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Results of the ASTM Instrumented/Miniaturized Round Robin Test Program

Reference: Manahan, M. P., Sr., Martin F. J., and Stonesifer, R. B., **"Results of the ASTM Instrumented/Miniaturized Round Robin Test Program"**, *Pendulum Impact Testing: A Century of Progress, ASTM STP 1380*, T. A. Siewert and M. P. Manahan, Sr., Eds., American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: Two related standards are currently being developed by ASTM Subcommittee E 28.07.07. The first is focused on test procedures for instrumented impact testing. It is intended that ASTM Standard E 23 will eventually reference the instrumented test standard for tests conducted using conventional Charpy V-notch (CVN) specimens. The second new standard covers miniaturized Charpy V-notch (MCVN) testing. The Instrumented/Miniaturized Charpy Round Robin Test Program was established to support development of these standards. The goal of the program is to test CVN and MCVN specimens in the transition region and in the upper-shelf region using an instrumented striker system. The test procedure for the round robin is prescribed in the draft standards. A total of six specimens are being tested in the upper-shelf region and six in the transition region for two materials.

Keywords: impact testing, instrumented striker, absorbed energy, miniaturized Charpy testing, round robin test program

Introduction

Eleven organizations, representing Japan, the United States, and Europe, are participating in the round robin test program. Table 1 lists the participants that are providing data for the CVN portion of the round robin and provides information on the testing equipment used in the program. Similar information for the MCVN portion of the program is given in Table 2. At the time of the writing of this paper, not all of the participants had completed the round robin testing. However, since more than half of the test results were submitted to Subcommittee E28.07.07 by the November 1998 deadline, a decision was made to publish the interim results of the program.

Two well-characterized materials were chosen for the program. The National Institute for Standards and Technology (NIST) has provided two heats of 4340 steel (material similar to that used for test machine verification). Oak Ridge National Laboratory (ORNL) has provided the other material, which is an A533B (HSST-03) reactor pressure

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Table 1 – *Round Robin Participants and Test Machine Characteristics for CVN Tests*

Participant	**1**	**3**	**4**	**7**	**8**	**9**	**11**
Organization	Nuc.Res. Institute, Czech R.	ENEL Research, Italy	CIEMAT, Spain	VTT Mfg. Tech., Finland	JRC-IAM-Petten, NL	SCK-CEN, Belgium	MPM Tech. Inc., USA
Machine	Pendulum	Pendulum	Pendulum	Pendulum	Pendulum	Pendulum	Pendulum
Hammer	C-hammer	U-hammer	C-hammer	C-hammer	C-hammer	C-hammer	U-hammer
Machine Mfr.	Tinius Olsen	Tinius Olsen	Wolpert	MFL	Wolpert	TONI-MFL	Tinius Olsen
Machine Capacity (J)	368	358	300	300	300	300	400
Impact Vel. (m/s)	5.1	5.12	5.53	5.43	5.52	5.42	5.47
Span (mm)	40	40	40	40	40	40	40
Striker Rad. (mm)	2	8	8	2	2	8	8
Anvil Rad. (mm)	1	1	1	1	1	1	1
Strain Gage (SG) Type		Semi-conductor		Metal wire	Metal wire	Semi-conductor	Metal wire
SG Position		Left, right		Top, bottom	Backside	Left, right	Left, right
SG Distance (cm)		1.5		1.5	1	1.5	0.762
Frequency Limit (kHz)		100	300	300	1000	1000	1000
Max Data Points	1024	4000	8000	10000	8000	8192	18182
Gen. Yield Method	2-region fit (A)	2-region fit (B)	2-region fit (A)	visual	2-region fit (A)	2-region fit (B)	Hooke's law intersect
Impact Vel. Method (C)	Light sensor	PE (No Loss)		PE (No Loss)	PE (No Loss)	PE (No Loss)	PE (W&F Loss)

Notes: Participants 2 (Imperial College, UK), 5 (Tohoku University, Japan), 6 (NIST, USA) and 10 (ORNL, USA) had not submitted data by the time of publication of this paper. Blank entries indicate data not reported.

(A) Region one is a line parallel and coincident with the rising part of the second peak. Region two is a fitted curve to the right of the General Yield Point. The intersection of the two curves defines General Yield.

(B) Region one is a linear fit to the initial load oscillations. Region two is a non-linear fit up to the maximum load. The intersection of the two curves defines General Yield.

(C) PE (No Loss) refers to calculation of the impact velocity using the pseudo mass of the hammer, the acceleration of gravity, and the potential energy without correction for windage and friction. PE (W&F Loss) refers to a revision of the PE (No Loss) procedure to include windage and friction corrections.

Table 2 –*Round Robin Participants and Test Machine Characteristics for Miniature Charpy V-Notch Tests*

Participant	**1**	**3**	**4**	**7**	**8**	**11**
Organization	Nuc.Res. Institute, Czech R.	ENEL Research, Italy	CIEMAT, Spain	VTT Mfg. Tech., Finland	JRC-IAM-Petten, NL	MPM Tech. Inc., USA
Machine	Pendulum	Drop weight	Pendulum	Pendulum	Pendulum	Pendulum
Hammer	C-hammer		C-hammer	C-hammer	C-hammer	U-hammer
Machine Mfr.	Roel Amsler	CEAST	Wolpert	Wolpert	Wolpert	Tinius Olsen
Machine Capacity (J)	50	34	25	50	15 (D)	400
Impact Vel. (m/s)	3.83	3.96	3.85	3.85	3.85	5.47
Span (mm)	19.3	19.3	19.3	19.3	19.3	19.3
Striker Rad. (mm)	2	4	2	2	2	4
Anvil Rad. (mm)	0.5	0.5	0.5	1	0.5	0.5
Strain Gage (SG) Type		Semi-conductor		Metal wire	Metal wire	Metal wire
SG Position		Lateral		Side faces	Backside	Left, right
SG Distance (cm)		2.4		1	1	0.762
Frequency Limit (kHz)		100	300	300	1000	1000
Max Data Points	20000	4000	8000	10000	8000	18182
Gen. Yield Method	2-region fit (A)	2-region fit (B)		Visual	2-region fit (A)	Hooke's law intersect
Impact Vel. Method (C)	PE (No Loss)	PE (No Loss)		PE (No Loss)	PE (No Loss)	PE (W&F Loss)

Notes: Participants 2 (Imperial College, UK), 5 (Tohoku University, Japan), 6 (NIST, USA) and 10 (ORNL, USA) had not submitted data by the time of publication of this paper. Participant 9 (SCK-CEN, Belgium) did not participate in MCVN testing. Blank entries indicate data not reported.

(A) Region one is a line parallel and coincident with the rising part of the second peak. Region two is a fitted curve to the right of the General Yield Point. The intersection of the two curves defines General Yield.

(B) Region one is a linear fit to the initial load oscillations. Region two is a non-linear fit up to the maximum load. The intersection of the two curves defines General Yield.

(C) PE (No Loss) refers to calculation of the impact velocity using the pseudo mass of the hammer, the acceleration of gravity, and the potential energy, without correction for windage and friction. PE (W&F Loss) refers to a revision of the PE (No Loss) procedure to include windage and friction corrections.

