

Chapter 14. Destructive Testing of Welds

Historically, the testing of welds in welded structures is as old as welding. Early testing was directed toward detecting gross defects and evidence of ductility. This evolved into tests designed to determine specifics such as chemical, mechanical, and metallurgical properties, and to locate defects such as cracks, porosity, incomplete fusion, inadequate joint penetration, entrapped slag, etc.

Some of these tests are, of necessity, destructive in nature. They are performed on sample weldments made with procedures similar to those to be used in the final fabrication. Tests are conducted for the qualification of welding procedures, the qualification of welders and welding operators, and for quality control. In terms of the weldments, destructive tests may be chemical tests, metallographic tests, mechanical tests, or any combination thereof. The tests generally specified are those that provide reasonable assurance of the dependability of the weldment in service.

The ideal test would, of course, be one that exactly duplicates the service conditions. However, the difficulty of applying such tests is obvious; thus, certain standard tests are alternatively used. Details of accepted destructive tests of welded joints and deposited filler metals can be found in AWS B4.0-77, Standard Methods for Mechanical Testing of Welds.

The inspector has the responsibility to confirm that specified tests are conducted properly and that test results are in compliance with required conditions. The inspector needs to be thoroughly familiar with the testing procedures, the effect of revealed defects on the test results, and the interrelation of defects in the test sample with the same types of defects in the production weldment. With a thorough background in these, he will be able to discuss test results with engineering personnel to gain final acceptance or rejection of production work. No matter

how carefully codes and specifications are written, much is left to the judgment of the inspector. In fairness to himself, the manufacturer, and his employer, he should equip himself with a thorough knowledge on which to base his decisions. The inspector has the sole responsibility of confirming that the weld joint properties are in accordance with the specification. Acceptance of material that gave test results that do not meet specification can only be made by an authorized engineer.

Brief descriptions of various types of standard destructive tests applied to welds and weldments follow. The effect of defects on the results of these tests is presented briefly. It is realized that much more could be written; but it is hoped that interested inspectors will avail themselves of opportunities for further study of the technical literature.

Tests should be performed with careful attention to specimen preparation and test procedure. The quality and reliability of test results is in direct proportion to the care taken in the test. In general, the term "destructive testing" is used to describe an evaluation process of a weld by a technique that of necessity destroys the test specimen or destroys its ability to function in its design application. The destructive testing technique must, therefore, be used with some form of partial sampling, rather than complete sampling (see Chapter 13).

The destructive testing techniques can be classified as three general types: chemical, metallographic, and mechanical.

Chemical Tests

Chemical tests are, ordinarily, used to determine either chemical composition or corrosion resistance. Tests for chemical composition are often required to ascertain whether the base metal and the weld metal meet the requirements of the codes or specifications. Special analyses

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of base metal and weld metal are used for special service requirements. Experience has shown what range of composition is suitable for a particular service condition.

Weld joint defects are sometimes caused by variations in chemical composition of the base or filler metals. These materials are designed to perform satisfactorily when used within the chemical composition limits specified. Variations in composition such as high sulfur or phosphorous, or residual elements such as tin, can cause harmful defects. Complete chemical analysis should be available to permit thorough review of material composition when cracking due to hot shortness or other defects persists.

In general, deposited composition of the weld metal is specified in the same range as that of the base metal. Sometimes, however, a weld metal of significantly different composition from the base metal is specified, depending upon the service requirements of the joint.

Corrosion Tests

Welded equipment for the chemical industry and other industries must perform satisfactorily in many environments; some of which are corrosive. Many tests have been devised to simulate the type of corrosion anticipated in operation. These tests can accelerate trans- or intergranular corrosion, stress corrosion, stress corrosion cracking, and many other types of attack. Tests are conducted under laboratory conditions and can provide an accurate forecast of the weldment performance in service.

Welding is used for joining a wide range of metals, including iron, nickel, copper, aluminum, magnesium, titanium, and their alloys. Corrosion tests are available for all constructional alloys. No effort will be made to describe any specific test in this text. Details of test procedures for conducting corrosion tests can be found in ASTM Standards (refer to the Annual Index to Standards for specific test procedures).

Metallographic Tests

Metallographic tests are not often required in specifications for weldments. However, they are used to determine:

- (1) The soundness of the welds

- (2) The distribution of nonmetallic inclusions in the weld

- (3) The number of weld passes

- (4) The metallurgical structure in the weld and fusion zone

- (5) The extent and metallurgical structure of the heat-affected zone

- (6) The location and depth of penetration of the weld

These may involve merely visual examination, in which case the specimens (called macro-specimens) are etched to bring out the gross structure and bead configuration and are examined by the unaided eye or at magnifications below 10×; or they may involve microscopic examination, in which case the specimens (called micro-specimens) are prepared and etched for examination at high magnifications over 10×.

Samples may be secured by sectioning test welds or production control welds including run-off tabs. They can be prepared by cutting, machining, or grinding to reveal the desired surface and can be subjected to further preparation as needed.

Sectioning production welds by core drilling or trepanning has been used for years as a quality control tool. However, the rewelding of the cored or trepanned areas was often more difficult than the original welding and frequently produced defects in the repair area. This concern, together with the extensive improvements in nondestructive testing, have made obsolete the sectioning of production welds as a quality control tool. In fact, many users prohibit sectioning for such purposes. However, sectioning remains an important tool for failure analysis.

Macro-Specimens: For macroscopic examination different metals require different methods of preparation. As an example, for plain carbon steel welds, the surface to be examined may be prepared by one of the following methods:

- (1) Without requiring any finishing or other preparation, place in a 50 percent solution of hydrochloric acid in water at 150° F (66° C) until there is a clear definition of the macro-structure of the weld. This will require approximately one-half hour immersion.

- (2) Grind and smooth specimens with emery

wheel or emery paper, and then etch by treating with a solution of one part ammonium persulfate (solid) and nine parts of water by weight. The solution should be used at room temperature and should be applied by swabbing the surface to be etched with a piece of cotton that is always saturated with the solution. The etching process should be continued until there is a clear definition of the macro-structure of the weld.

After being etched, the specimens are washed in clear water and the excess water is removed. The specimens are then immersed in ethyl alcohol and dried. The etched surface may be preserved by the application of a thin, clear lacquer. Figure 14.1 shows two typical macro-etched samples (see also illustrations of weld flaws in Chapter 9).

Macroscopic examination exposes a two-dimensional section of the welded joint and does not provide information on general weld quality. Defects known to exist by nondestructive testing or other means can be exposed for evaluation by using macro-specimens.

