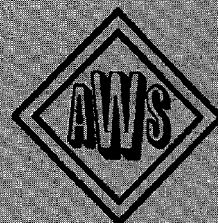


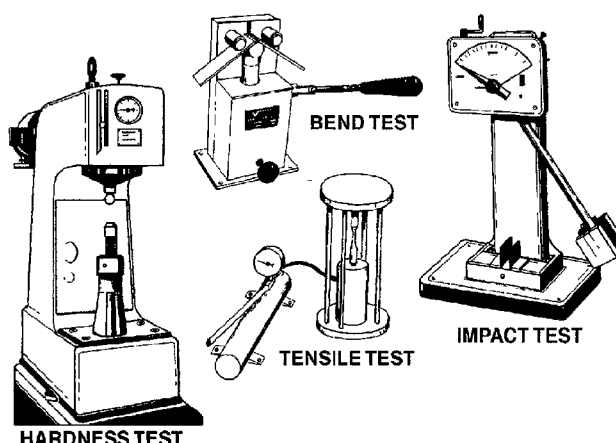
CHAPTER 7:**DESTRUCTIVE TESTING****Introduction**

In Chapter 6, there was a detailed discussion of many of the important properties of metals. Once it is recognized that these properties may be important to the suitability of a metal or a weld, it then becomes important to determine the actual values for those properties. That is, now the designer would like to put a number on each of these important properties so he can effectively design some structure using materials having the desired characteristics.

As mentioned in Chapter 6, there are numerous tests that are used to determine the various mechanical and chemical properties of metals. While some of these tests provide values for more than one property, most are designed to determine the value for a specific characteristic of the metal. Therefore, it may be necessary to perform several different tests to determine all the desired information.

It is important to understand each of these tests. At least, insofar as when the test is applicable, what results it will provide, and how to determine if the test results are in compliance with the specification requirements. It may also be helpful for the welding inspector to understand some of the methods used in the testing, even though he may not be directly involved with the actual testing.

As a group, these tests are referred to as destructive. They bear this name, because usually they render the test piece useless for service once the test has been performed. Generally, they destroy, or fail, the material to learn how it behaves in resisting failure. Some of these tests are referred to as destructive tests, even though



Inspectors must be able to interpret data from a variety of tests

they do not ruin the part to the extent it cannot be used (e.g., hardness testing). However, that depends on the shape, size and required surface condition of the part and its end-use.

Throughout this discussion there will be little mention made whether a specific destructive test is being used to determine a base metal or weld metal property. For the most part, this does not represent a significant change in the manner in which the test is performed. There will be occasion when testing is performed specifically to test the base or weld metal, but the mechanics of the testing operation will vary little, if any.

As these various methods are discussed, it is important to relate the actual test method with the appropriate material property(ies). In that way, it will be easier to understand and relate the values determined from the test with the properties that they describe.

The results of destructive testing are often indicated on Mill Test Reports. An inspector may be required to compare the Mill Test Report values with the applicable material specification to

determine conformance. Consequently, the following discussion should enable the inspector better understand the information appearing on a typical Mill Test Report.

Tensile Testing

The first destructive test method to be discussed will be the tensile test. This one test provides us with a great amount of information about a metal. Some properties that can be determined as a result of tensile testing include:

- Ultimate Tensile Strength
- Yield Strength
- Ductility
- Percent Elongation
- Percent Reduction of Area

Some of these values can be determined through a direct reading of a gage, while others can be quantified only after analysis of the stress-strain diagram that is produced during the test. The values for ductility can be found by making comparative measurements of the tensile specimen before and after testing. The percentage of that difference indicates the amount of ductility present.

When we perform a tensile test, one of the most important aspects of that test involves the preparation of the tensile specimen. If this part of the test operation is conducted carelessly, the validity of the test results will be severely reduced. Small imperfections in the surface finish, for example, can result in significant reductions in the apparent strength and ductility of the tensile specimen.

Sometimes, the sole purpose of the tensile test will be to show if the weld zone will perform as well as the base metal. All that is necessary for such an evaluation is removal of a specimen

(sometimes referred to as a strap) transverse to the longitudinal axis of the weld. The weld is roughly centered in the specimen. The two cut sides should be parallel using a saw or cutting flame, but no further surface treatment is essential, including the removal of any existing weld reinforcement.

This approach is used for procedure and welder qualification testing in accordance with API 1104. A successful tensile test is there described as a specimen that falls either:

- 1) In the base metal, or
- 2) In the weld metal (As long as it fails at some strength level above the specified base metal strength.)

For most cases in which the tensile test is required, however, there is a need to determine the actual values for strength and other properties exhibited by that metal, not just if the weld is as strong as the base metal. When the determination of these values is necessary, our specimen must be prepared in some configuration that provides a reduced section somewhere near the center of the length of the specimen.

This reduced section is intended to localize the failure. Otherwise the failure might tend to occur preferentially near the tensile test machine grips,, making the measurements for percent elongation extremely difficult. Also, this reduced section results in the increased uniformity of the stresses throughout the cross section of the specimen.

This reduced section must exhibit the following three features so valid results can be obtained:

- 1) The entire length of the reduced section must be of a uniform cross section.
- 2) That cross section should be of some configuration that can be easily measured

so that a cross sectional area can be calculated.

- 3) The surfaces of the reduced section should be free of surface irregularities, especially if they lie perpendicular to the longitudinal axis of the specimen and the applied stress.

