The NIST Charpy V-notch Verification Program: Overview and Operating Procedures

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This report documents the procedures used by NIST in the Charpy V-notch reference material program. It was prepared to provide outside observers with accurate and detailed information on how the Charpy verification program is conducted, and also to serve as the basis for an internal record that will be updated to reflect when and why changes were made to the program.

Keywords: Charpy V-notch test, impact testing, mechanical testing, NIST, reference material, verification program

1. **Introduction**

1.1 **Background**

Charpy impact testing is often specified as an acceptance test for structural materials, and companies performing acceptance tests are typically required to verify the performance of their impact machine periodically. The procedure for verifying the performance of Charpy impact machines has a physical part and an engineering part. The physical part covers the direct verification of the impact machine, through a detailed evaluation of the machine dimensions, alignment, etc. The engineering part covers the indirect verification of the machine performance, which entails breaking sets of Charpy impact reference specimens. The indirect verification procedure was added about 40 years ago, because the use of direct verification procedures alone could not explain some unacceptable differences among the results of the machines tested. Often these differences could be traced to interactions between the machine components and the specimens, and only testing with verification specimens could resolve these effects. NIST supplies the impact reference specimens used to indirectly verify the performance of machines according to ASTM Standard E 23. The procedures used to conduct this program are the focus of this report.

Originally, the U.S. Army (Watertown Arsenal, AMMRC) produced and distributed the reference specimens for the verification of impact machines in the United States. NIST took over the program from the Army in 1989, and Army personnel helped to transfer the Charpy machines and their evaluation procedures to NIST. The three Charpy machines owned by the Army, and now by NIST, have been defined in ASTM Standard E 23 as the “master Charpy impact machines” for the United States for more than 12 years. Some of these machines have been in the program for 30 years. Each year, the verification test results for approximately 1000 industrial machines are evaluated. If the results of the industrial machines agree with the results of the master machines within either 1.4 J or 5 %, the machines are certified for acceptance testing according to the requirements of ASTM Standard E 23.

1.2 Relationship to National and International Standards

ASTM Standard E 23 requires the indirect verification of Charpy V-notch impact machines annually. Also, the ASME *Boiler and Pressure Vessel Code*, many U.S. military procurement specifications, and several ISO Standards require Charpy impact machine verification. The European and Japanese verification programs provide traceability to national laboratories and some international agreements are written to require traceability to a national laboratory. The NIST verification specimens meet ASTM and ISO requirements for indirect verification testing of Charpy V-notch impact machines and also provide traceability to a national laboratory.

Currently there are four laboratories in the world that certify and distribute reference materials for the verification of Charpy impact machines: (1) The Institute for Reference Materials and Measurements (IRMM, Belgium), (2) Laboratoire National d'Essais (LNE, France), (3) The National Institute of Standards and Technology (NIST, USA), and (4) The National Research Laboratory of Metrology (NRLM, Japan). These four laboratories supply specimens to verify the performance of more than 2000 impact machines annually.

1.3 Industrial Needs Met by the Program

The primary purpose of the program is to provide U.S. industry a source for high-quality impact verification specimens. Because this program also offers an evaluation service for the results of verification tests, several additional benefits are provided to industry. There are direct benefits to the customer in the evaluation and interpretation of the test results by NIST, such as a verification letter that auditors acknowledge and rarely question. Indirect benefits, due to the centralized evaluation of all verification test results include: (1) some assurance that trading partners and competitors are reporting comparable impact values, and (2) a centralized database that can support arguments for or against changes to national and international impact standards that affect U.S. industries.

2. Program Design Philosophy and Scope

The NIST Charpy verification program is designed to provide a complete service for our customers. The program can be divided into three basic parts, as follows: (1) The production of the verification materials, which includes purchasing the raw materials, contracting for their heat treatment and machining, batch certifications of verification specimens, and distribution of the specimens. (2) The evaluation of verification test results, which entails evaluating the data and specimens received from our customers, entering the data into our database, writing verification letters that include specific remarks concerning the performance of the machines being evaluated, and communicating with customers by fax, phone, and email regarding the outcome of tests. (3) The evaluation of data in our database, which serves as a final quality-control tool on our verification specimens, and as a means to evaluate and track the performance of industrial machines.

The accurate and consistent certification of the absorbed energy for our verification materials is the central part of the program, upon which all else is based. As is the case for many measurements, these factors are difficult to address, particularly consistency over long-time intervals. Our procedures are based on the fact that the master machines at NIST are the designated reference machines for the United States (by ASTM E 23), and by our own definition the average value of the three machines is correct.

Our primary control for the program is tracking the performance of each master machine relative to the others. A change in the performance of one machine initiates an evaluation of that machine and the measurement system in general. Although this approach is a practical solution to a complex problem, and clearly has shortcomings, it has provided a robust and stable base for our certification procedures over the last 12 years. Additional controls to evaluate the quality of the verification specimens, such as the testing of control specimens and constant monitoring of the average energy values from customer verification test results are also used to monitor the quality of the specimens. In retrospect, we find that over the last 12 years, pooled data from the three master machines has proven to be a reliable and reasonable target for measuring the performance of industrial impact machines.

3. Description of Equipment and Personnel

The impact machines used by NIST were purchased from three different commercial suppliers, not custom built at NIST, and so represent the machines used by industries around the world. This is true for most of the equipment used in the program.

3.1 Impact Energy Measurement

We have five Charpy V-notch impact machines that are used for the measurement of absorbed impact energy in the program:*

Machine #1 Tokyo Koki Seizosho, "C" type pendulum, S/N 878303
359 Joule Capacity, Reference Machine

Machine #2 Tinius Olsen, Model 74, "U" type pendulum, S/N 130005
358 Joule Capacity, Reference Machine

Machine #3 Satec, Model SI-1C, "U" type pendulum, S/N 1262
325 Joule Capacity, Reference Machine

Machine #4 Satec, Model SI-1K3, "U" type pendulum, S/N 1662
407 Joule Capacity, Research Machine

Machine #5 Tinius Olsen, Model 84, "U" type pendulum, S/N 165153
407 Joule Capacity, Research Machine

*Trade names and names of manufacturers are included in several places in this report to accurately describe NIST activities. Such inclusion neither constitutes or implies endorsement by NIST or by the U.S. government.

Machines 1, 2, and 3 are the primary reference machines (the master machines). Machines 4 and 5 have higher capacity, newer designs that will eventually replace the older machines (as needed, once we are certain of their stability). All of the impact machines are equipped with optical encoders and digital readouts. Machine 4 has an instrumented striker.

The master machines are used only for assigning certified energy values to lots of verification specimens, and for occasional participation in measurement development programs and international round robins. The two backup machines are used for research on conventional and instrumented Charpy V-notch testing.

3.2 **Hardness Measurements**

Measurements are made on a commercial hardness testing machine. The tester is linked to a personal computer that is used to acquire and file data for the tests. These data are processed to evaluate the hardness level, and the uniformity in the hardness, of our verification specimens.

3.3 **Dimensional Measurements**

The notch depth, radius, angle, and centering are measured on a commercial optical comparator (50X) prior to impact testing. The squareness is measured with a gage described in ASTM E 23. The overall specimen dimensions are measured with digital calipers. A second, older optical comparator is used as a backup system for dimensional measurements. Data from the optical comparators and the calipers are output to a personal computer.

3.4 **Software**

Software was developed by NIST personnel to help manage specific tasks that are routinely performed when evaluating customer test results or certifying a production lot of verification specimens.

The database of customer data and information is organized as follows: (1) A main panel that contains fields for the serial number, manufacturer, capacity, and pendulum design of the machine, along with customer information such as the company name, address, and contact person, and also contains a comment field and the pass/fail status from the last verification test made on the machine. (2) A data panel that contains fields for the serial number of the machine, record number, test evaluation date, initials of the NIST operator who evaluated the data, data fields for the energy data (for four energy levels), the series number of the lot tested, automatically calculated fields for the customer's average energy, the NIST reference value, the difference between the customer and NIST energy values, and a pass/fail status field. (3) A panel containing information on test companies (so address information is available to address letters to third parties who conduct verification tests for the customer). (4) A reference value panel that contains all of the certified energy values for our verification lots.

A word processing program is used to help write customer letters. The program uses macros and Boolean logic to construct the letters according to operator input at various prompts. All of the pertinent data concerning the customers' test results and address information are accessible in the program, and in addition, approximately 60 "standardized comments" are available for selection by the operator to help construct the letter.

A NIST data program is also used to collect and calculate output from the hardness tester and the dimensional measurement equipment.

3.5 Personnel

Three people are involved with the Charpy verification program in Boulder. One specializes in the operation and maintenance of the impact machines, and typically handles all of the day-to-day operations of the program (customer evaluations and service, and pilot lot certifications). The second specializes in the issues relating to the materials used to produce the verification materials, and in standards governing impact verification testing (ASTM and ISO). The third oversees the program. All the personnel involved in the program are capable of filling in for the others, which provides adequate backup for the program.

4. Procurement Requirements for Verification Materials

Two materials are currently used to make the specimens for the indirect verification of Charpy impact machines. An AISI type 4340 steel is used to make specimens at the low-and-high energy levels. A type T-200 maraging steel is used to make specimens at the super-high energy level.

4.1 Type 4340 Steel

4.1.1 Compositional and melting requirements

We require AISI 4340 steel bars, from a single heat to minimize compositional and micro-structural variation. Because steel plants produce steel in different heat sizes (inherent to their facilities), we have tried to add some flexibility in our contracts by bracketing the quantity of the steel to be purchased. We prefer to purchase about 5000 kg (5 ton) heats. The bids are evaluated primarily on cost, but we also consider delivery time. The composition for the heat of type 4340 steel that NIST is currently using is given in **Table 1**.

Table 1. Composition of 4340 steel (mass %).

C	Si	Mn	Ni	Cr	Mo	S	P
0.4	0.28	0.66	1.77	0.83	0.28	0.001	0.004

The steel is required to be produced using a double-vacuum-melting procedure (vacuum-induction-melt vacuum-arc-remelt) and meet the compositional requirements of AISI-SAE alloy 4340. The steel must also meet the stricter requirements of AMS 6414, which describes steel production by a vacuum-melting procedure. In addition, we desire the phosphorus, sulfur, vanadium, niobium, titanium, and copper contents of the steel to be as low as possible. The maximum concentrations (in mass %) allowed for these elements are P = 0.010, S = 0.005, V = 0.030, Nb = 0.005, Ti = 0.003, and Cu = 0.35.[1]

The composition is certified using standard analytical procedures (such as optical emission spectroscopy or x-ray fluorescence), and the equipment is calibrated by standards traceable to NIST. The composition is measured at the top and bottom remelted ingot. These two measurements must be included in the documentation with the order, meet our compositional requirements, and meet the limits on residuals given above. Deviations between the two measurements (in mass percent between the top and bottom of VAR ingot) can not exceed 0.020 for C, Si, and Mo; 0.090 for Mn; 0.030 for Cr; 0.040 for Ni; 0.002 for P; and 0.001 for S.

The compositions of three heats of 4340 steel we have used are given in **Table 2**. The current alloy in use, heat number E4261, was processed from six ingots and the label on the bar indicates the location (top or bottom) in the ingot from which it was produced. This heat yielded 8699 kg of bar stock from a gross ingot weight of 9221 kg.

