NIST Special Publication 260-178

Certification Report for SRMs 2112 and 2113

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

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[2]Some elements at Boulder, CO

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Contents

Introduction 1
Description of Equipment 2
    Absorbed Energy and Force Measurement 2
    Force Measurement 2
    Hardness Measurements 2
    Dimensional Measurements 3
Procurement Requirements for the Steel 3
    Compositional and melting requirements 3
    Product form 3
    Packaging 3
Specimen Production 3
    Heat Treatment of Type 4340 steel 3
    Sampling 4
    Machining 5
    Hardness Testing 5
    Impact Testing 6
Program Controls 9
    Impact Machines 9
    Measurement Equipment Used in the Verification Program 9
    Specimens 10
Appendix I 11
Appendix II 14
Appendix III 17

Certification Report for SRMs 2112 and 2113

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This report documents the procedures used to develop certified maximum force and absorbed energy values for SRM 2112 (maximum force near 24 kN) and SRM 2113 (maximum force near 33 kN). The report serves to provide outside observers with accurate and detailed information on how the materials were certified and how the impact verification program was conducted. The 2112 and 2113 SRMs have certified absorbed energy values at 21 °C and -40 °C, and a certified maximum force value at 21 °C.

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

Introduction

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.

An indirect procedure to verify the performance of the absorbed energy scale on impact machines was added about 40 years ago, because the use of direct verification procedures alone could not explain large differences among the results of impact machines. Since then, indirect verification has played an important role in identifying and reducing the differences between machines. Currently, use of instrumented impact testing machines has introduced some similar concerns for the measurement of force. The instrumented strikers are calibrated statically using a load cell, but no dynamic test to gage the overall performance of the system is performed. SRMs 2112 and 2113 are designed to simultaneously verify the performance of the force and absorbed energy scales on an instrumented impact machine at room temperature.

Description of Equipment

The impact machines used by NIST, and instrumentation on these machines, were purchased from commercial suppliers. These reference machines are used to represent the machines used by industries around the world. Details of non-NIST impact machines used in the round robin testing to determine maximum force are given in another report[1].

Absorbed Energy and Force Measurement

We have six Charpy V-notch impact machines[2] that are used for the measurement of absorbed impact energy in the program:

Machine #1 Tokyo Koki Seizosho, "C" type pendulum, 359 Joule capacity
Machine #2 Tinius Olsen, Model 74, "U" type pendulum, 358 Joule capacity
Machine #3 Satec, Model SI-1C, "U" type pendulum, 325 Joule capacity
Machine #4 Satec, Model SI-1K3, "U" type pendulum, 407 Joule capacity
Machine #5 Tinius Olsen, Model 84, "U" type pendulum, 407 Joule capacity
Machine #6 MPM, 9000 Series, “Z” type pendulum, 950 Joule capacity

Machines 1, 2, and 3 were the primary reference machines (the master machines) transferred to NIST from the Army Materials Technology Laboratory (Watertown, Massachusetts). Machine 4 has now replaced machine 3, and machine 3 is used for Izod testing. Machine 5 is an instrumented machine used for force measurement. Machine 6 is an ultra-high capacity machine. All of the impact machines are equipped with optical encoders and digital readouts.

Force Measurement

The instrumented striker and data acquisition system used on Machine 5 is a commercial system. The system can collect up to 1,000,000 data points per test, with data acquisition time ranges from microseconds up to 100 milliseconds. The system includes a computer, a high-speed 12-bit acquisition board, a strain gage amplifier, and an instrumented striker. The striker is calibrated statically using a load cell. No post-test calibration of the force is made in the NIST software (using corrections based on the absorbed energy calculated using the force-displacement curve and the absorbed energy measured with the encoder on the machine). Such post-test software calibrations were made for some of the force values reported in the round robin results.

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.

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[1] Trade names and names of manufacturers are included in several places in this report to accurately describe NIST activities. Such inclusion neither constitutes nor implies endorsement by NIST or by the U.S. government..

[2] Dynamic Force Measurement: Instrumented Charpy Impact Testing, C. M. McCowan, J.D. Splett, and E. Lucon, NISTIR 6652.

Dimensional Measurements

The notch depth, radius, angle, and centering are measured on a commercial optical comparator (50 X) prior to impact testing. The squareness of the specimens is measured with a gage described in ASTM E 23. The overall specimen dimensions are measured with digital calipers. Data from the optical comparators and the calipers are output to a personal computer.

