in.)	
T Average	: 445.5	(J_{IC} at 0.15)	
K_{Jc}	: 333.8 MPa-m ^{0.5}		
J_{IC} Validity & Data Qualification (E 813-85)			
J_{max} Allowed	: 422.66 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)	
Data Limit	: J_{max} Ignored		
Δa (max) Allowed	: 2.073 mm	(at 1.5 Exclusion Line)	
Data Limit	: 1.5 Exclusion Line		
Data Points	: Zone A = 6	Zone B = 6	
Data Point Spacing	: OK		
b_{net} or b_0 Size	: Inadequate		
dJ/da at J_{IC}	: OK		
a_f Measurement	: Near-Surface	Outside Limit	
Initial Crack Shape	: OK		
Crack Size Estimate	: Inadequate	(by Compliance)	
E Effective	: OK		
J_{IC} Estimate	: INVALID		
J-R Curve Validity & Data Qualification (E 1152-86)			
J_{max} Allowed	: 301.98 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)	
Δa (max) Allowed	: 2.128 mm	($\Delta a = 0.1 b_0$)	
Δa (max) Allowed	: 5.138 mm	($\omega = 5$)	
Data Points	: Zone A = 21	Zone B = 7	
Data Point Spacing	: Inadequate		
J-R Curve Data	: INVALID		

Table A-76. Modified J_{IC} and J - R curve results for specimen 743-07T

Test Number	: 0106	Test Temp.	: 290°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 25°C	Aging Time	: 0 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.27 mm
Spec. Width	: 50.81 mm	σ_f	: 297.90 MPa
Modulus E	: 163.31 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 29.5313 mm	Init. a/w	: 0.5812 (Measured)
Final Crack	: 38.8688 mm	Final a/w	: 0.7649 (Measured)
Final Crack	: 37.7380 mm	Final a/w	: 0.7427 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 187.460 kJ/m ²	Slope M	: 273.11 kJ/m ² mm
Fit Coeff. R	: 0.9864	(18 Data Points)	
J_{IC}	: 243.2 kJ/m ²	(1388.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.204 mm	(0.0080 in.)	
T Average	: 502.6	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 473.52 kJ/m ²	Exponent N	: 0.6044
Fit Coeff. R	: 0.9896	(18 Data Points)	
J_{IC} (0.20)	: 289.4 kJ/m ²	(1652.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.443 mm	(0.0174 in.)	
T Average	: 490.0	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 258.2 kJ/m ²	(1474.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.367 mm	(0.0144 in.)	
T Average	: 498.4	(J_{IC} at 0.15)	
K_{Jc}	: 349.3 MPa-m ^{0.5}

Figure A-74. Deformation and modified J - R curves at 290°C for unaged Heat 74

Figure A-75. Deformation J_{IC} at 290°C for unaged Heat 74

Figure A-76. Modified J_{IC} at 290°C for unaged Heat 74

Table A-77. Test data for specimen 743-03T

Test Number	: 0102	Test Temp.	: 290°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.37 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.77 mm	Flow Stress	: 353.25 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	16.02	16.01	-0.0134	17.067	0.305
2	44.58	44.88	0.1477	21.098	0.607
3	65.99	66.06	0.0711	22.860	0.807
4	89.74	88.76	-0.1695	24.102	1.008
5	114.02	115.00	0.1738	25.181	1.208
6	138.37	139.55	0.2022	26.100	1.411
7	163.50	166.25	0.3862	26.924	1.610
8	190.35	191.79	0.2566	27.498	1.808
9	219.73	219.36	0.1019	28.024	2.007
10	246.59	249.71	0.3635	28.555	2.210
11	274.10	276.82	0.3367	28.805	2.409
12	298.18	307.93	0.7614	28.964	2.610
13	323.60	335.23	0.8647	29.085	2.809
14	352.76	364.76	0.8833	29.131	3.011
15	377.89	395.86	1.1601	29.169	3.210
16	402.76	425.22	1.3531	29.196	3.410
17	430.22	454.47	1.4249	29.181	3.608
18	455.46	485.99	1.6595	29.101	3.810
19	485.46	514.86	1.6197	28.973	4.010
20	500.38	549.64	2.2783	28.624	4.215
21	524.89	574.98	2.3045	28.336	4.410
22	550.48	606.73	2.4873	27.893	4.611
23	570.11	637.43	2.8005	27.570	4.810
24	593.66	666.43	2.9472	27.156	5.011
25	614.16	705.99	3.4341	26.587	5.262
26	638.49	740.72	3.6860	25.873	5.508
27	656.31	778.97	4.1582	25.237	5.761
28	678.99	813.53	4.4199	24.214	6.012
29	705.84	856.72	4.7596	23.227	6.315
30	720.94	897.97	5.2797	22.524	6.608
31	749.92	952.65	5.7592	21.435	7.013
32	767.76	1005.89	6.3840	20.194	7.412
33	795.14	1055.25	6.7506	19.215	7.811
34	805.56	1119.94	7.6050	17.780	8.312
35	813.87	1177.21	8.3359	16.251	8.809
36	827.11	1232.99	8.9377	14.995	9.311
37	827.80	1287.24	9.6601	13.535	9.809
38	836.09	1339.38	10.2241	12.760	10.325