(D) Weights added to increase test machine capacity to 50 J.

vessel plate material. This choice of materials provides one material with an inherently low data scatter and one with a relatively large data scatter. An additional advantage of this choice of materials is that most of the tests can be performed at room temperature to achieve transition region behavior and upper-shelf behavior. Only one series of tests had to be performed at elevated temperature to achieve upper-shelf behavior. However, the elevated test temperature was specified well into the ductile fracture temperature region. This approach has the advantage that test temperature variation effects are essentially eliminated from the results. In addition, the absence of time constraints on specimen placement for room temperature tests provided participants the opportunity to verify proper specimen centering on the supports. This paper summarizes the test results obtained by the participants for both the CVN and MCVN tests.

Test Procedure

The goal of an ASTM round robin is to have participant laboratories follow the same test procedure so that the validity of the test procedure and the data accuracy can be evaluated. The test procedure for the current round robin is described below. Since some participants have 8 mm strikers and others have 2 mm strikers, the choice of an 8 mm or 2 mm striker was left as an option since other studies have shown negligible effects of striker radius at low and intermediate energy ranges (up to ~ 175 J)[*1*].

In accordance with ASTM Test Methods for Notched Bar Impact Testing of Metallic Materials (E 23), conventional Charpy V-notch (CVN) specimens (10 mm x 10 mm x 55 mm) have been tested. Nominally half scale miniature Charpy V-notch (MCVN) specimens (~4.83 mm x 4.83 mm x 25 mm) have also been tested. The miniature specimen sizes are slightly below 5 mm in cross section to allow them to be machined from the broken halves of conventional specimens. The ASTM E 23 anvil geometry was required for conventional specimen testing. In particular, tests were conducted using a 40 mm span with anvils having a 1 mm radius. Participants were asked to test the miniature specimens using a scaled ASTM anvil geometry (19.3 mm span with anvils having a 0.5 mm radius) although not all of the participants were able to produce a miniature anvil meeting the round robin requirements, as indicated in Table 2.

CVN tests were conducted in accordance with the test requirements of ASTM E 23. Guidance concerning instrumented testing was provided in the draft ASTM standard given in Reference [*2*]. Similarly, guidance for MCVN testing was provided in Reference [*3*]. Participants were encouraged to complete the entire test matrix (given below) although several participants chose to complete only portions of the matrix.

As mentioned earlier, uncertainties due to alignment and temperature variation were minimized for tests conducted at room temperature. The upper-shelf energy tests for the A533B material were conducted at 150°C. Since this test temperature was chosen so that the test is conducted well into the upper-shelf, the effects of heat loss during bath transfer were not expected to have a large effect on the data. The test matrix is summarized below:

A533B Material	Transitional Fracture Behavior	Upper-shelf Behavior
CVN	6 tests at 20°C ± 1°C	6 tests at 150°C ± 1°C
MCVN	-----	6 tests at 150°C ± 1°C

4340 Material	Transitional Fracture Behavior	Upper-shelf Behavior
CVN	6 tests at 20°C ± 1°C	6 tests at 20°C ± 1°C
MCVN	-----	6 tests at 20°C ± 1°C

The impact velocity was specified in the range of 3 to 6 m/sec for all tests. For test machines capable of adjusting the impact velocity, the participants were requested to keep the impact velocity as close to 5.5 m/sec as possible. In order to avoid issues related to data acquisition accuracy, it was recommended that at least 1,000 data points should be recorded for each millisecond of acquisition, or for systems with lower storage capability, it was requested that the participants acquire as many data points as possible. The data storage capacities are summarized in Tables 1 and 2.

Materials

The A533B material was provided by Oak Ridge National Laboratory (ORNL). This material was chosen because it is representative of the scatter obtained in testing reactor grade steels. The material is an ASTM A533, grade B, class 1 plate designated as plate 03 by the Heavy Section Steel Technology (HSST) program at ORNL. The material has been well characterized by ORNL and the data and fabrication history are presented in Reference [*4*]. As discussed in the reference, the through thickness Charpy, drop weight, and fracture toughness properties do not vary significantly from the ¼ thickness (T) to the ¾ T positions.

The LT and TL data in Reference [*4*] were fit to provide reference data for comparison with the round robin tests. The software used to fit the Charpy data [*5*] in this study provides two alternative fitting functions. The first is a hyperbolic tangent function with four fitting parameters. The second is a polynomial of order two (three fitting parameters). In addition to fitting the mean energy versus temperature trend, the software also simultaneously fits the data with a three-parameter Weibull statistical distribution.

The orientation of specimens tested in the round robin is TL. However, there are more ORNL data for the LT orientation than for the TL orientation. While the TL data points are sufficient to obtain a reasonable mean trend behavior, the amount of data is not sufficient to obtain a reliable statistical behavior for the material. Therefore the LT data were used to determine the Weibull exponent and the results used to fit the TL data. The results of the fitting are given in Table 3 and these data are compared with the results of the round robin testing later in the paper.

Table 3 – *Plate 03 Charpy Energies at the Two Round Robin Test Temperatures*

Oak Ridge Plate O3 LT (RW) Data

Hyperbolic Tangent Fitting					
Temperature	Energy (J)				
(C)	1%	5%	50%	95%	99%
20	53	60	78	94	100
150	148	153	165	176	180
Polynomial Fitting					
Temperature	Energy (J)				
(C)	1%	5%	50%	95%	99%
20	48	56	76	94	101
150	152	155	163	171	174

Oak Ridge Plate O3 TL (WR) Data

Hyperbolic Tangent Fitting					
Temperature	Energy (J)				
(C)	1%	5%	50%	95%	99%
20	42	47	59	70	74
150	114	117	127	135	138
Polynomial Fitting					
Temperature	Energy (J)				
(C)	1%	5%	50%	95%	99%
20	35	41	55	69	74
150	117	120	126	131	134

The 4340 specimens provided by NIST were machined from double vacuum melted AISI-SAE 4340 steel bars. This material was chosen because of its inherently low data scatter. The material preparation has been optimized by NIST for use in the Charpy test machine verification program. The steel also meets the requirements of AMS 6414 and has P, S, V, Ni, Ti, and Cu contents as low as can be achieved. The bars are normalized at 350 C and hardened to approximately 35 HRC. The goal is to produce Charpy bars having a minimum of large carbides in the structure and with the most uniform carbide precipitation as possible. Since NIST has optimized the process for conventional CVNs only, the MCVN specimens were machined from the CVNs provided by NIST using an electrical discharge (EDM) wire machine.

NIST tested twenty of the low energy CVNs (designated LL68) and twenty of the high energy CVNs (designate HH71). These tests were conducted on the NIST reference machines. The results for the LL68 tests indicated an absorbed energy of 23.7 J with a $2\sigma = 3.3$ J. Similarly, the HH71 tests resulted in an absorbed energy of 122.2 J with a $2\sigma = 13.8$ J. The uncertainties for this heat of material are comparable to and only slightly higher than those of NIST verification lots.

