Pendulum Impact Machines

Procedures and Specimens for Verification

Thomas A. Siewert and
A. Karl Schmieder, editors

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Overview

This was the sixth symposium published by ASTM on the topic of impact testing. The five previous symposia, *Proceedings of ASTM,* Vol. 22-II (1922), *Proceedings of ASTM,* Vol. 38-II (1938), STP 176 (1956), STP 466 (1970), and STP 1072 (1990), were sponsored by ASTM Subcommittee E28.07 (prior to 1969 known as E-1.7). These symposia covered a broad range of topics and occurred rather infrequently. The period before 1985 might be characterized as one in which the Charpy test procedure was broadly accepted and changing very slowly. However, the last symposium (1989), "Charpy Impact Test: Factors and Variables," was driven by new forces: a recognition within ISO Technical Committee 164 (Mechanical Testing) Subcommittee 4 (Fracture) of shortcomings in the procedure and a desire to know the basis for the requirements. Although most of the requirements and procedure details were considered quite reasonable and still valid, there was a desire by the late 1980s to restudy a few of the relationships. Some felt that changes in materials and energy ranges (from those under which the original relationships were developed) might justify slight revisions to the procedures. Also, some other standards and users in other countries had adopted different procedures, which raised questions about comparison of data developed under these different procedures.

Authors from five countries presented a broad variety of test data at the 1989 Symposium, which encouraged spirited discussion and comparison of the results. The twelve papers in the proceedings (STP 1072) and another paper in the *Journal of Testing and Evaluation* provided a review of the effects of procedural and specimen variables in Charpy impact testing. The data proved to be of interest to many general users of the test, but was of particular interest to the members of ASTM Subcommittee E28.07 (the subcommittee responsible for Standard E-23 on the Charpy test). During the past five years, the data presented at the symposium have been the single most important factor in determining whether to change various requirements in Standard E-23. The data have also been useful in supporting tolerances and procedural details during the reballoting of ISO Standard 442 on Charpy testing.

By 1991, the E28 Subcommittee on Symposia suggested that it was time to schedule another symposium on Charpy impact testing. One reason was because the 1989 symposium did not answer certain questions about the choice of tolerances in the specifications. Indeed, several of the papers appeared to reach conflicting conclusions about the effect of certain variables.

The Call for Papers for the 1994 Symposium specifically invited studies on the issues of procedures and specimens for machine verification. The following paragraphs describe our success in attracting papers that study the procedural details and suggest changes in the tolerances in ASTM and ISO standards.

This publication includes three papers comparing the 8-mm and the 2-mm radius striker designs. These papers (Nanstad and Sokolov; Siewert and Vigliotti; and Tanaka et al.) confirm that the data taken with the two strikers are not interchangeable and suggest that the 8-mm radius typically produces higher energies below about 20 J and that the 2-mm radius striker produces higher energies above 100 J. In the intermediate range, the results are less consistent. During the final discussion period, we tried to find ways to resolve the use of different striker radii between countries. It became clear that there is no easy solution because each country has developed a large statistical database with their own striker design (8- or 2-mm radius). These data have been incorporated in a complex web of other standards and requirements. However, it was very encouraging to learn that the European standards (EN series) may add the 8-mm striker in the next revision (in about four years) and that the ASTM subcommittee plans to add the 2-mm striker in their next revision of E23. Unfortunately, there does not seem to be a similar activity in Japan.

We heard about the development of standardized specimens for indirect verification of machine performance to supplement direct measurements (primary physical characteristics of the machines). Papers by Hida and by Galban et al. described the development of standardized specimens for Japan and France, respectively. Building on the statistical calculations contained in these two papers, a paper by Splett and Wang provided more details on the determination of the quality of standardized specimens.

In the area of machine and specimen tolerances, we learned about the effect of machine alignment on second strike marks (Schmieder et al.), the effect of specimen edge squareness (Marsh), striker geometry tolerances (Ruth), striker surface finish (Ruth et al.), subsize specimens (Alexander et al. and Manahan et al.), and reconstitution of specimens (Williams et al.).

