A Study Of The Charpy Impact Test To Determine The Correlation Between The Standard U-Notch Specimen And A Geometrically Similar Non-Standard Specimen.

A Thesis Submitted In Partial Fulfillment Of The Requirements For The Degree Of Bachelor Of Science In Chemical Engineering At The University Of Tennessee.

By

John L. Ferrell
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Foreword

Graditude is expressed to Dr. W.O Harms whose help and advice was invaluable in this investigation.

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Summary

Charpy impact tests were made on S.A.E. 1020 Steel in the annealed condition. Tests were made using both the standard U-notch specimen and a geometrically similar non-standard specimen. The testing was carried out at various temperatures ranging from 100°C to -72°C.

The energy required to break the specimens, the per cent contraction of the specimen at the base of the notch, and the per cent of fibrous fracture of each specimen were plotted as a function of the test temperature. The resulting curves indicate a close relationship between the standard specimen and the non-standard specimen in each of the three cases. In the plot of impact energy versus temperature, the curves for the different specimens indicate a transition temperature range of 0°C to -15°C for both cases. The plot of per cent contraction at the base of the notch versus temperature also yields a transition temperature range of 0°C to -15°C. In the plot of per cent fibrous fracture versus temperature, the upper limit of the transition temperature range is not so clearly defined, but the lower limit of -15°C is very clearly defined.

The purpose of these tests was to show the correlation of the Charpy impact data yielded by the two different specimens. The results obtained by the various plots indicate a very close correlation between the two specimens.

It seems reasonable to state, therefore, that for the steel tested, the non-standard specimen yeilds sufficiently valid results to be used in place of the standard specimen. Through use of the various plots, it should be possible to interpret results yielded by the non-standard speciman in terms of the standard specimen.

Introduction

The notched-bar impact test is used primarily for determining which type of steel in a particular condition is best suited for a specific application where brittle fracture under severe loading conditions is an important design factor. The test is a comparative one, and in the impact values determined are used indirectly in design calculations for structural parts.

There are several standard impact tests for notched bars, the best known of which are the Izod and the Charpy tests. The test used in the present study was the Charpy test.

There are various standard Charpy test specimens that can be used in the test. These standard specimens are precision machined with very close tolerances, and are therefore quite expensive to prepare. It would be desirable, therefore, if some cheaply prepared non-standard specimen could be used to obtain the desired information.

A non-standard test specimen geometrically similar to the standard U-notch Charpy test specimen can be made readily and with little expence from standard one-half inch square steel stock.

It is, therefore, the object of this investigation to perform Charpy impact tests at the same conditions of varying temperature on the standard U-notch specimen and the non-standard geometrically similar specimen, both made from the same steel stock, and to compare the results.

Theoretical Discussion

In the testing of ferritic steels, normal tension tests have proved unreliable in evaluating its loss of ductility at low temperatures and under triaxial stresses. Since ferritic steel is the major engineering material available today for structual purposes, its loss of ductility at low temperatures and under triaxial stresses is of major commercial importance.

It is obvious that when multiaxial stresses exist, metal cannot be tested for indications as to reliability in service by the standard unnotched uniaxial tension test. It is here that the Charpy impact test proves useful. The Charpy impact test involves the test of a specimen in the form of a notched bar tested as a beam under impact from a hammer or pendulum. The presence of the notch invalidates the test for determining straight impact behavior in that the notch localizes the stress, altering the behavior of the material. (1)

The Charpy test is sometimes called the notch-bend test emphasizing the importance of the effect of the notch. (2) In the neighborhood of the base of the notch, bending of the specimen causes the appearance of radial and transverse tensile stresses as well as of the primary longitudinal tensile stress. (2) This condition of triaxial tension raises the stress at which plastic deformation begins and tends to cause fracture with little plastic flow.

The temperature at which the Charpy test is carried out has a very marked effect for ferritic steels on the type of fracture and hence the energy required to break the specimen. As the test temperature is lowered, there is a definite temperature range in which the fracture changes from a ductile fracture to a brittle fracture. This temperature range is called the "transition temperature range" for the specimen. Ductile fractures have a fibrous appearance while the brittle fractures have a "crystalline" appearance due to the cleavage mechanism whereby the brittle fracture occurs. In the transition range there may be a relatively sharp drop in impact value, or there may be a relatatively gradual falling off of impact value toward the lower temperatures.(1) As the test temperature is lowered in the transition range, the first sign of brittle fracture is found at the center of the test specimen cross-section. With continued lowering of the test temperature, the amount of brittle fracture increases progressively until there is no sign of ductile fracture.

The transition temperature range at which this embittling effect takes place varies considerably with the size of the test specimen and with the notch geometry. The notch behavior indicated in an individual test applies only to the specimen size, notch geometry, and testing conditions involved and cannot be generalized to other sizes of specimens and conditions.(1)

The significance of the Charpy test in limited to qualitative comparisons of different specimens. The energy values determined from the Charpy test cannot be converted into energy figures that would serve for engineering design calculations.(1) Metals that yield similar impact values under similar conditions of Charpy tests, as might be expected, behave similarly.(3)

It follows that in a study of the relative behavior of, say, two different heat treatments, evaluation by Charpy impact tests would place the methods of heat treatment in their proper order. The notched-bar impact test is the only conventional test that yields information about one of the most disturbing ways of metal failure, that of brittle fracture. It is one of the few tests in which material is subjected simultaneously to triaxial tension and high strain rates. It should therefore provide guidance as to the selection of the metal for parts likely to be similarly stressed.(3) The test was developed for the common steels, but has also been used for other metals.

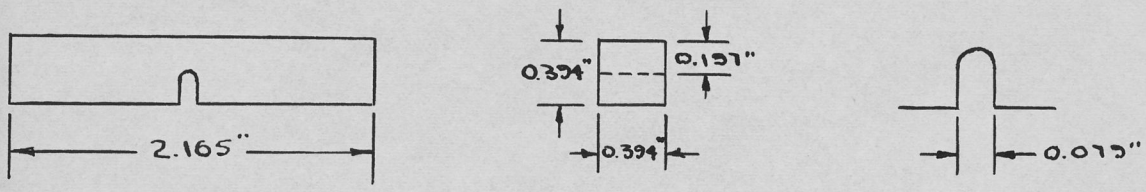
Materials and Equipment

The specimens tested in this investigation were of the U-notch Charpy type. Two sizes of specimens were tested. One was the standard U-notch Charpy specimen, and the other was the non-standard U-notch specimen. The specifications for the standard specimen are given in Figure 1. The non-standard specimens were prepared from standard one-half inch square steel stock. The notch in the non-standard specimen was made by a standard Aminco No. 5-2214 cut-off wheel of width 0.06 inches. The specifications for the non-standard specimen are given in Figure 2. Figure 3 shows the cutoff wheel used in preparing the non-standard specimens. The standard specimens were machined from the same stock which was used to prepare the non-standard specimens.

The stock from which the specimens were prepared was S.A.E. 1020 steel, cold rolled and fully annealed. Figure 4 shows the microstructure of this steel at 500X.

Thermocouples of 30 gauge iron and constantan wire fixed to each specimen near the base of the notch using the "tweezer-welder" shown in Figure 5.

The impact tester used in this investigation is shown in Figure 6.