Micro-Specimens: In examining for exceedingly small defects or for metallurgical struc-

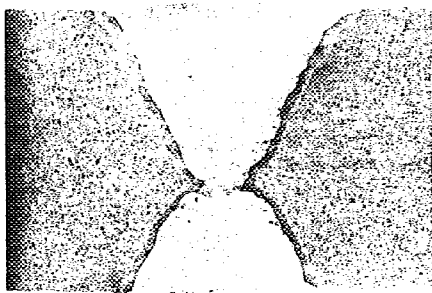


Fig. 14.1—Typical photomacrographs



Fig. 14.2—Photomicrograph illustrating the appearance of a crack in the heat-affected zone (100 ×, approx.)

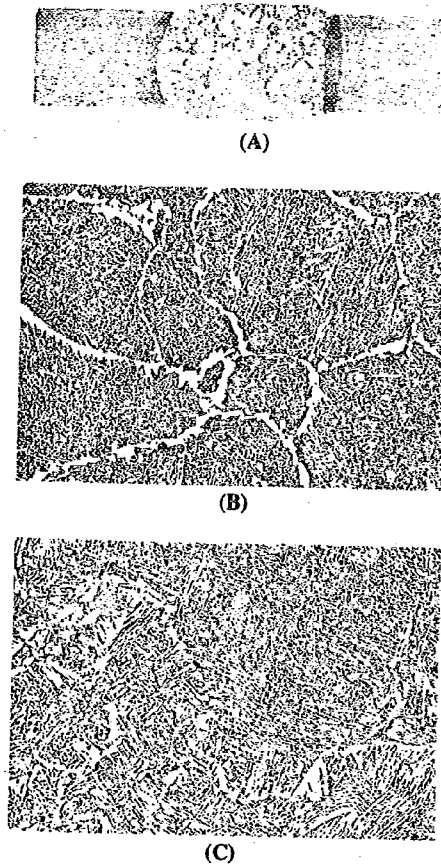
ture at high magnification, specimens may be cut from the actual weldment or from welded test samples. The samples are given a highly polished mirror-like surface and etched for examination with a metallograph at a desired magnification to reveal the structure of the base metal, heat-affected zone, fusion zone, and weld metal.

The specimens, called micro-specimens, are used when the weld structure is to be examined in detail at high magnification. Figure 14.2 shows a typical photomicrograph. Figure 14.3 shows photomicrographs and a photomacrograph of a 1 in. electroslag weld.

Samples such as these are required in only a few codes and specifications, but they are very useful in tracking down solutions to problems. A trained metallographer can read a great deal from microscopic examinations. However, the procedure is complicated; considerable skill is necessary to properly polish the samples and to use the proper etchants and technique to show what is desired. (For a detailed discussion of microscopic examination procedures, reference may be made to ASTM Standards E2 and E3.)

Hardness Tests

Hardness is affected by the composition of the base metal and the weld metal, the metallurgical effects of the welding process, cold working of the metal, heat treatment, and many



**Fig. 14.3—(A) Photomacrograph 1 in. thick electrosag weld in ASTM A236;
(B) Photomicrograph ($\times 100$) of heat-affected zone of same weldment;
(C) Photomicrograph ($\times 100$) of weld metal, same weldment**

other factors. Experience has dictated that limitations be placed on the hardness of the base metal, heat-affected zone, fusion line, and weld metal of certain metals, usually alloy steels. If too hard, they will not have sufficient ductility for the service conditions, their corrosion resistance may be impaired, or some other factor may dictate this limitation.

It is desirable, however, to cover the three most widely used methods of measuring hard-

ness and briefly mention their limitations and the factors that must be considered to obtain true readings. Portable machines using the same or very similar principles are often used, and the inspector should acquaint himself with the use and limitations of the several types. The three most widely used scales for hardness measurement are the Brinell, the Rockwell, and the Vickers hardness tests.

Equipment used for hardness testing differs in many respects, as indicated in subsequent paragraphs. For the welding inspector, the most important difference involves the size of the indicator, which may range from a 10 mm diameter ball to a small diamond tip. When such tools are used, the metal indentation may range between 5 mm and a small fraction of a millimeter. For reasonably homogenous base metal and weld metal, the size of the indentation has little effect on the test results. However, when an HAZ that may be 3 mm wide and contains several metallurgically differing zones is tested, the size of the indentation is of major importance. A small indenter may detect the hardened zone or the soft or tempered zone, while the 10 mm ball represents an average value. Thus, any test requirement that includes HAZ hardness should specify and record the size of the indenter employed.

Brinell: The Brinell hardness test consists of impressing a special hardened steel ball into the specimen under test, using a definite load for a definite time and accurately measuring the diameter of the impression. The specimen should be thick enough so that no anvil effect is encountered. Stationary machines employ hydraulic pressure to impress a 10 mm ball into the specimen. The load for steel is 3000 kg and for softer metals, 500 kg.

The diameter of the impression is measured by the eye, using a special, highpower Brinell microscope graduated in tenths of millimeters. The average of two diameters at right angles to each other is determined and the Brinell hardness number obtained from a chart or table of diameters of impression related to hardness numbers.

An alternate portable method of Brinell testing is available. This test consists of impressing

a 10 mm ball simultaneously into a specimen of known hardness and the test piece. To obtain a hardness number the tester is held in such a way that the ball is between the bar of known hardness and the specimen. The anvil is struck a sharp blow with a hammer and the diameters of the indentations made in the bar and the specimen are measured. The hardness is calculated from tables or a special slide rule. Brinell hardness numbers can be multiplied by 500 to obtain the approximate tensile strength of the material being tested.

Several precautions should be taken to ensure obtaining true hardness values. The surface to be tested should be flat and reasonably free from scratches. Impressions should be taken at representative locations. The specimen should be firmly supported in such a way that the load is applied normal to the surface of the specimen. The test should not be used on specimens of soft steel that are less than about 1/2 in. (13mm) thick, or on specimens so small as to produce flow of metal at the edges as a result of the ball impression. Impressions should not be taken closer than about two diameters from each other, else the cold work caused by the previous impression will produce erroneous data.

Rockwell: The Rockwell hardness tester measures the depth of residual penetration made by a small hardened steel ball or a diamond cone. The test is performed by applying a minor load of 10 kg which seats the penetrator in the surface of the specimen and holds it in position. The dial is turned to the point marked "Set" and the major load is applied. After the pointer comes to rest, the major load is released, leaving the minor load still on. The Rockwell hardness number is read directly on the dial.

As Rockwell hardness numbers are based on the difference between the depths of penetration at major and minor loads, it will be evident that the greater this difference, the less the hardness number and the softer the material. This difference is automatically registered when the major load is released (the minor load still being applied) by a reversed scale on the indicator dial, from which the Rockwell hardness number may be read directly. Hardened steel balls of 1/8 in. or 1/16 in. (3.2 mm or 1.6 mm) diameter

are used for the softer metals, and a cone-shaped diamond penetrator is used for hard metals.

