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Second Charpy Interlaboratory Comparison Between NIST and Anand Testing Machine Services LLP

Enrico Lucon
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Abstract

We report the results of the second Charpy Interlaboratory Comparison between NIST (National Institute of Standards and Technology, Boulder, Colorado, USA) and ATMS (Anand Testing Machine Services LLP, Kabnur, India). The first comparison was run in 2022, and was described in NIST Technical Report 2243. Each laboratory tested Charpy reference specimens that were certified and produced at different energy levels by the two institutions. Test results obtained at NIST and ATMS were compared using the same machine configuration (C-type hammer) and striker type (2 mm), and statistical methods (unpaired two-sample *t*-test) were employed to assess the significance of interlaboratory differences.

Keywords

Absorbed energy; certified Charpy reference specimens; Interlaboratory Comparison; unpaired two-sample *t*-test.

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1. Introduction

During the period September/October 2022, Anand Testing Machine Services LLP (ATMS, Kabnur, India) and the National Institute of Standards and Technology (NIST, Boulder, Colorado, USA) conducted a peer (interlaboratory) comparison, consisting of testing Charpy reference specimens produced by both institutes at different energy levels. Charpy impact tests were conducted at room temperature (21 °C) using C-type hammers and 2 mm strikers. Additional tests were performed at NIST on a U-type machine equipped with an 8 mm striker. The activity was detailed on a NIST Technical Note [1], which also included considerations on the influence of hammer type (C-type vs. U-type) and striker type (2 mm vs 8 mm) on test results.

On May 31st, 2024, Mr. Shital Anandache, Quality Manager of Anand Testing Machine Services LLP, contacted by email Enrico Lucon and Ray Santoyo, respectively Project Leader and Coordinator of the Charpy Machine Verification Program at NIST in Boulder, Colorado (USA). He proposed to run a second interlaboratory comparison, similar to the first one, and the proposal was accepted. Soon after, ATMS sent NIST 20 certified reference specimens, 10 from each of two nominal absorbed energy levels (25 J and 160 J). NIST shipped to ATMS 30 previously certified reference specimens, 10 from a low-energy lot (LL-198), 10 from a high-energy lot (HH-149), and 10 from a super-high energy lot (SH-67).

Specimens were tested at room temperature (20 °C – 21 °C) at ATMS and at NIST during the months of June and July 2024, using Charpy machines equipped with the same hammer type (C-type) and striker (2 mm striker). The C-type machine used at NIST is shown in **Figure 1**. As for the striker, 2 mm refers to the radius of the striking edge.

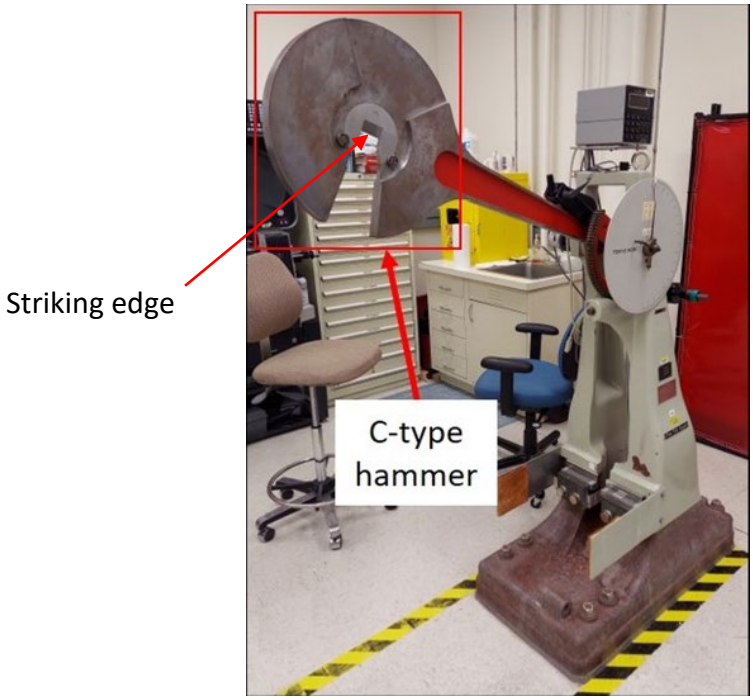

Figure 1. Charpy machine used for the tests at NIST, equipped with with a 2 mm striker.

Test results were exchanged between the two Institutes during the months of June and July 2024. This report presents a detailed comparison of such results, including basic statistical analyses.

Anand Testing Machine Services LLP (ATMS) are accredited as a Reference Material Producer in accordance with ISO 17034:2016 [2]. Their Charpy specimens are produced in accordance with ISO 148-3 [3], and can be used for the indirect verification of Charpy machine according to ISO 148-2 [4].

2. Specimens and Test Matrix

The following certified reference Charpy specimens were tested in this intercomparison.

- Specimens produced by ATMS
  - Low-energy specimens, batch ATMS-25J-M-32 (reference absorbed energy at 20 °C with 2 mm striker, KV_R = 24.6 J).
  - High-energy specimens, batch ATMS-160J-M-29 (reference absorbed energy at 20 °C with 2 mm striker, KV_R = 149.2 J).
- Specimens produced by NIST
  - Low-energy specimens, lot LL-198 (reference absorbed energy at 21 °C with 2 mm striker, KV_R = 19.1 J).
  - High-energy specimens, lot HH-149 (reference absorbed energy at 21 °C with 2 mm striker, KV_R = 134.7 J).
  - Super-high energy specimens, lot SH-67 (reference absorbed energy at 21 °C with 2 mm striker, KV_R = 206.3 J).

For each of the lots/batches listed above, 10 specimens were tested by each institute at 21 °C.