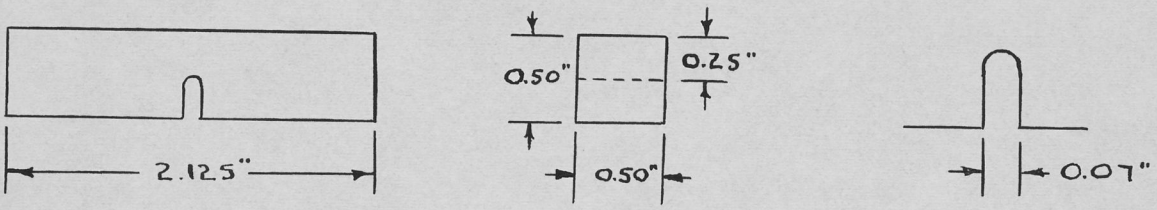


Permissible variations:

Cross-section dimensions	±0.001"
Length of specimen	±0.01"
Angle of notch	±1°

Figure 1

Standard Charpy U-notch specimen.



Variations amoung specimens prepared:

Cross-section dimensions----------±0.02"

Length of specimen ----------±0.075"

Width of notch ----------±0.01"

Figure 2

Non-Standard Charpy U-notch specimen.



Figure 3.

The cut-off wheel used to prepare the non-standard Charpy impact specimens. A piece of S.A.E. 1020 carbon steel from which the specimens were prepared is shown fixed in the vise.

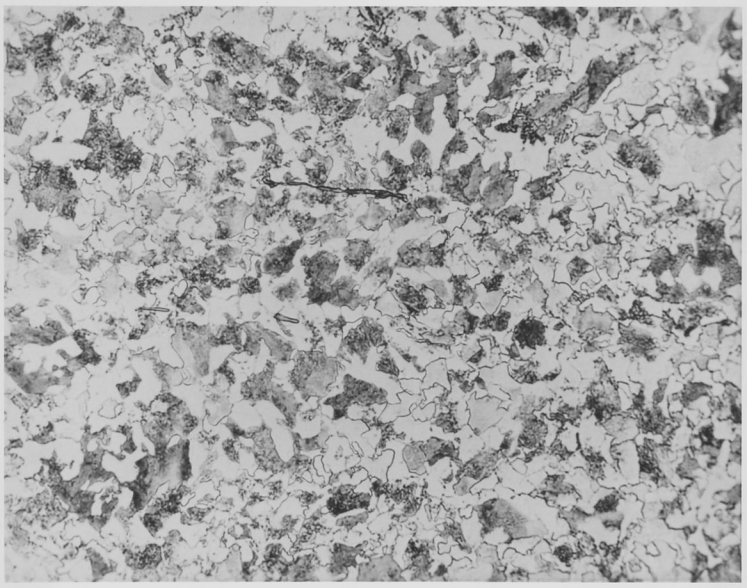


Figure 4

Microstructure of the steel from which the Charpy impact specimens were prepared. 500X

Etchant: Nital.



Figure 5

Tweezer welder used to fix thermocouples of iron and constantan to each test specimen. One of the non-standard test specimen is shown being fixed with a thermocouple.

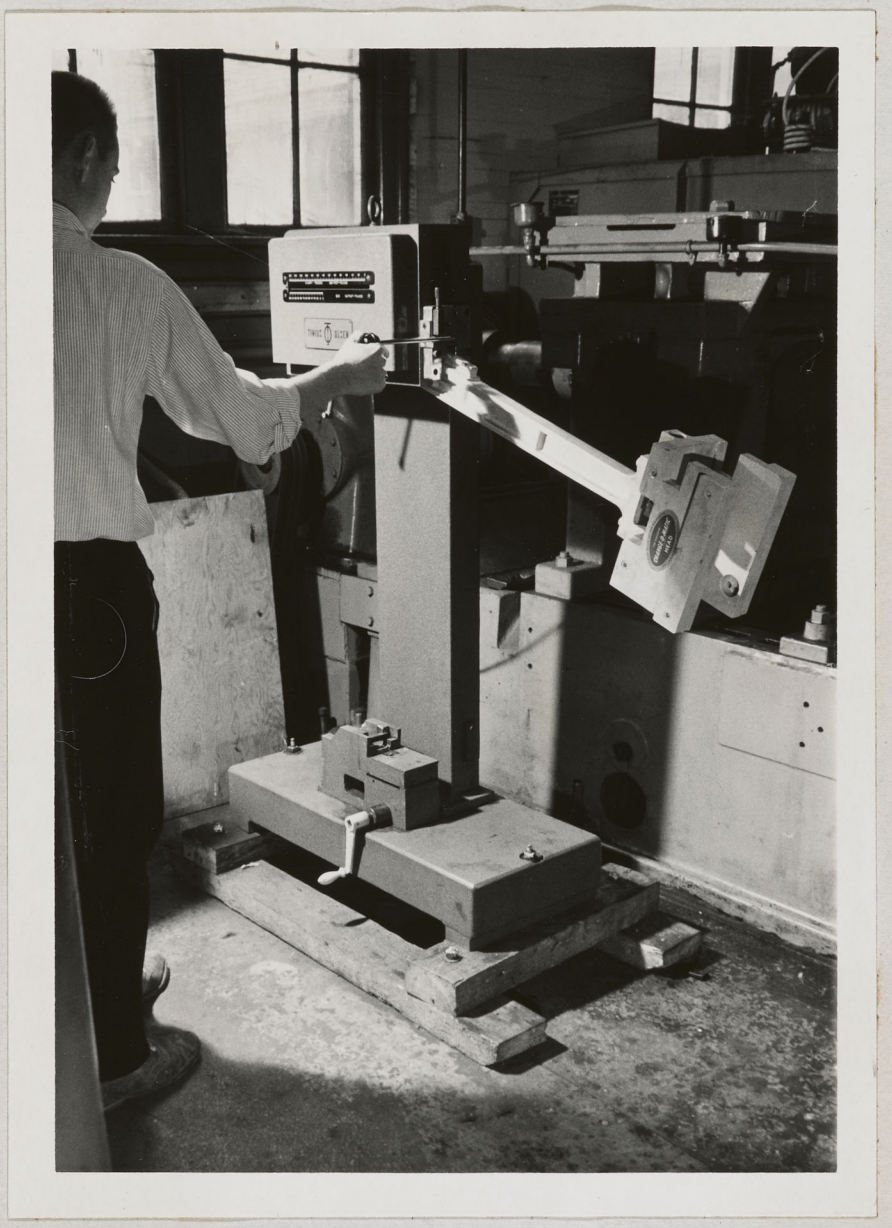


Figure 6

Tinius-Olsen impact tester. The pendulum, shown in the raised position, is used to break the test specimen placed in the anvil shown in the lower part of the apparatus. The pendulum release lever can be seen in the investigator's hand. The indicator shown in the upper part of the apparatus measures the impact energy required to break the test specimen in foot-pounds.

Experimental Procedure

The impact tests made in this investigation were carried out such that the pendulum of the impact tester delivered 120 foot-pounds kinetic energy to the test specimen. The amount of energy required to break the specimen was indicated on the scale indicator of the tester. It was noted in checking the impact tester that the scale indicator was in error by approximately two foot-pounds on the free swing of the pendulum. Since this investigation is concerned only with the relative impact values yielded by the two type specimens, the tedious job of recalibrating the scale was omitted, and two foot-pounds were added to the scale reading of each specimen. This total value was taken as the true energy required to break the specimen. The procedure for calibrating impact testers can be found in Selected ASTM Engineering Materials Standards published by the American Society for Testing Materials.