Procurement Requirements for the Steel

Compositional and melting requirements

We used AISI 4340 steel bars, from a single heat-treated batch to minimize compositional and microstructural variation. The composition for the steel 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

This steel was produced using a double-vacuum-melting procedure (vacuum-induction-melt vacuum-arc-remelt) and meets the compositional requirements of AISI-SAE alloy 4340. The steel also meets the stricter requirements of AMS 6414, which describes steel production by a vacuum-melting procedure. In addition, the maximum percentages allowed for phosphorus, sulfur, vanadium, niobium, titanium, and copper were P = 0.010, S = 0.005, V = 0.030, Nb = 0.005, Ti = 0.003, and Cu = 0.35.

Product form

The ingots were 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 is less than 0.76 mm. The maximum acceptable grain size was ASTM number 8. In other attributes (decarburization, surface condition, etc.), the steel was suitable for use as 10 mm square Charpy V-notch specimens (the standard size ASTM E23 test specimen).

The bar was normalized at 950 °C, and hardened to approximately 35 Rockwell C (HRC). The bar was machine straightened (for twist and bow), and shipped in lengths of no less than 2 m and no more than 4 m.

Packaging

The bar was packaged in bundles that identified the ingot position from which it was processed. This identification is used to limit the material used for a given production lot to a single ingot location, which helps reduce inhomogeneities between bars.

Specimen Production

Heat Treatment of Type 4340 steel

The 4340 steel was 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 °C and 400 °C. The high energy specimens are tempered near 600 °C. The microstructure of the specimens was 100 % tempered martensite. The heat treatments originally recommended by the Army Materials Technology Laboratory are shown in **Table 2** as an example (the specific treatments use for the force specimens are not known).

Table 2. 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

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 (or more). 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, thus increasing the scatter. The effects of differences in the heat treatments between specimens, slight inhomogeneities in the steel, and other considerations also affect material quality. However, with care, good specimens can be produced using 4340 steel, and it continues to be our preferred steel for impact verification specimens.

Our experience has shown that the heat treatments recommended by the Army can give good results for small lot sizes. However, to attain results of this quality for production lots of approximately 1200 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.

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 have coefficients of variation near 0.02.

Sampling

For both the low and high energy specimens, lots of approximately 1200 specimens were heat treated, and a spatial (not random) sample of 75 specimens was removed from the heat treating baskets for pilot-

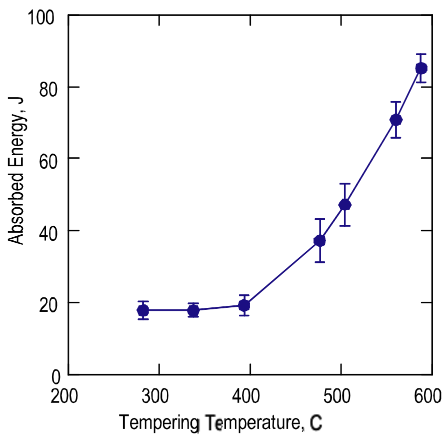

Figure 1. NIST data for 4340 verification material, 2001.

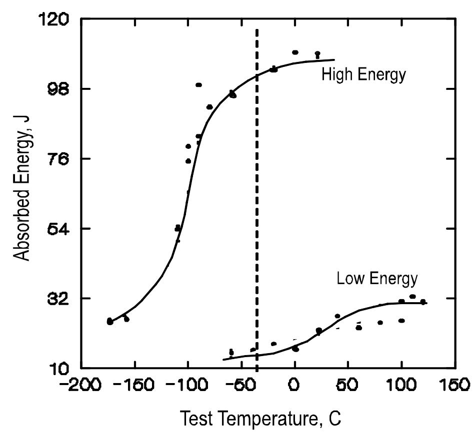

Figure 2. Transition curves for NIST 4340 steel that has been heat treated for low- and high-energy verification specimens.

lot quality evaluations. These quality check specimens were tested at -40 °C on the three reference machines (25 each) to evaluate variations in energy of the samples to their position in the heat treatment baskets. These data showed acceptable variability in energy, so the remaining specimens in the production lots were machined. When the production lots were delivered to NIST, 30 random samples were tested at -40 °C. The samples for the room temperature tests (absorbed energy and impact force) were all taken at random: 75 for the absorbed energy (divided among three NIST reference machines) and 80 for maximum force (divided among eight machines in the round robin).