4.1.2 **Product form**

The ingots are forged, hot rolled, then cold finished to 12.7 mm square bars (+3.8 mm, −0.0 mm) and annealed. The corner radius of the finished bars cannot exceed 0.76 mm. The maximum acceptable grain size is ASTM number 8. In other attributes (decarburization, surface condition, etc.), the steel must be suitable for use as 10 mm square Charpy V-notch specimens.

The bar is normalized at 950 °C, and hardened to approximately 35 Rockwell C (HRC). We will accept alternate heat-treating schedules by mutual agreement. Our goal here is to produce bars with a minimum of large carbides in the structure, the most uniform carbide precipitation possible, and a uniform hardness. The bar is required to be machine straightened (for twist and bow), and shipped in lengths of no less than 2 m and no more than 4 m.

Table 2. Composition of 4340 alloy, mass %.

Heat #	2397B	E4261	E4871
Year	1990	1993	1998
C	0.42	0.40	0.43
Mn	0.75	0.67	0.70
P	0.008	0.004	0.004
S	0.001	0.001	0.002
Si	0.30	0.28	0.30
Cr	0.84	0.83	0.82
Ni	1.83	1.77	1.78
Mo	0.27	0.28	0.24
Cu	0.03	NA	0.09

4.1.3 **Packaging**

The bar is packaged in bundles identified with reference to the ingot position from which it was processed. This identification is used to limit the material used for a given pilot lot to a single ingot location, which reduces microstructural inhomogeneities between bars. The bundles must weigh less than 900 kg (4000 lb), which is the capacity of our fork lift truck.

4.2 **Type T-200 Steel**

[1] There has been some question whether this very low sulfur level is the optimum level. Internal data from one steel producer indicate that sulfur levels of 0.01 to 0.03 may help reduce the variation in impact toughness for 4340 steels.

4.2.1 **Compositional and melting requirements**

We require double-vacuum-melted 18 Ni maraging steel bars. The steel must be of a single heat and the ingot(s) must be adequately forged prior to rolling to minimize compositional and microstructural variation in the final products. The steel must be produced using a vacuum-induction-melt vacuum-arc-remelt (VIM/VAR) procedure, and meet the nominal compositional requirements given in **Table 3**:

Table 3. Type T-200 steel (mass percent).

Ni	Mo	Ti	Al	Si, max	Mn, max	C, max	S, max	Co, max	P, max
18.5	3.0	0.7	0.1	0.1	0.1	0.01	0.01	0.5	0.01

The composition must be certified using standard analytical procedures, using equipment calibrated by standards traceable to NIST. The composition is measured at the top and bottom of the ingot. These two measurements are included in the documentation with the order, and must meet the requirements given above within reasonable tolerances for an 18 Ni maraging steel. If the presence of any residual elements (not included in the requirements above) are expected for the alloy, a maximum allowable concentration for this element must be agreed upon. Deviations between the two measurements (in mass percent between the top and bottom of VAR ingot) can not exceed those expected for high-quality VIM/VAR 18 Ni ingots (by current steel making standards).

Information on the current T-200 material we are using is given in **Table 4**. The three columns of data represent results of samples taken from the top and bottom of the VAR ingot, and the melt used to make the ingots. The alloy was melted in a vacuum induction furnace and cast into an electrode mold approximately 432 mm in diameter which weighed 3630 kg (4 ton). The electrode was remelted into an ingot with a diameter of 508 mm, which was cropped (3175 kg) and 100 % conditioned prior to chemical analysis (top and bottom). The 508 mm ingot was forged to a 432 mm octagon, then to 350 mm square, then to 250 mm square, and cut into 6 equal lengths. The 250 mm square was then forged to 152 mm square (billet) and air cooled. Each 152 mm billet was cut into three lengths, resulting in a total of 18. These 18 billets are coded and each bundle of bar that NIST received is from a single billet. The 152 mm billets were direct rolled on a mill to 57 mm and cut to lengths of approximately 660 mm prior to final rolling.

Table 4. T-200 composition.

	Top of Ingot	Bottom of Ingot	Melt
C	0.003	0.002	0.004
Mn	0.03	0.03	0.02
P	0.007	0.007	0.005
S	0.003	0.003	0.003
Si	0.01	0.01	0.01
Cr	0.20	0.21	0.20
Ni	18.79	18.77	18.77
Mo	3.01	2.97	2.89
W	0.02	0.01	<0.01
V	0.01	0.01	0.01
Co	0.47	0.47	0.51
Cu	0.01	0.01	0.01
Ti	0.79	0.78	0.80
Al	0.11	0.11	0.128
B	0.0008	0.0008	<0.002
Zr	0.005	0.005	NA

4.2.2 **Product form**
The heat is processed to 12.7 mm (+3.8 mm, −0.0 mm) square bar. The corner radius of the finished bars cannot exceed 0.76 mm. The maximum average grain size accepted is ASTM number 10. In other attributes (surface condition, etc), the steel is required to be suitable for use as 10 mm square Charpy V-notch specimens. The bars are delivered in the as-rolled condition. The bar is machine straightened (for twist and bow), and shipped in lengths of no less than 2 m and no more than 4 m.

4.2.3 **Packaging**
The bar is required to be packaged in bundles identified with reference to the ingot and which portion of the ingot it was processed from. If possible, the bundles consist of bar rolled from individual billets used for the rolling operation. The bundles must weigh less than 1815 kg (2 ton).

5. **Specimen Production**

5.1 **Heat Treatment**

5.1.1 **Type 4340 steel**
The 4340 steel is heat treated to produce low- and high-energy verification specimens. Typically, as indicated in **Figure 1**, low energy levels are attained by tempering at temperatures between 300 and 400 °C. The high energy specimens are tempered near 600 °C. The microstructure of the specimens must be 100 % tempered martensite.

The heat treatments originally recommended by the Army Materials Technology Laboratory are shown in **Table 5**.

Although the heat treatment of 4340 steel is straightforward for most commercial applications, it is not easy to produce the quality required for the impact verification specimens, particularly for production lots of approximately 1200 specimens.

One reason for this is that the transition behavior, shown in **Figure 2**, is not ideal for 4340 steel: at −40 °C the upper shelf of the high-energy specimens, and the lower shelf of the low-energy specimens are not flat. This can result in increasing the scatter during testing. Added to this are
the effects of slight differences in heat treating between specimens, slight inhomogeneities in the steel, and other considerations. So, for our case, where a maximum range in hardness of less than 0.5 HRC is needed for a production lot, slight differences in the thermal history of the specimens can quickly present problems. Our experience has shown that the heat treatments recommended by the Army can give good results for small lot sizes. For example, we had two heat treating shops follow these recommendations to produce two low-energy lots for impact testing. No additional heat treatment specifications were added to our instructions, so different quench oils, etc. were used by the shops.

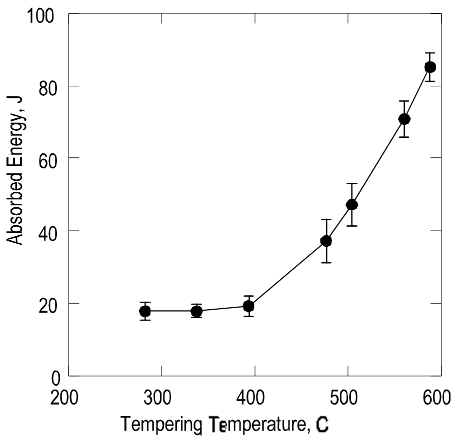

Figure 1. Data for 4340 verification material, 2001.

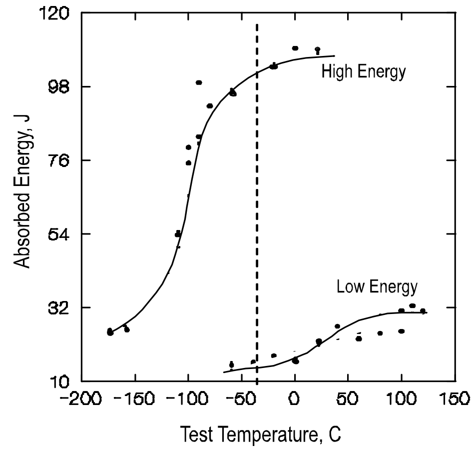

Figure 2. Transition curves for 4340 steel that has been heat treated for low- and high-energy verification specimens.

Table 5. Example heat treatments for low- and high-energy level type 4340 impact specimens.

Low-energy specimens, hardness 46 HRC ±1 HRC	High-energy specimens, hardness 32 HRC ±1 HRC
Normalize 900 °C (1650 °F) for 1 h, air cool	Normalize 900 °C (1650 °F) for 1 h, air cool
Harden 871 °C (1600 ° F) for 1 h, oil quench	Harden 871 °C (1600 ° F) for 1 h, oil quench
Temper 400 °C (750 ° F) for 1.5 h, oil quench	Temper 593 °C (1100 ° F) for 1.25 h, oil quench

The variation in energies for both lots was low: One lot had a coefficient of variation of 0.04 (an acceptable variation for impact verification specimen),
and the other lot had a coefficient of variation of 0.02 (a very low variation). However, to attain results of this quality for production lots of approximately1200 specimens, extremely well controlled processing is necessary, and typically double tempering, stress relief, cryo-treatment, and other steps are used to fine-tune the process for a given heat treating shop.

It is our experience that the specifics of the heat treatment should not be dictated to the shop. Each heat-treatment shop is different and needs leeway to adjust the process to best suit the equipment. Currently we use three shops and each uses a different process. All are capable of attaining similar quality specimens (after climbing difficult learning curves). A typical quality for impact verification specimens is characterized by a coefficient of variation (the ratio of the standard deviation to the average absorbed energy) of less than 0.04. The highest quality specimens approach coefficients of variation near 0.02.

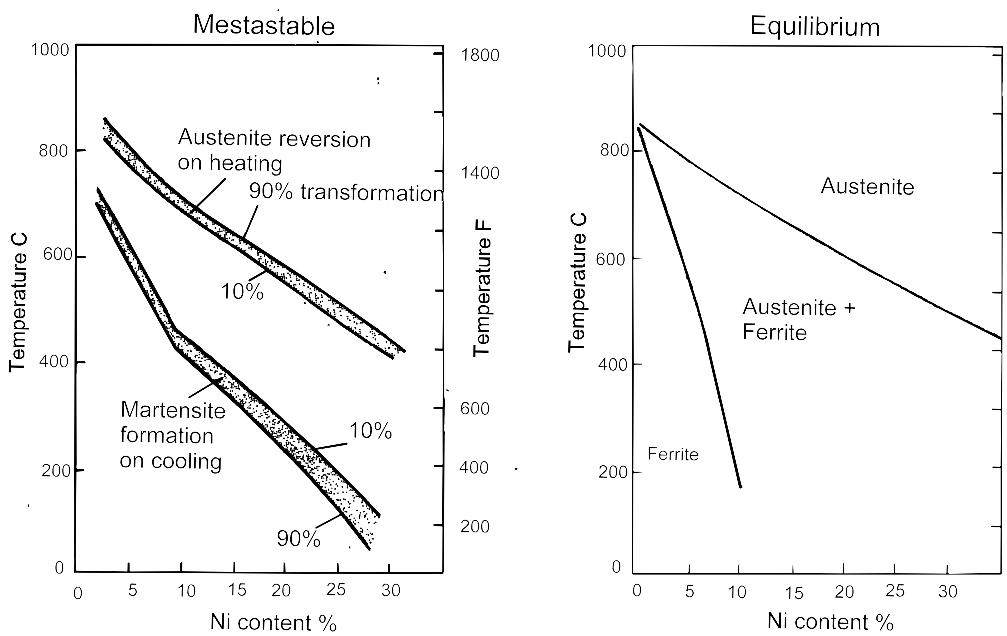

Figure 3: Phase diagrams for the Fe- Ni system.

