WATERTOWN ARSENAL
WATERTOWN 72, MASS.

AD

A950343

WAL TR 112/95

WATERTOWN ARSENAL LABORATORIES

SUBSIZE CHARPY CORRELATION WITH STANDARD CHARPY

TECHNICAL REPORT NO. WAL TR 112/95

BY

CHARLES H. CURLL

DECEMBER 1959

O.O. PROJECT: INDUSTRIAL PREPAREDNESS MEASURE - DEVELOPMENT OF SUBSIZE CHARPY STANDARD
P.E.S.D. NO.: 70304231-15-42606

WATERTOWN ARSENAL
WATERTOWN 72, MASS.

AD

Impact tests
Charpy, subsize

(6)

SUBSIZE CHARPY CORRELATION WITH STANDARD CHARPY.

(9) Technical Report No. (14) WAL-TR-112/95

(12) 33

By

(10) Charles H. Curll

(11) December 1959

O.O. Project: Industrial Preparedness Measure
Development of Subsize Charpy Standard
P.E.S.D. No.: 70304231-15-42606

WATERTOWN ARSENAL
WATERTOWN 72, MASS.

WATERTOWN ARSENAL LABORATORIES

TITLE

SUBSIZE CHARPY CORRELATION WITH STANDARD CHARPY

ABSTRACT

To provide a means of impact acceptance testing of specimens which must be obtained from thin or small diameter sections, a study was made, using various specimen sizes, of the Charpy V notch impact properties of steels over a range of temperatures encompassing transitions from ductile to brittle behavior.

The test data tend to verify a previously established nonlinear correlation between selected subsizes above the transition range and further indicate a linear correlation between the energy required to fracture standard-size and subsize V notch Charpy specimens at the normal acceptance testing temperature of -40°C.

Further engineering data, needed to incorporate requirements in a specification, are currently being obtained.

Charles H. Curll
CHARLES H. CURLL
General Engineer

APPROVED:

J. F. Sullivan
J. F. SULLIVAN
Director
Watertown Arsenal Laboratories

REPORT APPROVED
Date 12/30/59
WAL Board of Review
Chairman

INTRODUCTION

With the advent of thin-walled cylinders for rockets and tubes, it has become necessary to provide a means of impact testing materials from such sections for Ordnance acceptance purposes. Because it is not possible to obtain standard-size Charpy impact specimens from thin sections, a correlation between the energies to fracture standard and subsize Charpy V notch impact specimens needs to be established. It is the purpose of this report to develop a correlation between selected subsize and standard-size Charpy V notch impact specimens.

A previous investigation on size relationships in the impact test by Curll and Orner[1] developed a nonlinear correlation based upon data taken from above the transition zone. The current investigation tends to verify the previous relationship obtained.

This report describes the materials used, the experimental work done, and illustrates the graphs developed. It further develops an analytical correlation (using a reference to the Law of Similitude by Sachs[2] and the reduction of deformation) between the energy to fracture the standard and subsize Charpy V notch impact specimens.

MATERIALS

The following materials were used in this investigation:

1. AISI-2340 Modified Steel
2. AISI-3140 Modified Steel
3. AISI-4042 Modified Steel
4. AISI-4140 Steel
5. Class 90 Steel
6. Nickel Steel

CHEMICAL ANALYSES (% by Weight)

No.	Material	C	Mn	Si	S	P	Ni	Cr	Mo	V	Cu
1	2340	.43	.78	.24	-	-	1 78	.07	Trace		
2	3140	.44	1.11	.21	-	-	2.56	.96	Trace		
3	4042	.44	.73	.19	-	-	Trace	.03	.33		
4	4140	.38 - .43	.40 - .60	.20 - .35	.04	.04		.80 - 1.10	.15 - .25		
5	Class 90	.17	.33	.23	.03	.04	2.13	.97	.22	.03	.057
6	Ni Steel	.14	.50	.23	.04	.017	3.30				

NOTE: 1. Dash means analysis not made.
2. Chemical analyses for materials in Figures 2, 3, and 4 may be found in Reference 1.

The three steels designated "modified" were made in thirty-pound ingots in the Watertown Arsenal Laboratories melt laboratory. The modifications were made on the Ni, Cr, and Mo Contents.

The AISI-4140 steel was received as 5/8-inch-square rod. The class 90 steel was received as 5/8-inch-thick plate. The data on the nickel steel were obtained from a different investigation.[8] The three modified steels were obtained as ingots and homogenized at 2150°F for four hours. The AISI-3140 was air-cooled and normalized at 1600°F for four hours while the AISI-2340 and 4042 were furnace-cooled and homogenized at 1650°F for four hours to permit easier removal of the riser. The as-cast billets were hot-worked at 2000°F to the following schedule:

1. Heated for two hours.
2. Forged on 200-ton press to 1-5/8-inch-square bar in two reductions.
3. Hot rolled to 1/2" x 2-3/4" bar stock in two reductions.
4. Air cooled.

The materials received the following heat treatments:

1. AISI-2340

Normalize	1600°F	2 hrs.	Air Cool
Reheat	1475°F	2 hrs.	Agitated Oil Quench
Draw	1200°F	2 hrs.	Oil Quench

2. AISI-3140

Normalize	1600°F	2 hrs.	Air Cool
Reheat	1525°F	2 hrs.	Agitated Oil Quench
Draw	1100°F	2 hrs.	Oil Quench
Redraw	1200°F	2 hrs.	Oil Quench

3. AISI-4042

Normalize	1600°F	2 hrs.	Air Cool
Reheat	1550°F	2 hrs.	Agitated Oil Quench
Draw	1000°F	2 hrs.	Oil Quench

4. AISI-4140

Normalize	1600°F	1 hr.	Air Cool
Reheat	1550°F	1 hr.	Oil Quench
Draw	1000°F	½ hr.	Oil Quench

The class 90 steel was used in the as-received condition (quenched and tempered), but the heat treat was not available. The materials had the following Rockwell hardness:

	R_c	R_b
1. AISI-2340		99
2. AISI-3140	26.2	
3. AISI-4042	33.8	
4. AISI-4140	38.3	
5. Class 90 Steel	22.7	
6. Nickel Steel		82

The various specimen sizes (Figure 1) used in this investigation were selected as a result of the previous report by the author (Reference 1) with additional sizes to verify the theory presented in this report. The specimens of AISI-4140 were longitudinal and all others were transverse. The nickel steel data obtained from another investigation (Reference 3) add to the verification by use of a double-size specimen.

TEST PROCEDURE

V notched Charpy bars in various sizes, ranging from double size to one-quarter size (cross-sectional area measurement)(Figure 1), were tested over a range of temperatures encompassing their transitions from ductile to brittle behavior. All specimens were broken in a conventional manner on a Sonntag impact testing machine (capacity 240 ft-lb; pendulum velocity 16.8 ft/sec). Special anvils and shims were provided to maintain the point of impact at the center of percussion of the pendulum when nonstandard specimens were tested. For the shorter-length specimens, the anvil span was shortened to a distance of 0.787" from the normal span of 1.574". There is one exception to the above technique. The data for the double-width, half-depth specimen of the nickel steel were obtained from Reference 3.

TEST RESULTS AND DISCUSSIONS

Tables I through VI list testing temperatures, averaged energies absorbed (generally three at each temperature with one to two tests at extremely low temperatures), and percentages of fibrosity in the fractured faces. The energy versus temperature data are presented graphically in Figures 2 through 10. The graphs of Figures 2, 3, and 4 were taken from a previous report.[1]

In order to verify the previously established correlation, the data from the curves of Figures 5 through 9 (taken at their respective transition temperatures* as indicated in the tables) were plotted on the established correlation curves (Figure 11) and gave the following results:

1. 1/2 Size:

An average error of 0.62 ft-lb with a single maximum error of 1.75 ft-lb.

*Transition temperature is defined as the lowest temperature at which the specimen breaks with a 100% fibrous fracture.

2. <u>1/3 Size</u>:

An average error of 0.52 ft-lb with a single maximum error of 1.25 ft-lb.

3. <u>1/4 Size</u>:

An average error of 0.50 ft-lb with a single maximum error of 1.25 ft-lb.

Although these results tend to verify the correlation, the actual use of the relationship is limited to the 100% fibrous zone of the standard size specimens which has a minimal value as an acceptance test.

Since the objective was to obtain a correlation using only one parameter, an investigation was made to explain the phenomena in physical terms. Figure 12 is a macrophoto of the plastic deformation in a Charpy V notch impact specimen.[8] The specimen was subjected to a 30 ft-lb blow in impact and then heat-treated to bring out the grain growth due to plastic deformation. The photo shows that a certain amount of energy will be absorbed in the plastic deformation of a specimen prior to crack initiation and propagation. It is also evident that additional energy will be required to fracture the specimen; this energy has been designated as the rupture energy. Although this rupture energy is not specifically defined, it is known that this energy will consist of some plastic deformation - especially during crack propagation. That is, as the crack progresses, there will be some deformation just below the surface both preceding the crack extension and parallel to the crack. This energy is very nearly proportional to the crack area, while the deformation energy is related to the volume. By using this theory of total energy for fracture being composed of deformation and rupture energy ($E = Ed + Er$) coupled with the Law of Similitude,* an explanation of the physical phenomena of the Charpy relationship may be made. As the specimen size is reduced, the volume of deformation will be reduced, however, the deformation reduction is dependent upon the dimension reduced. That is, if the depth dimension is reduced, the volume of deformation will be reduced by the square of the depth dimension; but if the width dimension is reduced, the volume of deformation will be reduced in direct proportion. Further, if the material is so notch sensitive that negligible deformation will result, then the energies of the specimens will again be directly proportional to their sizes.