Several precautions should be taken to ensure obtaining true values. Surfaces that are ridged by rough grinding or coarse machining offer unequal support to the penetrator. Both the surface at the penetrator side and the underside should be free of perceptible ridges. The specimen should seat solidly, with no rocking, and should be of such thickness that the underside of the specimen does not show a perceptible impression. This thickness will vary greatly according to the hardness of the material treated. Softer material requires greater thickness of specimen, or lighter load, or both. Results from tests on a curved surface may be in error and should not be reported without stating the radius of curvature. In testing round specimens, the effect of curvature may be eliminated by filing a small flat spot on the specimen. Impressions should not be made within about two diameters of the edge of the specimen, nor closer than that to each other. When changing from one scale to another, a standard test block of a specified hardness in the range of the new scale should be used to check whether all the required changes have been made and whether the penetrator has seated properly. Care should be taken not to damage the penetrator or the anvil by forcing them together when a specimen is not in the machine. The minor load should be applied carefully so as not to overshoot the mark. The loading lever should be brought back gently. The ball penetrator tends to become flattened by use, especially in testing hardened steels, and should be checked occasionally and replaced when necessary. In the same manner, the cone penetrator should be examined and replaced when it is found to be blunted or chipped.

Vickers: The Vickers hardness test is another of the class of tests that measure resistance to penetration. It is generally used as a laboratory tool by the engineer to determine hardness of the constituents of the welded joint.

The Vickers hardness test consists of impressing a square-based pyramid indenter into the surface of a specimen under a predetermined load. The indenter is forced into the specimen and the diagonals of the square impression are

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measured and averaged.

$$\text{DPH (diamond pyramid hardness)} = 1.854 \frac{P}{D^2}$$

P = load in kilograms

D = average of the measured diagonals of the indentation expressed in mm.

The application and removal of the load after a predetermined interval are controlled automatically. Since the Vickers indenter is a diamond, it can be used in testing the hardest steels and remains practically undeformed. The load is light, varying from 1 to 120 kg, according to requirements. A normal loading of 30 kg is used for homogeneous materials, and 10 kg is used for soft, thin, or surface-hardened materials. The specimen surface preparation is very important; it should approach a metallographic polish.

Summary: Each of the above hardness tests supplements the others. The Brinell impression, being large, can only be used for obtaining hardness values over a relatively large area such as the face of a weld or the base metal. The Rockwell test and the Vickers test, however, can be applied to survey the hardness of small zones such as the cross section of a weld, the fusion line, the heat-affected zone, or various individual beads. Conversion data from the Rockwell to the Brinell to the Vickers are available. Table 14.1 shows a typical conversion chart. In using this chart, however, it should be remembered that the data were obtained from a large number of tests and represent average values. The scattering obtained in the actual tests was considerable and depended greatly upon the analyses of materials and their condition.

Mechanical Tests

For any engineering product, the quality of welds depends to a large extent on competent inspection and adequate testing. In general, experience indicates that mechanical tests for weld strength and other weld properties are reliable tests to determine the quality of welds. In addition, other tests (both destructive and non-destructive) can be used.

Mechanical tests for welds are similar to the mechanical tests applied to base metals, altered

as necessary to determine the properties of welds. There are other specialized tests used to determine material properties; however, these are beyond the scope of this section.

This section gives suggested requirements for specimen testing, and the methods of obtaining desired information. It is not a specification. Those who include these tests as a portion of a specification for a welded product should state definitely:

- (1) The one or more tests that are required
- (2) The AWS or other applicable standard that covers the procedures for testing
- (3) The limiting numerical values of the properties and whether these values are minimum or maximum
- (4) The interpretation, if any, of the properties

Although there is agreement among welding engineers on properties to be determined and, in general, on test procedures, there has been a wide divergence relative to the shape and size of the specimens and the details of the test procedures. This considerably increases the cost of the tests and decreases the usefulness of the results obtained, since different codes and specifications cannot be compared directly. Standardization in this field has advantages for all concerned.

In preparing this section, no attempt has been made to promote the use of new or unused tests, nor to elaborate upon the usual test procedure, however desirable this might appear from a theoretical viewpoint. The tests in wide use today are presented here, but modifications are to be expected as new materials and processes are brought into use.

This section will describe tests for determining the mechanical properties of weld metal and welded joints, including the standard tension tests, shear tests, and some other tests that are commonly used, though somewhat specialized.*

*All tests described may be carried out in accordance with applicable ASTM Standards. Some of these are:

- (1) E8, Tension Testing of Metallic Materials
- (2) E23, Notched Bar Impact Testing of Metallic Materials
- (3) E190, Guided Bend Test for Ductility of Welds

If there are specifications for the base metal, tests should be conducted in accordance with these specifications. If no such base metal specifications have been listed, yet a test is desired, the tests should be conducted in accordance with the standards of ASTM.

The terminology used in this section conforms to the ASTM Standard E6, Standard Definitions of Terms Relating to Methods of Testing. The term "soundness" as used here means a degree of freedom from defects discernible by visual inspection of any exposed surface of weld metal. In reports of tests made in accordance with this section, nomenclature should conform to the above standards and definitions.

Mechanical Properties: The weld metal properties most generally required by specifications (tensile strength, yield point, yield strength, and ductility) will be described briefly. (Reference may be made to AWS or ASTM Standards for detailed definition and explanation of these properties, as well as for others not covered.)

Tensile Strength. Since a large proportion of design is based on tensile properties, it is important that the tensile properties of the base metal, the weld metal, the bond between the base metal and weld metal, and the heat-affected zone conform to the design considerations of the weldment. Where butt joints are used, the weld metal should usually develop the minimum tensile properties of the base metal. In the case of fillet welds, plug welds, and spot welds, shear strength is usually the significant factor. Tensile strength of weld metal or weld joints is obtained by pulling a specimen to failure. All-weld-metal specimens are usually cylindrical (0.505 in. diam. [12.7mm]). Welded joint specimens are usually rectangular, reduced cross-section specimens as shown in AWS B4.0-77, Standard Methods for Mechanical Testing of Welds, section 4.1. Tensile strength is determined by dividing the maximum load by the cross-sectional area. The result will be in units of tension per cross-sectional area.

Yield Point and Yield Strength: These properties are determined with the same specimens that determine tensile strength. Yield properties are usually obtained for individual parts of the welded joints, such as base metal or

weld deposit.

Yield Point. Yield point is defined as the load per square inch of the original cross-sectional area that causes a marked increase in extension without increase in the load. The yield point may be determined by one of the methods described in the following paragraphs.

Drop of the Beam Method. In this method the load is applied to the specimen at a steady rate of increase. The operator keeps the beam in balance by running out the poise at an approximately steady rate. When the yield point of the material is reached, the increase of load stops, and the beam of the machine drops for a brief but appreciable interval of time. In a machine fitted with a self-indicating load-measuring device, there is a sudden halt of the load-indicating pointer. This point corresponds to the drop of the beam. The load at the "halt in the gage" or the "drop of the beam" is recorded, and the corresponding stress is taken as the yield point. This method of determining yield point requires only one operator to conduct the test.

