A Literature Review to Assess the Reliability of the Conversion Factors for Sub-Size Specimens Shown in ASTM A370 Table 9

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Scope:

This literature review addresses the applicability of the conversion factors contained in ASTM A370 Table 9 Charpy V-Notch Test Acceptance Criteria for Various Sub-Size Specimens including Note *A*.

Literature:

Curll and Orner published a report for Watertown Arsenal Laboratories describing the correlation between full size and subsized Charpy impact values for three different steels (Curll C. H., 1958). This report was in response to the increased use of thin walled tubes in military applications. The authors selected three steel hardness levels – an as-received cast gun steel (R_c 40) and AISI 4340 heat treated to R_c 27 (Heat Treatment #1) and R_c 35 (Heat treatment #2). Steel chemistries are listed in Table 1 and heat treatment cycles for the 4340 are listed in Table 2.

The subsized specimen designs used in this investigation were atypical to Table 9 in ASTM A370 with the exception of the full sized specimen and the authors noted that different designs will produce different energy values. The Charpy specimen designs used in this study are illustrated in Figure 1. The bars were tested in a conventional manner at a range of temperatures to encompass the ductile to brittle temperature range. The impact machine anvil was modified to account for the reduced length specimens. Three tests were performed at each temperature and averaged. Tables 3 through 5 lists the test temperature, average impact energy, percent fracture face fibrosity, and specimen design for all three steels. Plots of the impact energy versus test temperature are illustrated in Figures 2 through 4.

The authors observed a reduction in the transition temperature range for the heat treated 4340 steels with decreasing specimen size but not with the as-received cast gun steel. They defined the transition temperature as the lowest temperature tested with a 100% fibrous fracture surface. The cast steel had full size upper shelf energy of about 15 ft.-lbs. while the 4340 steels had upper shelf energies between 46 and 80 ft.-lbs. The response of the 4340 steel was attributed to reduced plastic constraint and strain rate in the subsized specimens. The reduced strain rate is geometrically related to the reduced ligament depth in these subsized specimens. The reduction in impact energy of the gun steel was almost directly proportional to specimen cross-sectional area. This steel did not show a well-defined transition curve.

The authors examined the relationship of upper and lower shelf energies to specimen size and found a non-linear correlation (Figures 5 and 6). However, when data taken from within the transition temperature range was added (Figure 6), this relationship degrades. The authors concluded that impact energy is proportional to cross-sectional area if the percentage of fibrosity is held constant.

Curll continued this work by testing six additional steels and developing an analytical correlation between impact energy and specimen size (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959). Tables 6, 7 and 8 list the chemistry, heat treatment, and hardness of these additional steels, respectively. The Class 90 steel was used in the as-received condition and heat treatment information was not available. The subsize specimen design was expanded to include two geometries that correspond to A370/Table 9 (½ S_D and 1/3 S_D). Figure 7 illustrates the various subsize geometries tested. All six steels are within A370/Table 9's 0-40 ft.-lb. limit. Tables 9 through 14 lists the test temperature, average impact energy, percent fracture face fibrosity, and specimen design for all six steels.

The author developed an analytical formula correlating specimen design, rupture energy, and deformation energy to subsize specimen energy (Equation 1). The energy of rupture was calculated from data taken at -40C for all nine steels. A tabulation comparing observed impact energies to predicted impact energies at an acceptance temperature of -40C using this formula is shown in Table 15. Since the depth under notch is constant in A370/Table 9, this formula reduces to the energy proportional to area relationship used in A370/Table 9.

Equation 1. Subsize energy relationship (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

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

Where
- e = predicted subsize impact energy per unit area
- E' = Energy per unit area of full size 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.

The author republished this report for ASTM in Materials Research and Standards in 1961 (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1961).

J.H. Gross conducted a study on the effect of tensile strength and thickness on notch ductility in five grades of structural steel (Gross, 1970). The 0.2% offset yield tensile strength for the five steels ranged from 40 to 140 ksi with microstructures ranging from ferritic to tempered martensite. The author measured Charpy impact properties and developed DBTT curves for full size, ¾ size, ½ size and ¼ size specimens using absorbed energy, lateral expansion, and fracture appearance. Full size (P-1) and subsize (P-3) drop weight NDT values were also measured for each steel. The author observed an increase in DBTT with increasing CVN specimen width using either 3.8 ft-lb/0.1 inch width (15 ft-lb full size) or a specific lateral expansion/fracture appearance value. Gross noted that temperature adjustments allowed in ASME Section VIII Table UG-84.2 were liberal compared to the variations he observed but were appropriate for

Section VIII. This is the only article found that links ASME UG-84.2 to Charpy impact properties.

