NIST Technical Note 2089

Influence of Anvil Wear on Charpy Test Results – NIST Contribution to an International Study

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https://doi.org/10.6028/NIST.TN.2089

National Institute of
Standards and Technology
U.S. Department of Commerce

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Influence of Anvil Wear on Charpy Test Results – NIST Contribution to an International Study

Enrico Lucon
Raymond L. Santoyo
Applied Chemicals and Materials Division
Material Measurement Laboratory

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March 2020

U.S. Department of Commerce
Wilbur L. Ross, Jr., Secretary

National Institute of Standards and Technology
Walter Copan, NIST Director and Undersecretary of Commerce for Standards and Technology

National Institute of Standards and Technology Technical Note 2089
Natl. Inst. Stand. Technol. Tech. Note 2089, 25 pages (March 2020)
CODEN: NTNOEF

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Abstract

We investigated the influence of the state of wear of Charpy machine anvils on test results by performing impact tests on NIST specimens of three energy levels with a machine equipped with new anvils (compliant with both ASTM E23 and ISO 148-2) and worn anvils (anvil corner radii and distance outside ASTM tolerances, but within ISO tolerances).
The results obtained, statistically analyzed, unequivocally show that worn anvils tend to increase absorbed energy at all energy levels. On the other hand, data variability does not appear to be significantly affected by anvil wear.
This study represents NIST contribution to an international effort spearheaded by the Japan Iron and Steel Federation Standardization Center (Tokyo, Japan).

Key words

Absorbed energy, ASTM E23, Charpy, ISO 148, machine anvils, span, wear.

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1. Introduction

Charpy impact testing is standardized in several national and international norms, the most widely used being ASTM E23-18 [1] and ISO 148-1 [2].

Test standards precisely define the dimensions and tolerances for test specimens and every part of the machine. This facilitates the comparison between results obtained by different laboratories.

While most of the specimen and machine dimensions are identical or at least very similar between ASTM and ISO, some tolerances are significantly different, with ASTM E23 typically more stringent than ISO 148. An example is the tolerance on the corner radius of the machine anvils[1] (nominal value = 1.00 mm), which ASTM E23 requires to be ±0.05 mm, while ISO 148-2 [3] prescribes $^{+0.50}_{-0.00}$ mm. Figure 1, taken from ASTM E23, shows the configuration of anvils (top) and supports[2] (bottom) of a Charpy machine.

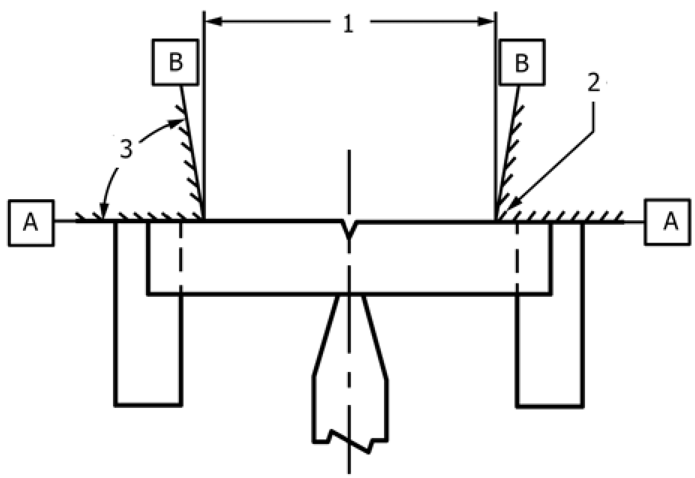


Figure 1 - Representation of a Charpy specimen being impacted during a test. Dimension "1" refers to the distance between the anvils (span), while "2" and "3" indicate anvil radius and angle, respectively [1].

Similar to any machine part in contact with the specimen during a test, anvils are subject to wear, which tends to increase the corner radii and eventually cause them to become out of tolerance. Other anvil features that are progressively modified by wear are surface roughness ("A" in Figure 1) and span ("1" in Figure 1). The nominal values and tolerances for these parameters in ASTM E23 and ISO 148-2 are:

- Surface roughness: Ra ≤ 0.1 µm (ASTM E23); not specified in ISO 148-2.
- Span: 40.00 mm ± 0.05 mm (ASTM E23); 40.00 mm $^{+0.50}_{-0.00}$ mm (ISO 148-2).

During the meeting of ASTM E28.07 subcommittee (*Impact Testing*) that took place in Atlanta, GA, in November 2017, Mr. Atsushi Ishikawa from the Japan Iron and Steel Federation (Tokyo, Japan) presented a proposal aimed at harmonizing anvil tolerances between ASTM and ISO. Specifically, he suggested revising ASTM E23 to allow the same tolerances

[1] According to the ISO 148-1 *Terms and Definitions* section (3.1.1), the anvil is a "portion of the machine that serves to properly position the test piece for impact with respect to the striker and the test piece supports, and supports the test piece under the force of the strike."
[2] Supports are the parts of the machine on which the specimen rests.

as in ISO 148-2 for anvil corner radius and span. A presentation by Mr. Ishikawa, summarizing his position on the topic, is included in Annex 1.

This ASTM E23 revision was balloted in 2018, but changes were rejected on account of the insufficient experimental data available to support a relaxation of the ASTM tolerances. Hence, Mr. Ishikawa decided to set up an international effort aimed at collecting experimental test data from Charpy tests performed with new and worn anvils. The Data Collection Protocol, written in collaboration with NIST in Boulder, is provided in Annex 2.