Total Strain Method Using Extensometer. An extensometer reading to 0.0001 inch per inch of gage length is attached to the specimen at the gage marks. When the specimen is in place and the extensometer attached, the load is increased at a uniform rate. The observer watches the elongation of the specimen as shown by the extensometer and notes for this determination the load at which the rate of elongation shows a sudden increase.

Note:

The strain method is more sensitive and may show the start of the yield elongation at a slightly lower stress than that given by the first method.

Yield Strength. Yield strength may be defined as the load per square inch of cross-sectional area that caused a specific set as determined by either of two methods.

Offset Method. For nearly all metals, if at any point on the stress-strain diagram the load is released, the curve of decreasing load will be approximately parallel to the initial portion of the curve of increasing load (see Fig. 14.4 for a typical stress-strain diagram). These curves may, however, be offset after the release of load. The value of this set is expressed in terms

Table 14.1
Typical Hardness Conversion Table (Approx.)

Left Column						Right Column					
Rockwell Hardness		Vickers Hardness*	Brinell Hardness†		Tensile strength, 1000 psi.	Rockwell Hardness		Vickers Hardness*	Brinell Hardness†		Tensile strength, 1000 psi.
C-150 kg. load, diamond	B-100 kg. load, 1-1/16 ball	Diamond pyramid	Tungsten carbide ball	Steel ball		C-150 kg. load, diamond	B-100 kg. load, 1-1/16 ball	Diamond pyramid	Tungsten carbide ball	Steel ball	
67	...	918	820	...	...	20	98.9	240	231	225	107
66	...	884	796	...	...	19†	93.1	235	226	220	106
65	...	852	774	...	...	18	97.5	231	222	215	103
64	...	822	753	...	...	17	96.9	227	218	210	102
63	...	793	732	...	...	16	96.2	223	214	206	100
62	...	765	711	...	...	15	95.5	219	210	201	99
61	...	740	693	...	...	14	94.9	215	206	197	97
60	...	717	675	...	...	13	94.1	211	202	193	95
59	...	694	657	...	...	12	93.4	207	199	190	93
58	...	672	639	...	...	11	92.6	203	195	186	91
57	...	650	621	...	...	10	91.8	199	191	183	90
56	...	630	604	...	...	9	91.2	196	187	180	89
55	...	611	588	...	...	8	90.3	192	184	177	88
54	...	592	571	...	...	7	89.7	189	180	174	87
53	...	573	554	...	283	6	89	186	177	171	85
52	...	556	538	...	273	5	88.3	183	174	168	84
51	...	539	532	500	264	4	87.5	179	171	165	83
50	...	523	508	488	256	3	87	177	169	162	82
49	...	508	494	476	246	2	86	173	165	160	81
48	...	493	479	464	237	1	85.5	171	163	158	80
47	...	479	465	453	231	0	84.5	167	159	154	78
46	...	465	452	442	221	...	83.2	162	153	150	76
45	...	452	440	430	215	...	82	157	148	145	74
44	...	440	427	419	208	...	80.5	153	144	140	72
43	...	428	415	408	201	...	79	149	140	136	70
42	...	417	405	398	194	...	77.5	143	134	131	68
41	...	406	394	387	188	...	76	139	130	127	66
40	...	396	385	377	181	...	74	135	126	122	64
39	...	386	375	367	176	...	72	129	120	117	62
38	...	376	365	357	170	...	70	125	116	113	60
37	...	367	356	347	165	...	68	120	111	108	58
36	...	357	346	337	160	...	66	116	107	104	56
35	...	348	337	327	155	...	64	112	104	100	54
34	...	339	329	318	149	...	61	108	100	96	52
33	...	330	319	309	147	...	58	104	95	92	50

Table 14.1 (cont.)
Typical Hardness Conversion Table (Approx.)

Rockwell Hardness						Rockwell Hardness					
Vickers Hardness*						Vickers Hardness*					
Brinell Hardness†						Brinell Hardness†					
C-150 kg. load, diamond	B-100 kg. load, 1-1/16 ball	Diamond pyramid	Tungsten carbide ball	Steel ball	Tensile strength, 1000 psi.	C-150 kg. load, diamond	B-100 kg. load, 1-1/16 ball	Diamond pyramid	Tungsten carbide ball	Steel ball	Tensile strength, 1000 psi.
32	...	321	310	301	142	...	55	99	91	87	48
31	...	312	302	294	139	...	51	95	86	83	46
30	...	304	293	286	136	...	47	91	83	79	44
29	...	296	286	279	132	...	44	88	80	76	42
28	...	288	278	272	129	...	39	84	76	72	40
27	...	281	271	265	126	...	35	80	72	68	38
26	...	274	264	259	123	...	30	76	67	64	36
25	...	267	258	253	120	...	24	72	64	60	34
24	...	261	252	247	118	...	20	69	61	57	32
23	...	255	246	241	115	...	11	65	57	53	30
22	100.2	250	241	235	112	...	0	62	54	50	28
21	99.5	245	236	230	110	...	...	...	...	...	...

*Vickers hardness values obtained with following loads:

918 to 171, inclusive	kg.
167 to 95, inclusive	50
91 to 61, inclusive	30
	10

†Brinell hardness values obtained with 3000 kg. load except tungsten carbide ball values 159 to 86, inclusive, obtained with 1500 kg. load and from 83 to 54, inclusive, with 500 kg. load.

Rockwell C values below 20 are not recommended for correlation; however, these values are sufficiently accurate to indicate the trend of relationship.

of the percentage of original gage length. Thus, yield strength may be determined by the offset method as follows:

On the stress-strain diagram shown in Fig. 14.4, a straight line is drawn parallel to the initial straight line portion of the diagram and at a distance to the right corresponding to the value of set specified. The load corresponding to the point where this straight line intersects the initial curve, divided by the original cross-sectional area of the specimen, is the value of the "yield strength."

In reporting values of yield strength obtained by this method, the specified value of offset used should be stated in parentheses after the term "yield strength." Thus, "52,000 psi yield strength (0.2 percent)" indicates that at a stress of 52,000 psi, the approximate permanent set of the metal is 0.2 percent of the original gage length. This method is devised for determining a stress corresponding to a well-marked plastic deformation.