Table A-78. Deformation J_{IC} and J-R curve results for specimen 743-03T

Test Number	: 0102	Test Temp.	: 290°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.37 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.77mm	Flow Stress	: 353.25 MPa
Modulus E	: 164.03 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.3125 mm	Init. a/w	: 0.5577 (Measured)
Final Crack	: 39.3031 mm	Final a/w	: 0.7742 (Measured)
Final Crack	: 38.5366 mm	Final a/w	: 0.7591 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 178.160 kJ/m ²	Slope M	: 175.37 kJ/m ² mm
Fit Coeff. R	: 0.9838	(9 Data Points)	
J_{IC}	: 203.4 kJ/m ²	(1161.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.144 mm	(0.0057 in.)	
T Average	: 230.5	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 362.98 kJ/m ²	Exponent N	: 0.4390
Fit Coeff. R	: 0.9726	(9 Data Points)	
J_{IC} (0.20)	: 233.2 kJ/m ²	(1331.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.365 mm	(0.0144 in.)	
T Average	: 207.8	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 214.5 kJ/m ²	(1225.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.302 mm	(0.0119 in.)	
T Average	: 213.0	(J_{IC} at 0.15)	
K_{Jc}	: 278.8 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)		
J_{max} Allowed	: 528.80 kJ/m ²	($J_{max}=b_0\sigma_f/15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.835 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 1	Zone B = 4
Data Point Spacing	: OK	
b_{net} or b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
a_0 Measurement	: 9 Outside Limit	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)		
J_{max} Allowed	: 358.23 kJ/m ²	($J_{max}=b_{net}\sigma_f/20$)
Δa (max) Allowed	: 2.245 mm	($\Delta a=0.1b_0$)
Δa (max) Allowed	: 4.098 mm	($\omega=5$)
Data Points	: Zone A = 7	Zone B = 10
Data Point Spacing	: OK	
J-R Curve Data	: INVALID	

Table A-79. Modified J_{IC} and J-R curve results for specimen 743-03T

Test Number	: 0102	Test Temp.	: 290°C
Material Type	: CF-8M	Heat Number	: 74
Aging Temp.	: 320°C	Aging Time	: 52,600 h
Spec. Thickness	: 25.37 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.77mm	Flow Stress	: 353.25 MPa
Modulus E	: 164.03 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 28.3125 mm	Init. a/w	: 0.5577 (Measured)
Final Crack	: 39.3031 mm	Final a/w	: 0.7742 (Measured)
Final Crack	: 38.5366 mm	Final a/w	: 0.7591 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 171.837 kJ/m ²	Slope M	: 196.97 kJ/m ² mm
Fit Coeff. R	: 0.9869	(9 Data Points)	
J_{IC}	: 199.7 kJ/m ²	(1140.2 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.141 mm	(0.0056 in.)	
T Average	: 258.9	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 378.83 kJ/m ²	Exponent N	: 0.4728
Fit Coeff. R	: 0.9754	(9 Data Points)	
$J_{IC} (0.20)$	: 235.8 kJ/m ²	(1346.5 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.367 mm	(0.0144 in.)	
T Average	: 232.0	(J_{IC} at 0.20)	
$J_{IC} (0.15)$	: 215.2 kJ/m ²	(1228.7 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.302 mm	(0.0119 in.)	
T Average	: 237.5	(J_{IC} at 0.15)	
K_{Jc}	: 288.6 MPa-m ^{0.5}