The procedure followed in determining the impact energy required to break the specimens is as follows: The specimen was placed in a bath at the desired test temperature. The various temperature baths are listed in Table I. The specimen was maintained at this temperature for approximately 30 minutes to allow the specimen to reach the equilibrium temperature of the baths, and the temperature of the specimen was measured by potentiometer readings of thermocouples fixed to each specimen. The specimen was then removed from the bath, placed in the impact tester, and broken, recording the energy required for fracture. The time allowed to remove the specimen from the bath and break it in the impact tester was five seconds. It was determined that the temperature change during five seconds was negligible.

TABLE I.

Temperature Baths

Test Temperature, $^{\circ}$ C	Baths
100° C	Boiling water
69° C	Heating water
22° C	Room temperature
11° C	Cold water
0° C	Ice water
-6° C	Ice brine soln.
-15° C	Ice brine soln.
-34.5° C	Dry ice-methyl alcohol
-72° C	Dry ice-methyl alcohol

After the specimens were broken in the impact tester the amount of contraction at the base of the notch was measured using a one-inch micrometer caliper. Photographs were taken of representative specimens at each test temperature.

Results and Discussion

The results of this investigation are presented graphically in Figures 7, 8, and 9.

Figure 7 is a plot of the impact energy required to break the specimens versus the test temperature. Figure 8 is a plot of the per cent contraction at the base of the notch versus the test temperature, and Figure 9 is a plot of the per cent fibrous fracture versus the test temperature.

Figures 10 through 18 are photographs which show the type of fracture obtained for both the standard and non-standard specimen at each test temperature.

It can be seen in Figure 7 that, as expected, the impact energy required to break the non-standard larger specimen is greater than the impact energy required to break the standard specimen at all test temperature. It can also be seen that as the test temperature is lowered the curves for the non-standard specimen and standard specimen converge, and in general the two curves have the same shape.

In Figure 8 it can be seen that the curves yielded by plotting the per cent contraction of the specimens at the base of the notch versus the test temperature are very similar for the two specimens. The curves are seen to converge at the lower test temperature. The curves also show that at each test temperature, the per cent contraction at the base of the notch was greater for standard specimen than for the larger non-standard specimen.

In Figure 9, the plot of per cent fibrous fracture versus the test temperature, the curves for the two specimens converge at the high and low test temperatures. Except where the curves converge, it can be seen that the per cent fibrous fracture is

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KEUFFEL & ESSER CO. MADE IN U.S.A.

