NIST Technical Note 2061

Charpy Interlaboratory Comparison between NIST and the Beijing Institute of Metrology (BIM)

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Abstract

The Beijing Institute of Metrology (BIM, China) and NIST have participated in an interlaboratory comparison, in which reference Charpy specimens of three energy levels were tested. Each laboratory tested 75 specimens supplied by the other institute, 25 per energy level, at room temperature (21 °C ± 1 °C) and using an impact machine equipped with a 2 mm striker. The results obtained show good to excellent agreement between BIM and NIST, except at the low-energy level (20 J to 25 J), where NIST data obtained using a U-type machine were significantly higher than BIM data obtained using a C-type machine. Twenty-five additional low-energy BIM specimens, tested by NIST using a C-type machine, showed excellent consistency with BIM reference data and therefore confirmed that, for low-energy specimens, the configuration of the swinging hammer may affect test results, due to the different stiffness/compliance of the two machine types. A similar, but unexpected, trend was observed for the NIST super-high-energy specimens, and will need to be explained though further investigations.

Key words

2 mm striker; Charpy reference specimens; C-type hammer; interlaboratory comparison; U-type hammer.

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1. Introduction

The Charpy Machine Verification Program at NIST has the objective of evaluating the performance of impact test machines used worldwide to qualify structural steels. The Program offers its national and international customers Standard Reference Materials (SRMs), in the form of certified Charpy specimens, that enable certification of impact machines to a traceable measurement system, in compliance with both ASTM E23 and ISO 148-2.

This program was originally launched in the 1960s by the U.S. Army (Watertown Arsenal, AMMRC), who produced and distributed Charpy reference specimens for the indirect verification of impact machines in the United States. NIST took over the program in 1989, and Army personnel helped to transfer the reference ("master") machines to Boulder, Colorado, along with their evaluation procedures. Note that two of the three NIST reference machines currently in use are the same owned and operated by the Army, while the third was replaced in the early 2000s with a similar one, but with higher potential energy.

During the last 10 years, the scope of the Charpy Program (which originally only included certified Charpy specimens of low, high, and super-high energy levels) was expanded to offer customers the following additional services and SRMs:

- Dynamic force Charpy specimens for the verification of instrumented strikers (SRM 2112 and SRM 2113)[1] [1,2].
- Certified miniaturized Charpy specimens for the indirect verification of small-scale impact machines (SRM 2216, SRM 2218, SRM 2219) [3,4].
- Certified low-energy and high-energy Charpy specimens for the indirect verification of impact machines equipped with 2 mm strikers (SRM 2197 and SRM 2198)[2].
- Official NIST Verification Letters in accordance with ISO 148-2, as well as ASTM E23.
- A website offering Proficiency Test Analysis, where customers can compare their results with data from the same certified lot obtained by other NIST customers and download free of charge a short statistical report.

As part of NIST Quality System [5], every Measurement Service is required to periodically participate in interlaboratory comparisons (or round-robins) with the objective of "*assuring the quality of its measurement services and to satisfy the requirement that the U.S. standards are consistent with those of other National Metrology Institutes and with the International System (SI), within stated uncertainty.*" Results of interlaboratory comparisons must be included in reports provided by the NIST Division Quality Manager and Division Chief to the Laboratory Director and the NIST Quality Manager.

The collaborative program between BIM (Beijing Institute of Metrology) and NIST described in this Technical Note is one of such interlaboratory comparisons, in line with similar previous exercises that the NIST Charpy Program led or participated in [1,4,6-8].

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[1] These specimens provide the customer with certified values of maximum force, as well as absorbed energy at 21 °C and -40 °C.

[2] All other Charpy SRMs offered by NIST are for machines equipped with 8 mm-strikers.

2. Experimental program

In the framework of this collaboration, certified reference Charpy specimens produced by NIST and BIM were exchanged between the two institutes and then tested. Results were collected, analyzed and compared with the respective reference (certified) absorbed energy values, KV_{ref}. Note that, in the case of NIST specimens, additional tests had to be performed in Boulder in order to provide BIM with meaningful KV_{ref} values. Indeed, the NIST lots used for this exercise had been previously certified at -40 °C with an 8 mm-striker, and therefore new reference values had to be generated at room temperature (21 °C ± 1 °C) with a 2 mm-striker. These KV_{ref} values were ultimately provided to BIM for evaluation of their test results.