Figure A-77. Deformation and modified J-R curves at 290°C for Heat 74 aged 52,600 h at 320°C

Figure A-78. Deformation J_{IC} at 290°C for Heat 74 aged 52,600 h at 320°C

Figure A-79. Modified J_{IC} at 290°C for Heat 74 aged 52,600 h at 320°C

Table A-80. Test data for specimen 753-02B

Test Number	: 0104	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.32 mm
Spec. Width	: 50.80 mm	Flow Stress	: 547.73 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	19.17	19.16	-0.0128	24.484	0.301
2	45.41	45.52	0.0729	31.431	0.504
3	76.09	76.19	0.0724	35.600	0.706
4	101.36	101.55	0.0937	37.851	0.855
5	128.43	129.01	0.1709	39.663	1.007
6	155.89	156.17	0.1247	40.976	1.157
7	184.73	187.20	0.3936	41.765	1.307
8	202.25	204.65	0.3874	42.248	1.408
9	221.70	225.44	0.5197	42.967	1.508
10	240.67	244.88	0.5620	43.084	1.609
11	259.42	266.41	0.7886	43.229	1.709
12	277.12	285.18	0.8693	43.303	1.808
13	296.03	306.77	1.0553	43.274	1.910
14	314.44	326.25	1.1245	42.965	2.011
15	332.46	347.84	1.3396	42.762	2.111
16	349.82	367.38	1.4629	42.814	2.212
17	367.48	387.43	1.5902	42.486	2.310
18	385.35	407.87	1.7196	42.318	2.410
19	405.76	431.71	1.8812	42.034	2.525
20	429.56	460.43	2.0965	41.304	2.663
21	453.86	490.41	2.3287	40.829	2.811
22	475.58	522.02	2.7075	39.887	2.963
23	497.27	551.10	2.9748	39.487	3.116
24	529.54	590.64	3.2180	38.833	3.314
25	556.94	632.22	3.6582	37.412	3.515
26	576.37	671.51	4.2371	35.236	3.718
27	594.01	725.52	5.2116	30.481	4.003
28	598.71	755.11	5.8559	29.092	4.211
29	623.00	803.46	6.4381	27.873	4.511
30	644.81	851.30	7.0274	26.094	4.811
31	662.49	915.43	8.0017	23.741	5.210
32	684.39	971.01	8.6615	22.296	5.610
33	708.36	1027.67	9.2587	20.875	6.008
34	728.05	1084.28	9.8888	19.103	6.414
35	742.14	1136.61	10.5036	17.447	6.816

Table A-81. Deformation J_{IC} and J-R curve results for specimen 753-02B

Test Number	: 0104	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.32 mm
Spec. Width	: 50.80 mm	Flow Stress	: 547.73 MPa
Modulus E	: 164.63 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 26.9250 mm	Init. a/w	: 0.5300 (Measured)
Final Crack	: 37.5969 mm	Final a/w	: 0.7401 (Measured)
Final Crack	: 37.4286 mm	Final a/w	: 0.7368 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 148.145 kJ/m ²	Slope M	: 140.35 kJ/m ² mm
Fit Coeff. R	: 0.9906	(11 Data Points)	
J_{IC}	: 158.3 kJ/m ²	(903.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.072 mm	(0.0028 in.)	
T Average	: 77.0	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 295.29 kJ/m ²	Exponent N	: 0.4400
Fit Coeff. R	: 0.9914	(11 Data Points)	
J_{IC} (0.20)	: 167.7 kJ/m ²	(957.9 in.-lb/in. ²)	
Δa (J_{IC})	: 0.277 mm	(0.0109 in.)	
T Average	: 176.4	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 151.4 kJ/m ²	(864.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.219 mm	(0.0086 in.)	
T Average	: 78.5	(J_{IC} at 0.15)	
K_{Jc}	: 246.8 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 871.88 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.669 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion line	
Data Points	: Zone A = 4	Zone B = 3
Data Point Spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
Initial Crack Shape	: OK	
Final Crack Shape	: OK	
Crack Size Estimate	: OK	(by Compliance)
E Effective	: Inadequate	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 556.41 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.388 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 4.109 mm	($\omega = 5$)
Data Points	: Zone A = 4	Zone B = 16
Data Point Spacing	: OK	
J-R Curve Data	: INVALID	