Extension Under Load Method. For tests to determine the acceptance or rejection of material

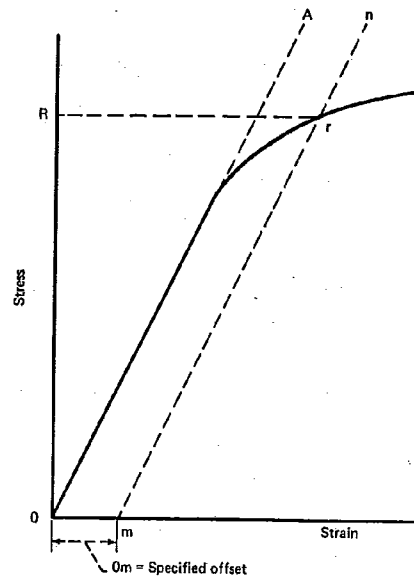


Fig. 14.4—Typical stress-strain diagram used in the offset method

whose stress-strain characteristics are well known from previous tests of similar material in which stress-strain diagrams were plotted, the total strain corresponding to the stress at which the specified permanent set occurs will be known within satisfactory limits.

Therefore, in such tests, a specified total strain may be used, and the stress on the specimen, when this total strain is reached, is the value of the yield strength. To determine yield strength by this method, the initial reading of the extensometer for the initial load is recorded, and the load increased until the extension in the specimen is that prescribed. The corresponding load divided by the original cross-sectional area of the specimen is the yield strength.

Ductility. Ductility, or percentage elongation and reduction of area, may also be obtained from the tensile test. Ductility values are not usually used in designing a structure; nevertheless, minimum values are included in most specifications because they indicate the quality of the weld metal.

Percentage elongation is obtained by placing

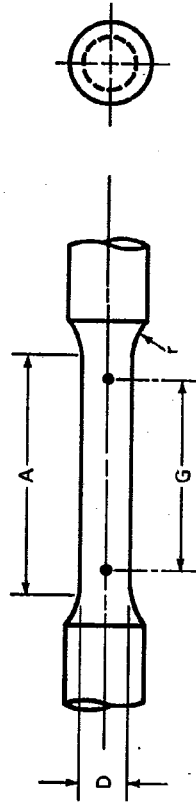
gage marks on the specimen (usually using a double center punch with the points accurately distanced to the gage length required) before testing. After testing, the broken specimen is fitted tightly together and the final distance between gage marks measured. The difference between the final and original gage lengths, divided by the original gage length and multiplied by 100, gives the percentage elongation in the specified gage length. Sometimes, because of defective machining or some other factor, the specimen will not break in the center portion of the gage length and may even break completely outside the gage length. In such cases, the test results are usually not acceptable, because most of the elongation has taken place at a position other than where originally intended.

Elongation of a specimen under tensile load is uniform until necking occurs. Thereafter, elongation is confined almost exclusively to the small area of the neck. This area of localized necking would be a greater proportion of a short gage length than of a long gage length. Other things being equal, the shorter the gage length, the higher the percent elongation obtained from any given specimen.

Reduction of area is determined by carefully fitting together the ends of the fractured specimen and measuring the dimensions of the smallest cross section. The difference between this area and the original cross-sectional area, expressed as a percentage of the original area, is defined as the reduction of area.

Standard Tension Test: The standard tension test specimen should comply with the requirements of Fig. 14.5. The standard specimen should be used unless the size of the welded joint or deposited weld is such that a specimen of this size cannot be machined from it. In this case, the 0.350 in. or 0.250 in. specimen may be used, choosing the specimen with the largest diameter that can be machined from the material to be tested. The portion of the specimen included in the gage length G should consist entirely of metal from the deposited zone of the joint. End preparation of tension specimens may be of any shape to fit the type jaws used in the tension testing machine.

All three specimens are geometrically similar in all significant dimensions. Therefore, the



Nominal diameter	Dimensions	
	Standard specimen 0.500 in. round	Small-size specimens proportional to standard 0.350 in. round
G — Gage length	2.000 ± 0.005	1.400 ± 0.005
D — Diameter (Note 1)	0.500 ± 0.010	0.350 ± 0.007
r — Radius of fillet, min	3/8	1/4
A — Length of reduced section (Note 2), min	2-1/4	1-3/4
		1-1/4

Notes:

1. The reduced section may have a gradual taper from the ends toward the center, with the ends not more than one percent larger in diameter than the center (controlling dimension).
2. If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gage length. Reference marks for the measurement of elongation should be spaced at the indicated gage length.
3. The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. If the ends are to be held in wedge grips, it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.

Fig. 14.5—Standard tension specimens

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properties determined from any one of them tend to be approximately the same as the properties determined from the others. However, it is desirable that comparisons be made only between specimens of the same size. Percent elongation is particularly affected by the gage length used for the test.

The apparatus, material, methods, and rate of depositing the weld metal in the test plate should, so far as practicable, be the same as those used in making welds with the given filler metal.

Note: Due to unavoidable differences in the method of depositing the filler metal and the rates of cooling, the properties of the weld metal determined from a specimen will depend upon the dimensions of the adjacent metal. Therefore, it is preferred that the test specimens be removed from a weldment geometrically similar to the production weldment. For thermit welds, a suitable refractory material may be used for a trough in which the weld metal is allowed to solidify.

In the standard tension test procedure, the diameter of the specimen at the middle of the reduced section should be measured in inches and the gage length defined by a gage mark at each end. The specimen is then ruptured under tensile load and the maximum load in pounds determined.

As a result of this type of test, the tensile strength, yield strength, percent elongation, and reduction in area may be determined.

Tests of Welded Joints

Test Specimens: Individual specifications may designate which specimens described in this section are to be used and the order in which they will be cut from any prepared pipe or plate sample. Specimens removed from the test piece should be located no closer than one inch from the start or end of the weld being tested.

Bend Specimens: Bend ductility specimens for pipe or plate should be in accordance with those shown in Fig. 14.6. Soundness and ductility specimens include face, root, side, and longitudinal guided bends.

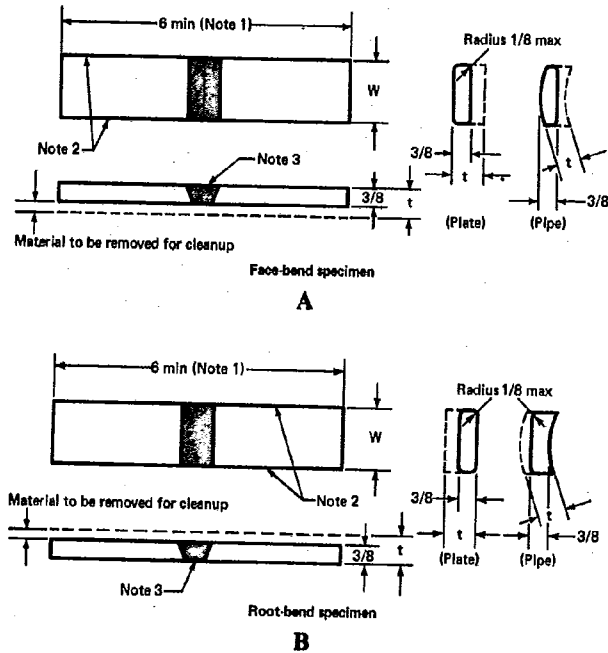
Face and root bends are generally used for

materials 3/8 inch (10 mm) or less in thickness. Pipe and plate specimen preparation and dimensions are shown in Fig. 14.6(A) and (B). Side bends are used for materials 3/8 inch and greater in thickness. Specimen preparation and dimensions are shown in Fig. 14.6(C). Longitudinal bends may be used for welded joints having differing mechanical properties. Specimens are prepared with the longitudinal axis of the weld running parallel to the long dimension of the specimen. Specimen preparation should be in accordance with dimensions and details shown in Fig. 14.6. Tool marks, if any, should be parallel to the long dimension of the specimen.