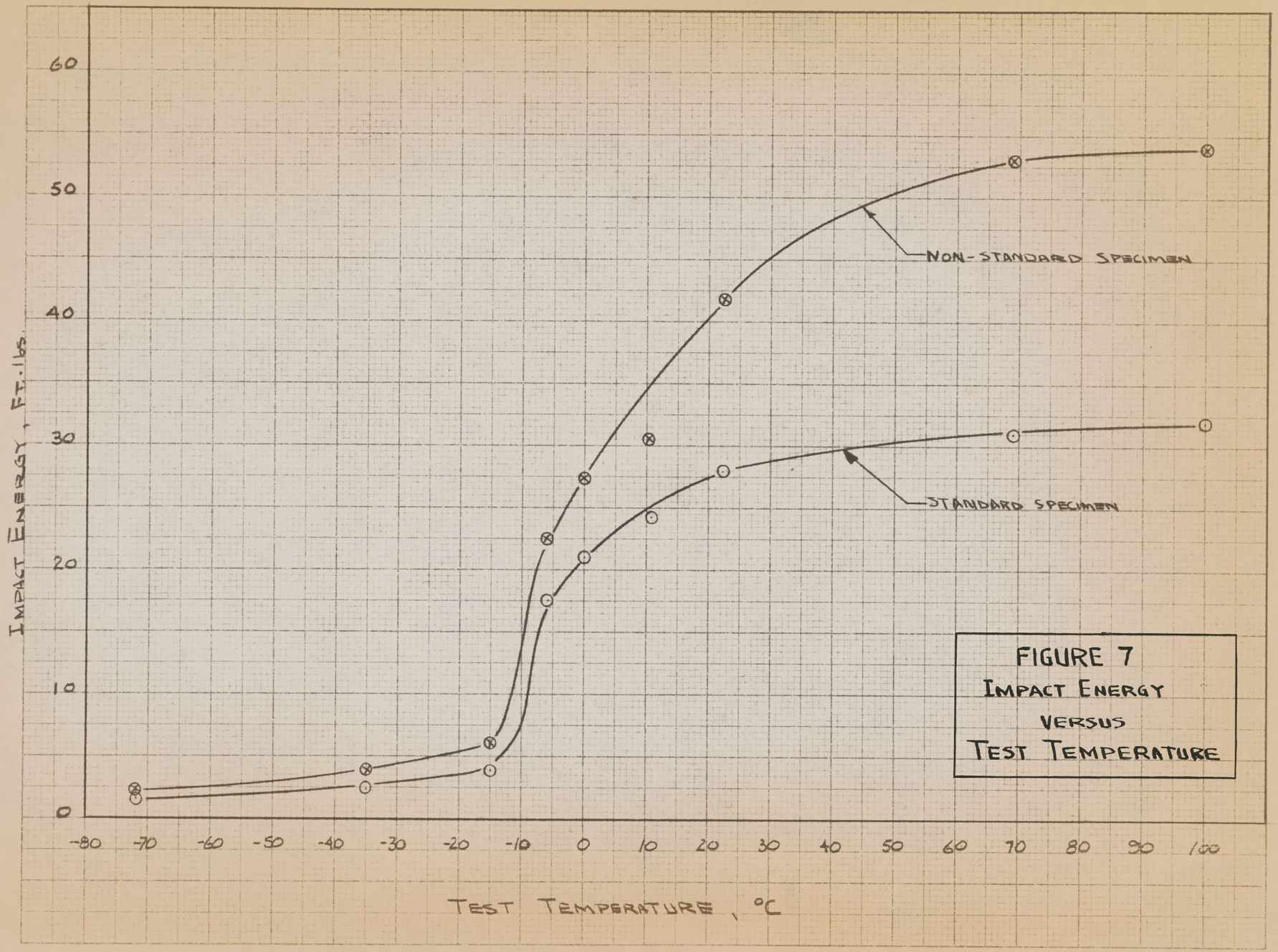

FIGURE 7
IMPACT ENERGY
VERSUS
TEST TEMPERATURE

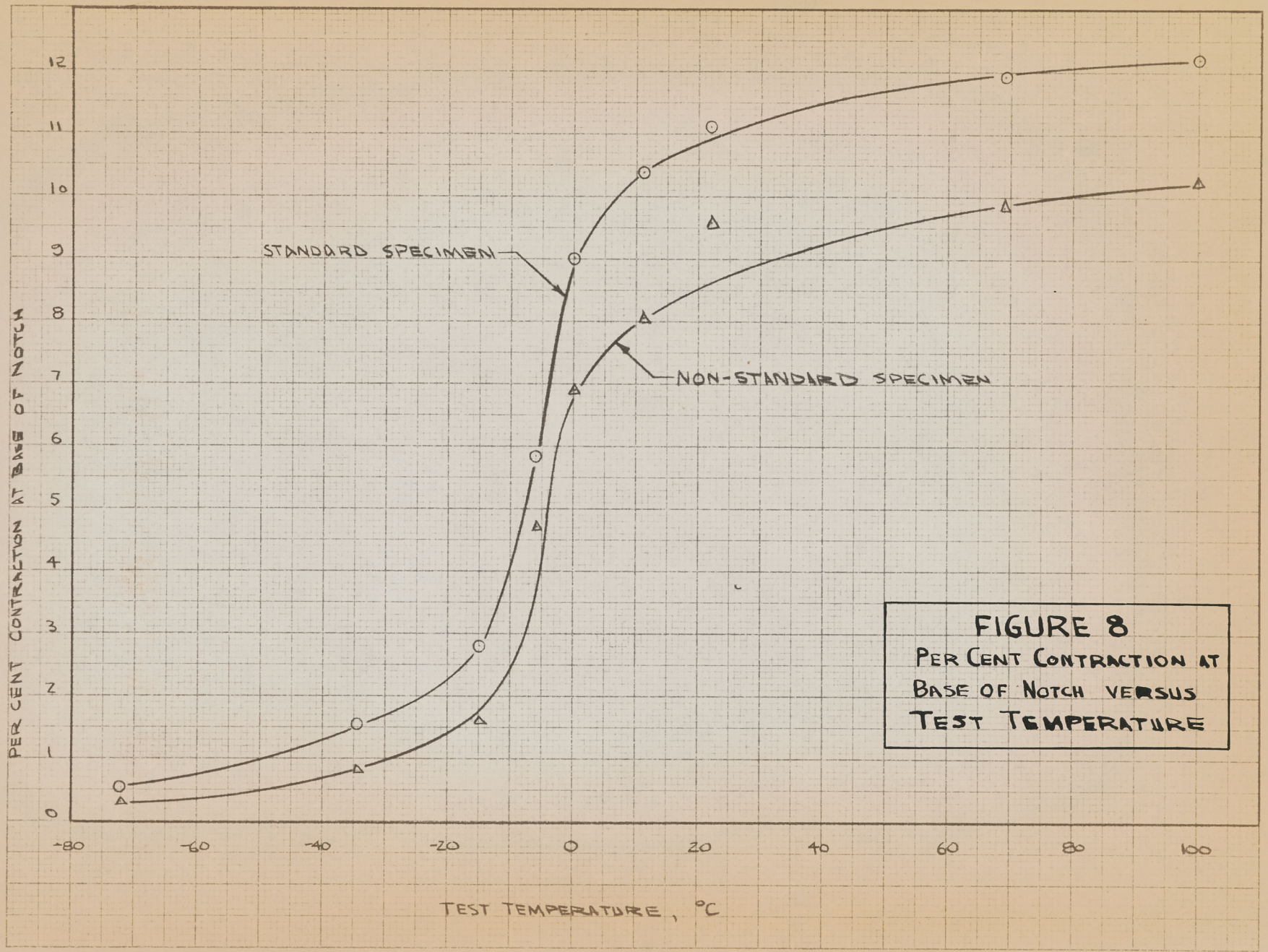

FIGURE 8
PER CENT CONTRACTION AT BASE OF NOTCH VERSUS TEST TEMPERATURE

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359-12
MADE IN U.S.A.

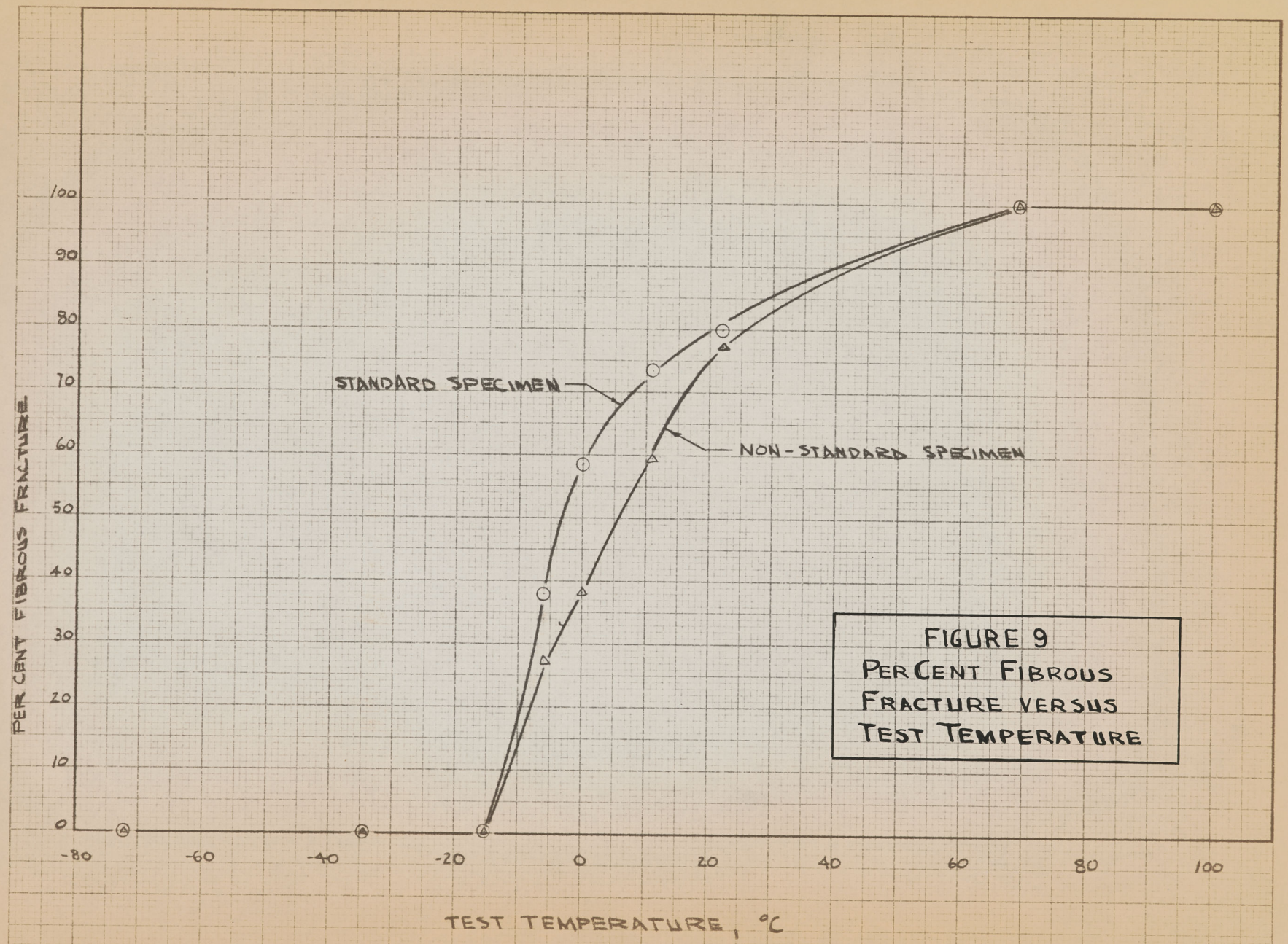

FIGURE 9
PER CENT FIBROUS
FRACTURE VERSUS
TEST TEMPERATURE



Figure 10.

