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The Development of Procedures for Charpy Impact Testing

ABSTRACT: This paper provides a broad overview of the progress in procedural improvements for Charpy impact testing. It includes a short summary of early developments, a discussion of topics that have been the subject of recent research, and a description of the importance of direct and indirect verification procedures. The need for standard procedures was recognized soon after the test was developed, and the early discoveries help to build the framework for our current procedures. Nevertheless, even after all these years of procedure development, researchers still find the need to learn more about certain aspects of the test procedures. Recent research seems to be concentrated in several broad categories: properties of the specimen (e.g., surface finish, tolerances, and miniature sizes for special applications), the anvils and striker (e.g., radii and surface finish), and general test procedures (e.g., time to reach test temperature and suitability for cryogenic testing).

KEYWORDS: impact testing, international intercomparison, machine verification, specimen notching and conditioning, striker radius, test procedures, test temperatures

Introduction

For over 100 years, researchers have been trying to understand and to measure the effect of impact loading on the performance of engineering materials. Once researchers found that impact-test results improved their understanding of the performance of materials in service, they began to focus their attention on reducing the scatter in the test results. In fact, the development of consistent impact procedures was recognized to be of such importance that, even in 1912, Committee 26 (on impact testing) of the International Association for Testing Materials (IATM) summarized its main goals as to "fix the conditions to be fulfilled by two distinct tests in order that the results may be comparable and to correlate these numerically definite results to the qualities determining the practical values of a material for different uses" [1].

Since then, impact-test procedures and analysis methods have been refined as various researchers have discovered additional parameters that affect the test results. In some cases, these new results have been widely and uniformly adopted. In other cases, different standards organizations or machine manufacturers have chosen different approaches. As a result of many such choices by the different standards organizations over the years, we now find some variation in impact-test procedures around the world. Certainly, worldwide comparison of test data would be simplified if the procedures could be further harmonized between countries and between the various standards. The following section describes recent work directed toward understanding the effect of various procedural details. Publication of such work can persuade the various standards committees around the world to choose the best procedural details (that produce the most consistent results) or determine that some existing differences in procedures have no effect (so data developed under different procedures are considered equivalent and are mutually recognized).

Recent Research on Procedures

The four most common impact-test procedures in use around the world are probably ISO 148 "Steel—Charpy impact test (V-notch)," ASTM E 23 "Standard Test Methods for Notched Bar Impact Testing of Metallic Materials," EN 10045 "Charpy Impact Test for Metallic Materials," and JIS Z2242 "Method for Impact Test for Metallic Materials." While the four have some similarities, they also have differences. Much current research is directed toward both improving these (and other) standardized procedures, trying

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to understand the effect of their differences, and moving toward harmonization.

Striker Radius

Perhaps the aspect of the procedure that has been receiving the most study recently is that of striker radius. At least five papers in the past 15 years have investigated the differences between using strikers with radii of 2 and 8 mm.

In 1989, Fink [2] compared the results of a number of variables, including notch preparation and striker radii, on impact data. He studied a number of types of steel including 4340 (a heat-treatable tool steel used for 15 J and 120 J reference specimens), ASTM A 537 (a carbon-manganese steel used in pressure vessels), and HY-80 (a quenched-and-tempered high-strength steel). For these steels, he reported a nearly 1:1 relation for data generated with the two strikers, where the 2 mm striker produced results about 4 % higher. The precise relationship was

$$E_2 = (1.042)^{*} E_8 + 0.516 \tag{1}$$

where E_2 and E_8 are the energies of the 2 mm and 8 mm strikers and where the values are in units of ft-lbf. He reported a coefficient of correlation (r^2) of 0.9987 and a standard error of 1.36.

Also in 1989, Naniwa et al. [3] compared the results of impact machines with strikers of 2 and 8 mm radius using steels with a range of absorbed energies. Figure 3 in their report showed a 1:1 trend for the two striker radii up to about 200 J, then a gradual increase in the data of the 8 mm radius striker above the data of the 2 mm striker. When the machine with the 2 mm striker reported 300 J, the machine with the 8 mm striker reported about 400 J. Data for percent shear and lateral expansion showed no trend, and the shape of the transition curves was the same. Additional impact testing with instrumented strikers showed that both striker designs produced similar shapes for the first part of the record, but for the 8 mm radius striker the load was substantially higher near the end of the record. This suggested that the difference was occurring near the end of the loading cycle. Further testing (load measurements combined with imaging of the specimen in the anvils) on a static bending machine confirmed that the higher energy in the tail region occurred when the sides of the impact specimen made contact with the shoulder of the 8 mm striker. Thus, they attributed the difference between the two strikers solely to the greater width of the striker with 8 mm radius.

