Effects of Nonstandard Heat Treatment Temperatures on Tensile and Charpy Impact Properties of Carbon-Steel Casting Repair Welds

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Prepared by
R. K. Nanstad, G. M. Goodwin, M. J. Swindeman

Oak Ridge National Laboratory

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U.S. Nuclear Regulatory Commission

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Prepared by

R. K. Nanstad, G. M. Goodwin, M. J. Swindeman

Oak Ridge National Laboratory

Operated by Martin Marietta Energy Systems, Inc.

Oak Ridge National Laboratory

Oak Ridge, TN 37831-6285

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Abstract

Carbon steel castings are used for a number of different components in nuclear power plants, including valve bodies and bonnets.

Components are often repaired by welding processes, and both welded components and the repair welds are subjected to a variety of postweld heat treatments (PWHT) with temperatures as high as 899°C (1650°F), well above the normal 593 to 677°C (1100 to 1250°F) temperature range. The temperatures noted are above the A1 transformation temperature for the materials used for these components. A test program was conducted to investigate the potential effects of such "nonstandard" PWHTs on mechanical properties of carbon steel casting welds. Four weldments were fabricated, two each with the shielded-metal-arc (SMA) and flux-cored-arc (FCA) processes, with a high-carbon and low-carbon filler metal in each case. All four welds were sectioned and given simulated PWHTs at temperatures from

621 to 899°C (1150 to 1650°F) in increments of 56°C (100°F) and for times of 5, 10, 20, and 40 h at each temperature. Hardness, tensile, and Charpy V-notch (CVN) impact tests were conducted for the as-welded and heat-treated conditions. Results were plotted versus a time-temperature relationship (tempering parameter) to enable a more direct comparison of the effects of the various PWHT conditions. Heat treatments at 621 and 677°C (1150 and 1250°F) gave results amenable to prediction, and regression analyses are presented for those conditions. Heat treatments at 732 to 899°C (1350 to 1650°F), however, resulted in substantial changes in mechanical properties of these SMA and FCA welds, with the changes not amenable to prediction and highly dependent on the weld metal. Heat treatments in that temperature range should not be applied to these materials without prior qualification for the intended use.

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Effects of Nonstandard Heat-Treatment Temperatures on Tensile and Charpy Impact Properties of Carbon-Steel Casting Repair Welds*

R. K. Nanstad, G. M. Goodwin, and M. J. Swindeman†

Introduction

Carbon steel castings are used for a number of different components in nuclear power plants, including valve bodies and bonnets. As a result of reviews of component manufacturing procedures by Region 1 of the U.S. Nuclear Regulatory Commission, it was noted that components are often repaired by welding processes and that both welded components and the repair welds are subjected to a variety of postweld heat treatments (PWHT) above the 593 to 677°C (1100 to 1250°F) temperature range.‡ In some cases, the repairs have been applied to components in the as-cast condition, followed by normalizing at 899°C (1650°F). In other cases, the previously heat-treated components are welded and then given a PWHT at 732°C (1350°F). The temperatures noted are above the A1 transformation temperature for the materials used for these components. Thus, a concern was expressed that such practices may cause undesirable changes in mechanical properties of the weld metals used to affect repairs. Therefore, a test program was conducted to investigate the potential effects of such "nonstandard" PWHTs on mechanical properties of carbon-steel casting welds.

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†Summer student, Oak Ridge National Laboratory.

‡Letter, Stewart D. Ebnetter to Charles Z. Serpan, U.S. Nuclear Regulatory Commission, "Development of Properties for Mild Steel Weld Metal Receiving PWHT at Inter Critical and Super Critical Temperatures," February 7, 1984.

Materials, Fabrication, and Heat Treatment

Four weldments were fabricated, two each with the shielded-metal-arc (SMA) and flux-cored-arc (FCA) processes. For each process, high- and low-carbon filler metals were used. The base plate was a 101.6-mm-thick (4-in.) plate of A 36 hot-rolled steel. The weldments are designated weld 1 (SMA, low carbon); weld 2 (SMA, high carbon); weld 3 (FCA, high carbon); and weld 4 (FCA, low carbon). The consumables used were 1/4-in.-diam SMA electrodes for welds 1 and 2, and 3/32-in.-diam flux-cored wire for welds 3 and 4. Table 1 provides the chemical composition of each weld as well as the applicable specifications and manufacturers. Also shown in Table 1 are values for carbon equivalent according to the *Welding Handbook*.¹ The carbon equivalent values range from 0.31 to 0.76, with the SMA welds giving both the lowest and highest values.

A single V-groove joint geometry was used with a 45° included angle and 50.8-mm-wide (2-in.) root gap. The very wide root gap was chosen to simulate a major repair in a large casting and, also, to provide an adequate volume of weld metal for the extensive heat-treatment test matrix. The SMA welds (1 and 2) were produced using stringer beads at 325- to 375-A dc-electrode positive (DCEP). The FCA welding (welds 3 and 4) was done at approximately 480 A and 30 V using 100% carbon dioxide shielding gas.

All four welds were sectioned and given simulated postweld heat treatments at temperatures from 621 to 899°C (1150 to 1650°F) in increments of 56°C (100°F) and for times of 5, 10, 20, and 40 h at each temperature. The weldments were furnace cooled from the PWHT

Table 1. Summary of specifications and chemical compositions for welds 1 through 4

Weld	Type ^a	Specification and manufacturer ^b	Composition (wt %)							Carbon equivalent ^c
			C	Mn	Si	Mo	P	S	V	
1	SMA low C	E7018-A1, H	0.041	0.72	0.35	0.40	0.020	0.013	0.007	0.31
2	SMA high C	E7018, M	0.270	1.17	0.79	0.05	0.007	0.011	0.012	0.76
3	FCA high C	E120T-KS, M	0.169	1.38	0.61	0.25	0.012	0.021	0.024	0.67
4	FCA low C	E70T-1, T	0.070	1.34	0.78	0.01	0.011	0.011	0.020	0.60
^a SMA [=] shielded metal-arc, FCA {=} flux cored-arc. ^b H = Hobart, M = McKay, T = Tri-Mark. ^c Carbon equivalent = % C + (% Mn/4) + (% Si/4).										

temperature to 371°C (700°F) with cooling rates from about 6 to 8°C (11 to 14°F/min).

Charpy V-notch (CVN) and tensile specimens were machined in the transverse orientation such that crack propagation in the CVN specimens was in the welding direction. Figure 1 schematically shows the location of specimens in the weldments, while Figures 2(a) and (b) show the configuration of the test specimens. One tensile and five CVN specimens were machined and tested from each weld section, with two weld sections representing each heat treatment; thus, 2 tensile and 10 CVN specimens were tested for each heat-treatment condition as well as for the as-welded condition. Table 2 provides the key used for identification of sections from which specimens were machined.

Testing and Analysis Procedures

Tensile tests were conducted at room temperature on a screwdriven tensile machine in accordance with the provisions of American Society for Testing and Materials (ASTM) E-8. The load versus time strip-chart test records were analyzed to obtain yield and ultimate strengths, and uniform and total elongations by constructing offset lines to allow for test system compliance.

Hardness tests were conducted with a Rockwell B (1/16-in.-diam) indenter and 100-kg load. Ten measurements for each condition were made and averaged.

CVN impact tests were conducted on a 407-J (300-ft-lb) pendulum-type Charpy machine in accordance with the provisions of ASTM E-23, except for the soaking time at temperature for which the provisions of ASTM E-184 were followed. Heated air and cold nitrogen gas were used to condition the specimens, and they were held at temperature sufficiently long that the entire specimen was at the test temperature. The tests were conducted over a suitable temperature range to obtain ductile-to-brittle transition behavior as well as the upper-shelf toughness. The data for each heat-treatment condition were fitted with a hyperbolic tangent function to allow for consistent

determinations of transition temperatures and the upper-shelf energy (USE). The transition temperatures determined are those corresponding to the energy midway between the upper and lower shelves (designated T_o), and those (arbitrarily chosen) at 27 and 68 J (20 and 50 ft-lb).

A time-temperature relationship was used to enable a more direct comparison of the effects of the various PWHT conditions. This so-called tempering parameter (TP) has the same form as that developed by Hollomon and Jaffee:²

$$TP = T^*(c + \log t) , \quad (1)$$

where T is PWHT temperature in absolute units, K ($^{\circ}\text{C} + 273$), c is a constant, and t is the time at the PWHT temperature in hours.

Often, " c " is taken to be 20, which was the number proposed by Larson and Miller to correlate creep-rupture data rather than tempering response.³ In this program, the test results were fitted with Eq. (1) to determine the best value for the constant " c ." The results were quite varied, ranging nominally from about 10 to 20, and a reasonable average value of 15 was chosen. Thus, the TP function used for all comparisons is:

$$TP = T^*(15 + \log t) . \quad (2)$$

For the PWHT conditions of this study, TP values ranged from 14,000 to 19,500.

Results and Discussion

Hardness Results

Tabular results of all the averaged hardness tests are provided in Tables A1 through A4 of Appendix A. Rockwell B hardness (HRB) measurements for the four welds ranged from about 62 to 104 HRB. Weld 1, with results from about 62 to 91 HRB, exhibited the widest range of hardness. Weld 2, with results from about 82 to 100, exhibited the narrowest range. Welds 1 and 2 have the lowest and highest carbon equivalents, respectively, of the four welds. Figures 3 through 6 show the hardness results for welds 1 through 4, respectively, plotted

Welding
Direction

Figure 1. Schematic drawing showing the locations for machining of Charpy impact and tensile test specimen blanks in welds 1 through 4.

Figure 2. Drawings of (a) tensile and (b) CVN impact test specimens for welds 1 through 4.

Table 2. Numbering scheme used to identify sections from which test specimens were machined for welds 1 through 4

WELD #	AS WELDED	1150° F				1250° F				1350° F			
		5 hrs	10 hrs	20 hrs	40 hrs	5 hrs	10 hrs	20 hrs	40 hrs	5 hrs	10 hrs	20 hrs	40 hrs
1	100	111	112	113	114	121	122	123	124	131	132	133	134
2	200	211	212	213	214	221	222	223	224	231	232	233	234
3	300	311	312	313	314	321	322	323	324	331	332	333	334
4	400	411	412	413	414	421	422	423	424	431	432	433	434

WELD #	1450° F				1550° F				1650° F			
	5 hrs	10 hrs	20 hrs	40 hrs	5 hrs	10 hrs	20 hrs	40 hrs	5 hrs	10 hrs	20 hrs	40 hrs
1	141	142	143	144	151	152	153	154	161	162	163	164
2	241	242	243	244	251	252	253	254	261	262	263	264
3	341	342	343	344	351	352	353	354	361	362	363	364
4	441	442	443	444	451	452	453	454	461	462	463	464

Figure 3. Plot of hardness (HRB) versus the TP, $T^*(15 + \log t)$, for weld 1, a low-carbon SMA weld. The equation shown is the result of a linear regression to the data at PWHT temperatures of 677°C (1250°F) and lower, while the solid line shows the resulting fit.

Figure 4. Plot of hardness (HRB) versus the TP, $T^*(15 + \log t)$, for weld 2, a high-carbon SMA weld. The equation shown is the result of a linear regression to the data at PWHT temperatures of 677°C (1250°F) and lower, while the solid line shows the resulting fit.

Figure 5. Plot of hardness (HRB) versus the TP, $T^*(15 + \log t)$, for weld 3, a high-carbon FCA weld. The equation shown is the result of a linear regression to the data at PWHT temperatures of 677°C (1250°F) and lower, while the solid line shows the resulting fit.

Figure 6. Plot of hardness (HRB) versus the TP, $T^*(15 + \log t)$, for weld 4, a low-carbon FCA weld. The equation shown is the result of a linear regression to the data at PWHT temperatures of 677°C (1250°F) and lower, while the solid line shows the resulting fit.

versus the TP. The TP scale is broken to allow for plotting of the as-welded results on a scale that provides a reasonable graphical presentation. In all cases, the as-welded condition has the highest hardness for each weld.

In each case, the data for PWHT temperatures of 677°C (1250°F) and lower (those below the lower critical temperature), are denoted with filled symbols and fitted with a linear regression (the as-welded results are not included in the regressions). The equations for the linear regressions are provided on the individual plots, as are the coefficients of correlation (R), which range from 0.82 to 0.94. Figure 7 provides a graphical comparison of the regression results for the four welds. In general, the scatter in results is greater for the higher temperature PWHTs (those above the A1 temperature and represented by the open symbols). The results at the higher temperatures were not fitted to the regression because they represent heat treatments at temperatures above normal PWHT temperatures. However, inspection of the data in each figure also reveals that, at the PWHT temperatures of 732°C (1350°F) and higher, the results showed generally consistent trends of decreasing hardness with increasing TP for each individual PWHT temperature, but the overall behavior showed too much scatter for inclusion in the trend line fitting.

As expected, for both the SMA and FCA welds, the high-carbon welds are harder than the low-carbon welds. Moreover, the two SMA welds exhibit similar hardness changes with increasing TP, as do the two FCA welds, with the response to heat treatment being much stronger for the FCA welds.

Tensile Results

Tabular results for all the tensile tests are provided in Tables B1 through B4 of Appendix B. In the as-welded condition, weld 1 is the weakest with average yield and ultimate strengths of 480 and 550 MPa (69.7 and 79.8 ksi), while weld 3 is the strongest with average yield and ultimate strengths of 812 and 891 MPa (118 and 129 ksi). The range of yield

strengths for all the heat-treated welds is from 226 to 801 MPa (32.8 to 116 ksi), while that of ultimate strengths is from 406 to 1131 MPa (58.9 to 164 ksi). In the as-welded condition, the average total elongations range from about 10 to 13%. For the heat-treated welds, the welds exhibited varying amounts of decreases and increases in the elongations with the highest total elongation exhibited by weld 1 at about 30%.

Figures 8 through 11 show the yield and ultimate strength results for welds 1 through 4, respectively, plotted versus the TP. Again, a broken scale is used on the abscissa. As with the hardness data, filled symbols are used to denote results from PWHT temperatures at 677°C (1250°F) and lower, and linear regressions were similarly performed. For welds 1, 2, and 3, the regression curves for yield and ultimate strength versus TP are essentially parallel. For weld 4, however, the yield strength decreases substantially faster with increasing TP than does the ultimate strength, at least over the fitted temperature range. Inspection of the figures reveals that the high-carbon welds show a more dramatic effect of PWHT at the higher temperatures, 732°C (1350°F) and higher, than do the low-carbon welds, with the least effect being that of the low-carbon SMA weld 1, and the greatest effect being that of the high-carbon FCA weld 3. Those observations apply to both yield and ultimate strengths but are most evident for the ultimate strength results. In fact, weld 3 is the only weld that exhibited a heat-treated ultimate strength higher than that in the as-welded condition. The average as-welded ultimate strength for weld 3 was 891 MPa (129 ksi), while it reached 1125 MPa (163 ksi) after the PWHT at 732°C (1350°F) for 5 h. In fact, the ultimate strength results from all the 732°C PWHTs of weld 3 were higher than those in the as-welded condition.

Figure 12 provides a graphical comparison of the yield strength response of the four welds. The two SMA welds exhibit similar hardness changes with increasing TP, as do the two FCA welds, with the response to heat treatment being much stronger for the FCA welds. These observations are similar to those for the

Figure 7. Comparison of linear regression curves to hardness (HRB) results versus the TP, $T^*(15 + \log t)$, for welds 1 through 4.

(a)

(b)

Figure 8. (a) Yield strength and (b) ultimate strength versus the TP, $T^*(15 + \log t)$, for weld 1, a low-carbon SMA weld. The equation shown is the result of a linear regression to the data at PWHT temperatures of 677 °C (1250 °F) and lower, while the solid line shows the resulting fit.

(a)

(b)

Figure 9. (a) Yield strength and (b) ultimate strength versus the TP, $T^*(15 + \log t)$, for weld 2, a high-carbon SMA weld. The equation shown is the result of a linear regression to the data at PWHT temperatures of 677°C (1250°F) and lower, while the solid line shows the resulting fit.

(a)

(b)

Figure 10. (a) Yield strength and (b) ultimate strength versus the TP, $T^*(15 + \log t)$, for weld 3, a high-carbon FCA weld. The equation shown is the result of a linear regression to the data at PWHT temperatures of 677 °C (1250 °F) and lower, while the solid line shows the resulting fit.

(a)

(b)

Figure 11. (a) Yield strength and (b) ultimate strength versus the TP, $T^*(15 + \log t)$, for weld 4, a low-carbon FCA weld. The equation shown is the result of a linear regression to the data at PWHT temperatures of 677 °C (1250 °F) and lower, while the solid line shows the resulting fit.

Figure 12. Comparison of linear regression curves to yield strength results versus the TP, $T^*(15 + \log t)$, for welds 1 through 4.

hardness results presented earlier. Figure 13 shows a similar comparison for the ultimate strength results, which exhibit trends similar to those for the yield strengths.