The test matrix of this interlaboratory comparison is shown in **Table 1**. Overall, 70 room temperature Charpy impact tests were performed (20 at NIST and 50 at ATMS).

Table 1. Test matrix for the second interlaboratory comparison between ATMS and NIST.

Specimen Producer	Testing institute	Lot/batch id	Number of specimens tested
ATMS	NIST	M-32	10
		M-29	10
	ATMS	M-32	10
		M-29	10
NIST	ATMS	LL-198	10
		HH-149	10
		SH-67	10

No tests on LL-198/HH-149/SH-67 were performed at NIST specifically for this intercomparison. However, for comparison purposes with the tests performed at ATMS, the certification tests conducted at NIST on the machine shown in **Figure 1** (TK machine) for the certification of the lots were used in section 4.2.

3. Test Results

3.1. Tests Performed at ATMS on NIST Reference Specimens

Three sets (units) of 10 specimens from lots LL-198 (low energy), HH-149 (high energy), and SH-67 (super-high energy) were tested at ATMS in Kabnur, India, on June 18th, 2024. The Charpy machine used (ITM-2) had a capacity of 400 J and was equipped with a C-type hammer and a 2 mm striker.

Before testing, all specimens were dimensionally checked for compliance with ASTM E23-24 [5]. The measurements are collected in Appendix A, and were all found acceptable.

The values of absorbed energy obtained are provided in **Table 2**. The detailed test reports are reproduced in Appendix B.

Table 2. Results of the Charpy tests performed at ATMS on NIST reference specimens.

Specimen Lot	*KV* (J)	Specimen Lot	*KV* (J)	Specimen Lot	*KV* (J)
LL-198	20.4	**HH-149**	135.2	**SH-67**	203.2
	18.4		134.4		197.2
	19.2		130.8		201.2
	Jammed		140.0		205.6
	19.2		137.2		197.6
	18.8		138.8		206.4
	21.2		140.0		197.6
	19.6		126.0		202.8
	21.6		134.0		198.0
	18.8		136.0		202.4
$\overline{KV}$ (J)	**19.7**		**135.2**		**201.2**
SD (J)	**1.13**		**4.34**		**3.44**
CV	**5.7 %**		**3.2 %**		**1.7 %**
KV_R (J)	**19.1**		**134.7**		**206.3**
$\lvert\Delta KV\rvert$	**0.6 J**		**0.4 %**		**2.5 %**
Repeatability	**2.8 J**		**10.4 %**		**4.1 %**

KV = absorbed energy; $\overline{KV}$ = mean absorbed energy; SD = standard deviation; CV = coefficient of variation, $\frac{\mathrm{SD}}{\overline{KV}}$; KV_R = reference absorbed energy (certified value); $|\Delta KV|$ = absolute difference between average and reference absorbed energy; repeatability = difference between largest and smallest test result.

At all three energy levels, the average absorbed energy reported by ATMS was within the largest between 1.4 J and 5 % of KV_R (ASTM E23 requirement), as well as within the largest between 4 J and 10 % of KV_R (ISO 148-2 requirement), with respect to the corresponding NIST certified values. The repeatability of the test results was also acceptable according to ISO 148-2 (within the largest between 6 J and 15 % of KV_R).

One of the low-energy specimens tested (#229) experienced jamming, and the corresponding value of absorbed energy was removed from the results and subsequent analyses. This occurrence is sometimes encountered at NIST in case of low-energy specimens, and has prompted an investigation aimed at minimizing the chance of jamming by lowering the impact

toughness of low-energy specimens. This will be achieved by changing the final tempering temperature in their heat treatment [6].

3.2. Tests Performed at ATMS on ATMS Reference Specimens

Two sets of 10 specimens from batches M-32 (low energy) and M-29 (high energy) were tested at ATMS in Kabnur, India, on July 11th, 2024, to be compared with the test conducted at NIST and described in the next section.

The values of absorbed energy obtained are provided in **Table 3**. The detailed test reports are reproduced in Appendix C.

Table 3. Results of the Charpy tests performed at ATMS on ATMS reference specimens.

Specimen Lot	*KV* (J)	Specimen Lot	*KV* (J)
M-32	24.8	**M-29**	137.2
	25.2		146.8
	24.8		138.8
	27.6		138.8
	25.2		140.0
	23.6		142.0
	26.0		141.2
	26.4		149.2
	24.0		150.0
	26.8		144.4
$\overline{KV}$ (J)	**25.4**		**142.8**
SD (J)	**1.25**		**4.54**
CV	**4.9 %**		**3.2 %**
KV_R (J)	**24.6**		**149.2**
$\lvert\Delta KV\rvert$	**0.8 J**		**4.3 %**
Repeatability	**4.0 J**		**8.6 %**

For both M-32 and M-29, the average absorbed energy is within the largest between 4 J and 10 % of KV_R (ISO 148-2 requirement) with respect to the reference values. The repeatability also fulfilled the requirements of ISO 148-2 (lower than the largest between 6 J and 15 % of KV_R).

3.3. Tests Performed at NIST on ATMS Reference Specimens

Two sets of 10 specimens from batches M-32 (low energy) and M-29 (high energy) were tested at NIST in Boulder, Colorado, on June 14th, 2024. The Charpy machine used (TK, **Figure 1**) had a capacity of 359 J and was equipped with a C-type hammer and a 2 mm striker.

Before testing, all specimens were dimensionally checked for compliance with ASTM E23. The measurements are collected in Appendix D. The length of three M-32 specimens (#501, 502, and 503) was found not compliant ($L > 55$ mm); for specimen #502, the notch root radius was also found not acceptable ($\rho < 0.225$ mm).

The values of absorbed energy obtained are provided in **Table 4**. The detailed test reports are reproduced in Appendix E.

Table 4. Results of the Charpy tests performed at NIST on ATMS reference specimens.