Results

The data submitted by the participants are summarized in Tables 4 through 6 and in Figures 1 through 7. As shown in Figure 1, the reference dial energy mean (NIST data) and the population mean (round robin participants) are in close agreement for the 4340 material. Similarly, the instrumented striker data given in Figure 1 for the 4340 material are in close agreement with the NIST reference data for all participants. As indicated in Table 5, tests on the low energy 4340 material exceeded the load limit of the instrumented test system used by participants 3 and 9. This experimental limitation resulted in the energy, brittle fracture load, and peak load data being under predicted or not measured at all. Overall, the measured means and 2σ levels are in good agreement for both the dial and instrumented energy measurement for the low energy 4340 tests.

As shown in Figure 1 for the low energy A533B material tests (top figures), the reference and population means are not in close agreement. This is believed to be due to the fact that the sample blocks were cut from different locations within the HSST 03 plate. One particularly notable feature of the Figure 1 A533B plots is the large scatter for the A533B energies. Examination of the data shows that the instrumented striker results track the dial closely, that is, a low dial reading corresponds with a low instrumented striker result. It has been concluded that the scatter is due to the statistical nature of the trigger particle fracture mechanism inherent in reactor pressure vessel steels. It is interesting to note that the scatter is larger for all of the C-hammer machines than that of the U hammer machines (Participants 3 and 11). Additional work will be required in the future to determine the cause of the low scatter for the U hammers machines as shown in Figure 1. The overall conclusion for the A533B material tests conducted in the transition region is that, in spite of the large scatter, the instrumented striker data is in good agreement with the dial energies (see Table 4).

Figure 2 presents a comparison of the dial and instrumented striker energies for CVN tests conducted on the upper-shelf. For the 4340 material, the instrumented, dial, and reference data are all in good agreement. The reference data for the A533B material does not agree with the population mean for the reasons discussed earlier. Overall, the dial and instrumented striker data for upper-shelf CVN tests for all of the participants are in very good agreement and the scatter is typical of that observed for these materials (2σ~12%).

The MCVN upper-shelf energy data are summarized in Figure 3 and in Table 6. The instrumented striker and dial energies reported for the A533B material are in close agreement, and the scatter is typical. However, the scatter for the 4340 MCVN instrumented data appears to be unacceptably large. Closer examination of the load-deflection data for participant 3 showed exceptionally large signal oscillations. Discounting the data for participants 1 (participant 1 did not submit load-deflection curves) and 3 would result in reasonable agreement between the average instrumented striker data and the average recorded dial energies. The instrumented data for Participants 4, 7, 8, and 11, which are in agreement, are on average lower than the dial energies. It is important to note that the MCVN data reported by participants 1,3,4,7, and 8 was taken using low energy capacity test machines. Hammer vibration could cause

Table 4 – *Summary of CVN Data for A533B Materials*

Participant	**1**	**3**	**4**	**7**	**8**	**9**	**11**	**Ref.**
CVN Data: Transitional Fracture Behavior – A533B Material								
Striker Rad. (mm)	2.00	8.00	8.00	2.00	2.00	4.00	8.00	8.00
Impact Vel. (m/s)	5.10	5.12	5.53	5.43	5.52	5.42	5.47	5.20
Dial Energy (J)	83.50	74.50	76.71	69.00	88.23	74.58	74.49	55.00
Dial Energy SD (J)	18.72	5.53	12.70	20.76	20.54	23.49	11.30	7.0
Instr. Striker (J)	84.77	75.16	75.75	67.20	85.74	74.58	74.49	
Instr. Striker SD (J)	19.06	5.33	13.45	22.02	20.52	23.49	11.30	
Instr.-Dial Diff. (J)	1.27	0.66	-0.96	-1.80	-2.49	†0.0	†0.0	
Gen. Yield (kN)	14.38	12.14	13.93	14.42	12.59	13.34	12.17	
Max. Load (kN)	18.81	18.50	19.29	17.34	18.20	19.34	19.19	
*PL Deflect. (mm)		3.20	3.22	2.88	2.55	2.91	3.28	
Brittle Fract. (kN)	17.37	17.94	18.08	16.38	16.92	18.97	18.62	
Brittle Arrest (kN)	7.56	4.25	10.61	5.22	8.44	7.652	9.31	
CVN Data: Upper-Shelf Fracture Behavior – A533B Material								
Striker Rad. (mm)	2.00	8.00	8.00	2.00	2.00	4.00	8.0	8.00
Impact Vel. (m/s)	5.10	5.12	5.53	5.43	5.52	5.42	5.47	5.20
Dial Energy (J)	128.2	134.2	131.8	127.6	130.5	128.3	130.0	126.0
Dial Energy SD (J)	5.64	5.72	5.18	5.41	3.91	6.19	4.60	2.75
Instr. Striker (J)	129.8	132.0	136.1	128.0	131.9	128.3	130.0	
Instr. Striker SD (J)	6.05	5.19	5.38	5.79	5.96	6.19	4.60	
Instr.-Dial Diff. (J)	1.63	-2.16	4.29	0.40	1.43	†0.0	†0.0	
Gen. Yield (kN)	11.63	10.42	11.38	11.84	12.59	11.2	10.26	
Max. Load (kN)	16.19	17.43	17.35	16.22	16.02	17.37	17.23	
*PL Deflect. (mm)		3.59	3.66	3.43	3.09	3.29	3.57	

Notes:* PL Deflect refers to the measured deflection at peak load. † The procedure used by Participants 9 and 11 employed a scaling of measured loads to match the instrumented energy with the dial energy.

Table 5 – *Summary of CVN Data for 4340 Materials*

Participant	1	3	4	7	8	9	11	Ref.
CVN Data: Transitional Fracture Behavior – 4340 Material								
Striker Rad. (mm)	2.00	8.00	8.00	2.00	2.00	4.00	8.00	8.00
Impact Vel. (m/s)	5.10	5.12	5.53	5.43	5.52	5.42	5.47	5.47
Dial Energy (J)	24.50	23.54	24.20	23.54	25.36	24.70	25.72	23.69
Dial Energy SD (J)	1.52	1.25	1.41	0.54	1.84	1.86	1.85	1.56
Instr. Striker (J)	26.80	†19.8	24.05	22.46	21.54	†	25.72	
Instr. Striker SD (J)	2.63	†0.98	2.45	1.29	1.08	†	1.85	
Instr.-Dial Diff. (J)	2.30	†-3.7	-0.15	-1.08	-3.83	†	‡0.0	
Gen. Yield (kN)	28.75							
Max. Load (kN)	33.17	†29.9	31.96	35.60	35.05	†		
*PL Deflect. (mm)		†0.85	0.88	0.80	0.89	†0.93		
Brittle Fract. (kN)	32.62	†29.6	29.63	35.60	31.45	†	36.0	
Brittle Arrest (kN)	4.90	0.15	0.00	0.00	1.03			
CVN Data: Upper-Shelf Fracture Behavior – 4340 Material								
Striker Rad. (mm)	2.00	8.00	8.00	2.00	2.00	4.00	8.00	8.00
Impact Vel. (m/s)	5.10	5.12	5.53	5.43	5.52	5.42	5.47	5.47
Dial Energy (J)	124.0	124.0	116.4	114.6	119.7	117.2	115.06	122.2
Dial Energy SD (J)	8.39	7.56	6.24	6.80	3.62	2.58	5.26	6.90
Instr. Striker (J)	127.0	122.7	118.8	116.2	119.7	117.2	115.06	
Instr. Striker SD (J)	8.29	6.44	7.12	6.69	4.14	2.58	5.26	
Instr.-Dial Diff. (J)	2.97	-1.34	2.39	1.60	-0.05	‡0.0	‡0.0	
Gen. Yield (kN)	22.61	17.09	21.36	21.04	20.40	18.87	18.503	
Max. Load (kN)	25.28	24.25	25.49	24.62	23.87	25.17	25.24	
*PL Deflect. (mm)		1.97	1.69	1.60	1.25	1.92	2.12	