In 1995, Nanstad and Sokolov [4] evaluated the data from machines with 2 mm and 8 mm strikers using six different materials. They studied two heats of ASTM A 533 (a pressure vessel steel), a submerged arc weld with a high upper-shelf energy, a submerged arc weld with a low upper-shelf energy, a Russian Cr-Mo-V forging steel and two kinds of reference materials (4340 steel and a maraging steel). Although one plate showed lower values with the 8 mm striker and the other plate (and the low upper-shelf weld) showed lower values with the 2 mm striker, they concluded there was no clear trend (within one standard deviation) up to 175 J. Only the reference materials of highest energy (near 220 J) showed a clear difference, where the 8 mm striker produced energies about 11 % higher than those for the 2 mm striker.

Also in 1995, Siewert and Vigliotti [5] evaluated the data from two different brands of U-type pendulum machines, each with striker radii of both the 2 mm and 8 mm. They used reference-grade specimens at energies of 18, 45, 100, and 200 J. The small standard deviation produced by these specimens allowed a very precise measurement of machine or striker effects. They found very small differences between the two strikers for the three lower energy ranges, and an even smaller effect between the two brands of machines. At 200 J, they noted that the 8 mm striker produced energies about 10 J higher than those for the 2 mm striker, and the 2 mm striker produced standard deviations that were higher by about a factor of three.

These four studies suggest that the striker radius does not seem to be an important variable up to about 150 or 175 J, at least for the steels that were evaluated. However, above 200 J the two striker radii produce results that diverge as the energy increases. Ruth [6] has attempted to produce a compromise striker, one with the narrower profile of the 2 mm striker, but also with a flatter surface on the very front edge. This was accomplished by grinding the front to an 8 mm radius, then blending this surface to the edges by the use of a 1.5 mm radius. So far, this approach has not reached its goal.

Specimen Fabrication

Koester and Barcus [7] compared grinding and broaching of the notch. They found that both procedures produced data that were equally consistent, but there was a bias between the two techniques. They attributed this to differences in either the microstructural damage due to the notching or to slight imperfections in the notch radii.

Fink [2] also looked at notch production by grinding, broaching, and milling (with a fly cutter). He concluded that grinding the notch produces the smoothest and most consistent profile.

Direct Verification (Machine Condition and Mounting)—Schmieder [8] found that direct verification of a machine is not a simple task. He based much of his work on the concept that the permitted uncertainty of a metrological measurement must be ten times smaller than the tolerances specified for the device. In other words, he tried to use instruments and techniques that were more precise by an order of magnitude than that required by the standard, to develop a better estimate of how closely the machine approached the prescribed tolerance.

He evaluated four C-type pendulum machines and five U-type pendulum machines, spanning capacities from 3 to 250 J. He found that the losses due to friction and windage could exceed the permited limits on machines of very small capacity or on multi-range machines (where the bearings are sized for the highest capacity, and so have too much friction for the lower capacity). He also found that checking the difference between the center of strike and the center of percussion requires extremely accurate measurement of the period of the pendulum (as the center of percussion varies as the square of the period of the pendulum). At a 5 degree angle of swing, the friction would damp the swing before enough cycles would occur. At higher angles, the nonlinear terms became important, and even the use of elliptic integrals in the analysis was unable to correct for these effects.

Schmieder et al. [9] later studied the effect of various machine dimensions, including: tilted anvils, thinner anvils (striker contacting anvils 5 mm past the normal position), and striker not contacting the specimen opposite the notch. All these were studied at levels in excess of the variation permitted by ASTM Standard E 23, and all variations noticeably increased the absorbed energies. Thus, these data support keeping the machine tolerances that are specified by E 23.

Porro et al. [10] studied the use of compliance to evaluate the quality of the machine mounting, in terms of such common problems as loose bolts on the base of anvils, or paint or other low friction materials under the base.

Ruth et al. [11] studied the effect of surface finish of the machine anvils and striker. They found that surfaces smoother than those required by the standard procedures better simulate the surfaces of these parts after a period of use. Thus, a better finish will reduce the discontinuity in apparent energies when these parts are replaced.

Ruth et al. [11] also studied the effect of radius on the corners of the 8 mm striker, because wear can rapidly exceed a 0.25 mm tolerance. He found that increasing this radius to 0.5 mm had little or no effect, but increasing the radius to 1 mm had a very strong effect on the energy.