NOTE: Tests have shown that the severity of the guided bend test increases to some extent with increasing width-to-thickness ratio of the specimen. Results of the side bend test are therefore not directly comparable when obtained on specimens shown in Fig. 14.6, having different widths, W . Other materials such as aluminum and copper alloys may be subject to different requirements.

Procedure. Each specimen should be bent in a jig with the working contour shown in Fig. 14.7, and otherwise substantially in accordance with that figure. However, steels and other materials with a tensile strength over 100,000 psi (690 MPa) require that rollers be used instead of shoulders hardened and greased. For higher yield strength steels and other materials, the plunger radius is sometimes increased to three times the thickness of the material, or more. Any convenient means may be used to move the plunger member with relation to the die member.

In performing this test, the specimen is placed on the die member of the jig with the weld at midspan. Face-bend specimens are placed with the face of the weld directed toward the gap. Root-bend specimens are placed with the root of the weld directed toward the gap. Side-bend specimens are placed with that side showing the greater defects, if any, directed toward the gap. The two members of the jig are forced together until the specimen attains a specified angle of bend. For steels containing less than approximately 2% alloying elements, the final shape is usually a "U" and the plunger is continued downward until a 1/8 in. (3.2 mm)



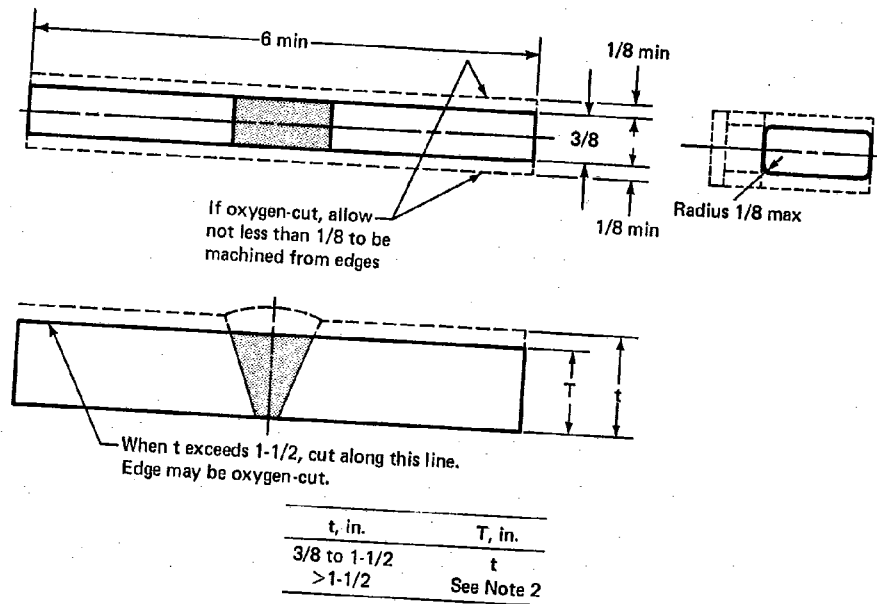
Dimensions	
Test weldment	Test specimen width, in. (W)
Plate	1-1/2
Test pipe 2 in. and 3 in. in diameter	1
Test pipe 6 in. and 8 in. in diameter	1-1/2

Notes:

1. A longer specimen length may be necessary when using a wraparound-type bending fixture or when testing steel with a yield point of 90 ksi or more.
2. These edges may be oxygen-cut and may or may not be machined.
3. The weld reinforcement and backing, if any, shall be removed flush with the surface of the specimen (see 3.6.3). If a recessed backing is used, this surface may be machined to a depth not exceeding the depth of the recess to remove the backing; in such cases, the thickness of the finished specimen shall be that specified above. Cut surfaces shall be smooth and parallel.
4. t = plate or pipe thickness.

Fig. 14.6A and B—Face- and root-bend specimens

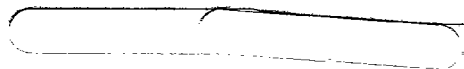
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Notes:

1. A longer specimen length may be necessary when using a wraparound-type bending fixture or when testing steel with a yield point of 90 ksi or more.
2. For plates over 1-1/2 in. thick, cut the specimen into approximately equal strips with T between 3/4 and 1-1/2 in. and test each strip.
3. t = plate or pipe thickness.

Fig. 14.6C—Side-bend specimens



diameter wire cannot be placed between the specimen and any point on the curvature of the plunger member of the jig. Welds with more than this alloy content, or tensile strengths in excess of 100,000 psi (690 MPa), seldom have sufficient ductility to make a complete "U" bend without fracture.

Materials having yield strength over 50,000 psi (345 MPa) minimum may be tested by bending the specimen to increased radii. Bend radii for various yield strengths are shown in Fig. 14.7. After testing, the specimen is removed from the jig and examined.

Results. The convex surface of the specimen is examined for the appearance of cracks or other open defects. Any specimen in which cracks or other open defects are present after the bending, in excess of a specified number and size, is considered as having failed. Cracks that occur on the corners of the specimens during testing generally are considered irrelevant.

Tensile Strength Specimens. For welded butt joints in plate, the tension specimen should comply with the requirements of Fig. 14.8, A-Test Plate. Circumferentially welded joints in pipe may be tested as sectioned specimens or a complete pipe or tube, depending on the diameter of the test piece. Pipe or tubing 2 in. (50 mm) in diameter and larger may be tested using tension specimens in Fig. 14.8(B) and (C). The ends of the specimens may be modified to accommodate the testing machine jaws. Pipe and tubing less than 2 in. (50 mm) in diameter may be tested using the complete welded specimen without sectioning. Weld reinforcement may or may not be removed depending upon the governing code or specification.

Procedure. For reduced tension specimens the least width and corresponding thickness of the reduced section is measured in inches (or mm). For small tube specimens, the average outside diameter (O.D.) of the base metal (at a distance not exceeding 1/2 in. [13 mm] from the boundary between the base metal and the weld metal) and the average inside diameter (I.D.) of the base metal at either end of the specimen are measured in inches (or mm). The specimen is ruptured under tensile load and the maximum load in pounds (or kg) is determined.