Specimen Lot	*KV* (J)	Specimen Lot	*KV* (J)
M-32	25.2	**M-29**	140.2
	22.8		141.9
	24.0		143.3
	23.7		149.7
	27.2		138.2
	26.3		145.7
	24.3		145.0
	23.6		147.4
	24.6		140.6
	26.0		153.9
$\overline{KV}$ (J)	**24.8**		**144.6**
SD (J)	**1.40**		**4.79**
CV	**5.6 %**		**3.3 %**
KV_R (J)	**24.6**		**149.2**
$\lvert\Delta KV\rvert$	**0.2 J**		**3.1 %**
Repeatability	**4.5 J**		**10.5 %**

At both energy levels, the average absorbed energy reported by NIST was within the largest between 4 J and 10 % of KV_R (ISO 148-2 requirement) with respect to the corresponding ATMS certified values. The repeatability of the test results was also acceptable according to ISO 148-2 (within the largest between 6 J and 15 % of KV_R).

4. Statistical Comparisons Between ATMS and NIST

4.1. ATMS Reference Specimens

The results obtained by ATMS and NIST on ATMS reference specimens from batches M-32 and M-29 (**Table 3** and **Table 4**) have been statistically compared by means of the unpaired two-sample *t*-test, which compares two datasets to see if their means are statistically different [7]. If the calculated probability (*p-value*) is larger than the threshold confidence level for statistical significance ($\alpha = 0.05$), the difference between the means is considered not statistically significant.
Mean values of absorbed energy and corresponding standard deviations are shown in **Table 5** for the three lots and the two institutes. The results of the *t*-tests are provided in **Table 6**.

Table 5. Sample sizes, means, and standard deviations for ATMS and NIST tests on ATMS reference specimens.

Institute	M-32			M-29		
	N	$\overline{KV}$ **(J)**	**SD (J)**	***N***	$\overline{KV}$ **(J)**	**SD (J)**
ATMS	10	25.4	1.25	10	142.8	4.54
NIST	10	24.8	1.40	10	144.6	4.79

Absorbed energy values are also illustrated in the form of box-and-whiskers plots in **Figure 2** (M-32) and **Figure 3** (M-29). It can be observed that no test result lies beyond the whiskers (corresponding to ±1.5 *IQR*, with *IQR* = interquartile range).

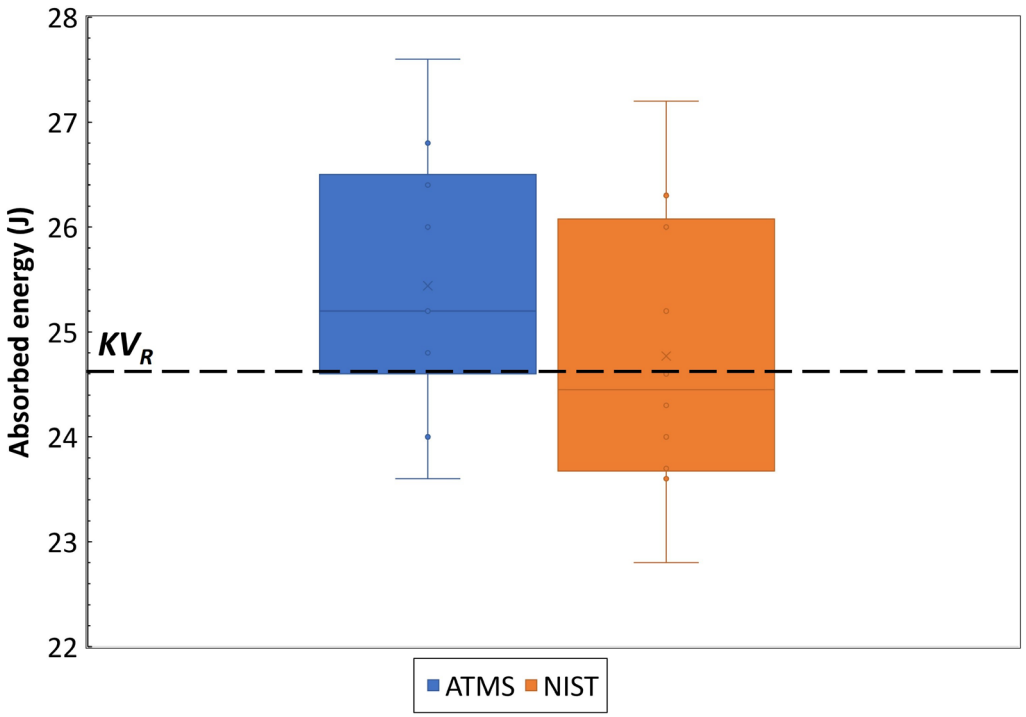

Figure 2 – Comparison between ATMS and NIST test results on M-32 specimens. Round symbols indicate individual test results. The crosses and the lines inside the boxes indicate mean and median values respectively. The whiskers correspond to 1.5 *IQR*, where *IQR* is the interquartile range. The thick dashed line represents the reference absorbed energy, K_R.