Table A-82. Modified J_{IC} and J - R curve results for specimen 753-02B

Test Number	: 0104	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.40 mm	Net Thickness	: 20.32 mm
Spec. Width	: 50.80 mm	Flow Stress	: 547.73 MPa
Modulus E	: 164.63 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 26.9250 mm	Init. a/w	: 0.5300 (Measured)
Final Crack	: 37.5969 mm	Final a/w	: 0.7401 (Measured)
Final Crack	: 37.4286 mm	Final a/w	: 0.7368 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 144.352 kJ/m ²	Slope M	: 154.72 kJ/m ² mm
Fit Coeff. R	: 0.9928	(11 Data Points)	
J_{IC}	: 155.3 kJ/m ²	(886.9 in.-lb/in. ²)	
Δa (J_{IC})	: 0.071 mm	(0.0028 in.)	
T Average	: 84.9	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 306.10 kJ/m ²	Exponent N	: 0.4681
Fit Coeff. R	: 0.9925	(11 Data Points)	
J_{IC} (0.20)	: 167.7 kJ/m ²	(1228.0 in.-lb/in. ²)	
Δa (J_{IC})	: 0.277 mm	(0.0109 in.)	
T Average	: 83.7	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 150.2 kJ/m ²	(857.8 in.-lb/in. ²)	
Δa (J_{IC})	: 0.219 mm	(0.0086 in.)	
T Average	: 85.8	(J_{IC} at 0.15)	
K _{Jc}	: 253.4 MPa-m ^{0.5}

Figure A-80. Deformation and modified J - R curves at room temp. for Heat 75 aged 50,000 h at 320°C

Figure A-81. Deformation J_{IC} at room temp. for Heat 75 aged 50,000 h at 320°C

Figure A-82. Modified J_{IC} at room temp. for Heat 75 aged 50,000 h at 320°C

Table A-83. Test data for specimen 752-05V

Test Number	: 0091	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.36 mm
Spec. Width	: 50.82 mm	Flow Stress	: 547.73 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	21.85	21.84	-0.0217	26.301	0.303
2	51.52	51.64	0.0621	33.616	0.504
3	85.59	85.51	-0.0015	37.822	0.703
4	114.96	114.95	0.0146	40.104	0.854
5	144.98	145.58	0.1132	41.645	1.004
6	176.34	177.60	0.1965	43.243	1.158
7	207.83	210.06	0.2978	44.341	1.307
8	239.43	242.62	0.3827	44.854	1.455
9	261.44	265.91	0.4838	45.564	1.559
10	293.99	299.92	0.5834	45.684	1.708
11	314.75	323.24	0.7446	45.483	1.809
12	335.63	345.78	0.8407	45.241	1.912
13	355.76	368.84	0.9978	44.927	2.011
14	375.22	391.42	1.1554	44.682	2.111
15	394.58	413.15	1.2677	44.421	2.210
16	413.03	436.92	1.5046	43.871	2.310
17	432.03	457.97	1.5915	43.742	2.412
18	451.01	481.06	1.7556	43.263	2.511
19	469.48	504.44	1.9417	42.524	2.615
20	486.04	526.12	2.1271	41.921	2.714
21	502.96	549.40	2.3455	40.748	2.819
22	527.02	581.78	2.6130	38.978	2.968
23	544.33	614.04	3.0690	37.848	3.116
24	559.44	642.92	3.4697	36.604	3.264
25	576.63	671.85	3.7952	35.411	3.414
26	613.80	734.40	4.4340	33.451	3.712
27	635.89	770.87	4.7768	32.367	3.921
28	658.24	807.35	5.0964	31.361	4.115
29	680.73	843.60	5.3922	30.343	4.311
30	714.88	901.00	5.8552	28.892	4.610
31	739.79	955.36	6.4025	26.431	4.913
32	748.42	1004.89	7.1211	23.521	5.213
33	746.23	1049.37	7.9110	22.021	5.512
34	768.77	1105.75	8.4484	20.714	5.904
35	791.74	1165.64	8.9962	18.942	6.308
36	781.21	1223.43	9.9599	16.545	6.727
37	769.95	1266.10	10.6930	14.905	7.106