5.1.2 **Type T-200 steel**

The T-200 steel is an 18 Ni, cobalt-strengthened maraging steel. This alloy can be solution-treated at 900 to 925 °C, control-cooled, grain-refined using multiple heating and cooling cycles near 760 to 815 °C, then aged to attain the appropriate strength/toughness combination. We age to produce a low-strength, high-toughness material. Recommended aging for a hardness of 30 HRC is 315 °C for 6 h. In general, the aging reactions are more sensitive to temperature than time.

The phase transformations for the T-200 steel that are of most interest are the martensite transformation on cooling, and the formation of austenite on heating (holding at temperature). As shown in **Figure 3**, the martensite in 18 Ni alloys is quite stable during heating to temperatures approaching 540 °C (1000 °F), which makes the aging of the martensite possible. However, substantial amounts of reverted austenite can form in Co-free maraging steels (and in other maraging steels) during aging treatments at temperatures of less than 540 °C (1000 °F), and it is not clear whether reverted or retained austenite would adversely affect the scatter in the Charpy impact energy.

For our alloy, we find that annealing temperatures of about 815 to 870 °C (1500 and 1600 °F) are high enough to avoid the two-phase region and produce a fully annealed structure, and low enough to avoid significant grain growth.

Most research does not include aging data for temperatures as low as 315 °C (600 °F), because it is not of commercial interest. There has been some indication, however, that different precipitates are formed when the alloys are aged at low temperatures. A study on an 18 Ni Co-containing 350 grade maraging steel showed distinct differences in the precipitates formed above and below 450 °C (845 °F). Ni_3Ti precipitates are formed in T-200 alloys at high aging temperatures, but actual precipitation probably doesn't occur at low aging temperatures (315 °C for 3 h). It is likely that clusters of Ni and Ti atoms cause the strengthening at low aging temperatures, and the toughness is lower for these under-aged clusters in maraging steels than it is for peak-aged steels (apparently because clusters or coherent precipitates restrict cross-slip in the matrix and Ni_3Ti precipitates allow more homogeneous slip).

Maraging steel can become embrittled during high-temperature solution treatments. The embrittlement is caused by precipitation of Ti(C,N) at grain boundaries during cooling, and can be retained even following re-annealing. Quenching from high temperature prevents the precipitation and subsequent embrittlement.

We have also found that quenching from high temperatures results in higher toughness (lower hardness) for our alloy, as indicated by the data in **Figure 4**. Quenching from the annealing temperature clearly results in a softer material, and the difference between the hardness of the air- cooled and water-quenched material is retained after aging. We found a difference of about

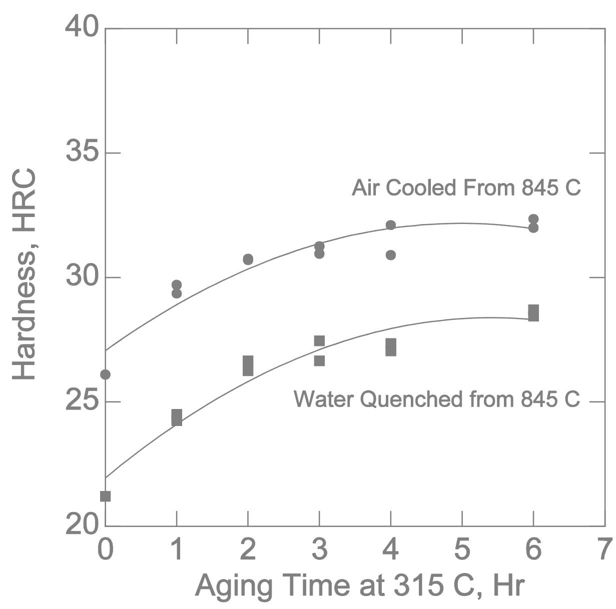

Figure 4. Hardness for air-cooled and water-quenched samples.

5 HRC, which is expected to result in a significant increase in the toughness of the material.

Initial heat treatments on the new heat of T-200 material provide a general understanding of the energy levels that might be expected from the material. The mechanical test results for various heat treatments are shown in **Figures 5 through 7**. In **Figures 5 and 6**, the samples were annealed at 954 °C (1750 °F) for one hour and air-cooled, then re-annealed at 760 °C (1400 °F) for 1 h and air-cooled. These samples were then divided into five groups and aged at 260, 290, 315, 345, and 370 °C (500, 550, 600, 650, and 700 °F) for three hours and air cooled. The data show the relationship between the impact toughness and the hardness of the material for these heat treatment conditions. The data in **Figure 7** are similar to those in **Figure 5**, but these samples were annealed at 900 °C (1650 °F) for 1 h and water- quenched, then reheated twice to 675 °C (1250 °F) and water quenched as a grain refinement treatment, and re-annealed at 815 °C (1500 °F) for 1 h and air-cooled prior to aging at 315 and 370 °C (600 and 700 °F) for 3 h. Other variations of these two heat treatment schedules produced similar results. Overall, it appears that this T-200 material can be aged to produce Charpy specimen having impact energies of near 215 J (160 ft·lbf).

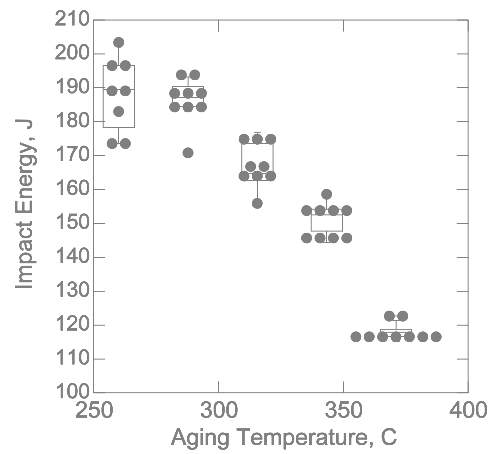

Figure 5. Impact energy of samples annealed at 954 °C and 760 °C, then aged.

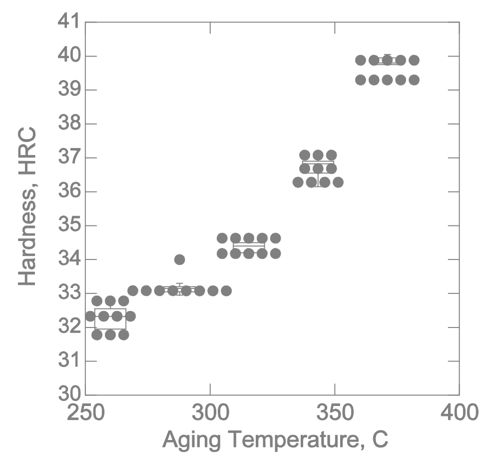

Figure 6. Hardness of samples plotted in figure 5.

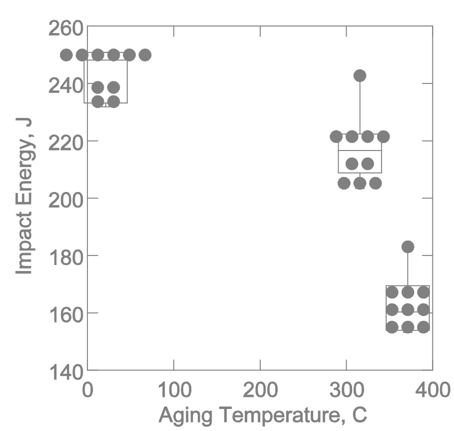

Figure 7. Impact energy of samples annealed at 900 °C, 675 °C and 815 °C prior to aging.

5.2 **Sampling**

A production lot of approximately 1200 specimens are heat treated together as a single furnace load. A spatial (not random) sample of at least 100 specimens is removed from the heat treating baskets for pilot-lot evaluations. As shown in **Figure 8**, a spatial sample allows us to evaluate and minimize any correlation between the variation in energy of the samples to their position in the heat treatment baskets. If the pilot-lot sample is acceptable, the remaining specimens in the production lot are completed. An additional 30 random samples are removed from the production lot (following delivery to NIST). These specimens are either used for evaluations of the production lot or held as control samples for future testing.

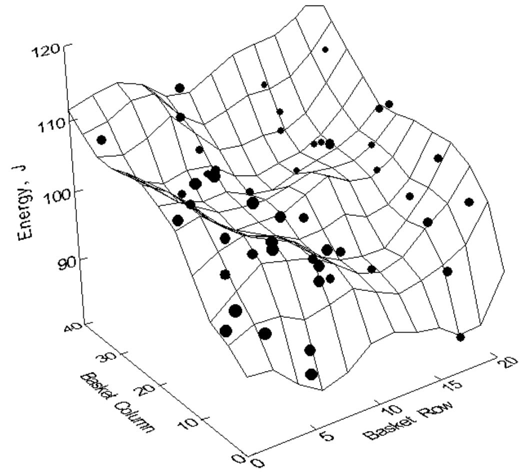

Figure 8. 4340 data showing the primary variation in the specimens correlates to the position of the specimen in the heat-treatment basket.

5.3 **Machining**

5.3.1 **Process**

Prior to heat treating, the square bars are cut to approximately 56 mm long blanks and ground to finished length. Then one end of the specimen blank is stamped with 'NIST', and other with a series number and a serial number. The series number identifies the production lot and the energy level (LL for low energy, HH for high energy, and SH for super high energy). The serial numbers range between one and the total number of specimens in the production lot. For the specimens made with 4340 steel, the surfaces are all ground to nominal size to remove surface flaws that might result in quench cracking during the heat- treatment operations.

From the production lot of heat-treated specimen blanks, 100 are machined to final dimensions for pilot lot testing (**Figure 9**).

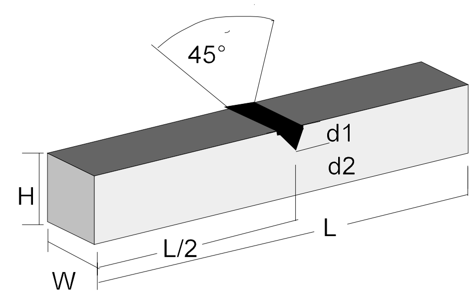

Figure 9. A Charpy V-notch sample with dimensions labeled in reference to Table 6.

5.3.2 **Machining requirements**

The dimensional requirements for NIST verification specimens, given in **Table 6**, meet or exceed the ASTM E 23 specifications. This minimizes variations in impact energy due to physical variations in the specimens. Also, the notch centering and the length tolerance for NIST specimens are equivalent to the ISO Standard 164, which permits the specimens to be used in impact machines with end-centering devices. The NIST requirement for surface finish is also equivalent to the ISO 164 requirement. All of these dimensional requirements can be met with standard machining practices.

Specimen notches are form ground on a surface grinder (machining with a fly cutter or multi-tooth cutter is not permitted). To avoid "burning" or cold working the material at the base of the notch, the next to the last cut is required to remove more than 0.25 mm and less than 0.38 mm and the final cut must not remove more than 0.12 mm. When the specimens are finished and ready for shipment, they are given a protective coating of oil.

Table 6. Dimensional requirements for NIST Charpy impact verification specimens.