Machining

Process

Prior to heat treating, the square bars are cut to approximately 56 mm long blanks and ground to finished length. One end of the specimen blank is stamped with "NIST" and the other with a series number and a serial number. The series number identifies the production lot and the energy level (LL for low energy and HH for 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. These blanks are heat-treated as a lot, and 75 to 100 blanks are machined to final dimensions for pilot lot testing (**Figure 3**).

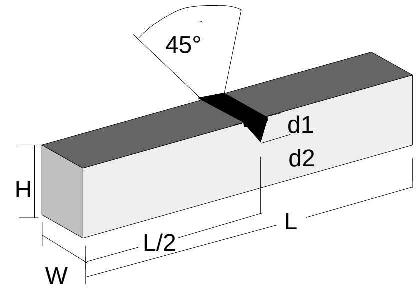

Figure 3. A Charpy V-notch sample with dimensions labeled in reference to Table 6.

Machining requirements

The dimensional requirements for NIST verification specimens, given in **Table 3**, 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 148-2, 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 148-2 requirement.

Table 3. 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 within 90 ° ± 9 min
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

Specimen notches are ground. To avoid "burning" or cold working the material at the base of the notch during grinding, 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.

Hardness Testing

Process

Two hardness measurements were 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 were averaged to estimate the hardness of the sample. Hardness is measured prior to impact testing of the specimens.

The average hardness of the SRM 2112 and SRM 2113 specimens was 31.8 HRC and 47.0 HRC respectively. The standard deviation at both energy levels was 0.4 HRC.

Requirements

The hardness criteria for verification specimens relates to three practical aspects of the impact test. (1) A minimum hardness of 44 HRC for low-energy lots ensures that 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 also ensures that the broken specimens exit the machines in a direction opposite the pendulum to check shroud performance. (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).

Impact Testing

Certified Absorbed Energy

The certified absorbed energy value was defined as the grand average of the specimens tested. All specimens tested were included in these calculations. Data used to determine average absorbed energy values for SRMs 2112 and 2113 are given in Appendix I and II.

At 21 °C

A group of 75 specimens was randomly selected from each of the low and high energy production lots and divided into three groups of 25. The groups were tested on machines 1, 2, and 5. The certified absorbed energy, at both energy levels, was calculated as the average absorbed energy for the 75 tests. The certified absorbed energy values for SRM 2113 and SRM 2112, at room temperature, are given in **Table 4**.

A -40 °C

A group of 75 of pilot-lot specimens was divided into three groups of 25 and tested on machines 1, 2, and 4. Then a randomly selected sample of 30 specimens was tested from the production lot. The average absorbed energy from these 105 specimens was used to determine the certified value of the specimens at -40 °C. The certified absorbed energy values for SRM 2113 and SRM 2112, at -40 °C, are given in **Table 4**.

Table 4: Certified absorbed energy values.

SRM	Lot	Room Temperature (21 °C ± 1 °C)		-40 °C ± 1 °C	
		Absorbed Energy, J	Expanded Uncertainty J	Absorbed Energy, J	Expanded Uncertainty J
2112	HH-103	105.3	0.6	97.5	0.6
2113	LL-103	18.2	0.1	15.3	0.1

Uncertainty calculation

Details of the uncertainty calculations for absorbed energy are given in *NIST Recommended Practice Guide 960-18, Computing Uncertainty for Charpy Impact Machine Test Results.*

Energy requirements

The most important requirement for SRM 2112 and SRM 2113 specimens is variability. The within-machine coefficients of variation for both SRM 2112 and SRM 2113 ranged between 0.03 and 0.04, which is considered low variation for impact verification specimens.

Certified Maximum Force

A round robin interlaboratory comparison was conducted to establish certified reference values for the maximum force measured for SRM 2112 and SRM 2113.[3] These SRMs provide dynamic force verification at two levels, near 25 kN and 30 kN. The specimens had already been certified by NIST for absorbed energy using conventional Charpy pendulum impact machines at room temperature, and at -40 °C. Certified maximum force values were developed at room temperature for the SRMs using the data given in Appendix III.

