

**NIST Technical Note
NIST TN 2243**

Charpy Interlaboratory Comparison Between NIST and Anand Testing Machine Services

Enrico Lucon and Raymond Santoyo

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[Status]

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Abstract

Results are reported of an Interlaboratory Comparison between NIST (National Institute of Standards and Technology, Boulder, Colorado, USA) and ATMS (Anand Testing Machine Services, Kabnur, India). The study consisted of testing certified Charpy reference specimens produced by both Institutes in both locations, corresponding to four different absorbed energy levels (18 J, 60 J, 108 J, and 150 J). Besides directly comparing test results obtained with the same machine configuration (C-type hammer and 2 mm striker), the use of a different hammer (U-type) and striker type (8 mm) at NIST allowed some insight into the influence of hammer and striker types on Charpy test results.

Keywords

Certified Charpy reference specimens, Charpy hammer type, Charpy striker type, Interlaboratory Comparison.

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1. Introduction

On September 27, 2022, Mr. Shital V. Anandache, Quality Manager of Anand Testing Machine Services (ATMS, Kabnur, India), contacted the NIST Charpy Machine Verification Program (E. Lucon and R. Santoyo) and proposed a peer (interlaboratory) comparison with NIST, consisting in testing Charpy reference specimens at two energy levels. Impact tests were to be conducted with a 2 mm striker¹ and at room temperature (21 °C).

The proposal was accepted by NIST, and an agreement was reached to exchange reference Charpy specimens between the two Institutes, and test them under the same conditions (striker type and test temperature).

Impact tests were performed at NIST and Anand Testing Machine Services, and results were exchanged, during the months of September/October 2022. This report presents a detailed comparison of such results, including basic statistical analyses.

Anand Testing Machine Services (ATMS) are accredited as a Reference Material Producer in accordance with ISO 17034:2016.

2. Specimens and Test Matrix

Certified reference Charpy specimens produced by both NIST and ATMS were used in this exercise, namely:

- Specimens from NIST
 - Low-energy specimens, lot LL-189 (reference absorbed energy at -40 °C with 8 mm striker, $KV_R = 15.6 \text{ J}$)².
 - High-energy specimens, HH-190 (reference absorbed energy at -40 °C and with 8 mm striker, $KV_R = 103.8 \text{ J}$)².
- Specimens from ATMS
 - Medium-energy specimens, batch ATMS-60J-M20 (reference absorbed energy at 20 °C with 2 mm striker, $KV_R = 62.5 \text{ J}$).
 - High-energy specimens, batch ATMS-160J-M21 (reference absorbed energy at 20 °C with 2 mm striker, $KV_R = 147.1 \text{ J}$).

For each of the lots/batches listed above, 10 specimens were tested by each institute. Due to a wrong selection of the machine striker (8 mm instead of 2 mm), 10 additional specimens of M20 and 10 additional specimens of M21 were shipped by ATMS to NIST and eventually tested. Furthermore, 10 additional LL-189 specimens and 5 additional HH-190 specimens were tested at NIST to assess the influence of the hammer type (C-type vs. U-type).

The complete test matrix of this interlaboratory comparison is shown in **Table 1**. Overall, 115 room temperature Charpy impact tests were performed (75 at NIST and 40 at ATMS).

¹ By “2 mm striker” we mean a striker having a radius of the striking edge equal to 2 mm, as opposed to 8 mm (“8 mm striker”), which is the most commonly used striker geometry in the United States.

² Currently, NIST low-energy and high-energy specimens are only certified at -40 °C ± 1 °C.

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

Specimen Producer	Lot/batch id	Striker type	Hammer type	Number of specimens tested (Institute)
NIST	LL-189	2 mm	U-type	10 (NIST)
			C-type	10 (NIST), 10 (ATMS)
	HH-190	2 mm	U-type	10 (NIST)
			C-type	5 (NIST), 10 (ATMS)
ATMS	M-20	2 mm	C-type	10 (NIST), 10 (ATMS)
		8 mm	U-type	10 (NIST)
	M-21	2 mm	C-type	10 (NIST), 10 (ATMS)
		8 mm	U-type	10 (NIST)

3. Test results

3.1. NIST reference specimens

3.1.1. Tests performed at NIST

Two groups of 10 specimens from lots LL-189 and HH-190 were tested at NIST in Boulder, Colorado, on September 29th, 2022. The machine used was one of the NIST reference machines, with a capacity of 359 J, equipped with a U-type hammer (**Fig. 1**) and a 2 mm striker.



Fig. 1. Reference Charpy machine (U-type hammer) used for the 1st series of tests performed at NIST on lots LL-189 and HH-190.

The results are provided in **Table 2**.

Table 2. Results of the 1st series of tests performed at NIST on LL-189 and HH-190 (U-type hammer, 2 mm striker).

Specimen Lot	KV (J)	Specimen Lot	KV (J)
LL-189	19.5	HH-190	112.3
	18.8		105.9
	18.8		108.4
	18.9		105.1
	19.7		108.7
	18.4		107.4
	19.8		105.3
	19.2		106.8
	19.2		109.0
	19.8		105.1
\overline{KV} (J)	19.2		107.4
SD (J)	0.48		2.28
CV	2.5 %		2.1 %

KV = absorbed energy; \overline{KV} = mean absorbed energy; SD = standard deviation; CV = coefficient of variation, $\frac{SD}{\overline{KV}}$.

A second series of tests on 10 specimens of LL-189 and 5 specimens of HH-190 was performed on October 19th, 2022, using a different NIST reference machine (**Fig. 2**), equipped with a C-type hammer and a 2 mm striker. This machine has a capacity of 360 J.

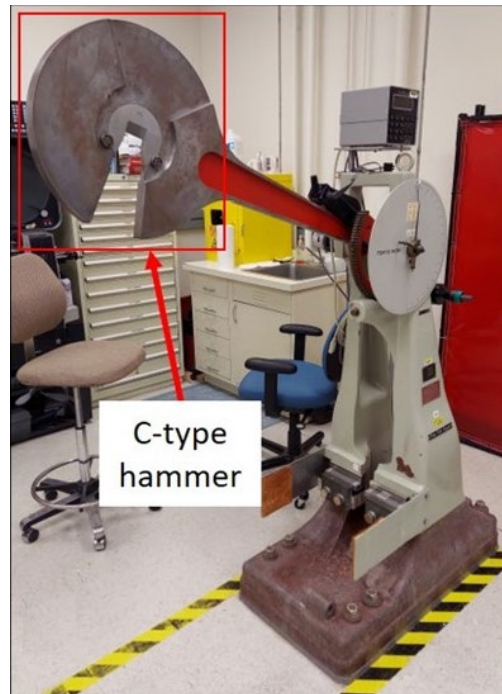


Fig. 2. Reference Charpy machine (C-type hammer) used for the 2nd series of tests performed at NIST on lots LL-189 and HH-190.

The results are provided in **Table 3**.

Table 3. Results of the 2nd series of tests performed at NIST on LL-189 and HH-190 (C-type hammer, 2 mm striker).

Specimen Lot	KV (J)	Specimen Lot	KV (J)
LL-189	17.7	HH-190	
	17.5		
	17.1		109.7
	17.8		112.3
	17.5		105.5
	17.6		106.4
	17.9		112.8
	17.6		
	17.3		
	18.3		
\overline{KV} (J)	17.6		109.4
SD (J)	0.33		3.33
CV	1.9 %		3.0 %

Pictures of the LL-189 and HH-190 specimens tested at NIST (both series) are provided in Appendix A.

3.1.2. Tests performed at ATMS

Two sets of 10 specimens from lots LL-189 and HH-190 were tested at ATMS in Kabnur, India, on October 16th, 2022. The test machine used (ITM-2) had a capacity of 400 J and was equipped with a C-type hammer and a 2 mm striker.

The results are provided in **Table 4**. The dimensional measurements performed by ATMS on the NIST specimens are reproduced in Appendix B.

Table 4. Results of the tests performed at ATMS on NIST lots LL-189 and HH-190 (C-type hammer, 2 mm striker).

Specimen Lot	KV (J)	Specimen Lot	KV (J)
LL-189	17.2	HH-190	104.4
	18.0		102.4
	18.4		105.6
	18.0		101.2
	18.4		106.0
	18.0		109.6
	18.4		108.0
	18.4		102.4
	17.6		102.0
	18.0		110.4
\overline{KV} (J)	18.0		105.2
SD (J)	0.40		3.29
CV	2.2 %		3.1 %

Pictures of the LL-189 and HH-190 specimens tested at ATMS are provided in Appendix C.