Height (H)	10 mm, ±0.03 mm, with adjacent sides square within 90° ±9 min
Width (W)	10 mm, ±0.03 mm,
Length (L)	55 mm, +0.00 mm, −0.3 mm
Notch position L/2	27.5 mm ±0.2 mm, perpendicular to the longitudinal axis of specimen within 90° ±9min
Notch radius	0.25 mm, ±0.025 mm, with radius tangent to the notch angle
Notch depth (d1)	2 mm, ±0.025 mm
Notch angle,	45° ±1°
Ligament depth (d2)	8.0 mm, ±0.025 mm
Surface finish	1.6 µm on notched surface and opposite face; 3.2 µm on other surfaces

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5.4 **Hardness Testing**

5.4.1 **Process**

Two hardness measurements are made on each of the pilot-lot samples, at positions approximately 10 mm from the specimen ends on the face opposite the notch. The two measurements are averaged to estimate the hardness of the sample.

The hardness criteria for verification specimens relate to three practical aspects of the impact test: (1) The minimum hardness requirement for low-energy lots assures an appropriate impulse load is transferred to the machine frame on impact to verify adequate mounting and overall stiffness of the machine. (2) The minimum hardness requirement for low-energy lots also determines the direction in which the 4340 impact specimens exit the machine.(3) The specimen-to-specimen variation in hardness provides an indication of the variation in energy of the specimens (particularly for the higher-energy specimens).

The verification specimens are produced so that different energy ranges leave the machine in different directions. Specimens with hardness of greater than 44 HRC leave the machine in a direction opposite to the direction of the swing, and are needed to evaluate how well the shrouds on U-type impact machines are functioning. Specimens with a hardness less than 44 HRC typically exit the machine in the same direction as the swing of the pendulum.

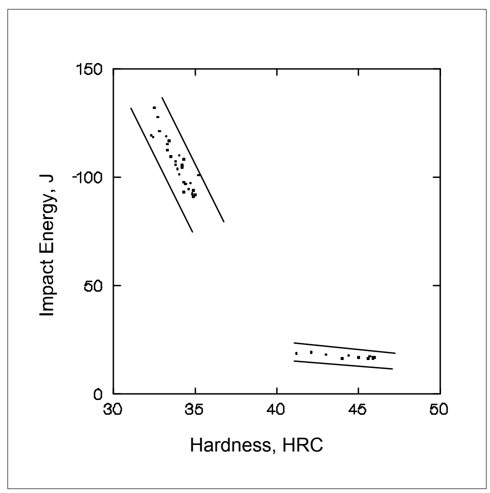

Figure 10. Hardness data for low and high energy verification specimens.

In practice we find that when the variation in hardness exceeds ±0.5 HRC the quality of the lot is questionable (i.e., the variation in energy is likely unacceptable). As shown in **Figure 10**, the correlation between energy and hardness is much more useful for evaluating variations of high-energy (lower hardness) specimens, because at high hardness, the slope of the trend decreases significantly. So, although hardness evaluations have worked well as a quality-control procedure in our program, hardness data are principally used to estimate the impact toughness of the specimens and to assure that the low-energy specimens exit the machine in the required direction.

5.4.2 **Requirements**

The average hardness of the pilot lot samples must be within ±1 HRC of the targeted hardness, unless otherwise agreed.[2] This requirement is most important for the low-energy specimens, which normally need to have a hardness of 44 HRC or more to exit the impact machine properly.

5.5 **Impact Testing**

5.5.1 **Process**

If the dimensional measurements of the specimens and the hardness results are acceptable, the pilot-lot specimens are divided into three groups of 25 (one group is tested on each of the three master impact machines) and the extra 25 specimens are held in reserve for any additional testing that may be required. In dividing the specimens into groups, the furnace locations from which the specimens were taken are considered and the groups are balanced accordingly.

The certified energy value for a production lot of verification specimens is defined as the grand average of the 75 specimens tested (25 specimens on each of the 3 master machines). In addition to the grand average impact energy, the standard deviation, sample size, and several other statistics are calculated for the verification set. These statistics are used to determine the acceptability of the lot and the performance of the machines. All 75 specimens are included in these calculations, with the following three exceptions: (1) specimens that are determined to be outliers as defined in section 6.5.2, (2) specimens having the same lateral expansion but significantly different energies, and (3) specimens with flaws apparent on their fracture surfaces.

5.5.2 **General statistics**

The average energy and grand average energy are defined as

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \ldots x_n}{n}, \tag{1}$$

[2] When using a single impact machine, the same amount of impact energy may be indicated by materials having different yield strengths. These same materials tested in another machine may indicate different values of impact energy. The difference is usually greater for the stronger materials, presumably due to the faster rate at which peak loading occurs. To accentuate these differences, materials of high yield strength are specified for the verification specimens at each energy level. These requirements are normally monitored by making hardness assessments rather than tensile testing.

where n is equal to 25 for calculating the averages of each machine, and n is equal to 75 for calculating the grand average for the pilot lot.

The standard deviation is defined as

$$s = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots (x_n - \bar{x})^2}{n - 1}} \tag{2}$$

The pooled standard deviation is defined as

$$s_p = \sqrt{\frac{s_1^2 + s_2^2 + s_3^2}{P}}, \tag{3}$$

where subscripts 1, 2, and 3 indicate the standard deviation of the 25 samples tested on the three master machines, and P is equal to three.[3]

The sample size, which represents the minimum number of specimens from a given production lot that should be tested in a verification test, is defined as

$$n = \left[\frac{3s_p}{E}\right]^2, \tag{4}$$

$$s_p = E\frac{\sqrt{n}}{3} = 1.4\frac{\sqrt{5}}{3} = 1.04\,J,$$

where E is 1.4 J or 5 % of the mean energy, whichever is greater. For example, for the low-energy specimens E is equal to 1.4 J, so the maximum pooled standard deviation allowed for a sample size of 5 is

(5)

which indicates a CV of around 0.07 for specimens with an average energy of 16 J (1.04/16 = 0.07).

For the higher-energy specimens, E is taken as 5 % of the average energy for the lot and the maximum pooled standard deviation allowed for a sample size of 5 is

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[3] The choice of the value of standard deviation depends on whether all the machines used to determine the reference value met the requirements for variability, k (see equation 7). If all the machines met the requirements, the value of s shall be equal to the pooled standard deviation. If all the machines did not meet that requirement, s shall be equal to the largest of the standard deviations of the machines considered separately.

$$s_P = (0.037)\ (\text{average energy})\ , \tag{6}$$

and in this case the CV is 0.037 by definition (s_P /average energy).

The outlier analysis is performed using box-and-whiskers plots to provide a graphical summary of the data and identify outliers.[4] Outliers are defined as values that are lower than the first quartile or higher than the third quartile by more than 1.5 times the absolute difference between the first and third quartiles. If a lot has more than 5 % outliers, it may be rejected.

The variation in energy values is calculated for each machine using a ratio of the standard deviation for the particular machine over the pooled standard deviation. This ratio, k, is expressed algebraically as

$$k_1 = \frac{s_1}{s_p},\quad k_2 = \frac{s_2}{s_p},\quad k_3 = \frac{s_3}{s_p}\ , \tag{7}$$

here s_n and s_p are the individual and pooled standard deviations for the three machines respectively. If the k ratio of any of the three machines exceeds 1.25 (assuming 25 specimens tested per machine), the variability in energy values due to that machine is questioned and appropriate actions are taken (repairs to the machine, testing of additional samples, etc.).[5]

5.5.3 **Uncertainty calculation**

The uncertainty of a single specimen in a given lot can be determined by combining three components of uncertainty: within-machine uncertainty (s_P), uncertainty due to machine bias (s_B), and the uncertainty of specimen homogeneity (s_H). The total uncertainty is given by

$$u_T = \sqrt{\left(s_P{}^2 + s_B{}^2 + s_H{}^2\right)}\ . \tag{8}$$

The within-machine uncertainty is the "pooled" standard deviation (see eq (3)) based on 25 verification specimens tested on each of the 3 master machines. The degrees of freedom associated with s_P is 72 (i.e., 25 + 25 + 25 − 3).

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[4] An outlier is defined statistically, but a specimen identified as an outlier is not removed from the analysis unless it shows physical evidence of jamming, material flaws, or other reasons for atypical behavior.

[5] If the k ratio of a machine is greater than 1.25, the results of this machine can be questioned by the contractor who supplied the specimens. This is considered a basis for retesting another group of 25 specimens prior to determining the acceptability of the lot.

The uncertainty due to machine bias accounts for possible bias in the observed averages associated with each master machine. The value of s_B can be quantified using a technique called "BOB" which models the unknown biases with a Type B uncertainty distribution.

The final component of uncertainty, s_H, can be thought of as a correction for specimen inhomogeneity and is typically based on engineering judgment. It is common practice to set the number of degrees of freedom associated with a Type B component of uncertainty, such as s_H , equal to infinity.

5.5.4 **Energy requirements**
The most important requirement is the variability in impact energy of the specimens. Our contracts allow us to reject a lot with a sample size of more than 5.

A lot can also be rejected if the average energy is outside the range specified in Table 6. The certified energy of the specimens must fall within the ranges of 14 to 20 J (10 to 15 ft·lbf) for the low energy level, 88 to 136 J (65 to 100 ft·lbf) for the high energy level, and 176 to 244 J (130 to 180 ft·lbf) for the super-high energy level, unless otherwise agreed.

6. **Certification and Acceptance of a Pilot Lot**

6.1 **Process**
Acceptance of a new batch of verification specimens is based on the data obtained from the pilot lot of 100 specimens, taken from a heat-treatment batch of approximately 1200 specimens. Although impact energy is the most important criterion, other criteria are also evaluated to determine the consistency and quality of the verification specimens. The pilot lot data (impact energy, hardness, and dimensional measurements are processed using a computer program to provide standardized output for review in determining the acceptability of the lot.

If the data indicate that the pilot lot is acceptable, the contractor is advised to machine the remainder of the production lot and submit it for final acceptance. If the random samples removed by NIST from the production lot are acceptable, a certified energy value is assigned to the lot and it is placed in inventory.

The certified energy of the lot is defined as the grand average energy of the lot. The number of specimens in a verification set is determined by the sample size calculation. Typically, a set size of five is used (for lots with sample sizes of three, four, or five), but occasionally sets having more or less than five samples are distributed.[6]

The number of degrees of freedom associated with each of the three components of uncertainty can be combined using the Welch-Satterthwaite formula to obtain the effective degrees of freedom associated with the total uncertainty, u_T . The effective degrees of freedom are used to determine the appropriate coverage factor for the confidence intervals.

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[6] We routinely reject lots with sample sizes greater than five, but when stocks are very low we have occasionally accepted lots with larger sample sizes.

6.2 **Requirements**
A pilot lot can be rejected for use as verification specimens if:

1. The verification specimens do not meet the dimensional requirements given in section 6.3.
2. The hardness and energy levels are not within the ranges specified in Table 7.[7]

Table 7: Required ranges for verification specimens.

Energy level	Low	High	Super-high
Absorbed Energy (J)	14 to 20	88 to 136	176 to 244
Hardness (HRC)	>44	∓1 of avg	∓1 of avg

3. The sample size for the lot exceeds 5.
4. The number of outliers exceeds 5 % of the number of specimens impact tested in the pilot lot (4 is the maximum for a pilot lot of 75).
5. The difference between a machine average and the grand average is greater than the larger of 1.4 J or 5 % of the grand average.[8]
6. The results from one of the three machines show excessive variability, according to the k ratio.[9]
7. The microstructure of the low energy and high energy specimens is not 100 % martensite (no ferrite, austenite, or bainite should be visible).