To verify the foregoing, a mathematical approach was made:

Let E = Total Energy of Fracture

Er = Energy of Rupture

Ed = Energy of Deformation

then $E = Er + Ed$

*Law of Similitude: "The basic values commonly considered responsible for the mechanical behavior of any material are the stresses. From this standpoint both a large and small article, made from the same homogeneous metal and of geometrically similar shapes, should behave identically, i.e., they should deform geometrically in a similar manner if subjected to the same stress values at corresponding points" (Reference 2).

and by Law of Similitude:

For 1/2-size specimens (Figure 1) $E. = 1/2\ Er + 1/4\ Ed$

1/3-size specimens $E. = 1/3\ Er + 1/9\ Ed$

1/4-size specimens $E = 1/4\ Er + 1/8\ Ed$

The data (taken at -40°C) from the curves of Figures 2, 3, and 4 and used in the above simultaneous equations produced a rupture energy (Er) of 21.6 ft-lb for ductile materials and a rupture energy (Er) of 12.0 ft-lb for brittle materials. The data taken (at -40°C) from the curves of Figures 5 through 10 and used in the above simultaneous equations yielded reasonably satisfactory results. By plotting the data obtained from the above curves, a graphical solution may be obtained which is in agreement with the previous simultaneous solution. The difference in the reduction of the volume of deformation is a measure of the degree of slope change. As would be expected, the brittle materials have a zero slope.

By using the curves in Figure 13, an equation for the solution of the energy of the subsize specimen may be developed based upon the energy of rupture (designated by K in Figure 13), the energy of deformation (tangent of the angle equal to the slope), and the specimen dimensions.

$E.'$ = Energy per unit area of full size bar

$e\frac{A.}{a}$ = Energy per unit area of subsize bar

$A.$ = Cross-sectional area of full size bar under notch

a = Cross-sectional area of subsize bar under notch

D = Depth under notch of full size bar

d = Depth under notch of subsize bar

K = Energy of rupture = Er

Since $\tan \alpha = \frac{E.' - K}{D}$ and

$$\tan \alpha = \frac{e\frac{A.}{a} - K}{d} \text{ then}$$

$$\frac{E.' - K}{D} = \frac{e\frac{A.}{a} - K}{d} \text{ which resolves to}$$

$$e = \left[K\left(1 - \frac{d}{D}\right) + E.'\frac{d}{D}\right]\frac{a}{A.}$$

the equation of energy for the subsize bar in terms of rupture (*K*) and energy of deformation based upon the ratios of cross-sectional area and depths of the standard size bars to the subsize bars. Table VII shows the agreement of the theoretical with the experimental results. As would be expected the notch-sensitive materials do not show any energy of deformation.

The material AISI-4140, which appears to be a ductile material according to the hardness results, fits the correlation much better when used with a *K* value of 12 in the solution of the equation based upon the data taken from the table. This is attributed to the fact that a transverse specimen would be in the brittle range and have a full-size energy of fracture at -40°C of approximately 13 ft-lb.

Although Table VII is based upon data taken from the curves of Figures 2 through 10, the same theoretical and experimental comparison was made for data taken directly from the tables with equally good results.

CONCLUSIONS

The results of this investigation indicate the following:

1. A reasonable corroboration of the empirical correlation developed in the previous report (Reference 1).

2. A linear correlation has been shown to exist, for the materials investigated, between the Charpy impact energy values for standard and selected subsize V notch specimens at an acceptance temperature of -40°, and an equation has been developed for calculating the energy of the subsize bar desired.

3. There is a physical relationship for the correlation between the specimen sizes based upon the energy of rupture and the energy of deformation for the materials investigated at the acceptance test temperature of -40°C.

ACKNOWLEDGMENT

The writer wishes to acknowledge the help of Mr. George Orner for his suggestions in regard to the physical and mathematical solutions obtained.

<u>TABLE I</u>

AVERAGED* IMPACT DATA - AISI-2340 MODIFIED - TRANSVERSE

TEMP.	F.S.		1/2 S		1/3 S		1/4 S		1/2 S_D		1/3 S_L	
(°C)	ENERGY (Ft-Lb)	FIBROUS CONTENT (%)	E	F	E	F	E	F	E	F	E	F
R.T.	39.7	100	15.2	100	8.7	100	8.9	100				
0	39.2	100					8.1	100				
- 10	36.3	95			8.5	100						
- 20	34.8	95	14.6	100	8.2	100	8.2	100				
- 30	34.6	95	14.9	95								
- 40	29.8	80	13.5	95	8.0	95	7.6	95	16.5	95	9.8	95
- 60	22.8	35	12.8	70	7.2	80	6.7	75				
- 80	15.2	20	9.7	45	6.4	65	5.8	50				
-100	14.5	10	8.5	30			5.2	30				
-120	6.0	0	7.0	15	5.0	40	4.0	20				
-155	5.0	0	5.0	10	4.0	20	3.0	10				
-196	3.5	0	1.2	5	1.8	5	1.1	5				

**Average of Three Data Points*

Transition Temperature = 0°C

<u>TABLE II</u>

AVERAGED* IMPACT DATA - AISI-3140 MODIFIED - TRANSVERSE

TEMP.	F.S.		1/2 S		1/3 S		1/4 S		1/2 S_D		1/3 S_L	
(°C)	ENERGY (Ft-Lb)	FIBROUS CONTENT (%)	E	F	E	F	E	F	E	F	E	F
R.T.	31.8	100	12.6	100	8.0	100	7.3	100			9.1	100
- 40	29.8	100	12.8	100	7.2	100	6.8	100	15.6	100	8.0	100
- 50	26.8	90			7.1	100	6.1	100				
- 60	24.0	65	10.5	95	6.8	100	5.7	95			7.5	100
- 70			9.7	60	7.0	95	5.4	80			7.4	95
- 80	19.5	40	9.3	55	6.2	75	5.3	60			6.3	55
-100	13.8	20	7.8	30	5.3	40	4.5	40			5.4	30
-120	13.2	10	6.8	20	5.0	35	4.0	25			4.1	20
-155	13.0	5	5.6	10	4.0	15	3.1	15			3.9	10
-196	7.4	5	4.8	5	3.7	5	2.4	10			3.2	5
0	33.2	100	12.6	100								

**Average of Three Data Points*

Transition Temperature = -40°C

TABLE III

AVERAGED* IMPACT DATA - AISI-4042 MODIFIED - TRANSVERSE

TEMP.	F.S.		1/2 S		1/3 S		1/4 S		1/2 S_D		1/3 S_D	
(°C)	ENERGY (Ft-Lb)	FIBROUS CONTENT (%)	E	F	E	F	E	F	E	F	E	F
100	26.3	100			7.1	100						
80	27.6	85	9.8	100	7.6	100	6.1	100	18.2	100	10.6	100
70	22.2	75			6.5	100						
60	20.9	100	11.2	100	6.8	95	5.8	95	13.5	100	8.5	100
50			9.8	85			5.3	90	14.6	75		
R.T.	17.0	70	9.1	40	6.2	70	4.9	60	9.5	60	10.0	75
0	15.0	10	7.8	25	5.3	40	4.1	30	6.8	20	4.8	20
-20	8.0	5	5.8	15	5.0	40	3.9	25	6.0	5	4.0	15
-40	10.8	5	6.5	15	4.4	30	3.5	25	5.5	5	4.0	10
-60			3.9	5	4.1	25	2.8	15	3.2	0	3.2	0
-80	4.0	0	3.5	5			2.8	5	3.0	0	3.0	0

**Average of Three Data Points*

Transition Temperature = +100°C

TABLE IV

AVERAGED* IMPACT DATA - AISI-4140 - LONGITUDINAL

TEMP.	F.S.		1/2 S		1/3 S		1/4 S		1/2 S_D		1/3 S_D	
(°C)	ENERGY (Ft-Lb)	FIBROUS CONTENT (%)	E	F	E	F	E	F	E	F	E	F
R.T.	42.1	100	13.1	100	7.3	100	6.8	100	23.4	100	15.7	100
- 10	33.8	100	14.2	100	6.8	100	6.7	100				
- 20	36.3	100	12.4	100	7.5	100	6.4	100				
- 40	34.6	95	11.8	100	6.6	100	6.2	100	20.9	100	12.0	100
- 60	27.3	70	10.8	70	7.0	100	5.3	85	17.8	95	13.0	100
- 80	20.4	35	8.2	45	5.0	60	4.9	75	9.2	60	8.8	75
-100	15.8	20	7.2	25	4.8	35	4.0	50	6.3	35	5.2	45
-120	14.0	15	6.6	20	3.9	20	3.3	30	6.2	15	4.2	30
-155	13.6	10	5.9	10	3.0	10	2.8	15	6.3	10	4.0	15
-196	9.3	5	5.5	5	2.9	5	2.4	5	4.2	5	3.7	5

**Average of Three Data Points*

Transition Temperature = -30°C

TABLE V

AVERAGED* IMPACT DATA - CLASS 90 STEEL - TRANSVERSE

TEMP.	F.S.		1/2 S		1/3 S		1/4 S		1/2 S_D		1/3 S_D	
(°C)	ENERGY (Ft-Lb)	FIBROUS CONTENT (%)	E	F	E	F	E	F	E	F	E	F
R.T.	34.8	100	14.6	100	8.8	100	7.5	100	19.4	100	12.1	100
- 40	32.9	100	14.3	100	8.9	100	7.6	100	17.8	100	12.7	100
- 60	31.2	100	13.5	100	8.6	100	7.0	100	18.8	100		
- 70	26.6	80	13.6	100	8.6	100	6.6	100	17.3	95		
- 80	22.1	60	13.2	90	8.1	100	6.6	95	14.5	90	12.7	100
- 90					7.9	100	6.5	90	11.6	65	10.4	95
-100	16.1	35	10.3	70	7.6	95	5.3	80	8.9	50	7.5	65
-120	12.8	15	8.4	40	7.0	80	4.8	50	8.0	20	6.8	40
-135							4.1	35				
-155	7.8	5	6.0	10	5.8	50	3.0	10	4.2	10	3.0	5
-196	4.2	5	2.0	5	2.8	15	1.1	5	3.0	5	2.5	5