3.2. ATMS reference specimens

3.2.1. Tests performed at NIST

Two groups of 10 specimens from batches M-20 (samples #022 and #023) and M-21 (samples #112 and 113) were tested at NIST on October 7th, 2022. The machine used was the same shown in **Fig. 1** – however, the wrong type of striker (8 mm instead of 2 mm) was used by mistake.

The results obtained are provided in **Table 5**. The dimensional measurements performed on the 20 specimens are reproduced in Appendix D.

Table 5. Results of the 1st series of tests performed at NIST on ATMS batches M-20 and M-21 (U-type hammer, 8 mm striker).

Specimen Batch	KV (J)	Specimen Batch	KV (J)
M-20	62.5	M-21	146.9
	61.5		160.2
	61.1		149.1
	61.3		153.6
	61.5		146.3
	60.7		149.5
	61.6		158.7
	58.6		150.6
	60.3		150.9
	62.5		157.0
\overline{KV} (J)	61.1		152.3
SD (J)	1.12		4.90
CV	1.8 %		3.2 %

A second series of tests on 10 specimens of M-20 and 10 specimens of M-21 was performed at NIST on October 25th, 2022, using the NIST reference machine shown in **Fig. 2**, equipped with a C-type hammer and a 2 mm striker.

The results obtained are provided in **Table 6**. The dimensional measurements performed on the second series of 20 specimens are reproduced in Appendix E.

For both series of tests and at both energy levels, the NIST results satisfy the requirements of both ASTM E23-18 ($|\overline{KV} - KV_R| \leq 5 \% KV_R$) and ISO 148-2:2016 ($|\overline{KV} - KV_R| \leq 10 \% KV_R$ and $KV_{max} - KV_{min} \leq 15 \%$) with respect to the certified values provided by ATMS.

Table 6. Results of the 2nd series of tests performed at NIST on ATMS batches M-20 and M-21 (C-type hammer, 2 mm striker).

Specimen Batch	KV (J)	Specimen Batch	KV (J)
M-20	61.1	M-21	144.0
	65.6		148.9
	63.6		146.6
	64.1		146.8
	66.1		146.8
	62.5		149.9
	66.0		149.3
	62.8		151.5
	64.3		153.0
	66.8		152.3
\overline{KV} (J)	64.3		148.9
SD (J)	1.83		2.88
CV	2.8 %		1.9 %

Pictures of the M-20 and M-21 specimens tested at NIST (both series) are provided in Appendix F.

3.2.2. Tests performed at ATMS

Two sets of 10 specimens from batches M-20 (samples #028-029) and M-21 (samples #070-071) were tested at ATMS in Kabnur, India, on October 16th, 2022. The test machine used (ITM-2) had a capacity of 400 J and was equipped with a C-type hammer and a 2 mm striker.

The results are provided in **Table 7**.

Table 7. Results of the tests performed at ATMS on batches M-20 and M-21 (C-type hammer, 2 mm striker).

Specimen Batches	KV (J)	Specimen Batches	KV (J)
M-20	61.6	M-21	147.6
	64.0		154.0
	63.6		144.0
	64.4		149.6
	62.4		148.0
	62.0		138.8
	61.6		145.6
	63.6		144.8
	62.0		143.6
	62.0		140.4
\overline{KV} (J)	62.7		145.6
SD (J)	1.06		4.43
CV	1.7 %		3.0 %

Pictures of the M-20 and M-21 specimens tested at ATMS are provided in Appendix G.

4. Result Comparisons and Statistical Analyses

4.1. Direct Comparisons (C-type Hammers, 2 mm Strikers)

Seventy-five of the 115 Charpy tests performed in the framework of this Interlaboratory Comparison were conducted under nominally identical experimental conditions:

- test temperature: 20 °C
- pendulum hammer type: C
- radius of striking edge: 2 mm.

Values of average absorbed energy, standard deviation, and coefficient of variation for these tests are summarized in **Table 8**. The same information is illustrated in the form of box-and-whiskers plots for the NIST (**Fig. 3**) and ATMS (**Fig. 4**) reference specimens. All results from the two Institutes partially overlap.

Table 8. Summary data from the tests performed with C-type hammers and 2 mm strikers.

Specimen Producer	Lot/batch id	Institute	Number of specimens tested	\overline{KV} (J)	SD (J)	CV (%)
NIST	LL-189	NIST	10	17.6	0.33	1.9
		ATMS	10	18.0	0.40	2.2
	HH-190	NIST	5	109.4	3.33	3.0
		ATMS	10	105.2	3.29	3.1
ATMS	M-20	NIST	10	64.3	1.83	2.8
		ATMS	10	62.7	1.06	1.7
	M-21	NIST	10	148.9	2.89	1.9
		ATMS	10	145.6	4.43	3.0

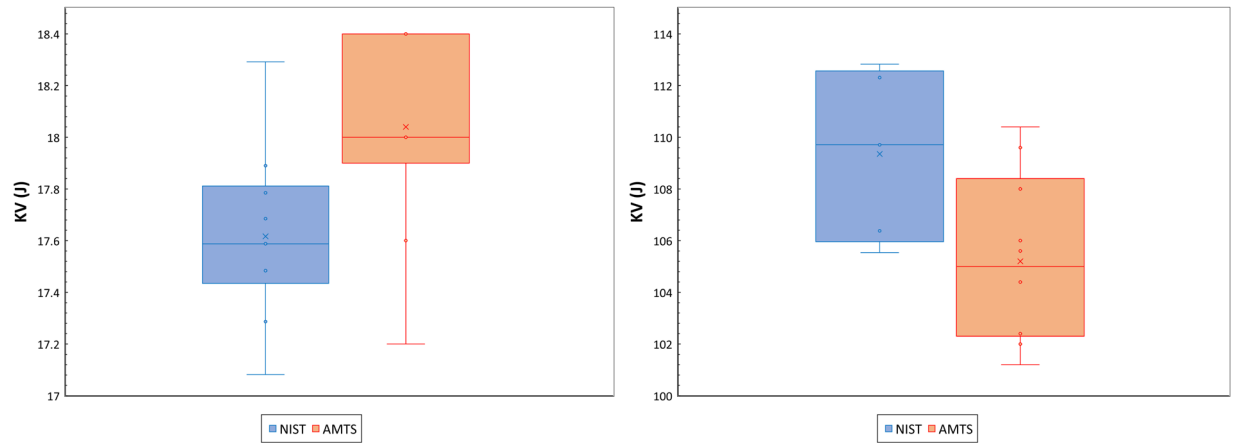


Fig. 3. Box-and-whiskers plots for NIST reference specimens tested with C-type hammers and 2 mm strikers. Left: LL-189; right: HH-190.

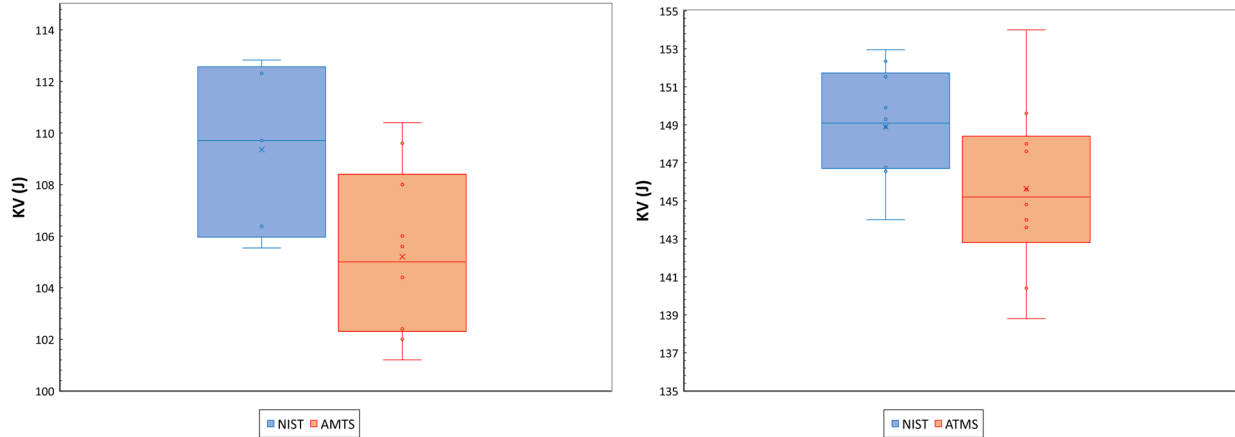


Fig. 4. Box-and-whiskers plots for ATMS reference specimens tested with C-type hammers and 2 mm strikers. Left: M-20; right: M-21.