The topic of machine verification is becoming important for nonmetallic materials as well. The Call for Papers was developed in discussions with ASTM Subcommittee D20.10 (Mechanical Properties of Plastics) and Section D20.10.02 (Impact Properties of Plastics) to include papers on Charpy and Izod testing of plastics. We received a paper by Mackin and Tognarelli on calibration of an impact machine for plastics and one by Kalthoff and Wilde on instrumented impact testing of polymeric materials.

Other papers covered the use of load-displacement curves for obtaining more information from impact tests (KarisAllen and Matthews and McCowan et al.) and the kinetic energy of the specimen being tossed from the machines (Chandavale and Dutta for an unbroken specimen; Kalthoff and Wilde for the two broken halves).

Many people commented that they found the information presented in this symposium to be particularly interesting. One reason for this may be that the 1994 symposium attracted contributions from many countries. Twenty-one of the forty-two authors and coauthors are from outside the U.S., an even broader participation that in the 1989 symposium. We believe that this is due partly to wide distribution of the Call for Papers at international meetings and because of the current importance of this topic in international commerce.

Although the 1994 symposium provided much useful information that will allow us to improve impact testing standards, it also identified other differences between standards and will require further study before a decision can be made. The following topics should be considered for inclusion in the Call for Papers for a future symposium:

1. The theoretical effect of striker contact radius on the state of elastic stress at or near the root of a Charpy specimen notch.
2. The use of instrumented strikers to separate the energies of crack initiation and of crack propagation for machines with 8-mm and 2-mm striker radii in the range below 25 J Charpy V-notch absorbed energy.
3. Correlation of results of static tests for plane-strain fracture toughness to those for Charpy V-notch impact tests at different temperatures, using both the ISO and the ASTM striker.
4. By finite element or other analytical techniques, determine the striker form that will minimize the plastic work of crushing and bending the specimen.
5. Compare the absorbed energy as measured by machines with C-type pendulums to U-type, including materials with high yield strength and absorbed energy less than 20 J.

Acknowledgments

We appreciate the assistance of E28.07 members, many of whom helped by chairing the sessions and by reviewing the manuscripts. We particularly appreciate the assistance of J. M. Holt who (in his role and Chairman of Subcommittee E28.93 on Symposia) helped us obtain sponsorship of the Symposium and provided valuable advice on the arrangements, and who (in his role as the U.S. delegate to ISO Committee 164-TC4) encouraged international participation. We also received wise advice from a large number of the ASTM staff on symposium arrangements, selection of reviewers, and the other myraid of details necessary for a successful symposium.

Contents

ESTABLISHING REFERENCE ENERGIES

TESTING PROCEDURES AND OTHER TOPICS

The Specimen

A. Karl Schmieder[1], Patrick T. Purtscher[2], and Daniel P. Vigliotti[2]

THE ROLE OF STRIKE MARKS ON THE REPRODUCIBILITY OF CHARPY IMPACT TEST RESULTS*

REFERENCE: Schmieder, A.K., Purtscher, P.T., and Vigliotti, D.P., "The Role of Strike Marks in the Study of Reproducibility of the Results of Charpy Impact Tests," Pendulum Impact Machines: Procedures and Specimens for Verification, ASTM STP 1248, T.T. Siewert and A.K. Schmieder, Eds., American Society for Testing and Materials, Philadelphia, 1995.