Fractured ends of impact specimens tested at 100°C. The smaller specimen on the right is the standard specimen. It can be seen that the fracture obtained for each specimen is completely fibrous, indicating completely ductile fracture. 6X

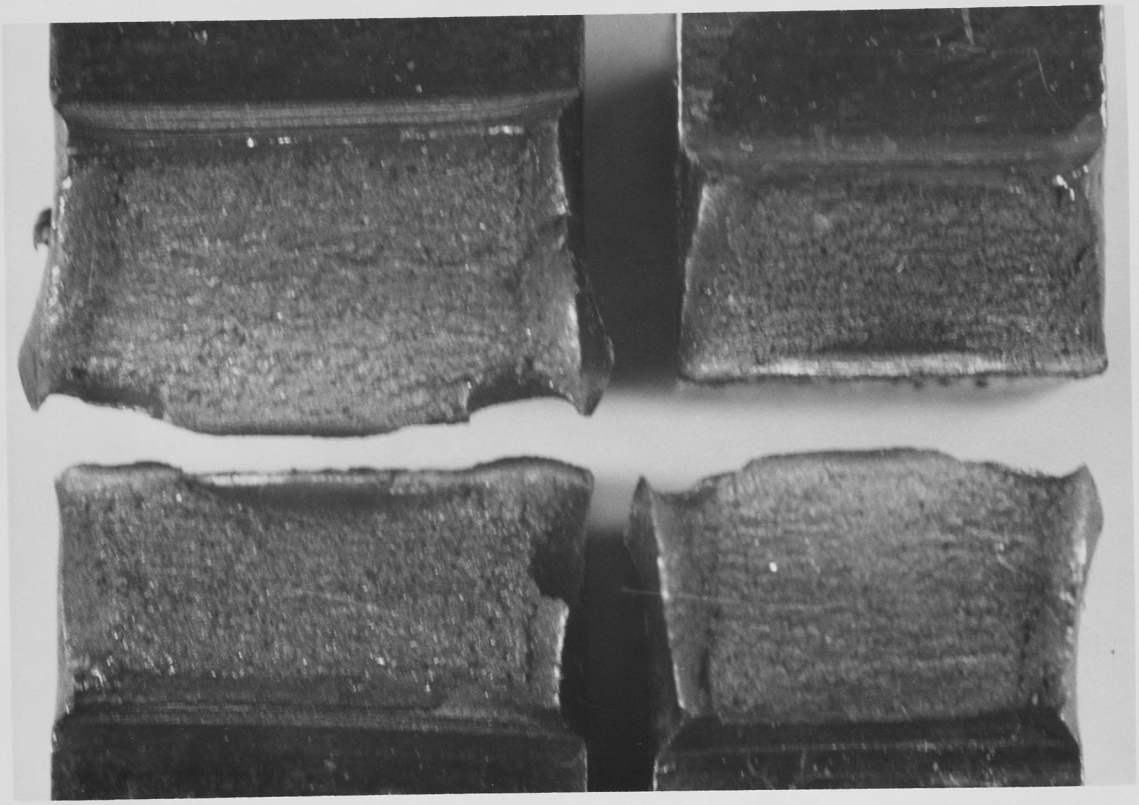

Figure 11.

Fractured ends of impact specimens tested at 69°C. The smaller specimen on the right is the standard specimen. Completely fibrous fracture is shown for both specimens at this test temperature, indicating completely ductile fracture. 6X

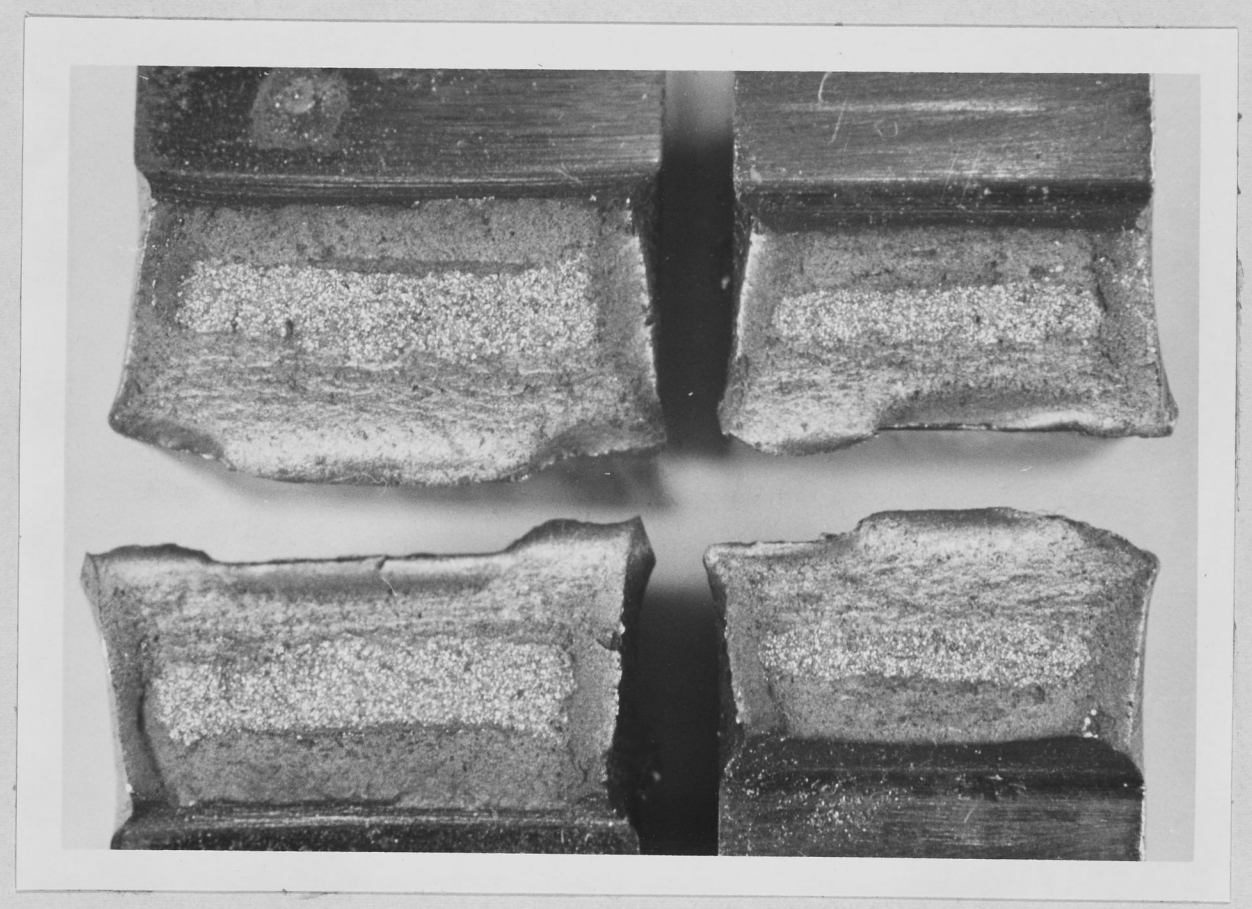

Figure 12.

Fractured ends of the impact specimens tested 22°C. The smaller specimen on the right is the standard specimen. At this test temperature, first signs of crystalline fracture were noted indicating the transition from ductile to brittle fracture. The crystalline type fracture can be seen in the center of the fractured ends. 6X



Figure 13.