NIST volunteered to participate in this joint effort, by testing and statistically analyzing Charpy data from specimens corresponding to different energy levels. This report presents the results and the statistical analyses of the tests performed.

2. Material and experimental

Three types of NIST Charpy specimens were selected for this study:

- low-energy specimens (4340 steel, lot LL-157),
- high-energy specimens (4340 steel, lot HH-170), and
- super-high-energy specimens (9310 steel, lot SH-56).

Tests were performed at room temperature (21 °C ± 1 °C) on a Charpy machine with a capacity (potential energy) of 953.6 J and an impact speed of 5.47 m/s. The machine was equipped with a non-instrumented striker with 8 mm radius of the striking edge.

For each anvil condition (new and worn), 60 Charpy tests were conducted (25 at low- and high-energy level, 10 at super-high-energy level).

3. Selection of the worn anvils

Four pairs of used (worn) anvils were available for the chosen machine. In order to select the best pair for investigating the "worn" condition, we obtained replicas (molds) of the used anvil profiles by means of a silicone-type material, generally used for dental impressions. Once dried and solidified, replicas were sectioned in two positions (P1, P2), both inside the contact area between anvil and specimen (worn area).

In accordance with Figure 2, taken from the Data Collection Protocol, radius measurements (r_{P1} and r_{P2} for the two replica sections) were obtained by taking pictures of the replica sections and inscribing a circle on each picture, tangent to both sides of the anvil. The average of the radii of the inscribed circles for the two replica sections was taken as the radius for each worn anvil (Table 1).

Table 1 – Corner radius measurements on worn anvils.

Anvil	r_{P1} (mm)	r_{P2} (mm)	$\bar{r}$ (mm)
A	1.28	1.17	1.14
B	1.15	1.26	1.21
C	1.52	1.56	1.54
D	1.32	1.68	1.50
E	1.06	1.11	1.09
F	1.17	1.21	1.19
G	1.44	1.31	1.38
H	1.47	1.19	1.33

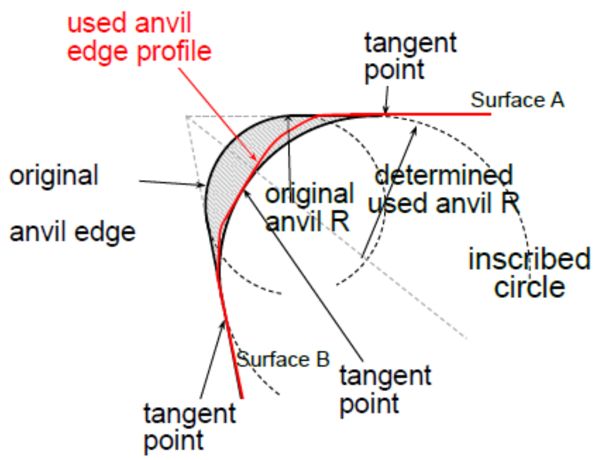


Figure 2 – Measurement of worn anvil radius (from *Data collection protocol*, Annex 2).

Annex 3 collects all the pictures taken from the replicas, showing also the inscribed circles and the corresponding corner radius (r).

Based on the measurements performed, anvils G (average radius, $\bar{r}$ = 1.38 mm) and H ($\bar{r}$ = 1.33 mm) were selected for the tests in the worn condition. They represent a case that is clearly beyond the ASTM allowable limit (r_{max} = 1.05 mm), but well within the ISO limit (r_{max} = 1.50 mm). Moreover, the difference between the measured radii and the two limits is large enough to provide some margin with respect to possible measurement uncertainties.

After worn anvils G and H were installed on the Charpy machine, we used a caliper to measure their distance (span), which was found to be equal to 40.10 mm. This is invalid according to ASTM E23 (> 40.05 mm), but acceptable per ISO 148-2 (≤ 40.20 mm).

4. Charpy test results

The values of absorbed energy, *KV* (J), obtained with new and worn anvils, are provided in Table 2 and Table 3, respectively.

Table 2 - Charpy test results obtained with new anvils, including average values ($\overline{KV}$) and standard deviations.

Low energy (LL-157)		High energy (HH-170)		Super-high energy (SH-56)	
Specimen ID	KV (J)	Specimen ID	KV (J)	Specimen ID	KV (J)
2056	30.30	586	95.84	1306	239.91
1244	29.27	1258	100.55	1581	245.35
55	26.98	519	108.00	1558	242.34
1224	25.01	846	101.86	1065	233.43
167	23.68	612	106.59	1251	244.09
437	21.72	830	110.47	1266	259.19
1119	18.92	1214	98.19	2056	241.17
965	19.23	983	97.58	1963	234.49
1726	21.49	432	102.82	1940	264.27
2357	27.61	667	96.36	1699	235.84
1939	30.46	1037	106.41		
2719	32.44	815	109.76		
2065	31.57	386	110.91		

Low energy (LL-157)		High energy (HH-170)		Super-high energy (SH-56)	
Specimen ID	KV (J)	Specimen ID	KV (J)	Specimen ID	KV (J)
1327	31.49	1223	111.44		
117	31.01	875	102.91		
2514	31.17	870	98.97		
1739	31.01	1246	97.93		
1545	25.56	622	102.99		
139	26.11	927	92.20		
2729	23.68	228	111.79		
1271	20.63	56	106.85		
938	20.87	1253	105.10		
1515	27.37	162	115.51		
1299	29.74	1257	97.76		
2349	32.20	72	104.40		
$\overline{KV}$ = 26.78 J ± 4.44 J		$\overline{KV}$ = 103.73 J ± 6.01 J		$\overline{KV}$ = 244.01 J ± 10.22 J	

Table 3 - Charpy test results obtained with worn anvils, including average values ($\overline{KV}$) and standard deviations.