A review of other code requirements with provisions for subsize Charpy specimens may be useful for comparison to A370/Table 9. The adequacy of code requirements for sub-sized Charpy testing was reviewed by Towers in 1986 (Towers, 1986). The author lists various codes which specify requirements for sub-size Charpy V notch specimens and includes codes or requirements that reduce specimen width only so the specimen design is compatible to A370/Table 9. The codes listed by the author are given in Table 16. The author does not indicate if the codes have an impact value range associated with the subsize Charpy requirement. The following are the observations from the author.

1) Most requirements are for ferritic structural steels and sub-sized CVN specimens are required for two reasons: the material is too thin for a full sized specimen or the material geometry does not allow a full sized specimen.

2) Sub-size requirements tend to be similar within industrial sectors, not so much by country. For example, ship building or construction codes from Japan, Norway, UK, and the US are similar while ASME section VIII is different from AWS D1.1.-81 which is different from ABS rules for steel vessels.

3) Two basic approaches are used to correlate sub-size to full sized specimens. The first approach is a modified test temperature method which reduces the test temperature of sub-sized specimens to account for the transition shift and normalizes for ligament area. This method is used by some US and Japanese standards especially when the material is to be used for low temperature service. The second method is a modified energy approach where normalized absorbed energy requirements are increased for sub-sized specimens but tested at the same temperature as full sized specimens. This approach is used by many international standards and some US standards. In most cases, the subsize energy requirements are directly proportional to area reduction or a fixed percentage of the full size specimen energy value.

The author recommends that when a sub-size specimen is used because the section is too thin for a larger specimen to be extracted, the reduced thickness of the test specimen is used to model the benefits of a reduced section thickness with regard to the risk of brittle fracture in ferritic steels, rather than attempting to correlate back to the result which would have been obtained in a full size specimen. He also recommends that when sub-size specimens are used due to an inconvenient configuration, a correlation may be required to deduce the result which would have been obtained in a full size specimen or at least a larger specimen. It is recommended for ferritic steels that the test temperature for the sub-size specimen should be reduced from that which would otherwise have been required for the full size specimen and to model the effect of thickness on the transition temperature. (Note: the data used by the author to arrive at these conclusions exceeded the Table 9 limit of 40 ft.-lbs.)

Table 9 in A370 can only be used for full size Charpy impact values less than or equal to 40 ft.-lbs. Steel quality has improved since Table 9 was developed, and impact properties at a particular test temperature have increased. Unless testing temperatures are reduced, the usefulness of A370/Table 9 will decrease.

American Iron and Steel Institute (AISI) sponsored a report on the mechanical properties of structural plate which included Charpy impact properties (Suwan, Manuel, & Frank, 2003). This study compared the tensile and Charpy properties produced in 2003 from A572 and A588 structural plate to properties generated in a similar study from 1989 (American Iron and Steel Institute, 1989). The Charpy impact data for the 2003 study was collected from four steel mills producing two different specifications (A572, A588) in four different plate thicknesses (≤ 0.75", 0.75"<t≤1.5", 1.5"< t ≤2.5", 2.5"< t ≤4") and at three different testing temperatures (0°F, 40°F, 70°F). Tables 17 and 18 list the statistics results for Charpy impact values from the 1989 study and the 2003 study, respectively. Charpy impact energies of the full size Charpy specimens increased between 200 and 300% in the time frame examined, depending on test temperature. These statistics were for all plate thicknesses. The tensile properties from a specific location in the plates were also compared with a previous study conducted by AISI in 1974 (American Iron and Steel Institute, 1974). The frequency distribution of ultimate strengths from these two studies is listed in Table 19. Tensile properties increased by about 30-50% although the earlier tensile property data generated in 1974 was only identified by carbon concentration. The carbon concentration range did however match that of both A572 and A588.

Conclusion:

Table 9 data agrees with the work performed by Curll and Orner when it was originally placed in A370 (1968) which correlates with 0-40 ft.-lb. impact properties proportional to area.

Bibliography

American Iron and Steel Institute. (1974). *The Variation of Product Analysis and Tensile Properties, Carbon Steel Plates and Wide Flange Shapes.* AISI.

American Iron and Steel Institute. (1989). *The Variations in Charpy V-Notch Impact Test Properties in Steel Plates.* AISI.

Curll, C. H. (1958). *Correlation of Selected Subsized Charpy Bars Versus the Standard Charpy Bar.* Watertown Arsenal Laboratories WAL TR 112/91.