Charpy V-Notch Impact Results

The individual CVN test results are provided in Tables C1 through C4 of Appendix C. As shown, there are up to 10 CVN tests for each weld in the as-welded condition and in each PWHT condition. As mentioned earlier, a hyperbolic tangent function was used to fit the CVN data. The function has the following general form:

$$E = A + B \cdot \tanh[(T - T_0)/C], \quad (3)$$

where E is absorbed energy (Joules); A , B , C , and T_0 are fitting constants [in this formulation, $(A + B)$ is the upper-shelf value and $(A - B)$ is the lower-shelf value]; and T is test temperature ($^{\circ}\text{C}$). A and B have units of Joules; T_0 and C are in $^{\circ}\text{C}$. In fitting the CVN data in this study, the lower-shelf energy was arbitrarily fixed at a low value of 5 J (3.7 ft-lb) because little data were available at the lower temperatures to enable consistent fits. The resulting fits enabled consistent determination of the 27- and 68-J (20- and 50-ft-lb) transition temperatures and USE for each condition. The effects of PWHT on CVN toughness can then be consistently evaluated.

The results of those analyses are provided in Tables 3 through 6 for welds 1 through 4, respectively. The tables give the tanh fitting constants as well as the 27- and 68-J (TT_{27} and TT_{68}) transition temperatures and the USE values. Figures 14 through 17 show the CVN energy versus test temperature for welds 1 through 4, respectively, in the as-welded condition. Figure 18 provides a graphical comparison of these curve fits. The T_0 temperatures (midpoint of the transition region) vary from -62°C (-79°F) for weld 3 to -7°C (19°F) for weld 4, while the 27-J (20 ft-lb) temperatures (TT_{27}) range from -81 to -34°C (-114 to -28°F). The USE values range from a very low 36 J (26 ft-lb) for weld 3 to 206 J (152 ft-lb) for weld 1. Both the SMA welds have higher USE values than do the FCA welds. It is

notable that weld 3, the high-carbon FCA weld, has a low T_0 temperature but the lowest USE. As shown in Table 5, weld 3 did not achieve 68 J in most cases. For both the SMA and FCA welds, higher carbon contents substantially decrease the USE. In the case of the FCA welds, the higher carbon content weld 3 had a substantially lower transition temperature than that for the lower carbon content weld 4. The opposite was true for the SMA welds, but the difference was not relatively large.

Figures 19 through 22 provide a series of plots that graphically depict the effect of PWHT on the transition temperatures and USE results for welds 1 through 4, respectively (note that a plot of TT_{68} versus TP is not given for weld 3 because of its low energy in almost every condition). In most cases, the heat-treated T_0 and TT_{27} temperatures were higher than those in the as-welded condition. That is not, however, the case for the TT_{68} results. The scatter in transition temperature results overwhelmed trends that may exist and, in most of the cases, the coefficients of correlation were extremely low. Thus, linear regression fits to the transition temperature results are not shown. The highest T_0 temperatures, at about 100°C (212°F), are shown by the low-carbon FCA weld 4 after PWHT at 899°C (1650°F) for 10 and 20 h. The USE results, however, were relatively well behaved, and linear regressions were performed as shown on the figures. In all four cases, the trend is for increasing USE with increasing TP. The scatter in USE results for the higher PWHT temperatures, however, was also large, and consistent trends were not observed. Figure 23 provides a graphical comparison of the USE results for the four welds. The relatively low USE of weld 3 is apparent. The change in USE for the low-carbon SMA weld 1 is greater than that for its high-carbon counterpart, but the opposite situation exists for the FCA welds with the high-carbon weld 3 showing greater changes than its low-carbon counterpart.

Metallography

Figures 24(a) through (d) show the microstructures of welds 1 through 4, respectively, in

Figure 13. Comparison of linear regression curves to ultimate strength results versus the TP, $T^*(15 + \log t)$, for welds 1 through 4.

Table 3. Summary of Charpy impact analysis for weld 1, low-carbon SMA weld

ANN TEMP ^a		ANN TIME ^a	T.P.	A	B	C	T ₀		T _{27J}		T _{68J}		USE	
(°C)	(°F)	(HR)	(x10 ⁻³)	(J)	(J)	(°C)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(J)	(ft-lb)
AW	AW	AW	0	108	101	57	-21.5	-6.7	-81.3	-114.34	-43.8	-48.84	206	152
621	1150	5	14.04	151	146	34	1.4	34.52	-40.7	-41.26	-20.3	-4.54	298	219
621	1150	10	14.31	162	157	43	-14.4	8.08	-70.1	-94.18	-44.1	-47.38	318	235
621	1150	20	14.58	172	167	41	-6.	21.2	-59.8	-75.64	-35.6	-32.08	340	250
621	1150	40	14.85	199	194	28	.8	33.44	-38.1	-36.58	-21.9	-7.42	393	290
677	1250	5	14.91	177	172	14	-18.9	-2.02	-38.1	-36.58	-28.6	-21.28	348	257
677	1250	10	15.20	204	199	26	-16.6	2.12	-52.8	-63.04	-37.9	-36.22	402	297
677	1250	20	15.48	195	190	25	-25.1	-13.18	-60	-76	-45.4	-49.72	386	284
677	1250	40	15.77	194	189	1	-24.5	-12.1	-26.2	-15.16	-25.5	-13.9	384	283
732	1350	10	16.09	202	197	25	-.5	31.1	-35.7	-32.28	-21.1	-5.98	398	294
732	1350	20	16.39	193	188	11	-14.1	6.62	-29.2	-20.58	-22.8	-9.04	382	282
732	1350	5	15.78	202	197	31	-4.5	23.9	-48	-54.4	-30	-22	399	295
732	1350	40	16.69	195	190	20	-15.2	4.64	-42.7	-44.86	-31.1	-23.98	385	284
788	1450	20	17.29	198	193	38	10.	50	-43.3	-45.94	-21	-5.8	390	288
788	1450	5	16.66	209	204	25	3.8	38.84	-31.3	-24.34	-17	1.4	414	305
788	1450	40	17.81	198	193	15	-9.5	14.9	-30.6	-23.08	-21.8	-7.24	391	289
788	1450	10	16.98	183	178	25	7.3	45.14	-26.7	-16.06	-11.9	10.58	361	266
843	1550	5	17.53	208	203	13	-31.6	-24.88	-49.5	-57.1	-42.2	-43.96	411	303
843	1550	10	17.86	194	189	15	-22.7	-8.86	-43.6	-46.48	-34.8	-30.64	384	283
843	1550	20	18.20	194	189	15	-31.5	-24.7	-52.4	-62.32	-43.6	-46.48	383	282
843	1550	40	18.54	179	174	10	-17.8	-0.04	-31.3	-24.34	-25.4	-13.72	353	280
899	1650	40	19.46	165	160	3	-23.	-9.4	-26.3	-15.34	-24.8	-12.64	324	239
899	1650	5	18.40	193	188	10	-14.4	6.08	-28.3	-18.94	-22.4	-8.32	380	280
899	1650	10	18.75	192	187	10	-16.5	2.3	-30.4	-22.72	-24.5	-12.1	379	280
899	1650	20	19.11	189	184	10	-6.4	20.48	-20.2	-4.36	-14.3	6.26	373	275

a AW-As-welded

Table 4. Summary of Charpy impact analysis for weld 2, high-carbon SMA weld

ANN TEMP ^a		ANN TIME ^a	T.P.	A	B	C	T ₀		T _{27J}		T _{68J}		USE	
(°C)	(°F)	(HR)	(x10 ⁻³)	(J)	(J)	(°C)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(J)	(ft-lb)
AW	AW	AW	0	48	43	64	-11.7	10.94	-45.8	-50.44	19.9	67.82	91	67
621	1150	10	14.31	59	54	47	-7.5	18.5	-39.5	-39.1	0.5	32.9	113	83
621	1150	5	14.04	62	57	67	.8	33.44	-46.9	-52.42	8.4	47.12	118	87
621	1150	20	14.58	65	60	62	-2.7	27.14	-49	-58.2	0	32	126	93
621	1150	40	14.85	69	64	52	-1.	30.2	-41.7	-43.08	-1.6	29.12	132	98
677	1250	5	14.91	66	61	56	-1.	30.2	-43.9	-47.02	0.5	32.9	128	94
677	1250	10	15.20	69	64	59	-5.1	22.82	-51.4	-60.52	-5.7	21.74	132	98
677	1250	20	15.48	73	68	45	-9.9	14.18	-47	-52.8	-13.5	7.7	142	105
677	1250	40	15.77	73	68	57	8.7	47.66	-38.3	-36.94	4.8	40.64	140	103
732	1350	5	15.78	59	54	56	-6.8	20.12	-45	-49	2.8	37.04	113	83
732	1350	10	16.09	66	61	61	-5.6	21.92	-51.6	-60.88	-3.2	26.24	126	93
732	1350	20	16.39	53	48	48	-16.5	2.3	-45.1	-49.18	-0.7	30.74	101	74
732	1350	40	16.69	56	51	45	-21.6	-6.88	-50.5	-58.9	-10.5	13.1	107	79
788	1450	5	16.68	59	54	88	0	32	-59.6	-75.28	14.8	58.64	113	83
788	1450	10	16.98	63	58	63	10.	50	-35.4	-31.72	15.4	59.72	121	89
788	1450	20	17.29	65	60	63	25.	77	-21.5	-6.7	28.4	83.12	125	92
788	1450	40	17.61	65	60	75	21.2	70.16	-35	-31	24.8	76.64	125	92
843	1550	40	18.54	56	51	50	40.6	105.08	8.6	47.48	53.2	127.76	106	78
843	1550	20	18.20	67	62	63	52.2	125.96	4.3	39.74	53.3	127.94	129	95
843	1550	5	17.53	56	51	45	23.	73.4	-6.1	21.02	33.7	92.66	107	79
843	1550	10	17.86	67	62	50	15.4	59.72	-23.2	-9.76	15.8	60.44	130	96
899	1650	10	18.78	70	65	63	28.8	80.24	-22.8	-8.04	25	77	136	99
899	1650	20	19.11	56	51	63	48.8	119.48	8.1	46.58	63.2	145.76	108	79
899	1650	40	19.48	58	53	63	46.8	116.24	5	41	58.8	137.84	111	82
899	1650	5	18.40	59	54	63	32.1	89.78	-10.2	13.64	43.3	109.94	112	83

a AW-As-welded

Table 5. Summary of Charpy impact analysis for weld 3, high-carbon FCA weld

ANN TEMP ^a		ANN TIME ^a	T.P.	A	B	C	T ₀		T _{27J}		T _{68J}		USE	
(°C)	(°F)	(HR)	(x10 ⁻³)	(J)	(J)	(°C)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(J)	(ft-lb)
AW	AW	AW	0	20	15	38	-61.9	-79.42	-44	-47.2	b	b	38	28
621	1150	5	14.04	30	25	75	-13.2	8.24	-21.3	-6.34	b	b	54	40
621	1150	10	14.31	30	25	59	-2.3	27.86	-10.1	13.82	b	b	56	41
621	1150	20	14.58	28	23	49	-7.2	19.04	-10	14	b	b	52	38
621	1150	40	14.85	32	27	41	-7.3	18.86	-15.5	4.1	b	b	60	44
677	1250	5	14.91	34	29	61	-10.9	12.38	-26.2	-15.16	b	b	63	47
677	1250	10	15.20	40	35	53	-4.7	23.54	-25.1	-13.18	55.9	132.62	74	55
677	1250	20	15.48	45	40	78	19.9	67.82	-18.1	-0.58	69.4	156.92	86	63
677	1250	40	15.77	45	40	52	32	89.6	7	44.6	67.7	153.86	84	62
732	1350	5	15.78	16	11	75	-91.2	-132.16	c	c	b	b	27	20
732	1350	10	16.09	18	13	72	-33.4	-28.12	21.6	70.88	b	b	32	23
732	1350	20	16.39	19	14	128	1.9	35.42	78.4	173.12	b	b	34	25
732	1350	40	16.69	17	12	74	-54.4	-65.92	42.5	108.5	b	b	29	21
788	1450	10	16.98	37	32	100	30.6	87.08	-1.5	29.3	249.2	480.56	69	51
788	1450	5	16.66	38	33	88	17.7	63.86	-11.9	10.58	163.2	325.76	70	52
788	1450	20	17.29	34	29	100	21.1	69.98	-3.2	26.24	b	b	63	46
788	1450	40	17.61	32	27	100	26.7	80.06	6.6	43.88	b	b	60	44
843	1550	5	17.53	23	18	100	50.3	122.54	72.7	162.86	b	b	41	30
843	1550	10	17.86	19	14	75	42.3	108.14	95.5	203.9	b	b	32	24
843	1550	20	18.20	31	26	75	58.2	136.76	46.5	115.7	b	b	57	42
843	1550	40	18.54	30	25	75	43.8	110.84	35.6	96.08	b	b	54	40
899	1650	5	18.40	27	22	88	63.8	146.84	65.8	150.44	b	b	48	35
899	1650	10	18.75	34	29	125	92.8	199.04	60.8	141.44	b	b	64	47
899	1650	20	19.11	28	23	75	51.8	125.24	47.2	116.96	b	b	52	38
899	1650	40	19.46	22	17	88	63	145.4	87.4	189.32	b	b	40	29

a AW - As-welded

b Did not achieve 68J.

c Did not achieve 27J in the transition region.

Table 6. Summary of Charpy impact analysis for weld 4, low-carbon FCA weld

ANN TEMP ^a		ANN TIME ^a	T.P.	A	B	C	T ₀		T _{27J}		T _{66J}		USE	
(°C)	(°F)	(HR)	($\times 10^{-3}$)	(J)	(J)	(°C)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(J)	(ft-lb)
AW	AW	AW	0	40	35	67	-7.	19.4	-33.8	-28.48	64.7	148.46	75	58
621	1150	5	14.04	45	40	58	10.8	51.44	-17.3	0.88	47.8	118.04	85	63
621	1150	10	14.31	47	42	45	11.8	53.24	-11.3	11.68	37.7	99.86	88	65
621	1150	20	14.58	48	43	45	9.3	48.74	-14.7	5.54	32.8	91.04	90	67
621	1150	40	14.85	51	46	44	4.8	40.64	-20.7	-5.26	22	71.6	97	71
677	1250	5	14.91	51	46	53	3.	37.4	-27.2	-18.98	23.7	74.66	97	71
677	1250	10	15.20	53	48	40	3.8	38.84	-20.7	-5.26	18.3	61.34	102	75
677	1250	20	15.48	60	55	33	16.2	61.16	-6.3	20.66	21.3	70.34	114	84
677	1250	40	15.77	70	65	48	25.7	78.26	-10.9	12.38	24.5	76.1	134	99
732	1350	5	15.78	46	41	61	-5.9	21.38	-36.5	-33.7	29.9	85.82	87	64
732	1350	10	16.09	53	48	81	9.	48.2	-40.2	-40.38	35	95	101	75
732	1350	20	16.39	51	48	62	-8.1	17.42	-44	-47.2	15.7	60.26	97	72
732	1350	40	16.69	54	49	64	3.	37.4	-37.2	-34.96	21.2	70.16	104	77
788	1450	5	16.66	58	53	75	12.	53.6	-38.1	-36.58	26.5	79.7	111	82
788	1450	10	16.98	54	49	75	9.	48.2	-37	-34.6	32.2	89.98	102	75
788	1450	20	17.29	60	55	75	20.2	68.36	-31.7	-25.08	31.4	88.52	115	85
788	1450	40	17.61	63	58	75	18.5	65.3	-36.1	-32.98	24.7	76.46	121	90
843	1550	5	17.53	70	65	50	.7	33.26	-39.2	-38.56	-1.1	30.02	136	100
843	1550	10	17.86	71	66	50	1.7	35.06	-38.4	-37.12	-0.3	31.46	136	100
843	1550	20	18.20	94	89	50	17.9	64.22	-31.2	-24.16	2.6	36.68	184	136
843	1550	40	18.54	91	86	50	3.5	38.3	-44.4	-47.92	-10	14	176	130
899	1650	5	18.40	111	106	100	71.3	160.34	-36.6	-33.88	28.2	82.76	217	160
899	1650	10	18.75	129	124	125	100.	212	-45.7	-50.26	32.6	90.68	253	187
899	1650	20	19.11	130	125	125	100.	212	-46.1	-50.98	32	89.6	255	188
899	1650	40	19.46	118	113	100	50.	122	-61.6	-78.7	2.3	38.14	232	171

a AW - As-welded

Figure 14. CVN energy versus test temperature for weld 1, a low-carbon SMA weld in the as-welded condition. The solid curve is the resulting fit of the data to a hyperbolic tangent function.

Figure 15. CVN energy versus test temperature for weld 2, a high-carbon SMA weld in the as-welded condition. The solid curve is the resulting fit of the data to a hyperbolic tangent function.

Figure 16. CVN energy versus test temperature for weld 3, a high-carbon FCA weld in the as-welded condition. The solid curve is the resulting fit of the data to a hyperbolic tangent function.