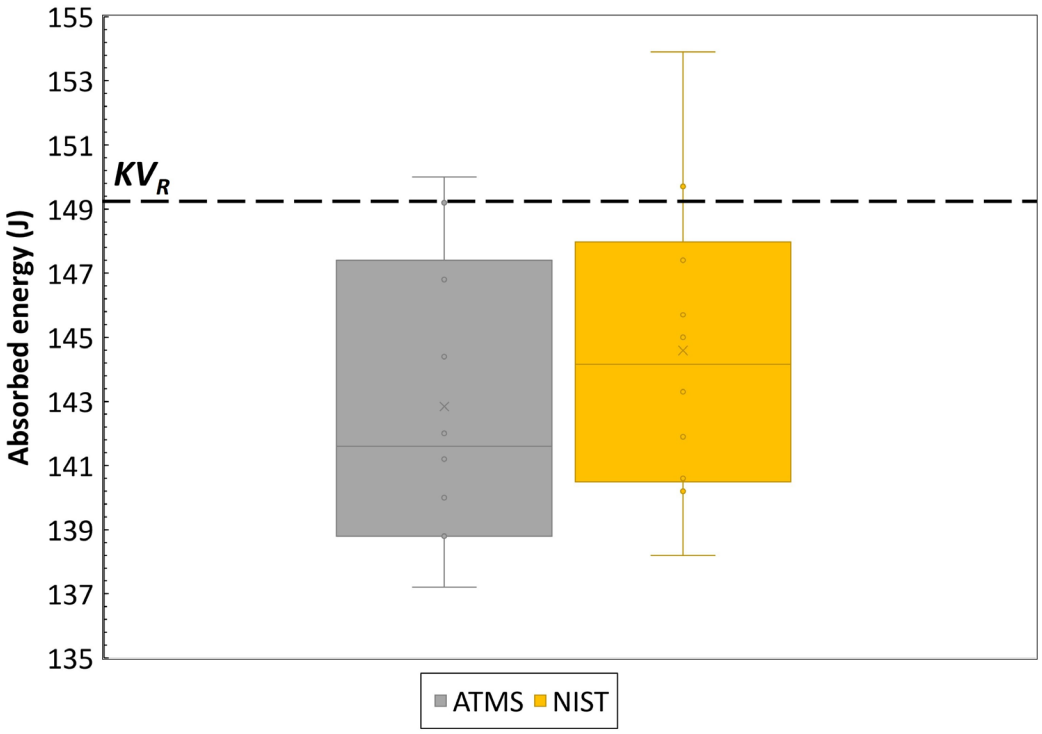

Figure 3 – Comparison between ATMS and NIST test results on M-29 specimens.

Table 6. Calculated probability values from *t*-tests for the Charpy tests on ATMS reference specimens.

Specimen lot	*p-value*	Interpretation
M-32	0.3254	Difference between means is not significant
M-29	0.3998	Difference between means is not significant

Based on the calculated *p*-values, differences between results obtained by ATMS and NIST on ATMS reference specimens are statistically not significant at both energy levels.

4.2. NIST Reference Specimens

The results obtained by ATMS on NIST reference specimens from lots LL-198, HH-149, and SH-67 (**Table 2**) have been statistically compared to the absorbed energy values obtained at NIST during the certification of the same three lots, only considering the TK machine shown in **Figure 1** (C-type hammer, 2 mm striker).
Average values of absorbed energy and corresponding standard deviations are summarized in **Table 7** for the three lots and the two institutes. Absorbed energy values are also illustrated in the form of box-and-whiskers plots in **Figure 4** (LL-198), **Figure 5** (HH-149), and **Figure 6** (SH-67).

Table 7. Sample sizes, means, and standard deviations for ATMS and NIST tests on NIST reference specimens.

Institute	LL-198			HH-149			SH-67		
	N	$\overline{KV}$ **(J)**	**SD (J)**	***N***	$\overline{KV}$ **(J)**	**SD (J)**	***N***	$\overline{KV}$ **(J)**	**SD (J)**
ATMS	10	19.7	1.13	10	135.2	4.34	10	201.2	3.44
NIST	23	17.4	1.16	24	135.8	4.66	25	207.7	2.95

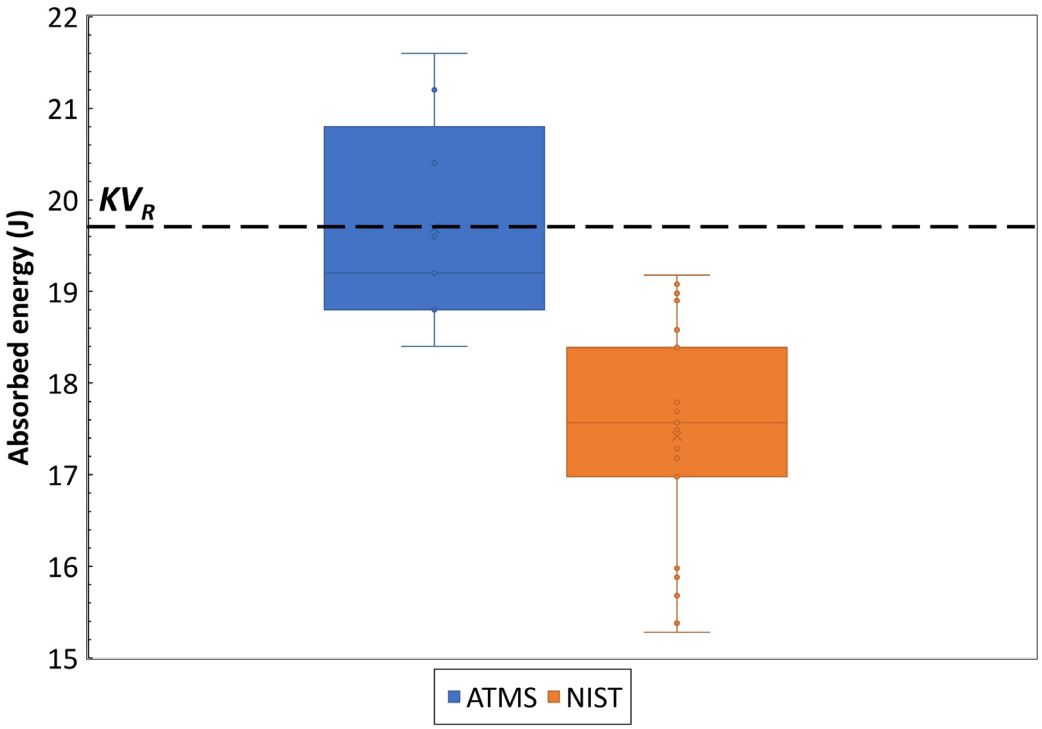

Figure 4 - ATMS and NIST test results on LL-198 specimens.