For these reasons, as well as considering the actual mechanics of preparing a specimen, the two most common cross sectional configurations for tensile specimens are circular and rectangular. Both are readily prepared and measured.

If you are required to perform a tensile test, you may have to calculate the actual cross sectional area of the reduced section of the tensile specimen. Examples 1 and 2 below show how, these calculations are done for both common cross sections.

Example 1: Area of a Circular Cross Section

Diameter (d) = 0.505 in

Radius (r) = $d/2 = 0.2525$ in.

Area (A) = πr^2 or $\pi d^2 \div 4$

$A = 3.1416 (0.2525)^2$

$A = 0.2$

or

$A = 3.1416 (0.505^2 \div 4)$

$A = 0.2 \text{ in}^2$

Example 2: Area of Rectangular Cross Section

Width (w) = 1.5 in

Thickness (t) = 0.5 in

Area (A) = $w \times t$

Area (A) = 1.5×0.5

Area (A) = 0.75 in^2

The determination of this cross-sectional area before testing is critical because that value will be used to determine the strength of the metal. This strength will be calculated by dividing the applied load by the original cross sectional area. Example 3 shows this calculation for a standard circular cross section specimen.

Example 3: Calculation of Tensile Strength

Load = 12,500 lb

Area = 0.2 in^2 (See Example 1)

Tensile Strength = Load/Area

Tensile Strength = $12,500/0.2$

Tensile Strength = $62,500 \text{ psi (lb/in}^2\text{)}$

The example above shows a typical tensile strength calculation for a standard circular specimen. This is a standard specimen because it yields an area of 0.2 in^2 . This is convenient since dividing some number by 0.2 is the same as multiplying that number by 5 . Therefore, if this standard tensile specimen is used, the calculation for tensile strength can be performed as shown in Example 4.

Example 4: Alternate Tensile Strength Calculation

Load = 12,500 pounds

Area = 0.2 in^2

Tensile Strength = $12,500 \times 5$

Tensile Strength = $62,500 \text{ psi (lb/in}^2\text{)}$

As can be seen, the result of this calculation is identical to that of Example 3. The use of a standard size tensile specimen was very, popular years ago before the arrival of modern calculators. Then, it appeared easier to machine a tensile specimen to exact size, than it was to determine arithmetically the strength by dividing the load by some complicated number. However, today we can easily calculate the exact tensile strength no matter what the actual area happens to be.

Another operation that must be performed before testing is marking a gage length on the reduced section. This gage length is normally marked using a pair of center punch marks spaced at some prescribed distance apart. The most common gage lengths are 2 and 8 inches. After testing, the new distance between these marks is compared to the original distance to enable us to determine the amount of elongation, or stretch, exhibited by that specimen when stressed.

Once properly measured and marked, the specimen is then placed firmly in the appropriate

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COUPON TEST REPORT							
Date _____				Test No. _____			
Location _____							
State _____				Weld Position: _____			
Welder _____				Roll ☐		Fixed ☐	
Welding time _____				Mark _____			
Mean temperature _____				Time of day _____			
Weather conditions _____				Wind break used _____			
Voltage _____				Amperage _____			
Welding machine type _____				Welding machine size _____			
Filler metal _____							
Reinforcement size _____							
Pipe type and grade _____							
Wall thickness _____				Outside diameter _____			

	1	2	3	4	5	6	7
Coupon stenciled							
Original specimen dimensions							
Original specimen area							
Maximum load							
Tensile strength per square inch of plate area							
Fracture location							

☐ Procedure	☐ Qualifying test	☐ Qualified
☐ Welder	☐ Line test	☐ Disqualified

Maximum tensile _____	Minimum tensile _____	Average tensile _____
Remarks on tensile-strength tests _____		
1. _____		
2. _____		
3. _____		
4. _____		
Remarks on bend tests		
1. _____		
2. _____		
3. _____		
4. _____		
Remarks on nick-break tests		
1. _____		
2. _____		
3. _____		
4. _____		
Test made at _____	Date _____	
Tested by _____	Supervised by _____	
Notes: Use back for additional remarks. This form can be used to report either a procedure qualification test or a welder qualification test.		

Sample Coupon Test Report Form (Source API 1104, 17th edition)



Dimensions

	Standard Specimen		Small-size specimens proportional to standard							
	in.	mm*	in.	mm*	in.	mm*	in.	mm*	in.	mm*
Nominal Diameter	0.500	12.5	0.350	8.90	0.250	6.35	0.160	4.05	0.113	2.85
G - gage length	2.000 ± 0.005	51.0 ± 0.125	1.400 ± 0.005	35.5 ± 0.125	1.000 ± 0.005	25.5 ± 0.125	0.640 ± 0.005	16.0 ± 0.125	0.450 ± 0.005	11.5 ± 0.125
D - diameter (Note 1)	0.500 ± 0.010	12.5 ± 0.255	0.350 ± 0.007	8.90 ± 0.180	0.250 ± 0.005	6.35 ± 0.125	0.160 ± 0.003	4.05 ± 0.075	0.113 ± 0.002	2.85 ± 0.05
R - radius of fillet min.	3/8	9.5	1/4	6.5	3/16	5.0	5/32	4.0	3/32	2.5
A - length of reduced section min. (Note 2)	2-1/4 min.	57.0 min	1-3/4 min.	44.5 min	1-1/4	32.0	3/4	19.0	5/8	16.0

Standard 0.500 in. round tension test specimens with 2 in. gage length and examples of small size specimens with 2 in. gage length and examples of small size specimens proportional to the standard specimen.