Figure 17. CVN energy versus test temperature for weld 4, a low-carbon FCA weld in the as-welded condition. The solid curve is the resulting fit of the data to a hyperbolic tangent function.

Figure 18. Comparison of hyperbolic tangent curve fits to CVN energy versus test temperature data for welds 1 through 4 in the as-welded condition.

Figure 19. Effects of PWHT on CVN impact behavior showing (a) T_0 , (b) TT_{27J} , (c) TT_{68J} , and (d) USE versus the TP, $T^*(15 + \log t)$, for weld 1, a low-carbon SMA weld. The equation shown in (d) is the result of a linear regression to the USE data at PWHT temperatures of 677°C (1250°F) and lower, while the solid line shows the resulting fit.

Figure 19. Continued.

Figure 20. Effects of PWHT on CVN impact behavior showing (a) T_0 , (b) TT_{27J} , (c) TT_{68J} , and (d) USE versus the TP, $T^*(15 + \log t)$, for weld 2, a high-carbon SMA weld. The equation shown in (d) is the result of a linear regression to the USE data at PWHT temperatures of 677°C (1250°F) and lower, while the solid line shows the resulting fit.

Figure 20. Continued.

Figure 21. Effects of PWHT on CVN impact behavior showing (a) T_0 , (b) TT_{27J} , and (c) USE versus the TP, $T^*(15 + \log t)$, for weld 3, a high-carbon FCA weld. The equation shown in (c) is the result of a linear regression to the USE data at PWHT temperatures of 677°C (1250°F) and lower, while the solid line shows the resulting fit.

Figure 21. Continued.

Figure 22. Effects of PWHT on CVN impact behavior showing (a) T_0 , (b) TT_{27J} , (c) TT_{68J} , and (d) USE versus the TP, $T^*(15 + \log t)$, for weld 4, a low-carbon FCA weld. The equation shown in (d) is the result of a linear regression to the USE data at PWHT temperatures of 677°C (1250°F) and lower, while the solid line shows the resulting fit.

Figure 22. Continued.

Figure 23. Comparison of linear regression curves to USE results versus the TP, $T^*(15 + \log t)$, for welds 1 through 4.

92-1396-1

92-1400-1

(b)

Figure 24. Micrographs of (a) through (d), welds 1 through 4, respectively, in the as-welded condition.

92-1403-1

(c)

400 μm

50X

92-1406-1

(d)

400 μm

50X

Figure 24. Continued.

the as-welded condition. They consist primarily of acicular ferrite and/or bainite, and the low-carbon welds (1 and 4) exhibit some proeutectoid ferrite at the prior austenite grain boundaries. Only weld 2 revealed existence of some blocky ferrite. Heat treatments of 1350°F and higher [Figures 25(a) through (c)] result in essentially complete transformation, and longer times at 1350°F do not coarsen the transformed structure [Figure 25(b) versus (c)]. Longer times at the highest temperature investigated (1650°F) cause substantial grain growth [Figures 26(a) through (e)], as noted by comparing Figure 26(a) with (b). The fully annealed structures consist of equiaxed ferrite, and varying amounts of pearlite, depending on carbon content. More detailed examination of the microstructures regarding inclusion content, carbide evolution, etc., was outside the scope of the current program.

Summary and Conclusions

Two SMA and two FCA welds (low- and high-carbon versions of each) were fabricated in 101.6-mm-thick (4-in.) A 36 hot-rolled steel plate. All four welds were given simulated PWHTs at temperatures from 621 to 899°C (1150 to 1650°F) in increments of 56°C (100°F) and for times of 5, 10, 20, and 40 h at each temperature. Hardness, CVN, and tensile tests were conducted on the welds in the as-welded condition and all the heat-treated conditions. The CVN tests were conducted to obtain results over the brittle-ductile transition range and fitted with hyperbolic tangent curves. The hardness, yield and ultimate strength, CVN transition temperatures, and USE were plotted versus a TP for comparison. For the hardness and tensile strength data, the results for PWHTs at 621 and 677°C (1150 and 1250°F) were fitted with linear regressions. Similar fitting of the CVN transition temperature results revealed very low correlation coefficients, and those fits were not presented, but the CVN USE results were amenable to such regression analyses.

Hardness measurements for the four welds ranged from about 62 to 104 HRB. In all cases, the as-welded condition had the highest hardness for each weld. As expected, there were general trends of decreasing hardness

with increasing values of the TP, but the results were more scattered at the higher temperatures, especially for the high-carbon welds. At the PWHT temperatures of 732°C (1350°F) and higher, the results showed generally consistent trends of decreasing hardness with increasing TP for each individual PWHT temperature, but the overall behavior showed too much scatter for inclusion in the trend line fitting.

As-welded strengths for the four welds ranged from 480 to 812 MPa (70 to 118 ksi) for yield strength, and from 550 to 891 MPa (80 to 129 ksi) for ultimate strength. After the PWHTs, the lowest yield and ultimate strengths measured were 226 and 406 MPa (33 and 59 ksi), respectively. The yield strength results showed somewhat less scatter overall than did the hardness data, but the data at 732°C (1350°F) and above still showed too much scatter, especially for the high-carbon welds, for inclusion in the fitting of the trend lines. In no case, as with the hardness results, did the heat-treated yield strength exceed that of the as-welded condition. Except for weld 1, the ultimate strength results showed even more such scatter than did the hardness and yield strength results, with the high-carbon welds again showing significant differences at the higher temperatures. This was especially true for weld 3, the high-carbon FCA weld, the only weld that exhibited higher ultimate strengths in some heat-treated conditions than in the as-welded condition. The average as-welded ultimate strength for weld 3 was 891 MPa (129 ksi), while it reached 1125 MPa (163 ksi) after the PWHT at 732°C (1350°F) for 5 h. In fact, the ultimate strength results from all the 732°C PWHTs of weld 3 were higher than those in the as-welded condition.

Regarding the CVN results, the 27-J (20 ft-lb) temperatures (TT_{27}) range from -81 to -34°C (-114 to -28°F), while the T_0 temperatures (midpoint of the transition region) range from about -62 to -7°C (-79 to 19°F). For the heat-treated welds, the highest T_0 temperature was 100°C (212°F) for the low-carbon FCA weld 4. The USE in the as-welded condition ranged from 36 to 206 J (26 to 152 ft-lb). The very low USE was for weld 3, the high-carbon FCA weld. The lowest USE for heat-treated welds was 27 J

Figure 25. Micrographs of (a) welds 1 and (b) 3, heat-treated at 1350°F for 5 h. Transformation is essentially complete, and longer times do not seem to coarsen the transformed structure, as shown in (c) for weld 3 heat treated for 40 h.

Figure 25. Continued.

Figure 26. Micrographs of welds 1 through 4, heat treated at 1650°F. Additional time at temperature for weld 1 at (a) 5 h and (b) 40 h, results in coarsening of the structure. Welds 2, 3, and 4 at 1650°F for 40 h are shown in (c), (d), and (e), respectively.

(c)

400 μm

50X

(d)

400 μm

50X

Figure 26. Continued.

(e)

Figure 26. Continued.

(20 ft-lb) and was also shown by weld 3 after PWHT at 732°C (1350°F) for 5 h. In most cases, the heat-treated T_0 and TT_{27} temperatures were higher than those in the as-welded condition. The results for TT_{68} in that regard were mixed. None of the transition temperature results were fitted for trends, however, because the scatter was too great. The USE results were relatively well behaved, however, and linear regressions at the two lowest PWHT temperatures showed consistent trends of increasing USE with increasing TP. The scatter in USE results for the higher PWHT temperatures, however, was also large, and consistent trends were not observed.

In general, the SMA welds had better overall toughness than the FCA welds. In particular, the high-carbon FCA weld (weld 4) had very poor toughness in the as-welded condition and achieved relatively good toughness only after certain PWHT conditions.

The principal conclusions from this study are:

1. For the hardness and tensile strength data, the results for heat treatments at 621 and 677°C (1150 and 1250°F) were amenable to linear regression analysis using a time-temperature parameter, but for Charpy impact tests only the USE results were amenable to such analyses.
2. Heat treatments from 732 to 899°C (1350 to 1650°F) resulted in substantial changes in mechanical properties of these SMA and FCA welds, with the changes not amenable to prediction and highly dependent on the weld metal. Heat treatments in that temperature range should not be applied to these materials without prior qualification for the intended use.
3. For all four SMA and FCA welds, the heat-treated hardnesses and yield strengths were lower than in the as-welded condition.
4. Heat treatment at 899°C (1650°F) resulted in yield strength reductions up to about 50% from those in the as-welded condition.
5. Scatter in hardness and tensile strengths versus the tempering parameter was relatively high for all results at heat-treatment temperatures of 732°C (1350°F) and above, but was greatest for the ultimate strength data.
6. In most cases, the Charpy impact 27-J (20 ft-lb) temperatures were raised by heat treatment but, except for the high-carbon FCA weld (weld 3), remained below 10°C (50°F).
7. In general, the SMA welds had better overall toughness than did the FCA welds. The high-carbon FCA weld exhibited substantial degradation in strength and toughness as a consequence of many of the heat treatments, and also showed a very low Charpy upper-shelf toughness.

References

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2. J. H. Hollomon and L. D. Jaffee, "Time-Temperature Relations in Tempering Steels," *Trans. Am. Inst. Min. Metall. Eng.* **162**, 223-49 (1945).
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Appendix A
Hardness Data for Welds 1 Through 4

Table A1. Hardness data for weld 1, low-carbon SMA

SPEC	ANN TEMP ^a		ANN TIME ^a	T.P.	HARDNESS
ID	(°C)	(°F)	(HR)	(x10 ⁻³)	(HRB)
100	AW	AW	AW	0	90.9
111	621	1150	5	14.04	85.7
112	621	1150	10	14.31	87.7
113	621	1150	20	14.58	85.1
114	621	1150	40	14.85	81.7
121	677	1250	5	14.91	82.8
122	677	1250	10	15.20	82.9
123	677	1250	20	15.48	79.8
124	677	1250	40	15.77	75.6
131	732	1350	5	15.78	73.8
132	732	1350	10	16.09	71.0
133	732	1350	20	16.39	69.2
134	732	1350	40	16.69	68.0
141	788	1450	5	16.66	73.3
142	788	1450	10	16.97	65.9
143	788	1450	20	17.29	61.4
144	788	1450	40	17.61	57.5
151	843	1550	5	17.53	62.9
152	843	1550	10	17.86	54.9
153	843	1550	20	18.20	58.0
154	843	1550	40	18.54	53.8
161	899	1650	5	18.40	66.5
162	899	1650	10	18.75	64.8
163	899	1650	20	19.11	67.5
164	899	1650	40	19.46	61.9

a AW - As-welded

Table A2. Hardness data for weld 2, high-carbon SMA

SPEC	ANN TEMP ^a		ANN TIME ^a	T.P.	HARDNESS
	(°C)	(°F)	(HR)	(x10 ⁻³)	(HRB)
200	AW	AW	AW	0	100.1
211	621	1150	5	14.04	98.2
212	621	1150	10	14.31	95.3
213	621	1150	20	14.58	94.5
214	621	1150	40	14.85	94.8
221	677	1250	5	14.91	90.7
222	677	1250	10	15.20	91.2
223	677	1250	20	15.48	87.9
224	677	1250	40	15.77	90.4
231	732	1350	5	15.78	92.4
232	732	1350	10	16.09	84.2
233	732	1350	20	16.39	84.1
234	732	1350	40	16.69	78.7
241	788	1450	5	16.66	93.6
242	788	1450	10	16.97	86.5
243	788	1450	20	17.29	81.5
244	788	1450	40	17.61	77.8
251	843	1550	5	17.53	89.5
252	843	1550	10	17.86	82.2
253	843	1550	20	18.20	83.0
254	843	1550	40	18.54	77.9
261	899	1650	5	18.40	88.2
262	899	1650	10	18.75	81.6
263	899	1650	20	19.11	80.8
264	899	1650	40	19.46	81.7

a AW - As-welded

Table A3. Hardness data for weld 3, high-carbon FCA

SPEC	ANN TEMP ^a		ANN TIME ^a	T.P.	HARDNESS
ID	(°C)	(°F)	(HR)	(x10 ⁻³)	(HRB)
300	AW	AW	AW	0	104.0
311	621	1150	5	14.04	101.6
312	621	1150	10	14.31	99.7
313	621	1150	20	14.58	102.7
314	621	1150	40	14.85	101.6
321	677	1250	5	14.91	99.1
322	677	1250	10	15.20	98.4
323	677	1250	20	15.48	90.5
324	677	1250	40	15.77	80.1
331	732	1350	5	15.78	99.7
332	732	1350	10	16.09	92.6
333	732	1350	20	16.39	90.4
334	732	1350	40	16.69	83.3
341	788	1450	5	16.66	96.8
342	788	1450	10	16.97	93.9
343	788	1450	20	17.29	90.5
344	788	1450	40	17.61	85.2
351	843	1550	5	17.53	94.7
352	843	1550	10	17.86	89.9
353	843	1550	20	18.20	86.3
354	843	1550	40	18.54	84.4
361	899	1650	5	18.40	90.7
362	899	1650	10	18.75	86.2
363	899	1650	20	19.11	84.3
364	899	1650	40	19.46	82.4

a AW - As-welded

Table A4. Hardness data for weld 4, low-carbon FCA

SPEC	ANN TEMP ^a		ANN TIME ^a	T.P.	HARDNESS
ID	(°C)	(°F)	(HR)	(x10 ⁻³)	(HRB)
400	AW	AW	AW	0	97.8
411	621	1150	5	14.04	96.0
412	621	1150	10	14.31	93.5
413	621	1150	20	14.58	92.8
414	621	1150	40	14.85	93.3
421	677	1250	5	14.91	91.1
422	677	1250	10	15.20	85.1
423	677	1250	20	15.48	80.2
424	677	1250	40	15.77	78.9
431	732	1350	5	15.78	83.4
432	732	1350	10	16.09	82.3
433	732	1350	20	16.39	80.1
434	732	1350	40	16.69	79.7
441	788	1450	5	16.66	81.5
442	788	1450	10	16.97	77.7
443	788	1450	20	17.29	76.5
444	788	1450	40	17.61	70.4
451	843	1550	5	17.53	77.7
452	843	1550	10	17.86	76.1
453	843	1550	20	18.20	77.3
454	843	1550	40	18.54	70.8
461	899	1650	5	18.40	77.3
462	899	1650	10	18.75	79.0
463	899	1650	20	19.11	77.2
464	899	1650	40	19.46	74.7

a AW - As-welded

Appendix B
Tensile Data for Welds 1 Through 4

Table B1. Tensile data for weld 1, low-carbon SMA

SPEC	ANN TEMP ^a		ANN TIME ^a	T.P.	YIELD STRENGTH		ULTIMATE STRENGTH		UNIFORM EL	TOTAL EL
ID	(°C)	(°F)	(HR)	(x10 ⁻³)	(ksi)	(MPa)	(ksi)	(MPa)	(%)	(%)
100A1	AW	AW	AW	0	67.7	467	79.2	546	7.7	16.5
100B1	AW	AW	AW	0	71.7	494	80.2	553	3.3	8.1
111A1	621	1150	5	14.04	65.3	450	76.4	526	8.6	16.7
111B1	621	1150	5	14.04	68.3	471	80.0	551	10.0	17.9
112A1	621	1150	10	14.31	63.3	436	75.8	523	8.6	17.5
112B1	621	1150	10	14.31	65.1	449	76.8	530	7.2	15.2
113A1	621	1150	20	14.58	61.7	425	73.9	509	8.9	18.2
113B1	621	1150	20	14.58	64.0	441	75.7	522	9.5	19.2
114A1	621	1150	40	14.85	61.3	422	72.9	502	7.9	19.0
114B1	621	1150	40	14.85	61.7	425	75.1	518	10.4	20.8
121A1	677	1250	5	14.91	60.9	420	73.5	507	9.0	18.4
121B1	677	1250	5	14.91	59.7	412	66.6	459	3.4	8.4
122A1	677	1250	10	15.20	58.7	405	71.5	493	9.8	18.5
122B1	677	1250	10	15.20	60.4	417	72.5	500	10.1	21.6
123A1	677	1250	20	15.48	56.4	389	69.8	481	10.6	19.7
123B1	677	1250	20	15.48	56.4	389	68.2	470	6.8	13.1
124A1	677	1250	40	15.77	53.1	366	67.8	467	9.5	19.9
124B1	677	1250	40	15.77	50.3	347	58.5	403	3.9	6.7
131A1	732	1350	5	15.78	49.2	339	69.0	476	13.2	22.7
132A1	732	1350	10	16.09	48.9	337	69.0	476	12.2	21.0
132B1	732	1350	10	16.09	47.8	329	67.9	468	13.2	22.8
133A1	732	1350	20	16.39	46.2	318	69.6	480	13.9	23.6
134A1	732	1350	40	16.69	43.9	302	67.0	462	14.9	24.5
134B1	732	1350	40	16.69	39.1	270	62.1	428	13.2	23.0
141A1	788	1450	5	16.66	47.1	325	69.3	478	13.5	22.6
141B1	788	1450	5	16.66	48.5	335	63.9	441	15.3	25.8
142A1	788	1450	10	16.97	40.7	281	69.0	476	15.5	24.8