Table A-84. Deformation J_{IC} and J-R curve results for specimen 752-05V

Test Number	: 0091	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.36 mm
Spec. Width	: 50.82 mm	Flow Stress	: 547.73 MPa
Modulus E	: 201.98 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.5250 mm	Init. a/w	: 0.5613 (Measured)
Final Crack	: 40.0813 mm	Final a/w	: 0.7887 (Measured)
Final Crack	: 39.2180 mm	Final a/w	: 0.7717 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 184.643 kJ/m ²	Slope M	: 161.69 kJ/m ² mm
Fit Coeff. R	: 0.9842	(11 Data Points)	
J_{IC}	: 199.4 kJ/m ²	(1138.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.091 mm	(0.0036 in.)	
T Average	: 108.9	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 355.76 kJ/m ²	Exponent N	: 0.4195
Fit Coeff. R	: 0.9973	(11 Data Points)	
J_{IC} (0.20)	: 214.0 kJ/m ²	(1221.9 in.-lb/in. ²)	
Δa (J_{IC})	: 0.298 mm	(0.0117 in.)	
T Average	: 106.0	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 195.2 kJ/m ²	(1114.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.239 mm	(0.0094 in.)	
T Average	: 108.9	(J_{IC} at 0.15)	
K _{Jc}	: 299.7 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 814.11 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.703 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion line	
Data Points	: Zone A = 4	Zone B = 3
Data Point Spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
Initial Crack Shape	: OK	
Final Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 557.53 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.230 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 3.934 mm	($\omega = 5$)
Data Points	: Zone A = 4	Zone B = 14
Data Point Spacing	: OK	
J-R Curve Data	: INVALID	

Table A-85. Modified J_{IC} and J-R curve results for specimen 752-05V

Test Number	: 0091	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.38 mm	Net Thickness	: 20.36 mm
Spec. Width	: 50.82 mm	Flow Stress	: 547.73 MPa
Modulus E	: 201.98 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.5250 mm	Init. a/w	: 0.5613 (Measured)
Final Crack	: 40.0813 mm	Final a/w	: 0.7837 (Measured)
Final Crack	: 39.2180 mm	Final a/w	: 0.7717 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 180.155 kJ/m ²	Slope M	: 180.12 kJ/m ² mm
Fit Coeff. R	: 0.9886	(11 Data Points)	
J_{IC}	: 196.3 kJ/m ²	(1120.9 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.090 mm	(0.0035 in.)	
T Average	: 121.3	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 370.05 kJ/m ²	Exponent N	: 0.4485
Fit Coeff. R	: 0.9983	(11 Data Points)	
$J_{IC} (0.20)$	: 215.1 kJ/m ²	(1228.0 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.298 mm	(0.0117 in.)	
T Average	: 117.1	(J_{IC} at 0.20)	
$J_{IC} (0.15)$	: 194.7 kJ/m ²	(1111.8 in.-lb/in. ²)	
$\Delta a (J_{IC})$	: 0.239 mm	(0.0094 in.)	
T Average	: 120.1	(J_{IC} at 0.15)	
K _{Jc}	: 308.5 MPa-m ^{0.5}

Figure A-83. Deformation and modified J-R curves at room temp. for Heat 75 aged 50,000 h at 320°C

Figure A-84. Deformation J_{IC} at room temp. for Heat 75 aged 50,000 h at 320°C

Figure A-85. Modified J_{IC} at room temp. for Heat 75 aged 50,000 h at 320°C

Table A-86. Test data for specimen 753-06B

Test Number	: 0107	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 400°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.37 mm
Spec. Width	: 50.80 mm	Flow Stress	: 569.60 MPa

Unload Number	J _d (kJ/m ²)	J _m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	21.00	21.00	0.0144	23.861	0.304
2	63.41	63.43	0.0177	32.436	0.605
3	106.64	106.77	0.0457	36.827	0.855
4	154.36	155.08	0.1290	39.629	1.106
5	204.34	207.18	0.3481	41.330	1.357
6	233.73	240.63	0.7004	41.241	1.514
7	249.68	258.05	0.8172	41.372	1.610
8	279.85	291.30	1.0307	41.277	1.762
9	307.30	323.78	1.3419	41.344	1.911
10	335.07	354.70	1.5168	41.097	2.063
11	361.77	387.82	1.8411	40.867	2.210
12	387.02	420.50	2.1824	39.626	2.363
13	410.96	451.65	2.4878	38.933	2.513
14	435.10	483.21	2.7801	38.361	2.665
15	457.28	513.11	3.0642	37.546	2.809
16	491.46	555.66	3.3448	37.008	3.011
17	522.98	600.22	3.7439	35.044	3.220
18	544.19	639.01	4.2452	33.028	3.413
19	566.93	675.49	4.6133	31.803	3.613
20	587.48	712.60	5.0321	30.878	3.808
21	610.56	749.45	5.3603	29.676	4.012
22	632.49	798.42	5.9609	27.663	4.266
23	642.12	840.18	6.6364	25.406	4.512
24	661.06	886.78	7.1816	23.484	4.810
25	670.78	934.32	7.8848	21.376	5.109
26	683.43	984.95	8.5457	19.011	5.465
27	682.87	1032.13	9.3361	17.334	5.811
28	683.81	1082.23	10.1029	15.091	6.210