Average of Three Data Points
Transition Temperature = -60°C

TABLE VI*

TEST RESULTS OF NICKEL STEEL - TRANSVERSE

TEMP.	2 - S		F.S.		F.S_W		1/2 S_D		—		—	
(°C)	ENERGY (Ft-Lb)	FIBROUS CONTENT (%)	E	F	E	F	E	F	—	—	—	—
23	78.4	100	41.9	100			20.1					
- 20			39.0	100								
- 40	77.9	100	37.7	95			20.5					
- 50	71.2	90	30.2	80								
- 60	55.3	60	24.7	55			18.8					
- 70	48.3	40	22.9	40								
- 80	26.7	20	14.5	20	18.8		12.5					
- 90			12.1		16.3		8.7					
-100	14.5	5	11.5		12.7		8.1					
-110			7.8									
-120	9.5	0	5.4	0			4.1					
-155	4.7		3.2									

Transition Temperature = -40°C
Obtained from investigation of Reference 3.

TABLE VII

COMPARISON - THEORETICAL VERSUS EXPERIMENTAL DATA

$$e = \left[K\left(1 - \frac{d}{D}\right) + E'\frac{d}{D}\right]\frac{a}{A}$$

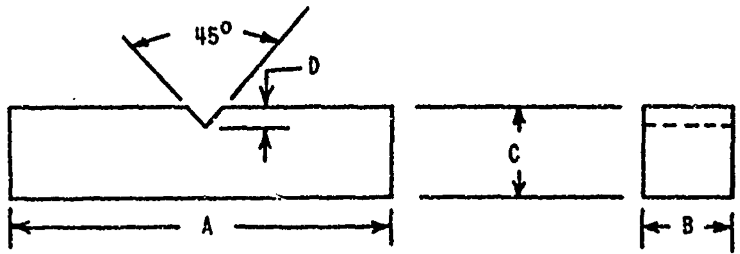
Material	Size	Theoretical Energy (Ft-Lb)	Experimental Energy (Ft-Lb)	Δ Energy (Ft-Lb)	Allowable Tolerance* (Ft-Lb)	K
** AISI-4340 H.T. #1 Full Size, Energy = 70 Ft-Lb	1/2 S 1/3 S 1/4 S	22.9 12.6 11.5	22.0 13.0 12.0	+0.9 -0.4 -0.5	±1.1 ±1.0 ±1.0	21.6
** AISI-4340 H.T. #2 Full Size, Energy = 37 Ft-Lb	1/2 S 1/3 S 1/4 S	14.7 8.9 7.4	14.7 9.0 8.0	0.01 -0.1 -0.6	±1.0 ±1.0 ±1.0	21.6
** Cast Steel, Full Size, Energy = 12 Ft-Lb	1/2 S 1/3 S 1/4 S	6.0 4.0 3.0	6.0 4.0 3.0	0.0 0.0 0.0	±1.0 ±1.0 ±1.0	12
AISI-2340 Modified F.S. Energy = 30 Ft-Lb	1/2 S 1/3 S 1/4 S 1/2 S_D 1/3 S_L	12.9 8.1 6.5 15.0 8.1	13.5 8.0 7.0 16.5 9.8	-0.6 +0.1 -0.5 -1.5 -1.7	±1.0 ±1.0 ±1.0 ±1.0 ±1.0	21.6
AISI-3140 Mod. Full Size Energy = 28.75 Ft-Lb	1/2 S 1/3 S 1/4 S 1/2 S_D 1/3 S_L	12.6 8.0 6.3 14.4 8.0	12.0 7.7 6.7 15.6 8.0	+0.6 +0.2 -0.4 -1.2 0.0	±1.0 +1.0 ±1.0 ±1.0 ±1.0	21.6
AISI-4042 Mod. Full Size Energy = 11.0 Ft-Lb	1/2 S 1/3 S 1/4 S 1/2 S_D 1/3 S_D	5.7 3.9 2.9 5.5 3.7	5.7 4.5 3.0 5.5 4.0	0.0 -0.8 -0.1 0.0 -0.3	±1.0 ±1.0 ±1.0 ±1.0 ±1.0	12
AISI-4140 Full Size Energy = 31.75 Ft-Lb	1/2 S 1/3 S 1/4 S 1/2 S_D 1/3 S_D	10.9 6.2 5.5 15.7 10.5	11.7 7.5 6.0 20.9 12.0	-0.8 -1.3 -0.5 -5.1 -1.5	±1.0 ±1.0 ±1.0 ±1.0 ±1.0	12
Class 90 Steel Full Size Energy = 33.25 Ft-Lb	1/2 S 1/3 S 1/4 S 1/2 S_D 1/3 S_D	13.7 8.5 6.8 16.6 11.1	14.5 8.7 7.5 17.8 12.7	-0.8 -0.3 -0.6 -1.2 -1.6	±1.0 ±1.0 ±1.0 ±1.0 ±1.0	21.6
Ni-Steel F.S. Energy = 37 Ft-Lb	2 S_D F.S_W 1/2 S_D	74.0 29.3 18.5	75.0 30.5 20.5	-1.0 -1.2 -2.0	±3.7 ±1.5 ±1.0	21.6

*Allowable Tolerance

±5% over 20 ft-lb of energy

±1 ft-lb under 20 ft-lb of energy

**Reference 1.

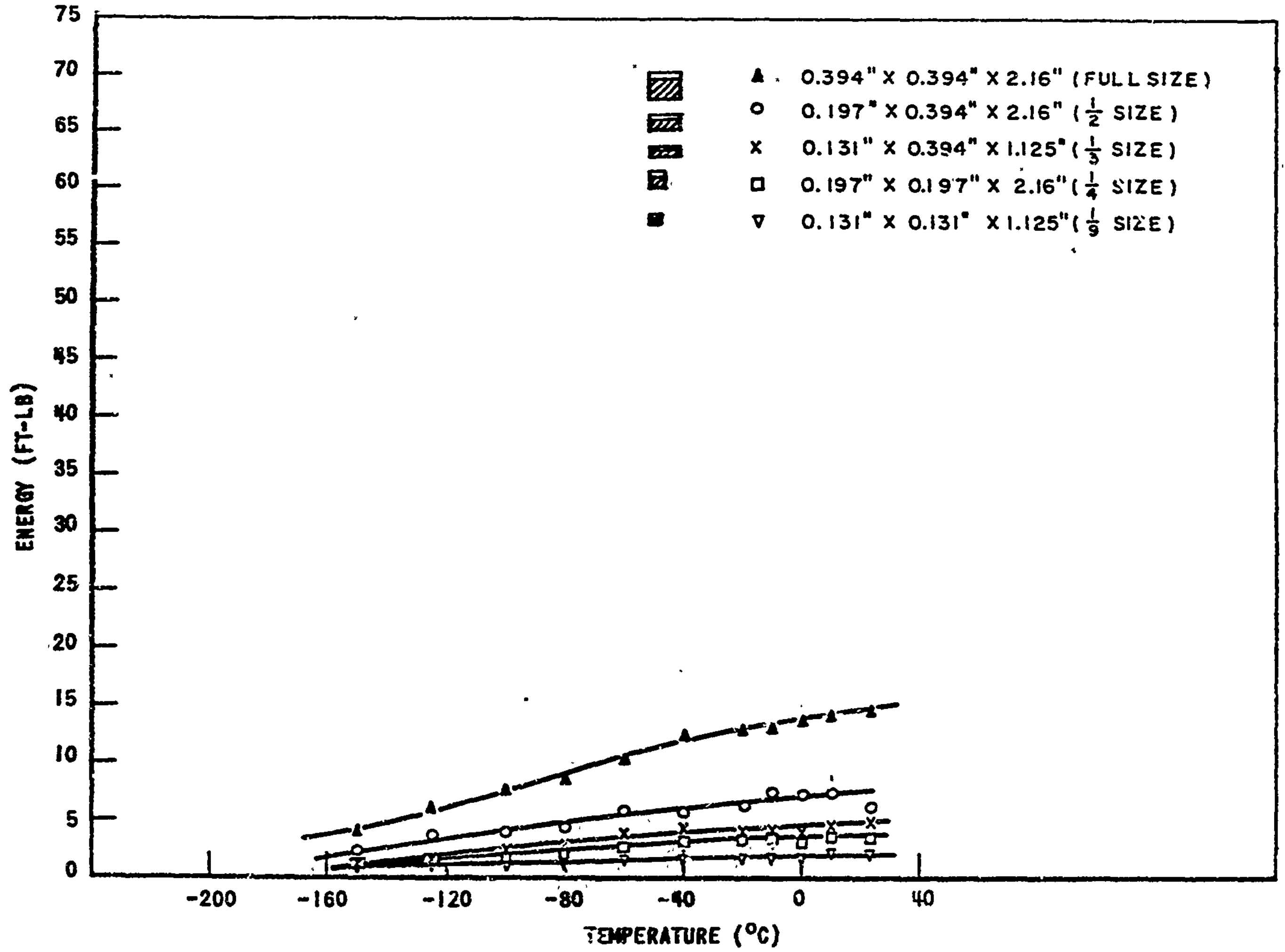


ALL NOTCH RADII = 0.010"