Testing Details for Round Robin

- ***Materials:*** Two steels (LL-103 low energy and HH-103 high energy)
- ***Specimens:*** Standard size ASTM E23 Charpy V-notch specimens (10 mm x 10 mm x 55 mm)
- ***Anvil Geometry:*** The ASTM E23 or ISO 148 anvil geometry
- ***Striker Geometry:*** Testing on either 2 mm or 8 mm radius striker geometries
- ***Machine Type:*** Testing on instrumented pendulum impact machines
- ***Test Procedure:*** Testing conducted in accordance with ASTM E23 and ASTM work item WK383 (Method for Instruments Impact Tests of Metallic Materials) or ISO 148 -1 and ISO 14556
- ***Test Matrix:*** Ten specimens at each energy level tested for each striker geometry used
- ***Test Temperature:*** Room temperature
- ***Test Time:*** Test the specimens within three months of receiving them

Participants in Round Robin

- ***Hans-Werner Viehri,*** Forschungszentrum Rossendorf
- ***Enrico Lucon***, SCK-CEN, Institute of Nuclear Materials
- ***Wolfgang Böhme,*** Fraunhofer Institute for Mechanics of Materials
- ***Harald Diem***, MPA University of Stuttgart
- ***Václav Mentl,*** SKODA Research
- ***Chris McCowan,*** National Institute of Standards and Technology

Certified Force and Uncertainty

A total of 10 specimens were tested on each of eight Charpy machines for the force verification round robin. The data were evaluated from averaged force-signals according to ISO 14556 or ASTM WK383. The raw data from the round robin are shown in Appendix III. There are a total of 90 tests, because two sets of ten verification specimens were tested with machine #8 (identified as 8a and 8b in Appendix III). The measurements for machine #8 were combined since there is no statistical difference between the averages of the two sets and no apparent trend in the data. Machine 2 and machine 8 used 8 mm strikers, the remaining machines all used 2 mm strikers. **Figures 4** and **5** display the maximum force for low-

[3] Dynamic Force Measurement: Instrumented Charpy Impact Testing, C. M. McCowan, J.D. Splett, and E. Lucon, NISTIR 6652.

energy and high-energy specimens, respectively.

The data appear to be fairly consistent among machines, with the exception of machine 4, which has test results that are much lower than the rest of the data for both low and high energies. Since machine 4 produces consistently low values, we exclude it from further analyses.

This general result shows that the static force calibration of instrumented strikers is quite robust, and that the various striker designs evaluated here performed in a predictable manner. No clear differences were observed between strikers with 2 mm and 8 mm radii.

Figure 4. Low-energy maximum force for eight machines

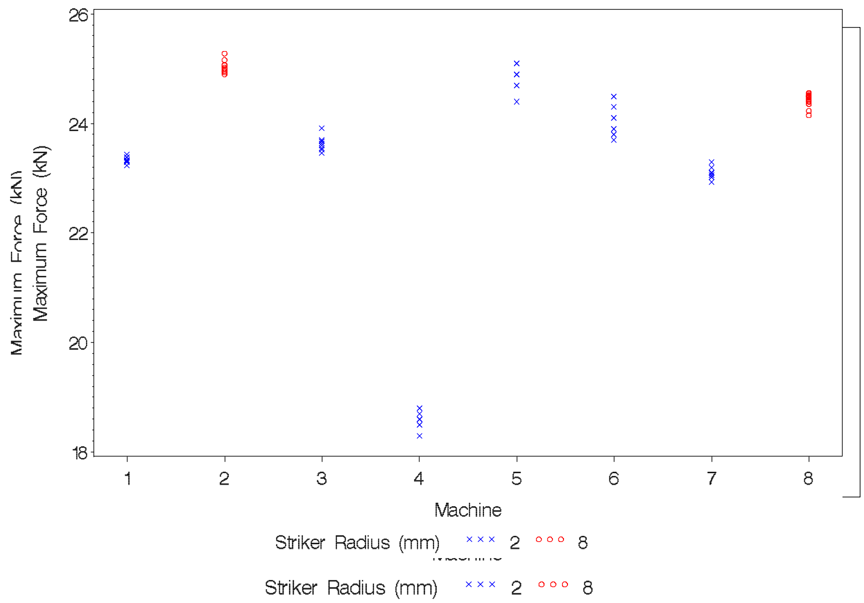

Figure 5. High-energy maximum force for eight machines.