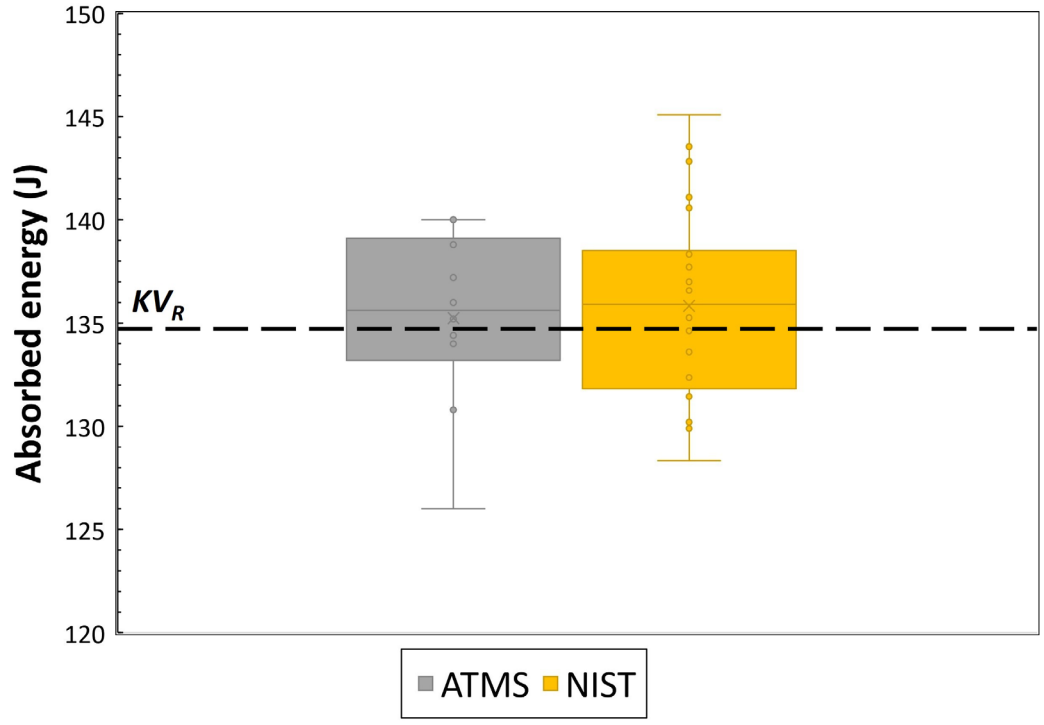

Figure 5 - ATMS and NIST test results on HH-149 specimens.

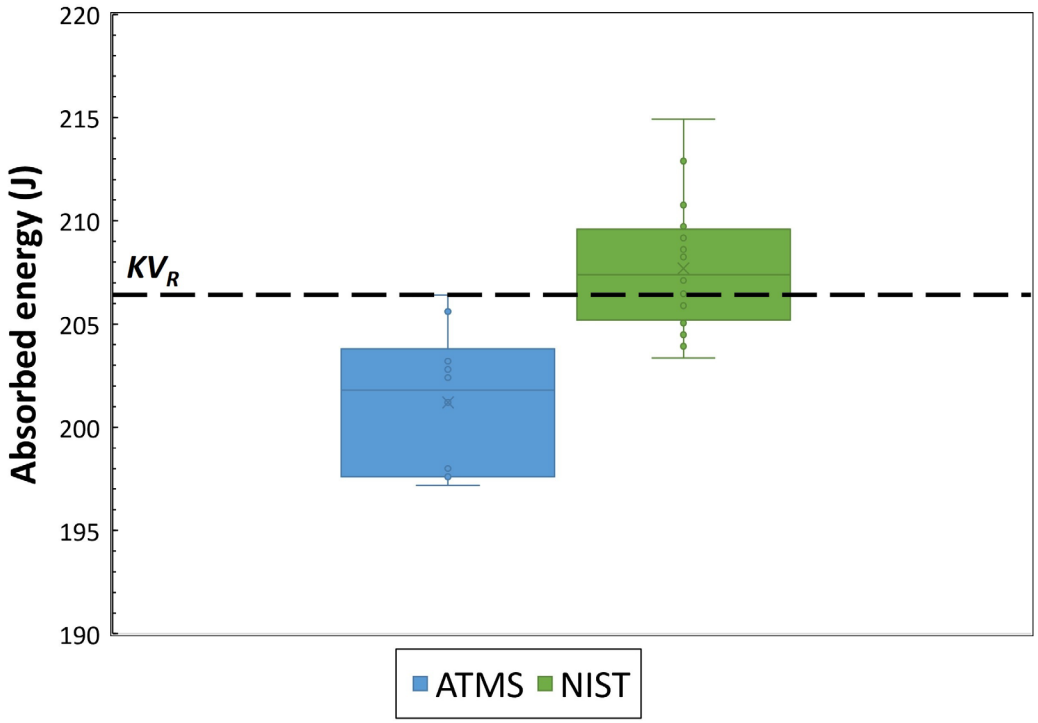

Figure 6 - ATMS and NIST test results on SH-67 specimens.

Once again, statistical comparisons consisted in running unpaired two-sample *t*-tests on mean values and standard deviations. For the data in **Table 7**, the calculated *p*-values and their interpretation are shown in **Table 8**.

Table 8. Calculated probability values from *t*-tests for the Charpy tests on NIST reference specimens.