Three absorbed energy levels were considered:

- 20 J – 25 J (defined as low energy by both NIST and BIM),
- 95 J – 110 J (defined as high energy by NIST and medium energy by BIM), and
- 145 J – 175 J (defined as super-high energy by NIST and high energy by BIM).

The test matrix of this exercise is given in **Table 1**. This includes the preliminary tests on NIST specimens mentioned above, as well as additional tests on the C-type reference NIST machine that were conducted on both NIST super-high specimens and BIM low-energy specimens, in order to clarify whether some of the differences observed could be attributed to the use of different machine types (C-type vs. U-type). The results from the additional tests and the influence of the machine type will be analyzed in the "Discussion" section of this Technical Note.

Table 1 – Summary of Charpy tests performed in the framework of the interlaboratory comparison between BIM and NIST.

Specimens manufactured by NIST				
Lot id	Energy level	Testing lab	Tests performed	Remarks
LL-157	Low	BIM	25	
HH-171	High	NIST	25	Preliminary tests (21 °C, 2 mm-striker)
		BIM	25	
SH-50	Super-high	NIST	25	Tested on a U-type machine
			25	Tested on a C-type machine
		BIM	25	
Specimens manufactured by BIM				
Lot id	Energy level	Testing lab	Tests performed	Remarks
L2018	Low	NIST	25	Tested on a U-type machine
			25	Tested on a C-type machine
M2018	Medium	NIST	25	
G2018	High	NIST	25	

2.1. Equipment used

According to information provided by Frank Fu, Marketing Director of Beijing Cap High Technology Co., Ltd., who acted as spokesperson for BIM, tests in Beijing were conducted on a C-type machine manufactured by Beijing Metrology and Measurement Testing Machinery Co., model CJN-300, with 300 J capacity [9][3].

For the tests performed in Boulder, two of the three NIST reference impact machines were used:

- a U-type machine manufactured by Tinius Olsen, model 74, with 359 J capacity (machine id: TO2), and
- a C-type machine manufactured by Tokyo Koki Co. Ltd., with 360 J capacity (machine id: TK).

The denomination “U-type” and “C-type” refers to the configuration of the swinging hammer/pendulum. The two hammer types (machines TO2 and TK) are illustrated in Fig. 1.

Fig. 1 – U-type (left, TO2) and C-type (right, TK) impact machines used by NIST.

For all tests performed, absorbed energy was measured (in J) from the machine encoder. No other parameter was measured or reported.

2.2. Data analysis

Besides calculating average value, $\overline{KV}$, and standard deviation, s_{KV}, for absorbed energy, the results obtained from each test series (row in **Table 1**) were analyzed according to the following procedure, which is used at NIST to qualify lots of certified Charpy specimens [10,11].

The acceptability of a lot depends on the value of the sample size (n_{ss}), which is defined as:

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[3] Certain commercial software, equipment, instruments or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the equipment or materials identified are necessarily the best available for the purpose.

$$n_{\mathrm{SS}} = \left(\frac{3s_{\mathrm{p}}}{E}\right)^2 \qquad , \tag{1}$$

where s_{p} is the pooled standard deviation (coincides with s_{KV} when just one machine is used) and E is the larger between 1.4 J or 5 % of $\overline{KV}$. If n_{ss} is smaller than or equal to 5.0, the lot is considered acceptable[4]. In the context of this investigation and of the NIST Charpy Program in general, the sample size is *the minimum number of specimens that a customer must test to have a statistically reliable comparison between* $\overline{KV}$ *and* KV_{ref}, *within the limits stated by ASTM E23 (larger between 1.4 J and 5 % of* KV_{ref}*).*

In addition to the calculation of the sample size according to Eq. (1), the average value $\overline{KV}$ for each test series was compared with the corresponding reference value KV_{ref} within the acceptable range of ASTM E23, given by the larger between 1.4 J or 5 % of KV_{ref}. In other words, we assessed whether the machine would be successfully verified with respect to a specific certified lot. Reference absorbed energy values and ranges of acceptability according to ASTM E23 are summarized in **Table 2** for the six lots considered in this exercise. Note that for two of the NIST lots (LL-157 and SH-50), different values of KV_{ref} correspond to U-type and C-type machines. Individual test results are provided in Appendices 1 to 5 at the end of this report.