Statistical comparisons between mean absorbed energy values produced by NIST and ATMS on the same type of reference specimens and under the same test conditions were performed by means of two-sample t -tests assuming unequal variances [1]. Calculated p -values smaller than the confidence level $\alpha = 0.05$ indicate that the differences between data set means are statistically significant. The smaller the p -value, the more significant the difference.

Calculated p -values for the 4 types of reference specimens are listed in **Table 9**.

Table 9. Two-tailed t -test results calculated for the tests performed with C-type hammers and 2 mm strikers.

Specimen Producer	Lot/batch id	Institute	\overline{KV} (J)	p	Difference between means is statistically...
NIST	LL-189	NIST	17.6	0.0194	Significant
		ATMS	18.0		
	HH-190	NIST	109.4	0.0516	Not significant
		ATMS	105.2		
ATMS	M-20	NIST	64.3	0.0349	Significant
		ATMS	62.7		
	M-21	NIST	148.9	0.0707	Not significant
		ATMS	145.6		

For two of the reference specimen types considered, differences between NIST and ATMS means are statistically significant. Note, however, that all calculated p -values are quite close to the significance limit of 0.05.

The acceptability of the results in **Table 8** with respect to the requirements of ASTM E23 and ISO 148-2 can only be assessed for the ATMS specimens, as the certified values for the NIST lots can be only used for tests performed at -40°C . Despite statistical differences between Labs for the M-20 batch, as displayed in **Table 9**, results from both Institutes at both energy levels (based on 10 tests per conditions instead of 5, which is the typical number of tests required for indirect machine verification) are acceptable in accordance with both standards.

4.2. Influence of Hammer Type (C-type vs. U-type, 2 mm Strikers)

Thirty-five of the 75 Charpy tests performed at NIST were conducted on LL-189 and HH-190 lots using machines equipped with the same striker type (2 mm), but with different hammer types (C and U).

Values of average absorbed energy, standard deviation, and coefficient of variation for these tests are summarized in **Table 10**. The same information is illustrated in the form of box-and-whiskers in **Fig. 5**.

The influence of hammer type appears to increase as reference energy decreases, with the U-type hammer absorbing more energy for LL-189 specimens. This is in agreement with a recent NIST investigation [2], which showed that C-type hammers tend to absorb less energy at lower energy levels due to their higher stiffness/lower compliance (and therefore smaller vibrational energy losses).

Table 10. Summary data from the tests performed at NIST using U-type and C-type hammers and 2 mm strikers.

Specimen Producer	Lot/batch id	Hammer Type	Number of specimens tested	\overline{KV} (J)	SD (J)	CV (%)
NIST	LL-189	U-type	10	19.2	0.48	2.5
		C-type	10	17.6	0.33	1.9
	HH-190	U-type	10	107.4	2.28	2.1
		C-type	5	109.4	3.33	3.0

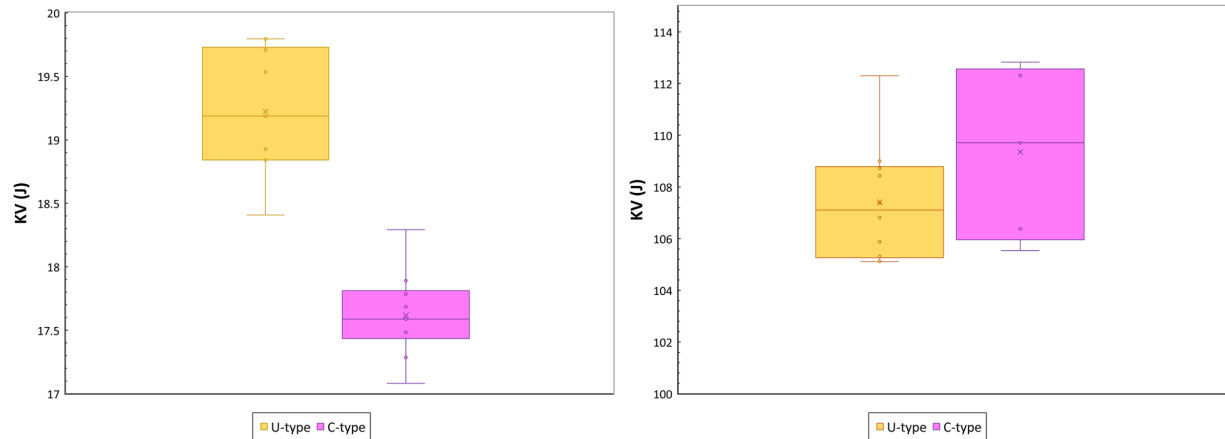


Fig. 5. Box-and-whiskers plots for NIST reference specimens tested at NIST with U-type and C-type hammers and 2 mm strikers. Left: LL-189; right: HH-190.

Based on two-tailed *t*-tests, the calculated *p*-values are listed in **Table 9**.

Table 11. Two-tailed t -test results for the tests performed at NIST with U-type and C-type hammers and 2 mm strikers.

Specimen Producer	Lot/batch id	Hammer Type	\overline{KV} (J)	p	Difference between means is statistically...
NIST	LL-189	U-type	19.2	1.69×10^{-7}	Very significant
		C-type	17.6		
	HH-190	U-type	107.4	0.2846	Not significant
		C-type	109.4		

The calculated p -values confirm that there is strong evidence of a difference in mean absorbed energies at the lower energy level (LL-189), while at the higher energy level (HH-190) the differences is not statistically significant.

4.3. Influence of Striker Type (2 mm vs. 8 mm, U-type and C-type Hammers)

Based on the tests performed in this interlaboratory comparison, it's difficult to investigate the influence of striker type, as its effects are confounded by the fact that two different hammers were used (U-type with the 8 mm striker and C-type with the 2 mm striker). Within this sub-set, 40 Charpy tests were performed at NIST on ATMS reference specimens.

Values of average absorbed energy, standard deviation, and coefficient of variation for these tests are summarized in **Table 10**. The same information is illustrated in the form of box-and-whiskers in **Fig. 6**.

Table 12. Summary data from the tests performed at NIST on ATMS specimens using two different hammer/striker combinations (U-type/8 mm and C-type/2 mm).

Specimen Producer	Lot/batch id	Institute	Hammer Type	Striker Type	Number of specimens tested	\overline{KV} (J)	SD (J)	CV (%)
ATMS	M-20	NIST	U-type	8 mm	10	61.1	1.12	1.8
			C-type	2 mm	10	64.3	1.83	2.8
	M-21	NIST	U-type	8 mm	10	152.3	4.90	3.2
			C-type	2 mm	10	148.9	2.89	1.9

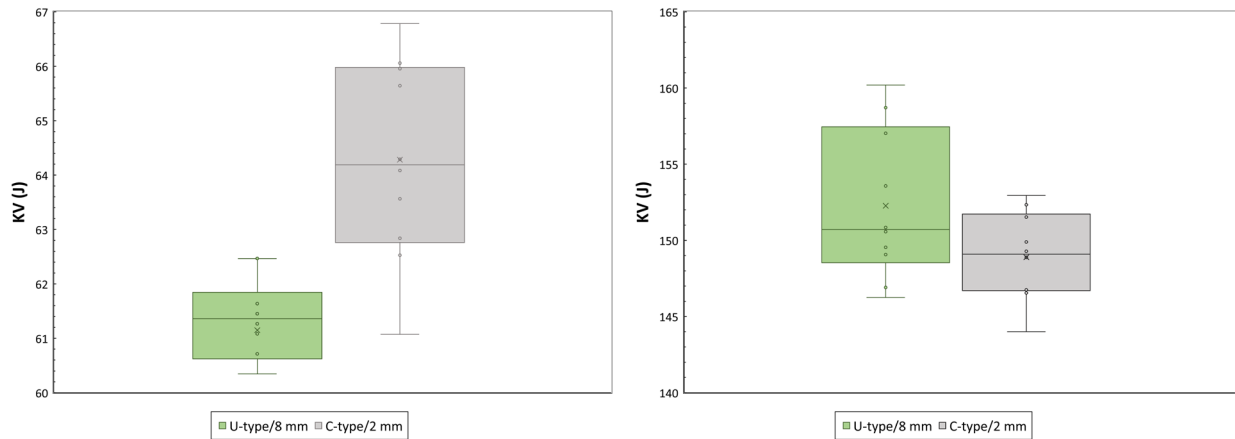


Fig. 6. Box-and-whiskers plots for ATMS reference specimens tested at NIST with two different hammers/striker combinations (U-type/8 mm and C-type/2 mm). Left: M-20; right: M-21.

Based on two-tailed t -tests, the probabilities calculated for the 2 types of reference specimens are listed in **Table 13**.

Table 13. Two-tailed t -test probabilities calculated for the tests performed at NIST on ATMS reference specimens with U-type hammer/8 mm striker and C-type hammer/2 mm striker.