Curll, C. H. (1959). *Subsize Charpy Correlation with Standard Charpy.* Watertown Arsenal Laboratories.

Curll, C. H. (1961, February). Subsize Charpy Correlation with Standard Charpy. *Materials Research and Standards, 1*, 91-94.

Gross, J. (1970). Effect of Strength and Thickness on Notch Ductility. *ASTM Special Technical Publication 466* (pp. 21-52). ASTM.

Suwan, S., Manuel, L., & Frank, K. H. (2003). *Statistical Analysis of Structural Plate Mechanical Properties.* Austin: American Iron and Steel Institute.

Towers, L. (1986, May). Testing Sub-size Charpy Specimens; Part 3 - The adequacy of Current Code Requirements. *Metal Construction, 18*(5), 319-322.

Table 1. Chemistry of selected (American Iron and Steel Institute, 1989) **steels** (Curll C. H.,

CHEMICAL COMPOSITIONS

Material	C	Mn	Si	P	S	Ni	Cr	Mo
Cast Steel	.28	.61	.26	-	-	2.37	.86	.45
AISI-4340	.37 to .385	.75 to .77	.27 to .28	.013 to .016	.013 to .015	1.70 to 1.80	.83 to .86	.25 to .27

1958)**.**

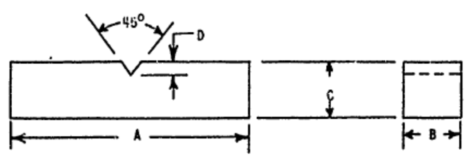
Table 2. Heat treatment of AISI 4340 steel (Curll C. H., 1958)**.**

AISI-4340 - Heat-Treat #1

Austenitize	1600°F	2 hrs.	Oil Quench
Draw	1200°F	2 hrs.	Oil Quench
Draw	570°F	3 hrs.	Air Cool

AISI-4340 - Heat-Treat #2

Normalize	1650°F	2 hrs.	Air Cool
Austenitize	1600°F	2 hrs.	Oil Quench
Draw	1035°F	2 hrs.	Oil Quench
Draw	570°F	3 hrs.	Air Cool



ALL NOTCH RADII = 0.010"

SIZE	A	B	C	D
	DIMENSIONS IN INCHES			
FULL	2.16	0.394	0.394	0.079
1/2	2.16	0.394	0.197	0.039
1/3	1.125	0.394	0.131	0.026
1/4	2.16	0.197	0.197	0.039
1/9	1.125	0.131	0.131	0.026

CHARPY V NOTCH SPECIMENS

Figure 1. Charpy specimen design (Curll C. H., 1958).

Table 3. Averaged* impact results of cast steel (Curll C. H., 1958).

TEMPER-ATURE °C	FULL SIZE ENERGY FT-LB	FULL SIZE FRACTURE % FIBROUS	1/2 SIZE E	1/2 SIZE F	1/3 SIZE E	1/3 SIZE F	1/4 SIZE E	1/4 SIZE F	1/9 SIZE E	1/9 SIZE F
R.T.	14.5†	100	6.6	100	4.8	100	3.5	100	1.7	100
+10	14.1	100	7.3	100	4.6	100	3.7	100	1.8	100
0	13.7	95	7.2†	95	4.0	95	3.4	100	1.4	100
-10	13.6	80	7.4†	90	4.2	95	3.6	95	1.5	100
-20	13.0	55	6.2	65	4.2	90	3.6	85	1.6	95
-40	12.5†	45	5.6	40	4.3	60	3.3	55	1.5	85
-60	10.2†	30	5.6	25	3.8	50	2.7	45	1.4	65
-80	8.8‡	20	4.3†	20	3.0	30	1.9	30	1.4	55
-100	7.7†	15	3.8	15	2.3	20	1.6	25	1.0	45
-125	6.1	10	3.6	10	1.6	15	1.5	20	.8	25
-150	4.2†	5	1.8	5	1.2	10	1.3	15	.9	20

*NOTE: Values with greater than 25% deviation from average were discarded.

† Represents one datum point discarded.

‡ Represents two data points discarded.

Table 4. Averaged* impact results of AISI 4340 - Heat Treatment #1 (Curll C. H., 1958).