*Rounded to the nearest 0.5 mm or 0.05 mm

Notes:

1. The reduced section may have a gradual taper from the ends toward the center with the ends not more than 1 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 nevertheless be spaced at the indicated gage length.

grips of the stationary and moving heads of the tensile machine.

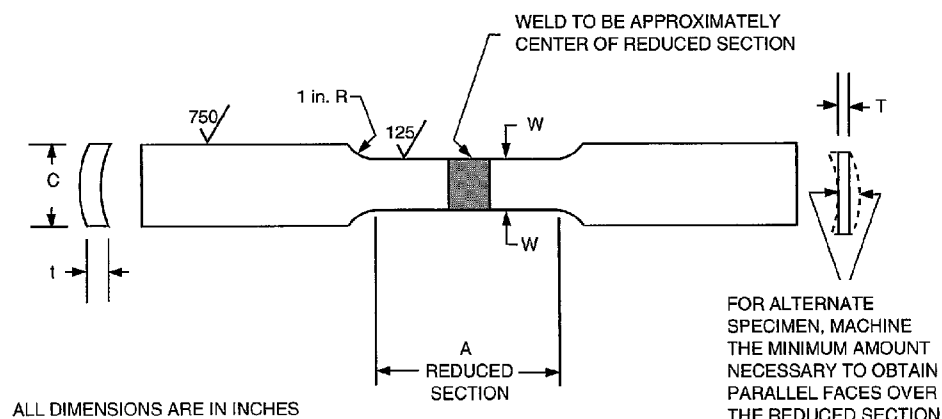
Once in place, the tensile load is then applied at some steady rate. Differences in this rate of loading could result in testing inconsistencies. Before this load application, a device known as an extensometer is connected to the specimen at the gage length marks. During the application of the load, the extensometer will measure the amount of elongation that results from a certain load. Load and elongation data are fed into a strip chart recorder resulting in a plot of the variation in the elongation as a function of the applied load. This is referred to as a load versus deflection curve. However, we normally see tensile test results expressed in terms of stress and strain.

Stress is equivalent to strength, since it is the applied load at any time divided by the cross

sectional area. The strain is simply the amount of stretch apparent in a given length. Stress is expressed in terms of psi (lb/in²) while strain is expressed as in/in.

When these values are plotted from the test data, the result is referred to as a stress-strain diagram. Looking at this stress-strain diagram, there are several important features that should be discussed. The test begins with the stress and strain both equal to zero. As the load is applied, the amount of strain increases linearly with stress. This shows what we refer to as elastic behavior, where the stress and strain are proportional. For any given material, the slope of this line is some known value. This slope is referred to as the modulus of elasticity.

For steel, the modulus of elasticity (or Young's modulus) is approximately equal to



$\sqrt[125]{\text{ }} = 4 \text{ MICROMETERS}$

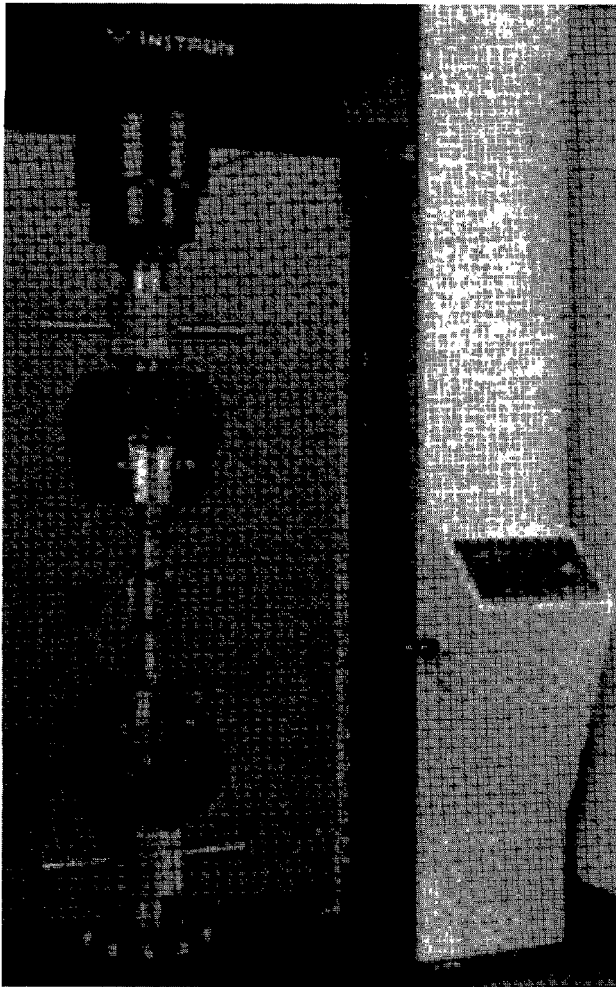
$\sqrt[750]{\text{ }} = 24 \text{ MICROMETERS}$

Specimen No.	W	C	A
1	$1/2 \pm 1/64$	3/4 approx.	2-1/4 min
2	$3/4 \pm 1/32$	1 approx	2-1/4 min
3	$1 \pm 1/16$	1-1/2 approx	4-1/2 min
4	$1-1/2 \pm 1/8$	2 approx	2-1/4 min
			4-1/2 min
			9 min

in.	mm
0.01	0.3
1/64	0.4
1/32	0.8
1/16	1.5
1/8	3.0
3/8	9.5
1/2	12.5
3/4	19.0
1	25.5
1-1/16	27.0
1-1/2	38.0
2	51.0
2-1/4	57.0
4	101.5
4-1/2	114.5
8	203.0
9	228.5