Low energy (LL-157)		High energy (HH-170)		Super-high energy (SH-56)	
Specimen ID	KV (J)	Specimen ID	KV (J)	Specimen ID	KV (J)
666	35.55	454	119.87	1059	258.50
1711	34.99	995	120.13	418	246.90
367	35.87	270	132.96	355	270.55
1187	35.15	1026	118.80	11	263.49
2019	32.76	498	121.02	305	257.43
402	31.25	770	118.89	313	251.67
2807	27.61	924	115.78	999	261.24
1672	24.86	956	111.08	986	239.33
1769	23.76	1128	108.97	910	261.53
637	21.26	660	116.31	882	266.14
1100	22.19	112	124.42		
1623	26.98	456	122.90		
2317	30.14	844	124.78		
178	34.35	1239	107.12		
959	33.79	1052	114.18		
1962	34.99	1255	121.02		
2342	35.39	668	120.58		
989	34.99	391	125.76		
1329	34.11	692	119.95		
2389	32.36	319	120.85		
1905	31.81	1238	109.14		
1104	28.08	892	110.38		
659	27.45	1137	114.53		
24	24.86	672	125.32		
2547	26.19	1233	125.05		
$\overline{KV}$ = 30.43 J ± 4.69 J		$\overline{KV}$ = 118.79 J ± 6.28 J		$\overline{KV}$ = 257.68 J ± 9.36 J	

All specimens at the low- and high-energy level fractured completely during the test, while all the super-high-energy specimens exited the machine unbroken.

All specimens tested came from failed verification lots (*i.e.*, not satisfying the NIST certification requirements), as no certified reference specimens were available at the time of testing.

5. Statistical analyses

In order to compare the results from new and worn anvils, we first assessed whether the variances of the *KV* values were affected by anvil condition. To accomplish this, a two-tailed *F*-test was conducted [4,5] to test against the alternative that the variances were not equal at a 0.05 significance level (α). The results are summarized in Table 4.

Table 4 - Summary of two-tailed *F*-tests on the equality of variances (α = 0.05).

Energy level	Low (LL-157)		High (HH-170)		Super-high (SH-56)	
Anvil condition	New	Worn	New	Worn	New	Worn
Mean (J)	26.78	30.43	103.73	118.79	244.01	257.68
Variance (J^2)	19.71	21.99	36.16	39.50	104.41	87.58
N	25	25	25	25	10	10
df	24	24	24	24	9	9
$\boldsymbol{F}$	**1.1160**		**1.0923**		**1.1921**	
$\boldsymbol{F_{critical}}$	**1.9838**		**1.9838**		**3.1789**	
p	0.3951		0.4153		0.3989	

LEGEND N = number of test results; $df = N - 1$ = degrees of freedom; p = probability value, providing evidence against the null hypothesis (*i.e.*, variances are different), to be compared with the significance level (0.05).

At all energy levels, the calculated F values (ratio between the variances) are lower than the critical values ($F_{critical}$): therefore, there is not enough evidence to reject the null hypothesis that the two anvil conditions have different variance. In other words, we found that anvil condition has a negligible influence on the variability/scatter of Charpy results.

Next, we used the two-sample *t*-test (assuming equal variances) [4,5] to assess whether the influence of anvil condition on *KV* values was statistically significant. Here, the null hypothesis is that the means of the two populations are equal with a significance level α = 0.05. The results for the three energy levels are provided in Table 5.

Table 5 - Summary of two-tailed *t*-tests on the equality of means (α = 0.05).

Energy level	Low (LL-157)		High (HH-170)		Super-high (SH-56)	
Anvil condition	New	Worn	New	Worn	New	Worn
Mean (J)	26.78	30.43	103.73	118.79	244.01	257.68
Variance (J^2)	19.71	21.99	36.16	39.50	104.41	87.58
Pooled variance (J^2)	20.85		37.83		96.00	
N	25	25	25	25	10	10
df	48		48		18	
$\boldsymbol{t}$	**2.8252**		**8.6595**		**3.1198**	
$\boldsymbol{t_{critical,two-tail}}$	**2.0106**		**2.0106**		**2.1009**	
$p_{two-tail}$	0.0069		2.26×10^{-11}		0.0059	

As in the case of the *F*-test, the results are unequivocal at all energy levels: the influence of anvil condition on Charpy absorbed energy is statistically significant, with worn anvils providing consistently higher values.

6. Conclusions

Our test results at different energy levels showed that worn anvils (outside ASTM tolerances but well within ISO tolerances, in terms of both corner radii and distance) tend to increase absorbed energy in a statistically significant manner.

These results do not support the proposal to relax the ASTM E23 upper tolerances on anvil radius and span to match the ISO 148-2 values (1.50 mm and 10.20 mm, respectively). On the contrary, should test results from other laboratories confirm our conclusions, it would be appropriate to propose a revision of ISO 148-2 aimed at tightening these upper tolerances.

References

[1] ASTM E23-18, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials, ASTM International, West Conshohocken, PA.

[2] ISO 148-1:2016, Metallic materials — Charpy pendulum impact test — Part 1: Test methods, International Standardization Organization, Geneva, Switzerland.