Specimen Producer	Lot/batch id	Hammer Type	\overline{KV} (J)	p	Difference between means is statistically...
ATMS	M-20	U-type	61.1	0.0003	Significant
		C-type	64.3		
	M-21	U-type	152.3	0.0803	Not significant
		C-type	148.9		

Based on relatively well-established knowledge [3-7], the influence of striker type is typically observed above 100 J – 150 J, when significant interactions occur between the plastically deforming specimen and the two sharp corners of the 8 mm striker (**Fig. 7**). It has also been shown that absorbed energy differences become pronounced when specimens do not fully break in two parts after impact [8], with 8 mm strikers absorbing more energy than 2 mm strikers.

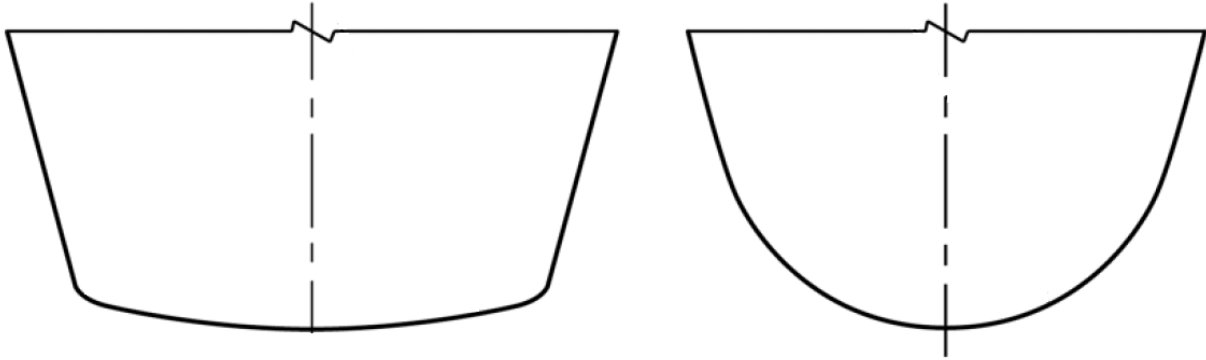


Fig. 7. Comparison between the profiles of an 8 mm striker (left) and a 2 mm striker (right).

As shown in **Table 11**. Two-tailed t -test results **for the tests** performed at NIST with U-type and C-type hammers and 2 mm strikers. the difference between the mean energies for the M-21 batch were not statistically significant. At this energy level, differences were in the expected direction (energy from 8 mm striker > energy from 2 mm striker), but the fact that all specimens fully broke, coupled with the relatively small number of available data points (10 per condition) and the fact that we also varied the hammer type, most likely caused the difference to be statistically not significant.

5. Conclusions

An interlaboratory comparison between the National Institute of Standards and Technology (NIST, Boulder, Colorado, USA) and Anand Testing Machine Services (ATMS, Kabnur, India) was conducted by performing room temperature impact tests on certified Charpy reference specimens of different energy levels produced by both Institutes. Absorbed energies for the four specimen types were approximately 18 J and 108 J for NIST lots, and 60 J and 150 J for ATMS batches.

Direct comparisons between the two Institutes were only possible when similar machine setups were employed (2 mm strikers and C-type hammers). Based on two-tailed *t*-tests, mean absorbed energies from NIST and ATMS were found to be statistically different for the two lowest energy levels.

It's interesting to note that all tests performed at both Institutes on ATMS specimens would satisfy the indirect verification requirements of both the ASTM E23 and ISO 148-2 standards. Additional tests performed at NIST using different machine characteristics (8 mm striker, U-type hammer) allowed insight into the effect of hammer and striker type on the results:

- Using 2 mm strikers, (statistically) significantly lower energy is absorbed by the C-type hammer at the 18 J level, confirming previous investigations that highlighted the role of hammer compliance and corresponding vibrational losses. At the 108 J level, the C-type hammer absorbed more energy, but the difference is not statistically significant.
- The influence of striker type was unfortunately confounded by the use of two different hammers (U-type with 8 mm striker and C-type with 2 mm striker), so observations are inconclusive. Furthermore, all specimens broke in two pieces, which tends to reduce the effect of striker type. As a consequence, the 8 mm striker was found to absorb more energy than the 2 mm striker at the 150 J level, as expected, but the difference was not statistically significant.