SOURCE: ANSI/AWS B4.0-92

TENSION SPECIMEN FOR PIPE SIZE GREATER THAN 2 INCHES NOMINAL

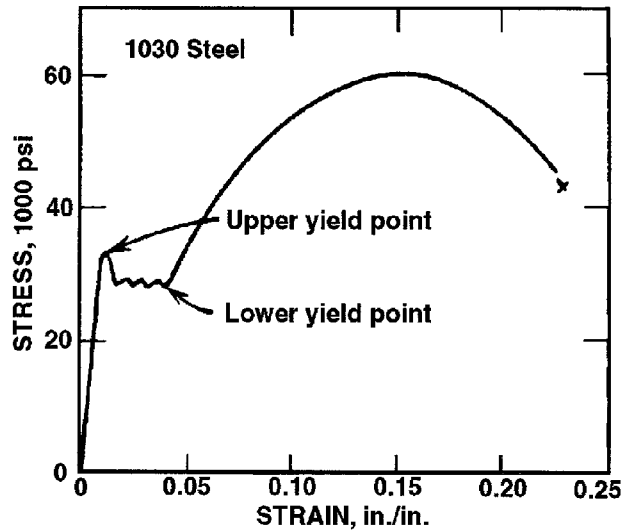


TENSILE MACHINE

30,000,000 psi as compared to 10,500,000 psi for aluminum. What this number indicates is the stiffness of the metal; that is, the higher the modulus of elasticity, the stiffer the metal.

Eventually, the strain will begin to increase faster than the stress, meaning that the metal is stretching more for a given amount of applied stress. This change marks the end of elastic behavior and the onset of plastic, or permanent deformation. The point on the curve showing the extent of the linear behavior is referred to as the elastic, or proportional, limit. If the load were removed at any time up to this point, the specimen would return to its original length.

Many metals tend to exhibit a drastic departure from the initial elastic behavior. With



Abrupt Yielding or Yield Point in a mild steel

these metals, not only are stress and strain no longer proportional, but the stress may drop or remain steady while the strain increases. This phenomenon is characteristic of yielding in ductile steel. The stress increases to some maximum limit and then drops to some lower limit.

These limits are referred to as the upper and lower yield points. The upper yield point is that stress at which there is a noticeable increase in strain, or plastic flow, without an increase in stress. The stress then drops and remains relatively constant at the lower yield point while the strain continues to increase during what is known as the yield point elongation.

In a metal that exhibits this behavior, we describe the yield strength as the stress corresponding to the upper yield point or some point midway between the upper and lower yield points. During the tensile test, the yield point can be seen as a drop in the gage or recording device. We therefore can determine the yield strength simply by observing and noting this load reduction. When this method is utilized, we refer to it as the "drop-of-beam" technique.

During this yielding phenomenon, the plastic flow of the metal is increasing at such a rate that stresses are being relieved faster than they are formed. When this plastic flow occurs at room

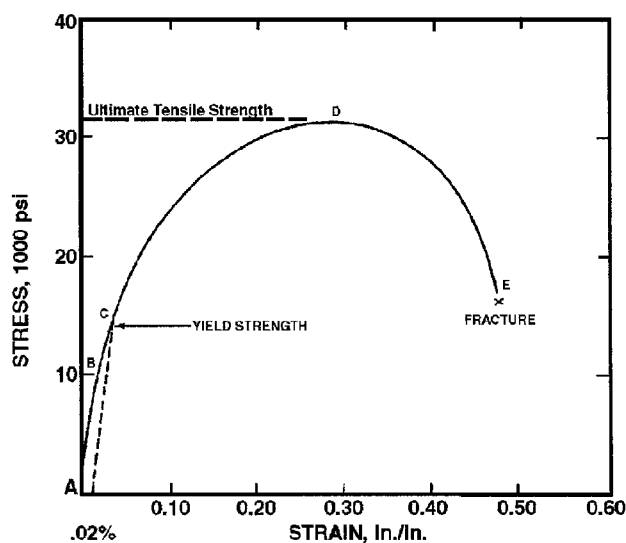
temperature, we refer to it as cold working. This action causes the metal to become stronger and harder and it is said to be work hardened. The yielding will therefore continue until the metal becomes work hardened to the extent that it now requires additional stress to produce any further elongation. Corresponding to this, the curve begins to climb in some nonlinear fashion.

The stress and strain continue to increase at varying rates until some maximum stress is reached. We refer to this point as the maximum stress, or ultimate tensile strength. It can be noted that this maximum stress is reached, followed by an apparent decrease in stress even though the strain continues to increase. This phenomenon is due to the fact that the specimen is "necking down" so that the actual cross section resisting the applied stress is less than the original area. Since the stress is calculated based on the original area this gives the appearance that the load is dropping when actually it continues to increase.

For less ductile metals, there may not be a pronounced change in behavior between elastic and plastic deformation. Therefore, we cannot use the drop-of-beam method to determine the yield strength. An alternative method is referred to as the offset technique.

When the offset method is used, a line is drawn parallel to the modulus of elasticity at some prescribed amount of strain. The amount of strain is usually described in terms of some percentage. The most common offset is 0.02%, of the strain; however, other amounts may also be specified. The stress corresponding to the intersection of this offset line with the stress-strain curve is therefore the yield stress. It should be reported as a 0.02% offset yield stress so that others know how it was determined.