Table A-87. Deformation J_{IC} and J-R curve results for specimen 753-06B

Test Number	: 0107	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 400°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.37 mm
Spec. Width	: 50.80 mm	Flow Stress	: 569.60 MPa
Modulus E	: 200.59 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.9250 mm	Init. a/w	: 0.5694 (Measured)
Final Crack	: 39.5750 mm	Final a/w	: 0.7790 (Measured)
Final Crack	: 39.0279 mm	Final a/w	: 0.7682 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 160.611 kJ/m ²	Slope M	: 112.30 kJ/m ² mm
Fit Coeff. R	: 0.9955	(6 Data Points)	
J_{IC}	: 168.9 kJ/m ²	(964.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.074 mm	(0.0029 in.)	
T Average	: 69.4	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 277.83 kJ/m ²	Exponent N	: 0.3341
Fit Coeff. R	: 0.9731	(6 Data Points)	
J_{IC} (0.20)	: 181.5 kJ/m ²	(1036.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.280 mm	(0.0110 in.)	
T Average	: 63.0	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 168.5 kJ/m ²	(962.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.224 mm	(0.0088 in.)	
T Average	: 65.0	(J_{IC} at 0.15)	
K _{Jc}	: 256.5 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 830.74 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.644 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 1	Zone B = 2
Data Point Spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
a_f Measurement	: Near-Surface	Outside Limit
Initial Crack Shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 580.17 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.188 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 3.182 mm	($\omega = 5$)
Data Points	: Zone A = 4	Zone B = 8
Data point spacing	: OK	
J-R Curve Data	: INVALID	

Table A-88. Modified J_{IC} and J - R curve results for specimen 753-06B

Test Number	: 0107	Test Temp.	: 25°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 400°C	Aging Time	: 10,000 h
Spec. Thickness	: 25.35 mm	Net Thickness	: 20.37 mm
Spec. Width	: 50.80 mm	Flow Stress	: 569.60 MPa
Modulus E	: 200.59 GPa	(Effective)	
Modulus E	: 193.10 GPa	(Nominal)	
Init. Crack	: 28.9250 mm	Init. a/w	: 0.5694 (Measured)
Final Crack	: 39.5750 mm	Final a/w	: 0.7790 (Measured)
Final Crack	: 39.0279 mm	Final a/w	: 0.7682 (Compliance)
Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 157.670 kJ/m ²	Slope M	: 126.78 kJ/m ² mm
Fit Coeff. R	: 0.9960	(6 Data Points)	
J_{IC}	: 167.0 kJ/m ²	(953.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.073 mm	(0.0029 in.)	
T Average	: 78.4	(J_{IC} at 0.15)	
Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 289.68 kJ/m ²	Exponent N	: 0.3634
Fit Coeff. R	: 0.9745	(6 Data Points)	
J_{IC} (0.20)	: 182.4 kJ/m ²	(1041.6 in.-lb/in. ²)	
Δa (J_{IC})	: 0.280 mm	(0.0110 in.)	
T Average	: 70.8	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 168.1 kJ/m ²	(960.1 in.-lb/in. ²)	
Δa (J_{IC})	: 0.224 mm	(0.0088 in.)	
T Average	: 73.0	(J_{IC} at 0.15)	
K_{Ic}	: 264.1 MPa-m ^{0.5}

Figure A-86. Deformation and modified J - R curves at room temp. for Heat 75 aged 10,000 h at 400°C, then recovery-annealed and aged again for 10,000 h at 400°C