Table 2 – Reference values and acceptable ranges for the six lots used in this exercise (room temperature, 2 mm-striker).

Reference institute	Lot id	KV_{ref} (J)	Acceptable range (ASTM E23)	Remarks	Raw data
NIST	LL-157	19.4 18.2	18.0 J – 20.8 J 16.8 J – 19.6 J	U-type C-type	Appendix 1 Appendix 2
	HH-171	111.9	106.3 J – 117.5 J		Appendix 3
	SH-50	191.7 166.6	182.2 J – 201.3 J 158.3 J – 174.9 J	U-type C-type	Appendix 4 Appendix 5
BIM	L2018	24.8	23.4 J – 26.2 J		
	M2018	98.5	93.6 J – 103.4 J		
	G2018	149.8	142.3 J – 157.3 J		

3. Results

3.1. BIM reference specimens

Seventy-five Charpy specimens (25 for lot L2018, 25 for M2018, 25 for G2018) were tested at NIST in Boulder using the TO2 U-type machine (Fig. 1, left). The results obtained are presented in **Table 3**.

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[4] Provided that dimensional and hardness measurements are also acceptable.

Table 3 – Results obtained at NIST on BIM specimens using the TO2 (U-type) machine.

Lot L2018		**Lot M2018**		**Lot G2018**	
Specimen id	*KV* (J)	Specimen id	*KV* (J)	Specimen id	*KV* (J)
160	27.7	262	100.9	203	148.6
97	25.4	234	92.0	238	150.6
144	27.5	121	96.9	180	137.8
156	27.5	130	93.7	105	135.4
196	25.2	108	90.7	228	137.0
203	26.4	277	90.7	166	153.4
240	29.1	227	92.8	75	155.1
260	28.6	238	100.0	290	149.4
170	25.5	102	94.8	60	143.1
70	26.9	74	96.2	287	150.3
226	26.1	60	92.6	129	136.2
280	28.3	13	107.1	113	149.9
291	26.8	208	101.5	198	152.1
77	27.5	153	93.1	163	145.2
201	27.8	267	87.1	134	144.9
208	26.9	136	93.2	110	143.3
194	27.3	209	98.0	181	139.0
79	26.3	194	101.0	195	144.3
62	27.3	94	85.5	279	141.3
186	26.9	166	108.6	257	149.3
250	28.6	149	96.3	31	141.2
114	27.2	107	91.5	151	151.4
301	26.8	178	95.7	137	141.0
13	28.2	174	99.0	268	155.6
121	26.2	299	91.0	55	137.8
$\overline{KV}$ = 27.1 J **s_{KV} = 1.02 J**		**$\overline{KV}$ = 95.6 J** **s_{KV} = 5.55 J**		**$\overline{KV}$ = 145.3 J** **s_{KV} = 6.23 J**	

Twenty-five additional tests were performed on L2018 (low energy) specimens using the TK (C-type) machine (Fig. 1, right). The results are presented in **Table 4**.

Table 4 – Results obtained at NIST on BIM specimens using the TK (C-type) machine.

Lot L2018			
Specimen id	*KV* (J)	Specimen id	*KV (J)*
173	25.1	42	24.0
293	25.1	266	24.8
256	25.5	161	26.6
163	25.2	265	24.9
38	22.9	268	23.8
137	26.6	200	24.7
297	27.5	155	25.3
276	24.7	206	25.5
133	23.5	277	25.0
45	24.1	89	27.1
49	27.3	24	25.4
214	24.9	31	25.3
123	24.4		
$\overline{KV}$ = 25.2 J – s_{KV} = 1.13 J			

3.2. NIST reference specimens

Seventy-five Charpy specimens (25 for lot LL-157, 25 for HH-171, 25 for SH-50) were tested at BIM in Beijing using a C-type machine. The results are presented in **Table 5**.