Notes:* PL Deflect refers to the measured deflection at peak load. †A portion of measured loads for each specimen of Transitional Fracture Behavior 4340 Material were out of range for Participants 3 and 9. ‡ The procedure used by Participants 9 and 11 employed a scaling of measured loads to match the instrumented energy with the dial energy.

Table 6 – *Summary of MCVN Data for A533B and 4340 Materials*

Participant	**1**	**3**	**4**	**7**	**8**	**11**
MCVN Data: Upper-Shelf Fracture Behavior – A533B Material						
Striker Rad. (mm)	2.000	4.000	2.000	2.000	2.000	4.000
Impact Vel. (m/s)	3.830	3.960	3.850	3.850	3.850	5.470
Dial Energy (J)	10.78		10.98	10.90	11.29	10.73
Dial Energy SD (J)	0.325		0.603	0.292	0.186	0.231
Instr. Striker (J)	11.22	11.64	10.84	11.00	10.40	10.73
Instr. Striker SD (J)	0.360	0.581	0.623	0.292	0.185	0.231
Instr.-Dial Diff. (J)	0.433		-0.138	0.100	-0.942	0.00
Gen. Yield (kN)	2.445	2.790	2.547	2.482	2.530	2.580
Max. Load (kN)	3.263	3.668	3.358	3.392	3.254	3.399
*PL Deflect. (mm)		1.307	1.498	1.272	1.380	1.325
MCVN Data: Upper-Shelf Fracture Behavior – 4340 Material						
Striker Rad. (mm)	2.000	4.000	2.000	2.000	2.000	4.000
Impact Vel. (m/s)	3.830	3.960	3.850	3.850	3.850	5.470
Dial Energy (J)	11.12		10.62	10.78	11.28	10.84
Dial Energy SD (J)	0.172		0.224	0.179	0.347	0.177
Instr. Striker (J)	11.75	11.63	9.76	10.74	10.13	10.84
Instr. Striker SD (J)	0.176	0.305	0.207	0.241	0.350	0.177
Instr.-Dial Diff. (J)	0.633		-0.867	-0.040	-1.147	0.0†
Gen. Yield (kN)	3.975	3.482	4.08	3.946	4.007	3.741
Max. Load (kN)	4.735	5.500	4.477	4.848	4.663	4.971
*PL Deflect. (mm)		0.818	0.733	0.748	0.732	0.786

Notes:* PL Deflect refers to measured deflection at peak load. † The procedure used by participant 9 employed a scaling of measured loads to match the instrumented energy with the dial energy.

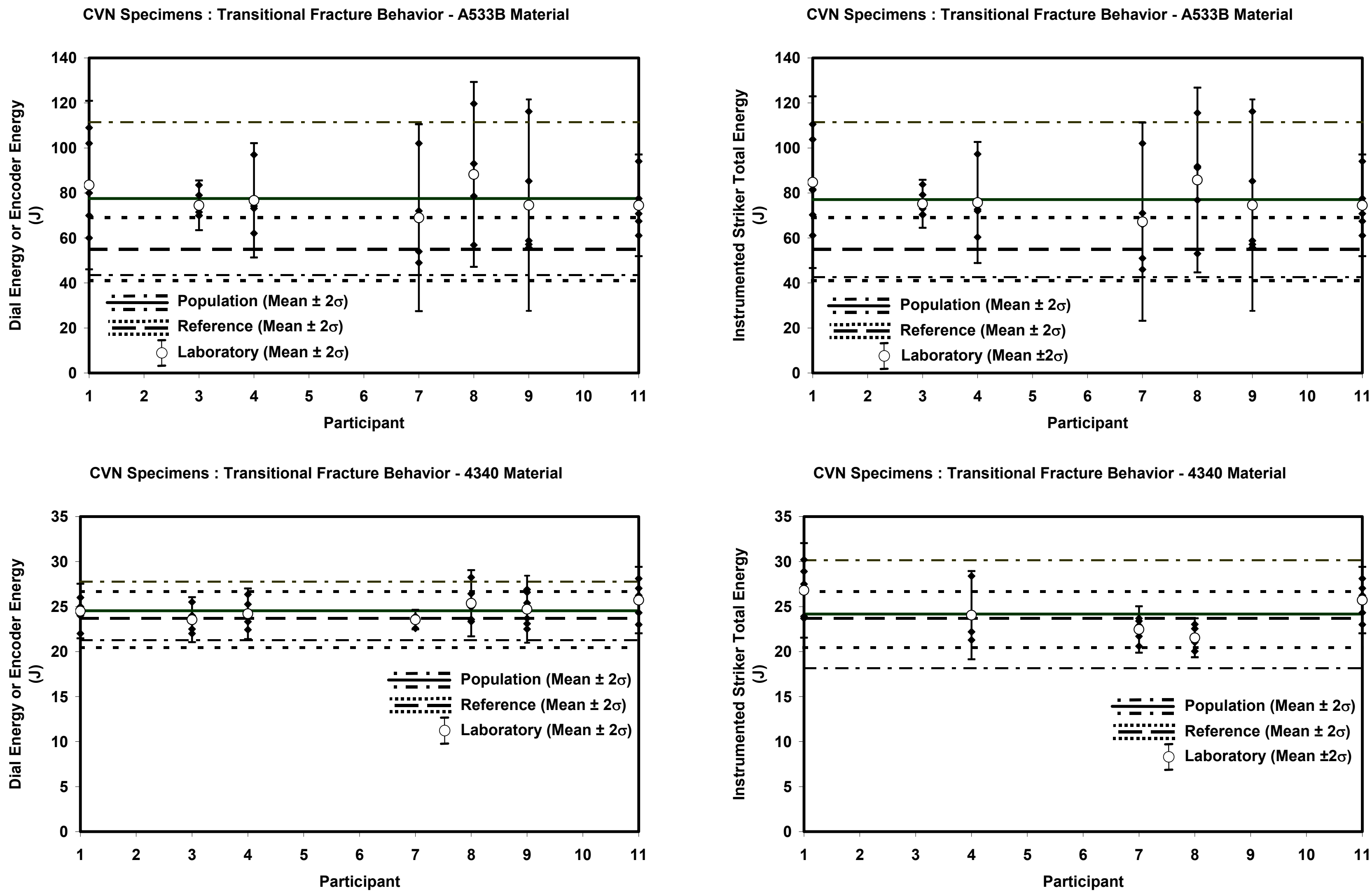

Figure 1 – *Comparison of Dial and Instrumented Striker Energies for CVN Tests Conducted in the Transition Region*