[3] ISO 148-2:2016, Metallic materials — Charpy pendulum impact test — Part 2: Verification of testing machines, International Standardization Organization, Geneva, Switzerland.

[4] Snedecor, G. W. and Cochran, W. G. (1989), Statistical Methods, Eighth Edition, Iowa State University Press.

[5] NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, update April 2012.

ANNEX 1

Presentation by A. Ishikawa

Japan Iron and Steel Federation

(5/14/2019)

Tolerance of anvil radius in Charpy impact test machines

2019 May 14

The Japan Iron and Steel Federation

Proposal of revision (anvil tolerance)

ASTM E23 ; +0.05 mm/-0.05 mm

⇕

[ISO 148-2 ; +0.5 mm/-0 mm]

⇩

Proposal of revision (SB)

	Radius	Distance
Initial	+0.05 mm/-0.05 mm	+0.05 mm/-0.05 mm
After use	+0.50 mm/-0.05 mm	+0.20 mm/-0.05 mm

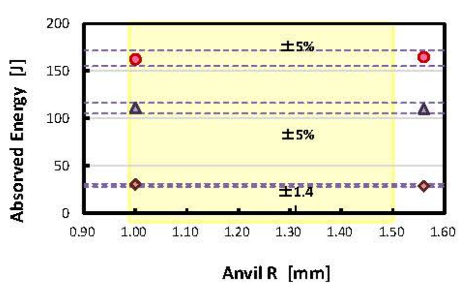
Result of voting [E28.07(18-02)]

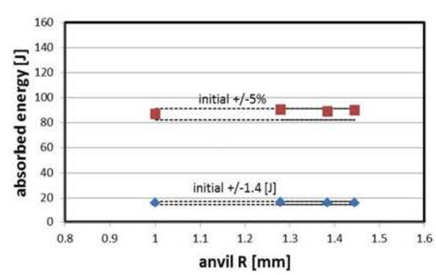
Affirmative ; 36
Negative ; 4+2* (2 technical & 4 editorial)
[*; non-official voting member]

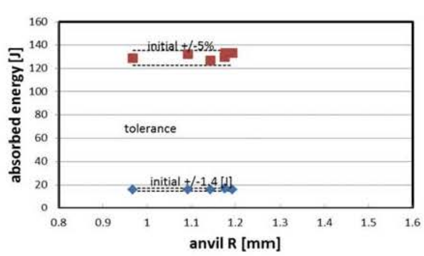
Technical 1)Needs more lab data
2)Worry unknown effects

Editorial 1)Unclear & confusing
2)Separate initial condition and used condition
3)Add figure of used condition

Actual data (provided by 3 labs)







All of these data were presented E28.07 meetings.

Surround of ISO based standard

- Tolerance of anvil radius of ISO based standards
  ; +0.5mm/-0mm
  (ISO based standards are widely used in European countries and Japan)
- They don't have any problems for about 30 years.

Suggestion from negative voter

- The tolerance of anvil radius shall be +0.5mm/-0.05mm between verification, but +/-0.05mm when indirect verification is performed.

Proposed re-ballot

- Initial condition and naturally worn (used) condition will be specified separately.
- Add;

  -Figure of naturally worn (used) condition

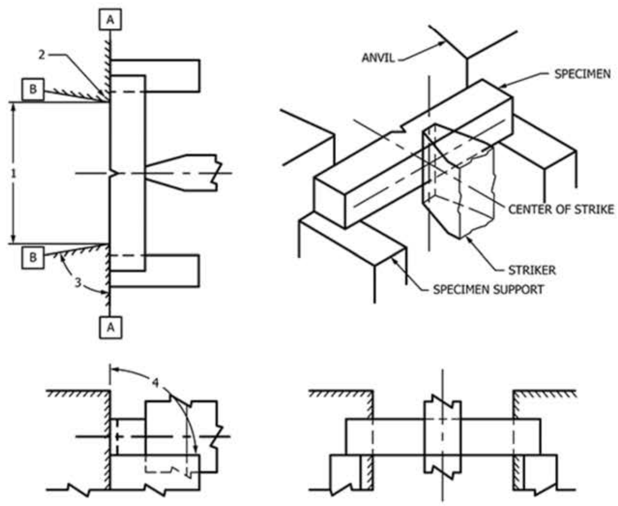
  -"The tolerance of anvil radius shall be +0.5mm/-0.05mm between verification, but +/-0.05mm when indirect verification is performed."

Initial Condition of Charpy Anvils and Supports

Initial (new) condition of Charpy anvils and supports shall conform to the dimensions and tolerances shown in Fig. A1.2. Other dimensions of the pendulum and supports should be such as to minimize interference between the pendulum and broken specimens.