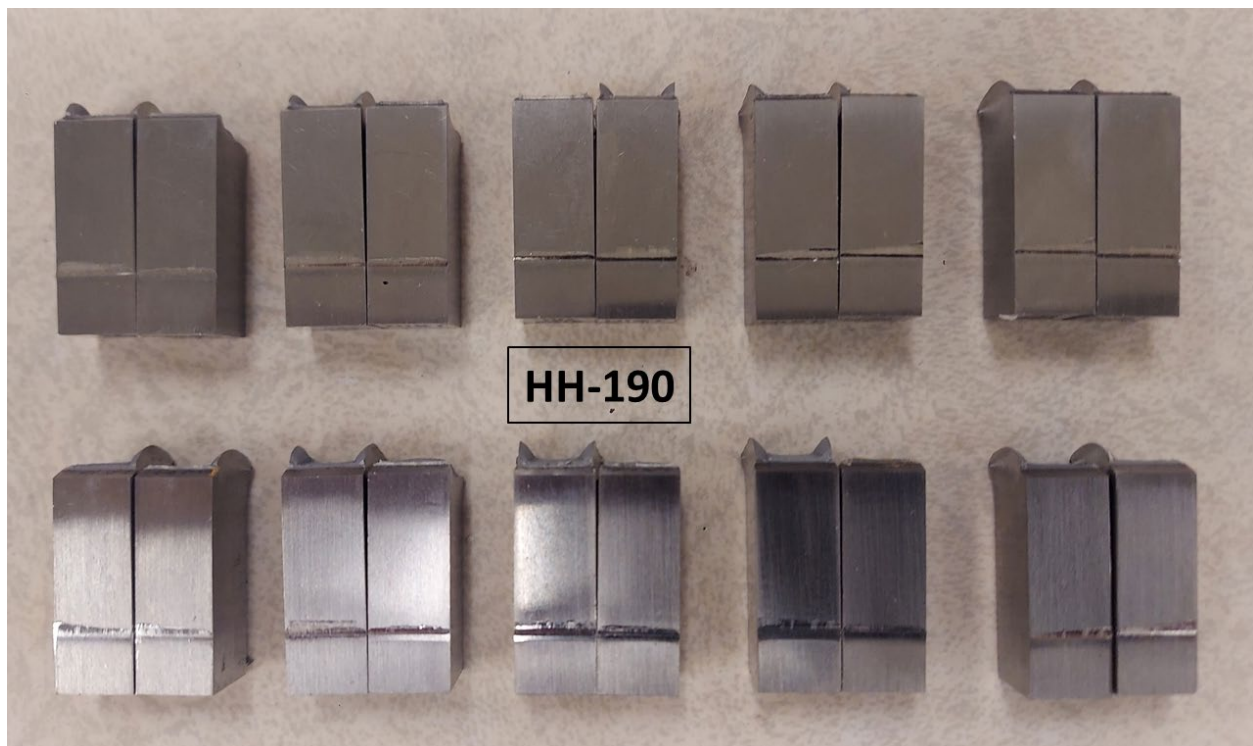
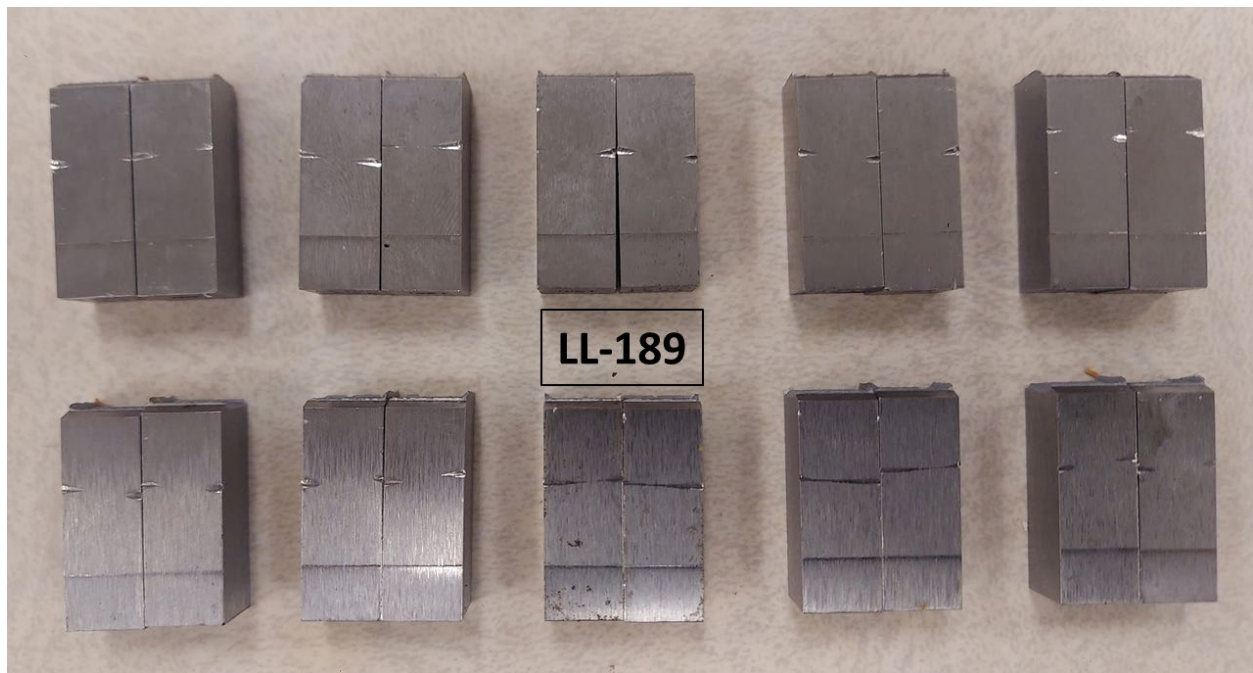
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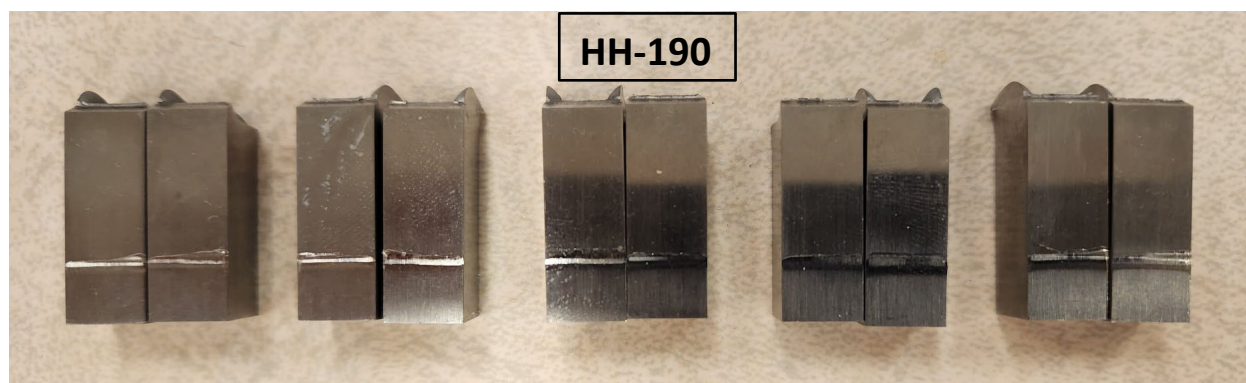
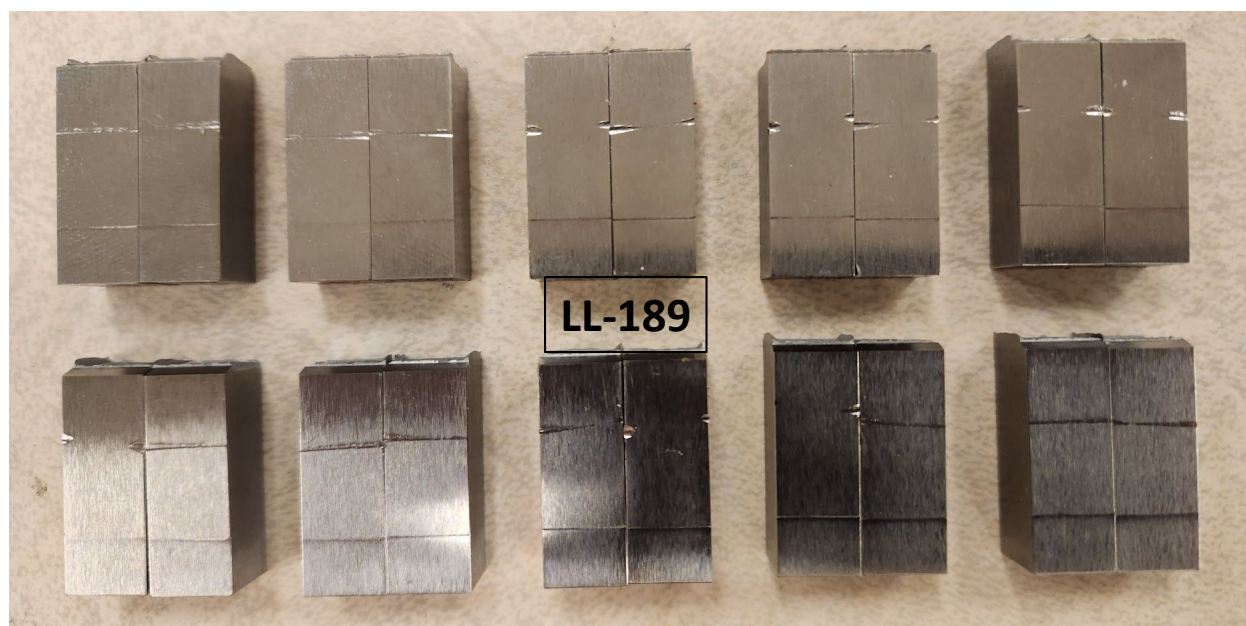
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Appendix A. Pictures of LL-189 and HH-190 specimens tested at NIST

U-type machine, 2 mm striker



C-type machine, 2 mm striker



Appendix B. Dimensional measurements of LL-189 and HH-190 specimens performed at ATMS

ATMS Tolerance	ANAND TESTING MACHINE SERVICES, 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 : 13.10.2022

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
307	54.9667	0.042	9.990	9.991	0.2511	0.2504	44.27	44.49	8.023	8.023	89.98	89.98	89.98	90.03
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
319	54.9414	0.042	9.992	9.99	0.2547	0.2511	44.16	44.23	8.023	8.023	89.97	89.97	89.95	89.97
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
782	54.8726	0.006	9.997	9.992	0.2516	0.2497	44.51	44.67	8.015	8.014	89.92	89.95	90.02	90.02
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1059	54.8631	0.072	9.995	9.99	0.2503	0.2534	44.21	44.14	8.012	8.013	89.95	89.98	89.95	90.02
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1887	54.9469	0.012	9.996	9.998	0.2496	0.2534	44.23	44.74	8.016	8.019	90.02	89.95	89.98	89.98
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
554	54.896	0.034	9.996	9.998	0.2500	0.2539	44.11	44.19	8.025	8.024	89.98	90.02	89.98	89.98
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
639	54.8785	0.063	9.992	9.988	0.2466	0.2434	44.24	44.10	8.013	8.014	89.93	89.98	89.95	89.98
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
655	54.9069	0.038	9.994	9.995	0.2563	0.2509	44.37	44.66	8.02	8.017	89.95	89.98	89.98	89.98
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1453	54.837	0.064	9.991	9.998	0.2529	0.2479	44.41	44.65	8.012	8.012	89.98	89.98	89.97	89.98
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1730	54.9253	0.042	9.994	9.998	0.2508	0.2487	44.48	44.54	8.015	8.015	89.95	89.95	89.98	89.97
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

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

Lot No. : HH - 190

MEASUREMENT OF FINAL DIMENSIONS

Date : 13.10.2022

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
0009	54.8893	0.045	10.005	10.005	0.2604	0.2623	44.54	44.21	8.015	8.015	89.95	89.98	90.05	89.95
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0019	54.889	0.041	10.020	10.008	0.2559	0.2612	44.42	44.44	8.016	8.013	89.93	89.93	90.03	90.03
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0034	54.8847	0.040	10.018	10.007	0.2678	0.2673	44.55	44.50	8.024	8.016	89.93	89.97	89.97	89.98
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0035	54.8849	0.036	10.020	10.005	0.2606	0.2573	44.59	44.31	8.011	8.017	89.98	89.97	89.98	89.93
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0044	54.8672	0.034	10.008	10.015	0.2636	0.2533	44.49	44.56	8.011	8.015	89.95	89.97	89.97	90.02
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0060	54.8938	0.042	10.000	10.003	0.2658	0.2608	44.49	44.64	8.014	8.012	89.97	89.98	89.98	89.95
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0065	54.8846	0.015	10.020	10.003	0.2605	0.2643	44.12	44.64	8.017	8.013	89.98	89.98	90.05	89.95
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0069	54.8996	0.033	10.020	10.005	0.2548	0.264	44.44	44.42	8.014	8.015	89.97	89.97	89.98	89.98
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0085	54.8847	0.039	10.020	10.001	0.2671	0.2586	44.60	44.52	8.013	8.005	89.95	89.98	89.98	89.98
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
0095	54.8972	0.024	10.008	10.007	0.2638	0.2636	44.52	44.68	8.016	8.018	89.98	89.98	90.07	89.95
Acceptable (Yes / No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Appendix C. Pictures of LL-189 and HH-190 specimens tested at ATMS