Table B1. Continued

142B1	788	1450	10	16.97	43.9	303	68.2	470	17.1	29.3
143A1	788	1450	20	17.29	41.7	287	67.6	466	14.5	25.0
143B1	788	1450	20	17.29	45.1	311	65.3	450	13.2	22.6
144A1	788	1450	40	17.61	41.0	282	64.8	446	16.1	27.4
144B1	788	1450	40	17.61	43.2	298	64.6	446	16.5	26.9
151A1	843	1550	5	17.53	42.4	293	64.1	442	17.6	28.5
152A1	843	1550	10	17.86	39.0	269	63.8	440	19.0	29.7
153B1	843	1550	20	18.20	41.5	286	63.1	435	15.2	25.9
154A1	843	1550	40	18.54	39.6	273	63.4	437	19.3	30.9
154B1	843	1550	40	18.54	41.8	288	63.1	435	17.0	27.1
161A1	899	1650	5	18.40	38.2	264	61.4	424	19.7	33.1
161B1	899	1650	5	18.40	38.2	264	61.0	421	15.8	26.0
162A1	899	1650	10	18.75	35.6	246	59.7	412	17.7	28.3
163A1	899	1650	20	19.11	32.8	226	58.9	406	17.2	28.3
163B1	899	1650	20	19.11	38.5	266	59.6	411	16.0	26.0
164A1	899	1650	40	19.46	35.4	244	58.9	406	17.3	29.0
164B1	899	1650	40	19.46	35.5	245	59.0	407	18.9	27.4

a AW - As-welded

Table B2. Tensile data for weld 2, high-carbon SMA

SPEC	ANN TEMP ^a		ANN TIME ^a	T.P.	YIELD STRENGTH		ULTIMATE STRENGTH		UNIFORM EL	TOTAL EL
ID	(°C)	(°F)	(HR)	(x10 ⁻³)	(ksi)	(MPa)	(ksi)	(MPa)	(%)	(%)
200A1	AW	AW	AW	0	91.2	629	113.9	785	7.8	14.7
200B1	AW	AW	AW	0	103.8	716	122.7	846	6.7	11.2
211A1	621	1150	5	14.04	77.7	536	100.2	691	7.9	15.5
211B1	621	1150	5	14.04	87.6	604	107.9	744	8.3	13.1
212A1	621	1150	10	14.31	80.4	554	100.4	692	6.8	9.0
212B1	621	1150	10	14.31	86.0	593	106.0	731	9.9	18.6
213A1	621	1150	20	14.58	79.2	546	100.7	694	8.2	13.5
213B1	621	1150	20	14.58	82.8	571	98.3	678	4.9	8.2
214A1	621	1150	40	14.85	77.0	531	96.7	667	9.7	15.0
214B1	621	1150	40	14.85	81.6	563	102.7	708	9.6	16.3
221A1	677	1250	5	14.91	73.7	508	96.0	662	9.5	16.8
221B1	677	1250	5	14.91	78.4	540	98.5	679	9.3	16.5
222A1	677	1250	10	15.20	69.7	481	84.0	579	4.2	7.6
222B1	677	1250	10	15.20	78.4	540	98.5	679	9.3	16.5
223A1	677	1250	20	15.48	73.3	506	91.8	633	10.2	18.0
223B1	677	1250	20	15.48	73.9	510	92.7	639	8.7	15.1
224A1	677	1250	40	15.77	66.9	461	83.7	577	6.4	10.2
224B1	677	1250	40	15.77	69.7	481	89.4	616	9.6	14.3
231A1	732	1350	5	15.78	76.1	525	101.4	699	12.2	19.4
231B1	732	1350	5	15.78	81.6	563	105.3	726	12.6	19.7
232A1	732	1350	10	16.09	73.7	508	99.6	687	12.7	19.3
232B1	732	1350	10	16.09	72.5	500	88.5	610	4.1	5.9
233A1	732	1350	20	16.39	71.1	490	96.5	666	8.2	12.3
233B1	732	1350	20	16.39	79.9	551	101.0	696	7.1	8.3
234A1	732	1350	40	16.69	75.2	518	103.7	715	10.1	17.0
234B1	732	1350	40	16.69	82.7	570	105.6	728	11.2	19.5
241A1	788	1450	5	16.66	71.9	496	99.3	684	11.5	15.4

Table B2. Continued

241B1	788	1450	5	16.66	72.0	496	95.1	656	6.6	9.0
242A1	788	1450	10	16.97	73.5	507	100.8	695	14.2	21.9
242B1	788	1450	10	16.97	72.0	497	100.3	692	12.9	17.9
243A1	788	1450	20	17.29	64.0	441	87.4	603	6.3	8.4
244A1	788	1450	40	17.61	67.6	466	97.2	670	13.3	20.5
251A1	843	1550	5	17.53	59.2	408	93.2	643	13.9	17.0
251B1	843	1550	5	17.53	57.5	397	93.5	644	13.1	20.8
252A1	843	1550	10	17.86	60.6	418	91.4	630	12.1	16.1
252B1	843	1550	10	17.86	63.3	437	92.1	635	12.9	15.2
253A1	843	1550	20	18.20	57.1	394	92.4	637	12.6	18.9
253B1	843	1550	20	18.20	57.3	395	92.8	640	13.8	21.1
254A1	843	1550	40	18.54	54.7	377	89.2	615	12.3	18.6
254B1	843	1550	20	18.20	56.9	392	92.2	636	12.8	17.8
261A1	899	1650	5	18.40	57.1	393	90.9	627	12.1	15.5
261B1	899	1650	5	18.40	55.4	382	90.7	626	13.1	20.4
262A1	899	1650	10	18.75	57.9	399	89.1	615	12.1	15.1
262B1	899	1650	10	18.75	60.7	419	90.3	622	13.4	20.9
263A1	899	1650	20	19.11	52.3	360	90.5	624	12.8	20.8
263B1	899	1650	20	19.11	52.7	363	90.5	624	12.0	18.0
264A1	899	1650	40	19.46	51.6	356	89.5	617	13.0	18.9
264B1	899	1650	40	19.46	50.6	349	88.8	612	10.9	13.6

a AW - As-welded

Table B3. Tensile data for weld 3, high-carbon FCA

SPEC	ANN TEMP ^a		ANN TIME ^a	T.P.	YIELD STRENGTH		ULTIMATE STRENGTH		UNF ELONG	TOT ELONG
ID	(°C)	(°F)	(HR)	(x10 ⁻³)	(ksi)	(MPa)	(ksi)	(MPa)	(%)	(%)
300A1	AW	AW	AW	0	126.0	869	137.3	947	4.2	10.6
300B5	AW	AW	AW	0	109.5	755	121.2	836	4.2	11.1
311A1	621	1150	5	14.04	108.6	749	122.0	841	6.2	12.2
312C1	621	1150	10	14.31	110.5	762	122.0	841	8.2	13.5
312B6	621	1150	10	14.31	116.1	801	125.7	867	5.8	11.5
313A1	621	1150	20	14.58	106.7	736	117.8	812	6.1	13.0
314A1	621	1150	40	14.85	101.2	698	113.8	785	6.6	13.3
314B6	621	1150	40	14.85	106.3	733	116.1	801	7.2	15.0
321A1	677	1250	5	14.91	103.3	712	114.1	787	6.2	12.4
321B6	677	1250	5	14.91	104.7	722	114.3	788	6.8	14.3
322A1	677	1250	10	15.20	95.2	656	106.9	737	6.4	14.2
322B6	677	1250	10	15.20	100.0	690	111.7	770	4.9	14.7
323A1	677	1250	20	15.48	89.0	614	101.9	703	7.3	14.8
324A1	677	1250	40	15.77	69.6	480	91.4	630	7.3	13.0
324B6	677	1250	40	15.77	91.0	627	102.5	707	10.1	17.7
331A1	732	1350	5	15.78	103.9	716	164.0	1131	4.4	6.2
331B6	732	1350	5	15.78	104.5	721	162.4	1120	7.0	10.9
332A1	732	1350	10	16.09	87.0	600	147.3	1016	6.9	11.9
333A1	732	1350	20	16.39	103.6	714	148.9	1027	5.6	9.7
334A1	732	1350	40	16.69	100.2	691	157.0	1083	6.1	11.0
334B6	732	1350	40	16.69	101.3	698	149.9	1034	7.0	12.1
341A1	788	1450	5	16.66	76.9	530	129.6	894	11.4	17.2
342A1	788	1450	10	16.97	75.2	519	130.8	902	10.5	16.0
342B5	788	1450	10	16.97	69.0	476	122.0	841	10.4	15.9
343A1	788	1450	20	17.29	78.0	538	129.1	890	11.4	17.4
343B6	788	1450	20	17.29	73.1	504	122.9	847	12.7	17.6
344A1	788	1450	40	17.61	75.9	523	124.6	859	9.8	14.5

Table B3. Continued

344B6	788	1450	40	17.61	74.1	511	123.8	854	13.4	18.8
351A1	843	1550	5	17.53	73.5	507	124.8	860	9.5	12.1
351B6	843	1550	5	17.53	73.5	507	106.9	737	4.2	6.4
352A1	843	1550	10	17.86	68.8	474	118.8	819	8.1	12.3
352B5	843	1550	10	17.86	67.0	462	113.1	780	9.1	14.3
353A1	843	1550	20	18.20	64.0	441	101.2	698	5.1	10.1
354A1	843	1550	40	18.54	64.8	447	104.9	723	6.9	11.3
361A1	899	1650	5	18.40	74.3	512	118.8	819	7.0	11.9
361B5	899	1650	5	18.40	60.5	417	104.9	723	10.9	16.8
362A1	899	1650	10	18.75	72.1	497	119.6	825	8.4	12.5
362C1	899	1650	10	18.75	77.1	532	121.2	836	9.6	14.5
363A1	899	1650	20	19.11	69.7	481	103.1	711	5.6	11.2
363B6	899	1650	20	19.11	66.3	457	105.1	725	6.4	11.2
364A1	899	1650	40	19.46	70.0	483	112.7	777	6.4	10.3
364B5	899	1650	40	19.46	63.5	438	103.1	711	9.0	14.8

a AW - As-welded

Table B4. Tensile data for weld 4, low-carbon FCA

SPEC ID	ANN TEMP ^a		ANN TIME ^a (HR)	T.P. (x10 ⁻³)	YIELD STRENGTH		ULTIMATE STRENGTH		UNF ELONG (%)	TOT ELONG (%)
	(°C)	(°F)			(ksi)	(MPa)	(ksi)	(MPa)		
400A1	AW	AW	AW	0	85.1	587	97.4	672	6.4	12.1
400B1	AW	AW	AW	0	86.0	593	96.2	663	5.7	9.4
411A1	621	1150	5	14.04	79.7	550	95.0	655	7.8	15.6
411B1	621	1150	5	14.04	77.0	531	92.0	634	9.0	15.7
412A1	621	1150	10	14.31	78.4	541	91.8	633	8.7	16.5
412B1	621	1150	10	14.31	71.7	494	84.9	585	6.6	13.7
413A1	621	1150	20	14.58	75.0	517	89.6	618	8.4	15.3
413B1	621	1150	20	14.58	68.8	474	85.1	587	9.5	17.0
414A1	621	1150	40	14.85	73.9	510	89.0	614	8.4	16.8
414B1	621	1150	40	14.85	70.7	487	84.4	582	10.9	18.6
421A1	677	1250	5	14.91	76.6	528	90.0	621	10.8	19.0
421B1	677	1250	5	14.91	71.7	494	85.9	592	9.0	17.6
422A1	677	1250	10	15.20	71.1	490	87.4	603	11.3	20.1
422B1	677	1250	10	15.20	63.0	434	79.1	545	10.3	17.5
423A1	677	1250	20	15.48	55.3	381	76.4	527	10.8	18.8
423B1	677	1250	20	15.48	54.7	377	74.6	514	10.4	18.4
424A1	677	1250	40	15.77	49.8	343	71.4	492	9.6	17.1
424B1	677	1250	40	15.77	49.2	339	71.5	493	12.1	21.1
431A1	732	1350	5	15.78	62.6	432	92.0	634	8.0	14.9
431B1	732	1350	5	15.78	58.3	402	88.6	611	10.0	17.3
432A1	732	1350	10	16.09	56.9	392	92.8	640	12.7	19.8
432B1	732	1350	10	16.09	51.8	357	87.2	601	11.4	17.9
433A1	732	1350	20	16.39	56.9	392	91.0	627	11.3	17.8
433B1	732	1350	20	16.39	51.9	358	82.7	570	13.0	22.1
434A1	732	1350	40	16.69	55.6	383	90.8	626	12.2	17.9
434B1	732	1350	40	16.69	50.4	348	81.7	563	10.6	18.4
441A1	788	1450	5	16.66	62.3	430	91.0	627	10.4	17.1

Table B4. Continued

441B1	788	1450	5	16.66	56.2	387	79.5	548	10.8	18.4
442A1	788	1450	10	16.97	55.4	382	91.2	629	12.8	21.5
442B1	788	1450	10	16.97	50.7	350	83.1	573	11.3	18.5
443A1	788	1450	20	17.29	56.8	392	89.2	615	14.4	23.1
443B1	788	1450	20	17.29	53.9	372	82.0	565	12.4	20.4
444A1	788	1450	40	17.61	55.0	379	89.4	616	15.4	22.1
444B1	788	1450	40	17.61	49.2	339	79.7	550	11.5	17.9
451A1	843	1550	5	17.53	53.8	371	76.9	530	14.7	22.4
451B1	843	1550	5	17.53	49.4	341	73.1	504	17.2	25.8
452A1	843	1550	10	17.86	49.0	338	74.3	512	14.7	22.7
452B1	843	1550	10	17.86	46.9	323	71.4	492	16.9	26.2
453A1	843	1550	20	18.20	52.7	363	74.6	514	15.9	25.1
453B1	843	1550	20	18.20	43.0	296	68.5	472	16.9	25.9
454A1	843	1550	40	18.54	49.0	338	72.7	501	14.1	23.1
454B1	843	1550	40	18.54	43.8	302	67.7	467	15.9	25.0
461A1	899	1650	5	18.40	44.4	306	70.8	488	16.3	26.9
461B1	899	1650	5	18.40	41.9	289	65.4	451	16.1	24.8
462A1	899	1650	10	18.75	51.4	354	72.3	499	15.7	25.5
462B1	899	1650	10	18.75	45.5	314	67.6	466	18.3	25.5
463A1	899	1650	20	19.11	44.3	305	68.4	472	17.0	27.3
463B1	899	1650	20	19.11	41.4	285	64.2	443	14.8	23.5
464A1	899	1650	40	19.46	42.3	292	68.3	471	16.5	25.7
464B1	899	1650	40	19.46	40.4	279	65.0	448	17.5	27.2

a AW - As-welded

Appendix C

Charpy Impact Data for Welds 1 Through 4

Note:

Set names identify the weld and heat treatment given.