ID Num	Designation	Dimension	Tolerance
1	Span between anvils	40.00 mm	±0.05 mm
2	Anvil radius	1.00 mm	±0.05 mm
3	Anvil angle	80°	±2°
4	Anvil-Support angle	90°	±0.15°
A & B	Surface finish, Anvils	0.1 µm (Ra)	≤

FIG. A1.2



<u>Naturally Worn (used) Condition </u>of Charpy Anvils

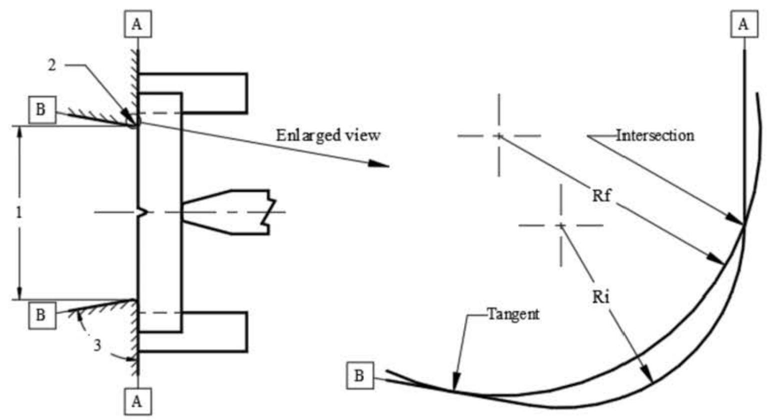
Naturally worn (used) condition of Charpy the profile shall remain contained between the initial profile and an arc with radius Rf = 1.50 mm, as shown in Fig. A1.3. With the naturally worn (used) condition), the allowable tolerance for the span between anvils shall become $^{+0.20}_{-0.05}$ mm.

NOTE The arc with radius Rf = 1.50 mm has the intersection on the tangent point with the maximum initial radius of Ri = 1.05 mm on Surface A, and the tangent point on Surface B.

ID Num	Designation	Dimension	Tolerance
1	Span between anvils	40.00 mm	+0.20mm/-0.05mm
2	Anvil radius	1.00 mm	+0.50mm/-0.05mm
3	Anvil angle	80°	±2°

The tolerance of anvil radius shall be +0.5mm/-0.05mm between verification, but +/-0.05mm when indirect verification is performed.

FIG. A1.3



Thank you for your attention.

ANNEX 2

Data Collection Protocol

Data collection/Inter-laboratory exercise for the revision of anvil radius tolerance in Charpy impact testing (ISO 148-1)

1. Introduction

When the revision of the anvil radius tolerance for Charpy testing in the ASTM E23 standard was balloted at E28.07 sub-committee, a negative voter pointed out that more actual test data should be collected and assessed. The E28.07 sub-committee decided to set up a Task Force to respond to this negative.

This is my proposal for collecting the required test data.

2. Data collection

2.1 Timing for testing test pieces

1) Just before the periodic verification (absorbed energy data using worn anvil)

2.2 Test pieces

1) Standard test pieces which have verified value of absorbed energy

2.3 Absorbed energy

1) Measure absorbed energy of test pieces (3-5 specimens/set), with the timing specified in 2.1.
2) Calculate average value of the set.
3) Calculate relative error with respect to the certified value of the specimens.

$$\text{Relative error} = \frac{(\text{Absorbed energy using worn anvil}) - (\text{Certified value of absorbed energy})}{(\text{Certified value of absorbed energy})}$$

2.4 Anvil profile

1) Mold the profile of the worn (end-of-life) anvils, obtaining replicas.
2) Measure the anvil radius in accordance with the attached procedure.

2.5 Distance between anvils

1) Measure the distance between anvils (anvil span) just before the periodic verification.

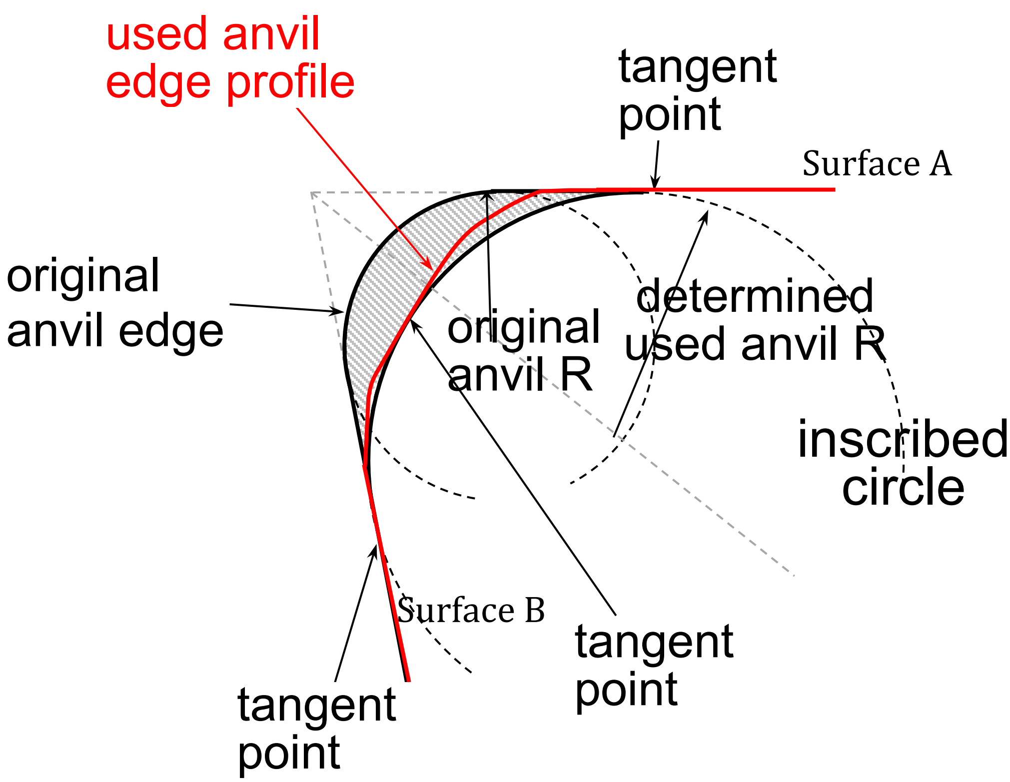
3. Report

1) Certified absorbed energy (if available)
2) Absorbed energy using worn anvils (mean value)
3) Absorbed energy using new anvils (mean value)
4) Photographs of worn anvil radius and its replicas
5) Distance between anvils (anvil span) just before periodic verification