SIZE CROSS-SECTIONAL AREA		DIMENSIONS (INCHES)			
		A	B	C	D
STANDARD	F.S.	2.16	.394	.394	.079
HALF	1/2 S	2.16	.394	.197	.039
THIRD	1/3 S	1.125	.394	.131	.026
QUARTER	1/4 S	2.16	.197	.197	.039
DOUBLE	2 S	2.16	.788	.394	.079
NONSTANDARD	F. S_W	2.16	.788	.197	.039
HALF	1/2 S_D	2.16	.197	.394	.079
THIRD	1/3 S_D	2.16	.131	.394	.079
THIRD	1/3 S_L	2.16	.394	.131	.026
NINTH	1/9 S	1.125	.131	.131	.026

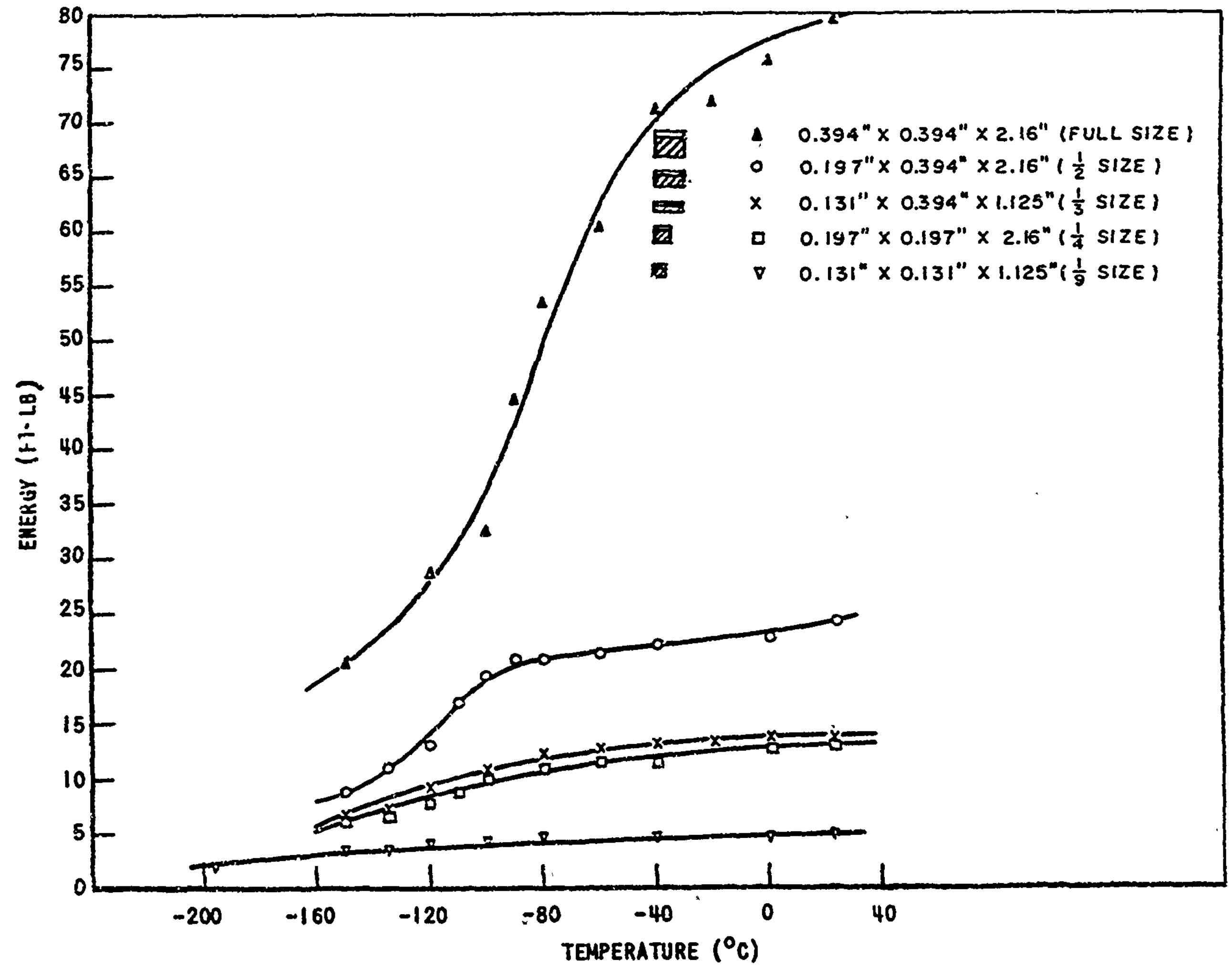
NOTE: Subscripts denote equivalent cross-sectional area with changes in dimensions.