The certified value determined for the maximum force of the low-energy SRM 2113 (LL-103) specimens is 33.00 kN. The combined standard uncertainty associated with the certified value is 0.76 kN (2.3 %), and the expanded uncertainty is 1.86 kN (5.6 %). The expanded uncertainty (based on a coverage factor, *k*, of 2.447 for 6 degrees of freedom) is associated with a 95 % uncertainty interval.

.The certified value determined for the maximum force of the high-energy SRM 2112 (HH-103) specimens is 24.06 kN. The combined standard uncertainty associated with the certified value is 0.28 kN (1.2 %), and the expanded uncertainty is 0.70 kN (2.9 %). The expanded uncertainty (based on a coverage factor, *k*, of 2.447 for 6 degrees of freedom) is associated with a 95 % uncertainty interval.

The precision of the maximum force measured for the HH-103 specimens is higher than that measured for the LL-103 measurements. The 95 % repeatability and reproducibility limits (based on procedures described in ASTM E 691-05) for the HH-103 measurements were 0.45 kN and 2.16 kN, respectively (compared with 1.90 kN and 5.96 kN for LL-103).

Table 6: Certified maximum force values.

SRM	Lot	Room Temperature Maximum Force, kN	Expanded Uncertainty, kN
2112	HH-103	24.06	0.70
2113	LL-103	33.00	1.86

Program Controls

Impact Machines

The impact machines are inspected and adjusted by NIST personnel, and experts contracted by NIST annually. 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.

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 is compared as each pilot lot is tested, and these results are compared with the past performance of the machines.[4] 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. We also compare our machines to machines at other national measurement institutes whenever possible.

We maintain a log book 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, 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) is kept and serves as source of control specimens. When a change in the relative performance of a machine is suspected, a set of control specimens can be tested and compared to the original results for this machine. Control specimens are also used to check machines following a repair.

Since we have only one instrumented machine, the performance of our striker is evaluated by static calibration, comparison with the absorbed energy scale, and comparison with other instrumented machines in round robins.

Measurement Equipment Used in the Verification Program

A commercial hardness tester, calibrated annually, is used to measure hardness. 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 equipped with a digital readout. The comparator is calibrated annually. Both the hardness tester and the optical comparator send measurements directly to a personal computer using NIST developed software.

[4] 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.

Digital calipers are used to measure specimen length, width, and thickness. The calipers are calibrated annually. 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 using the drawing in ASTM Standard E 23. The performance of the gage is checked with a calibration block, and both the gage and block are calibrated annually.

The striker on our instrumented impact machine is calibrated annually using a load cell, traceable to NIST. The calibration is typically done in a uniaxial test machine, with the striker removed from the impact machine.

Specimens

The quality and consistency of the verification specimens are first controlled by the steel used for their production. Our contractors are shipped bundles of steel bar that are coded with references 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 uniform 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 for absorbed energy scales involves a feedback loop using data from customer verification tests. Customer data are collected and stored in a database so that pass/fail ratios can easily be calculated for a lot of verification specimens that is questioned by either a customer or program administrators. If these data show normal ratios, then it is likely that 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, then it is possible that the certified energy value of the lot has changed or that the average energy determined for the lot was not an accurate estimate.

Appendix I

Table A1.1: Data used to develop the certified absorbed energy value for the SRM 2112 specimens.

Absorbed Energy J	Machine ID	Test Temperature ° C	Absorbed Energy J	Machine ID	Test Temperature ° C
17.97	TO2	21	17.82	TO3	21
17.65	TO2	21	18.75	TO3	21
17.60	TO2	21	18.54	TO3	21
18.67	TO2	21	17.69	TO3	21
17.91	TO2	21	18.20	TO3	21
18.51	TO2	21	18.68	TO3	21
19.28	TO2	21	19.08	TO3	21
17.72	TO2	21	18.41	TO3	21
19.31	TO2	21	18.53	TO3	21
18.41	TO2	21	18.05	TO3	21
18.37	TO2	21	18.07	TO3	21
17.77	TO2	21	18.68	TO3	21
19.08	TO2	21	18.26	TO3	21
18.11	TO2	21	19.02	TO3	21
18.55	TO2	21	18.43	TO3	21
18.56	TO2	21	19.16	TO3	21
19.47	TO2	21	18.56	TO3	21
18.71	TO2	21	18.36	TO3	21
18.59	TO2	21	18.64	TO3	21
17.63	TO2	21	19.21	TO3	21
18.41	TO2	21	18.62	TO3	21
19.34	TO2	21	18.25	TO3	21
17.53	TO2	21	16.66	TK	21
19.27	TO2	21	17.37	TK	21
19.08	TO2	21	17.57	TK	21
19.28	TO2	21	17.77	TK	21
19.80	TO2	21	16.76	TK	21
19.54	TO2	21	17.57	TK	21
19.80	TO2	21	16.66	TK	21
18.85	TO2	21	16.66	TK	21
18.50	TO3	21	17.37	TK	21
18.24	TO3	21	17.77	TK	21
19.24	TO3	21	18.27	TK	21