Specimen lot	*p-value*	Interpretation
LL-198	< 0.0001	Difference between means is extremely significant
HH-149	0.7167	Difference between means is not significant
SH-67	< 0.0001	Difference between means is extremely significant

Based on the calculated *p*-values, differences between results obtained by ATMS and NIST on NIST reference specimens are statistically extremely different at low (LL-198) and super-high (SH-67) energy levels, while the difference is not significant at the high (HH-149) energy level. This outcome is essentially consistent with the statistical results that emerged from the first ATMS/NIST Intercomparison [1], when differences were found statistically significant at the low-energy level, but not at the high-energy level (super-high energy specimens had not been tested).

Additionally, in order to compare approximately equally-sized data sets, we generated 5 samples for each Charpy lot, by randomly extracting 10 *KV* values from the 23 to 25 test results obtained by NIST during the certification of LL-198, HH-149, and SH-67 using the C-type machine and the 2 mm striker. The results obtained by ATMS (**Table 2**) were then compared with each of the random samples, and the statistical significance of the differences were

assessed by two-sample *t*-tests. Once again, *p*-values above the significance level $\alpha = 0.05$ indicate that differences are not significant, while *p*-values < 0.05 are obtained when differences are statistically significant.

The results shown in **Table 9** are fully consistent with those presented in **Table 8**. At the low- and super-high energy level, ATMS and NIST test results remain different with a very high level of statistical significance, while differences are not significant at the high-energy level.

Table 9. NIST reference specimens: *t*-test results for the statistical comparisons between ATMS test results and random samples extracted from NIST certification tests.

NIST Lot id	Random sample	Mean ATMS tests (J)	Mean random sample (J)	*p-value*	Interpretation
LL-198	1	19.7	17.2	0.000195	Difference between samples is very significant
	2		17.4	0.000671	Difference between samples is very significant
	3		17.5	0.000948	Difference between samples is very significant
	4		17.4	0.000744	Difference between samples is very significant
	5		17.3	0.000262	Difference between samples is very significant
HH-149	1	135.2	136.7	0.497625	Difference between samples is not significant
	2		136.3	0.632273	Difference between samples is not significant
	3		135.1	0.946425	Difference between samples is not significant
	4		138.4	0.119371	Difference between samples is not significant
	5		136.8	0.464989	Difference between samples is not significant
SH-67	1	201.2	207.7	0.000132	Difference between samples is very significant
	2		208.3	0.000109	Difference between samples is very significant
	3		207.4	0.000367	Difference between samples is very significant
	4		207.4	0.000142	Difference between samples is very significant
	5		206.6	0.000757	Difference between samples is very significant

5. Conclusions

In June and July 2024, Anand Testing Services (ATMS, India) and the National Institute of Standards and Technology (NIST, USA) conducted a second interlaboratory comparison of Charpy tests on reference specimens produced by both Institutes, following up on a similar exercise conducted in 2022.

Considering the most popular reference test standards, the tests run by ATMS on NIST reference specimens fulfilled the conditions of a valid indirect machine verification according to both ASTM E23 and ISO 148-2 at all energy levels (low, high, and super-high). Similarly, the tests conducted by NIST on ATMS reference specimens were found to be in compliance with the requirements of ISO 148-2 both in terms of bias and repeatability.

Statistical comparisons between results from the two Institutes, conducted by means of unpaired two-sample *t*-tests, showed the following:

- Differences between ATMS and NIST results on ATMS reference specimens (batches M-32 and M-29) are not statistically significant.
- Differences between ATMS and NIST results (these latter generated during the certification of the lots) on NIST reference specimens (lots LL-198, HH-149, and SH-67) are not statistically significant for HH-149 (high-energy specimens), but are statistically extremely significant for both LL-198 (low-energy specimens) and SH-67 (super-high energy specimens). This was observed both considering mean values and standard deviations and comparing ATMS results and equally-sized randomly generated samples extracted from NIST certification tests.

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[7] Student, “The Probable Error of a Mean,” *Biometrika*, vol. 6, no. 1, p. 1, Mar. 1908, doi: 10.2307/2331554.

Appendix A. Dimensional measurements performed by ATMS on NIST reference specimens

ANAND TESTING MACHINE SERVICES LLP, RMP DIVISION						
No.	RMP-7.3 / QR - 20	Revision No.	01	Revision Date	01.01.2017	Page 1 of 1

Lot No. : LL - 189

MEASUREMENT OF FINAL DIMENSIONS

Date : 18 JUNE 2024

ATMS Tolerance	54.7 to 55.0 mm	± 0.2 mm	9.97 - 10.03 mm	9.97 - 10.03 mm	0.225 to 0.275 mm		44.00 to 46.00 deg		7.975 to 8.025 mm		89.85 to 90.15 deg			
TP No. / Accepted Yes / No.	Length in mm, L	Centring in mm, 27.5 mm	Width in mm, W	Thickness in mm, B	Radius in mm		Angle in degrees		Ligament Length in mm, 8.00 mm		Angle Adjacent Sides in degree			
					1	2	1	2	1	2	A	B	C	D
0226	54.9	0.003	10.015	10.015	0.2481	0.2531	44.46	44.36	8.007	8.008	89.98	90.02	89.98	90.03
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0227	54.89	0.015	10.015	10.008	0.2501	0.2466	44.45	44.32	8.008	8.012	90.03	89.95	90.03	89.97
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0228	54.87	0.006	10.010	10.005	0.2498	0.251	44.54	44.35	8.008	8.008	90.00	89.93	89.98	89.98
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0229	54.89	0.005	10.005	10.01	0.2501	0.2526	44.33	44.41	7.996	8	90.05	89.95	90.03	89.97
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0230	54.89	0.009	10.010	10.005	0.2583	0.2495	44.53	44.51	8.012	8.012	90.03	89.98	90.02	89.97
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0786	54.78	0.042	10.022	10.011	0.2508	0.2481	44.55	44.62	8.011	8.007	89.93	90.05	89.93	90.02
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0787	54.89	0.076	10.010	10.008	0.2478	0.2492	44.37	44.43	8.008	8.006	89.95	90.02	89.93	90.03
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0788	54.9	0.012	10.011	10.008	0.2524	0.2501	44.42	44.27	8.009	8.01	89.97	89.97	89.97	90.02
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0789	54.9	0.001	10.006	10.012	0.2554	0.2531	44.73	44.68	8.013	8.011	90.00	90.02	89.95	90.02
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0790	54.9	0.027	10.005	10.01	0.2528	0.2522	44.48	44.05	8.005	8.009	89.93	89.93	90.03	89.93
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Lot No. : HH - 149