TEMPER-ATURE °C	FULL SIZE ENERGY FT-LB	FULL SIZE FRACTURE % FIBROUS	1/2 SIZE E	1/2 SIZE F	1/3 SIZE E	1/3 SIZE F	1/4 SIZE E	1/4 SIZE F	1/9 SIZE E	1/9 SIZE F
R.T.	79.5	100	24.2	100	13.7	100	12.9	100	4.8	100
0	75.7	100	22.7	100	13.8	100	12.5	100	4.3	100
-20	72.0	100			13.4	100				
-40	71.3	100	21.9	100	13.2	100	11.4	100	4.6	100
-60	60.5	95	21.1	100	12.7	100	11.5	100		
-80	53.4	95	20.8	100	12.1	100	10.7	100	4.6	100
-90	44.7	80	20.5	100						
-100	32.5	60	19.1	95	10.6	100	10.1	95	4.2	100
-110			16.6	75	10.8	90				
-120	28.6	55	12.7	50	9.2	80	8.8	90	4.0†	100
-135			10.9	45	7.4	55	7.0	65	3.6	95
-150	20.4	15	8.8	25	6.7	45	6.7	45	3.5	90
-196									1.9	40

*NOTE: Values with greater than 25% deviation from average were discarded.

† Represents one datum point discarded.

Table 5. Averaged* impact results of AISI 4340 - Heat Treatment #2 (Curll C. H., 1958).

TEMPER-ATURE °C	FULL SIZE		1/2 SIZE		1/3 SIZE		1/4 SIZE		1/9 SIZE	
	ENERGY FT-LB	FRACTURE % FIBROUS	E	F	E	F	E	F	E	F
R.T.	45.8	100	16.2	100	8.5	100	7.9	100	2.8	100
-10	43.9	100							2.8	100
-40	40.0†	95	15.4	100	7.9	100	7.9	100	2.7	100
-50			14.3	100						
-60	28.6	75	11.7	80	7.9	100	6.6	95		
-80	26.7‡	60	9.3	55	6.5	85	5.5	70	2.5	95
-100	18.3‡	30	7.7	40	5.3	55	4.8†	55		
-120	15.6	20	6.2	20	4.5	40	3.8	35	2.2	85
-155	14.2	10	5.9	15	4.0†	30	3.1	20	1.4†	60
-196	13.1	10	5.7	10	3.6	25	2.7	10	0.6†	15

**NOTE:* *Values with greater than 25% deviation from average were discarded.*

† *Represents one datum point discarded.*

‡ *Represents two data points discarded.*

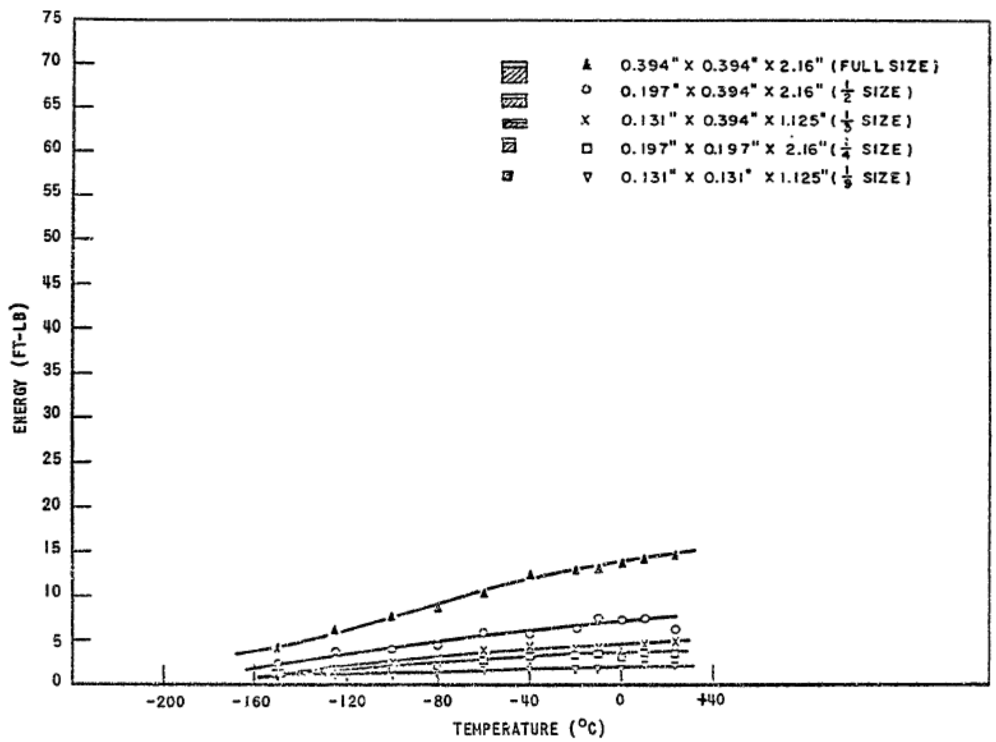


Figure 2. Energy versus temperature - Charpy V-notch cast gun steel (Curll C. H., 1958).