Absorbed Energy J	Machine ID	Test Temperature ° C	Absorbed Energy J	Machine ID	Test Temperature ° C
17.06	TK	21	15.05	TO2	-40
16.46	TK	21	15.56	TO2	-40
17.26	TK	21	16.08	TO2	-40
17.87	TK	21	16.86	TO2	-40
17.57	TK	21	15.91	TO2	-40
18.07	TK	21	15.65	TO2	-40
17.97	TK	21	15.56	TO2	-40
18.87	TK	21	17.03	TO2	-40
17.77	TK	21	15.82	TO2	-40
16.96	TK	21	16.94	TO2	-40
17.06	TK	21	16.25	TO2	-40
18.07	TK	21	16.62	TO3	-40
17.26	TK	21	15.66	TO3	-40
16.66	TK	21	15.37	TO3	-40
15.48	TO2	-40	16.91	TO3	-40
15.65	TO2	-40	15.96	TO3	-40
16.34	TO2	-40	15.44	SI3	-40
15.82	TO2	-40	15.08	SI3	-40
15.05	TO2	-40	15.58	SI3	-40
15.91	TO2	-40	16.15	SI3	-40
15.57	TO2	-40	15.72	SI3	-40
15.83	TO2	-40	15.44	SI3	-40
16.17	TO2	-40	15.93	SI3	-40
15.65	TO2	-40	15.15	SI3	-40
15.31	TO2	-40	16.64	SI3	-40
16.51	TO2	-40	14.87	SI3	-40
16.52	TO2	-40	16.57	SI3	-40
17.03	TO2	-40	16.00	SI3	-40
16.94	TO2	-40	15.72	SI3	-40
15.74	TO2	-40	16.08	SI3	-40
16.60	TO2	-40	15.93	SI3	-40
16.26	TO2	-40	15.58	SI3	-40
16.69	TO2	-40	15.23	SI3	-40
16.69	TO2	-40	15.44	SI3	-40
15.74	TO2	-40	16.72	SI3	-40
15.74	TO2	-40	15.58	SI3	-40
15.39	TO2	-40	15.65	SI3	-40
15.48	TO2	-40	15.58	SI3	-40

Absorbed Energy J	Machine ID	Test Temperature ° C
15.93	SI3	-40
16.36	SI3	-40
16.15	SI3	-40
16.99	SI3	-40
15.57	SI3	-40
15.08	SI3	-40
15.93	SI3	-40
16.49	SI3	-40
16.28	SI3	-40
15.93	SI3	-40
15.22	SI3	-40
16.07	SI3	-40
16.56	SI3	-40
13.81	TK	-40
14.81	TK	-40
14.91	TK	-40
14.91	TK	-40
14.51	TK	-40
14.01	TK	-40
13.51	TK	-40
14.50	TK	-40
14.01	TK	-40
15.11	TK	-40
13.21	TK	-40
14.01	TK	-40

Absorbed Energy J	Machine ID	Test Temperature ° C
14.61	TK	-40
14.61	TK	-40
14.11	TK	-40
13.51	TK	-40
14.31	TK	-40
13.51	TK	-40
13.91	TK	-40
13.31	TK	-40
13.31	TK	-40
14.01	TK	-40
14.21	TK	-40
14.20	TK	-40
13.91	TK	-40
14.91	TK	-40
14.31	TK	-40
14.51	TK	-40
13.71	TK	-40
13.91	TK	-40
13.51	TK	-40
14.61	TK	-40
14.11	TK	-40
14.11	TK	-40
13.81	TK	-40

Appendix II

Table A2.1: Data used to develop the certified absorbed energy value for the SRM 2113 specimens.