<Attached Procedure>

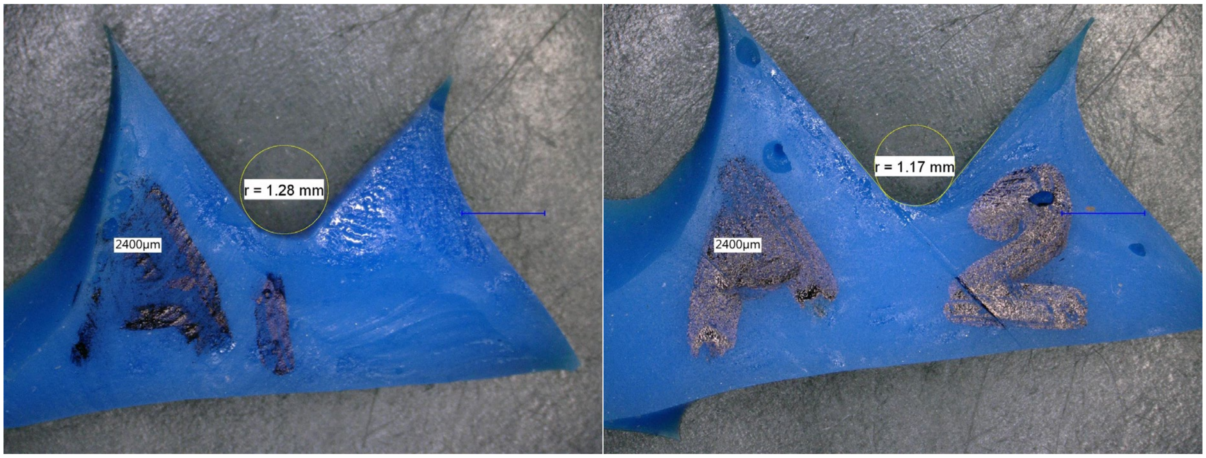
How to determine worn anvil radius

1) Mold (obtain replicas) of the worn anvils.
2) Slice the replicas in the middle of the worn areas.
3) Take a photo of the replica profiles.
4) Determine the inscribed circle which is tangent to the profile in 3 tangent points (see figure);
   - Surface A
   - Maximum worn point
   - Surface B