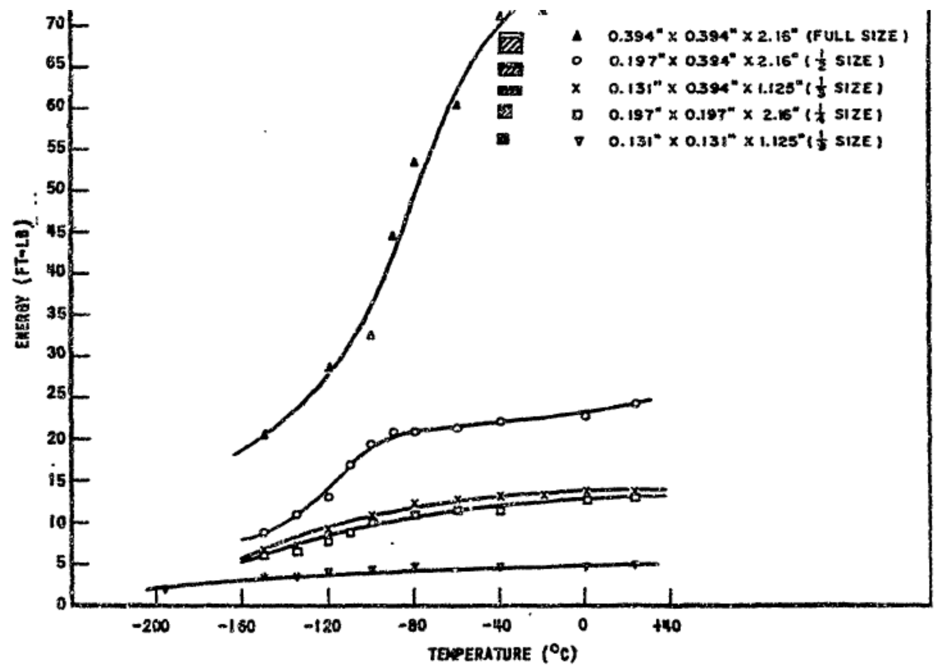


Figure 3. Energy versus temperature – Charpy V-notch AISI 4340 Heat Treatment #1 (Curll C. H., 1958).

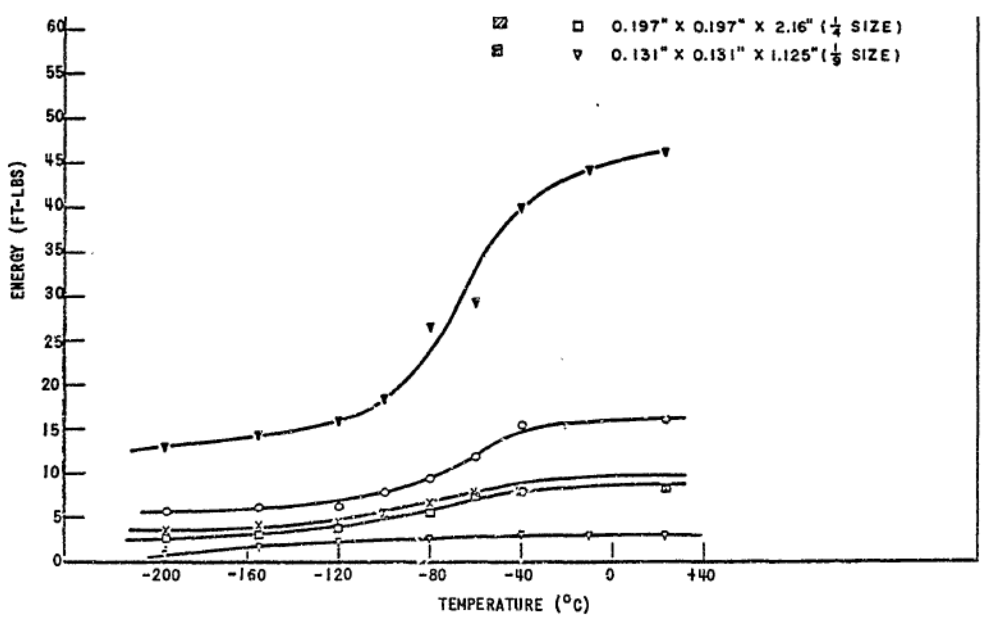


Figure 4. Energy versus temperature - Charpy V-notch AISI 4340 Heat Treatment #2 (Curll C. H., 1958).