Table 5 – Results obtained at BIM on NIST specimens using a C-type machine.

Lot LL-157		**Lot HH-171**		**Lot SH-50**	
Specimen id	*KV (J)*	Specimen id	*KV* (J)	Specimen id	*KV* (J)
1606	19.9	401	110.7	741	180.2
1933	17.7	402	109.4	742	156.8
1698	16.1	403	118.6	743	180.3
1659	18.4	404	116.8	744	183.9
1254	18.4	405	110.5	745	157.2
856	17.4	421	111.0	721	182.5
2344	17.5	422	116.4	722	181.6
1251	17.7	423	110.0	723	144.7
499	19.0	424	105.6	724	150.8
1539	17.5	425	110.8	725	182.6
669	17.1	426	106.8	726	180.0
1926	17.5	427	112.5	727	188.4
1555	17.1	428	105.5	728	151.5
387	19.2	429	113.5	729	177.9
993	19.8	430	109.0	730	178.8
1259	18.2	431	110.7	731	189.0
863	17.8	432	111.1	732	178.2
813	18.4	433	114.2	733	183.3
1102	18.0	434	112.6	734	173.9
978	17.9	435	108.7	735	179.6
1717	18.0	436	107.4	736	156.7
2801	18.3	437	112.3	737	162.6
1293	17.9	438	104.4	738	183.6
2880	16.7	439	111.4	739	174.3
676[5]	*28.1*	440	104.1	740	185.5
$\overline{KV}$ = 18.0 J **s_{KV} = 0.88 J**		**$\overline{KV}$ = 110.6 J** **s_{KV} = 3.72 J**		**$\overline{KV}$ = 173.8 J** **s_{KV} = 13.16 J**	

4. Discussion

4.1. Establishment of new reference values for NIST lots

As previously mentioned, the available certified values for NIST lots had been obtained using 8 mm-strikers and, as far as LL-157 and HH-171 are concerned, at -40 °C (NIST super-high energy specimens are certified at room temperature). Therefore, new reference values had to be obtained at room temperature using a 2 mm-striker.

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[5] Specimen jammed during the test. The result was excluded from all subsequent analyses.

4.1.1. LL-157

The low-energy lot LL-157 (AISI 4340 steel) had been unsuccessfully qualified at -40 °C with 8 mm-strikers, and was therefore made available for a subsequent study aimed at investigating the influence of the striker radius (2 mm vs. 8 mm) on the reference values of NIST certified lots [12].

Seventy-five LL-157 specimens were tested at room temperature on the three NIST reference machines (25 per machine) with 2-mm strikers. The overall results were excellent, yielding a sample size value, n_{ss}, close to 1. The average values and standard deviations of absorbed energy for each machine are shown in **Table 6**, as well as the values of KV_{ref}, expanded uncertainty U^6, and sample size n_{ss}.

Table 6 – NIST reference values for LL-157 at room temperature and for 2 mm-strikers.

Machine	Machine type	$\overline{KV}$ (J)	s_{KV} (J)
TO2	U-type	19.4	0.43
TK	C-type	18.2	0.41
SI3[7]	U-type	19.2	0.59
All machines		**KV_{ref} = 18.9 J** **U = 0.11 J** **n_{ss} = 1.07**	

4.1.2. HH-171

The high-energy lot HH-171 (AISI 4340 steel) had been successfully certified at -40 °C with 8 mm-strikers. To establish a NIST reference value for comparison with results obtained at BIM, twenty-five specimens were tested at 21 °C ± 1 °C on the TO2 machine equipped with a 2 mm-striker. The following results were obtained:

- $\overline{KV}$ = 111.9 J
- s_{KV} = 3.12 J
- n_{ss} = 2.81.

4.1.3. SH-50

The super-high-energy lot SH-50 (AISI 9310 steel) had been successfully certified at room temperature (21 °C ± 1 °C) with 8 mm-strikers. All specimens from this lot were side-grooved by 1 mm per side, in order to avoid the additional variability caused by the random distribution of shear lips on the two broken halves, either symmetrical (both shear lips on one broken half specimen) or asymmetrical (one shear lip on each half) [13].