MEASUREMENT OF FINAL DIMENSIONS

Date : 18 JUNE 2024

ATMS Tolerance	54.7 to 55.0 mm	± 0.2 mm	9.97 - 10.03 mm	9.97 - 10.03 mm	0.225 to 0.275 mm		44.00 to 46.00 deg		7.975 to 8.025 mm		89.85 to 90.15 deg			
TP No. / Accepted Yes / No.	Length in mm, L	Centring in mm, 27.5 mm	Width in mm, W	Thickness in mm, B	Radius in mm		Angle in degrees		Ligament Length in mm, 8.00 mm		Angle Adjacent Sides in degree			
					1	2	1	2	1	2	A	B	C	D
1264	54.94	0.041	10.002	10	0.2549	0.2605	44.89	44.92	8.012	8.012	90.00	90.00	90.02	89.98
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1368	54.95	0.023	10.008	9.995	0.2706	0.2686	45.19	45.12	8.013	8.013	89.98	90.02	89.98	90.03
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1650	54.93	0.033	9.998	10.01	0.256	0.264	45.15	45.09	8.006	8.002	89.97	90.02	90.02	90.02
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2078	54.94	0.011	10.010	9.994	0.2493	0.2588	44.89	44.96	8.006	8.008	90.03	89.97	89.97	90.02
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2261	54.93	0.044	10.008	9.992	0.2589	0.2536	45.00	45.02	8.008	8.001	89.98	90.02	90.02	90.02
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0356	54.94	0.057	10.000	10	0.2537	0.2540	45.13	45.27	8.01	8.007	89.98	89.98	90.02	89.98
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0528	54.92	0.080	9.998	9.998	0.2552	0.2595	45.14	44.92	8.007	8.003	89.98	90.02	89.98	90.02
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1543	54.92	0.037	9.996	10.004	0.2465	0.2484	45.02	45.32	8.004	8.009	90.07	89.97	90.05	89.95
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1961	54.94	0.056	10.004	9.998	0.2515	0.2545	45.01	45.24	8.004	8.003	89.98	90.02	90.00	90.00
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2189	54.92	0.091	10.010	10.01	0.2603	0.2545	44.42	44.34	8.002	7.993	89.98	90.02	90.00	90.02
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Lot No. : SH - 67

MEASUREMENT OF FINAL DIMENSIONS

Date : 18 JUNE 2024

ATMS Tolerance	54.7 to 55.0 mm	± 0.2 mm	9.97 - 10.03 mm	9.97 - 10.03 mm	0.225 to 0.275 mm		44.00 to 46.00 deg		7.975 to 8.025 mm		89.85 to 90.15 deg			
TP No. / Accepted Yes / No.	Length in mm, L	Centring in mm, 27.5 mm	Width in mm, W	Thickness in mm, B	Radius in mm		Angle in degrees		Ligament Length in mm, 8.00 mm		Angle Adjacent Sides in degree			
					1	2	1	2	1	2	A	B	C	D
0291	54.87	0.001	10.010	10.000	0.2602	0.2595	44.09	44.26	7.991	7.995	89.97	89.98	90.02	90.03
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0292	54.88	0.031	9.990	10.012	0.2631	0.2615	44.57	44.50	7.995	7.995	89.98	90.02	90.10	89.90
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0293	54.88	0.029	10.015	9.988	0.2628	0.2641	44.07	44.26	7.994	7.997	90.07	89.93	90.07	89.92
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0294	54.88	0.057	9.986	10.005	0.2618	0.2635	44.94	44.67	8.001	8.002	90.00	90.00	89.88	90.12
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0295	54.87	0.054	9.995	10.020	0.2555	0.2515	44.47	44.66	7.996	7.998	89.95	90.05	89.87	90.10
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0296	54.88	0.003	10.020	10.010	0.2573	0.2590	44.41	44.51	7.997	7.997	90.00	90.00	89.95	90.02
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0297	54.84	0.012	9.990	10.010	0.2559	0.2581	44.05	44.32	7.997	7.995	90.00	89.97	90.02	89.97
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0298	54.83	0.012	10.000	10.010	0.2647	0.2621	44.30	44.63	7.998	7.997	90.00	89.98	89.93	89.95
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0299	54.89	0.023	10.010	10.000	0.2516	0.2571	44.42	44.26	8.002	7.995	89.97	90.02	89.93	90.03
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0300	54.87	0.022	9.996	10.010	0.2526	0.2541	44.17	44.13	7.98	7.982	89.98	90.03	89.93	90.02
Accetable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Appendix B. Results of Charpy tests performed at ATMS on NIST reference specimens

ANAND TESTS (JUNE 18, 2024)