Yamaguchi et al. [12] studied the effect of anvil radius and taper. They reported a measurable reduction in absorbed energy as the taper angle is increased from 9 to 12 degrees, and a 5 % change in energy as the anvil radius is increased from 1 to 1.5 mm.

Specimen Size and Dimension Effects

Alexander and Klueh [13] compared Charpy specimens of standard size (10 mm by 10 mm) to specimens of half and third size. They found that the smaller specimens allowed more specimens to be produced from a given amount of material (especially important for irradiated materials), but produced different upper-shelf energies and different transition temperatures. They concluded that the upper-shelf energies could be corrected with a simple volumetric normalization procedure, but the shift in transition temperature was more complex. Later, Alexander et al. [14] revisited this issue and developed sub-size verification specimens that could be used to verify the performance of machines used to test sub-size specimens.

Manahan et al. [15] also looked at sub-size specimens, and developed a test machine design. They proposed a minimum cross section of 5 mm by 5 mm, and recommended side grooves to increase the amount of material in these smaller sections that is exposed to plane strain conditions.

Marsh [16] studied the effect of changing the tolerance on the right angle between the two 10 mm faces of the specimen. He varied the angles outside of the tolerance of 10 min of arc and found that greater variations produced statistically significant changes in the energies, especially for specimens with absorbed energies near 100 J. He concluded that a tolerance of 10 min on the right angles should be maintained.

Test Temperatures and Specimen Conditioning

Nanstad et al. [17] studied the effect of thermal conditioning, the process of bringing the specimen to the desired test temperature. They investigated a number of media including water, oil, acetone, and methanol at temperatures above and below ambient. They found that water was a poor choice between 50 and 100 °C because evaporative cooling is so significant that the specimen may cool below the temperature tolerance even if the specimen is broken within 5 s of leaving the bath. Also, they found that soaking times used with gaseous media need to be increased to ensure that the specimen has reached equilibrium.

The growing use of cryogenic magnets has promoted the use of impact testing to measure the ductile-brittle transition of structural materials at temperatures down to 4 K. Tobler et al. [18] offer several cautions. They found that the very low specific heat of metals below 77 K causes the specimens to heat rapidly as they are transferred from the bath to the anvils. For this reason alone, valid tests cannot be performed according to the procedures of Standard E 23. Further, even cooling the specimen in place in the anvils is unable to provide accurate data, as the work hardening during the initiation and propagation of the crack raises the temperature substantially. Thus they concluded that pendulum impact testing is not valid below 77 K, and any attempt to correlate performance from specimens cooled to 4 K is confounded by the variations in work-hardening rates in the various materials.

Manahan [19] reported that conditioning of the specimen when on the machine anvil and in position for testing (by use of a special fixture) reduces the changes in temperature that can occur when a specimen is transferred from a conditioning bath to the anvils. In addition, this procedure doubles the precision in centering the specimen in relation to the striker, since there is no rush to position the specimen.

Other Procedure Details

Sundqvist and Chai [20] reported on the production of in-house standard specimens (from a stable nickel-based alloy) for tracking the performance of an impact machine between the formal reverifications required by standards. They found that this was an excellent method of tracking the performance of machines that are used to test specimens made of materials that induce excessive wear of the striker and anvils.

In spite of the widespread use of notched specimens for evaluating material performance, Galban et al. [21] reported that unnotched specimens can provide standard deviations as small as, or smaller than, notched specimens of the same material. Since verification of machine performance is separate from evaluation of material performance, use of such specimens (with low standard deviations) could reduce the cost of the verification specimens.

Comparison of Data—Machine-to-Machine and Country-to-Country

Several recent round-robins or comparisons of national reference machines confirm that today's Charpy test procedures are at least as reproducible as those reported by Driscoll [22] in 1955, and are consistent between countries. These recent round robins have shown that the certified energies of verification specimens distributed by national metrological authorities usually agree within 1 % with the values determined by other national authorities. A 1998 study [23] compared the four organizations or laboratories that were found to certify the verification specimens for Charpy impact machines. These organizations were the Institute for Reference Materials and Measurements (IRMM, in Belgium), Laboratoire National D'Essais (LNE, in France), National Institute for Standards and Technology (NIST, in the United States), and National Research Laboratory for Metals (NRLM, in Japan). The study involved a comparison of the 2 and 8 mm radius strikers, three absorbed energy levels, and a large number of replicate tests for each of these conditions at each of these organizations. This study concluded that the other organizations developed average energies very close to those assigned by the laboratory that produced them, the specimens produced by the four organizations have similar spread in the data (coefficient of variations between 0.02 and

0.04), and the 2 and 8 mm radius strikers produced similar results for 4340 steel (absorbed energies below 200 J). Therefore, in spite of the various differences in procedures between the major standards in use around the world, the basic test procedure is quite reproducible, so the results developed in different countries and on different designs of (verified, high-quality) machines can be compared with confidence.