FIGURE 1



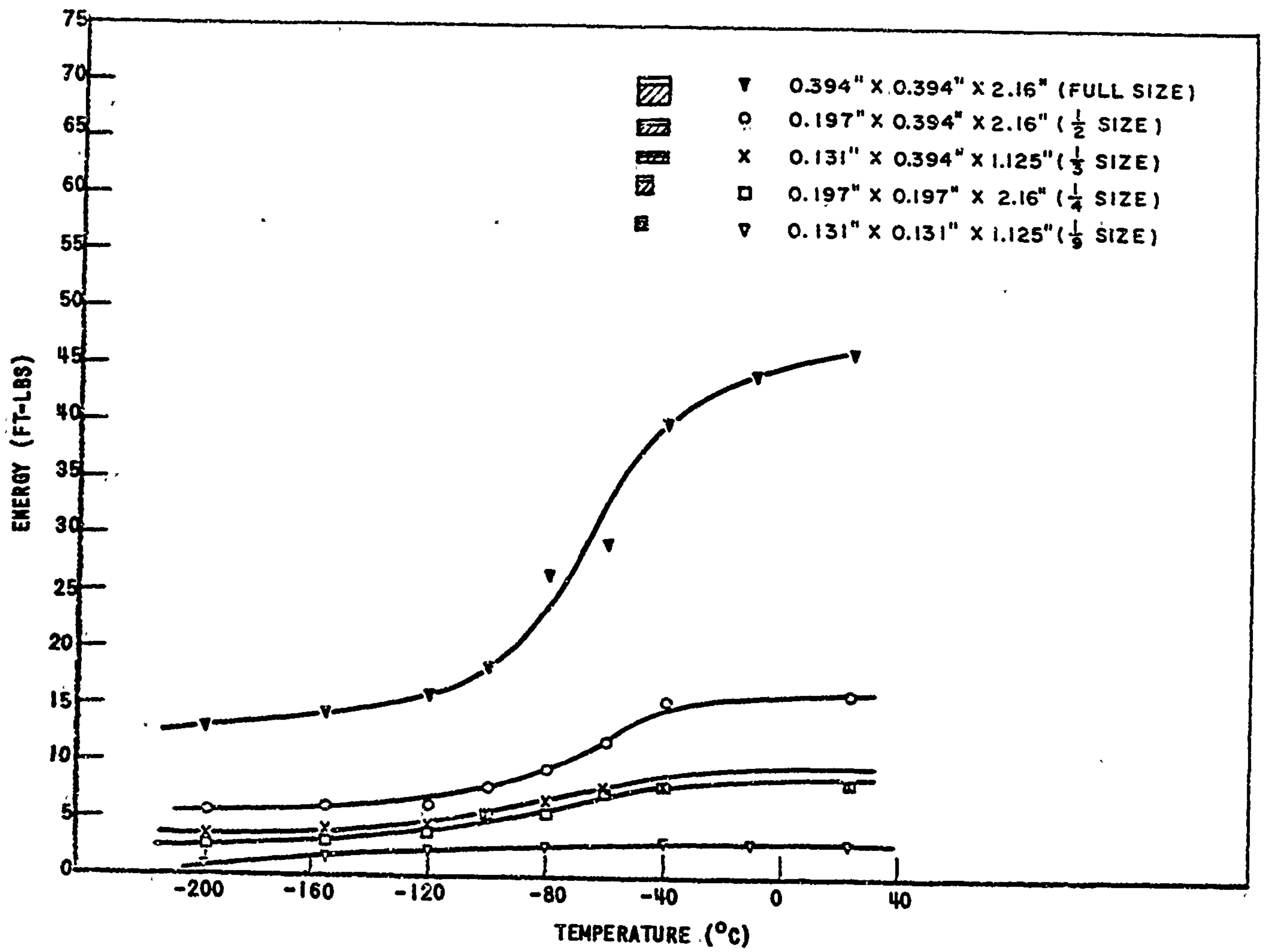
ENERGY VERSUS TEMPERATURE - CHARPY V NOTCH CAST GUN STEEL

FIGURE 2



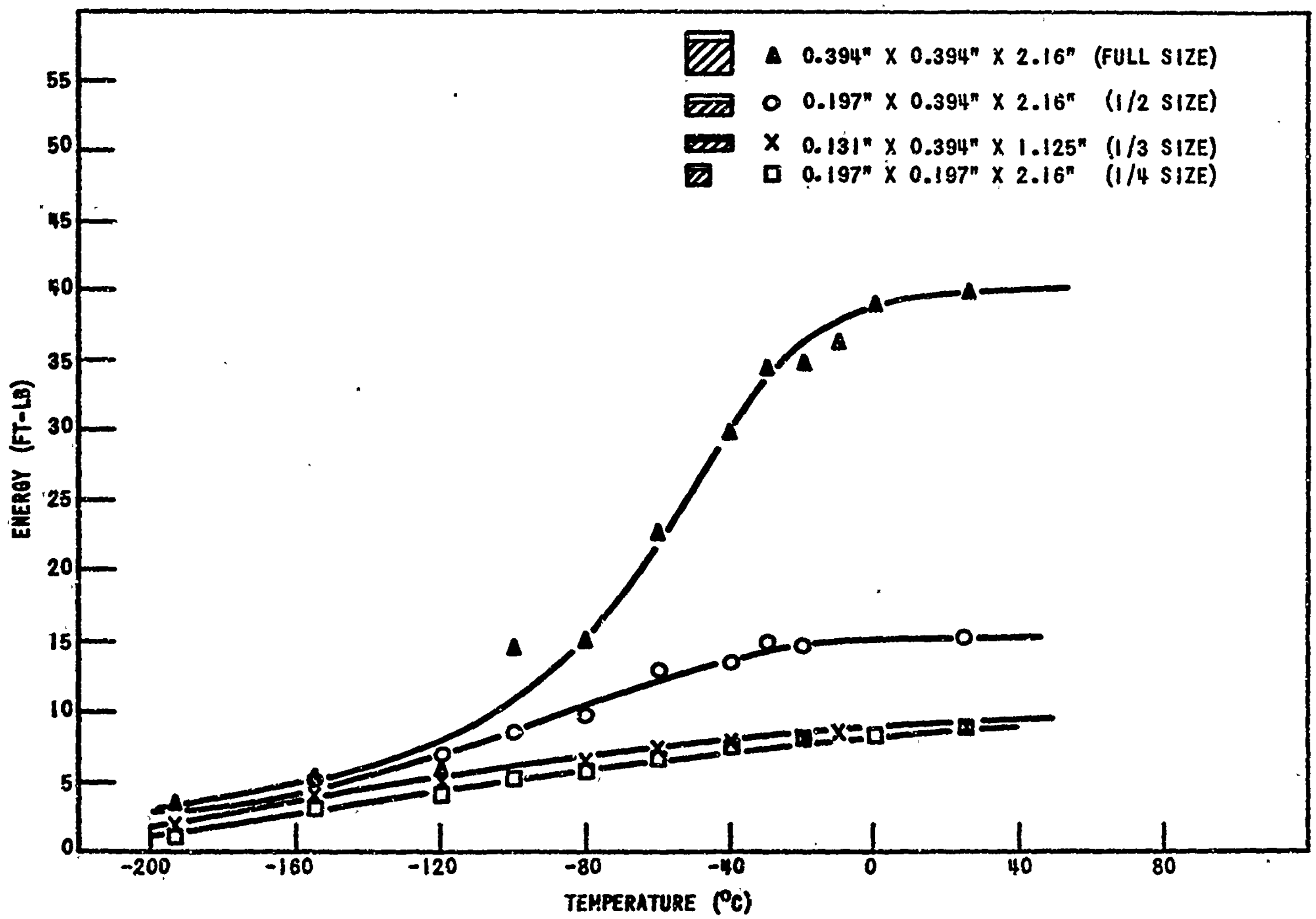
ENERGY VERSUS TEMPERATURE - CHARPY V NOTCH AISI-4340 HEAT TREAT #1

FIGURE 3



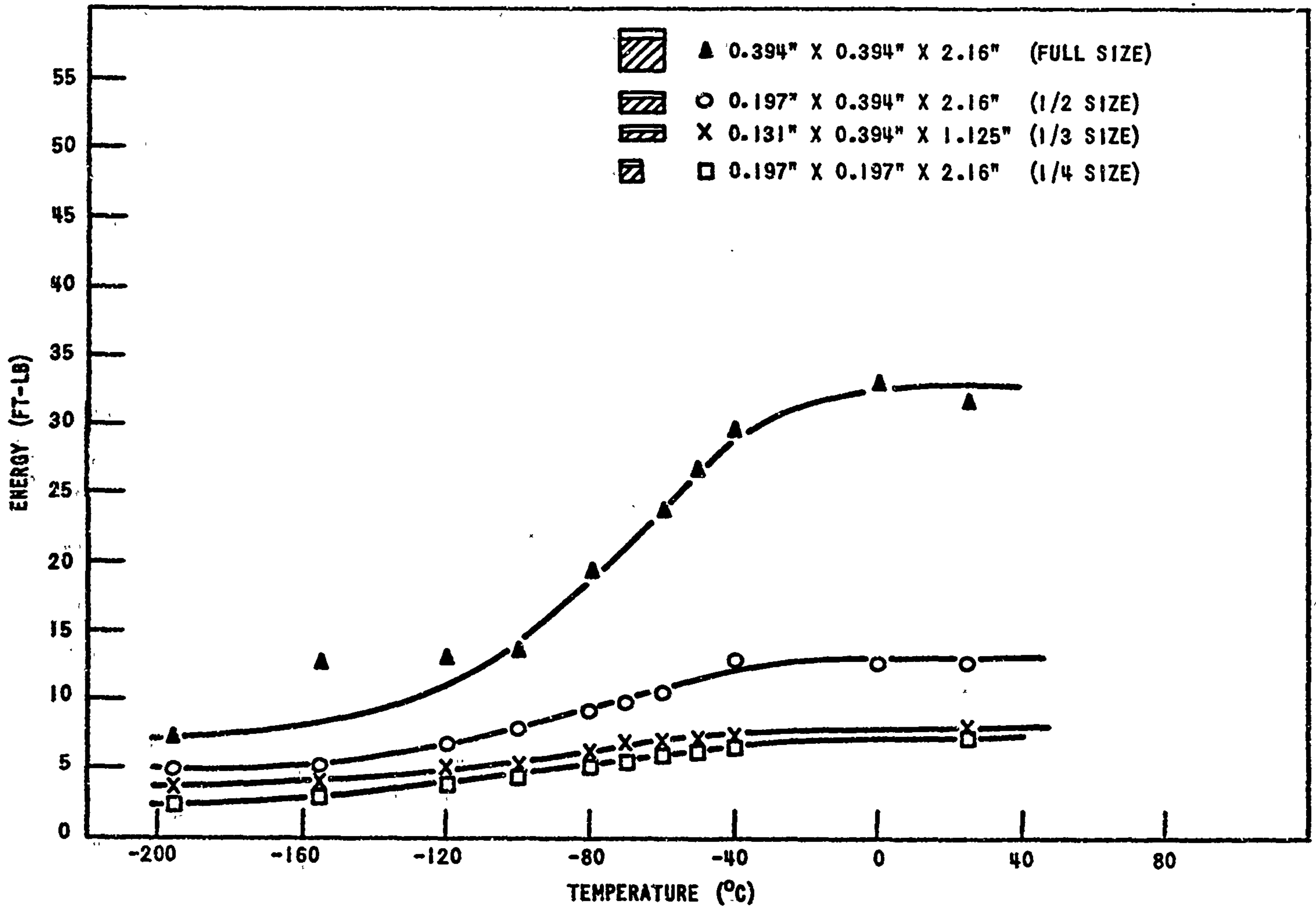
ENERGY VERSUS TEMPERATURE - CHARPY V NOTCH AISI-4340 HEAT TREAT #2

FIGURE 4



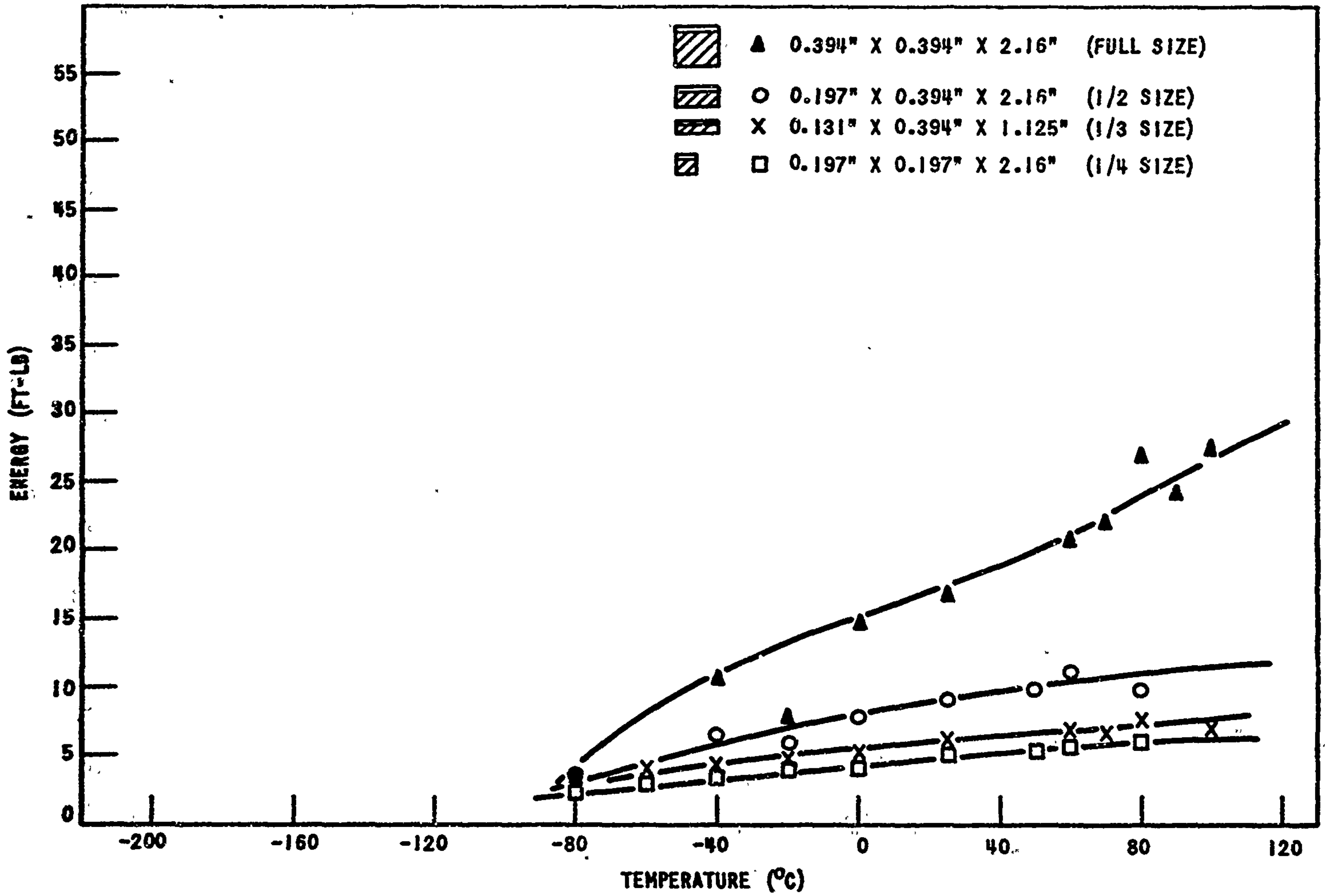