Following the actual testing, it is now necessary to make a determination of the metal's ductility. This is done in one of two ways, both of which involve making measurements both before and after testing. We remember that the two ways



Engineering Stress-Strain Diagram for polycrystalline copper

in which we express ductility are in terms of percent elongation and percent reduction of area.

To determine the percent elongation, it is necessary to have placed gage marks on the specimen before pulling. After the specimen has failed, the two pieces are placed together and the new distance between the gage marks is measured.

Knowing this information, plus the original gage length, it is possible to calculate the percent elongation as shown in Example 5.

Example 5: Determination of Percent Elongation

Original length = 2.0 in

Final length = 2.6 in

%Elongation = (Final length - Original length)/Original length x 100

%Elongation = (2.6 - 2.0)/2.0 x 100

%Elongation = 0.6/2.0 x 100

%Elongation = 0.3 x 100

%Elongation = 30%

The metal's ductility can also be expressed in terms of how much it necks down during the tensile test. This is referred to this as percent reduction of area, where the original and final areas of the tensile specimen are measured and compared. It can be seen in Example 6 how this calculation is performed.

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Example 6: Determination of Percent Reduction of Area:Original Area = 0.2 in²Final Area = 0.1 in²

%Reduction of Area = (Original Area - Final Area)/Original Area x 100

%Reduction of Area = (0.2 - 0.1)/0.2 x 100

%Reduction of Area = 0.1/0.2 x 100

%Reduction of Area = 0.5 x 100

%Reduction of Area = 50%

While both percent elongation and percent reduction of area represent expressions for the amount of ductility exhibited by a tensile specimen, their values will seldom, if ever, be equal. Typically, the value for percent reduction of area may be as much as twice the value for percent elongation.

COMMERCIALLY USED HARDNESS TESTS

Test	Indenter	Shape of Indentation
Brinell	10mm sphere of steel or tungsten carbide	
Vickers	Diamond pyramid	
Knoop microhardness	Diamond pyramid	
Rockwell		
A C D	Diamond cone	
B F G		
E		
	1/16 in. diameter steel sphere	
	1/8 in. diameter steel sphere	

Shapes and types of indenters used with various hardness tests.

Hardness Testing

Strength is described as the ability of a material to transmit some load. It can be determined directly by performing a tensile test, or it can be approximated by conducting a hardness test on the material. This is permissible because the hardness and strength of many metal are directly related. Hardness testing is most often employed to provide us with a measurement of the metal's hardness, which is described as the ability of a metal to resist penetration.

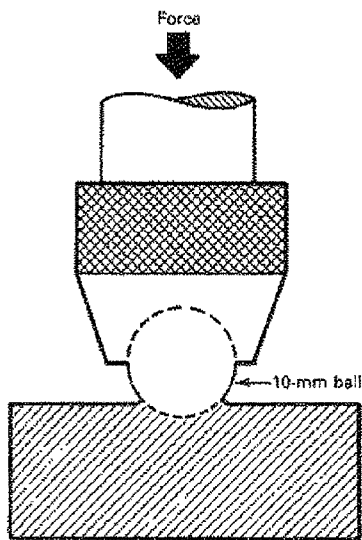
Consequently, hardness tests are performed, for the most part, using some type of penetrator that is forced against the surface of the test object. Depending upon the type of hardness test being used, either the diameter or depth of the resulting indentation is measured. The following discussion will point out some of the important features and methods involved in the various hardness tests.

Hardness is one of the most measurable features of a metal. This is primarily due to the vast variety of methods that can be used to determine a metal's hardness. There will be a discussion of three of the more common types of hardness tests: Brinell, Rockwell and microhardness. In general, the three groups differ from one another in the size of indentation which is produced, with the Brinell being largest and microhardness the smallest.

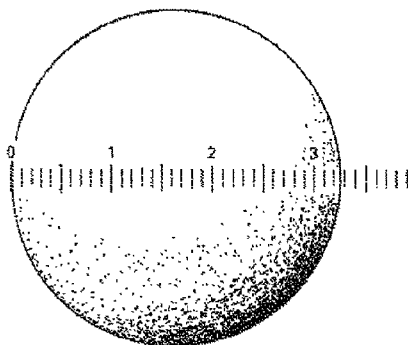
The Brinell test is commonly used for determining the hardness of metal stock. It is well suited for this purpose because the indentation covers a relatively large area, eliminating problems associated with localized hard or soft spots in the metal. The characteristically higher loads used for Brinell tests also assist in reducing errors produced by surface irregularities.

Before Brinell testing, it is necessary to prepare the surface so that test error will be minimized. This includes grinding or sanding the surface to remove scale, rust, paint, etc., and to achieve a relatively flat test area. The surface should also be of sufficient smoothness so that

BRINELL INDENTATION PROCESS



(a) Schematic of the principle of the Brinell indentation process.



(b) Brinell indentation with measuring scale in millimeters.

Indenter Measurements

the size of the indentation can be accurately measured. To perform a Brinell test, a penetrator is forced into the surface of the test object at some prescribed load. Once this load is removed, the diameter of the indentation is then measured using some graduated magnifier. On the basis of the size and type of the indenter, the applied load, and the resulting diameter of the impression, a Brinell Hardness Number (BHN) can be determined. Since this is a mathematical relationship, a BHN

can be determined for a variety of indenter types and loads. As mentioned above, strength and hardness are directly related. For steels, the approximate tensile strength can be determined by multiplying the BHN times 500.