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[6] The expanded uncertainty U was obtained by multiplying the standard uncertainty u by a k factor = 1.999, for a number of degrees of freedom = 62.

[7] The machine labeled “SI3” is the third NIST reference machine, equipped with a U-type hammer like TO2. It has a potential energy of 409 J, and it replaced one of the original Army machines in the early 2000s.

To establish a NIST reference value for comparison with BIM test results, twenty-five specimens were tested at room temperature on the TO2 (U-type) machine equipped with a 2-mm striker. The following results were obtained:

- $\overline{KV} = 191.7$ J
- $s_{KV} = 8.54$ J
- $n_{ss} = 7.14$.

The mean value was much higher than the reference value previously obtained for 8 mm-strikers, $KV_{ref} = 165.3$ J. This was unexpected, as 8 mm-strikers are known to provide higher absorbed energies than 2 mm-strikers above a threshold that has been set between 150 J and 200 J [14,15].

Therefore, it was decided to run a second series of 25 tests on the TK machine (C-type, like the BIM machine) equipped with a 2 mm-striker. The results obtained were:

- $\overline{KV} = 166.6$ J
- $s_{KV} = 16.36$ J
- $n_{ss} = 34.71$.

The average value was much closer to KV_{ref} for 8 mm-strikers (165.3 J). On the other hand, the result variability was huge. Statistically, the results from the two machines (TO2 and TK) are different, based on a simple *t*-test[8] conducted at a 5 % significance level.

The reasons for the high average value of the TO2 tests and the atypical scatter of the TK results, as well as the discrepancy between the two machines, are unclear and need to be further investigated.

4.2. Result analyses

4.2.1. Tests performed at BIM

A summary of the 74[9] tests performed at BIM in the framework of this interlaboratory exercise is provided in **Table 7** in terms of $\overline{KV}$, s_{KV}, range (difference between maximum and minimum absorbed energy), *CV* (coefficient of variation, given by the ratio between s_{KV} and $\overline{KV}$), and sample size, calculated in accordance with Eq. (1).

Table 7 – Results of the tests performed at BIM. Sample size values are highlighted in bold green when less than or equal to 5.0, in bold red otherwise.

Lot	No. of tests	$\overline{KV}$ (J)	s_{KV} (J)	Range (J)	CV	n_{ss}
LL-157	24	18.0	0.88	3.7	4.9 %	**3.58**
HH-171	25	110.6	3.72	14.2	3.4 %	**4.09**
SH-50	25	173.8	13.16	44.3	7.6 %	**20.65**

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[8] A *t*-test is a type of inferential statistic used to determine if there is a significant difference between the means of two groups, therefore allowing to determine if the two groups come from the same population. The null hypothesis is that the two means are equal. Assuming a significance level $\alpha = 0.05$, the null hypothesis is rejected if the calculated probability $p < \alpha$, or accepted if $p > \alpha$.

[9] As already mentioned, one of the LL-157 specimens tested, which jammed, was removed from the analyses.

LL-157

The $\overline{KV}$ value obtained by BIM is at the very lower limit of the ASTM E23 acceptable range when compared to the results from the NIST U-type machine (TO2) shown in **Table 2** (difference = -1.4 J). Conversely, the BIM $\overline{KV}$ value falls comfortably inside the ASTM E23 range when compared to the value from the NIST C-type machine (TK), with a difference of just -0.2 J.

These results were confirmed by two-tailed *t*-tests on the equality between average values. The mean of the BIM tests is statistically different from the NIST mean for the U-type machine and statistically not different for the C-type machine at a significance level $\alpha = 0.05$.

The variability obtained is acceptable ($n_{ss} < 5.0$), albeit not as good as the sample size resulting from the NIST tests (1.07).

HH-171

The average absorbed energy obtained by BIM is in excellent agreement with the NIST reference value in **Table 2**, within the acceptable range of ASTM E23 (difference = -1.2 %).

This result was confirmed by a two-tailed *t*-test, which showed that the BIM mean is statistically not different than the NIST mean at a significance level $\alpha = 0.05$.