ENERGY VERSUS TEMPERATURE - CHARPY V NOTCH AISI-2340 MODIFIED

FIGURE 5



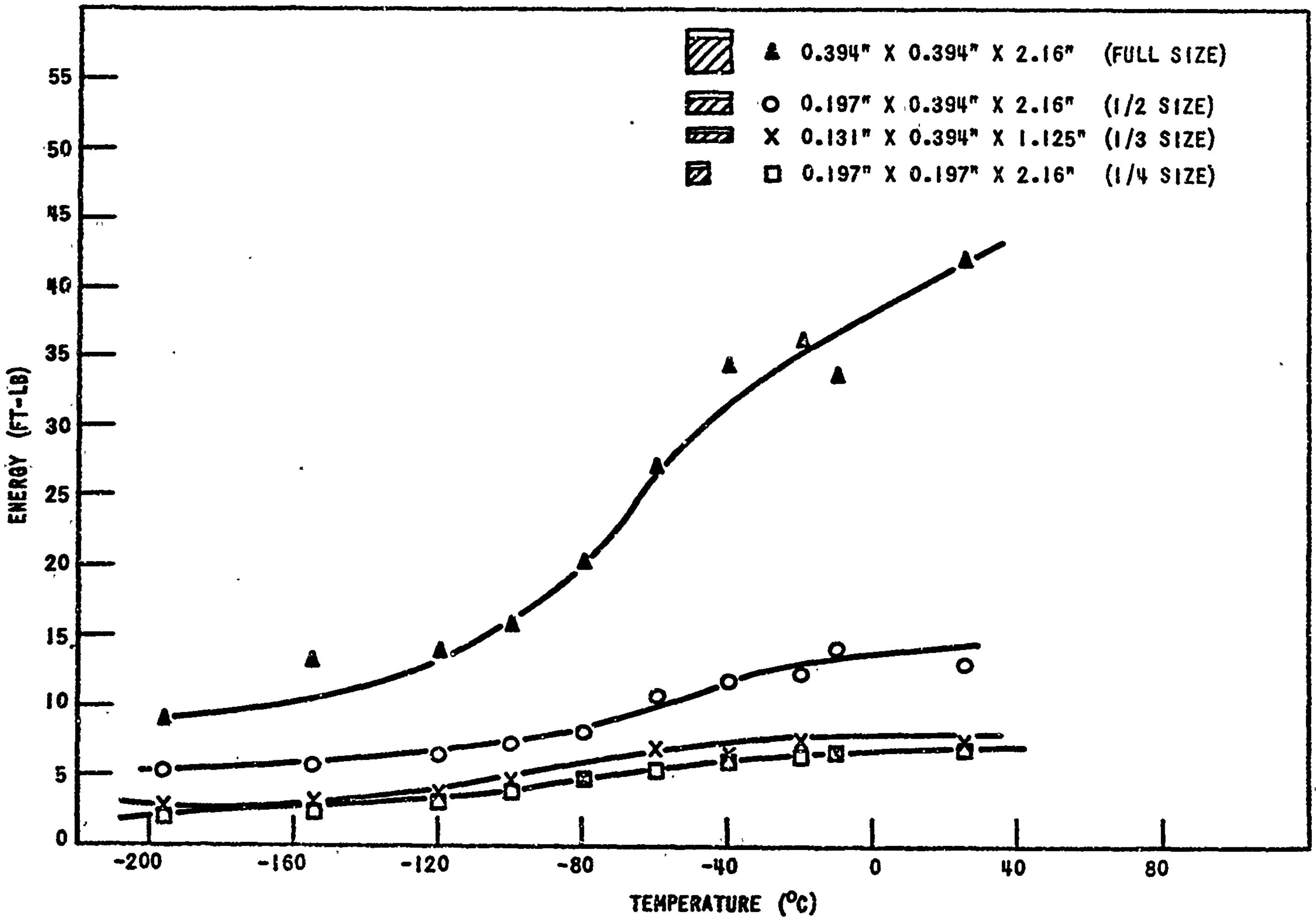
ENERGY VERSUS TEMPERATURE - CHARPY V NOTCH AISI-3140 MODIFIED

FIGURE 6



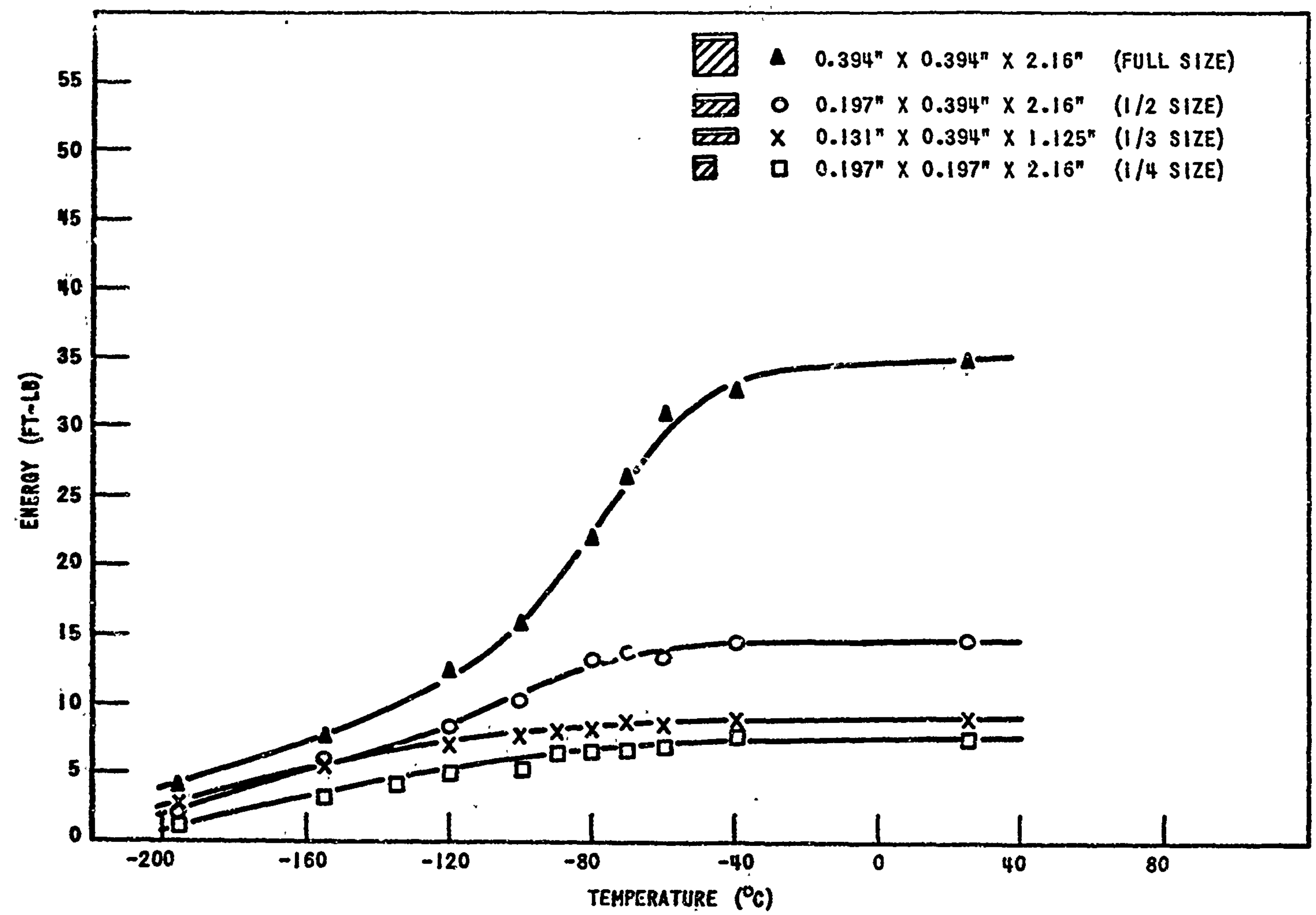
ENERGY VERSUS TEMPERATURE - CHARPY V NOTCH AISI-4042 MODIFIED

FIGURE 7



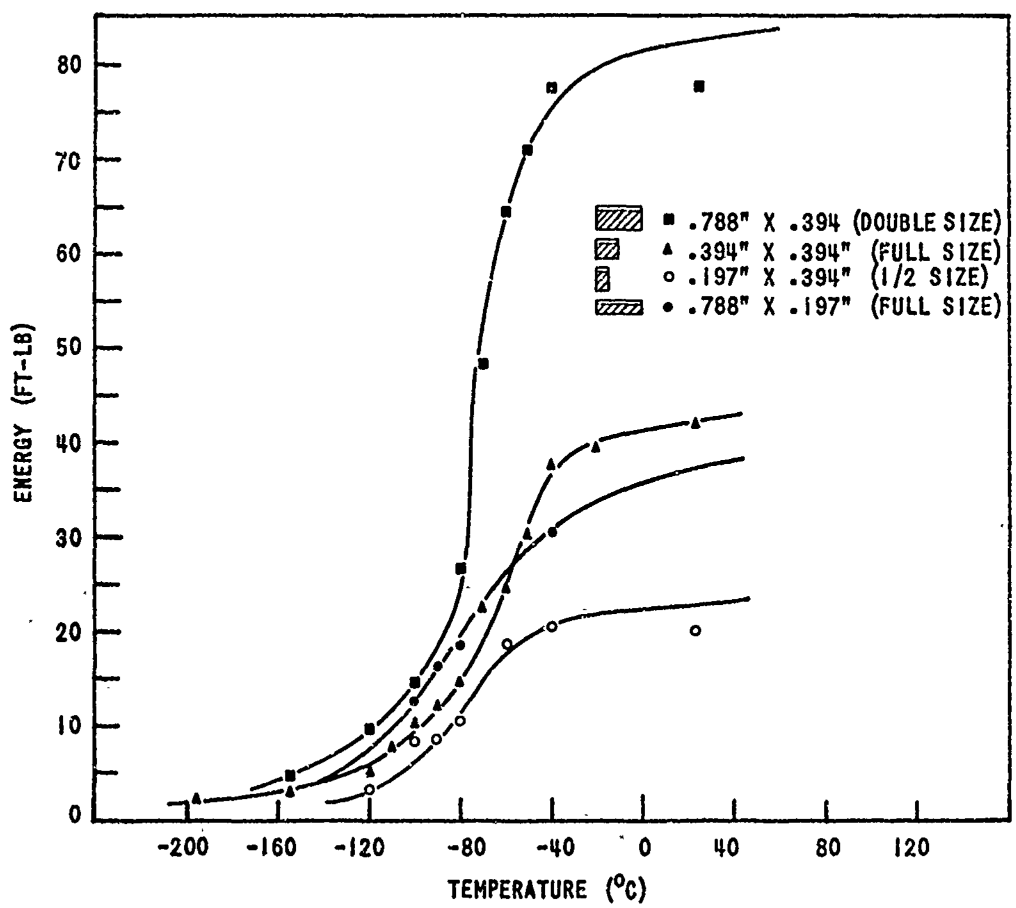
ENERGY VERSUS TEMPERATURE - CHARPY V NOTCH AISI-4140