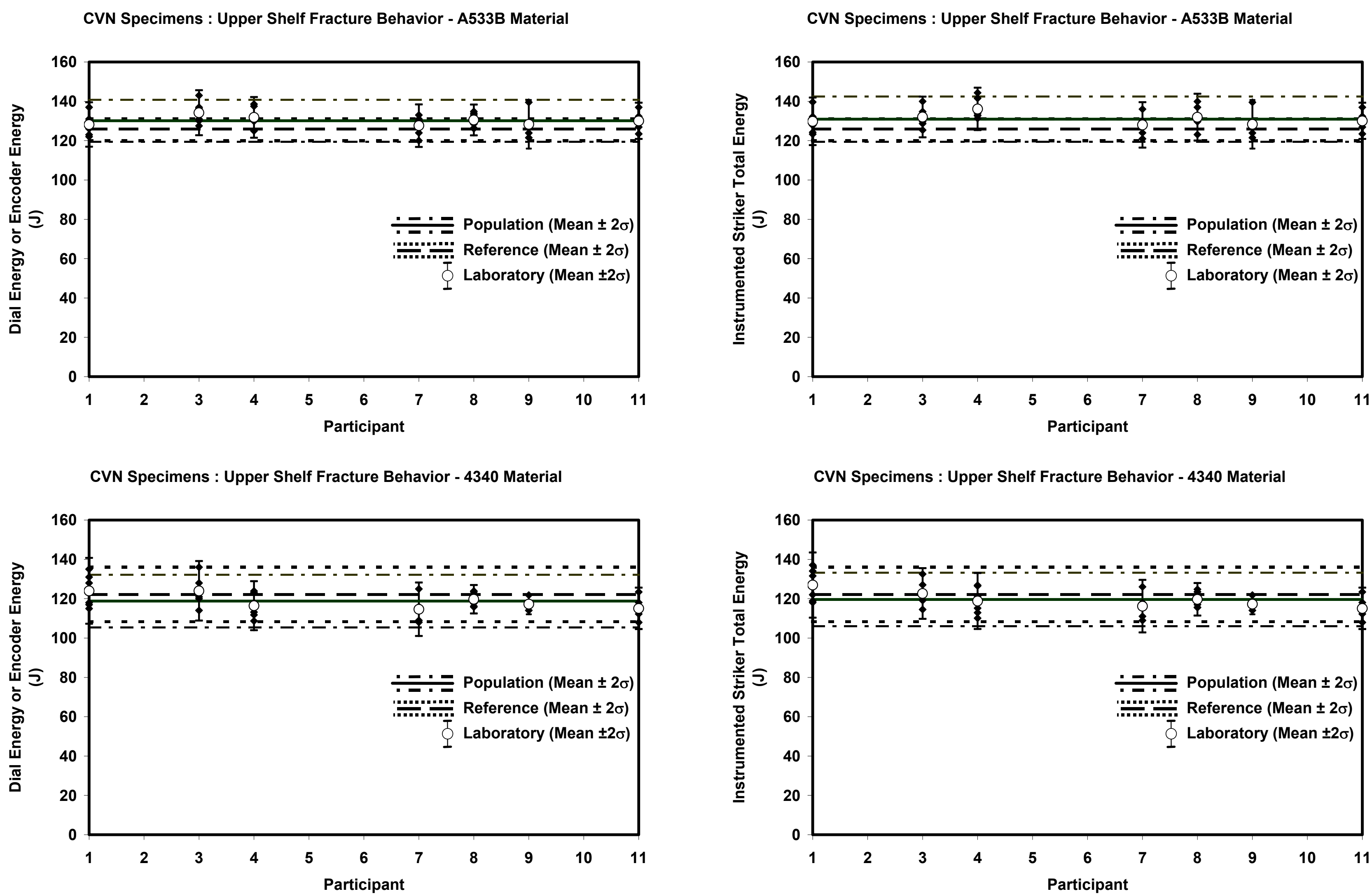

Figure 2 – *Comparison of Dial and Instrumented Striker Energies for CVN Tests Conducted on the Upper-shelf*