The most commonly used Brinell test uses a 10 mm hardened steel ball and a 3000 kg load. However, some test conditions, such as specimen hardness and thickness, will require variations in the type of ball and the amount of the applied load. Other types of balls that can be used include the 5 mm hardened steel ball and the 10 mm tungsten carbide ball. For soft metals, loads as low as 500 kg may be used. Other loads between 500 and 3000 kg can also be used with equivalent results.

Normally the BHN can be determined by simply measuring the diameter of the impression and reading the value from some table that has results already calculated.

For additional information regarding Brinell testing, please refer to ASTM E10, *Standard Test Method for Brinell Hardness of Metallic Materials*.

Quite often, there is a need for the testing of objects too large to be placed in a stationary Brinell test machine. In such cases, portable test machines can be employed. These come in a variety of types and configurations, but the basic test principles are similar to field testing procedures.

The next hardness test to be discussed will be the Rockwell hardness test. This is a group of tests encompassing numerous different variations of the same basic principle. Like the Brinell test, the basic test can be modified by using different indenters as well as different test loads. As mentioned, the Rockwell tests result in smaller indentations than would be expected for Brinell testing. This allows for the localized testing of relatively small areas of a metal.

Like the Brinell test, Rockwell testing uses different indenters for different hardness ranges. The indenters used are the diamond Brale, 1/16", 1/8", 1/4", and 1/2" diameter hardened steel balls.

BRINELL HARDNESS NUMBERS

Ball diameter 10 mm

Ball Impression, diam., mm	Brinell hardness number						Ball Impression, diam., mm	Brinell hardness number					
	Load, kg							Load, kg					
	500	1000	1500	2000	2500	3000		500	1000	1500	2000	2500	3000
2.00	158	316	473	632	788	945	4.25	33.6	67.2	101	134	167	201
2.05	150	300	450	600	750	899	4.30	32.8	65.6	98.3	131	164	197
2.10	143	286	428	572	714	856	4.35	32.0	64.0	95.9	128	160	192
2.15	136	272	408	544	681	817	4.40	31.2	62.4	93.6	125	156	187
2.20	130	260	390	520	650	780	4.45	30.5	61.0	91.4	122	153	183
2.25	124	248	372	496	621	745	4.50	29.8	59.6	89.3	119	149	179
2.30	119	238	356	476	593	712	4.55	29.1	58.2	87.2	116	145	174
2.35	114	228	341	456	568	682	4.60	28.4	56.8	85.2	114	142	170
2.40	109	218	327	436	545	653	4.65	27.8	55.6	83.3	111	139	167
2.45	104	208	313	416	522	627	4.70	27.1	54.2	81.4	108	136	163
2.50	100	200	301	400	500	601	4.75	26.5	53.0	79.6	106	133	159
2.55	96.3	193	289	385	482	578	4.80	25.9	51.8	77.8	104	130	156
2.60	92.6	185	278	370	462	555	4.85	25.4	50.8	76.1	102	127	152
2.65	89.0	178	267	356	445	534	4.90	24.8	49.6	74.4	99.2	124	149
2.70	85.7	171	257	343	429	514	4.95	24.3	48.6	72.8	97.2	122	146
2.75	82.6	165	248	330	413	495	5.00	23.8	47.6	71.3	95.2	119	143
2.80	79.6	159	239	318	398	477	5.05	23.3	46.6	69.8	93.2	117	140
2.85	76.8	154	230	307	384	461	5.10	22.8	45.6	68.3	91.2	114	137
2.90	74.1	148	222	296	371	444	5.15	22.3	44.6	66.9	89.2	112	134
2.95	71.5	143	215	286	358	429	5.20	21.8	43.6	65.5	87.2	109	131
3.00	69.1	138	207	276	346	415	5.25	21.4	42.8	64.1	85.6	107	128
3.05	66.8	134	200	267	334	401	5.30	20.9	41.8	62.8	83.6	105	126
3.10	64.6	129	194	258	324	388	5.35	20.5	41.0	61.5	82.0	103	123
3.15	62.5	125	188	250	313	375	5.40	20.1	40.2	60.3	80.4	101	121
3.20	60.5	121	182	242	303	363	5.45	19.7	39.4	59.1	78.8	98.5	118
3.25	58.6	117	176	234	293	352	5.50	19.3	38.6	57.9	77.2	96.5	116
3.30	56.8	114	170	227	284	341	5.55	18.9	37.8	56.8	75.6	95.0	114
3.35	55.1	110	165	220	276	331	5.60	18.6	37.2	55.7	74.4	92.5	111
3.40	53.4	107	160	214	267	321	5.65	18.2	36.4	54.6	72.8	90.8	109
3.45	51.8	104	156	207	259	311	5.70	17.8	35.6	53.5	71.2	89.2	107
3.50	50.3	101	151	201	252	302	5.75	17.5	35.0	52.3	70.0	87.5	105
3.55	48.9	97.8	147	196	244	293	5.80	17.2	34.4	51.5	68.8	85.8	103
3.60	47.5	95.0	142	190	238	285	5.85	16.8	33.6	50.5	67.2	84.2	101
3.65	46.1	92.2	138	184	231	277	5.90	16.5	33.0	49.6	66.0	82.5	99.2
3.70	44.9	89.8	135	180	225	269	5.95	16.2	32.4	48.7	64.8	81.2	97.3
3.75	43.6	87.2	131	174	218	262	6.00	15.9	31.8	47.7	63.6	79.5	95.5
3.80	42.4	84.8	127	170	212	255	6.05	15.6	31.2	46.8	62.4	78.0	93.7
3.85	41.3	82.6	124	165	207	248	6.10	15.3	30.6	46.0	61.2	76.7	92.0
3.90	40.2	80.4	121	161	201	241	6.15	15.1	30.2	45.2	60.4	75.3	90.3
3.95	39.1	78.2	117	156	196	235	6.20	14.8	29.6	44.3	59.2	73.8	88.7
4.00	38.1	76.2	114	152	191	229	6.25	14.5	29.0	43.5	58.0	72.6	87.1
4.05	37.1	74.2	111	148	186	223	6.30	14.2	28.4	42.7	56.8	71.3	85.5
4.10	36.2	72.4	109	145	181	217	6.35	14.0	28.0	42.0	56.0	70.0	84.0
4.15	35.3	70.6	106	141	177	212	6.40	13.7	27.4	41.2	54.8	68.8	82.5
4.20	34.4	68.8	103	138	172	207	6.45	13.5	27.0	40.5	54.0	67.5	81.0