FIGURE 8



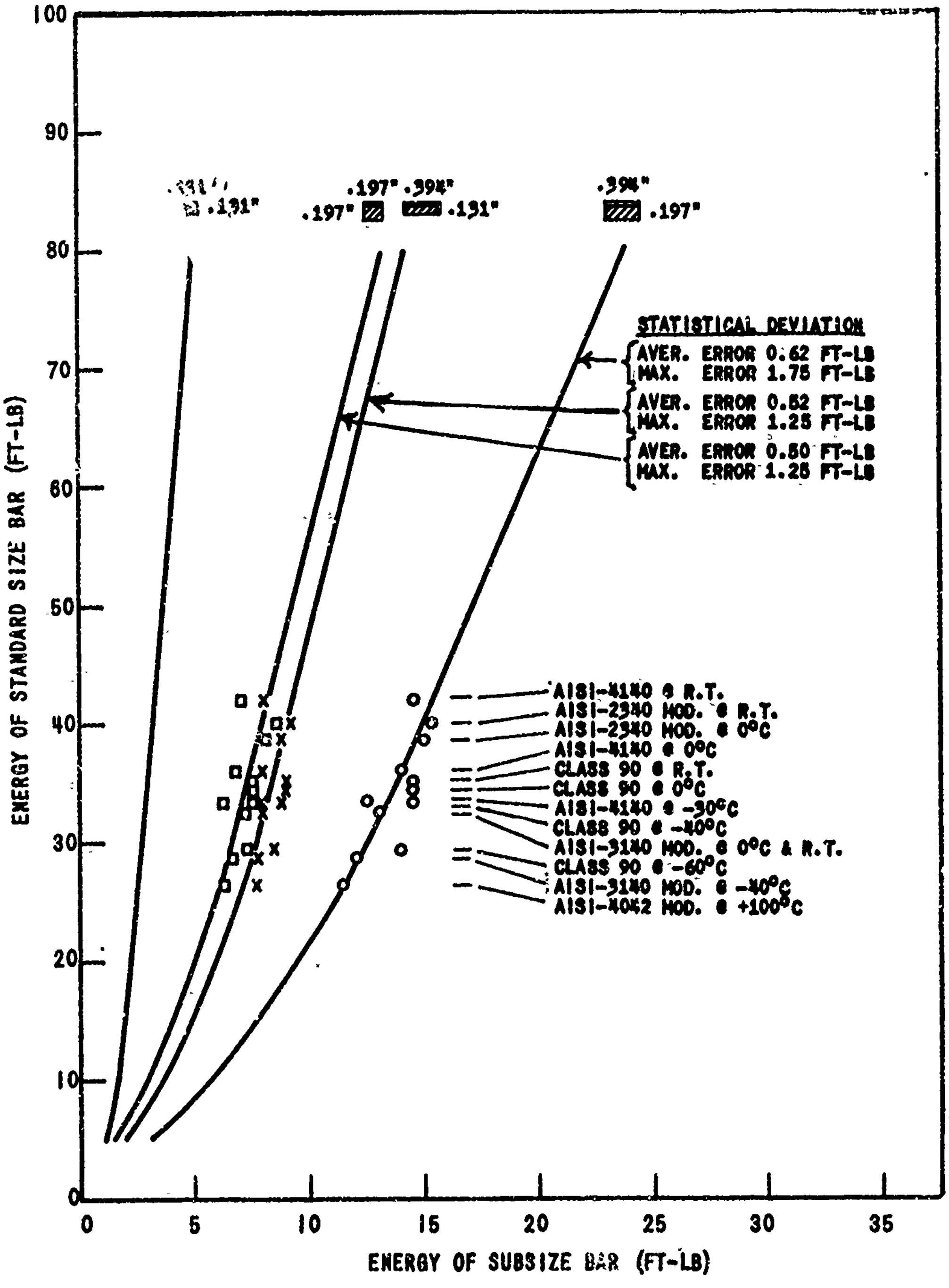
ENERGY VERSUS TEMPERATURE - CHARPY V NOTCH - CLASS 90 STEEL

FIGURE 9



ENERGY VERSUS TEMPERATURE - CHARPY V NOTCH NICKEL STEEL
(TAKEN FROM REFERENCE 3)

FIGURE 10



CORRELATION CURVES FOR SUBSIZE CHARPY IMPACT SPECIMENS ABOVE TRANSITION RANGE WITH DATA FROM FIVE OTHER STEELS PLOTTED ON ESTABLISHED CURVES FOR VERIFICATION OF CORRELATION