ABSTRACT: Charpy V-notch specimens from one lot of high-strength steel were tested using three machines to determine reference values for three measures of toughness: absorbed energy, lateral expansion, and height of shear lips. The broken specimens were examined to determine the location and magnitude of changes in specimen features made during testing. The features of interest were the height and location of the shear lips, the location of the lateral expansion projections ranked by height, and the location, length, width, and angle of the first- and second-strike marks. Changes in these features were compared to the changes in average absorbed energy for each of the machines in its standard condition. To correlate changes in these features with intentional machine modifications, ten series of tests were made on a fourth machine. Patterns which could predict the direction of change in absorbed energy for most modifications were observed. The trends indicated by these data are: (1) each modification resulted in an increase in absorbed energy, (2) the distance between second-strike marks is a measure of the compliance of the striking edge and anvil, (3) the offset of the first-strike marks is largely due to lift-off of the specimen at the moment the striker hits the specimen, (4) offset and the angle of second-strike marks are measures of general asymmetry of loading, and (5) lateral expansion and shear lips are valuable as means to detect scale errors and excess losses not related to the work of fracture.

KEYWORDS: Absorbed energy, Charpy V-notch, high-strength steel, high-speed photography, impact machine, lateral expansion, shear lips, strike marks

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NOMENCLATURE

composite postfracture energy -- a measure of the work done to create the fracture surface, excluding energy expended in shock losses, toss losses, and work to form depressions in the specimen at points of contact.

lift-off -- the momentary loss of contact between the specimen and the anvils, which occurs immediately after first contact.

offset -- the horizontal distance from the striking edge to the notch.

reference value -- a value obtained from tests made by a machine in standard condition.

specimen locations -- when the specimen is in the position for testing.

in direction of swing:
(N)[3] notched surface -- the surface parallel to the notch root and nearest it.
(S) struck surface -- the surface parallel to notch root and farthest from it.

vertically:
(U) upper horizontal surface.
(L) lower horizontal surface.

transversely:
(I) inboard half -- portion of specimen originally between the striking edge and the machine column.
(O) outboard half -- the portion originally adjacent to the inboard half.

first-strike mark -- the mark made on the specimen by the anvils before fracture (see Fig. 1).

second-strike mark -- the mark made on the specimen if the broken halves fly away from the pendulum and strike the anvils (see Fig. 1).

third-strike mark -- additional mark made on the specimen after fracture by striking a machine part or other solid object in the vicinity.

types of second-strike marks:

line -- the second-strike mark which completely crosses the notched surface (see Fig. 2, codes A, I and J).

nick -- a second-strike mark which impacts both edges, but not in the center, of the notched surface (see Fig. 2, codes B and F).

others -- a nick at one edge only, or a nick on one half and a line on the other half, or no second-strike marks on one half.

INTRODUCTION

Relative to hardness and tension tests of metal, impact tests have poor reproducibility. This is economically important since it requires more tests to ensure a given degree of precision. This testing

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[3]Letters are abreviations used in Tables.

problem has been long recognized [1-4]. Although significant improvements have been made during the last three decades [5], limited reproducibility remains one of the principal disadvantages of impact testing. The objective of this study is to reduce the variability of impact test results by identifying machine deficiencies through inspection of the broken specimens.

This inspection included the usual measurement of absorbed energy, lateral expansion, and shear lips. In addition, another less well-known measurement was made, the characterization of subsequent strike marks. The process of forming the marks is shown schematically in Fig. 1. High-speed photographs confirm the transverse flight of the broken halves and the strike against the anvils. Enlarged photographs in Fig. 2 show various types of first- and second-strike marks.

EXPERIMENTAL PROCEDURES

Specimens

All specimens were drawn at random from a large lot of verification-grade specimens. The material specification is published in ASTM Standard Practice for Qualifying Charpy Verification Specimens of Heat Treated Steel, E 1271, Appendix X1. The specimen dimensions were those for Type A shown in Fig. 6 of ASTM Standard Methods for Notched Bar Impact Testing of Metallic Materials E 23 except that the tolerances are smaller.