Examples:

1_AW: Weld 1, as-welded
2_20_1650: Weld 2, 20 h at 1650°F

Table C1. Charpy impact data for weld 1, low-carbon SMA

SOURCE: ANALYSIS SET

ANALYSIS SETS

1_AW 1_5_1150 1_10_1150

SET NAME: 1_AW

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	100B6	-100	-148	4.2	3.1	0.076	0.003	0
2	100A6	-75	-103	6.4	4.7	0.076	0.003	1
3	100B5	-50	-58	105.6	77.9	1.549	0.061	33
4	100A5	-25	-13	74.4	54.9	1.118	0.044	27
5	100B4	0	32	141.3	104.2	1.803	0.071	66
6	100A2	22	72	180.6	133.2	2.032	0.08	81
7	100B2	22	72	164.3	121.2	2.108	0.083	78
8	100B3	65	149	199.6	147.2	2.057	0.081	100
9	100A3	100	212	192.8	142.2	2.21	0.087	100
10	100A4	150	302	212.3	156.6	2.159	0.085	100

SET NAME: 1_5_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	111B6	-100	-148	3	2.2	0.102	0.004	0
2	111A6	-75	-103	5.8	4.3	0.152	0.006	5
3	111B5	-50	-58	8.8	6.5	0.229	0.009	10
4	111A5	-25	-13	36.9	27.2	0.762	0.03	21
5	111B4	0	32	182.4	134.5	2.184	0.086	72
6	111A2	22	72	177.9	131.2	2.159	0.085	78
7	111B3	22	72	242.7	179	2.159	0.085	99
8	111B2	65	149	357.7	263.8	2.083	0.082	100
9	111A3	100	212	218	160.8	2.261	0.089	100
10	111A4	150	302	329.3	242.9	2.21	0.087	100

SET NAME: 1_10_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	112B6	-100	-148	3.5	2.6	0.178	0.007	0
2	112A6	-75	-103	3.7	2.7	0.102	0.004	0
3	112B5	-50	-58	14.6	10.8	0.356	0.014	10
4	112A5	-25	-13	150	110.6	2.032	0.08	58
5	112B4	0	32	251.4	185.4	2.438	0.096	100
6	112A2	22	72	244.7	180.5	2.21	0.087	99
7	112B2	22	72	238.4	175.8	2.108	0.083	99
8	112B3	65	149	262.4	193.5	2.235	0.088	100
9	112A3	100	212	363.5	268.1	2.057	0.081	100
10	112A4	150	302	337.7	249.1	2.032	0.08	100

Table C1. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

1_20_1150 1_40_1150 1_5_1250

SET NAME: 1_20_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)		(FT-LB)	(MM)	
1	113B6	-100	-148	3	2.2	0.127	0.005
2	113A6	-75	-103	3.1	2.3	0.076	0.003
3	113B5	-50	-58	34.7	25.6	0.711	0.028
4	113A5	-25	-13	115.9	85.5	1.727	0.068
5	113B4	0	32	173.8	128.2	2.083	0.082
6	113A2	22	72	250.8	185	2.108	0.083
7	113B2	22	72	320.9	236.7	1.651	0.065
8	113B3	65	149	281.1	207.3	1.956	0.077
9	113A3	100	212	388.3	286.4	2.362	0.093
10	113A4	150	302	325	239.7	2.388	0.094

SET NAME: 1_40_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)		(FT-LB)	(MM)	
1	114B6	-100	-148	2.7	2	0.127	0.005
2	114A6	-75	-103	3.7	2.7	0.178	0.007
3	114B5	-50	-58	54	39.8	0.914	0.036
4	114A5	-25	-13	17.8	13.1	0.432	0.017
5	114B3	-25	-13	161.6	119.2	2.235	0.088
6	144A4	0	32	140.6	103.7	2.007	0.079
7	114B4	0	32	170.3	125.6	1.93	0.076
8	114A2	22	72	342.9	252.9	1.727	0.068
9	114B2	22	72	379.1	279.6	2.261	0.089
10	114A3	100	212	360.1	265.6	2.286	0.09

SET NAME: 1_5_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)		(FT-LB)	(MM)	
1	121B6	-100	-148	3.1	2.3	0.102	0.004
2	121A6	-75	-103	3.8	2.8	0.025	0.001
3	121B5	-50	-58	16	11.8	0.406	0.016
4	121A3	-25	-13	154.3	113.8	1.956	0.077
5	121A4	-25	-13	144.9	106.9	1.803	0.071
6	121A5	-25	-13	46.5	34.3	0.889	0.035
7	121B3	-15	5	185.1	136.5	2.286	0.09
8	121B4	0	32	385.7	284.5	2.083	0.082
9	121A2	22	72	380.8	280.9	2.235	0.088
10	121B2	22	72	273.1	201.4	1.702	0.067

Table C1. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

1_10_1250 1_20_1250 1_10_1350

SET NAME: 1_10_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	122B6	-100	-148	2.6	1.9	0.178	0.007	0
2	122A6	-75	-103	4.3	3.2	0.127	0.005	1
3	122b5	-50	-58	23.9	17.6	0.508	0.02	20
4	122A3	-25	-13	191.7	141.4	2.311	0.091	64
5	122A5	-25	-13	157.7	116.3	2.057	0.081	55
6	122A4	-15	5	146.3	107.9	1.854	0.073	57
7	122b3	-15	5	186.2	137.3	2.134	0.084	75
8	122b4	0	32	384.4	283.5	1.803	0.071	100
9	122A2	22	72	377.1	278.1	2.134	0.084	100
10	122b2	22	72	367.6	271.1	2.032	0.08	100

SET NAME: 1_20_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	123B6	-100	-148	2.6	1.9	0.127	0.005	0
2	123A6	-75	-103	4.3	3.2	0.051	0.002	9
3	123A4	-50	-58	92.6	68.3	1.448	0.057	37
4	123B5	-50	-58	136.5	100.7	1.981	0.078	42
5	123A3	-25	-13	133.3	98.3	1.88	0.074	40
6	123A5	-25	-13	182	134.2	2.184	0.086	57
7	123B4	0	32	399.6	294.7	2.159	0.085	100
8	123A2	22	72	387.4	285.7	1.372	0.054	100
9	123B2	22	72	362.7	267.5	1.956	0.077	100
10	123B3	75	167	361.7	266.8	2.464	0.097	100

SET NAME: 1_10_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	132B6	-100	-148	5	3.7	0.127	0.005	0
2	132A6	-75	-103	8.1	6	0.076	0.003	2
3	132B5	-50	-58	32.3	23.8	0.66	0.026	20
4	132A4	-25	-13	75.8	55.9	1.245	0.049	42
5	132A5	-25	-13	85.4	63	1.295	0.051	34
6	132A3	0	32	174.2	128.5	2.057	0.081	69
7	132B4	0	32	179.5	132.4	2.108	0.083	61
8	132A2	22	72	372	274.4	2.464	0.097	100
9	132B2	22	72	377.5	278.4	2.337	0.092	100
10	132B3	75	167	363.2	267.9	2.54	0.1	100

Table C1. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

1_20_1350 1_40_1250 1_5_1350

SET NAME: 1_20_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	133B6	-100	-148	5.7	4.2	0.102	0.004	1
2	133A6	-75	-103	6.1	4.5	0.102	0.004	5
3	133B5	-50	-58	25.6	18.9	0.483	0.019	18
4	133A3	-25	-13	83.4	61.5	1.118	0.044	49
5	133A5	-25	-13	45.7	33.7	0.737	0.029	30
6	133A4	-15	5	156.3	115.3	2.057	0.081	54
7	133B4	0	32	389.1	287	2.54	0.1	100
8	133A2	22	72	377.3	278.3	2.413	0.095	100
9	133B2	22	72	384.5	283.6	2.464	0.097	100
10	133B3	75	167	357.3	263.5	2.692	0.106	100

SET NAME: 1_40_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	124B6	-100	-148	5.3	3.9	0.127	0.005	0
2	124A6	-75	-103	7.7	5.7	0.127	0.005	3
3	124B5	-50	-58	18.6	13.7	0.483	0.019	15
4	124A3	-25	-13	88.7	65.4	1.499	0.059	37
5	124A5	-25	-13	168.4	124.2	2.057	0.081	59
6	124A4	-15	5	392.6	289.6	2.337	0.092	100
7	124B4	0	32	392.9	289.8	2.642	0.104	100
8	124A2	22	72	386.1	284.8	2.388	0.094	100
9	124B2	22	72	387	285.4	2.464	0.097	100
10	124B3	75	167	360.4	265.8	2.438	0.096	100

SET NAME: 1_5_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	131B6	-100	-148	6.8	5	0.203	0.008	0
2	131A6	-75	-103	7.3	5.4	0.102	0.004	3
3	131B5	-50	-58	19.1	14.1	0.432	0.017	13
4	131A4	-25	-13	101.3	74.7	1.448	0.057	42
5	131A5	-25	-13	128.3	94.6	1.829	0.072	33
6	131A3	0	32	207.2	152.8	2.083	0.082	71
7	131B4	0	32	175.7	129.6	2.083	0.082	70
8	131A2	22	72	372.4	274.7	2.362	0.093	100
9	131B2	22	72	388.6	286.6	2.464	0.097	100
10	131B3	75	167	360.9	266.2	2.54	0.1	100

Table C1. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

1_10_1450 1_20_1450 1_40_1350

SET NAME: 1_10_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	142B6	-100	-148	5.6	4.1	0.102	0.004	0
2	142A6	-75	-103	9.9	7.3	0.127	0.005	0
3	142B5	-50	-58	21.7	16	0.508	0.02	21
4	142A5	-25	-13	57.4	42.3	0.838	0.033	40
5	142B3	-25	-13	48.7	35.9	0.991	0.039	34
6	142A4	0	32	150.9	111.3	1.93	0.076	60
7	142B4	0	32	85	62.7	1.372	0.054	46
8	142A2	22	72	199.8	147.4	2.489	0.098	65
9	142B2	22	72	372.6	274.8	2.565	0.101	100
10	142A3	75	167	351.2	259	2.515	0.099	100

SET NAME: 1_20_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	143B6	-100	-148	5.4	4	0.076	0.003	0
2	143A6	-75	-103	7.7	5.7	0.076	0.003	0
3	143B5	-50	-58	22.8	16.8	0.533	0.021	16
4	143A5	-25	-13	106.6	78.6	1.626	0.064	42
5	143A4	0	32	145.3	107.2	1.981	0.078	62
6	143B4	0	32	139.1	102.6	1.88	0.074	57
7	143B3	10	50	122.6	90.4	1.778	0.07	54
8	143A2	22	72	214.9	158.5	2.464	0.097	69
9	143B2	22	72	372.7	274.9	2.616	0.103	100
10	143A3	75	167	366.2	270.1	2.591	0.102	100

SET NAME: 1_40_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	134B6	-100	-148	5.7	4.2	0.127	0.005	0
2	134A6	-75	-103	6.4	4.7	0.025	0.001	3
3	134B5	-50	-58	28.6	21.1	0.508	0.02	17
4	134A3	-25	-13	139.6	103	2.261	0.089	29
5	134A5	-25	-13	146	107.7	1.854	0.073	48
6	134A4	-15	5	98.2	72.4	1.651	0.065	53
7	134B4	0	32	389.4	287.2	2.489	0.098	100
8	134A2	22	72	377.7	278.6	2.845	0.112	100
9	134B2	22	72	366.5	270.3	2.591	0.102	100
10	134B3	75	167	363	267.7	2.388	0.094	100

Table C1. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

1_5_1450 1_40_1450 1_5_1550

SET NAME: 1_5_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	141B6	-100	-148	7.1	5.2	0.178	0.007	0
2	141A6	-75	-103	5.4	4	0.051	0.002	0
3	141B5	-45	-49	29.6	21.8	0.635	0.025	25
4	141A3	-25	-13	77.4	57.1	1.295	0.051	34
5	141A5	-25	-13	136.9	101	1.854	0.073	44
6	141A4	0	32	99.7	73.5	1.626	0.064	50
7	141B4	0	32	155.6	114.8	1.956	0.077	54
8	141A2	22	72	387.2	285.6	2.515	0.099	100
9	141B2	22	72	373.9	275.8	2.464	0.097	100
10	141B3	75	167	370.4	273.2	2.311	0.091	100

SET NAME: 1_40_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	144B6	-100	-148	4.3	3.2	0.076	0.003	0
2	144A6	-75	-103	3.7	2.7	0.076	0.003	0
3	144B5	-50	-58	21.2	15.6	0.533	0.021	16
4	144A3	-25	-13	29	21.4	0.686	0.027	23
5	144A5	-25	-13	66.4	49	1.118	0.044	48
6	144A4	-15	5	61.4	45.3	1.168	0.046	36
7	144B4	0	32	397	292.8	2.718	0.107	100
8	144A2	22	72	374.7	276.4	2.692	0.106	100
9	144B2	22	72	378.5	279.2	2.616	0.103	100
10	144B3	75	167	360.9	266.2	2.413	0.095	100

SET NAME: 1_5_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	151B6	-100	-148	3.5	2.6	0.305	0.012	0
2	151A6	-75	-103	11.5	8.5	0.203	0.008	9
3	151B5	-50	-58	32.9	24.3	0.686	0.027	19
4	151A4	-35	-31	112	82.6	1.676	0.066	36
5	151B3	-35	-31	53.1	39.2	0.914	0.036	33
6	151A3	-25	-13	388.8	286.8	2.413	0.095	100
7	151A5	-25	-13	397.3	293	2.489	0.098	100
8	151B4	0	32	400.4	295.3	2.54	0.1	100
9	151A2	22	72	383.6	282.9	2.413	0.095	100
10	151B2	22	72	370.8	273.5	2.464	0.097	100

Table C1. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

1_10_1550 1_20_1550 1_20_1650

SET NAME: 1_10_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	152B6	-100	-148	2.8	2.1	0.076	0.003	0
2	152A6	-75	-103	6.8	5	0.051	0.002	9
3	152B5	-50	-58	22.1	16.3	0.508	0.02	18
4	152A3	-25	-13	156.6	115.5	2.464	0.097	39
5	152A5	-25	-13	90.6	66.8	1.448	0.057	53
6	152A4	-15	5	384.5	283.6	2.667	0.105	100
7	152B4	0	32	385.7	284.5	2.464	0.097	100
8	152A2	22	72	370.1	273	2.616	0.103	100
9	152B2	22	72	372	274.4	2.54	0.1	100
10	152B3	75	167	350.1	258.2	2.489	0.098	100

SET NAME: 1_20_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	153B6	-100	-148	4.5	3.3	0.229	0.009	0
2	153A6	-75	-103	3.8	2.8	0.076	0.003	0
3	153B5	-50	-58	40.4	29.8	0.864	0.034	28
4	153A3	-35	-31	103.3	76.2	1.575	0.062	53
5	153A4	-35	-31	93.1	68.7	1.549	0.061	43
6	153A5	-25	-13	385.9	284.6	2.819	0.111	100
7	153B4	0	32	392.5	289.5	2.54	0.1	100
8	153A2	22	72	365.9	269.9	2.565	0.101	100
9	153B2	22	72	365	269.2	2.54	0.1	100
10	153B3	75	167	360.4	265.8	2.565	0.101	100

SET NAME: 1_20_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	163A3	-50	-58	12.5	9.2	0.343	0.0135	11
2	163A4	-25	-13	12.6	9.3	0.394	0.0155	13
3	163A5	-15	5	25.9	19.1	0.622	0.0245	29
4	163A6	-10	14	29.7	21.9	0.521	0.0205	30
5	163B4	-8	18	74.6	55	1.308	0.0515	30
6	163B2	-5	23	357.4	263.6	2.413	0.095	100
7	163A2	0	32	366.3	270.2	2.54	0.1	100
8	163B3	25	77	351.7	259.4	2.311	0.091	100
9	163B5	100	212	328.4	242.2	2.337	0.092	100

Table C1. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

1_40_1550 1_5_1650 1_10_1650

SET NAME: 1_40_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	154A4	-100	-148	6.5	4.8	0.089	0.0035	3
2	154B2	-75	-103	8.1	6	0.14	0.0055	3
3	154B4	-60	-76	20.7	15.3	0.419	0.0165	18
4	154A3	-50	-58	100.6	74.2	1.524	0.06	27
5	154B5	-50	-58	21.6	15.9	0.533	0.021	20
6	154B3	-40	-40	27.8	20.5	0.673	0.0265	20
7	154A6	-25	-13	65.1	48	0.889	0.035	48
8	154A5	0	32	368.2	271.6	2.489	0.098	100
9	154A2	25	77	366.6	270.4	2.718	0.107	100
10	154B6	100	212	315.2	232.5	2.807	0.1105	100

SET NAME: 1_5_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	161A4	-100	-148	2.3	1.7	0.076	0.003	3
2	161B2	-75	-103	5	3.7	0.064	0.0025	3
3	161A3	-50	-58	38.4	28.3	0.775	0.0305	25
4	161A6	-25	-13	53	39.1	0.902	0.0355	27
5	161B3	-15	5	67.1	49.5	1.168	0.046	32
6	161B6	-10	14	381.7	281.5	2.502	0.0985	100
7	161B5	-5	23	368.6	271.9	2.21	0.087	100
8	161A5	0	32	369.2	272.3	2.248	0.0885	100
9	161A2	25	77	358.7	264.6	2.311	0.091	100
10	161B4	100	212	334.1	246.4	2.362	0.093	100

SET NAME: 1_10_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	162A4	-75	-103	3.7	2.7	0.025	0.001	3
2	162A3	-50	-58	38.5	28.4	0.737	0.029	25
3	162A5	-25	-13	35.3	26	0.686	0.027	25
4	162B5	-20	-4	83.5	61.6	1.003	0.0395	48
5	162A6	-15	5	130.7	96.4	1.816	0.0715	29
6	162B6	-12	10	377.9	278.7	2.413	0.095	100
7	162B4	-10	14	379.8	280.1	2.388	0.094	100
8	162A2	0	32	372.2	274.5	2.477	0.0975	100
9	162B3	25	77	359.2	264.9	2.502	0.0985	100
10	162B2	100	212	324.2	239.1	2.324	0.0915	100