Fillet Weld Test: The fillet weld soundness

test is used to evaluate procedures and welders for T or lap joints.

Specimen. The fillet weld break specimen should be prepared as shown in Fig. 14.9. Material used for the test plate should have sufficient yield strength to cause fracture in the weld zone without bending. The weld is deposited using the material, position, and procedure intended for production welds. Recommended material thicknesses for various size fillets are shown in Fig. 14.9.

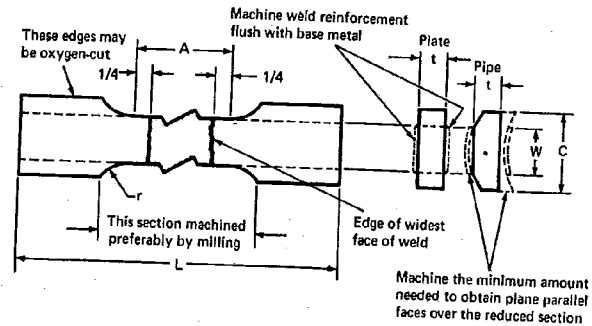
Procedure. The test plate is welded on one side of the T joint. Specimens for evaluation are removed for break and macroetch tests as shown in Fig. 14.9. The fillet weld break specimen is broken by applying pressure to cause the fracture to occur at the welded joint. The macroetch specimen is prepared by polishing and etching the cross section with a suitable reagent.

Results. The surfaces of the fracture are examined for compliance with the applicable code or specification. The macroetched specimen is examined for bead configuration and evidence of defects.

Notched-Bar Impact Tests: Impact testing of ferritic steels is necessary because certain types fail by brittle fracture at service temperatures even though they exhibit normal properties during the standard tensile test. This failure by brittle fracture may occur when the material is used in the notched condition. Notched conditions include restraint due to deformation in directions perpendicular to the major stress, multi-axial stress, and stress concentrations. It is in this field that the impact tests prove useful to determine susceptibility of the steels to notch-brittle behavior. However, test results cannot be used directly to appraise the serviceability of a structure.

Notched impact tests, such as Charpy V-Notch, bring out notched behavior by applying a single overload of stress. The absorbed energy "values" determined are quantitative comparisons based on a selected specimen; they cannot be converted into energy values that would serve for engineering design calculations.

Whenever possible, testing should be performed using the standard size specimen. In-

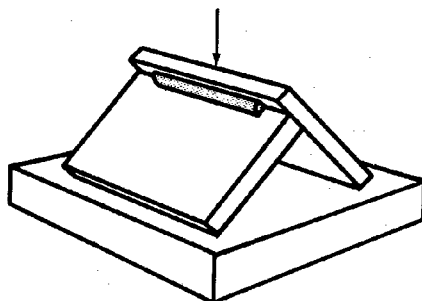


	Dimensions			Test pipe	
	Test plate			2 in. & 3 in. diameter	6 in. & 8 in. diameter or large job size pipe
	$T_p \leq 1$ in.	$1 < T_p < 1\frac{1}{2}$ in.	$T_p \geq 1\frac{1}{2}$ in.		
A—Length of reduced section	Widest face of weld + $\frac{1}{2}$ in., 2- $\frac{1}{4}$ min			Widest face of weld + $\frac{1}{2}$ in., 2- $\frac{1}{4}$ min	
L—Overall length, min (Note 2)	As required by testing equipment			As required by testing equipment	
W—Width of reduced section (Notes 3,4)	$1\frac{1}{2} \pm 0.01$	1 ± 0.01	1 ± 0.01	$1\frac{1}{2} \pm 0.01$	$3\frac{3}{4} \pm 0.01$
C—Width of grip section, min (Notes 4,5)	2	1- $\frac{1}{2}$	1- $\frac{1}{2}$	1 approx.	1- $\frac{1}{4}$ approx.
t—Specimen thickness (Notes 6,7)	T_p	T_p	T_p/n (Note 7)	Maximum possible with plane parallel faces within length A	
r—Radius of fillet, min	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	1

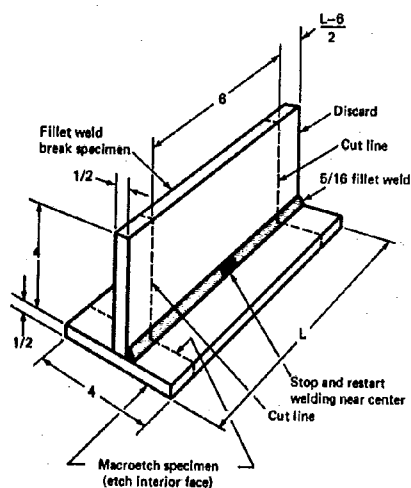
Notes:

1. T_p = thickness of the plate.
2. It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.
3. The ends of the reduced section shall not differ in width by more than 0.004 in. Also, there may be a gradual decrease in width from the ends to the center, but the width at either end shall not be more than 0.015 in. larger than the width at the center.
4. Narrower widths (W and C) may be used when necessary. In such cases, the width of the reduced section should be as large as the width of the material being tested permits. If the width of the material is less than W, the sides may be parallel throughout the length of the specimen.
5. For standard plate-type specimens, the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.25 in. except for referee testing, in which case the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.10 in.
6. The dimension t is the thickness of the test specimen as provided for in the applicable material specifications. The minimum nominal thickness of 1- $\frac{1}{2}$ in. wide specimens shall be $\frac{3}{16}$ in. except as permitted by the product specification.
7. For plates over 1- $\frac{1}{2}$ in. thick, specimens may be cut into the minimum number of approximately equal strips not exceeding 1- $\frac{1}{2}$ in. in thickness. Test each strip and average the results.

Fig. 14.8—Reduced-section tension specimens



Method of rupturing specimen



Notes:

1. $L = 15$ min.
2. Plate thickness and dimensions are minimum.
3. Dimensions in inches.