Machines

The first three machines, which were used to determine the reference values, were manufactured by different companies to meet the specifications of ASTM E 23. All had capacities of 300 J (220 ft·lbf) or more. All were directly verified within a year of making the tests

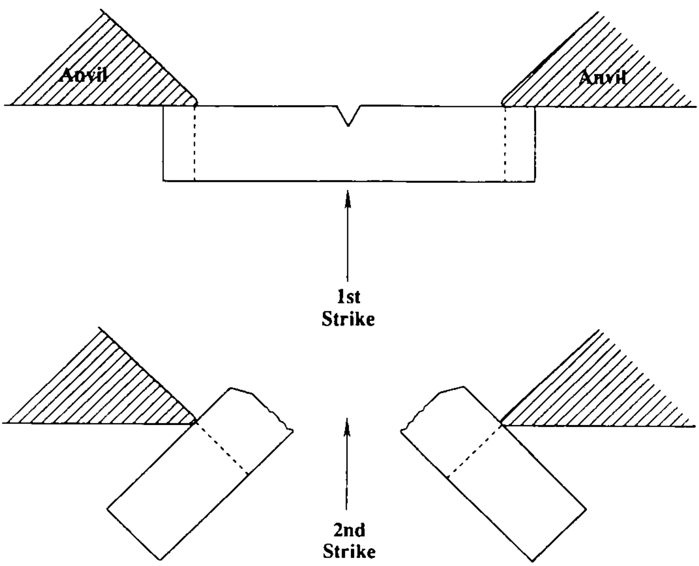

Fig. 1 -- Schematic diagram shows how the first- and second-strike marks are produced.

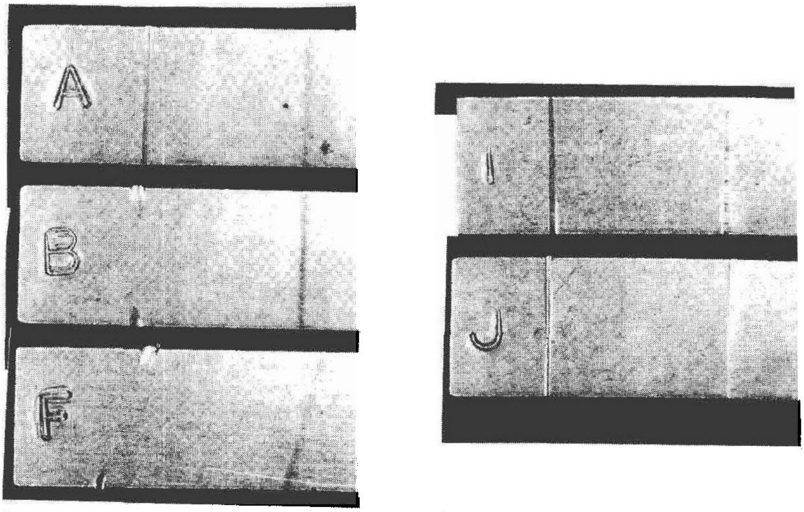

Fig. 2 -- Photographs of the struck surfaces on a broken half from each of the following series: A, B, F, I, and J. The first-strike marks are on the right-hand side and the second-strike marks are on the left-hand side.

reported here. The fourth machine, which was modified during these tests, had less than half the capacity of the others. The machine designations used in this study, the pendulum types (as described in ASTM E 23, Fig. 1), and the scale errors in percentage of the reading are:

Designation	R1C	R1U	R2U	M1C
Type of pendulum	C	U	U	C
Scale error	-3.0%	-0.8%	-0.3%	0.0%

All reported values are corrected for the scale errors that are known. A method to estimate the scale error for M1C is discussed later. The modifications made to Machine M1C are given letter designations and are listed below. The same letters are used to identify the test series in the tables of results.

A. As received. History of prior use unknown. Tightness of bolts unknown.

B. Old anvils replaced by new anvils. Bolts tightened to 100 J (75 ft·lbf) at each installation.

C. Old anvils reinstalled.

D. Place specimen on the supports so that they are offset 2 mm toward the machine pedestal.

E. New taller supports installed to raise the specimen 10.6 mm above the standard position. During this and each subsequent replacement of the supports, the bolts were tightened to 27 J (20 ft·lbf).