6.3 **Reports**
The pilot-lot data calculations are done by a computer program to provide a consistent appearance and quality for our records. The evaluation report documents the lot identification, the reference machine it was tested on, and the energy and hardness of each specimen that was tested. The calculated values in the report are as follows: (1) the grand average energy and standard deviation, (2) the average energy and standard deviation for each machine, (3) the average hardness and standard deviation, (4) the pooled standard deviation in energy for the lot, (5) the sample size, and (6) the k ratio of each machine. A set of standardized plots in the report shows outlier data, the distribution in energy for each machine, and the combined distribution in energy for the three reference machines. The data collected from dimensional measurements on the specimens are kept separately. The evaluation report and raw data for the pilot lots are filed

[7] The average hardness values of the high and super-high energy specimens are not specified, but we require a maximum variation of ±1 HRC for the lot.

[8] In this case, both the quality of the specimens and the performance of the machine are questioned. Appropriate actions are taken that are agreed to between the NIST and the contractor supplying the specimens.

[9] In this case, both the quality of the specimens and the performance of the machine are questioned. Appropriate actions are taken that are agreed to between NIST and the contractor supplying the specimens.

for future reference and a copy of the report is sent to the contractor who supplied the pilot lot (with our comments).

7. **Distribution**

7.1 **Packaging**

Specimens are drawn from the production lot at random to make up the sets of impact verification specimens. These sets are distributed for verification testing. Each set of verification specimens is retained henceforth in the sets, as originally drawn.

If a purchaser can demonstrate that one or more specimens of a set are defective, the set is replaced without charge.

7.2 **Information**

Each set of verification specimens is accompanied by a certificate (Appendix 1) that gives the following information: name, address, and telephone number of NIST contacts; the test temperature; the identification of steel used; the designation number of the practice or practices whose specifications for verification specimens are met by the specimens supplied.

8. **Customer Certification Procedure**

8.1 **Process**

The results of a verification test are returned to NIST, along with the broken specimens and a questionnaire that is filled out by the customer. Information from each of these three sources is used in the evaluation of the test. Based on the results of this evaluation a letter is written to the customer. If the results are acceptable, a verification letter and accompanying verification sticker serve as documentation that the machine meets the requirements of ASTM Standard E23. If the results are unacceptable, the letter explains why we think the test does not meet the requirements of E 23 and suggests how the machine might be brought into compliance.[10]

8.2 **Customer Questionnaire**

The information provided by the customer is used to help us understand anomalies in the test data and provide background that allows us to better advise the customer. If test results are uniformly high, for example, the questionnaire might be referenced to determine how the test temperature was measured and the last time the temperature equipment was calibrated, which might explain the result (test conducted at wrong temperature). Other, nontechnical information is also provided by the questionnaire that is used to update our database. A copy of the questionnaire is given in Appendix 2.

8.3 **Test Data**

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[10] Customers are not required by E 23 to have their machines verified by NIST. They can verify the results of the test themselves, or have a private testing company verify the test results. ASTM E 23 does require that the energy value of the impact verification specimens be "established on the three reference machines owned, maintained, and operated by NIST in Boulder, CO".

The verification test results are calculated and compared with the certified value of the lot, and with the results of previous verification test results for the machine. A machine is classified as unacceptable if the difference between the average energy of the machine being verified and the certified value is greater than 1.4 J or 5 % (whichever is larger) of the certified energy of the verification lot.

8.4 **Examination of Broken Specimens**

The specimens are checked to determine the following information: (1) if the anvil marks indicate that the specimens were centered for the test, (2) if the striker mark indicates that the striker on the impact machine was centered, (3) if the anvil markings indicate excessive or unusual wear, (4) if the size of the shear lips on the specimens indicate that the test was done at the proper temperature, and (5) if markings on the fracture surfaces of the specimens show material flaws or unusual textures.

These observations are used either to remove a specimen from the data analysis (in the case of a flaw or off-center strike), or as a basis to fail the test due to worn anvils, etc. More specific information on how and why the specimen are examined in the NIST procedure are given in Special Publication 960-4.

8.5 **Customer Letter**

Based on our judgement and the requirements of ASTM E 23, a pass or fail letter is developed for the customer. The letters are composed using a word processing program that is integrated with our database, and with a list of standard paragraphs covering commonly observed problems with verification test results. The program merges customer data with the selected standard paragraphs, and then allows final editing for the addition of more specific comments, if applicable. The letter also includes a table that presents the customers' data and the values that were computed by the program to evaluate the data.

If a customer fails the verification test, he/she is typically contacted by fax, phone, or email to discuss the results. If a customer passes the verification test, the letter serves as a file record.

8.6 **Verification Sticker**

A verification sticker (to put on the impact test machine) is mailed with each pass letter. The stickers have a NIST logo and give the serial number of the machine, the date of the next verification, and the range in energy over which the machine is verified.

The stickers are made using a Brady 200M label printer and Codesoft version six software by Teklynx.

The inclusion of stickers in the customer letters was initiated in September 2001.

9. **Program Controls**

9.1 **Impact Machines**

The impact machines are inspected and adjusted by NIST personnel, and experts contracted by NIST. Critical direct verification measurements were made when the machines were installed, and are made when a change in the performance of a machine is noted. Example data for the master machines are given in Appendix 3.

The performance of the impact machines is routinely evaluated for each lot of specimens tested. This evaluation is principally a comparison of the mean and standard deviation of each machine to the other machines used in the program. The performance of the machines are compared as each pilot lot is tested, and these results are compared with the past performance of the machines.[11] A plot showing the average energy of each machine and the grand average for each pilot lot is updated for each pilot lot tested, to document and evaluate the relative performance of the impact machines. Example data are given in Appendix 3.

A log book on the machines is maintained that contains records for the “daily check” procedures that are conducted on the machines prior to testing a pilot lot: these records allow us to track the friction and windage, and other factors that affect the performance of impact machines. The log book also documents maintenance to the machines and the number and types of specimens tested.

A reserve of impact verification specimens (from past pilot lot tests) are kept and serve as control specimens. When a change to a machine is suspected, due to its relative performance, a set of control specimens can be tested and compared to the original performance for this machine with these specimens. Control specimens are also used to check machines following a repair.

9.2 **Measurement Equipment Used in the Verification Program**

A Newage Deltronic hardness tester is used to measure hardness. The hardness tester is calibrated annually by Leco Corporation. The hardness tester is checked with calibration blocks prior to each use. An optical comparator is used to measure the notch angle, notch depth, notch radius, and L/2 (notch centering in relation to specimen length). The optical comparator is a Deltronic Model DH 216 and is equipped with an MPC-5 readout. The comparator is calibrated annually by Precision Gage, Inc. Both the hardness tester and the optical comparator read directly to a personal computer using NIST developed software.

Mitutoyo, Model CD-6"C, digital calipers are used to measure specimen length, width, and thickness. The calipers are calibrated annually by Precision Gage, Inc. The calipers are checked with a one-inch calibration block prior to each use. The caliper data are automatically stored on a personal computer.

Squareness is measured with a gage manufactured by Laboratory Testing, Inc. The gage was manufactured using the drawing in ASTM Standard E 23. The gage is calibrated annually by Laboratory Testing, Inc. The gage is checked with a calibration block furnished by, and

[11] The impact machines have characteristic differences from one another in energy level and variation. Changes in these relative differences indicate changes to our program, and are investigated to determine the cause.

annually calibrated by, Laboratory Testing, Inc. All calibrations by outside companies are traceable to NIST.

9.3 **Specimens**
The quality and consistency of the verification specimens is first controlled by the steel used for their production. Our contractors are shipped bundles of steel bar that are coded with reference to ingot location, and production lots are made using steel from a given bundle. This is our best assurance that the steel used for a given production lot is as similar as possible. In the event that some portion of the bar contains melting or rolling flaws, this procedure would help us to more quickly identify and remove this material from the stock.

Our second control of specimen quality is careful sampling and pilot lot evaluations. In our experience we have found that geometric rather than random sampling produces a better estimate of the mean energy for our pilot lots. Our samples are taken from predetermined positions within the heat-treating baskets and labeled.

Our final control involves a feedback loop using data from customer verification tests. As customer data are collected they are stored in a database, and pass/fail ratios can easily be calculated for a lot of verification specimens that is questioned by either a customer or ourselves. If these data show normal ratios, this is strong evidence the average energy of the lot was accurately estimated by our pilot-lot sample. If these data show more machines than normal are failing using a particular lot of specimens, and the mean energy of the customer data is significantly different from the certified energy value of the lot, this is evidence that the certified energy value of the lot has changed or that the average energy determined for the lot was not an accurate estimate.[12]

9.4 **Customer Evaluation and Service**
In an attempt to control the quality of our customer assessment, we look at both current and past tests results for the machine. This often helps in understanding a customers' problems and allows us to better help the customer with comments concerning the performance of the machine. To provide prompt service for the program, we have two back-up personnel who are capable of filling in to cover the day-to day operation of the program.

To preserve good documentation of customer verification tests, we save the test specimens for one year. We save customer letters for two years as a hard copy. Digital files of letters are kept indefinitely, and all database information is saved.

9.5 **Database**
The software used in the program is managed by one person only. No changes are made without adequate follow-up. The personnel using the software are always consulted before and after making software revisions. The database (and software) is backed-up to tape on a regular basis.

[12] In the last 10 years approximately 3 lots have been suspected of having inaccurate certified energies assigned to them. In all 3 cases, sampling is suspected to have caused the error. The stability of the specimens has not been suspected as the cause (because the energies increased rather than decreased).

10. **Support of National and International Impact Standards**

The data gathered from customer verification tests and from our pilot lot tests provide a unique source of information for statistical studies on impact testing. These data allow us to review how specific designs, capacities, and ages of impact machines perform under the rules of the various impact standards used in the world. They also allow us to evaluate how well our estimates for the average energies of pilot lots compare with the average of all the machines in the world that tested them.

The principal use for these data is to help address issues concerning the indirect verification rules of ASTM and ISO impact testing standards. For example, currently there are major differences between the pass/fail range for ASTM and ISO verification tests, and our data can be used to make a strong argument that the ISO tolerance is too large (and the ASTM tolerance may be too small). Since the data are from actual tests, and include results from many countries, we can more accurately evaluate (and demonstrate) the impact of verification rules to our customers and the standards community than can any other country in the world. Our database is currently estimated to have results for more than 14000 tests (sets) and approximately 150 pilot lots.

11. **Education and Training**

11.1 **Customers**

Misunderstandings with our customers are minimized once they understand the NIST program, and how they can best take advantage of it. To help educate our customers we have developed a video that provides an overview of the Charpy test and the NIST verification program. We also have a brochure detailing our specimen evaluation procedures, Special Publication 960-4. Occasionally we have provided group training to companies that manufacture and repair Charpy impact machines.

11.2 **Staff**

General experience is the most valuable education and training for our staff, particularly experience gained from talking to customers. In addition, we attend ISO and ASTM meetings to gather feedback on the program. Comments at these meetings, and other technical meetings concerning impact testing, help to keep the program and personnel on track.

12. **Safety Considerations**

The operation of impact machines requires good safety practices to avoid injury. During our impact tests, the laboratory is locked and signs are posted on the doors to indicate that testing is in progress. Partitions are used to shield the operator and other equipment in the room from flying specimen halves as they exit the machine after impact. Safety glasses are worn when impact tests are conducted.

Appendix 1. Sample Charpy Verification Certificate

Example of a Certificate that was distributed with Charpy verification samples in 2000.