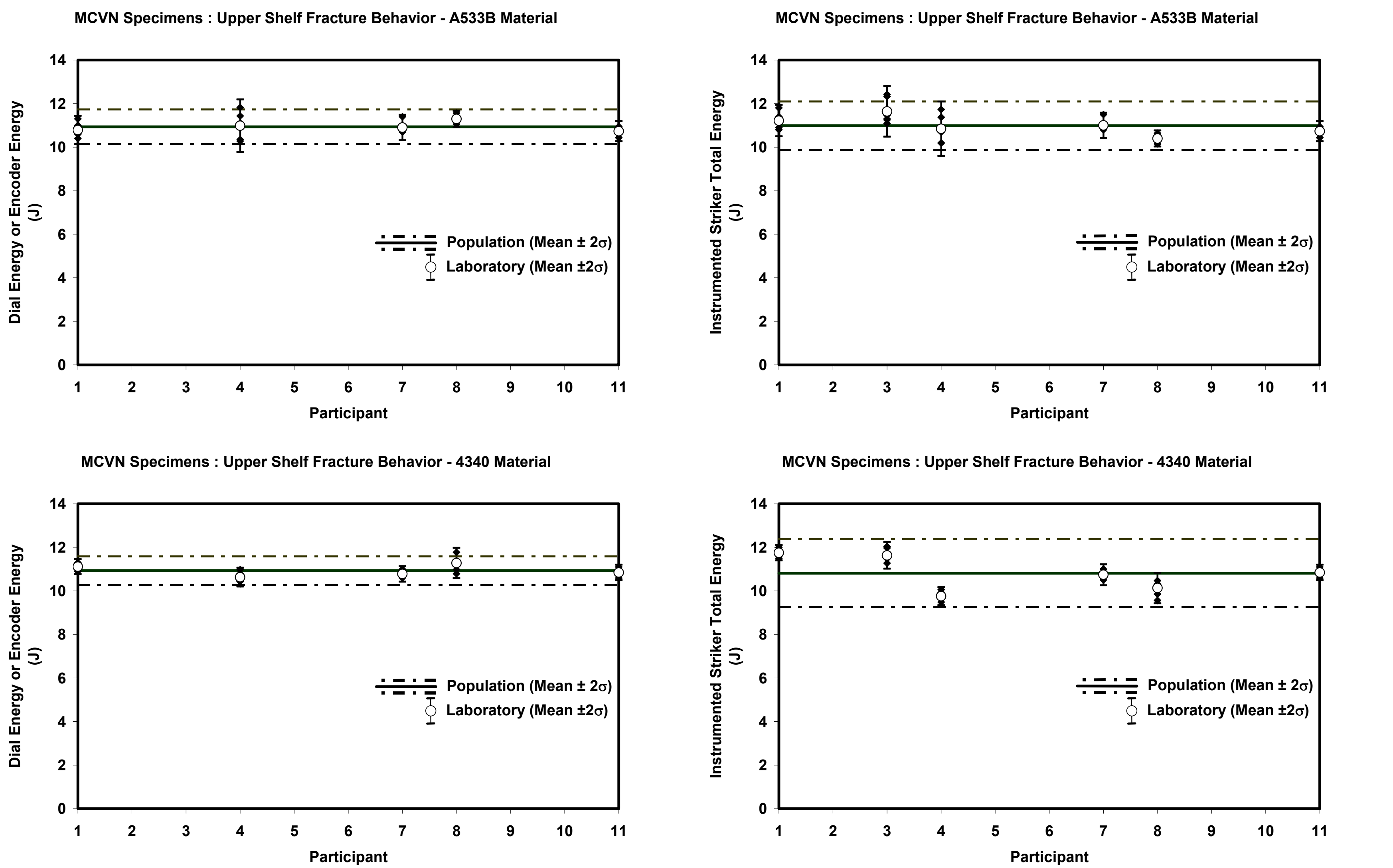

Figure 3 – *Comparison of Dial and Instrumented Striker Energies for MCVN Tests Conducted on the Upper-shelf*

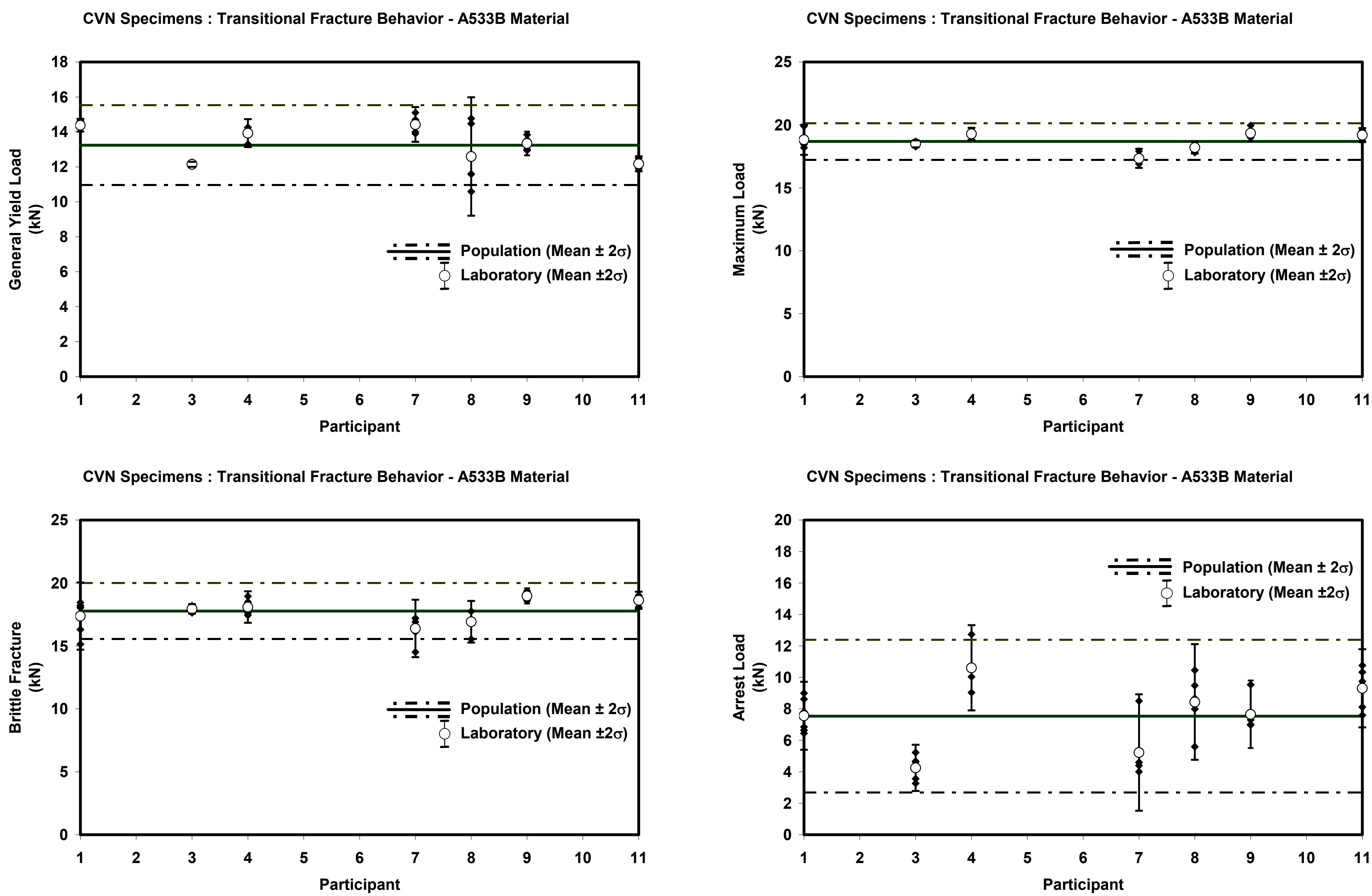

Figure 4 – *Instrumented Striker Loads for CVN Tests Conducted on A533B Material in the Transition Region*