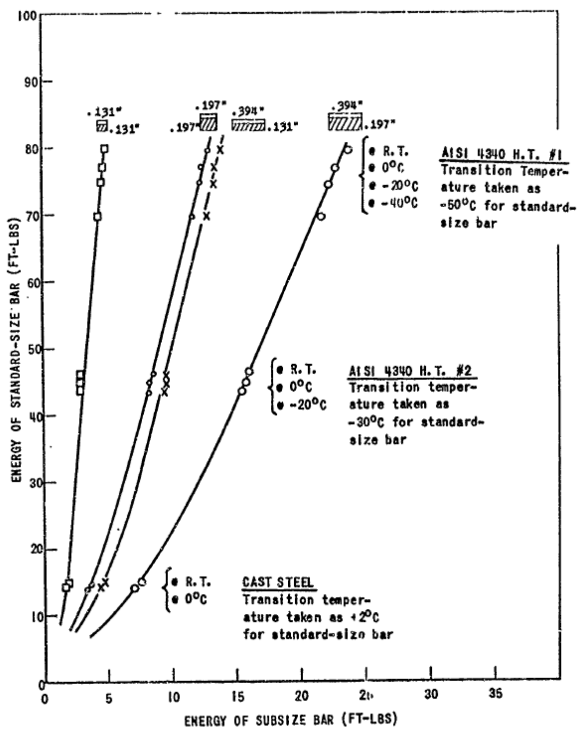


Figure 5. Correlation curves for subsize Charpy impact specimens above transition range (Curll C. H., 1958).

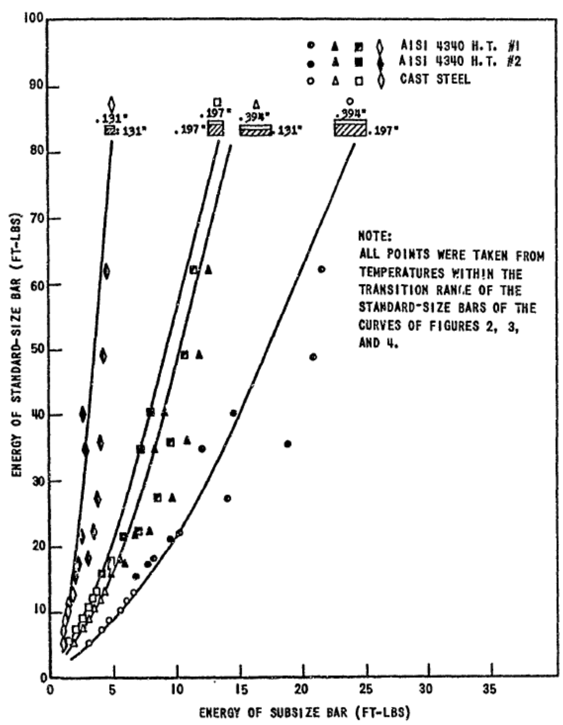


Figure 6. Effect of transition range on energy values as plotted on the correlation curves (Curll C. H., 1958).

Table 6. Chemistries of steels used in study (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

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.

Table 7. Heat treatment cycles for steels used in study (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

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

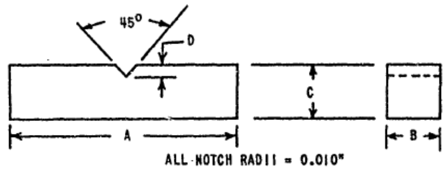
Normalize	1600°F	2 hrs.	Air Cool
Reheat	1550°F	2 hrs.	Agitated Oil Quench
Draw	1000°F	2 hrs.	Oil Quench

4. AISI-4140

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

Table 8. Hardness of steels used in study (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

	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



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 7. Geometry of Charpy specimens used in study (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

Table 9. Averaged* impact data AISI 2349 modified - transverse (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

TEMP. (°C)	F.S. ENERGY (Ft-Lb)	F.S. FIBROUS CONTENT (%)	1/2 S E	1/2 S F	1/3 S E	1/3 S F	1/4 S E	1/4 S F	1/2 S_D E	1/2 S_D F	1/3 S_L E	1/3 S_L 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

Table 10. Averaged* impact data AISI 3140 modified - transverse (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

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	13.6	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 11. Averaged* impact data AISI 4042 modified - transverse (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

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 12. Averaged* impact data AISI 4140 - longitudinal (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

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	6.8	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 13. Averaged* impact data Class 90 steel - transverse (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

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	6.8	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 14. Test results of nickel steel - transverse (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

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			19.8					
- 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

Table 15. Comparison of theoretical to experimental data (Curll C. H., Subsize Charpy Correlation with Standard Charpy, 1959).