National Institute of Standards & Technology

Certificate

Standard Reference Materials ®

2092 - Low-Energy
2096 - High-Energy
2098 - Super High-Energy

Verification Specimens for Charpy V-Notch Impact Machines
Lot No.:

Standard Reference Materials (SRMs) 2092, 2096, and 2098 are intended primarily for the verification of Charpy V-Notch machines in accordance with the current ASTM Standard E 23 [1]. Each SRM consists of a set of individual 10 mm × 10 mm × 55 mm specimens needed to perform one verification. These SRMs comply with both ASTM Standard E 23 and International Organization for Standardization ISO/DIS 12736 dimensional requirements [2].

Material Description: SRMs 2092 and 2096 are made from 4340 alloy steel. SRM 2098 is made from a high strengthmaraging steel. The bars are finished to length, stamped, heat-treated, and machined in SRM specimen lots ofapproximately 1200. Each specimen has a lot number and an identification number (three or four digits) stamped on oneend of the specimen. Additional information can be found in References [3-5].

SRM Certification Procedure: Specimens taken at random from each SRM lot are tested by the NIST Materials Reliability Division on Charpy V-Notch reference machines. The specimen data generated are then statistically evaluated to assure the homogeneity of the lot, establish the certified value, and determine the number of SRM specimens required for a user to perform a valid test. See Table 1 for a list of the approximate energy ranges within which the individual certified values should fall.

If certified values are required immediately after testing, contact the NIST Charpy Program Coordinator as follows: telephone (303) 497-3351; fax (303) 497-5939; or e-mail vigliotti@boulder.nist.gov. The lot number and energy results of the tested specimens must be provided in order to obtain certified values by telephone or fax.

Expiration of Verification: The verification report issued on an acceptable machine is valid for one year from the date that the SRM was tested. If a user's machine is moved or undergoes any major repairs or adjustments, the current verification will be invalidated and the machine must be retested and reverified. The overall direction and coordination of the technical measurements leading to verification of test specimens and machines, evaluation of test results, and issuance of the report on machine conformance are under the direction of the NIST Materials Reliability Division, Boulder, CO.

The support aspects involved in the original preparation, certification, and issuance of these SRMs were coordinated through the NIST Standard Reference Materials Program by R.J. Gettings. Revision of this certificate was coordinated through the NIST Standard Reference Materials Program by C.R. Beauchamp.

Fred R. Fickett, Chief
Materials Reliability Division
Gaithersburg, MD 20899 Nancy M. Trahey, ChiefCertificate Issue Date: 14 May 2001 Standard Reference Materials Program

NOTE: THESE ARE NOT CERTIFIED VALUES. THESE ARE THE APPROXIMATE RANGES FOR EACH ENERGY LEVEL.

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Table 1. Approximate Charpy SRM Energy Ranges.

SRM	No.	(J) (ft·lbf)
2092	13-20	10-15
2096	88-136	65-100
2098	176-244	130-180

Storage: The SRMs are composed of specimens anticipated to have an indefinite shelf life under normal storage conditions. Each specimen is coated with oil, wrapped in a corrosion inhibiting paper, and sealed in a plastic envelope.

It is recommended that the specimen be retained in this package to protect them from moisture until used. The protective oil coating should be wiped from each specimen just prior to testing.

Use: Prior to testing a Charpy V-Notch machine, the machine should be checked to assure compliance with the appropriate sections of the current ASTM Standard E 23 [1]. To comply with the testing procedures specified in the standard, SRM 2092 and SRM 2096 shall be tested at −40 ˚C ± 1 ˚C (-40 ˚F ± 2 ˚F). SRM 2098 shall be tested at 21 ˚C ± 1 ˚C (70 ˚F ± 2 ˚F). All SRM specimens are to be tested in accordance with the testing procedures of the appropriate sections of the current ASTM Standard E 23. All SRMs shall be tested at the same time. An acceptable machine will produce an average value within 1.4 J (1.0 ft·lbf) or 5 % of the certified energy value, whichever is greater, providing the specimens appear to have normal markings. Because the source(s) and magnitude of error for energy values at one energy level may not be the same at different energy levels, calibration or correction curves shall not be used.

Verification of User's Machine: The NIST Charpy Program Coordinator will issue a report of findings to the user's facility upon receipt of the fractured specimens and completed questionnaire. If the machine to be verified produces acceptable values and the specimens appear to have normal markings, this report will verify its conformance. If the machine produces values outside the allowable tolerance of the certified energy values or the specimens have abnormal markings, the report may suggest repair or replacement of machine parts, changes in testing techniques, or other appropriate corrective actions. Fractured specimens and completed questionnaires should be returned to the NIST Charpy Program Coordinator, Mail Code 853.07, 325 Broadway, Boulder, CO 80305-3328. A plastic, self-locking bag is provided for the return of broken specimens. The broken specimens shall be taped together as described in the wrapping instructions included with the questionnaire.

Important Information: Shipping charges for the return of broken specimens are the responsibility of the user. The mailing label provided with each SRM must be used to expedite shipping and, for overseas shipments, clearance by U.S. Customs.

Note to International Customers: Regular overseas shipments of broken specimens should be sent airmail so that after they are cleared by U.S. Customs, they can be forwarded directly to NIST-Boulder. If a more rapid shipping mode is necessary, choose an overnight delivery service that will handle U.S. Customs clearance **AND** will deliver directly to NIST-Boulder. Unless such delivery is assured, air freight packages may be returned to the customer by U.S. Customs.

REFERENCES

[1] ASTM E 23, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials, Annual Book of ASTM Standards, **03.01**, ASTM, West Conshohocken, PA.
[2] ISO/DIS 12736, Metallic Materials - Impact Testing - Preparation and Characterization of Charpy V Reference Test Pieces for Verification of Pendulum Impact Testing Machines, ISO, Geneva, Switzerland.
[3] Siewert, T.A. and Schmieder, A.K., "Pendulum Impact Machines: Procedures and Specimens for Verification," ASTM STP 1248, ASTM, West Conshohocken, PA, (1995).
[4] Shepherd, D.A. and Siewert, T.A., "Interlaboratory Test Study for the Determination of Precision and Bias in Charpy V-Notch Impact Testing," ASTM Research Report E 28-1014, ASTM, Philadelphia, PA, (1991).
[5] Holt, J.M., "Charpy Impact Test - Factors and Variables," ASTM STP 1072, ASTM, Philadelphia, PA, (1990).
Users of this SRM should ensure that the certificate in their possession is current. This can be accomplished by contacting the SRM Program at: telephone (301) 975-6776; fax (301) 926-4751; e-mail srminfo@nist.gov; or via the Internet [http://www.nist.gov/srm.](http://www.nist.gov/srm)

Certificate Revision History: 14 May 2001 (updated email address for Boulder contact); 09 August 2000 (updated mail and zip codes for Boulder facility); 22 March 2000 (editorial revision); 26 July 99 (editorial revision); 20 February 97 (original certificate date).

Appendix 2: Sample Customer Questionnaire

Example of a customer questionnaire used for the Charpy program.

QUESTIONNAIRE FOR CHARPY IMPACT MACHINE VERIFICATION

<u>IMPORTANT</u>: This questionnaire contains information to help you perform a successful verification test. Energy results are required for verification. Other specific information is requested to help evaluate the condition of your machine. The questionnaire and the fractured specimens should be shipped to the Charpy Program Coordinator, NIST, Division 853, 325 Broadway, Boulder, CO 80305-3328. Phone: 303/497-3351 Fax: 303/497-5939.

Location of Machine

Company ____

Address ____

____

City ____________________ State/ Province ____________________

Country ____________________ Zip/ Postal Code ____________________

Mailing Address for Verification Letter (if different from above)

Company ____

Address ____

____

City ____________________ State/ Province ____________________

Country ____________________ Zip/ Postal Code ____________________

Test Machine (circle appropriate units where indicated)

1. Machine Manufacturer and Serial Number ______________________________

2. What is the maximum energy capacity of the machine? ____________________ (J ft·lbf)

3. If the machine is adjustable, what capacity was used for this test? ____________________ (J ft·lbf)

4. The machine should be securely bolted to a concrete foundation or a steel block having a mass not less than 40 times that of the pendulum.

   (a) What type of bolts are used to mount the machine? (J, lag, etc.) ____________________

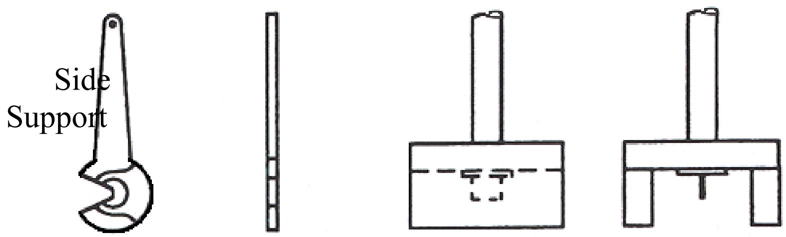
   (b) The machine should be level according to the current ASTM Standard E 23.

5. Is your machine equipped with a carbide striker? ____________________

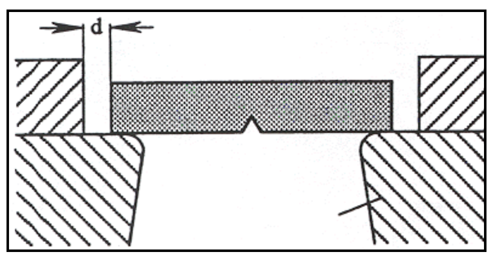
6. Is your machine equipped with carbide anvils? ______________________________________

7. Check the appropriate pendulum design below.

A ____________ B____________ C (Other) ____________

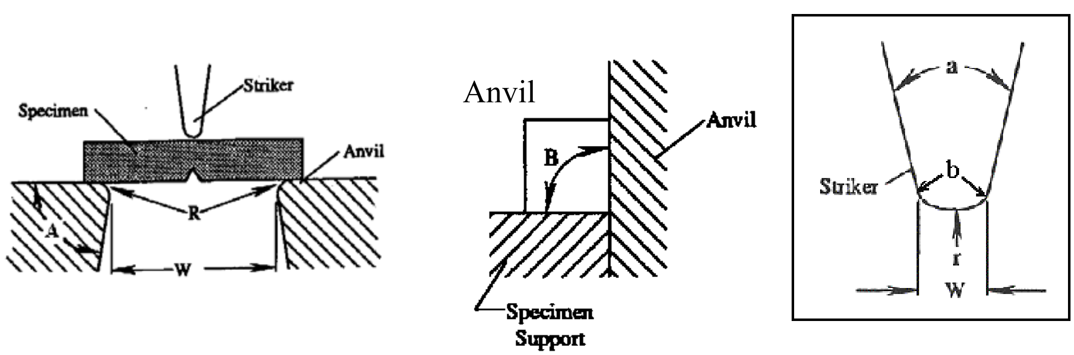


Please Sketch



8. If side supports or shrouds are used, what is dimension “d”? ____________________________
Circle: (mm or in)

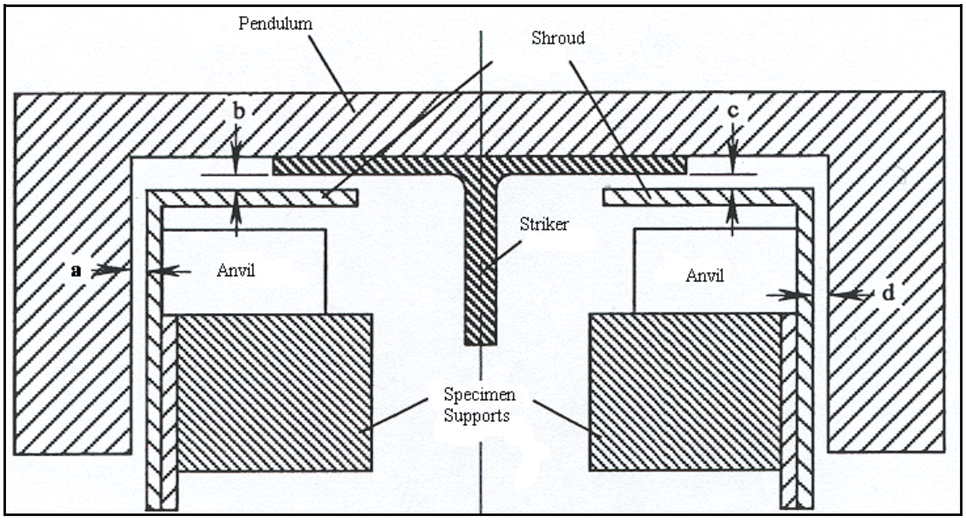
9. Your anvils and striker should conform to the dimensions below:



	Anvils		Striker
A:	80° approx.	a:	30° approx.
R:	1 ± 0.05 mm	r:	8 ± 0.25 mm
	(0.039 ± 0.002 in)		(0.315 ± 0.010 in)
W:	40 ± 0.05 mm	w:	4 mm approx.