A follow-on three-year study [24] has just been completed and is reported in another presentation.

Machine Installation

The data obtained from a machine are not reliable unless the machine is mounted properly. NIST has published a Technical Note to help users to achieve an adequate mount [25]. The following is a summary of our recommendations.

The recommended foundation is a block of high-strength concrete measuring about 1.5-m long by 1-m wide by 0.5-m thick. Usually this requires cutting a hole in the floor to accommodate the new foundation. If other equipment in the area could affect the machine operation, you may want to isolate it from the floor with expansion-joint material.

Hold-down bolts used to secure the machine to the foundation should be of the inverted “T” or “J” type, and should be embedded in the concrete. The bolts, nuts, and washers should have a high strength (for example, AISI grade 8 or higher). NIST machines were mounted with 22-mm diameter grade 8 threaded rod, cut into pieces that were about 600-mm long. Then, 150-mm long pieces of the same threaded rod were welded to the end of the 610 mm (24 in.) pieces to make inverted “T” bolts.

After 72 h of curing, the machines were positioned over the foundation (supported by nuts on the rods) and leveled to a tolerance of 3:1000. The critical leveling procedure was done using the four nuts under the machine. After the machine was leveled, the outside of the nuts were wrapped with duct-seal putty to facilitate their removal from the “T” bolts later in the process. Then, the base was grouted and the machine was left in this position for 72 h.

After 72 h, the machine was lifted off the “T” bolts one last time. The putty was removed from around the nuts, the machine was repositioned on the “T” bolts and the nuts were torqued to about 500 N-m.

Direct Verification

This section explains direct verification requirements (based on those in ASTM Standard E 23), which confirm that a machine is in good operating condition, without the use of verification specimens. The direct verification tests are physics-based tests, which assure that the machine is functioning as closely as possible to a simple pendulum, with only small losses, due to friction and windage. Direct verification is most important when the machine is first installed or when major parts are replaced, but is also important during the periodic reinspections. While these tests are required for the periodic reinspection in ASTM E 23, NIST recommends that the free-swing test and windage-and-friction test be performed each day that the machine is used. The records of these tests then serve as a convenient measure of bearing performance. The following recommendations also come from a Technical Note distributed by NIST [25]. Space limitations prevented including illustrations of these characteristics here. The illustrations are available in the Technical Note.

Since the Charpy test is a dynamic test with vibration and impact loads, the hold-down bolts may loosen over time. In extreme cases, this may introduce error sufficient to cause a machine to exceed the tolerance limits of the indirect verification test. In marginal cases, the movement may still be sufficient to add a bias to the results that reduces the likelihood of passing. The tightness of all bolts should be checked periodically, especially the anvil bolts, the striker bolts, and the base-plate bolts. The manufacturer can supply the torque values for the anvil and striker bolts. The base-plate bolts should be torqued to the recommended torque values for the grade and size of the nuts and bolts. Only “J” or “T” bolts should be used; lag-type bolts can lead to errors. These are made to withstand only static loads. We believe that in some cases, the insert portion of lag bolts can loosen in the concrete. When lag bolts are retightened, they can pull out of the concrete and be pulled against the base of the machine, giving the impression of a properly mounted machine. This condition is very difficult to detect. A machine with this problem will exhibit erroneously high energy values at the low-energy level. The mounting procedure used to eliminate this problem for the NIST Master Reference Machines was described in the previous section.

Standard E 23 describes a routine check procedure that should be performed weekly. It consists of a free-swing check and a friction-and-windage check. The free swing is a quick and simple test to determine whether the dial or readout is performing accurately. A proper zero reading after one swing from the latched position is required on a machine that is equipped with a compensated dial. Some machines are equipped with a non-compensated dial. Such a dial is one on which the indicator cannot be adjusted to read zero after one free swing. The user should understand the procedure for dealing with a noncompensated dial. This information should be available from the manufacturer.