Using one or the other of these indenters, various loads can also be used. These loads are much lower than those used for Brinell testing, ranging from 60 to 150 kg.

Just as with the Brinell test, the test surface must be properly prepared before applying a Rockwell test. Once prepared, the proper scale should be selected based on the approximate range of hardness expected. The "B" and "C" scales are by far the most commonly used scales for steel, with the "B" scale chosen for softer alloys and the "C" scale used for the harder types. When in doubt as to which scale might be chosen for some

unknown alloy, the "A" scale could be employed because it includes a range of hardness covering both the "B" and "C" scales. Once the proper scale has been selected, the test object is placed on the anvil. The anvil can be of various shapes depending upon the configuration of the test piece. The object must be adequately and fully supported. Otherwise, test errors will result. The Rockwell method relies on the accurate depth of penetration measurement of the indenter. So, if the test object is not properly supported, this measurement could be inaccurate. A variation in this depth measurement of only 0.00008 inch will

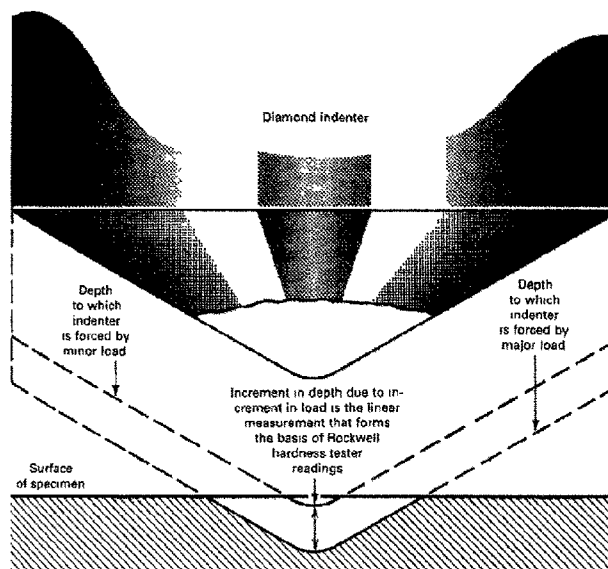
result in a change of one Rockwell number. After the specimen has been prepared and placed in the Rockwell machine, the load is applied and the results read directly from the dial on the machine. For further information regarding the Rockwell tests, refer to ASTM E18, *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*.

Like Brinell testing, there are also portable devices that can be used to determine the Rockwell hardness of a metal. Although their operation may vary slightly from that of the stationary models, the results will be equivalent.

The next group of hardness tests to be discussed are those which are referred to as microhardness tests. They bear this name because their impressions are so small that high magnification is required to facilitate their measurement. Microhardness testing is very beneficial in the investigation of metal microstructures, because these hardness tests can

PRINCIPLE OF THE ROCKWELL TEST

Although a diamond indenter is illustrated, the same principle applies for steel ball indenters and other loads.



be performed on single grains of a metal to determine the hardness in that microscopic region. Therefore, the metallurgist is primarily interested in this type of hardness testing.

There are two major types of microhardness tests: Vickers and Knoop. Both use diamond indenters, but their configurations are slightly different. The square-based Vickers indenter provides an indentation in which the two diagonals are approximately equal. The Knoop indenter, however, makes an indentation having a long and a short dimension.

As with the other test methods, the tester has a selection of test loads as well as indenter types. The term microhardness implies that the applied loads will range from 1 to 1000 g. However, the majority of microhardness tests use loads in the range of 100 to 500 g.