	(1.574 ± 0.002 in)		(0.157 in)
B:	90° ± 10 min	b:	0.25 mm (0.010”)

10. If shrouds are used to contain broken specimens, the following requirements should apply:



(A) The shrouds should have a minimum hardness of 45 HRC.
(B) The thickness of the shrouds should be approximately 1.5 mm (0.06 in).
(C) Dimensions a, b, c, and d below should not exceed 1.5 mm (0.06 in).
(D) If dimension “d” in item 8 is more than 13 mm (0.5 in), requirements (B) and (C) above do not apply.

11. The striker should pass through the center of the anvils within 0.40 mm (0.016 in).

12. With the pendulum in the free hanging position, engage the energy indicator. The indicator should read within 0.2% of the maximum energy range being used.

13. What is the friction /windage loss of your machine? ________________________________
(J ft·lbf)
   (a) Raise the pendulum to the latched position. Without a specimen in the machine, release the pendulum and permit it to swing 11 half cycles; after the pendulum starts its 11th half cycle, move the pointer to between 5 to 10 % of scale range capacity and record the dial reading.

   (b) Divide the value by 11, then divide by the maximum scale range of the machine and multiply by 100. The result, friction and windage loss, should not exceed 0.4 %.

14. With the specimen removed from the machine and the pendulum released from its latched position, what is the dial reading after one swing? ________________________________
(J ft·lbf)

This reading should be zero. If this reading is not zero and your machine is equipped with a compensated scale, please adjust the dial to read zero. If your machine is equipped with a non-compensated scale, please compensate the energy values for windage and friction by subtracting the windage and friction value calculated in item 13.

15. When was this machine last verified by the NIST? Date: ____________________________

16. Is your machine equipped with a direct reading scale or a noncompensated scale? ________

IMPORTANT INFORMATION

To obtain accurate results the following procedures should be followed closely. For the NIST reference specimens the test temperature is near the ductile-brittle transition temperature of the steel. Therefore small variances in temperature and procedure may cause considerable error in energy values.

- The cooling bath should be placed directly beside the machine. This enables the operator to remove specimens from the bath and fracture them in the machine quickly.
- It is very important that the specimens be removed from the bath and fractured in less than 5 s. Taking longer than five seconds can increase the energy values, which may cause the low energy specimens to exceed the allowable energy limit.
- If your machine is equipped with a centering device, we do not recommend that you use it to center specimens when performing low temperature testing. Instead, we recommend the use of centering tongs as described in the current ASTM Standard E 23. The centering tongs should be cooled with the specimens.
- Verify temperature-measuring equipment at least twice annually. The measurement equipment can be checked immediately before the test by checking a medium with a constant temperature such as dry ice [−78.6 °C (−109.3° F)] or ice water [0.0 °C (32.0° F)].
- When testing super-high energy level specimens or other ductile materials, the anvils should be checked between each test for material left by the previous test.
- When the anvils are replaced it is recommended that practice specimens be broken before NIST specimens are tested.

TESTING TECHNIQUE

1. Test temperature for SRM 2092 low energy and SRM 2096 high energy level specimens should be −40 ± 1° C (−40 ± 2° F).

2. Test temperature for SRM 2098 super-high energy level specimens should be 21 ± 1° C (70 ± 2° F).

3. How long were the specimens held at temperature? (NIST recommends a minimum of 10 min)

____

4. What instrument was used to remove the specimens from the bath and center them in the machine?

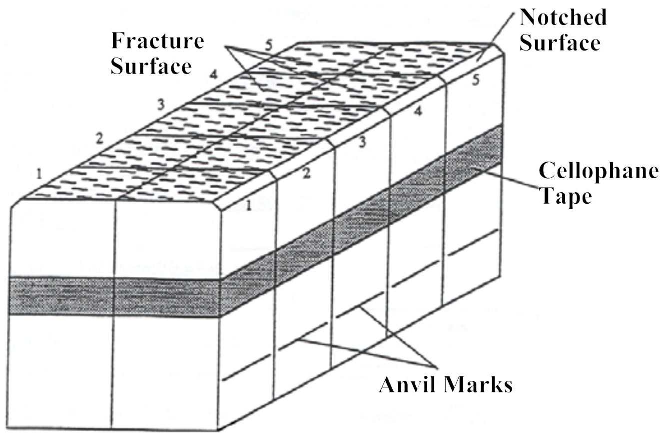
____

STATE REASON FOR VERIFICATION

1. Compliance with annual ASTM Standard E 23 Indirect Verification ____________________
2. Changed striker and/or anvils ____
3. Moved machine ____
4. Changed bearings or pendulum ____

WRAPPING INSTRUCTIONS

To expedite the evaluation of your machine, please secure the 5 broken specimens (10 halves) from a particular energy series, as one unit with **clear cellophane tape** according to the following instructions. See diagram below.



1. Keep broken halves correctly paired (back to back) with the fracture surfaces facing upward and notched surfaces facing outward.

2. Coat the **FRACTURE SURFACES ONLY** with a light coat of oil. **DO NOT** use grease or coat in plastic.

3. Include this completed questionnaire with the fractured specimens.

4. Be sure that you use the **MAILING LABEL**, provided with the specimens, and attach the label so that it is clearly displayed on the **OUTSIDE** of the package. This will expedite delivery to the Charpy Coordinator. Customers returning specimens from outside the United States should include the following statement on the U.S. Customs Declaration:

   Contents include U.S. manufactured steel test bars being returned to the U.S. for evaluation and are valued at less than 10 U.S. dollars.

Sample Test Results Report

NOTE: Use ONE questionnaire only to report the NET ENERGY RESULTS of all energy levels used to test this machine at this time.

INDICATE ENERGY UNITS (circle units used)

Joules ft·lbf

Series ________________ SRM 2092		**Series ________________ SRM 2096**		**Series ________________ SRM 2098**	
Specimen Number	**Value**	**Specimen Number**	**Value**	**Specimen Number**	**Value**
Average Value		**Average Value**		**Average Value**	

Date of Test ______________________
(Month/ Day/ Year)

Test Operator
PRINT____ Telephone
____

Test Operator
SIGNATURE_______________________________________ FAX
____

Company Representative
PRINT____ Telephone
____

Company Representative
SIGNATURE_______________________________________ FAX
____

If you require approval of your machine by the Defense Contract Management Command (DCMC), a DCMC representative should provide his or her signature and the DCMC seal to indicate that the preceding information was witnessed by a government representative.

____

Print Name of DCMC Official **Seal**

____

Signature of DCMC Official and Seal

____

DCMC Office Location

Appendix 3. Machine Performance Data

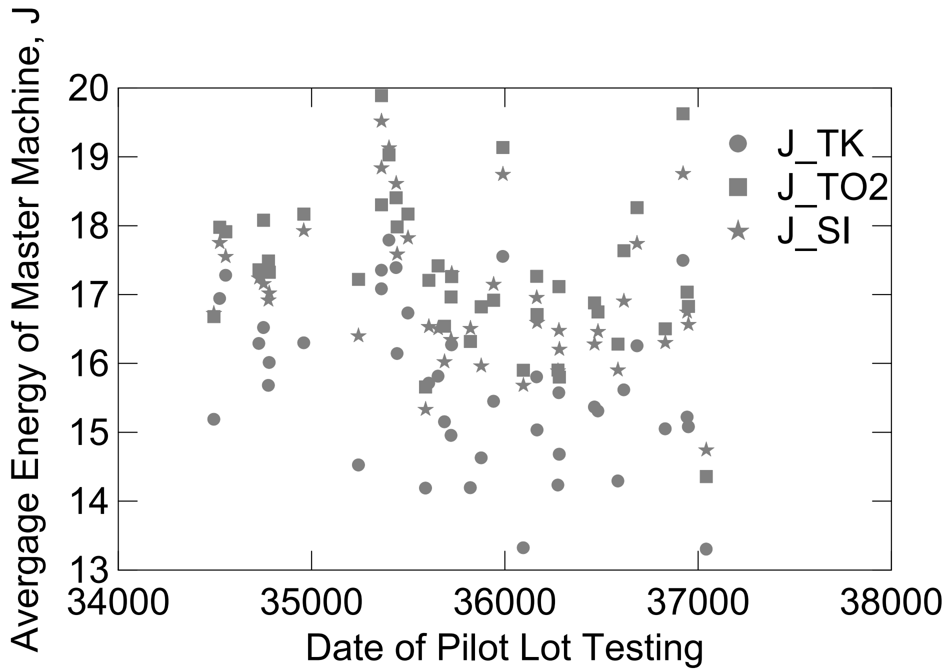


Figure A4.1.

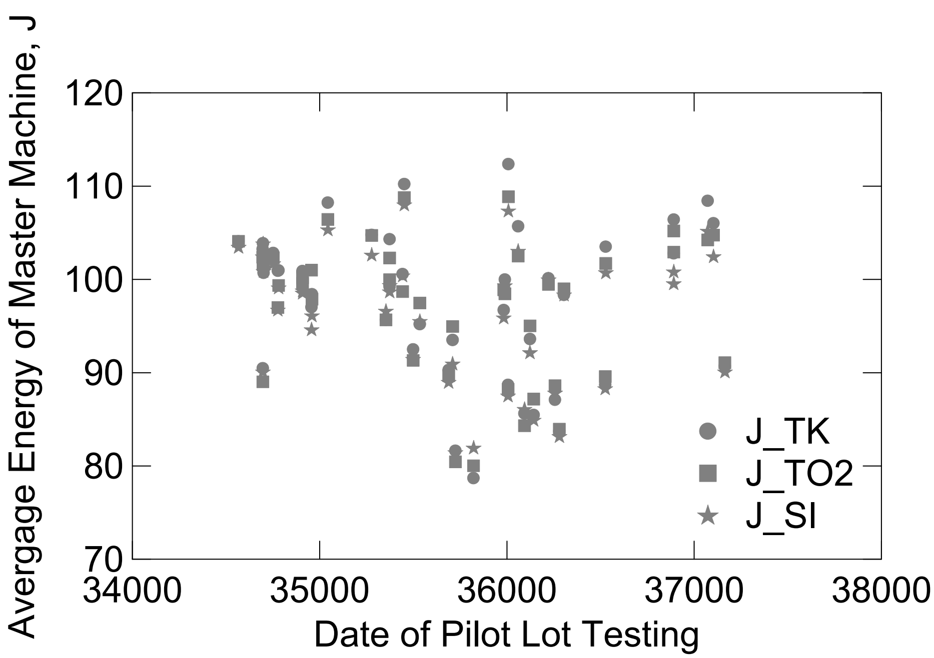


Table A4.1.