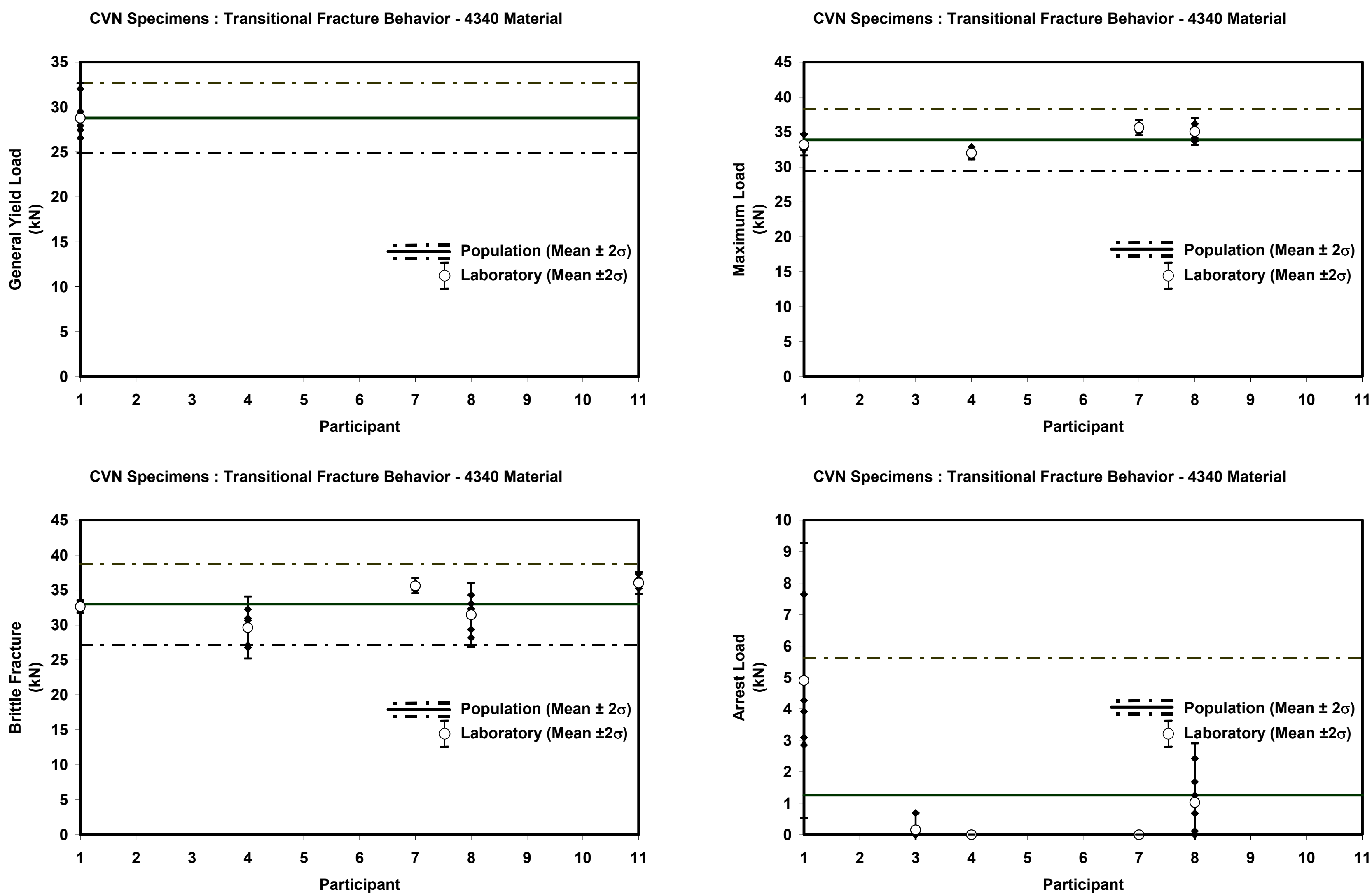

Figure 5 – *Instrumented Striker Loads for CVN Tests Conducted on 4340 in the Transition Region*

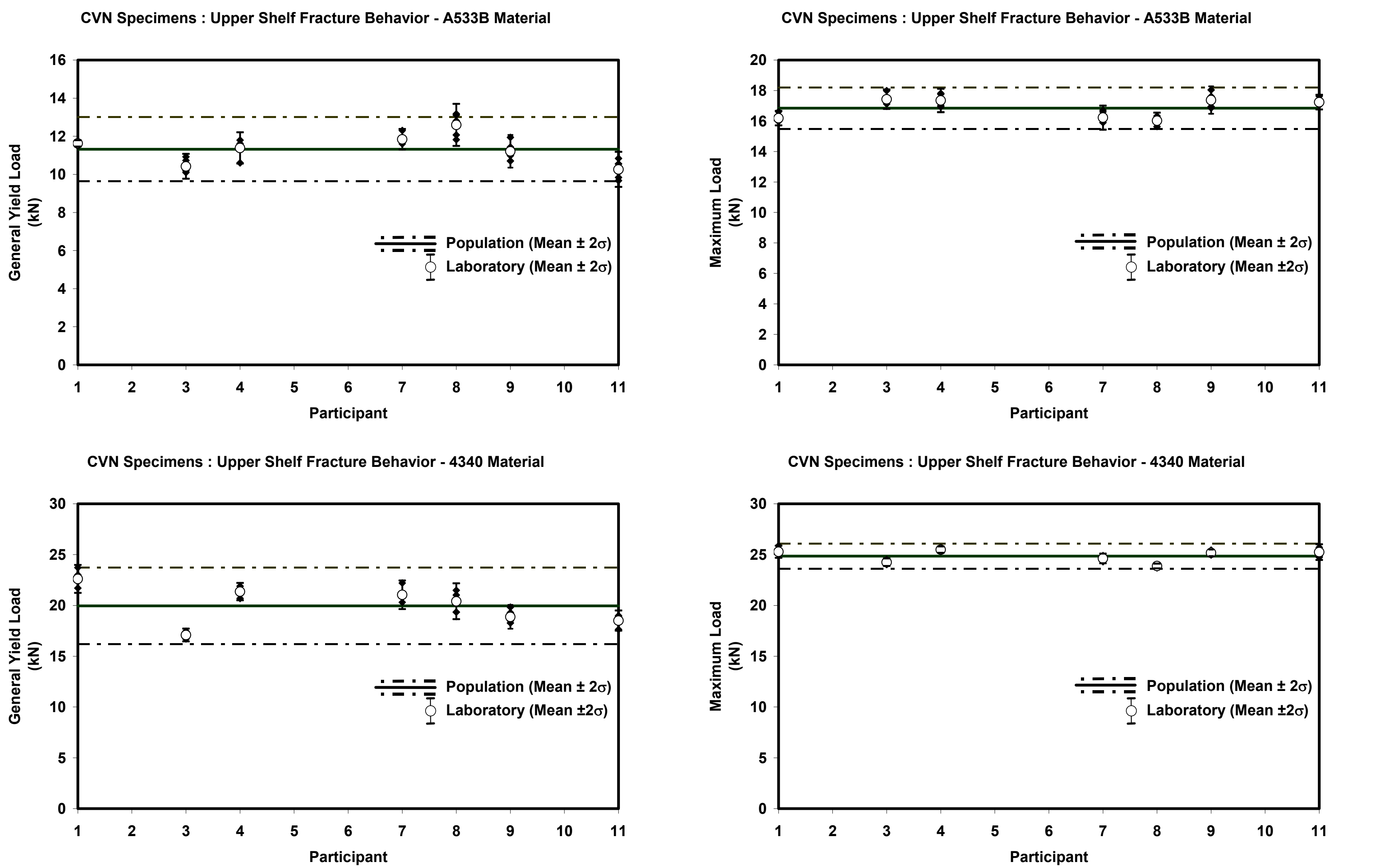

Figure 6 – *Instrumented Striker Loads for CVN Tests Conducted on the Upper-shelf*