Table C1. Continued

SOURCE: ANALYSIS SET
ANALYSIS SET: 1_40_1650

SET NAME: 1_40_1650
REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	164A3	-75	-103	5.7	4.2	0.025	0.001	5
2	164B4	-50	-58	6.1	4.5	0.127	0.005	11
3	164A4	-25	-13	26.3	19.4	0.559	0.022	23
4	164B6	-20	-4	364	268.5	2.667	0.105	100
5	164B3	-15	5	186.2	137.3	2.362	0.093	49
6	164B5	-10	14	357.5	263.7	2.718	0.107	100
7	164A5	0	32	338.1	249.4	2.388	0.094	100
8	164A2	25	77	349.4	257.7	2.642	0.104	100
9	164A6	50	122	341.8	252.1	2.337	0.092	100
10	164B2	100	212	315.1	232.4	2.515	0.099	100

Table C2. Charpy impact data for weld 2, high-carbon SMA

SOURCE: ANALYSIS SET

ANALYSIS SETS

2_AW 2_10_1150 2_5_1150

SET NAME: 2_AW

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	200A4	-50	-58	25.9	19.1	0.406	0.016	22
2	200B4	-25	-13	42	31	0.66	0.026	40
3	200A3	0	32	49.9	36.8	0.533	0.021	39
4	200B3	25	77	70.9	52.3	0.991	0.039	95
5	200A2	50	122	86.6	63.9	1.27	0.05	99
6	200B2	100	212	85.4	63	1.168	0.046	99

SET NAME: 2_10_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	212A2	-50	-58	28.5	21	0.432	0.017	20
2	212B4	-25	-13	32.5	24	0.584	0.023	31
3	212A3	0	32	67.7	49.9	0.965	0.038	57
4	212B3	25	77	94.6	69.8	1.422	0.056	95
5	212A4	50	122	103.7	76.5	1.6	0.063	100
6	212B2	100	212	110.2	81.3	1.575	0.062	100

SET NAME: 2_5_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	211B4	-75	-103	18.8	13.9	0.229	0.009	8
2	211A4	-50	-58	25.1	18.5	0.483	0.019	20
3	211A3	0	32	59.8	44.1	1.016	0.04	67
4	211B3	25	77	77.3	57	1.219	0.048	89
5	211A2	50	122	103.9	76.6	1.626	0.064	99
6	211B2	100	212	109.8	81	1.727	0.068	100

Table C2. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

2_20_1150 2_40_1150 2_5_1250

SET NAME: 2_20_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	213A2	-50	-58	25.8	19	0.381	0.015	18
2	213B4	-25	-13	41.4	30.5	0.711	0.028	33
3	213A3	0	32	73.1	53.9	1.118	0.044	62
4	213A4	50	122	102.9	75.9	1.499	0.059	100
5	213B2	100	212	123.7	91.2	1.803	0.071	100
6	213B3	150	302	125.1	92.3	1.88	0.074	100

SET NAME: 2_40_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	214A2	-50	-58	18.8	13.9	0.33	0.013	28
2	214B4	-25	-13	46.1	34	0.711	0.028	36
3	214A3	0	32	67.8	50	1.092	0.043	55
4	214B3	25	77	95	70.1	1.422	0.056	88
5	214A4	50	122	122	90	1.778	0.07	100
6	214B2	100	212	127.7	94.2	2.032	0.08	100

SET NAME: 2_5_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	221A2	-50	-58	22.4	16.5	0.356	0.014	10
2	221B4	-25	-13	45.1	33.3	0.787	0.031	31
3	221A3	0	32	63.5	46.8	1.067	0.042	52
4	221B3	25	77	94.2	69.5	1.524	0.06	80
5	221A4	50	122	111.6	82.3	1.727	0.068	100
6	221B2	100	212	123.7	91.2	1.778	0.07	100

Table C2. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

2_10_1250 2_40_1250 2_20_1250

SET NAME: 2_10_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	222A2	-50	-58	27.1	20	0.483	0.019	23
2	222B4	-25	-13	52.6	38.8	0.838	0.033	34
3	222A3	0	32	69.1	51	1.143	0.045	45
4	222A4	50	122	117.4	86.6	1.651	0.065	100
5	222B2	100	212	132.7	97.9	1.854	0.073	100
6	222B3	150	302	127.3	93.9	1.981	0.078	100

SET NAME: 2_40_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	224A2	-50	-58	24.4	18	0.305	0.012	19
2	224A3	0	32	64.9	47.9	1.067	0.042	48
3	224B4	25	77	80.5	59.4	1.397	0.055	76
4	224A4	50	122	123	90.7	1.905	0.075	95
5	224B2	100	212	141.3	104.2	2.032	0.08	100
6	224B3	150	302	131.6	97.1	1.956	0.077	100

SET NAME: 2_20_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	223A2	-50	-58	28.3	20.9	0.533	0.021	13
2	223B4	-25	-13	45	33.2	0.686	0.027	28
3	223A3	0	32	95.3	70.3	1.499	0.059	64
4	223B3	25	77	111.3	82.1	1.676	0.066	80
5	223A4	50	122	136.9	101	1.905	0.075	95
6	223B2	100	212	139.9	103.2	2.007	0.079	100

Table C2. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

2_5_1350 2_10_1350 2_20_1350

SET NAME: 2_5_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	231A2	-50	-58	22.9	16.9	0.406	0.016	20
2	231B4	-25	-13	44.3	32.7	0.711	0.028	44
3	231A3	0	32	63.7	47	1.067	0.042	66
4	231A4	50	122	100.2	73.9	1.626	0.064	100
5	231B2	100	212	114	84.1	1.727	0.068	100
6	231B3	150	302	110	81.1	1.753	0.069	100

SET NAME: 2_10_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	232A2	-50	-58	28.6	21.1	0.381	0.015	26
2	232B4	-25	-13	45.4	33.5	0.813	0.032	34
3	232A3	0	32	75.1	55.4	1.143	0.045	60
4	232B3	25	77	86.6	63.9	1.372	0.054	88
5	232A4	50	122	115.5	85.2	1.727	0.068	99
6	232B2	100	212	120.8	89.1	1.854	0.073	100

SET NAME: 2_20_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	233A2	-50	-58	27.3	20.1	0.559	0.022	35
2	233B4	-25	-13	36.9	27.2	0.635	0.025	42
3	233A3	0	32	75.9	56	1.245	0.049	59
4	233A4	50	122	86.9	64.1	1.397	0.055	99
5	233B2	100	212	107	78.9	1.803	0.071	100
6	233B3	150	302	98.3	72.5	1.6	0.063	100

Table C2. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

2_5_1450 2_10_1450 2_20_1450

SET NAME: 2_5_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY		EXPANSION		SHEAR (PERCENT)
		(DEG F)	(DEG C)	(FT-LB)	(J)	(IN)	(MM)	
1	241B2	-148	-100	2.6	3.5	0.001	0.025	0
2	241A4	-58	-50	20.9	28.3	0.017	0.432	10
3	241A2	77	25	54.5	73.9	0.049	1.245	55
4	241B4	212	100	79.7	108.1	0.072	1.829	100
5	241A3	392	200	88.7	120.3	0.075	1.905	100
6	241B3	482	250	74.8	101.4	0.066	1.676	100

SET NAME: 2_10_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY		EXPANSION		SHEAR (PERCENT)
		(DEG F)	(DEG C)	(FT-LB)	(J)	(IN)	(MM)	
1	242A2	-148	-100	3	4.1	0.005	0.127	0
2	242B4	-58	-50	9.3	12.6	0.012	0.305	5
3	242A3	32	0	51.8	70.2	0.045	1.143	45
4	242B3	122	50	65.5	88.8	0.061	1.549	95
5	242A4	212	100	90	122	0.074	1.88	100
6	242B2	482	250	84	113.9	0.075	1.905	100

SET NAME: 2_20_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY		EXPANSION		SHEAR (PERCENT)
		(DEG F)	(DEG C)	(FT-LB)	(J)	(IN)	(MM)	
1	243A4	-148	-100	2	2.7	0.005	0.127	0
2	243B3	-58	-50	6	8.1	0.008	0.203	5
3	243B4	32	0	28.8	39	0.03	0.762	30
4	243A2	77	25	52	70.5	0.05	1.27	60
5	243A3	212	100	90	122	0.081	2.057	100
6	243B2	392	200	85.5	115.9	0.078	1.981	100

Table C2. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

2_40_1350 2_40_1450 2_5_1650

SET NAME: 2_40_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	(DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	(IN)	SHEAR (PERCENT)
1	234A2	-50	-58	33.2	24.5	0.533	0.021	33
2	234B4	-25	-13	43.4	32	0.711	0.028	35
3	234A3	0	32	85.4	63	1.143	0.045	60
4	234B3	25	77	89.6	66.1	1.473	0.058	99
5	234A4	50	122	109.1	80.5	1.651	0.065	100
6	234B2	100	212	102	75.2	2.083	0.082	100

SET NAME: 2_40_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	(DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	(IN)	SHEAR (PERCENT)
1	244A2	-50	-58	20.6	15.2	0.356	0.014	11
2	244A3	0	32	38	28	0.737	0.029	30
3	244B4	25	77	72.3	53.3	1.219	0.048	53
4	244A4	50	122	92.1	67.9	1.499	0.059	78
5	244B2	100	212	118.6	87.5	1.956	0.077	100
6	244B3	150	302	113.9	84	2.007	0.079	100

SET NAME: 2_5_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	(DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	(IN)	SHEAR (PERCENT)
1	261B2	-50	-58	6.5	4.8	0.152	0.006	5
2	261A4	0	32	37.7	27.8	0.66	0.026	18
3	261A2	50	122	65.6	48.4	1.016	0.04	47
4	261B4	75	167	96	70.8	1.549	0.061	70
5	261A3	100	212	105.8	78	1.6	0.063	95
6	261B3	200	392	107.1	79	1.651	0.065	100

Table C2. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

2_40_1550 2_20_1550 2_40_1650

SET NAME: 2_40_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	254A3	-50	-58	4.3	3.2	0.152	0.006	3
2	254B2	0	32	11.3	8.3	0.279	0.011	13
3	254A2	25	77	41.2	30.4	0.737	0.029	27
4	254B3	50	122	68.3	50.4	1.118	0.044	50
5	254A4	100	212	104.4	77	1.702	0.067	100
6	254B4	200	392	99.1	73.1	1.778	0.07	100

SET NAME: 2_20_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	253B2	-75	-103	6.1	4.5	0.076	0.003	0
2	253B3	-25	-13	14.9	11	0.279	0.011	4
3	253A3	0	32	44.7	33	0.711	0.028	18
4	253A2	25	77	44.7	33	0.737	0.029	31
5	253B4	50	122	48.5	35.8	0.864	0.034	37
6	253A4	100	212	111.2	82	1.956	0.077	100

SET NAME: 2_40_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	264B2	-50	-58	2.6	1.9	0.076	0.003	UNKNOWN
2	264A4	0	32	26.2	19.3	0.533	0.021	9
3	264A2	50	122	57.5	42.4	0.787	0.031	46
4	264A3	100	212	99.9	73.7	1.473	0.058	85
5	264B3	150	302	112.5	83	1.778	0.07	100
6	264B4	200	392	102.2	75.4	1.676	0.066	100

Table C2. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

2_10_1550 2_20_1650 2_5_1550

SET NAME: 2_10_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	(DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	(IN)	SHEAR (PERCENT)
1	252B4	-75	-103	9.5	7	0.178	0.007	3
2	252A4	-50	-58	21.7	16	0.483	0.019	8
3	252A3	0	32	46.1	34	0.838	0.033	30
4	252A2	25	77	78.6	58	1.219	0.048	57
5	252B2	75	167	122.7	90.5	1.981	0.078	100
6	252B3	125	257	126.1	93	1.93	0.076	100

SET NAME: 2_20_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	(DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	(IN)	SHEAR (PERCENT)
1	263B2	-50	-58	5.4	4	0.076	0.003	3
2	263A4	0	32	16.3	12	0.381	0.015	11
3	263A2	50	122	48.9	36.1	0.889	0.035	37
4	263B4	75	167	89.5	66	1.499	0.059	71
5	263A3	100	212	97.1	71.6	1.626	0.064	90
6	263B3	150	302	94.9	70	1.6	0.063	100

SET NAME: 2_5_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	(DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	(IN)	SHEAR (PERCENT)
1	251A2	-50	-58	6.8	5	0.025	0.001	0
2	251A3	0	32	30.5	22.5	0.508	0.02	16
3	251A4	25	77	58.3	43	0.965	0.038	37
4	251B4	50	122	82.7	61	1.27	0.05	59
5	251B2	100	212	122.7	90.5	1.778	0.07	100
6	251B3	150	302	89.5	66	1.575	0.062	100

Table C2. Continued

SOURCE: ANALYSIS SET
ANALYSIS SET: 2_10_1650

SET NAME: 2_10_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY		EXPANSION		SHEAR
		(DEG C)	(DEG F)	(J)	(FT-LB)	(MM)	(IN)	(PERCENT)
1	262B2	-75	-103	14.1	10.4	0.305	0.012	3
2	262A4	0	32	46.2	34.1	0.838	0.033	34
3	262B3	25	77	64.5	47.6	1.092	0.043	40
4	262A2	50	122	90.4	66.7	1.473	0.058	60
5	262A3	100	212	132.2	97.5	2.032	0.08	100
6	262B4	200	392	128.4	94.7	2.007	0.079	100

Table C3. Charpy impact data for weld 3 high-carbon FCA

SOURCE: ANALYSIS SET

ANALYSIS SETS

3_5_1150 3_10_1150 3_20_1150

SET NAME: 3_5_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	311B2	-75	-103	13.7	10.1	0.229	0.009	13
2	311A2	-50	-58	17.8	13.1	0.203	0.008	25
3	311B3	-25	-13	27.4	20.2	0.381	0.015	46
4	311A3	0	32	31.3	23.1	0.406	0.016	56
5	311B4	25	77	44.9	33.1	0.533	0.021	75
6	311A4	50	122	40	29.5	0.559	0.022	82
7	311B5	75	167	54.2	40	0.864	0.034	97
8	311A5	100	212	55.9	41.2	0.889	0.035	100
9	311A6	150	302	52.9	39	0.762	0.03	100
10	311B1	200	392	51.7	38.1	0.914	0.036	100

SET NAME: 3_10_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	312B3	-75	-103	6.4	4.7	0.076	0.003	7
2	312C2	-50	-58	14.5	10.7	0.152	0.006	26
3	312B4	-25	-13	16.8	12.4	0.178	0.007	23
4	312C3	0	32	38	28	0.533	0.021	63
5	312B5	25	77	40.5	29.9	0.61	0.024	74
6	312C4	50	122	43.7	32.2	0.711	0.028	94
7	312B2	75	167	51	37.6	0.94	0.037	100
8	312C5	100	212	58.3	43	1.016	0.04	99
9	312C6	150	302	56.8	41.9	0.94	0.037	100
10	312B1	200	392	54.4	40.1	0.914	0.036	100

SET NAME: 3_20_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	313A2	-50	-58	11.8	8.7	0.127	0.005	32
2	313B2	-25	-13	17.8	13.1	0.254	0.01	30
3	313B5	-10	14	28.2	20.8	0.432	0.017	37
4	313A3	0	32	35.1	25.9	0.457	0.018	21
5	313B3	25	77	37.8	27.9	0.508	0.02	68
6	313A4	50	122	48.8	36	0.737	0.029	92
7	313B4	75	167	47.7	35.2	0.686	0.027	97
8	313A5	100	212	56	41.3	0.94	0.037	99
9	313A6	150	302	52.2	38.5	0.787	0.031	100
10	313B1	200	392	48.8	36	0.889	0.035	100

Table C3. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

3_40_1150 3_5_1250 3_10_1250

SET NAME: 3_40_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	314A2	-50	-58	13.4	9.9	0.127	0.005	23
2	314B4	-25	-13	19.9	14.7	0.33	0.013	32
3	314A3	0	32	31.3	23.1	0.483	0.019	46
4	314B5	10	50	51.2	37.8	0.762	0.03	75
5	314B2	25	77	51.5	38	0.813	0.032	82
6	314A4	50	122	50.3	37.1	0.838	0.033	89
7	314B3	75	167	58.6	43.2	0.991	0.039	98
8	314A5	100	212	62.9	46.4	1.143	0.045	100
9	314A6	150	302	55.6	41	1.041	0.041	100
10	314B1	200	392	64.4	47.5	1.245	0.049	100

SET NAME: 3_5_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	321A2	-50	-58	17.6	13	0.279	0.011	18
2	321B4	-25	-13	24.7	18.2	0.381	0.015	33
3	321B5	-10	14	31.5	23.2	0.584	0.023	40
4	321A3	0	32	48.8	36	0.762	0.03	73
5	321B3	25	77	46.2	34.1	0.737	0.029	61
6	321A4	50	122	54.2	40	0.965	0.038	98
7	321B2	75	167	59	43.5	0.965	0.038	95
8	321A5	100	212	65.2	48.1	1.168	0.046	100
9	321A6	150	302	59.8	44.1	1.168	0.046	100
10	321B1	200	392	66	48.7	1.27	0.05	100