C-type hammer, 2 mm striker

LL189



HH190



Appendix D. Dimensional measurements of M-20 and M-21 specimens performed at NIST (first series)

CHARPY LOT DIMENSIONAL MEASUREMENT REPORT

Measurement date: 10/7/2022

Machine: T02

Lot id: Anand Services 60 J M-20 #22-23

Measuring instruments: Keyence IM-7030 + Mitutoyo perpendicularity gage (*)

Specimen 106

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9319	54.9254	55	54.7	55	YES	
Notch centering	mm	0.0497	0.0497	0	-0.2	0.2	YES	
Width [W]	mm	9.9982	9.9922	10	9.97	10.03	YES	
Thickness [B]	mm	9.9988	9.9928	10	9.97	10.03	YES	
Ligament [b]	mm	8.0016	7.9972	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2448	0.2448	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.28	45.28	45	44	46	YES	
Angle adj sides 1	°	89.98		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.01		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.03		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.05		90	89.85	90.15	YES	(*)

Specimen 107

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.914	54.9075	55	54.7	55	YES	
Notch centering	mm	0.0354	0.0354	0	-0.2	0.2	YES	
Width [W]	mm	10.002	9.996	10	9.97	10.03	YES	
Thickness [B]	mm	10.0033	9.9973	10	9.97	10.03	YES	
Ligament [b]	mm	8.0019	7.9975	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2513	0.2513	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.78	44.78	45	44	46	YES	
Angle adj sides 1	°	90.05		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.01		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.06		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.00		90	89.85	90.15	YES	(*)

Specimen 108

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9052	54.8987	55	54.7	55	YES	
Notch centering	mm	0.038	0.038	0	-0.2	0.2	YES	
Width [W]	mm	10.004	9.998	10	9.97	10.03	YES	
Thickness [B]	mm	9.9998	9.9938	10	9.97	10.03	YES	
Ligament [b]	mm	8.0005	7.9961	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2477	0.2477	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.38	45.38	45	44	46	YES	
Angle adj sides 1	°	90.05		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.03		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.04		90	89.85	90.15	YES	(*)

Specimen 109

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9437	54.9372	55	54.7	55	YES	
Notch centering	mm	0.0317	0.0317	0	-0.2	0.2	YES	
Width [W]	mm	10.0064	10.0004	10	9.97	10.03	YES	
Thickness [B]	mm	10.0023	9.9963	10	9.97	10.03	YES	
Ligament [b]	mm	7.9957	7.9913	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2464	0.2464	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.14	45.14	45	44	46	YES	
Angle adj sides 1	°	90.07		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.06		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.06		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.02		90	89.85	90.15	YES	(*)

Specimen 110

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9683	54.9618	55	54.7	55	YES	
Notch centering	mm	0.057	0.057	0	-0.2	0.2	YES	
Width [W]	mm	10.0036	9.9976	10	9.97	10.03	YES	
Thickness [B]	mm	10.0007	9.9947	10	9.97	10.03	YES	
Ligament [b]	mm	8.0016	7.9972	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2511	0.2511	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.53	45.53	45	44	46	YES	
Angle adj sides 1	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.00		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.03		90	89.85	90.15	YES	(*)

Specimen 111

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9279	54.9214	55	54.7	55	YES	
Notch centering	mm	0.0261	0.0261	0	-0.2	0.2	YES	
Width [W]	mm	9.9975	9.9915	10	9.97	10.03	YES	
Thickness [B]	mm	10.0025	9.9965	10	9.97	10.03	YES	
Ligament [b]	mm	7.9908	7.9864	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2455	0.2455	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.08	45.08	45	44	46	YES	
Angle adj sides 1	°	90.01		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.06		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.03		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.11		90	89.85	90.15	YES	(*)

Specimen 112

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9578	54.9513	55	54.7	55	YES	
Notch centering	mm	0.0441	0.0441	0	-0.2	0.2	YES	
Width [W]	mm	10.0031	9.9971	10	9.97	10.03	YES	
Thickness [B]	mm	10.0047	9.9987	10	9.97	10.03	YES	

Ligament [b]	mm	7.9885	7.9841	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2483	0.2483	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.16	45.16	45	44	46	YES	
Angle adj sides 1	°	90.01		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.07		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.10		90	89.85	90.15	YES	(*)

Specimen 113

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9123	54.9058	55	54.7	55	YES	
Notch centering	mm	0.005	0.005	0	-0.2	0.2	YES	
Width [W]	mm	10.0049	9.9989	10	9.97	10.03	YES	
Thickness [B]	mm	10.0029	9.9969	10	9.97	10.03	YES	
Ligament [b]	mm	7.9905	7.9861	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2472	0.2472	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.14	45.14	45	44	46	YES	
Angle adj sides 1	°	90.10		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.11		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.00		90	89.85	90.15	YES	(*)

Specimen 114

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9798	54.9733	55	54.7	55	YES	
Notch centering	mm	0.0583	0.0583	0	-0.2	0.2	YES	
Width [W]	mm	10.0053	9.9993	10	9.97	10.03	YES	
Thickness [B]	mm	10.0044	9.9984	10	9.97	10.03	YES	
Ligament [b]	mm	7.9949	7.9905	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2482	0.2482	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.85	44.85	45	44	46	YES	
Angle adj sides 1	°	90.04		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.00		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.08		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.02		90	89.85	90.15	YES	(*)

Specimen 115

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9798	54.9733	55	54.7	55	YES	
Notch centering	mm	0.0583	0.0583	0	-0.2	0.2	YES	
Width [W]	mm	10.0053	9.9993	10	9.97	10.03	YES	
Thickness [B]	mm	10.0044	9.9984	10	9.97	10.03	YES	
Ligament [b]	mm	7.9949	7.9905	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2482	0.2482	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.85	44.85	45	44	46	YES	
Angle adj sides 1	°	90.06		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.03		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.05		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.05		90	89.85	90.15	YES	(*)

CHARPY LOT DIMENSIONAL MEASUREMENT REPORT

Measurement date: 10/7/2022

Machine: TO2

Lot id: Anand Services 160 J M-21 #112-113

Measuring instruments: Keyence IM-7030 + Mitutoyo perpendicularity gage (*)

Specimen 556

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.8917	54.8852	55	54.7	55	YES	
Notch centering	mm	0.0682	0.0682	0	-0.2	0.2	YES	
Width [W]	mm	10.0143	10.0083	10	9.97	10.03	YES	
Thickness [B]	mm	10.0117	10.0057	10	9.97	10.03	YES	
Ligament [b]	mm	8.0013	7.9969	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2316	0.2316	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.65	45.65	45	44	46	YES	
Angle adj sides 1	°		90.05	90	89.85	90.15	YES	(*)
Angle adj sides 2	°		89.99	90	89.85	90.15	YES	(*)
Angle adj sides 3	°		90.02	90	89.85	90.15	YES	(*)
Angle adj sides 4	°		89.99	90	89.85	90.15	YES	(*)

Specimen 557

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9768	54.9703	55	54.7	55	YES	
Notch centering	mm	0.1128	0.1128	0	-0.2	0.2	YES	
Width [W]	mm	10.0127	10.0067	10	9.97	10.03	YES	
Thickness [B]	mm	10.0103	10.0043	10	9.97	10.03	YES	
Ligament [b]	mm	7.9971	7.9927	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2285	0.2285	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.23	45.23	45	44	46	YES	
Angle adj sides 1	°		90.02	90	89.85	90.15	YES	(*)
Angle adj sides 2	°		89.98	90	89.85	90.15	YES	(*)
Angle adj sides 3	°		90.04	90	89.85	90.15	YES	(*)
Angle adj sides 4	°		90.00	90	89.85	90.15	YES	(*)