Absorbed Energy J	Machines ID	Test Temperature ° C	Absorbed Energy J	Machines ID	Test Temperature ° C
99.86	TO2	21	100.94	TO3	21
102.71	TO2	21	104.39	TO3	21
99.53	TO2	21	106.84	TO3	21
107.90	TO2	21	109.50	TO3	21
107.26	TO2	21	104.02	TO3	21
101.26	TO2	21	102.44	TO3	21
103.97	TO2	21	102.06	TO3	21
100.34	TO2	21	101.83	TO3	21
99.34	TO2	21	105.59	TO3	21
106.94	TO2	21	101.93	TO3	21
103.17	TO2	21	105.86	TO3	21
99.38	TO2	21	104.71	TO3	21
102.40	TO2	21	104.81	TO3	21
102.54	TO2	21	107.86	TO3	21
104.49	TO2	21	106.04	TO3	21
101.21	TO2	21	105.78	TO3	21
101.83	TO2	21	105.47	TO3	21
102.33	TO2	21	105.69	TK	21
104.38	TO2	21	106.42	TK	21
103.22	TO2	21	105.79	TK	21
106.79	TO2	21	110.06	TK	21
102.34	TO2	21	110.06	TK	21
101.58	TO2	21	111.72	TK	21
104.51	TO2	21	107.04	TK	21
99.83	TO2	21	102.67	TK	21
103.92	TO3	21	108.08	TK	21
101.60	TO3	21	105.48	TK	21
109.18	TO3	21	107.98	TK	21
104.33	TO3	21	111.83	TK	21
106.24	TO3	21	109.23	TK	21
102.67	TO3	21	109.64	TK	21
107.41	TO3	21	110.79	TK	21
101.74	TO3	21	107.98	TK	21

Absorbed Energy J	Machines ID	Test Temperature ° C
105.06	TK	21
107.46	TK	21
104.86	TK	21
111.31	TK	21
105.06	TK	21
112.45	TK	21
111.20	TK	21
110.89	TK	21
113.39	TK	21
103.84	TO2	-40
95.33	TO2	-40
98.45	TO2	-40
95.52	TO2	-40
95.71	TO2	-40
101.29	TO2	-40
94.58	TO2	-40
95.43	TO2	-40
101.29	TO2	-40
95.62	TO2	-40
97.13	TO2	-40
96.66	TO2	-40
99.68	TO2	-40
100.91	TO2	-40
96.84	TO2	-40
96.47	TO2	-40
102.33	TO2	-40
96.28	TO2	-40
104.12	TO2	-40
99.77	TO2	-40
98.45	TO2	-40
99.49	TO2	-40
96.28	TO2	-40
97.51	TO2	-40
95.62	TO2	-40
99.01	TO2	-40
98.63	TO2	-40
99.58	TO2	-40
96.27	TO2	-40

Absorbed Energy J	Machines ID	Test Temperature ° C
97.02	TO2	-40
101.94	TO2	-40
102.32	TO2	-40
97.87	TO2	-40
100.80	TO2	-40
100.43	TO2	-40
96.58	TO3	-40
94.01	TO3	-40
99.60	TO3	-40
95.05	TO3	-40
95.01	TO3	-40
96.83	SI3	-40
98.25	SI3	-40
94.97	SI3	-40
94.97	SI3	-40
100.75	SI3	-40
99.78	SI3	-40
96.66	SI3	-40
99.41	SI3	-40
102.62	SI3	-40
94.09	SI3	-40
93.56	SI3	-40
94.53	SI3	-40
96.03	SI3	-40
97.01	SI3	-40
100.03	SI3	-40
94.80	SI3	-40
94.35	SI3	-40
98.97	SI3	-40
95.68	SI3	-40
95.50	SI3	-40
96.66	SI3	-40
96.66	SI3	-40
94.18	SI3	-40
100.30	SI3	-40
97.63	SI3	-40
98.13	SI3	-40
94.94	SI3	-40
95.47	SI3	-40