The sample size (4.09) is acceptable and somewhat higher than the value obtained by NIST (2.81).

SH-50

Similar to LL-157, the value $\overline{KV}$ recorded by BIM is in poor agreement (difference = -9.4 %) with the NIST reference value corresponding to the U-type machine (TO2) and in much better agreement (difference = 4.3 %) with the reference value corresponding to the C-type machine (TK). Accordingly, from two-tailed *t*-tests the reference value from BIM is statistically very different from the mean of NIST tests for the U-type machine ($p << 0.05$), and statistically not different for the C-type machine ($p > 0.05$).

The sample size from the BIM tests is very high (20.65), and falls between the n_{ss} values obtained by NIST on the U-type machine (7.14) and on the C-type machine (34.71).

4.2.2. Tests performed at NIST

A summary of the 100 tests performed at NIST in the framework of this interlaboratory exercise is provided in **Table 8** in terms of $\overline{KV}$, s_{KV}, range (difference between maximum and minimum absorbed energy), *CV* (coefficient of variation, given by the ratio between s_{KV} and $\overline{KV}$), and sample size, calculated in accordance with Eq. (1). The type of machine (U-type or C-type) is also indicated in **Table 8**.

Table 8 – Results of the tests performed at NIST. Sample size values are highlighted in bold green when less than or equal to 5.0, in bold red otherwise.

Lot	No. of tests	Machine	$\overline{KV}$ (J)	s_{KV} (J)	Range (J)	CV	n_{ss}
L2018	25	U-type	27.1	1.02	3.9	3.8 %	**4.82**
	25	C-type	25.2	1.13	4.6	4.5 %	**5.87**
M2018	25	U-type	95.6	5.55	23.1	5.8 %	**12.15**
G2018	25	U-type	145.3	6.23	20.2	4.3 %	**6.62**

L2018

The $\overline{KV}$ value obtained from the U-type NIST machine (TO2) falls outside the ±1.4 J ASTM E23 acceptable range in **Table 2** by almost 1 J. Conversely, the mean from the tests performed on the C-type machine (TK) falls comfortably inside the acceptable range.

The sample size is acceptable for the U-type machine and unacceptable for the C-type machine. The combined sample size (TO2 + TK) is unacceptable, n_{ss} = 9.59.

M2018

The average absorbed energy obtained by NIST is in good agreement with the BIM reference value in **Table 2**, within the ±5 % acceptable range of ASTM E23 (difference = -3.0 %).

Variability, however, is very high (n_{ss} =12.15).

G2018

The value $\overline{KV}$ obtained by NIST is in good agreement (difference = -3.0 %) with the BIM reference value.

The sample size calculated from the NIST tests is high (6.62).

4.3. Influence of hammer configuration (machine type) on Charpy test results

At NIST, it has been long known that the C-type machine (TK) consistently measures lower absorbed energies than the U-type machines (TO2 and SI3) at the low-energy level.

In 2016 [16], the authors published an investigation of historical Charpy data for the NIST reference machines in the period May 1995-February 2016. Differences between the machines were statistically analyzed in terms of mean values and coefficients of variation at three energy levels (low, high, and super-high). A relatively simple analysis of variance, ANOVA, conducted at a significance level α = 5 %, showed a statistically significant tendency of the C-type machine (TK) to provide lower energy values than the U-type machines (TO2 and SI3) for low-energy specimen lots. On the other hand, differences between the two U-type machines at the low-energy level or between the three machines at the high or super-high energy levels were not statistically significant.

A possible explanation of these findings was proposed in [16], based on previous work conducted by Manahan *et al*. in cooperation with NIST [17]. Based on calculations performed on a simple two-mass, two-spring model of the striker/specimen assembly, it was suggested that the difference in absorbed energies can be explained in terms of frequency shift in the applied force, caused by the stiffer design of the striker assembly in the TK machine[10]. This difference in stiffness was confirmed by subsequent measurements of machine compliance [18], which yielded lower compliance (*i.e.*, higher stiffness) for the TK machine than both TO2 and SI3. A 20 % higher stiffness of the striker assembly corresponds to a 7 % increase in the natural frequency of the striker/specimen combination and causes the critical fracture force to be reached at a lower specimen deflection: under prevalently brittle/elastic conditions, this translates into less absorbed energy needed for specimen fracture.