Figure A-87. Deformation J_{IC} at room temp. for Heat 75 aged 10,000 h at 400°C, then recovery-annealed and aged again for 10,000 h at 400°C

Figure A-88. Modified J_{IC} at room temp. for Heat 75 aged 10,000 h at 400°C, then recovery-annealed and aged again for 10,000 h at 400°C

Table A-89. Test data for specimen 753-02T

Test Number	: 0103	Test Temp.	: 290°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.41 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.81 mm	Flow Stress	: 415.00 MPa

Unload Number	J_d (kJ/m ²)	J_m (kJ/m ²)	Δa (mm)	Load (kN)	Deflection (mm)
1	16.15	16.30	0.3897	17.670	0.304
2	46.43	45.81	-0.0211	23.121	0.606
3	72.47	72.46	0.1634	25.325	0.805
4	98.65	98.04	0.0351	27.083	1.007
5	127.87	125.90	-0.1788	28.336	1.208
6	156.27	158.75	0.3804	29.433	1.407
7	185.06	184.87	0.1019	30.455	1.608
8	216.97	219.61	0.3478	31.152	1.809
9	246.65	250.66	0.4503	31.631	2.008
10	280.81	283.79	0.3839	32.000	2.216
11	309.91	318.24	0.6937	32.118	2.409
12	338.79	350.64	0.8780	32.118	2.609
13	368.06	384.69	1.1046	31.974	2.810
14	396.26	418.53	1.3500	31.796	3.011
15	423.51	451.78	1.5898	31.305	3.209
16	444.60	487.23	2.1280	31.218	3.409
17	474.04	516.57	2.1245	30.829	3.609
18	499.91	554.78	2.5246	30.205	3.814
19	526.82	585.11	2.6289	29.974	4.010
20	552.82	620.40	2.8948	29.347	4.212
21	580.61	671.98	3.5261	28.341	4.509
22	612.96	718.47	3.8738	27.023	4.811
23	629.59	768.58	4.6490	25.862	5.110
24	656.80	810.41	4.9670	24.589	5.408
25	672.58	858.50	5.6299	23.119	5.709
26	699.30	898.91	5.8959	22.523	6.009
27	720.62	945.81	6.3659	21.543	6.314
28	751.08	985.61	6.5285	21.082	6.611
29	774.51	1046.93	7.1465	19.829	7.008
30	803.49	1101.90	7.5446	18.849	7.422
31	818.31	1169.36	8.3008	17.289	7.910
32	844.98	1230.07	8.7591	16.075	8.409
33	848.22	1292.01	9.5066	14.391	8.909
34	863.25	1347.55	9.9959	13.502	9.414

Table A-90. Deformation J_{IC} and J-R curve results for specimen 753-02T

Test Number	: 0103	Test Temp.	: 290°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.41 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.81 mm	Flow Stress	: 415.00 MPa
Modulus E	: 175.61 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 29.1219 mm	Init. a/w	: 0.5731 (Measured)
Final Crack	: 39.9906 mm	Final a/w	: 0.7870 (Measured)
Final Crack	: 39.1178 mm	Final a/w	: 0.7698 (Compliance)

Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 194.657 kJ/m ²	Slope M	: 150.58 kJ/m ² mm
Fit Coeff. R	: 0.9671	(8 Data Points)	
J_{IC}	: 214.1 kJ/m ²	(1222.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.129 mm	(0.0051 in.)	
T Average	: 153.5	(J_{IC} at 0.15)	

Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 354.53 kJ/m ²	Exponent N	: 0.3848
Fit Coeff. R	: 0.9618	(8 Data Points)	
J_{IC} (0.20)	: 234.4 kJ/m ²	(1338.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.341 mm	(0.0134 in.)	
T Average	: 142.0	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 217.6 kJ/m ²	(1242.3 in.-lb/in. ²)	
Δa (J_{IC})	: 0.281 mm	(0.0111 in.)	
T Average	: 146.0	(J_{IC} at 0.15)	
K_{Jc}	: 278.4 MPa-m ^{0.5}		

J_{IC} Validity & Data Qualification (E 813-85)