SET NAME: 3_10_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	322A2	-50	-58	14.9	11	0.203	0.008	25
2	322B4	-25	-13	21.3	15.7	0.33	0.013	38
3	322B5	-10	14	43.4	32	0.686	0.027	55
4	322A3	0	32	43.3	31.9	0.686	0.027	55
5	322B2	25	77	56	41.3	0.94	0.037	74
6	322A4	50	122	63.7	47	1.397	0.055	87
7	322B3	75	167	69.1	51	1.27	0.05	95
8	322A5	100	212	77.3	57	1.041	0.041	99
9	322A6	150	302	76.6	56.5	1.295	0.051	100
10	322B1	200	392	71.9	53	1.346	0.053	100

Table C3. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

3_20_1250 3_40_1250 3_5_1350

SET NAME: 3_20_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	323A2	-50	-58	17.2	12.7	0.229	0.009	13
2	323B4	-25	-13	24.9	18.4	0.457	0.018	30
3	323A3	0	32	28.5	21	0.483	0.019	46
4	323B5	10	50	50.8	37.5	0.737	0.029	50
5	323B3	25	77	43.9	32.4	0.66	0.026	54
6	323A4	50	122	57.2	42.2	0.991	0.039	77
7	323B2	75	167	69	50.9	1.27	0.05	90
8	323A5	100	212	81.3	60	1.372	0.054	99
9	323A6	150	302	84.2	62.1	1.245	0.049	100
10	323B1	200	392	81.6	60.2	1.524	0.06	100

SET NAME: 3_40_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	324A2	-50	-58	7.5	5.5	0.178	0.007	9
2	324B4	-25	-13	15	11.1	0.305	0.012	25
3	324A3	0	32	19.7	14.5	0.406	0.016	35
4	324B5	10	50	31.2	23	0.635	0.025	50
5	324B2	25	77	41.6	30.7	0.838	0.033	70
6	324A4	50	122	52.9	39	1.041	0.041	82
7	324B3	75	167	72.1	53.2	1.219	0.048	89
8	324A5	100	212	83.4	61.5	1.524	0.06	96
9	324A6	150	302	81.3	60	1.549	0.061	100
10	324B1	200	392	82.7	61	1.727	0.068	100

SET NAME: 3_5_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	331B4	-100	-148	11.8	8.7	0.051	0.002	3
2	331B2	-75	-103	16.3	12	0.102	0.004	11
3	331A2	-50	-58	30.5	22.5	0.178	0.007	13
4	331B3	-25	-13	20.1	14.8	0.381	0.015	20
5	331A3	0	32	23.2	17.1	0.254	0.01	73
6	331B5	25	77	25.2	18.6	0.279	0.011	95
7	331A4	50	122	24.4	18	0.203	0.008	98
8	331A5	100	212	27.5	20.3	0.33	0.013	100
9	331A6	150	302	26.4	19.5	0.33	0.013	100
10	331B1	200	392	27.9	20.6	0.33	0.013	100

Table C3. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

3_10_1350 3_20_1350 3_40_1350

SET NAME: 3_10_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	332B3	-75	-103	7.9	5.8	0.102	0.004	10
2	332A2	-50	-58	18.3	13.5	0.178	0.007	20
3	332B4	-25	-13	20.9	15.4	0.203	0.008	90
4	332A3	0	32	23.2	17.1	0.279	0.011	68
5	332B5	25	77	28.2	20.8	0.33	0.013	54
6	332A4	50	122	27.3	20.1	0.305	0.012	90
7	332A5	100	212	29.7	21.9	0.381	0.015	99
8	332B2	150	302	32.7	24.1	0.483	0.019	100
9	332B1	200	392	33.2	24.5	0.483	0.019	100

SET NAME: 3_20_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	333B4	-75	-103	10.2	7.5	0.051	0.002	11
2	333A2	-50	-58	15	11.1	0.127	0.005	20
3	333B5	-25	-13	17.9	13.2	0.178	0.007	21
4	333A3	0	32	18	13.3	0.152	0.006	37
5	333B3	25	77	23	17	0.229	0.009	68
6	333A4	50	122	21.7	16	0.33	0.013	95
7	333B2	75	167	27.9	20.6	0.356	0.014	95
8	333A5	100	212	26.4	19.5	0.254	0.01	100
9	333A6	150	302	36.5	26.9	0.152	0.006	100
10	333B1	200	392	29.3	21.6	0.457	0.018	100

SET NAME: 3_40_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	334B4	-75	-103	12.3	9.1	0.152	0.006	11
2	334A3	-50	-58	19.3	14.2	0.33	0.013	13
3	334B5	-25	-13	20.7	15.3	0.33	0.013	31
4	334A2	0	32	25.1	18.5	0.305	0.012	40
5	334B3	25	77	24.4	18	0.254	0.01	69
6	334A4	50	122	26.8	19.8	0.356	0.014	80
7	334B2	75	167	28.1	20.7	0.33	0.013	95
8	334A5	100	212	30	22.1	0.457	0.018	100
9	334A6	150	302	26.4	19.5	0.406	0.016	100
10	334B1	200	392	30	22.1	0.533	0.021	100

Table C3. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

3_5_1450 3_10_1450 3_20_1450

SET NAME: 3_5_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	341A4	-100	-148	7.7	5.7	0.051	0.002	3
2	341A3	-50	-58	17.4	12.8	0.203	0.008	5
3	341B4	0	32	33.2	24.5	0.559	0.022	50
4	341A2	25	77	40.8	30.1	0.686	0.027	76
5	341B5	75	167	53.4	39.4	0.965	0.038	95
6	341A5	100	212	59.9	44.2	1.067	0.042	100
7	341B1	200	392	70	51.6	1.346	0.053	100
8	341B2	250	482	72.3	53.3	1.245	0.049	100
9	341B3	300	572	69.8	51.5	1.067	0.042	100

SET NAME: 3_10_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	342A4	-100	-148	8.8	6.5	0.051	0.002	5
2	342A3	-50	-58	13.2	9.7	0.178	0.007	13
3	342B4	0	32	31.7	23.4	0.584	0.023	35
4	342A2	25	77	34.6	25.5	0.559	0.022	77
5	342A5	100	212	53.3	39.3	1.041	0.041	100
6	342B1	200	392	64.5	47.6	1.194	0.047	100
7	342B2	250	482	70.8	52.2	1.245	0.049	100
8	342B3	300	572	69.3	51.1	1.143	0.045	100

SET NAME: 3_20_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	343B3	-75	-103	9.6	7.1	0.178	0.007	6
2	343A4	-50	-58	15	11.1	0.229	0.009	21
3	343A3	0	32	30.2	22.3	0.419	0.0165	43
4	343A2	25	77	36.3	26.8	0.61	0.024	72
5	343B2	75	167	42.2	31.1	0.737	0.029	95
6	343A5	100	212	52.9	39	0.927	0.0365	100
7	343A6	150	302	71.2	52.5	1.207	0.0475	100
8	343B1	200	392	58.3	43	1.08	0.0425	100
9	343B4	250	482	60.2	44.4	1.181	0.0465	100
10	343B5	300	572	59	43.5	1.194	0.047	100

Table C3. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

3_10_1650 3_40_1450 3_AW

SET NAME: 3_10_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	362A4	-50	-58	6.9	5.1	0.114	0.0045	3
2	362A2	0	32	13.4	9.9	0.178	0.007	13
3	362A3	25	77	14.8	10.9	0.241	0.0095	18
4	362C4	50	122	24.7	18.2	0.394	0.0155	37
5	362C3	75	167	32.8	24.2	0.61	0.024	65
6	362A5	100	212	44.2	32.6	0.838	0.033	90
7	362A6	150	302	43.7	32.2	0.8	0.0315	99
8	362C2	200	392	51.5	38	1.092	0.043	100
9	362C5	250	482	58.7	43.3	1.181	0.0465	100
10	362C6	300	572	64.1	47.3	1.295	0.051	100

SET NAME: 3_40_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	344B5	-75	-103	9.6	7.1	0.076	0.003	5
2	344A2	-50	-58	15.2	11.2	0.203	0.008	15
3	344B4	-25	-13	19.5	14.4	0.381	0.015	27
4	344A3	0	32	29	21.4	0.457	0.018	31
5	344B3	25	77	30.5	22.5	0.508	0.02	40
6	344A4	50	122	40.7	30	0.711	0.028	90
7	344B2	75	167	37.3	27.5	0.584	0.023	95
8	344A5	100	212	52.9	39	1.041	0.041	100
9	344A6	150	302	57.2	42.2	0.94	0.037	100
10	344B1	200	392	57.6	42.5	1.041	0.041	100

SET NAME: 3_AW

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	300A6	-100	-148	8.1	6	0.229	0.009	10
2	300B3	-85	-121	10.8	8	0.051	0.002	23
3	300B1	-75	-103	17.6	13	0.127	0.005	22
4	300B4	-65	-85	16.7	12.3	0.229	0.009	25
5	300A5	-50	-58	27	19.9	0.127	0.005	39
6	300A4	0	32	31.2	23	0.356	0.014	66
7	300A2	50	122	35.3	26	0.483	0.019	95
8	300A3	100	212	32.9	24.3	0.432	0.017	99
9	300B2	200	392	40.9	30.2	0.66	0.026	100

Table C3. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

3_5_1550 3_10_1550 3_20_1550

SET NAME: 3_5_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	351A4	-50	-58	7.2	5.3	0.102	0.004	5
2	351A2	0	32	13.3	9.8	0.229	0.009	15
3	351A3	25	77	16.9	12.5	0.241	0.0095	23
4	351B2	60	140	25.5	18.8	0.406	0.016	72
5	351B4	75	167	24.4	18	0.406	0.016	73
6	351A5	100	212	34.7	25.6	0.622	0.0245	90
7	351A6	150	302	45.8	33.8	0.889	0.035	100
8	351B1	200	392	36.2	26.7	0.686	0.027	100
9	351B3	250	482	34.8	25.7	0.635	0.025	100
10	351B5	300	572	41.5	30.6	0.965	0.038	100

SET NAME: 3_10_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	352A4	-50	-58	7.3	5.4	0.152	0.006	3
2	352B3	-25	-13	9.8	7.2	0.216	0.0085	3
3	352A2	0	32	12.7	9.4	0.279	0.011	18
4	352A3	25	77	13.6	10	0.178	0.007	26
5	352B2	50	122	19.3	14.2	0.406	0.016	48
6	352B4	75	167	24	17.7	0.419	0.0165	85
7	352A5	100	212	30.5	22.5	0.559	0.022	95
8	352A6	150	302	30.8	22.7	0.66	0.026	100
9	352B1	200	392	30.5	22.5	0.673	0.0265	100

SET NAME: 3_20_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	353A4	-50	-58	6.9	5.1	0.089	0.0035	3
2	353B5	-25	-13	10.3	7.6	0.229	0.009	11
3	353A2	0	32	13.4	9.9	0.254	0.01	14
4	353A3	25	77	19.5	14.4	0.394	0.0155	33
5	353B2	50	122	28.2	20.8	0.508	0.02	47
6	353B3	75	167	32.8	24.2	0.61	0.024	66
7	353A5	100	212	49.5	36.5	1.016	0.04	98
8	353A6	150	302	57.1	42.1	0.914	0.036	100
9	353B1	200	392	52.1	38.4	1.041	0.041	100
10	353B4	250	482	55.3	40.8	1.156	0.0455	100

Table C3. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

3_20_1650 3_40_1550 3_40_1650

SET NAME: 3_20_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	363A4	-50	-58	6.1	4.5	0.076	0.003	3
2	363A2	0	32	11.4	8.4	0.216	0.0085	5
3	363A3	25	77	18.3	13.5	0.318	0.0125	20
4	363B5	50	122	32.9	24.3	0.622	0.0245	52
5	363B2	75	167	33.2	24.5	0.61	0.024	56
6	363A5	100	212	45.3	33.4	0.876	0.0345	85
7	363B3	150	302	41.9	30.9	0.876	0.0345	99
8	363A6	200	392	58.3	43	1.156	0.0455	100
9	363B1	250	482	51.4	37.9	1.054	0.0415	100
10	363B4	300	572	48.8	36	1.13	0.0445	100

SET NAME: 3_40_1550

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	354A4	-50	-58	7.3	5.4	0.14	0.0055	3
2	354B5	-25	-13	14	10.3	0.178	0.007	9
3	354A2	0	32	18.2	13.4	0.279	0.011	16
4	354A3	25	77	22.1	16.3	0.368	0.0145	30
5	354B4	50	122	29.8	22	0.61	0.024	56
6	354B2	75	167	35.9	26.5	0.711	0.028	74
7	354A5	100	212	54.4	40.1	1.092	0.043	99
8	354B3	125	257	39.7	29.3	0.737	0.029	99
9	354A6	150	302	68.1	50.2	1.13	0.0445	100
10	354B1	200	392	42.7	31.5	0.914	0.036	100

SET NAME: 3_40_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	363A4	-50	-58	4.7	3.5	0.038	0.0015	3
2	364A2	0	32	9.8	7.2	0.203	0.008	9
3	363A3	25	77	13.8	10.2	0.318	0.0125	13
4	363B2	75	167	20.2	14.9	0.394	0.0155	33
5	363A5	100	212	37.6	27.7	0.838	0.033	75
6	363B4	150	302	32.9	24.3	0.635	0.025	99
7	363A6	200	392	48.9	36.1	1.092	0.043	100
8	363B3	250	482	35	25.8	0.686	0.027	100
9	363B1	300	572	33.1	24.4	0.8	0.0315	100

Table C3. Continued

SOURCE: ANALYSIS SET
ANALYSIS SET: 3_5_1650

SET NAME: 3_5_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	361A4	-50	-58	6.1	4.5	0.152	0.006	3
2	361A2	0	32	11.5	8.5	0.14	0.0055	9
3	361A3	25	77	13.4	9.9	0.216	0.0085	18
4	361B3	50	122	22.5	16.6	0.381	0.015	41
5	361B1	75	167	27.7	20.4	0.495	0.0195	52
6	361A5	100	212	44.7	33	0.876	0.0345	90
7	361A6	150	302	39.7	29.3	0.914	0.036	100
8	361B2	200	392	46.9	34.6	0.927	0.0365	100
9	361B4	250	482	45.3	33.4	0.927	0.0365	100

Table C4. Charpy impact data for weld 4, low-carbon FCA

SOURCE: ANALYSIS SET

ANALYSIS SETS

4_AW 4_5_1150 4_10_1150

SET NAME: 4_AW

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	400A4	-50	-58	14.5	10.7	0.178	0.007	23
2	400B2	-25	-13	35.4	26.1	0.279	0.011	48
3	400A3	0	32	50.2	37	0.787	0.031	59
4	400B3	25	77	44.7	33	0.635	0.025	74
5	400A2	50	122	69.8	51.5	1.194	0.047	95
6	400A5	100	212	71.7	52.9	1.27	0.05	99
7	400A6	200	392	75.9	56	1.372	0.054	100

SET NAME: 4_5_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	411A2	-50	-58	10.6	7.8	0.127	0.005	18
2	411B5	-25	-13	23.7	17.5	0.432	0.017	28
3	411B6	-10	14	26.4	19.5	0.483	0.019	35
4	411A3	0	32	47.5	35	0.762	0.03	48
5	411B4	25	77	50.3	37.1	0.94	0.037	78
6	411A4	50	122	69.1	51	1.219	0.048	97
7	411B3	75	167	75.8	55.9	1.372	0.054	95
8	411A5	100	212	85.4	63	1.549	0.061	100
9	411A6	150	302	87.5	64.5	1.626	0.064	100
10	411B2	200	392	81.8	60.3	1.6	0.063	100

SET NAME: 4_10_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	412A2	-50	-58	7.6	5.6	0.076	0.003	11
2	412B4	-25	-13	21.7	16	0.406	0.016	23
3	412A3	0	32	28.5	21	0.61	0.024	39
4	412B6	15	59	56.8	41.9	1.067	0.042	66
5	412B3	25	77	58.3	43	0.991	0.039	62
6	412A4	50	122	76.3	56.3	1.321	0.052	95
7	412B5	75	167	78	57.5	1.397	0.055	89
8	412A5	100	212	81.8	60.3	1.372	0.054	100
9	412A6	150	302	87.9	64.8	1.524	0.06	100
10	412B2	200	392	95.3	70.3	1.727	0.068	100

Table C4. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

4_20_1150 4_40_1150 4_5_1250

SET NAME: 4_20_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	413A2	-50	-58	10.2	7.5	0.203	0.008	18
2	413B3	-25	-13	15.5	11.4	0.254	0.01	23
3	413B6	-10	14	35.3	26	0.584	0.023	33
4	413A3	0	32	39.7	29.3	0.635	0.025	36
5	413B4	25	77	61.1	45.1	0.991	0.039	82
6	413A4	50	122	78.5	57.9	1.346	0.053	88
7	413B5	75	167	86	63.4	1.448	0.057	99
8	413A5	100	212	84.3	62.2	1.499	0.059	99
9	413A6	150	302	91.5	67.5	1.727	0.068	100
10	413B2	200	392	93.6	69	1.753	0.069	100