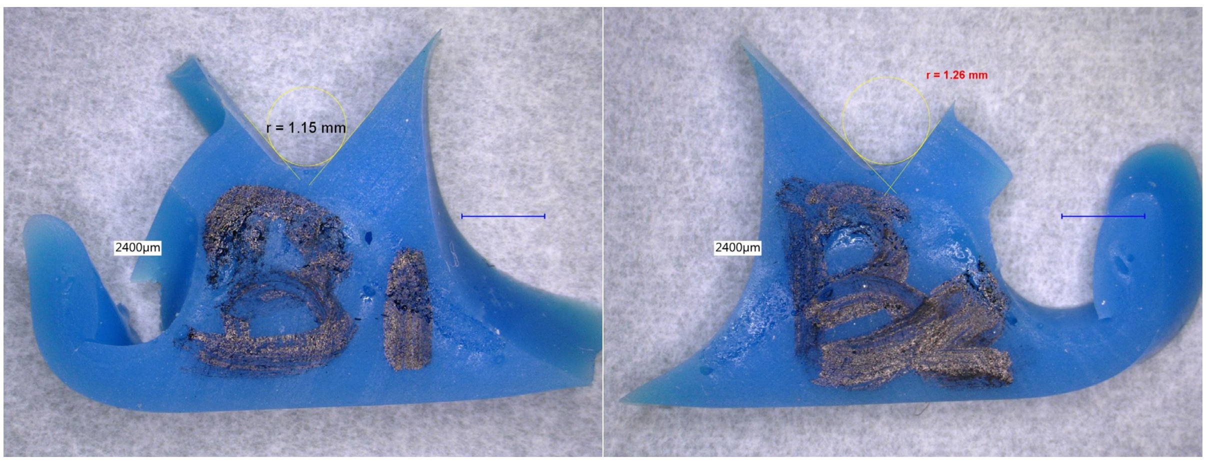


ANNEX 3

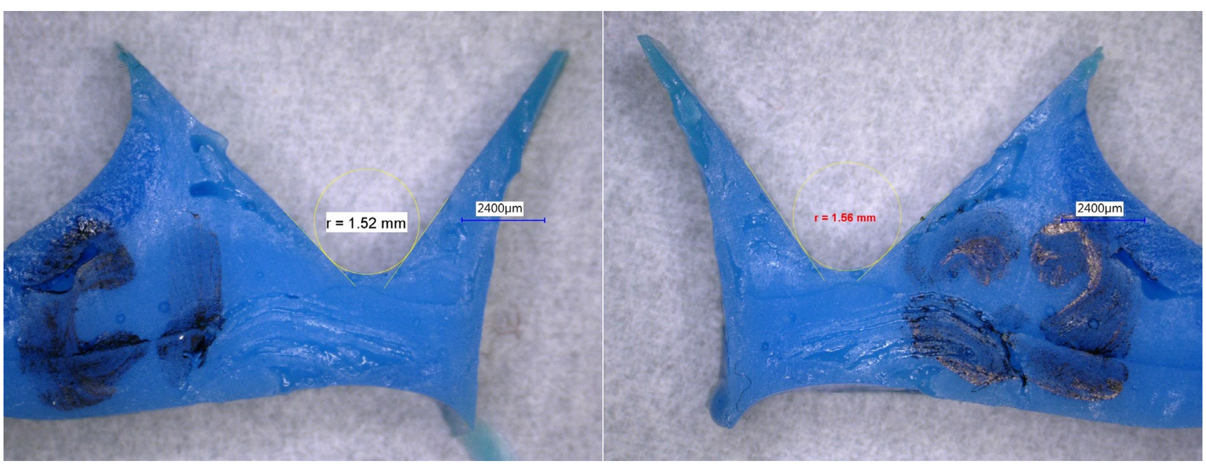
Pictures of anvil replicas with inscribed circles



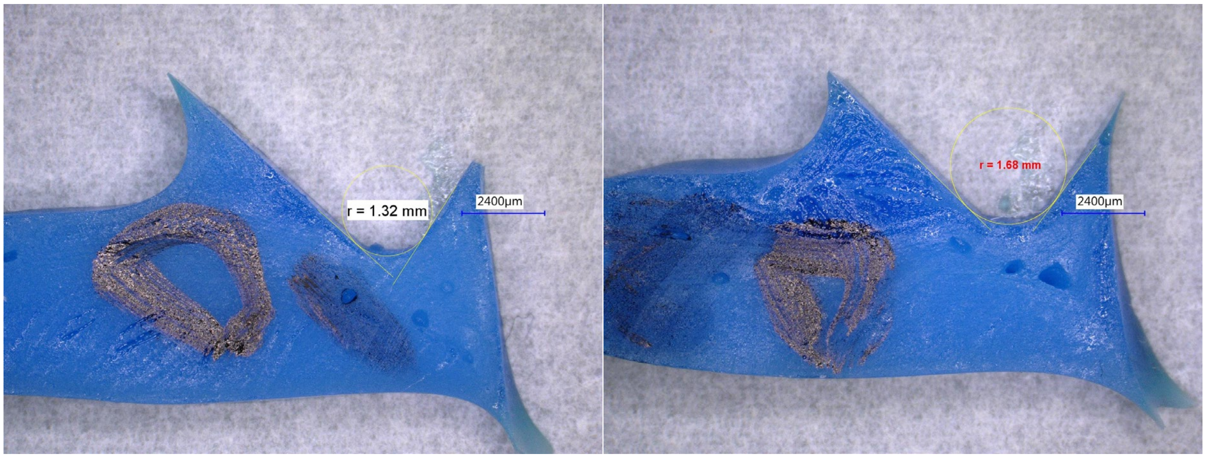
Anvil A – Positions P1 (left) and P2 (right)



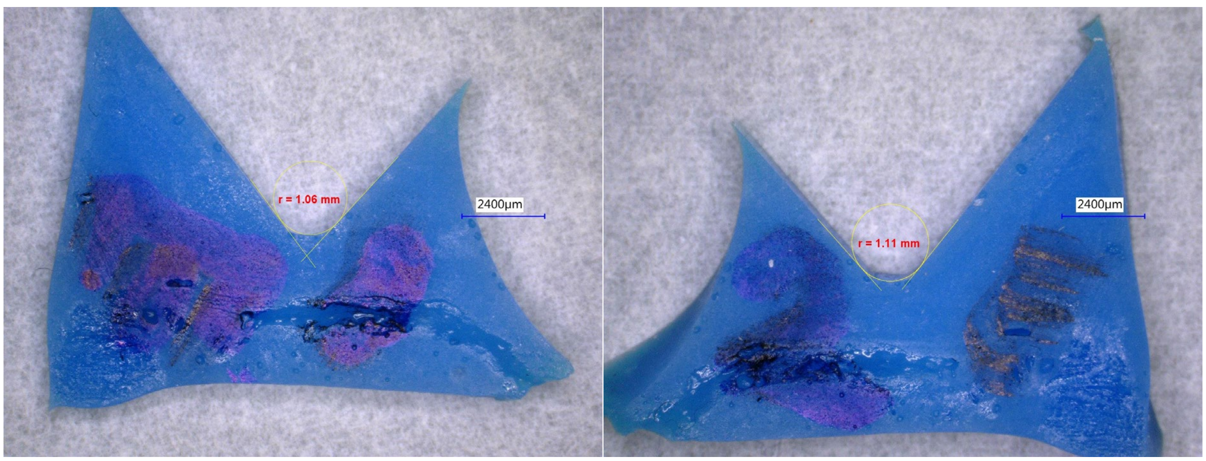
Anvil B – Positions P1 (left) and P2 (right)