Fig. 14.9—Fillet weld break and macroetch test piece

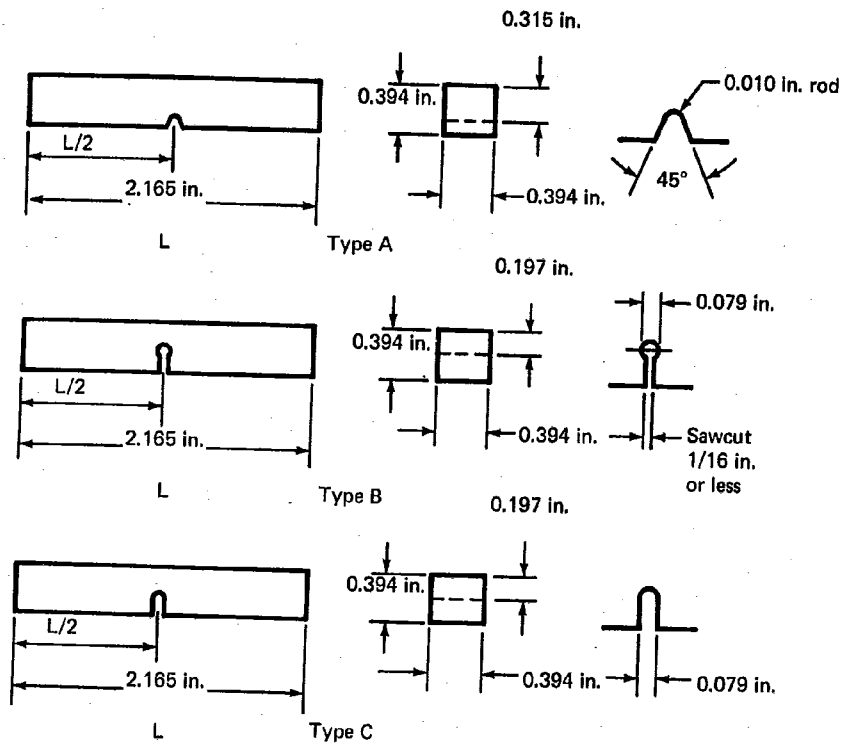
creasing either the width or depth of the specimen increases the volume of metal subject to distortion and the energy absorption when the specimen is broken. However, any increase in size, particularly in width, also tends to increase the degree of restraint and, by increasing the tendency to induce brittle fracture, may decrease the amount of energy absorbed. Thus, while a standard size specimen may be on the verge of brittle fracture, a double-width specimen may actually require less energy to rupture than one of standard width. For these reasons, correlation of the energy values obtained from specimens of different size or shape is, in general, not feasible.

Testing conditions also affect the notched behavior. So pronounced is the effect of temperature on the behavior of notched steel, that comparisons are frequently made by examining specimen fractures and plotting energy value and fracture appearance against temperature from tests of notched bars at a series of temperatures. When the test temperature has been carried low enough to start cleavage fracture, there may be either an extremely sharp drop in impact value or a relatively gradual falling off toward the lower temperatures. The transition temperature at which this embrittling effect takes place varies considerably with chemical composition, welding procedure, and postweld heat treatment.

NOTE: Some of the many definitions of transition temperature currently being used are:

- (1) The lowest temperature at which the specimen exhibits a fibrous structure
- (2) The temperature at which the specimen fracture shows a 50 percent crystalline and a 50 percent fibrous appearance
- (3) The temperature corresponding to the energy value that equals 50 percent of the difference between values obtained at 100 percent fibrous and zero fibrous
- (4) The temperature corresponding to a specific energy value
- (5) Lateral expansion at hinge of at least 0.010 in. (0.25 mm)

Specimens. The Charpy specimen is prepared as shown in Fig. 14.10. It is very important that the root of the notch have the proper radius and



Note: Permissible variations shall be as follows:

Adjacent sides shall be at	$90^\circ \pm 10 \text{ min}$
Cross-section dimensions	$\pm 0.001 \text{ in. } (\pm 0.025 \text{ mm})$
Length of specimen (L)	$+0, -0.100 \text{ in. } (2.5 \text{ mm})$
Centering of notch ($L/2$)	$\pm 0.039 \text{ in. } (1 \text{ mm})$: When an end-centering device is necessary to center the specimen in the anvil, see 8.3, it is necessary that the notch be accurately centered to ensure compliance with 4.2.1.
Angle of notch	$\pm 1^\circ$
Radius of notch	$\pm 0.001 \text{ in. } (0.025 \text{ mm})$
Dimensions to bottom of notch:	
Type A specimen	$0.315 \pm 0.001 \text{ in. } (8 \pm 0.025 \text{ mm})$
Types B and C specimen	$0.197 \pm 0.002 \text{ in. } (5 \pm 0.05 \text{ mm})$
Finish requirements	63 $\mu\text{in.}$ (2 μm) on notched surface and opposite face: 125 $\mu\text{in.}$ (4 μm) on other two surfaces

Fig. 14.10—Charpy (simple-beam) impact test specimens, types A, B, and C

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be machined with sharp (preferably carbide) cutters, to minimize tearing and other non-uniform notch contour.

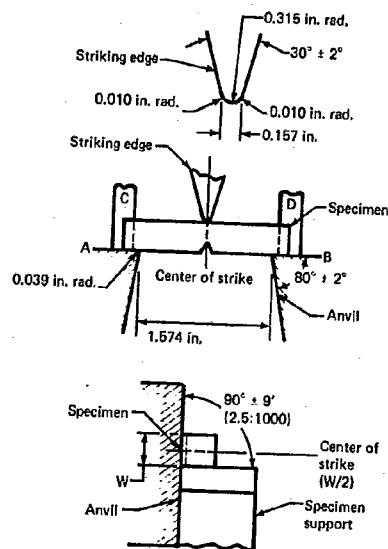
Procedure. Testing is performed on a pendulum type apparatus. The supports and striking edge should be of the form and dimensions shown in Fig. 14.11. Other dimensions of the pendulum and support should be such as to minimize interference between pendulums, supports, and broken specimens.

The support should be such that the center of gravity of the test specimen is on a line tangent to the arc of travel of the striking point of the pendulum, drawn at the position of impact.

The machine should be furnished with scales graduated either in degrees, joules, or foot-pounds force. Percentage of error in energy of blow caused by variations in the weight of the pendulum, height of fall, or friction should not exceed ± 0.4 percent. Several machines of this type are made commercially and should be calibrated at least once a year with standard specimens. These may be obtained from the Watertown Arsenal, Watertown, Mass.

A complete description of notched-bar impact testing is contained in ASTM Standard A370.

Results. After testing all specimens, the complete report should contain: (1) the type and model of machine used; (2) the type of specimen used; (3) machine calibration; (4) the temperature of the specimen, or the room condition if both are the same; (5) the energy actually absorbed by the specimen in breaking reported in total joules or foot-pounds force; (6) appearance of fractured surface (percent



All dimensional tolerances shall be ± 0.05 mm (0.002 in.) unless otherwise specified.

Notes:

1. A shall be parallel to B within 2:1000 and coplanar with B within 0.002 in. (0.05 mm).
2. C shall be parallel to D within 2.0:1000 and coplanar with D within 0.005 in. (0.125 mm).
3. Finish on unmarked parts shall be 125 μ m. (4 μ m).

Fig. 14.11—Charpy (simple-beam) impact test

shear [dull], percent cleavage or crystalline [shiny]); (7) the number of specimens failing to break; (8) lateral expansion at hinge of impact specimen.