Specimen 558

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9354	54.9289	55	54.7	55	YES	
Notch centering	mm	0.0354	0.0354	0	-0.2	0.2	YES	
Width [W]	mm	10.014	10.008	10	9.97	10.03	YES	
Thickness [B]	mm	10.0083	10.0023	10	9.97	10.03	YES	
Ligament [b]	mm	8.0031	7.9987	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2307	0.2307	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.55	45.55	45	44	46	YES	
Angle adj sides 1	°		90.03	90	89.85	90.15	YES	(*)
Angle adj sides 2	°		89.97	90	89.85	90.15	YES	(*)
Angle adj sides 3	°		90.07	90	89.85	90.15	YES	(*)
Angle adj sides 4	°		90.00	90	89.85	90.15	YES	(*)

Specimen 559

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9508	54.9443	55	54.7	55	YES	
Notch centering	mm	0.0121	0.0121	0	-0.2	0.2	YES	
Width [W]	mm	10.0175	10.0115	10	9.97	10.03	YES	
Thickness [B]	mm	10.0138	10.0078	10	9.97	10.03	YES	
Ligament [b]	mm	8.0032	7.9988	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2314	0.2314	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.19	45.19	45	44	46	YES	
Angle adj sides 1	°	90.07		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.04		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.01		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.05		90	89.85	90.15	YES	(*)

Specimen 560

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9509	54.9444	55	54.7	55	YES	
Notch centering	mm	0.0477	0.0477	0	-0.2	0.2	YES	
Width [W]	mm	10.0075	10.0015	10	9.97	10.03	YES	
Thickness [B]	mm	10.0133	10.0073	10	9.97	10.03	YES	
Ligament [b]	mm	8.0107	8.0063	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2312	0.2312	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.57	45.57	45	44	46	YES	
Angle adj sides 1	°	90.11		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.08		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.97		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.02		90	89.85	90.15	YES	(*)

Specimen 561

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	55.0471	55.0406	55	54.7	55	NO	
Notch centering	mm	0.0516	0.0516	0	-0.2	0.2	YES	
Width [W]	mm	10.0011	9.9951	10	9.97	10.03	YES	
Thickness [B]	mm	10.0125	10.0065	10	9.97	10.03	YES	
Ligament [b]	mm	8.0088	8.0044	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2321	0.2321	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.9	44.9	45	44	46	YES	
Angle adj sides 1	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.00		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.03		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.01		90	89.85	90.15	YES	(*)

Specimen 562

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.9466	54.9401	55	54.7	55	YES	
Notch centering	mm	0.0189	0.0189	0	-0.2	0.2	YES	
Width [W]	mm	10.015	10.009	10	9.97	10.03	YES	
Thickness [B]	mm	10.0125	10.0065	10	9.97	10.03	YES	

Ligament [b]	mm	7.9984	7.994	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2289	0.2289	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.55	45.55	45	44	46	YES	
Angle adj sides 1	°		90.03	90	89.85	90.15	YES	(*)
Angle adj sides 2	°		90.05	90	89.85	90.15	YES	(*)
Angle adj sides 3	°		90.05	90	89.85	90.15	YES	(*)
Angle adj sides 4	°		90.04	90	89.85	90.15	YES	(*)

Specimen 563

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.8943	54.8878	55	54.7	55	YES	
Notch centering	mm	0.0164	0.0164	0	-0.2	0.2	YES	
Width [W]	mm	10.0179	10.0119	10	9.97	10.03	YES	
Thickness [B]	mm	10.0124	10.0064	10	9.97	10.03	YES	
Ligament [b]	mm	8.0087	8.0043	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2304	0.2304	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.35	45.35	45	44	46	YES	
Angle adj sides 1	°		90.10	90	89.85	90.15	YES	(*)
Angle adj sides 2	°		89.98	90	89.85	90.15	YES	(*)
Angle adj sides 3	°		90.07	90	89.85	90.15	YES	(*)
Angle adj sides 4	°		89.96	90	89.85	90.15	YES	(*)

Specimen 564

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.8983	54.8918	55	54.7	55	YES	
Notch centering	mm	0.0129	0.0129	0	-0.2	0.2	YES	
Width [W]	mm	10.0152	10.0092	10	9.97	10.03	YES	
Thickness [B]	mm	10.0059	9.9999	10	9.97	10.03	YES	
Ligament [b]	mm	8.006	8.0016	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2349	0.2349	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.46	45.46	45	44	46	YES	
Angle adj sides 1	°		90.02	90	89.85	90.15	YES	(*)
Angle adj sides 2	°		90.03	90	89.85	90.15	YES	(*)
Angle adj sides 3	°		89.85	90	89.85	90.15	YES	(*)
Angle adj sides 4	°		90.01	90	89.85	90.15	YES	(*)

Specimen 565

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	55.0247	55.0182	55	54.7	55	NO	
Notch centering	mm	0.007	0.007	0	-0.2	0.2	YES	
Width [W]	mm	10.0145	10.0085	10	9.97	10.03	YES	
Thickness [B]	mm	10.008	10.002	10	9.97	10.03	YES	
Ligament [b]	mm	8.0092	8.0048	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.2334	0.2334	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.66	45.66	45	44	46	YES	
Angle adj sides 1	°		90.06	90	89.85	90.15	YES	(*)
Angle adj sides 2	°		90.05	90	89.85	90.15	YES	(*)
Angle adj sides 3	°		90.00	90	89.85	90.15	YES	(*)
Angle adj sides 4	°		90.05	90	89.85	90.15	YES	(*)

Appendix E. Dimensional measurements of M-20 and M-21 specimens performed at NIST (second series)

CHARPY LOT DIMENSIONAL MEASUREMENT REPORT

Measurement date: 10/24/2022

Machine: TK

Lot id: Anand Services 60 J M-20 #26-27

Measuring instruments: Keyence IM-7030 + Mitutoyo perpendicularity gage (*)

Specimen 126

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.933	54.927	55	54.7	55	YES	
Notch centering	mm	0.055	0.055	0	-0.2	0.2	YES	
Width [W]	mm	9.992	9.986	10	9.97	10.03	YES	
Thickness [B]	mm	10.027	10.021	10	9.97	10.03	YES	
Ligament [b]	mm	8.013	8.009	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.251	0.251	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.12	44.12	45	44	46	YES	
Angle adj sides 1	°	89.91		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.07		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.98		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.15		90	89.85	90.15	YES	(*)

Specimen 127

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.870	54.863	55	54.7	55	YES	
Notch centering	mm	0.055	0.055	0	-0.2	0.2	YES	
Width [W]	mm	10.005	9.999	10	9.97	10.03	YES	
Thickness [B]	mm	9.992	9.986	10	9.97	10.03	YES	
Ligament [b]	mm	8.021	8.017	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.240	0.240	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.57	44.57	45	44	46	YES	
Angle adj sides 1	°	89.91		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.12		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.95		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.08		90	89.85	90.15	YES	(*)

Specimen 128

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.732	54.725	55	54.7	55	YES	
Notch centering	mm	0.143	0.143	0	-0.2	0.2	YES	
Width [W]	mm	9.983	9.977	10	9.97	10.03	YES	
Thickness [B]	mm	9.995	9.989	10	9.97	10.03	YES	
Ligament [b]	mm	7.986	7.982	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.271	0.271	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.36	44.36	45	44	46	YES	
Angle adj sides 1	°	90.04		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	89.88		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.96		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.00		90	89.85	90.15	YES	(*)

Specimen 129

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.970	54.963	55	54.7	55	YES	
Notch centering	mm	0.160	0.160	0	-0.2	0.2	YES	
Width [W]	mm	9.998	9.992	10	9.97	10.03	YES	
Thickness [B]	mm	10.004	9.998	10	9.97	10.03	YES	
Ligament [b]	mm	8.025	8.020	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.234	0.234	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.34	44.34	45	44	46	YES	
Angle adj sides 1	°	89.95		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.15		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.14		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.13		90	89.85	90.15	YES	(*)

Specimen 132

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.731	54.724	55	54.7	55	YES	
Notch centering	mm	0.186	0.186	0	-0.2	0.2	YES	
Width [W]	mm	10.028	10.022	10	9.97	10.03	YES	
Thickness [B]	mm	10.002	9.996	10	9.97	10.03	YES	
Ligament [b]	mm	7.988	7.983	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.237	0.237	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.51	45.51	45	44	46	YES	
Angle adj sides 1	°	89.86		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	89.92		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	89.86		90	89.85	90.15	YES	(*)

Specimen 131

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.906	54.900	55	54.7	55	YES	
Notch centering	mm	0.064	0.064	0	-0.2	0.2	YES	
Width [W]	mm	9.996	9.990	10	9.97	10.03	YES	
Thickness [B]	mm	10.012	10.006	10	9.97	10.03	YES	
Ligament [b]	mm	8.015	8.011	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.266	0.266	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.83	45.83	45	44	46	YES	
Angle adj sides 1	°	89.95		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.15		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.96		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.09		90	89.85	90.15	YES	(*)