Fractured ends of the impact specimens tested at 11°C. The smaller specimen on the right is the standard specimen. The crystalline appearance noted in the center of the fracture surfaces indicates brittle fracture while ductile fracture is indicated by the surrounding fibrous appearance. 6X

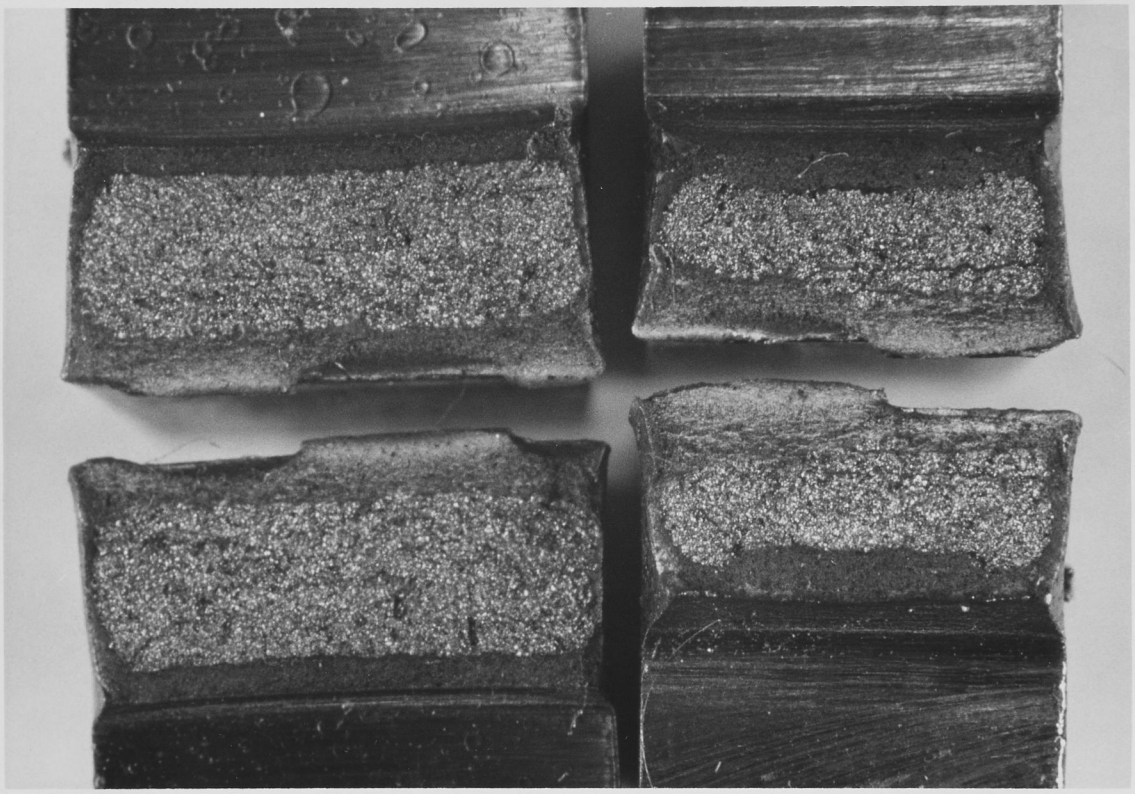

Figure 14.

Fractured ends of the impact specimens tested at 0°C. The smaller specimen on the right is the standard specimen. The crystalline appearance indicates brittle fracture and the surrounding fibrous appearance indicates ductile fracture. 6X

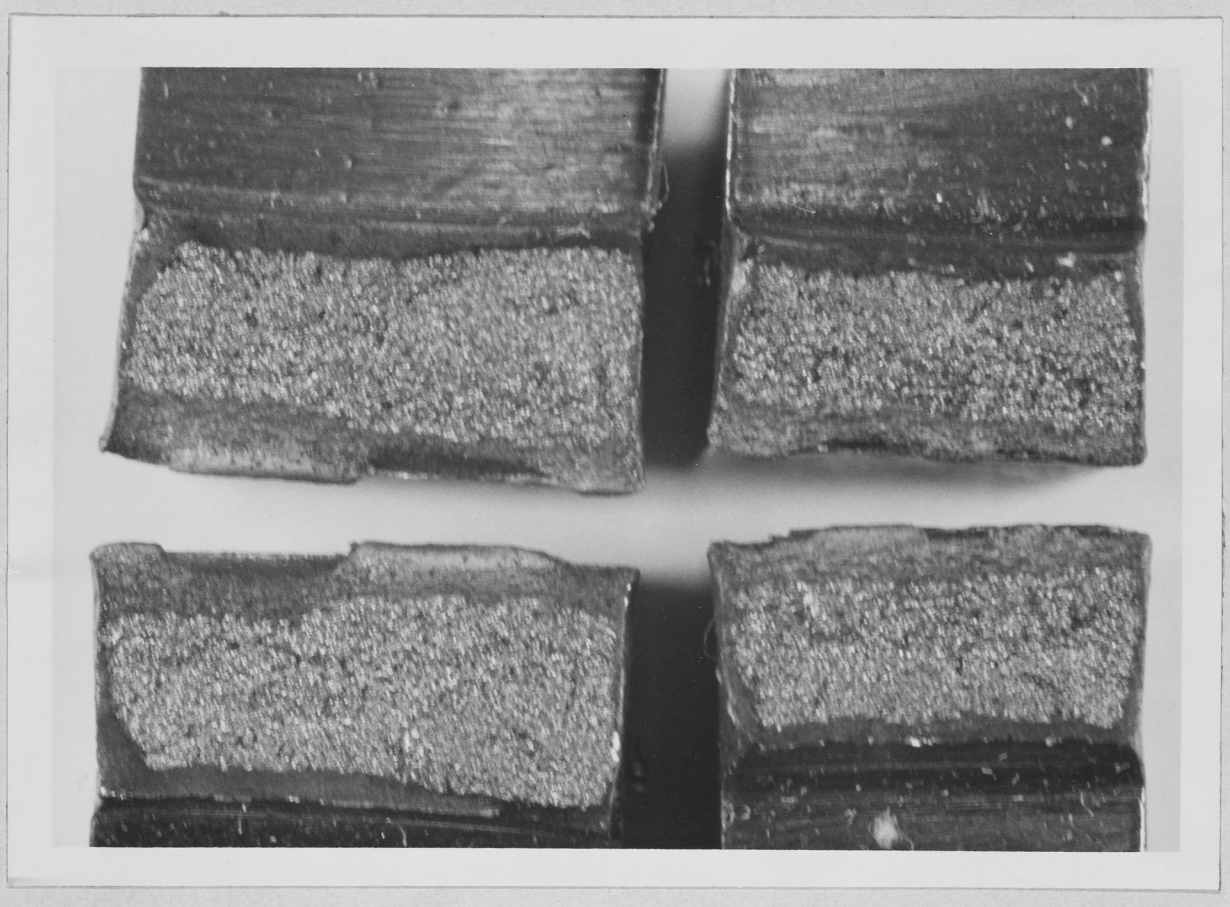

Figure 15.