The friction-and-windage test assesses the condition of the bearings. The pendulum should be released and allowed to swing 10 half cycles (5 full swings). (The release mechanism should be held down this whole time to avoid additional friction when the pendulum swings back up to where it may push on the latch.) As the pendulum starts its 11th half swing, the pointer should be reset to about 5 % of the scale capacity. Record the actual value and divide by the 11 half swings. Divide this number by the machine range capacity, then multiply by 100. Any loss of more than 0.4 % of the machine capacity is excessive, and the bearings should be inspected.

Keeping a daily log or shift log with the machine is also recommended. The log can be used to track the zero and friction values. The log can also include information such as number of tests, materials tested, maintenance, and any other useful comments.

The anvil and striker radii should be carefully inspected for damage and for proper dimensions. Damage (chips or burrs) can be detected easily by visual inspection and by running a finger over the radii to check for smoothness. Measurement of the dimensions requires more sophisticated equipment. Radius gages are usually inadequate to measure the critical radii. Making molds of the radii (such as with silicone rubber) or making an indentation in a soft, ductile material (such as annealed pure aluminum), then measuring the impressions on an optical comparator is recommended. Occasionally even a new set of anvils and striker may have incorrect radii. Thus, new anvils and strikers should always be inspected before being installed in the machine. Since the radii will not have local wear before use (the radii are consistent along their length), they can be measured directly on an optical comparator or other optical measurement system.

Indirect Verification

Indirect verification uses carefully characterized test specimens to stress the test machine components to levels similar to those experienced during routine usage. Since many machine problems, such as loose anvils or striker, cannot be detected during direct verification, indirect verification serves as an important supplemental test of the machine performance.

Some reference specimens are designed to be tested at −40°C (−40°F) and some at room temperature. Since the absorbed energy changes with temperature, accurate temperature control is necessary to obtain valid test data. The temperature indicator should be calibrated immediately before testing. Ice water (0°C) and dry ice in ethyl alcohol (−78.5°C) are very convenient calibration media.

Post-Fracture Examination

Just matching the reference energies is not sufficient to confirm that the machine is fully satisfactory. For example, worn anvils can combine with high-friction bearings to compensate for each other and produce an artificially correct value during the verification test. These are called compensating errors. Unfortunately, these errors compensate only over part of the range, so the machine produces generally inaccurate values. The post-fracture examination of standardized verification specimens is a good way to identify such effects. Therefore, the NIST verification specimens come with a questionnaire (with critical questions about the machine and the test procedure) and a mailing label so the specimens can be returned to NIST. All specimens are examined and compared to the data on the questionnaire before a response is sent to the customers.

Following are the most common of the problems observed during examination of fractured specimens. In many cases, suggestions on how to correct or avoid them in the future are included.

Worn Anvils

Most of the wear of an impact test machine occurs on the anvils and striker. This wear can be evaluated by examining the gouge marks that are formed on the sides of high-energy specimens when they are forced through the anvils. Anvils that are within the required tolerance of the standard will make a thin, even gouge mark all the way across both pieces of the broken specimen. As the anvils wear, they will make a wider, smeared mark across the specimen halves. When wide, smeared marks are observed on a customer's specimens, the anvils should be changed, because the reduction in energy needed to push the specimens through worn anvils eventually drops the machine below the lower tolerance in the energy range. You can monitor the wear on your machine by retaining some specimens that are tested with new anvils and comparing them to specimens of similar composition and hardness that are tested as the anvils wear. For specimens at a similar absorbed energy, the gouge marks will grow wider and smoother as the anvils wear.

Off-Center Specimen

An off-center specimen strike occurs when a specimen is not centered against the anvils, so the striker contacts the specimen to the side of the notch. The low-energy specimen best indicates when an off-center strike occurs. This condition can be identified on the specimens by finding that the gouge marks caused by the anvils are not equidistant from the machined notch edges, and the striker gouge mark is offset the same amount from the notch. Also, the fracture surface of a correctly tested low-energy specimen is flat and both halves are even. However, the fracture surfaces of a specimen that has been tested off-center are on an angle. The more off-center the strike, the steeper the angle will be. This problem increases the energy needed to fracture a specimen. The most common causes for this slipping are worn or damaged centering tongs, a worn or misaligned machine centering device, careless test procedures, or the use of a cooling fluid that is too viscous at the test temperature (which causes the specimen to float on the specimen supports). Most machine manufacturers should be able to provide new centering tongs. Ethyl alcohol seems to be one of the best cooling media because it evaporates quickly from the bottom of the specimen to prevent specimen floating.