Specimen 132

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.782	54.776	55	54.7	55	YES	
Notch centering	mm	0.150	0.150	0	-0.2	0.2	YES	
Width [W]	mm	10.009	10.003	10	9.97	10.03	YES	
Thickness [B]	mm	9.986	9.980	10	9.97	10.03	YES	

Ligament [b]	mm	8.013	8.009	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.272	0.272	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.55	45.55	45	44	46	YES	
Angle adj sides 1	°	90.12		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.14		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.00		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	89.89		90	89.85	90.15	YES	(*)

Specimen 133

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.727	54.721	55	54.7	55	YES	
Notch centering	mm	0.131	0.131	0	-0.2	0.2	YES	
Width [W]	mm	10.019	10.013	10	9.97	10.03	YES	
Thickness [B]	mm	9.999	9.993	10	9.97	10.03	YES	
Ligament [b]	mm	7.995	7.991	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.271	0.271	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.04	45.04	45	44	46	YES	
Angle adj sides 1	°	90.14		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.06		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.09		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	89.89		90	89.85	90.15	YES	(*)

Specimen 134

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.855	54.848	55	54.7	55	YES	
Notch centering	mm	0.075	0.075	0	-0.2	0.2	YES	
Width [W]	mm	9.990	9.984	10	9.97	10.03	YES	
Thickness [B]	mm	10.008	10.002	10	9.97	10.03	YES	
Ligament [b]	mm	8.019	8.014	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.269	0.269	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.43	45.43	45	44	46	YES	
Angle adj sides 1	°	90.04		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.07		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.11		90	89.85	90.15	YES	(*)

Specimen 135

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.862	54.856	55	54.7	55	YES	
Notch centering	mm	0.111	0.111	0	-0.2	0.2	YES	
Width [W]	mm	9.978	9.972	10	9.97	10.03	YES	
Thickness [B]	mm	10.026	10.020	10	9.97	10.03	YES	
Ligament [b]	mm	7.981	7.977	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.244	0.244	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.20	44.20	45	44	46	YES	
Angle adj sides 1	°	89.94		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	89.95		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.00		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	89.89		90	89.85	90.15	YES	(*)

CHARPY LOT DIMENSIONAL MEASUREMENT REPORT

Measurement date: 10/24/2022

Machine: TO2

Lot id: Anand Services 160 J M-21 #111-114

Measuring instruments: Keyence IM-7030 + Mitutoyo perpendicularity gage (*)

Specimen 551

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.749	54.743	55	54.7	55	YES	
Notch centering	mm	0.153	0.153	0	-0.2	0.2	YES	
Width [W]	mm	10.008	10.002	10	9.97	10.03	YES	
Thickness [B]	mm	9.998	9.992	10	9.97	10.03	YES	
Ligament [b]	mm	8.005	8.001	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.274	0.274	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.33	45.33	45	44	46	YES	
Angle adj sides 1	°	90.12		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.03		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.01		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	89.88		90	89.85	90.15	YES	(*)

Specimen 552

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.906	54.899	55	54.7	55	YES	
Notch centering	mm	0.042	0.042	0	-0.2	0.2	YES	
Width [W]	mm	10.024	10.018	10	9.97	10.03	YES	
Thickness [B]	mm	9.984	9.978	10	9.97	10.03	YES	
Ligament [b]	mm	8.011	8.006	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.230	0.230	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.330	45.33	45	44	46	YES	
Angle adj sides 1	°	90.14		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.14		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.00		90	89.85	90.15	YES	(*)

Specimen 553

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.764	54.758	55	54.7	55	YES	
Notch centering	mm	0.014	0.014	0	-0.2	0.2	YES	
Width [W]	mm	10.020	10.014	10	9.97	10.03	YES	
Thickness [B]	mm	10.020	10.014	10	9.97	10.03	YES	
Ligament [b]	mm	7.993	7.989	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.239	0.239	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.52	44.52	45	44	46	YES	
Angle adj sides 1	°	90.00		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.11		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	89.98		90	89.85	90.15	YES	(*)

Specimen 554

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.974	54.967	55	54.7	55	YES	
Notch centering	mm	0.007	0.007	0	-0.2	0.2	YES	
Width [W]	mm	10.030	10.024	10	9.97	10.03	YES	
Thickness [B]	mm	9.990	9.984	10	9.97	10.03	YES	
Ligament [b]	mm	8.006	8.002	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.244	0.244	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.05	45.05	45	44	46	YES	
Angle adj sides 1	°	89.89		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	89.99		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.91		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.09		90	89.85	90.15	YES	(*)

Specimen 555

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.791	54.784	55	54.7	55	YES	
Notch centering	mm	0.076	0.076	0	-0.2	0.2	YES	
Width [W]	mm	9.996	9.990	10	9.97	10.03	YES	
Thickness [B]	mm	9.994	9.988	10	9.97	10.03	YES	
Ligament [b]	mm	8.008	8.004	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.240	0.240	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.28	44.28	45	44	46	YES	
Angle adj sides 1	°	90.05		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.04		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.87		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	89.88		90	89.85	90.15	YES	(*)

Specimen 566

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.771	54.764	55	54.7	55	YES	
Notch centering	mm	0.149	0.149	0	-0.2	0.2	YES	
Width [W]	mm	10.019	10.013	10	9.97	10.03	YES	
Thickness [B]	mm	10.001	9.995	10	9.97	10.03	YES	
Ligament [b]	mm	8.007	8.002	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.264	0.264	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.09	44.09	45	44	46	YES	
Angle adj sides 1	°	89.92		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.07		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.99		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.07		90	89.85	90.15	YES	(*)

Specimen 567

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.912	54.906	55	54.7	55	YES	
Notch centering	mm	0.006	0.006	0	-0.2	0.2	YES	
Width [W]	mm	9.999	9.993	10	9.97	10.03	YES	
Thickness [B]	mm	9.987	9.981	10	9.97	10.03	YES	

Ligament [b]	mm	7.980	7.976	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.271	0.271	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.44	44.44	45	44	46	YES	
Angle adj sides 1	°	90.03		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.86		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.06		90	89.85	90.15	YES	(*)

Specimen 568

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.990	54.984	55	54.7	55	YES	
Notch centering	mm	0.041	0.041	0	-0.2	0.2	YES	
Width [W]	mm	10.030	10.024	10	9.97	10.03	YES	
Thickness [B]	mm	9.997	9.991	10	9.97	10.03	YES	
Ligament [b]	mm	8.024	8.019	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.270	0.270	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.97	45.97	45	44	46	YES	
Angle adj sides 1	°	89.93		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.11		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	90.15		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	89.97		90	89.85	90.15	YES	(*)

Specimen 569

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.736	54.729	55	54.7	55	YES	
Notch centering	mm	0.134	0.134	0	-0.2	0.2	YES	
Width [W]	mm	9.976	9.970	10	9.97	10.03	NO	
Thickness [B]	mm	9.970	9.964	10	9.97	10.03	NO	
Ligament [b]	mm	7.983	7.979	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.233	0.233	0.25	0.225	0.275	YES	
Notch angle [α]	°	44.94	44.94	45	44	46	YES	
Angle adj sides 1	°	89.98		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	89.96		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.89		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	90.03		90	89.85	90.15	YES	(*)

Specimen 570

Dimension	Unit	Measured value	Corrected value	Nominal value	NIST tolerances		Acceptable? (YES/NO)	NOTES
					Min	Max		
Length [L]	mm	54.977	54.971	55	54.7	55	YES	
Notch centering	mm	0.101	0.101	0	-0.2	0.2	YES	
Width [W]	mm	9.979	9.973	10	9.97	10.03	YES	
Thickness [B]	mm	9.972	9.966	10	9.97	10.03	NO	
Ligament [b]	mm	8.022	8.017	8	7.975	8.025	YES	
Notch radius [ρ]	mm	0.242	0.242	0.25	0.225	0.275	YES	
Notch angle [α]	°	45.66	45.66	45	44	46	YES	
Angle adj sides 1	°	90.07		90	89.85	90.15	YES	(*)
Angle adj sides 2	°	90.02		90	89.85	90.15	YES	(*)
Angle adj sides 3	°	89.92		90	89.85	90.15	YES	(*)
Angle adj sides 4	°	89.95		90	89.85	90.15	YES	(*)

Appendix F. Pictures of M-20 and M-21 specimens tested at NIST (both series)

U-type machine, 8 mm striker



C-type machine, 2 mm striker



Appendix G. Pictures of M-20 and M-21 specimens tested at ATMS

C-type machine, 2 mm striker