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	21.5

*Allowable Tolerance
±5% over 20 ft-lb of energy
±1 ft-lb under 20 ft-lb of energy

Table 16. Subsize Charpy energy and temperature requirements for codes and standards (Towers, 1986).

Standard or code	Relating to:	Energy requirement as a fraction of that for a full size specimen. (Specimen thickness (mm) given in parentheses)	Modifications to test temperature for sub-size specimens relative to full size
Australia			
AS1204-1980	Structural steels	0.85 (7.5), 0.67 (5)	None
AS1205-1980	Structural steels		
AS1210-1977	Unfired pressure vessels	0.80 (7.5), 0.70 (5), 0.35 (2.5)	None
Canada			
CSA G40.20-M1978	Rolled or welded structural steel	0.85 (7.5), 0.75 (6.7), 0.67 (5), 0.5 (3.3), 0.33 (2.5)	None
F R Germany			
DIN 17100-1980	Structural steels	Proportional to area, down to 5mm thickness	None
France			
NFA36-208 (1978)	Non-alloy and nickel alloy steel plates for low temperature pressure vessels	Same energy as for full size specimen down to 5mm thickness	None
NFA36-209 (1976)	Austenitic stainless steel for low and very low temperature pressure vessels	Proportional to area	None
Bureau Veritas 1977	Rules and regulations for the construction and classification of steel vessels	0.83 (7.5), 0.67 (5)	None
Japan			
JIS G3126-1975	C-steel plates for pressure vessels for low temperatures	>half maximum absorbed energy	Reduced test temperature is required for some of the steels covered by G3126, by 5 and 15°C for 7.5 and 5mm thickness specimens, respectively
JIS G3211-1977	Forgings for steel pressure vessels	0.83 (7.5), 0.67 (5)	None
JIS G3460-1978	Steel pipes for low temperatures	0.86 (7.5), 0.67-0.71 (5), 0.33-0.36 (2.5)	None
JIS G3464-1978	Steel heat exchanger tubes for low temperatures	0.86 (7.5), 0.67-0.71 (5), 0.33-0.36 (2.5)	None
JIS G5201-1978	Cast steel pipes for welded structures	0.86 (7.5), 0.71 (5)	None
JWS WES3001-1973	Evaluating structural steels for low temperature service	>half maximum absorbed energy, except for 9%Ni steel for which 0.83 (7.5), 0.69 (5)	Reduced test temperature of 10 or 20°C for 7.5 or 5mm thickness, respectively, specified if required temperature for full size specimen is <20°C, but only when requirement is for >half maximum absorbed energy
Nippon Kaiji Kyokai 1978	Rules and regulations for the construction and classification of ships	0.83 (7.5), 0.67 (5)	None
Norway			
Det norske Veritas 1981	Rules for classification of steel ships	0.82-0.85 (7.5), 0.66-0.68 (5), 0.50-0.52 (2.5)	None

Table 176 (continued). Subsize Charpy energy and temperature requirements for codes and standards (Towers, 1986).

Standard or code	Relating to:	Energy requirement as a fraction of that for a full size specimen. (Specimen thickness (mm) given in parentheses)	Modifications to test temperature for sub-size specimens relative to full size
Det norske Veritas 1981	Rules for submarine pipeline systems	0.83 (7.5); 0.67 (5)	None
Det norske Veritas 1981	Rules for the design, construction and inspection of offshore structures	0.83 (7.5); 0.67 (5)	None
United Kingdom			
BS 1501: Part 1: 1980	C and C-Mn steels for pressure vessels	0.80-0.81 (7.5); 0.70-0.71 (5)	None
BS 1501: Part 2: 1970 (Addendum 1, 1973)	Alloy steels for pressure vessels	0.70-0.92 (7.5); 0.49-0.76 (5); 0.26-0.32 (2.5)	None
BS 1510: 1958	Low temperature supplementary requirements for BS 1501 to BS 1506	1.00 (7.5); 1.00 (5)	None
BS 4360: 1979	Weldable structural steels	0.82-0.85 (7.5); 0.66-0.68 (5)	None
BS 4741: 1971 (amendment 2: 1980)	Welded storage tanks for temperatures down to −50°C	0.80-0.81 (7.5); 0.70-0.71 (5); 0.37 (2.5)	None
BS 5500: 1982	Unfired fusion welded pressure vessels	0.80 (7.5); 0.70 (5)	None
Lloyd's Register 1981	Rules and regulations for the construction and classification of steel ships	0.81-0.84 (7.5); 0.66-0.68 (5)	None
USA			
ASTM A20-81b	Steel plates for pressure vessels	Proportional to area	None
ASTM A320-81	Alloy steel bolting materials for low temperature service	0.80 (7.5)	None
ASTM A333-81a	Seamless and welded pipe for low temperature service	Proportional to area	Test temperature should be reduced if testpiece samples less than 80% of the section thickness. Temperature reduction depends on the degree by which the testpiece thickness is less than section thickness, see Table 11.
ASTM A334-79	Seamless and welded carbon and alloy steel tubes for low temperature service	Proportional to area	
ASTM A350-81	Carbon and low alloy forgings requiring notch toughness testing for piping components	Proportional to area	
ASTM A673-81a	Sampling procedure for impact testing of structural steel	Proportional to area	None
API 5LX-1982 (SR8)	High test line pipe	Proportional to area	None
API 620-1978	Large, welded low pressure storage tanks	For storage of liquefied hydrocarbon gases: 0.75 (7.5); 0.65 (6.7); 0.50 (5); 0.35 (3.3); 0.25 (2.5). For storage of refrigerated products: 0.83 (7.5); 0.67 (5)	None
API 650-1980	Welded steel tanks for oil	Proportional to area	None