Off-Center Striker

This differs from the off-center specimen in that the specimen is centered against the anvils so the anvil gouge marks are equidistant from the machined notch edges. However, the striker does not contact the specimen precisely opposite the notch. An off-center striker is usually attributed to the pendulum shaft shifting off center. This shift can be the result of a loose alignment ring on the shaft or a loose bearing block on the machine. This problem also increases the energy needed to fracture specimens at all energy levels.

Uneven Anvil Marks

Frequent testing of subsize specimens can cause the anvils to wear unevenly. Since this wear is restricted to only a fraction of the area that the full-size reference specimen contacts, there is usually no effect on the energy required to fracture the specimen. This anvil condition presents two problems. First, since subsize wear is usually not indicated by a change in the energy required to break a reference specimen, inspection of the broken specimen is required. This wear will cause the anvils to be out of tolerance according to the requirements in the standard. This means that the machine does not meet the direct verification requirements of the standard, and is therefore not eligible for the indirect verification process. The second, and more important, problem is that the subsize specimens are being tested in an area of the anvil that is worn. When the wear is substantial, this condition will produce artificially low energy values for the subsize specimens. The anvils should be replaced on a machine with this condition.

Chipped Anvils

Sometimes an anvil can be chipped. Lower-energy specimens are affected the least amount because they are the hardest specimens and therefore have a more brittle fracture. High-energy specimens will produce higher than normal energy results and very-high-energy specimens are affected most by a chipped anvil. This condition should be detected easily by a visual inspection before using the machine. When an anvil is chipped, it must be replaced by a new anvil.

Anvil Relief

Some manufacturers of Charpy machines have designed a machined relief at the bottom of the anvil. This anvil design does not meet the direct verification requirements of ASTM Standard E 23. The relief increases the energy for high and very-high-energy specimens. It can also cause twisting of the specimens during fracture, which may also contribute to energy values higher than normal at all energy levels. However, this feature does not appear to add an excessive amount of energy to the test. (The results are usually within the allowed tolerances.)

Damaged Anvils

Under some test conditions, usually for elevated-temperature testing, the anvils can wear to a rough finish that creates excessive friction. This damaged condition is detected best on higher energy specimens. Rough anvils usually cause the gouge marks to become wider and push the specimen material to form a ridge that can easily be detected with the fingernail. This damage usually causes artificially high energy results. Damaged anvils must be replaced.

Bent Pendulum

A pendulum bent in the direction of the swing produces gouge marks on a specimen. This gouge mark is usually deeper on the top edge of the specimen as it sits in the machine. The striker contacts the top edge of the specimen first, causing excessive tumbling and twisting. This excessive activity can cause the specimen to interact with the striker or the pendulum after fracture and create additional energy loss. A bent pendulum can be detected by placing an unbroken reference specimen in the machine and placing a piece of carbon paper on the surface opposite the notch. At this point, lightly tap the striker against the specimen. This will make a mark on the specimen that can be inspected. If the pendulum is not bent, the mark should appear the same width across the specimen. If the pendulum is bent, the mark will be wider at one edge and become thinner or even not visible at the other edge. A new pendulum should be installed on such a machine to correct this problem.

Summary of Indirect Verification

Some aspects of Charpy machine condition and accuracy can be assessed only through the use of reference specimens. Further, some machine problems cause artificially low results, while other machine problems cause artificially high results. In addition, deviations in procedures can cause similar results. These machine problems and procedural deviations may go undetected for years without some sort of physical check. For this reason, examination of the broken specimens is a critical part of the verification process. Many machine problems can be avoided or corrected with the information presented in this paper. Also, suggested changes in procedure can help to ensure a successful test. Verification specimens are available from various organizations around the world, including:

- the Institute for Reference Materials and Measurements (IRMM, in Belgium),
- Laboratoire National D'Essais (LNE, in France),
- National Institute for Standards and Technology (NIST, in the United States), and
- National Research Laboratory for Metals (NRLM, in Japan).

Summary

1. Recent refinements in the procedures continue to improve the accuracy of the test. Topical areas include the striker, anvils, specimens, and temperatures.
2. The Charpy scales used by the various NMIs are consistent, and the current round-robin promises further harmonization of the various procedures.
3. The history of past international interactions shows that a free and open interchange of ideas between countries is of benefit to all.
4. Direct and indirect verification testing is needed to ensure the validity of data developed on a Charpy impact machine.

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