The observation that the test machine design can interact with low-energy specimens to materially affect their fracture behavior, by promoting early fracture and therefore lower *KV* values, is a major point and implies that absorbed energy is not fully a material "property", but depends on the test machine design, at least in case of brittle materials. It also provides support to the decision (taken very early in the history of the Army/NIST Charpy Program) to include multiple machines with different hammer configurations in the program, so that certified values could at least partially account for the characteristics of different Charpy machines used in the world.

As far as the outcomes of this interlaboratory exercise are concerned, the main consequence is that the comparison between the results of NIST and BIM at the low-energy level (LL-157 and L2018) is only meaningful if data from machines of the same type (C-type) are considered.

Differences observed at the super-high-energy level for NIST specimens (SH-50), however, cannot be readily explained and the reasons for these differences should be further investigated.

5. Conclusions

The Beijing Institute of Metrology, China and NIST in Boulder conducted an interlaboratory exercise (round-robin) that consisted in exchanging and testing Charpy reference specimens of different energy levels. All tests were performed at room temperature (21 °C ± 1 °C) on Charpy machines equipped with 2 mm-strikers.

Using the acceptability range provided in ASTM E23 for indirect verification tests (larger between ±1.4 J and ±5 % of the reference absorbed energy) as the metric for successful agreement between the two institutes, acceptable results have been obtained for all the specimen lots tested, with the following exceptions. In all cases, this good agreement was confirmed by the outcome of simple t-tests.

- For both NIST and BIM low-energy lots, the agreement is excellent only if results obtained on C-type machines (BIM machine and NIST TK machine) are compared; if results obtained at NIST on the U-type TO2 machine are considered, the difference is larger than ±1.4 J for both BIM and NIST specimens.
- Unexpectedly, the same holds for tests on the NIST super-high-energy specimens (lot SH-50). The difference between the labs is acceptable (within ±5 %) only with respect to

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[10] Besides the shape of the hammer, another prominent difference between TK and TO2/SI3 is that in the former, the pendulum swings between two columns supporting the hammer, whereas the U-type machines have a single column.

NIST results from the C-type machine, but not when tests on the U-type machine are considered. The reasons for this are unclear and need to be further investigated.

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Appendix 1

NIST tests on LL-157 lot (U-type machine)

KV (J)
19.71
19.01
19.27
19.62
19.62
19.27
19.27
19.01
19.10
19.45
18.84
19.45
19.79
20.31
19.71
20.05
18.75
18.41
19.19
19.45
19.45
19.36
19.45
19.01
20.05

Appendix 2

NIST tests on LL-157 lot (C-type machine)

KV (J)
18.39
18.69
18.39
17.79
18.69
18.19
18.29
18.19
18.29
18.19
18.19
17.39
17.69
18.89
18.69
17.39
17.59
18.09
18.09
18.49
18.39
18.19
17.89
18.19
17.59

Appendix 3

NIST tests on HH-171 lot (U-type machine)

KV (J)
112.03
108.43
110.04
110.14
111.27
117.15
110.89
113.07
109.76
113.74
115.25
119.04
106.63
108.24
106.54
112.50
112.41
112.41
114.30
116.29
109.00
110.42
112.22
110.99
114.68

Appendix 4

NIST tests on SH-50 lot (U-type machine)

KV (J)
179.67
180.13
193.45
186.87
197.21
190.12
197.75
184.78
193.90
196.50
200.51
193.90
202.01
203.34
207.92
192.28
169.93
187.23
193.72
202.01
190.12
190.21
189.04
188.49
182.41

Appendix 5

NIST tests on SH-50 lot (C-type machine)

KV (J)
157.76
148.75
172.07
153.31
168.79
175.73
146.61
149.56
157.06
191.54
153.82
144.57
187.57
149.66
177.60
185.05
146.71
173.16
176.82
160.38
152.40
168.59
195.96
178.29
193.17