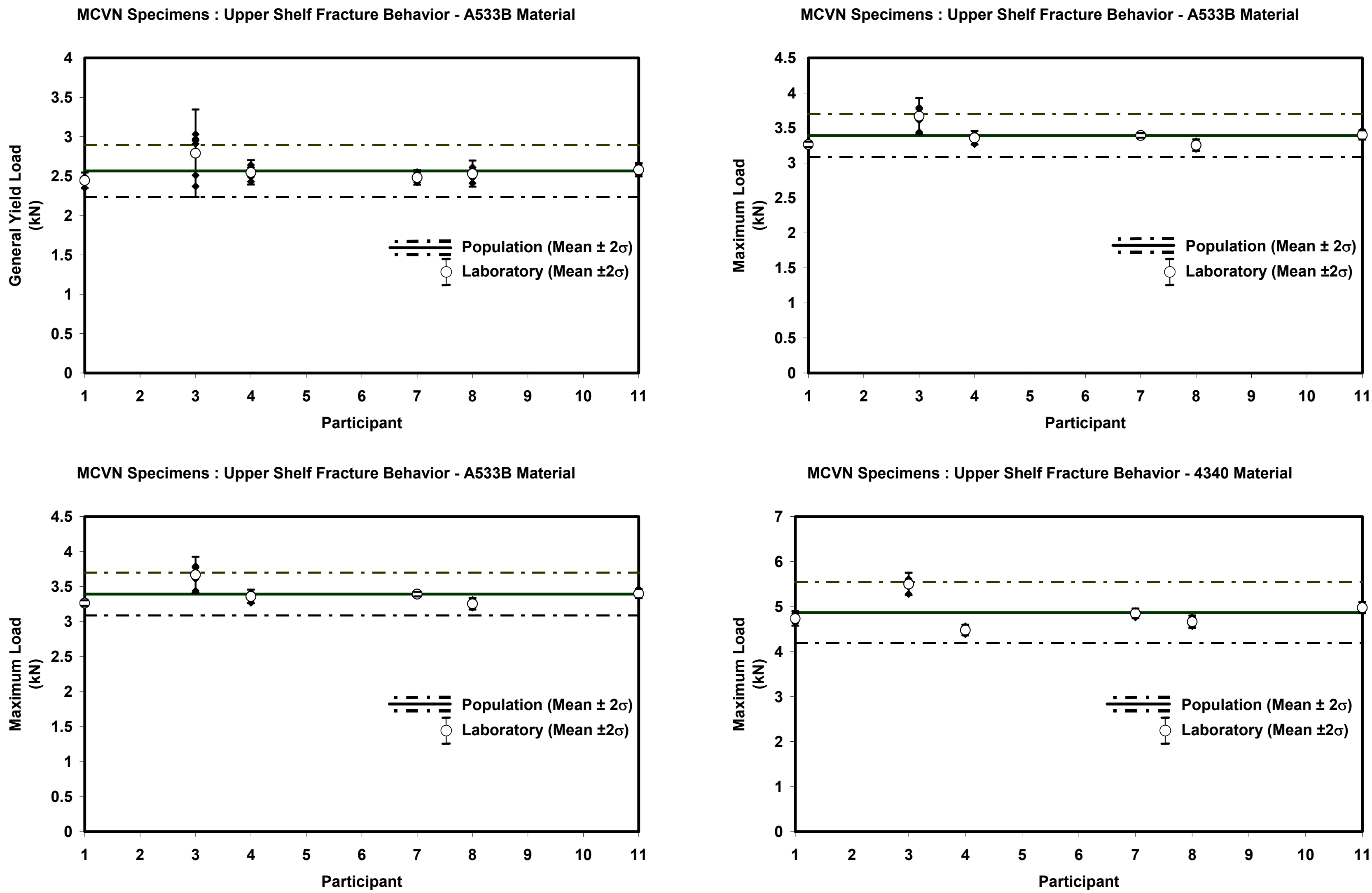

Figure 7 – *Instrumented Striker Loads for the MCVN Tests Conducted on the Upper-shelf*

lower measured energies for the instrumented measurements and several of the participant's data support this hypothesis (participants 4 and 8). The effects of hammer vibration on energy measurement are discussed in Reference [*6*], and the data of Figure 3 are consistent with conclusions of [*6*].

The instrumented striker loads for CVN tests conducted in the transition region for the A533B material are given in Figure 4 and Table 4. The results for general yield load, peak load, and brittle fracture load were consistent for all of the participants. Participant 8 experienced large scatter for general yield load and this scatter could not be analyzed because the instrumented signals were not submitted. As shown in Figure 4, the scatter in arrest load is significantly larger than that for the general yield load, peak load, and brittle fracture load. A large part of the scatter is due to the inherent uncertainty in the fracture process itself. Examination of the load-deflection curves indicates that part of the scatter is due to the procedure used by some participants, which is to extrapolate a curve fitted to the post-brittle ductile tearing data and intersect this curve with the nearly vertical unloading line of the brittle fracture event to define the crack arrest load. This approach may not be desirable because there is no physical relationship between post-brittle tearing and unstable crack propagation. Other participants have defined the crack arrest load as the lowest load recorded at the end of the brittle fracture event.

The instrumented striker loads for CVN tests conducted in the transition region for the 4340 material are given in Figure 5 and Table 5. The results for peak load, brittle fracture load, and arrest load are in good agreement. Since this material undergoes brittle fracture shortly after peak load, the crack arrest load is nearly zero for most tests. Since this material reaches peak load shortly after general yield, most participants were not able to determine the general yield load because of limited data for curve fitting.

Figure 6, and Tables 4 and 5 present the instrumented striker loads for CVN tests conducted on the upper-shelf. Similar data are presented in Figure 7 and Table 6 for MCVN tests conducted on the upper-shelf. As shown in the figures, the agreement among the participants is good and the uncertainties are relatively low.

Summary and Conclusions

The round robin testing has been performed on materials with widely differing data scatter. The 4340 material has very low scatter from specimen to specimen while the A533B material shows large transition region scatter which is typical of reactor pressure vessel steels. The draft ASTM test procedures used in this round robin have yielded results that show good agreement among the various laboratories. Accordingly, it is concluded that the standards should proceed to full ASTM Committee ballot.

It has been concluded also that several modifications and additions should be made to the existing draft standards to clarify the procedures. In particular, it has been observed that excessive vibrations in the instrumented signal may result in exceptionally large variations in the instrumented striker loads. These large oscillations are believed to be caused by insufficient test machine stiffness. The upper-shelf material behavior is characterized by dynamic oscillations during initial loading which are damped out significantly due to plasticity by the time at which peak load is reached. Therefore, instrumented signals that exhibit large load oscillations after peak load indicate insufficient test machine stiffness. The instrumented draft standard should be modified to include this caution.

Two of the participants exceeded the load capacity of their instrumented test system when testing the 4340 material. This lead to under prediction of the total absorbed energy and incorrect estimation of the peak load, brittle fracture load, and deflection to peak load. The instrumented standard should be modified to include a caution, which requires verification that the instrumented striker calibration range has not been exceeded. This clarification is particularly important in cases where test machines are not equipped with dial gages or optical encoders for independent energy measurement. In such cases, the load-time curve must be inspected for evidence of load signal saturation.

The draft standard defined the brittle fracture arrest load as "The force at the end (arrest) of unstable crack propagation…" and prescribed that this force "is determined as the force at the intersection of the steep drop of the force-displacement curve and the smoothed curve through oscillations of the subsequent part of the force-displacement curve." This determination was originally adopted because it provides a convenient means for automatic determination of the arrest load. However, as mentioned earlier, there is no physical basis for this determination. It is proposed that the draft standard be modified to define the crack arrest load as the lowest load measured at the end of the brittle fracture event unloading to ensure that an accurate and conservative crack arrest load is measured.

References

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