J_{max} Allowed	: 600.12 kJ/m ²	($J_{max} = b_0 \sigma_f / 15$)
Data Limit	: J_{max} Ignored	
Δa (max) Allowed	: 1.766 mm	(at 1.5 Exclusion Line)
Data Limit	: 1.5 Exclusion Line	
Data Points	: Zone A = 3	Zone B = 2
Data Point Spacing	: OK	
b_{net} and b_0 Size	: OK	
dJ/da at J_{IC}	: OK	
Initial Crack Shape	: OK	
Final Crack shape	: OK	
Crack Size Estimate	: Inadequate	(by Compliance)
E Effective	: OK	
J_{IC} Estimate	: INVALID	

J-R Curve Validity & Data Qualification (E 1152-86)

J_{max} Allowed	: 420.85 kJ/m ²	($J_{max} = b_{net} \sigma_f / 20$)
Δa (max) Allowed	: 2.169 mm	($\Delta a = 0.1 b_0$)
Δa (max) Allowed	: 3.631 mm	($\omega = 5$)
Data Points	: Zone A = 4	Zone B = 11
Data Point Spacing	: OK	
J-R Curve Data	: INVALID	

Table A-91. Modified J_{IC} and J - R curve results for specimen 753-02T

Test Number	: 0103	Test Temp.	: 290°C
Material Type	: CF-8M	Heat Number	: 75
Aging Temp.	: 320°C	Aging Time	: 50,000 h
Spec. Thickness	: 25.41 mm	Net Thickness	: 20.28 mm
Spec. Width	: 50.81 mm	Flow Stress	: 415.00 MPa
Modulus E	: 175.61 GPa	(Effective)	
Modulus E	: 180.00 GPa	(Nominal)	
Init. Crack	: 29.1219 mm	Init. a/w	: 0.5731 (Measured)
Final Crack	: 39.9906 mm	Final a/w	: 0.7870 (Measured)
Final Crack	: 39.1178 mm	Final a/w	: 0.7698 (Compliance)
Linear Fit	$J = B + M(\Delta a)$		
Intercept B	: 189.400 kJ/m ²	Slope M	: 171.04 kJ/m ² mm
Fit Coeff. R	: 0.9751	(8 Data Points)	
J_{IC}	: 211.2 kJ/m ²	(1205.7 in.-lb/in. ²)	
Δa (J_{IC})	: 0.127 mm	(0.0050 in.)	
T Average	: 174.4	(J_{IC} at 0.15)	
Power-Law Fit	$J = C(\Delta a)^n$		
Coeff. C	: 370.21 kJ/m ²	Exponent N	: 0.4188
Fit Coeff. R	: 0.9684	(8 Data Points)	
J_{IC} (0.20)	: 236.3 kJ/m ²	(1349.4 in.-lb/in. ²)	
Δa (J_{IC})	: 0.342 mm	(0.0139 in.)	
T Average	: 160.3	(J_{IC} at 0.20)	
J_{IC} (0.15)	: 217.6 kJ/m ²	(1242.5 in.-lb/in. ²)	
Δa (J_{IC})	: 0.281 mm	(0.0111 in.)	
T Average	: 164.5	(J_{IC} at 0.15)	
K_{Jc}	: 287.8 MPa-m ^{0.5}

Figure A-89. Deformation and modified J - R curves at room temp. for Heat 75 aged 50,000 h at 320°C

Figure A-90. Deformation J_{IC} at room temp. for Heat 75 aged 50,000 h at 320°C

Figure A-91. Modified J_{IC} at room temp. for Heat 75 aged 50,000 h at 320°C

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

This progress report summarizes work performed by Argonne National Laboratory on long-term thermal embrittlement of cast duplex stainless steels in LWR systems during the six months from October 1991 to March 1992. Charpy-impact, tensile, and fracture toughness J-R curve data are presented for several heats of cast stainless steel that were aged 10,000-58,000 h at 290, 320, and 350°C. The results indicate that thermal aging decreases the fracture toughness of cast stainless steels. In general, CF-3 steels are the least sensitive to thermal aging and CF-8M steels are the most sensitive. The values of fracture toughness J_{IC} and tearing modulus for CF-8M steels can be as low as ≈ 90 kJ/m² and ≈ 60 , respectively. The fracture toughness data are consistent with the Charpy-impact results, i.e., unaged and aged steels that show low impact energy also exhibit lower fracture toughness. All steels reach a minimum saturation fracture toughness after thermal aging; the time to reach saturation depends on the aging temperature. The results also indicate that low-strength cast stainless steels are generally insensitive to thermal aging.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating this report.)

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