Figure A4.2.

LEVEL	Avg Energy, J	Energy_TK, J	Energy_TO, J	Energy_SI, J	STDPOOL, J	STDTK, J	STDTO, J	STDSI, J	CV
HIGH	103.89	104.08	104.10	103.47	2.34	2.65	2.48	3.21	0.02
HIGH	102.70	103.25	102.39	102.44	2.76	3.64	2.52	3.32	0.03
HIGH	89.87	90.48	89.03	90.11	2.14	2.04	2.73	2.08	0.02
HIGH	103.10	103.88	101.59	103.84	2.85	3.02	3.47	3.26	0.03
HIGH	101.09	100.71	101.67	100.90	3.31	3.85	3.87	3.13	0.03
HIGH	102.29	102.84	102.31	101.71	2.56	2.67	3.05	3.15	0.02
HIGH	98.20	100.94	96.99	96.74	2.60	3.53	2.38	2.21	0.03
HIGH	99.82	100.97	99.35	99.12	2.30	2.41	2.66	3.04	0.02
HIGH	99.76	100.90	99.57	98.81	2.73	3.56	2.43	3.74	0.03
HIGH	99.84	100.77	100.17	98.56	3.07	3.61	3.35	3.98	0.03
HIGH	97.55	97.03	101.00	94.63	2.76	3.67	2.60	2.53	0.03
HIGH	97.48	98.42	97.88	96.13	3.04	4.03	2.81	3.58	0.03
HIGH	106.67	108.23	106.44	105.35	3.04	3.96	2.85	3.92	0.03
HIGH	104.05	104.77	104.72	102.64	2.60	3.30	2.52	3.01	0.02
HIGH	95.99	95.67	95.67	96.63	2.45	2.54	3.02	2.48	0.03
HIGH	99.34	99.23	99.97	98.70	4.98	5.63	6.03	6.18	0.05
HIGH	102.00	104.32	102.30	99.38	6.02	6.93	7.27	7.86	0.06
HIGH	99.78	100.58	98.70	100.41	2.99	3.61	3.22	3.37	0.03
HIGH	109.01	110.23	108.78	108.03	3.41	3.46	4.41	3.46	0.03
HIGH	91.76	92.50	91.32	91.46	2.28	3.14	1.54	3.34	0.02
HIGH	96.07	95.21	97.47	95.53	2.78	3.26	3.00	3.53	0.03
HIGH	89.66	90.29	89.69	89.00	2.43	3.49	2.25	0.49	0.03
HIGH	93.14	93.51	94.96	90.96	3.19	3.86	3.50	3.30	0.03
HIGH	81.21	81.64	80.45	81.46	1.89	2.21	1.82	2.46	0.02
HIGH	80.05	78.69	80.02	81.95	3.40	3.83	4.02	3.72	0.04
HIGH	97.21	96.71	98.90	95.91	2.96	2.73	3.97	3.06	0.03
HIGH	99.26	99.98	98.46	99.34	1.89	2.19	1.86	2.43	0.02
HIGH	88.13	88.69	88.20	87.54	2.65	3.53	2.49	2.31	0.03
HIGH	109.52	112.37	108.87	107.38	3.25	4.27	3.12	3.80	0.03
HIGH	103.75	105.69	102.52	103.04	3.43	3.39	4.48	3.76	0.03
HIGH	85.34	85.62	84.32	86.09	2.88	2.98	3.63	2.88	0.03
HIGH	93.55	93.61	95.02	92.17	2.22	2.31	2.66	2.33	0.02
HIGH	85.82	85.46	87.17	84.94	2.08	1.72	2.78	2.31	0.02
HIGH	99.86	100.12	99.48	99.97	2.18	2.54	2.30	2.49	0.02
HIGH	87.86	87.10	88.61	87.84	2.52	3.29	2.45	2.30	0.03
HIGH	83.65	83.73	83.94	83.19	1.53	1.68	1.64	1.48	0.02
HIGH	98.57	98.34	99.00	98.37	2.17	2.36	2.39	2.87	0.02
HIGH	88.80	88.70	89.59	88.31	2.40	2.55	2.91	2.33	0.03
HIGH	101.96	103.51	101.71	100.75	2.94	2.95	3.62	4.22	0.03
HIGH	102.50	102.79	105.20	99.56	3.05	3.28	3.70	3.37	0.03
HIGH	106.97	106.42	102.93	100.84	3.37	3.69	4.18	3.09	0.03
HIGH	105.89	108.43	104.24	105.20	3.36	4.25	3.58	3.00	0.03
HIGH	104.40	106.03	104.75	102.47	2.71	2.96	3.29	2.46	0.03
HIGH	90.57	90.71	91.07	90.11	2.68	3.52	2.58	2.56	0.03
LOW	16.19	15.19	16.68	16.73	0.85	0.87	0.85	0.70	0.05
LOW	17.56	16.94	17.98	17.76	0.78	0.95	0.61	0.57	0.04
LOW	17.59	17.28	17.91	17.56	0.70	0.83	0.61	0.43	0.04
LOW	16.97	16.29	17.36	17.25	0.75	0.65	0.76	0.68	0.04
LOW	17.26	16.52	18.08	17.16	0.77	0.83	0.77	0.51	0.04
LOW	16.71	15.68	17.49	16.93	0.64	0.58	0.33	0.78	0.04
LOW	16.79	16.01	17.32	17.03	0.71	0.69	0.47	0.80	0.04
LOW	17.46	16.30	18.17	17.93	0.87	0.96	0.67	0.90	0.05
LOW	15.77	14.52	17.22	16.41	0.84	1.08	0.60	0.60	0.05
LOW	18.07	17.08	18.30	18.85	0.93	0.84	0.93	1.03	0.05
LOW	18.92	17.35	19.89	19.52	1.32	1.19	1.59	1.29	0.07
LOW	18.70	17.79	19.03	19.14	0.76	0.56	0.74	0.85	0.04
LOW	18.12	17.39	18.41	18.62	0.63	0.55	0.54	0.59	0.03
LOW	17.24	16.14	17.98	17.59	0.92	0.91	0.97	0.79	0.05
LOW	17.57	16.73	18.17	17.83	0.83	0.72	0.88	0.76	0.05
LOW	15.07	14.19	15.66	15.34	1.01	1.04	1.06	0.83	0.07
LOW	16.49	15.71	17.21	16.54	0.85	0.94	0.76	0.70	0.05
LOW	16.58	15.81	17.42	16.51	0.73	0.58	0.69	0.78	0.04
LOW	15.92	15.15	16.54	16.03	0.67	0.54	0.77	0.47	0.04
LOW	16.09	14.95	16.97	16.35	0.96	0.79	1.20	0.73	0.06
LOW	16.95	16.27	17.26	17.31	0.75	0.53	0.86	0.64	0.04
LOW	15.68	14.20	16.32	16.51	0.91	0.84	0.93	0.91	0.06
LOW	15.81	14.63	16.82	15.97	0.83	0.84	0.81	0.73	0.05
LOW	16.51	15.45	16.92	17.15	0.65	0.60	0.61	0.53	0.04

LOW	18.44	17.55	19.13	18.75	0.95	1.00	0.75	1.11	0.05
LOW	14.91	13.32	15.90	15.69	0.60	0.58	0.58	0.42	0.04
LOW	16.68	15.80	17.26	16.96	0.70	0.59	0.68	0.65	0.04
LOW	16.13	15.03	16.71	16.60	1.03	0.91	1.16	0.99	0.06
LOW	15.34	14.23	15.90	15.90	0.57	0.65	0.46	0.36	0.04
LOW	16.41	15.57	17.12	16.49	0.71	0.68	0.68	0.60	0.04
LOW	15.59	14.68	15.80	16.21	0.66	0.73	0.39	0.60	0.04
LOW	16.13	15.37	16.88	16.29	0.67	0.76	0.46	0.57	0.04
LOW	15.05	15.31	16.75	16.47	0.81	0.72	0.89	0.67	0.05
LOW	15.46	14.29	16.28	15.91	0.59	0.56	0.56	0.42	0.04
LOW	16.68	15.61	17.64	16.91	0.87	0.89	0.90	0.65	0.05
LOW	17.35	16.26	18.26	17.75	0.74	0.71	0.70	0.66	0.04
LOW	16.00	15.05	16.50	16.31	0.69	0.57	0.65	0.66	0.04
LOW	18.63	17.50	19.63	18.76	1.03	1.12	1.04	0.86	0.06
LOW	16.27	15.22	17.03	16.75	0.70	0.54	0.67	0.74	0.04
LOW	16.26	15.08	16.83	16.57	0.66	0.59	0.65	0.52	0.04
LOW	14.10	13.30	14.36	14.75	0.71	0.48	0.76	0.69	0.05
SUPERHI	222.52	223.38	219.04	225.14	6.98	8.69	7.93	7.76	0.03
SUPERHI	224.82	225.40	222.86	226.21	4.38	4.65	5.39	6.71	0.02
SUPERHI	230.78	228.58	229.89	233.86	4.02	5.22	3.85	6.48	0.02
SUPERHI	245.98	243.49	245.69	248.65	6.51	8.72	6.43	9.57	0.03
SUPERHI	227.09	224.65	227.88	228.59	6.45	9.35	5.46	7.71	0.03
SUPERHI	237.45	236.42	235.43	240.27	6.52	8.48	6.95	7.26	0.03
SUPERHI	245.45	245.30	244.25	246.91	5.98	8.08	5.82	8.21	0.02
SUPERHI	260.10	261.00	260.09	252.88	5.21	5.89	6.28	7.32	0.02
SUPERHI	209.92	203.05	219.72	206.87	6.89	8.86	7.58	6.42	0.03
SUPERHI	258.02	260.09	261.00	252.88	5.21	5.89	6.28	7.32	0.02
SUPERHI	209.88	203.05	219.72	206.87	6.89	8.86	7.58	6.42	0.03
SUPERHI	220.90	222.49	222.78	217.42	6.88	6.32	9.57	10.56	0.03
SUPERHI	227.29	226.12	225.68	230.07	7.27	8.64	8.71	8.10	0.03
SUPERHI	222.76	222.22	224.25	221.54	6.24	7.62	7.06	8.74	0.03
SUPERHI	222.76	222.22	224.25	221.54	6.24	7.62	7.06	8.74	0.03
SUPERHI	214.08	210.20	210.51	221.83	5.51	7.39	5.51	6.31	0.03
SUPERHI	205.95	206.54	200.70	210.49	5.35	6.61	6.10	5.14	0.03
SUPERHI	238.49	239.66	234.46	241.24	6.04	6.87	7.41	7.37	0.03
SUPERHI	200.79	200.19	199.41	202.69	6.23	8.37	6.26	7.21	0.03
SUPERHI	219.91	224.95	222.24	212.44	5.35	6.62	6.00	6.18	0.02
SUPERHI	220.86	221.38	220.89	220.15	6.52	8.70	6.78	5.86	0.03
SUPERHI	219.54	220.13	224.00	214.54	6.28	7.71	7.22	6.64	0.03