Fractured ends of the impact specimens tested at -6°C. The smaller specimen on the right is the standard specimen. The crystalline appearance seen to dominate the fracture surface is indicative of brittle fracture, and the surrounding fibrous appearance indicates ductile fracture. 6X

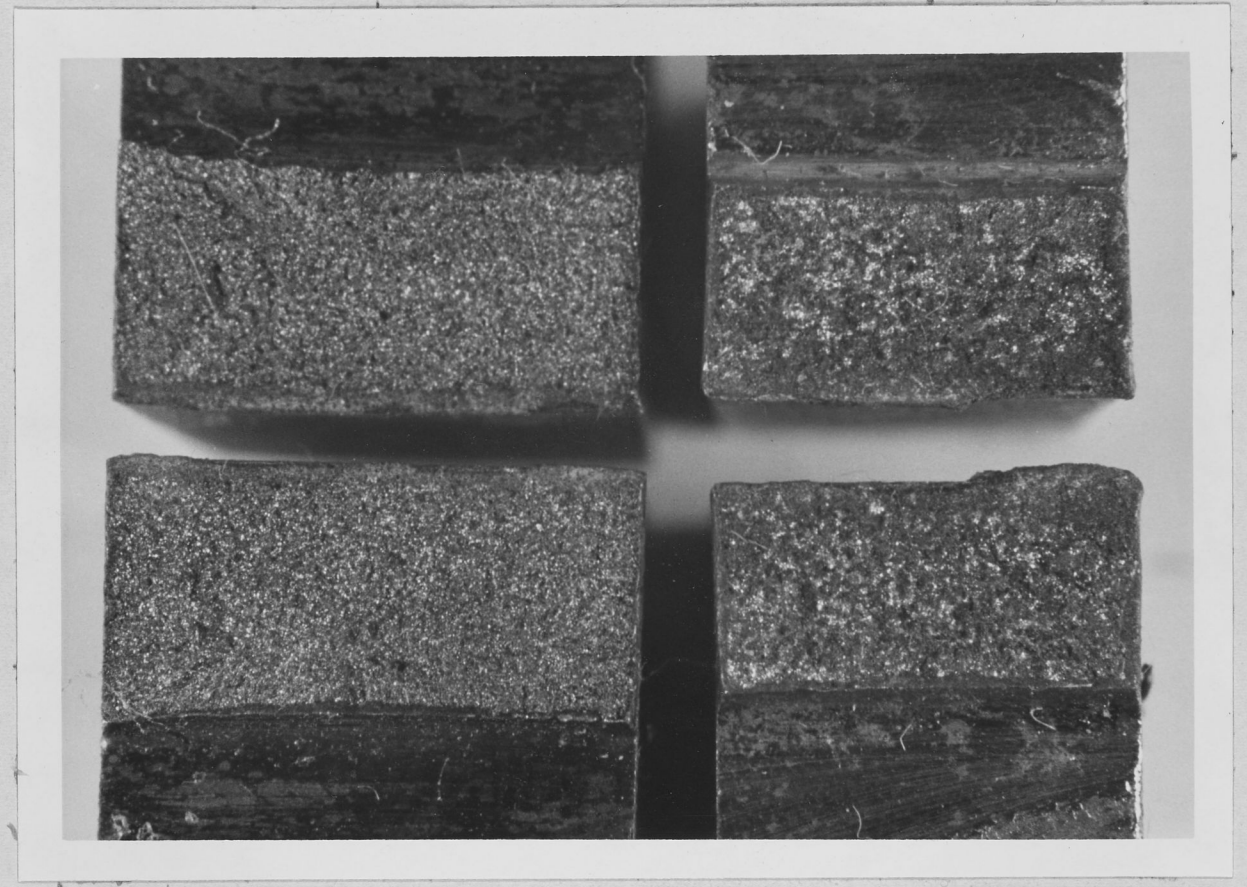

Figure 16.

Fractured ends of the impact specimens tested -15°C. The smaller specimen on the right is the standard specimen. As can be seen, the fracture appearance is completely crystalline indicating brittle fracture. 6X

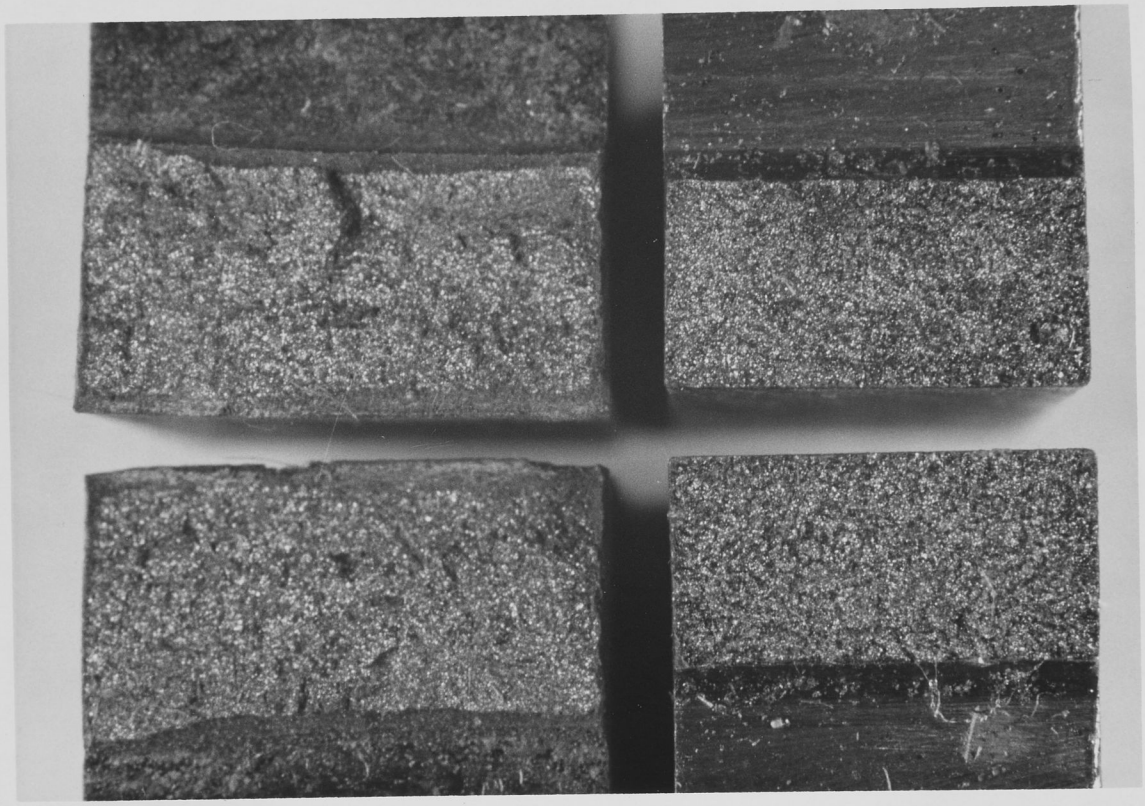

Figure 17.