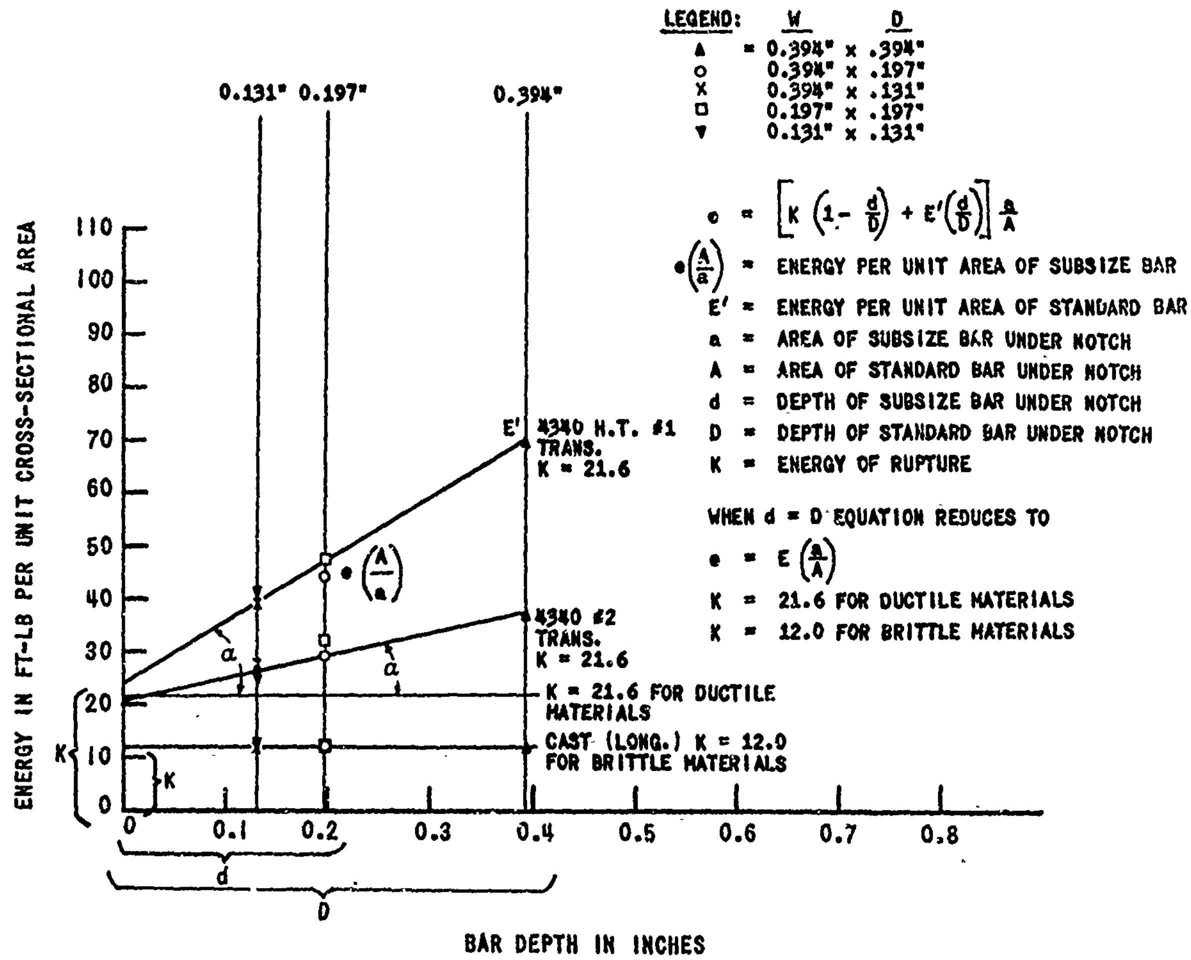
FIGURE 11

MACROPHOTO OF DEFORMATION DUE TO IMPACT

THIS SECTION FROM A V NOTCH CHARPY BAR CUT FROM A 0.04%C STEEL, WAS STRUCK A 30 FT-LB BLOW AND ANNEALED FOR 45 HOURS AT 850°C TO PROMOTE ABNORMAL GRAIN GROWTH IN THE PLASTICALLY DEFORMED AREAS. THE SPECIMEN WAS SUBSEQUENTLY SECTIONED, POLISHED, AND ETCHED, AND SHOWS THE CENTRAL AREA WHERE LITTLE OR NO PLASTIC DEFORMATION HAS TAKEN PLACE.

Wtn. 639-17,088

FIGURE 12



ENERGY VERSUS BAR DEPTH - SHOWING RELATIONSHIP OF RUPTURE AND DEFORMATION DATA TAKEN FROM CURVES OF FIGURES 2, 3, AND 4 AT -40°C TEST TEMPERATURE

FIGURE 13

REFERENCES

1. CURLL, C. H., and ORNER, G. M., Correlation of Selected Subsize Charpy Bars Versus the Standard Charpy Bar, *Watertown Arsenal Laboratories Report* WAL TR 112/91, May 1958.

2. SACHS, G., Some Fundamentals of the Flow and Rupture of Metals, *AIME. Transactions*, v. 143, 1941, p. 13-19.

3. ORNER, G. M., and HARTBOWER, C. E., The Effect of Notch and Specimen Geometry on Charpy Low-Blow Transition Temperature, *Watertown Arsenal Laboratories Report* WAL TR 112/87-4, September 1957.

AD____________ Accession No.____________
Watertown Arsenal Laboratories, Watertown 72, Mass.
SUBSIZE CHARPY CORRELATION WITH STANDARD CHARPY -
C. H. Curll

Report No. WAL TR 112/95, Dec 1959, 8 pp - tables - illus, OO Proj Industrial Preparedness Measure, P.E.S.D. No. 70304231-15-42606, Unclassified Report

To provide a means of impact acceptance testing of specimens which must be obtained from thin or small diameter sections, a study was made, using various specimen sizes, of the Charpy V notch impact properties of steels over a range of temperatures encompassing transitions from ductile to brittle behavior.

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Impact tests
2. Charpy, subsize

I. Curll, C. H.

AD____________ Accession No.____________
Watertown Arsenal Laboratories, Watertown 72, Mass.
SUBSIZE CHARPY CORRELATION WITH STANDARD CHARPY -
C. H. Curll

Report No. WAL TR 112/95, Dec 1959, 8 pp - tables - illus, OO Proj Industrial Preparedness Measure, P.E.S.D. No. 70304231-15-42606, Unclassified Report

To provide a means of impact acceptance testing of specimens which must be obtained from thin or small diameter sections, a study was made, using various specimen sizes, of the Charpy V notch impact properties of steels over a range of temperatures encompassing transitions from ductile to brittle behavior.

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Impact tests
2. Charpy, subsize

I. Curll, C. H.

AD____________ Accession No.____________
Watertown Arsenal Laboratories, Watertown 72, Mass.
SUBSIZE CHARPY CORRELATION WITH STANDARD CHARPY -
C. H. Curll

Report No. WAL TR 112/95, Dec 1959, 8 pp - tables - illus, OO Proj Industrial Preparedness Measure, P.E.S.D. No. 70304231-15-42606, Unclassified Report

To provide a means of impact acceptance testing of specimens which must be obtained from thin or small diameter sections, a study was made, using various specimen sizes, of the Charpy V notch impact properties of steels over a range of temperatures encompassing transitions from ductile to brittle behavior.

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Impact tests
2. Charpy, subsize

I. Curll, C. H.

AD____________ Accession No.____________
Watertown Arsenal Laboratories, Watertown 72, Mass.
SUBSIZE CHARPY CORRELATION WITH STANDARD CHARPY -
C. H. Curll

Report No. WAL TR 112/95, Dec 1959, 8 pp - tables - illus, OO Proj Industrial Preparedness Measure, P.E.S.D. No. 70304231-15-42606, Unclassified Report

To provide a means of impact acceptance testing of specimens which must be obtained from thin or small diameter sections, a study was made, using various specimen sizes, of the Charpy V notch impact properties of steels over a range of temperatures encompassing transitions from ductile to brittle behavior.

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Impact tests
2. Charpy, subsize

I. Curll, C. H.

WATERTOWN ARSENAL
TECHNICAL REPORT DISTRIBUTION

Report No.: WAL TR 112/95 Title: Subsize Charpy Correlation with Standard Charpy

To:	No. of Copies
Commanding Officer Watertown Arsenal Watertown 72, Mass.	
Attn: Technical Info. Section	5
Author	1
OMRO	1
WAL Coordinator, IPM	1
Activity Manager, IPM	7
(5 copies to be distributed as follows:) Commanding General Ordnance Weapons Command Rock Island, Illinois	
Attn: ORDOW-IX, Industrial Division	1
ORDOW-IM, Ind. Mob. Branch	1
ORDOW-TX, Research Division	1
ORDOW-GU, Security Office	2
Office, Chief of Ordnance Department of the Army Washington 25, D. C.	
Attn: ORDIX	1
ORDIR, Wpns & Fire Control Br.	2
ORDTB, Research & Materials	2
Commanding General Frankford Arsenal Philadelphia 37, Pa.	2
Commanding Officer Picatinny Arsenal Dover, New Jersey	2
Commanding Officer Rock Island Arsenal Rock Island, Illinois	
Attn: 9310, Res. & Dev. Division	1
5100, Ind. Eng. Division	1
Commanding Officer Springfield Armory Springfield 1, Mass.	
Attn: ORDBD-TX, Res. & Dev. Div.	1
ORDBD-EG, Eng. Div.	1

Trans date: 12/31/59

To:	No. of Copies
Commanding Officer Watervliet Arsenal Watervliet, New York	2
Commanding General Aberdeen Proving Ground Aberdeen, Maryland	2
Commanding Officer Detroit Arsenal Center Line, Michigan	2
Commanding General U.S. Army Ordnance Missile Command Redstone Arsenal, Alabama	2
Commander Army Rocket & Guided Missile Agency Redstone Arsenal, Alabama Attn: ORDXR-OTL, Technical Library	2
Commanding General Army Ballistic Missile Agency Redstone Arsenal, Alabama	2
Commanding Officer Ordnance Ammunition Command Joliet, Illinois	2
Commanding General Ordnance Tank-Automotive Command 1501 Beard Street Detroit 9, Michigan	2
Commanding Officer Office of Ordnance Research Box CM, Duke Station Durham, North Carolina	1
Chief, Bureau of Ordnance Department of the Navy Washington 25, D. C.	1
Chief, Bureau of Ships Department of the Navy Washington 25, D. C.	1

To:	No. of Copies
Director Naval Research Lab. Anacostia Station Washington 25, D. C.	1
Chief, Office of Naval Research Department of the Navy Washington 25, D. C.	1
Commander Armed Services Tech. Info. Agency Arlington Hall Station Arlington 12, Virginia Attn: TIPDR	10
Commanding General Wright Air Development Center Wright-Patterson Air Force Base Ohio Attn: WCRRL	2
Defense Metals Information Center Battelle Memorial Institute Columbus 1, Ohio	2
Commanding General U.S. Army Ordnance Special Weapons Ammunition Command Dover, New Jersey	2
Superintendent Naval Gun Factory Department of the Navy Washington 25, D. C.	1
Oak Ridge National Laboratories Atomic Energy Commission Box P Oak Ridge, Tennessee Attn: Mr. J. J. Prislinger	1
Defense Research Board Canadian Armament Research and Development Establishment P. O. Box 1427 Quebec, P. Q., Canada Attn: Mr. H. P. Tardif	1

TOTAL COPIES DISTRIBUTED -- 68

Total number of copies printed 80
Extra copies to author 5
Extra copies to Publ. Ed. 5
2 cys fwd to OTS 12/31/59 2