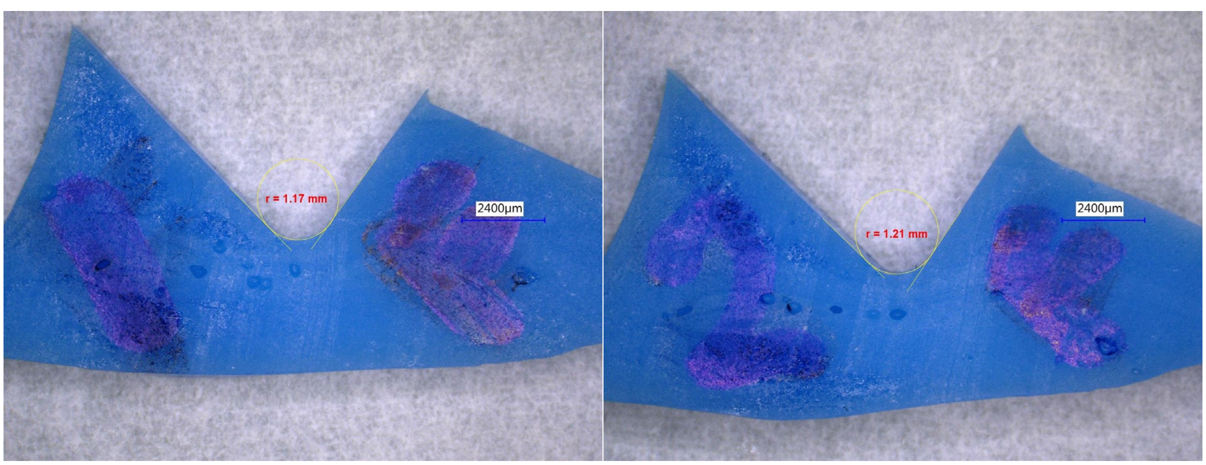
Anvil C – Positions P1 (left) and P2 (right)



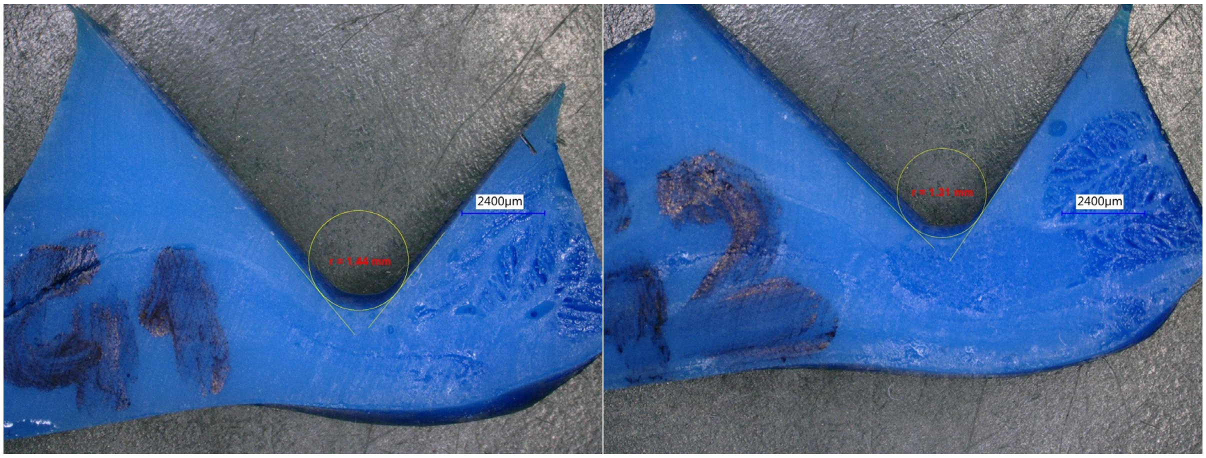
Anvil D – Positions P1 (left) and P2 (right)



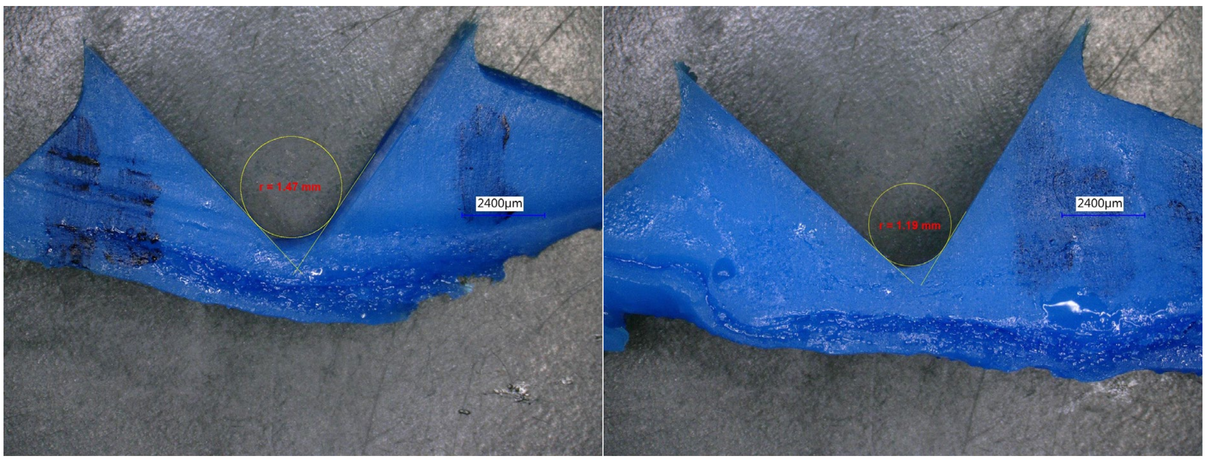
Anvil E – Positions P1 (left) and P2 (right)



Anvil F – Positions P1 (left) and P2 (right)



Anvil G – Positions P1 (left) and P2 (right)



Anvil H – Positions P1 (left) and P2 (right)