Fractured ends of the impact specimens tested at -34.5°C. The smaller specimen on the right is the standard specimen and the larger is the non-standard specimen. Completely brittle fracture is indicated for both specimens by the crystalline appearance of the fracture surfaces. 6X

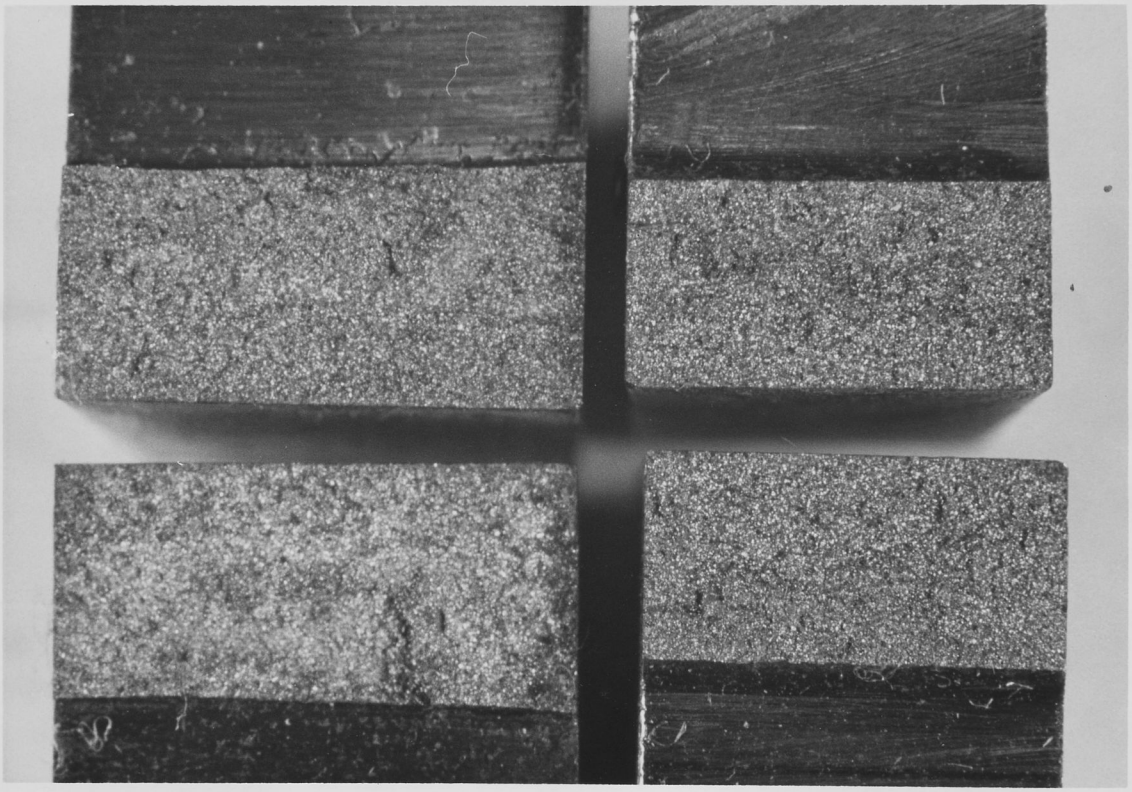

Figure 18.

Fractured ends of the impact specimens tested at -72°C. The smaller specimen on the right is the standard specimen. As indicated by the smooth crystalline appearance, the fractures obtained at this temperature are completely brittle. 6X

greater for the standard specimen than for the non-standard specimen.

A transition temperature range of 0°C to -15°C for both specimens is indicated by the plot of impact energy versus temperature in Figure 7 and by the plot of per cent contraction at base of notch versus temperature in Figure 8. In Figure 9, the plot of per cent fibrous fracture versus temperature, the upper limit of the transition temperature range is not so clearly defined as in the other plots, but the lower limit of -15°C is very clearly defined.

From the results of this investigation, it may be concluded that there is a close correlation of the Charpy impact data yielded by the standard and non-standard specimens, and that the evaluation of different steels in different conditions can be accomplished with equal validity using the non-standard specimen instead of the standard specimen. It may be further concluded that although the energy required to break the non-standard specimen is greater than that required to break the standard specimen, the per cent contraction at the base of the notch is greater for the standard specimen than for the non-standard specimen, and that the per cent of fibrous fracture is greater for the standard specimen than for the non-standard specimen except at high and low temperatures where the curves converge.

Although there is insufficient proof from this investigation, it seems reasonable to conclude that transition-temperature data yielded by the non-standard specimen can by interpreted in terms of the standard specimen through use of the three types of plots.

For example, say a different steel is tested using the non-standard specimen, and values of impact energy, per cent fibrous fracture, and per cent contraction at the base of the notch are plotted on the respective plots included in this report; then from the relative positions of the three curves of each plot, one should be able to construct a pseudo-standard specimen test curve for the different steel for each plot.

It is recommended that such an investigation as just described be carried out and that the pseudo-standard specimen test curves be compared with those actually yielded by the standard specimen.

Selected Bibliography

(1) Selected ASTM Engineering Materials Standards, Published by American Society for Testing Materials, Baltimore(1956).

(2) Guy, Abert G., Elements of Physical Metallurgy, Addison-Wesley Publishing Co. Reading Mass. (1956).

(3) Teed, P.L., The Properties of Metallic Materials at Low Temperatures Volume I, John Wiley & Sons, Inc. New York (1950).

(4) Foster, P.F., The Mechanical Testing of Metals and Alloys, Sir Isaac Pitman & Sons, Ltd. London (1942).

(5) Queneau, B.R., The Embittlement of Metals, Published by American Society for Metals, Cleveland (1956).

(6) Brick, Low, and Lorig, Behavior of Metals at Low Temperatures, Published by the American Society for Metals, Cleveland (1953).

APPENDIX

Table II.

Charpy Impact Data For Standard Specimens.

No.	Potentiometer Reading Millivolts	Test Temperature °C	Impact Energy Absorbed, Ft.-Lbs.
1.	---	22	26
2.	---	22	28
3.	---	22	28
4.	4.12	100	32
5.	4.12	100	32
6.	4.12	100	34
7.	2.50	69	31
8.	2.50	69	30
9.	2.50	69	31
10.	-1.13	0	21
11.	-1.13	0	21.5
12.	-1.13	0	21
13.	-1.90	-15	3
14.	-1.90	-15	4
15.	-1.90	-15	10
32.	-1.90	-15	4
16.	-4.60	-72	1.5
17.	-4.60	-72	1.5
18.	-4.60	-72	1.5
22.	-2.80	-34.5	2.0
23.	-2.80	-34.5	2.5
24.	-2.80	-34.5	2.0
25.	-0.66	11	24
26.	-0.66	11	25
27.	-0.66	11	25
28.	-1.50	-6	19
29.	-1.50	-6	15
30.	-1.50	-6	17
31.	-1.50	-6	-18

Table III.

Charpy Impact Data For Non-Standard Specimens.

No.	Potentiometer Reading Millivolts	Test Temperature °C	Impact Energy Absorbed, Ft.-Lbs.
1.	---	22	42
2.	---	22	45
3.	---	22	40
4.	4.12	100	58
5.	4.12	100	54
6.	4.12	100	52
7.	2.50	69	61
8.	2.50	69	53
9.	2.50	69	53
10.	-1.13	0	29
11.	-1.13	0	25
12.	-1.13	0	26
13.	-1.90	-15	7
14.	-1.90	-15	5
15.	-1.90	-15	6
16.	-4.60	-72	2
17.	-4.60	-72	2
18.	-4.60	-72	2
19.	-2.80	-34.5	4
21.	-2.80	-34.5	5
22.	-2.80	-34.5	4
23.	-0.66	11	32
24.	-0.66	11	30
25.	-0.66	11	27
29.	-1.50	-6	21
30.	-1.50	-6	22
32.	-1.50	-6	24

Approval

The foregoing Thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not endorse or approve any statement made, opinions expressed, or conclusions drawn therein but approves the Thesis only for the purpose for which it is submitted.

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