Table 186 (continued). Subsize Charpy energy and temperature requirements for codes and standards (Towers L. , 1986).

Standard or code	Relating to:	Energy requirement as a fraction of that for a full size specimen. (Specimen thickness (mm) given in parentheses)	Modifications to test temperature for sub-size specimens relative to full size
ASME BPV-VIII-I (1980) BPV-VIII-II (1980)	Construction of pressure vessels	Proportional to area	Test temperature should be reduced if testpiece samples less than 80% of the section thickness. Temperature reduction depends on the degree by which the testpiece thickness is less than section thickness, see Table 11.
ASME B31.3a-1981	Chemical plant and petroleum refinery piping	Proportional to area	
AWS D1.1.-1981	Structural welding code—steel	0.84 (7.5) 0.67 (5) 0.33 (2.5)	None
ABS, rules for building and classing steel vessels, 1981	Low temperature materials for steel vessels	0.83 (7.5) 0.67 (5) 0.50 (2.5)	None
SAE J231-1980 J1043-1980	Falling object protective structures.	0.86 (7.5) 0.77 (6.7) 0.68 (5) 0.55 (3.3) 0.50 (2.5)	None

Table 197. Statistics of Charpy impact energies from 1989 study (American Iron and Steel Institute, 1989).

ASTM Specification	Test Temperature	Three-Test Average of Absorbed Energy (ft-lbs)					No. of Tests
		Mean	SD	COV (%)	Min	Max	
A 572	0°F	21.2	11.2	52.8	4.7	77.0	785
	40°F	36.4	15.0	41.2	8.0	91.0	785
	70°F	53.5	19.4	36.3	16.0	124.7	785
A 588	0°F	40.6	28.5	70.2	3.7	165.0	417
	40°F	62.9	39.5	62.8	5.3	290.0	417
	70°F	85.2	45.2	53.1	11.3	256.0	417

Table 18. Statistics of Charpy impact energies from 2003 study (Suwan, Manuel, & Frank, 2003).

ASTM Specification	Test Temperature	Three-Test Average of Absorbed Energy (ft-lbs)					No. of Tests
		Mean	SD	COV (%)	Min	Max	
A 572	0°F	61.9	46.2	74.6	3.0	175.0	224
	40°F	82.9	48.1	58.0	5.7	194.7	224
	70°F	100.7	48.2	47.8	7.7	210.0	224
A 588	0°F	108.6	71.9	66.2	7.0	303.3	259
	40°F	143.7	74.5	51.9	12.0	299.0	259
	70°F	162.4	66.5	40.9	17.7	318.7	259

Table 19. Frequency distributions of tensile strength at reference location (Suwan, Manuel, & Frank, 2003).

Range (ksi)	Frequency (%)		
	1974 Study	Present Study	
	Carbon Steel	A572	A588
$20 \leq F_u < 30$	-	-	-
$30 \leq F_u < 40$	-	-	-
$40 \leq F_u < 50$	2.3	-	-
$50 \leq F_u < 60$	18.8	-	-
$60 \leq F_u < 70$	56.5	-	-
$70 \leq F_u < 80$	16.8	22.8	42.1
$80 \leq F_u < 90$	5.6	74.3	52.6
$F_u \geq 90$	-	2.9	5.3
No. of Tests	357	35	38