Absorbed Energy J	Machines ID	Test Temperature ° C
95.21	SI3	-40
100.18	SI3	-40
100.45	SI3	-40
96.89	SI3	-40
96.89	SI3	-40
101.25	SI3	-40
99.02	SI3	-40
95.40	TK	-40
97.39	TK	-40
100.30	TK	-40
93.01	TK	-40
95.61	TK	-40
98.12	TK	-40
95.20	TK	-40
95.51	TK	-40
95.30	TK	-40
97.49	TK	-40
96.23	TK	-40
96.23	TK	-40
100.41	TK	-40
99.99	TK	-40
98.53	TK	-40
100.30	TK	-40
98.95	TK	-40

Absorbed Energy J	Machines ID	Test Temperature ° C
95.82	TK	-40
96.34	TK	-40
96.34	TK	-40
98.85	TK	-40
99.68	TK	-40
99.26	TK	-40
94.26	TK	-40
96.46	TK	-40
95.73	TK	-40
97.09	TK	-40
96.25	TK	-40
94.17	TK	-40
95.52	TK	-40
100.84	TK	-40
102.61	TK	-40
97.19	TK	-40
102.30	TK	-40
96.58	TO3	-40
94.01	TO3	-40
99.56	TO3	-40
95.05	TO3	-40
95.01	TO3	-40

Appendix III

Table A2.1: Data used for the certified maximum impact force values (SRM 2113 and SRM 2112).

Machine Number	Test Number	Fm (kN) Low Energy	Fm (kN) High Energy	Machine Number	Test Number	Fm (kN) Low Energy	Fm (kN) High Energy
1	1	33.12	23.39	4	8	23.00	18.80
1	2	33.14	23.44	4	9	23.20	18.70
1	3	33.03	23.32	4	10	22.90	18.80
1	4	33.06	23.31	5	1	31.70	24.40
1	5	33.31	23.38	5	2	31.90	24.90
1	6	33.07	23.24	5	3	32.20	24.70
1	7	32.89	23.30	5	4	31.90	25.10
1	8	33.11	23.32	5	5	32.20	24.90
1	9	33.36	23.30	5	6	31.90	25.10
1	10	33.44	23.33	5	7	32.60	24.90
2	1	36.65	25.06	5	8	32.20	25.10
2	2	37.58	25.16	5	9	31.90	24.70
2	3	37.00	24.93	5	10	31.70	24.90
2	4	38.32	24.90	6	1	31.90	24.30
2	5	35.72	24.96	6	2	31.80	24.50
2	6	37.17	24.96	6	3	32.80	24.50
2	7	35.89	25.07	6	4	31.40	24.10
2	8	34.00	25.00	6	5	32.10	23.90
2	9	36.05	25.02	6	6	31.20	23.80
2	10	36.33	25.28	6	7	30.70	23.70
3	1	34.90	23.60	6	8	32.30	23.90
3	2	34.81	23.52	6	9	31.80	23.80
3	3	34.96	23.68	6	10	31.20	24.10
3	4	34.21	23.68	7	1	30.42	23.30
3	5	33.60	23.91	7	2	30.24	23.10
3	6	33.42	23.46	7	3	30.09	23.02
3	7	35.30	23.64	7	4	30.40	23.11
3	8	35.01	23.70	7	5	30.25	23.03
3	9	33.06	23.55	7	6	30.57	22.94
3	10	36.31	NA	7	7	30.07	23.06
4	1	22.90	18.50	7	8	30.25	23.19
4	2	22.70	18.30	7	9	30.25	23.10
4	3	22.70	18.50	7	10	29.88	23.06
4	4	23.20	18.60	8a	1	33.35	24.40
4	5	22.70	18.60	8a	2	33.14	24.43
4	6	23.00	18.60	8a	3	32.69	24.47
4	7	22.70	18.60	8a	4	33.40	24.44

Machine Number	Test Number	Fm (kN) Low Energy	Fm (kN) High Energy	Machine Number	Test Number	Fm (kN) Low Energy	Fm (kN) High Energy
8a	5	33.23	24.50	8b	3	32.82	24.52
8a	6	32.26	24.48	8b	4	32.79	24.41
8a	7	33.53	24.15	8b	5	33.64	24.51
8a	8	33.20	24.50	8b	6	31.75	24.36
8a	9	32.59	24.48	8b	7	33.45	24.40
8a	10	31.88	24.36	8b	8	33.79	24.56
8b	1	32.54	24.23	8b	9	32.26	24.55
8b	2	33.84	24.51	8b	10	33.79	24.44

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