Test Machine : ITM-2 (400 J)
Striker Type : 2 mm
Temparature : 21°C

Lot	Specimen No.	KV (J)	B / NB / FB	A / S
LL - 189	0226	20.4	B	S
	0227	18.4	B	S
	0228	19.2	B	A
	0229	jammed		
	0230	19.2	B	A
	0786	18.8	B	S
	0787	21.2	B	S
	0788	19.6	B	A
	0789	21.6	B	A
	0790	18.8	B	S
	Reference Absorbed Energy = 19.1			
	Average Absorbed Energy = 19.7			
	Standard Deviation = 1.13			
	Coefficient of Variation = 0.057			

Lot	Specimen No.	KV (J)	B / NB / FB	A / S
HH - 149	1264	135.2	B	S
	1368	134.4	B	S
	1650	130.8	B	S
	2078	140.0	B	S
	2261	137.2	B	S
	0356	138.8	FB	A
	0528	140.0	B	S
	1543	126.0	B	S
	1961	134.0	FB	A
	2189	136.0	FB	A
	Reference Absorbed Energy = 134.7			
	Average Absorbed Energy = 135.2			
	Standard Deviation = 4.34			
	Coefficient of Variation = 0.032			

Lot	Specimen No.	KV (J)	B / NB / FB	A / S
SH - 67	0291	203.2	NB	- - - - -
	0292	197.2	NB	- - - - -
	0293	201.2	NB	- - - - -
	0294	205.6	NB	- - - - -
	0295	197.6	NB	- - - - -
	0296	206.4	NB	- - - - -
	0297	197.6	NB	- - - - -
	0298	202.8	NB	- - - - -
	0299	198.0	NB	- - - - -
	0300	202.4	NB	- - - - -
	Reference Absorbed Energy = 206.3			
	Average Absorbed Energy = 201.2			
	Standard Deviation = 3.44			
	Coefficient of Variation = 0.017			

Appendix C. Results of Charpy tests performed at ATMS on ATMS reference specimens

ANAND TESTS (JULY 11, 2024)

Test Machine : ITM-2 (400 J)
Striker Type : 2 mm
Temparature : +20°C

Lot	Specimen No.	KV (J)	B / NB / FB	A / S
M 32	066	24.8	B	A
	067	25.2	B	A
	068	24.8	B	A
	069	27.6	B	A
	070	25.2	B	S
	071	23.6	B	A
	072	26.0	B	S
	073	26.4	B	S
	074	24.0	B	A
	075	26.8	B	S
	Reference Absorbed Energy = 24.6			
	Average Absorbed Energy = 25.4			
	Standard Deviation = 1.25			
	Coefficient of Variation = 0.049			

Lot	Specimen No.	KV (J)	B / NB / FB	A / S
M 29	176	137.2	B	S
	177	146.8	FB	A
	178	138.8	B	S
	179	138.8	B	S
	180	140.0	B	S
	226	142.0	B	S
	227	141.2	B	S
	228	149.2	FB	A
	229	150.0	FB	A
	230	144.4	B	S
	Reference Absorbed Energy = 149.2			
	Average Absorbed Energy = 142.8			
	Standard Deviation = 4.54			
	Coefficient of Variation = 0.032			

Appendix D. Dimensional measurements performed by NIST on ATMS reference specimens

Lot	Specimen id	*L* (mm)	*W* (mm)	*B* (mm)	Notch cntr (mm)	α (°)	ρ (mm)	*b* (mm)
M-32	501	55.018	10.002	10.002	0.029	45.39	0.225	7.994
	502	55.014	10.000	10.008	0.056	45.56	0.224	8.000
	503	55.004	10.006	9.999	0.020	45.52	0.236	8.004
	504	54.891	10.006	10.003	0.077	45.43	0.236	7.993
	505	54.856	10.006	10.003	0.013	45.43	0.232	7.992
	656	54.940	9.997	10.001	0.052	45.15	0.252	7.984
	657	54.943	10.002	10.000	0.047	45.61	0.238	7.990
	658	54.942	10.004	9.990	0.064	45.31	0.250	7.990
	659	54.967	10.000	10.001	0.012	45.60	0.250	7.993
	660	54.898	10.009	10.005	0.066	45.22	0.248	8.002
M-29	56	54.828	10.001	9.989	0.038	45.17	0.252	7.989
	57	54.872	9.998	10.004	0.003	45.59	0.249	7.987
	58	54.860	10.000	9.994	0.006	45.39	0.252	7.991
	59	54.831	9.998	9.996	0.005	45.43	0.244	7.987
	60	54.845	10.004	9.996	0.004	45.00	0.247	7.986
	101	54.845	10.001	9.994	0.093	45.30	0.230	8.007
	102	54.908	9.991	9.995	0.107	44.83	0.248	7.992
	103	54.849	9.997	9.993	0.098	45.18	0.245	7.999
	104	54.838	9.991	9.996	0.143	44.98	0.236	8.000
	105	54.944	9.997	9.998	0.123	45.64	0.241	8.000

Appendix E. Results of Charpy tests performed at NIST on ATMS reference specimens

Lot	Specimen id	*KV* (J)	B/NB/FB	A/S
M-32	501	25.2	B	A
	502	22.8	B	A
	503	24.0	B	A
	504	23.7	B	A
	505	27.2	B	S
	656	26.3	B	A
	657	24.3	B	A/S
	658	23.6	B	A
	659	24.6	B	A
	660	26.0	B	S
	Reference absorbed energy = 24.6 J Average absorbed energy = 24.8 J Standard deviation = 1.4 J Coefficient of variation = 0.056			
M-29	56	140.2	B	S
	57	141.9	B	S
	58	143.3	FB	A
	59	149.7	FB	A
	60	138.2	B	S
	101	145.7	FB	A
	102	145.0	FB	A
	103	147.4	FB	A
	104	140.6	B	S
	105	153.9	FB	A
	Reference absorbed energy = 149.2 J Average absorbed energy = 144.6 J Standard deviation = 4.8 J Coefficient of variation = 0.033			