F. Reinstall the original inboard support only.

G. Remove both supports so the specimen is 10.9 mm below the standard position.

H. *Shorten and grind the top surface of the new supports so that the* specimen is slanted upward toward the anvil at one degree with the horizontal and reinstall.

I. Reinstall the original standard supports. Remove old anvils and grind the face which bears against the specimen so that it has an angle of 10:1000 to the original surface, measured in a vertical plane when installed. Restore the corner radii and surface finish. Reinstall modified anvils.

J. Remove anvils and restore contact faces to original condition, also reduce the thickness in the direction of swing by 5 mm. Reinstall modified anvils.

K. Reinstall new anvils, restoring the machine to standard condition. Photograph specimen half as it flies transversely and strikes the anvil.

Methods of Testing

All specimens were tested at -40°C (-40°F) in accordance with ASTM E 23. The lateral expansion of the broken specimens was measured as prescribed in ASTM E 23-93a, Section 12.4.2.

The location, length, and width of the strike marks were measured with an optical comparator in the reflective mode. Magnifications of 10X and 20X were used for the first- and second-strike marks, respectively.

Many of the first-strike marks had poorly defined outer boundaries. To be consistent, we reported the distance from the notch root center-line to the inner boundary of the mark. For a few marks, both boundaries were poorly defined and no dimension was recorded.

The high-speed photographs were taken at 2000 frames per second with a video system. The lighting system included two banks of incandescent lights arranged around the outboard side of the impact machine, for a total of 1500 watts of power.

Methods of Calculation

The statistical calculations were made according to the mathematical definitions of the average and standard deviation. The lateral expansion was measured as prescribed by ASTM E 23, that is, by the sum of the two highest of the projections at the ends of the pendulum strike marks on both broken halves. This method is based on test results which correlate lateral expansion and absorbed energy over a wide range, mostly at energies higher than those reported here. Some information is available in the range of these tests [6].

Since four measurements are taken in any case, they were added to see if the correlation with absorbed energy was improved in the range of these tests. To make the results compatible with the standard value, the sum of the four measurements is divided by two when reported.

The composite postfracture energy index reported is calculated by dividing the average value for a series by the average of all specimens tested during the program. This is repeated for each of the three types of measurements of postfracture energy, and then the three values are averaged. The result is a dimensionaless number for each series which allows the series to be compared but does not indicate the magnitude or units of the energy measurement. To allow comparison to other published results, the composite number is multiplied by the average value for all tests for the lateral expansion measured according to ASEM E 23. The average values for all tests are shown on the bottom line of Table 1 and the values for Series R1C on the top line. Using these values, the composite postfracture index for Series R1C is

$$0.133\left[\frac{\left(\frac{0.12}{0.133}\right)+\left(\frac{0.11}{0.111}\right)+\left(\frac{1.35}{1.403}\right)}{3}\right] = 0.126\ mm.$$

The distance reported as a measure of position of second-strike marks is the distance from the centerline of the notch to the centerline of the mark. The offset is equal to one half of the difference between first-strike marks, measured on the inboard and the outboard halves. Unless stated otherwise, the distances at the upper and lower surfaces are averaged before the difference is calculated.

RESULTS

Table 1 shows averages and standard deviations of energy measurements for some single series and for combinations of related series. Table 2 shows the energy measurements for all of the series as a dimensionless ratio to the average values for Machine M1C. This permits comparison of quantities, such as lateral expansion to absorbed energy, which have different units and magnitudes varying by a factor of over one hundred.

TABLE 1 -- Weighted average values for for quantities which are given as a single number for both broken ends.