SET NAME: 4_40_1150

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	414A2	-50	-58	12.1	8.9	0.279	0.011	18
2	414B4	-25	-13	26.2	19.3	0.432	0.017	32
3	414B6	-10	14	33.8	24.9	0.61	0.024	37
4	414A3	0	32	48.3	35.6	0.864	0.034	37
5	414B3	25	77	65.5	48.3	1.118	0.044	75
6	414A4	50	122	92.2	68	1.575	0.062	100
7	414B5	75	167	97.5	71.9	1.6	0.063	95
8	414A5	100	212	86.8	64	1.575	0.062	100
9	414A6	150	302	96.3	71	1.778	0.07	100
10	414B2	200	392	100.1	73.8	2.007	0.079	100

SET NAME: 4_5_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	421A2	-50	-58	10.8	8	0.203	0.008	20
2	421B5	-25	-13	27.7	20.4	0.533	0.021	39
3	421A3	0	32	50.8	37.5	0.864	0.034	58
4	421B6	10	50	55.6	41	1.016	0.04	65
5	421B3	25	77	77.3	57	1.422	0.056	90
6	421A4	50	122	70.6	52.1	1.372	0.054	94
7	421B4	75	167	91.4	67.4	1.6	0.063	99
8	421A5	100	212	97.3	71.8	1.651	0.065	100
9	421A6	150	302	97.8	72.1	1.676	0.066	100
10	421B2	200	392	97.3	71.8	1.702	0.067	100

Table C4. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

4_10_1250 4_20_1250 4_40_1250

SET NAME: 4_10_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	422A2	-50	-58	7.5	5.5	0.076	0.003	3
2	422B5	-25	-13	25.8	19	0.457	0.018	35
3	422A3	0	32	50.3	37.1	0.94	0.037	50
4	422B6	15	59	66.3	48.9	1.168	0.046	67
5	422B3	25	77	72.7	53.6	1.321	0.052	89
6	422A4	50	122	96.3	71	1.6	0.063	98
7	422B4	75	167	104.4	77	1.727	0.068	99
8	422A5	100	212	93.6	69	1.803	0.071	100
9	422A6	150	302	99	73	1.727	0.068	100
10	422B2	200	392	105.9	78.1	1.803	0.071	100

SET NAME: 4_20_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	423A2	-50	-58	6.8	5	0.076	0.003	4
2	423B5	-25	-13	20.5	15.1	0.432	0.017	49
3	423A3	0	32	36.5	26.9	0.737	0.029	18
4	423B4	25	77	59.5	43.9	1.016	0.04	48
5	423B6	35	95	99.4	73.3	1.727	0.068	25
6	423A4	50	122	102	75.2	1.727	0.068	82
7	423B3	75	167	124.7	92	1.93	0.076	100
8	423A5	100	212	101.7	75	1.803	0.071	100
9	423A6	150	302	110	81.1	2.007	0.079	100
10	423B2	200	392	115.4	85.1	2.007	0.079	100

SET NAME: 4_40_1250

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C)	TEMPERATURE (DEG F)	ENERGY (J)	(FT-LB)	EXPANSION (MM)	EXPANSION (IN)	SHEAR (PERCENT)
1	424A2	-50	-58	6.6	4.9	0.152	0.006	9
2	424B5	-25	-13	26.8	19.8	0.584	0.023	36
3	424A3	0	32	51.2	37.8	0.965	0.038	19
4	424B4	25	77	44.7	33	0.991	0.039	49
5	424B6	35	95	82.7	61	1.499	0.059	63
6	424A4	50	122	109.8	81	1.753	0.069	85
7	424B3	75	167	126.2	93.1	2.007	0.079	99
8	424A5	100	212	141	104	2.032	0.08	100
9	424A6	150	302	126.1	93	2.007	0.079	100
10	424B2	200	392	126.8	93.5	2.261	0.089	100

Table C4. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

4_5_1350 4_10_1350 4_20_1350

SET NAME: 4_5_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	431A2	-50	-58	21.7	16	0.381	0.015	12
2	431B5	-25	-13	32.8	24.2	0.533	0.021	35
3	431A3	0	32	41.1	30.3	0.762	0.03	41
4	431B6	10	50	62.1	45.8	1.067	0.042	66
5	431B4	25	77	73.2	54	1.295	0.051	88
6	431A4	50	122	77.3	57	1.448	0.057	100
7	431B3	75	167	74.7	55.1	1.448	0.057	98
8	431A5	100	212	76.7	56.6	1.473	0.058	100
9	431A6	150	302	88.3	65.1	1.727	0.068	100
10	431B2	200	392	95.6	70.5	1.854	0.073	100

SET NAME: 4_10_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	432A2	-50	-58	19.7	14.5	0.33	0.013	10
2	432B5	-25	-13	34	25.1	0.61	0.024	39
3	432A3	0	32	50.2	37	0.94	0.037	48
4	432B4	25	77	63.7	47	1.143	0.045	76
5	432A4	50	122	76.1	56.1	1.448	0.057	95
6	432B3	75	167	82.7	61	1.549	0.061	100
7	432A5	100	212	90.8	67	1.651	0.065	100
8	432A6	150	302	94.1	69.4	1.854	0.073	100
9	432B2	200	392	110.5	81.5	2.057	0.081	100
10	432B6	250	482	96.3	71	1.829	0.072	100

SET NAME: 4_20_1350

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	(FT-LB)	EXPANSION		SHEAR (PERCENT)
		(DEG C)	(DEG F)			(MM)	(IN)	
1	433A2	-50	-58	23.2	17.1	0.406	0.016	13
2	433B6	-25	-13	34.6	25.5	0.61	0.024	28
3	433A3	0	32	63	46.5	1.143	0.045	68
4	433B5	25	77	74.8	55.2	1.245	0.049	83
5	433A4	50	122	79.9	58.9	1.499	0.059	95
6	433B4	75	167	92.1	67.9	1.803	0.071	99
7	433A5	100	212	93.6	69	1.905	0.075	100
8	433A6	150	302	85.6	63.1	1.626	0.064	100
9	433B2	200	392	108.5	80	1.93	0.076	100
10	433B3	250	482	99	73	2.032	0.08	100

Table C4. Continued

SOURCE: ANALYSIS SET
ANALYSIS SETS
4_20_1550 4_5_1450

SET NAME: 4_20_1550
REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	453A3	-50	-58	8.3	6.1	0.203	0.008	18
2	453A2	0	32	64.9	47.9	1.067	0.042	37
3	453A4	25	77	113.1	83.4	1.791	0.0705	67
4	453A5	100	212	147.2	108.6	2.261	0.089	100
5	453B3	150	302	139	102.5	2.159	0.085	100
6	453A6	200	392	154.8	114.2	2.21	0.087	100
7	453B2	250	482	279.7	206.3	2.324	0.0915	100
8	453B5	250	482	239.3	176.5	1.562	0.0615	100
9	453B4	300	572	179.1	132.1	2.057	0.081	100
10	453B6	300	572	135.6	100	2.121	0.0835	100

SET NAME: 4_5_1450
REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	441A3	-50	-58	17.4	12.8	0.394	0.0155	23
2	441B4	-25	-13	32	23.6	0.597	0.0235	20
3	441A2	0	32	49.2	36.3	0.953	0.0375	47
4	441A4	25	77	81.8	60.3	1.41	0.0555	88
5	441B5	25	77	68.6	50.6	1.27	0.05	63
6	441B6	50	122	74.7	55.1	1.359	0.0535	95
7	441B3	75	167	83.4	61.5	1.511	0.0595	100
8	441A5	100	212	101	74.5	1.867	0.0735	100
9	441A6	150	302	111	81.9	2.007	0.079	100
10	441B2	200	392	114.7	84.6	2.019	0.0795	100

Table C4. Continued

SOURCE: ANALYSIS SET
ANALYSIS SETS

4_40_1450 4_5_1550 4_10_1550

SET NAME: 4_40_1450
REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	444A2	-50	-58	12.7	9.4	0.279	0.011	18
2	444B5	-25	-13	31.3	23.1	0.699	0.0275	35
3	444A3	0	32	54.1	39.9	1.194	0.047	60
4	444A4	25	77	69.7	51.4	1.372	0.054	63
5	444B4	75	167	94.1	69.4	1.994	0.0785	100
6	444A5	100	212	114.7	84.6	2.146	0.0845	100
7	444B3	150	302	122.3	90.2	2.299	0.0905	100
8	444A6	200	392	128.4	94.7	1.994	0.0785	100
9	444B6	250	482	118.6	87.5	2.273	0.0895	100
10	444B2	300	572	111	81.9	2.172	0.0855	100

SET NAME: 4_5_1550
REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	451A3	-50	-58	9.8	7.2	0.216	0.0085	16
2	451B5	-25	-13	31	22.9	0.686	0.027	30
3	451A2	0	32	63.7	47	1.118	0.044	38
4	451B6	12	54	94.5	69.7	1.778	0.07	73
5	451A4	25	77	110.6	81.6	1.842	0.0725	95
6	451B4	50	122	118	87	2.083	0.082	88
7	451B3	75	167	124.5	91.8	2.032	0.08	100
8	451A5	100	212	138.8	102.4	2.35	0.0925	100
9	451B2	150	302	132.9	98	2.223	0.0875	100
10	451A6	200	392	131.2	96.8	2.273	0.0895	100

SET NAME: 4_10_1550
REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	452A3	-50	-58	9.9	7.3	0.203	0.008	15
2	452B4	-25	-13	50.3	37.1	0.787	0.031	30
3	452A2	0	32	62.5	46.1	1.168	0.046	43
4	452B6	12	54	67.8	50	1.08	0.0425	30
5	452A4	25	77	123	90.7	1.626	0.064	88
6	452B3	50	122	113.2	83.5	1.969	0.0775	95
7	452A5	100	212	128.5	94.8	2.121	0.0835	100
8	452A6	150	302	132.1	97.4	2.159	0.085	100
9	452B2	200	392	142.9	105.4	2.108	0.083	100
10	452B5	250	482	136.5	100.7	2.248	0.0885	100

Table C4. Continued

SOURCE: ANALYSIS SET
ANALYSIS SETS
4_20_1450 4_40_1550

SET NAME: 4_20_1450
REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	443A3	-50	-58	16.3	12	0.305	0.012	18
2	443B6	-25	-13	29.3	21.6	0.572	0.0225	29
3	443A2	0	32	43.8	32.3	0.813	0.032	35
4	443A4	25	77	69.3	51.1	1.321	0.052	66
5	443B5	50	122	77.4	57.1	1.511	0.0595	99
6	443B4	75	167	94	69.3	1.842	0.0725	99
7	443A5	100	212	105.6	77.9	1.994	0.0785	100
8	443A6	150	302	106.8	78.8	1.943	0.0765	100
9	443B2	200	392	122.7	90.5	2.172	0.0855	100
10	443B3	250	482	108.1	79.7	2.108	0.083	100

SET NAME: 4_40_1550
REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	454A3	-50	-58	22.4	16.5	0.508	0.02	26
2	454B5	-25	-13	58.4	43.1	1.029	0.0405	28
3	454A2	0	32	69.7	51.4	1.232	0.0485	41
4	454B6	10	50	95.6	70.5	1.626	0.064	50
5	454A4	25	77	141.8	104.6	2.172	0.0855	81
6	454A5	100	212	164.2	121.1	2.324	0.0915	100
7	454B4	150	302	104.4	77	2.032	0.08	100
8	454A6	200	392	177.6	131	2.146	0.0845	100
9	454B3	250	482	248.8	183.5	1.994	0.0785	100
10	454B2	300	572	177.7	131.1	2.311	0.091	100

Table C4. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

4_20_1650 4_40_1650 4_10_1450

SET NAME: 4_20_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	463A3	-50	-58	3.3	2.4	0.025	0.001	3
2	463A2	0	32	37.4	27.6	0.724	0.0285	20
3	463A4	25	77	79.6	58.7	1.308	0.0515	34
4	463B5	50	122	110.5	81.5	1.74	0.0685	43
5	463A5	100	212	145.3	107.2	2.21	0.087	100
6	463B4	150	302	165	121.7	2.096	0.0825	100
7	463A6	200	392	215.3	158.8	1.905	0.075	100
8	463B6	250	482	271.8	200.5	2.311	0.091	100
9	463B2	300	572	268	197.7	2.464	0.097	100
10	463B3	350	662	182.5	134.6	1.638	0.0645	100

SET NAME: 4_40_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	464A2	-50	-58	3	2.2	0.114	0.0045	3
2	464B6	-25	-13	4.9	3.6	0.14	0.0055	3
3	464A3	0	32	55.5	40.9	0.953	0.0375	16
4	464A4	25	77	111.4	82.2	1.791	0.0705	39
5	464A5	100	212	158.5	116.9	2.235	0.088	78
6	464B4	150	302	15.3	11.3	2.121	0.0835	100
7	464A6	200	392	249.6	184.1	1.969	0.0775	100
8	464B5	250	482	260.5	192.1	1.702	0.067	100
9	464B2	300	572	264.9	195.4	2.223	0.0875	100
10	464B3	350	662	198.5	146.4	1.588	0.0625	100

SET NAME: 4_10_1450

REMARK: NONE

NMBR	IDENT	TEMPERATURE (DEG C) (DEG F)		ENERGY (J)	(FT-LB)	EXPANSION (MM) (IN)		SHEAR (PERCENT)
1	442A4	-50	-58	25.6	18.9	0.495	0.0195	3
2	442A2	0	32	39	28.8	0.8	0.0315	37
3	442A3	25	77	72.7	53.6	1.384	0.0545	74
4	442B4	75	167	83.8	61.8	1.524	0.06	100
5	442A5	100	212	89.5	66	1.702	0.067	100
6	442A6	150	302	108.6	80.1	1.93	0.076	100
7	442B2	200	392	114.3	84.3	1.918	0.0755	100
8	442B3	250	482	85.8	63.3	1.676	0.066	100
9	442B5	250	482	104.5	77.1	1.956	0.077	100
10	442B6	300	572	99.1	73.1	1.969	0.0775	100

Table C4. Continued

SOURCE: ANALYSIS SET

ANALYSIS SETS

4_40_1350 4_5_1650 4_10_1650

SET NAME: 4_40_1350

REMARK: NONE

		TEMPERATURE		ENERGY	EXPANSION		SHEAR	
NMBR	IDENT	(DEG C)	(DEG F)	(J)	(FT-LB)	(MM)	(IN)	(PERCENT)
1	434A2	-50	-58	18.6	13.7	0.381	0.015	23
2	434B5	-25	-13	35.3	26	0.686	0.027	32
3	434A3	0	32	50.2	37	1.016	0.04	50
4	434B6	10	50	61	45	1.143	0.045	55
5	434B4	25	77	72.9	53.8	1.397	0.055	75
6	434A4	50	122	88	64.9	1.651	0.065	99
7	434B3	75	167	84.5	62.3	1.702	0.067	100
8	434A5	100	212	103	76	1.93	0.076	100
9	434A6	150	302	102.4	75.5	2.083	0.082	100
10	434B2	200	392	105.9	78.1	2.057	0.081	100

SET NAME: 4_5_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	EXPANSION		SHEAR (PERCENT)	
		(DEG C)	(DEG F)		(FT-LB)	(MM)		(IN)
1	461A3	-50	-58	11.3	8.3	0.229	0.009	3
2	461B4	-25	-13	8.9	6.6	0.229	0.009	13
3	461A2	0	32	77.7	57.3	1.359	0.0535	13
4	461A4	25	77	71.9	53	1.232	0.0485	40
5	461A5	100	212	125.3	92.4	2.108	0.083	81
6	461B3	150	302	155.2	114.5	2.223	0.0875	100
7	461A6	200	392	246.6	181.9	1.829	0.072	100
8	461B5	250	482	271.3	200.1	2.083	0.082	100
9	461B2	300	572	229.5	169.3	1.88	0.074	100
10	461B6	350	662	129.8	95.7	1.93	0.076	100

SET NAME: 4_10_1650

REMARK: NONE

NMBR	IDENT	TEMPERATURE		ENERGY (J)	EXPANSION		SHEAR (PERCENT)	
		(DEG C)	(DEG F)		(FT-LB)	(MM) (IN)		
1	462B6	-75	-103	2.8	2.1	0.038	0.0015	3
2	462A3	-50	-58	37.3	27.5	0.724	0.0285	6
3	462B5	-25	-13	45.3	33.4	0.826	0.0325	21
4	462A2	0	32	70.4	51.9	1.168	0.046	38
5	462A4	25	77	124.6	91.9	1.994	0.0785	73
6	462A5	100	212	149	109.9	2.261	0.089	100
7	462A6	200	392	205.1	151.3	2.197	0.0865	100
8	462B4	250	482	298.7	220.3	1.994	0.0785	100
9	462B2	300	572	275.4	203.1	2.197	0.0865	100
10	462B3	350	662	131.5	97	1.956	0.077	100

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