Machine or Class	Absorbed Energy J, ft·lbf	Lateral Expansion[a]		Sum of Shear Lips, mm
		E 23, mm	Sum/2, mm	
R1C	15.9, 11.7 (0.3%)[b]	0.12 (0.01)[c]	0.11 (0.01)[c]	1.35 (0.11)[c]
R1U	17.2, 12.7 (0.5)	0.14 (0.03)	0.12 (0.01)	1.43 (0.14)
R2U	17.5, 12.9 (0.5)	0.14 (0.03)	0.12 (0.01)	1.40 (0.13)
M1C-A	15.2, 11.2 (0.6)	0.11 (0.10)	0.09 (0.01)	1.36 (0.09)
A,B,C,K	15.3, 11.3 (0.2)	0.13 (0.02)	0.10 (0.01)	1.34 (0.04)
M1C-Others	15.9, 11.7 (0.3)	0.14 (0.01)	0.11 (0.01)	1.45 (0.09)
All RXX	16.9, 12.4 (0.6)	0.13 (0.01)	0.12 (0.09)	1.39 (0.04)
All XXU	17.4, 12.8 (0.2)	0.14 (0.00)	0.12 (0.00)	1.40 (0.04)
All Std.C[d]	15.5, 11.4 (0.2)	0.13 (0.00)	0.10 (0.00)	1.34 (0.01)

[a] E 23 is sum of two highest projections. "Sum/2" is one half the sum of the four readings.
[b] Values in parenthesis are coefficients of variation.
[c] Values are standard deviation in mm.
[d] Values from R1C and M1C: Series A,B,C,K.

TABLE 2 -- Deviations[a] of energy-related measurements in Table 1 from the corresponding values for Machine R1C.

ID[b]	Absorbed Energy	Lateral Expansion		Height of Shear Lip
		E 23 method	Sum of Four	
R1C (10)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
R1U (10)	8.5 (0.7)	14.6 (2.7)	12.5 (0.9)	15.9 (0.3)
R2U (10)	10.3 (0.7)	15.2 (1.6)	15.9 (0.6)	2.4 (0.3)
M1C-A (6)	-4.5 (1.1)	-6.3 (0.7)	-14.0 (0.3)	0.7 (-0.2)
B (6)[c]	-5.3 (0.4)	5.7 (5.4)	-1.5 (3.5)	0.7 (0.5)
C (5)[c]	-3.0 (0.2)	13.3 (-0.6)	15.1 (-0.4)	-4.8 (0.1)
D (5)	2.6 (0.6)	28.5 (0.2)	1.1 (0.4)	14.1 (0.7)
E (5)	-1.7 (0.5)	5.3 (1.4)	-4.2 (0.7)	3.0 (-0.3)
F (6)	-2.7 (0.6)	7.8 (-0.4)	-4.5 (0.5)	3.0 (0.1)
G (5)	-0.9 (0.6)	12.1 (2.8)	6.8 (1.3)	3.0 (0.9)
H (5)	1.7 (0.0)	18.4 (1.4)	13.9 (0.2)	4.4 (0.9)
I (5)	1.3 (1.1)	20.5 (0.6)	4.6 (0.8)	0.7 (-0.2)
J (5)	3.4 (0.2)	18.4 (3.3)	16.3 (0.2)	10.8 (0.2)

[a] Deviation of measured quantities are shown as percentages, deviation of the coefficient of variation of that quantity as a ratio.
[b] Machine identification, series, and number of specimens.
[c] One of the halves not available for measurement.

Table 3 presents the various second-strike measurements. Table 4 is a tally showing the number of occurrences of various deformations at specified locations. Its primary use is to identify asymmetrical conditions. Table 5 presents statistics on first- and third-strike marks and compares absorbed energy to the composite postfracture energy.

DISCUSSION

Significance and Limitations of Various Measurements

One of the main objectives of the impact test is to measure the energy required to produce the fracture surface. The loss of potential energy of the pendulum during the swing is reported as absorbed energy, but it also includes:

A. friction losses due to pendulum motion,

B. shock losses due to vibration and displacement of the machine parts,