ROCKWELL STANDARD HARDNESS			
Scale symbol	Indenter	Major load, kgf	Typical applications
A	Diamond (two scales—carbide and steel)	60	Cemented carbides, thin steel, and shallow case-hardened steel
B	1/16-in. (1.588-mm) ball	100	Copper alloys, soft steels, aluminum alloys, malleable iron
C	Diamond	150	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case-hardened steel, and other materials harder than HRB 100
D	Diamond	100	Thin steel and medium case-hardened steel and pearlitic malleable iron
E	1/8-in. (3.175-mm) ball	100	Cast iron, aluminum and magnesium alloys, bearing metals
F	1/16-in. (1.588-mm) ball	60	Annealed copper alloys, thin soft sheet metals
G	1/16-in. (1.588-mm) ball	150	Phosphor bronze, beryllium copper, malleable irons. Upper limit HRG 92 to avoid possible flattening of ball
H	1/8-in. (3.175-mm) ball	60	Aluminum, zinc, lead
K	1/8-in. (3.175-mm) ball	150	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
L	1/4-in. (6.350-mm) ball	60	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
M	1/4-in. (6.350-mm) ball	100	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
P	1/4-in. (6.350-mm) ball	150	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
R	1/2-in. (12.70-mm) ball	60	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
S	1/2-in. (12.70-mm) ball	100	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
V	1/2-in. (12.70-mm) ball	150	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.

Fig. 1 Indentations made by Knoop and Vickers indenters in the same work metal at the same load

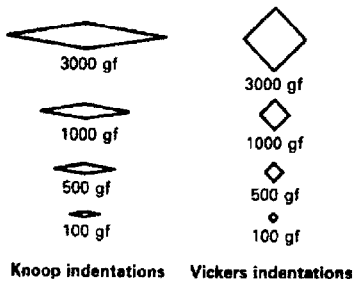


Fig. 2 Pyramidal Knoop indenter and resulting indentation in the workpiece

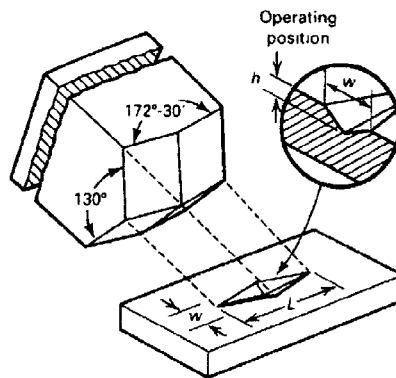
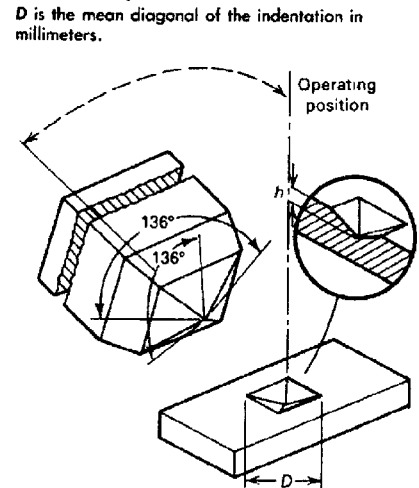


Fig. 3 Diamond pyramid indenter used for the Vickers test and resulting indentation in the workpiece



To perform either Vickers or Knoop microhardness testing, the preparation of the surface is of utmost importance. Since the area of interest is quite minute, even the smallest surface irregularity could cause inaccuracies. Normally, preparation of the surface for microhardness testing is identical to that for other metallographic investigations. The importance of this surface finish increases as the applied test load is reduced.

Once prepared, the specimen is securely clamped in some type of test fixture or holder so that the indentations can be accurately placed. Many microhardness machines employ some type of moving stage that facilitates accurate movement of the specimen without the need for its removal and adjustment. Such a device is handy when taking a number of readings across some region of the metal. An example of this type of application would be the determination of the hardness variation across the weld heat affected zone. The result would be referred to as a "microhardness traverse."

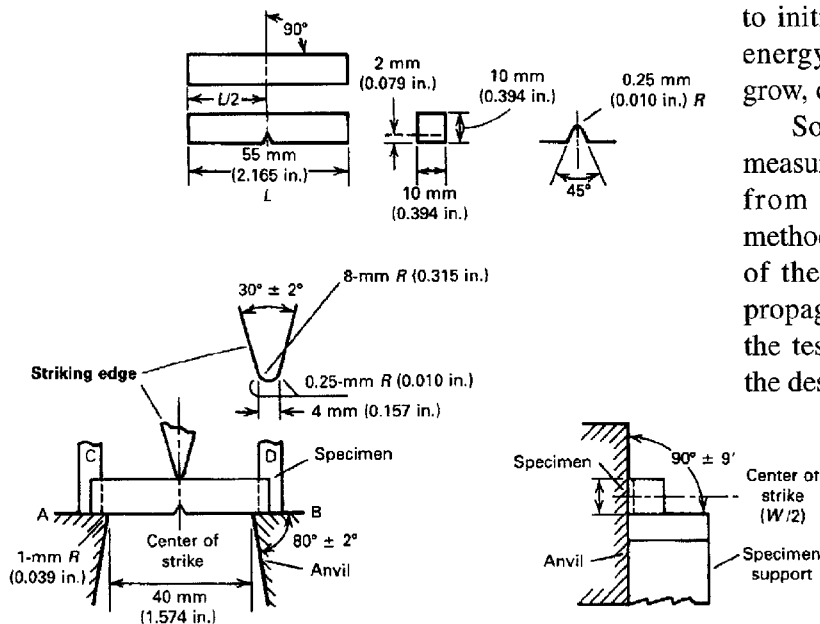
The use of hardness testing will provide us with a great deal of useful information about a metal. However, as can be seen from the preceding discussion, we must specify which hardness method will be used for a given

application. If not, the desired results may not be obtained.

Toughness Testing

Another metal property of interest is toughness. Toughness is the property that describes the material's ability to absorb energy. Regarding this property, the most important information relates to how the material absorbs energy when a load is applied very rapidly, as in an impact, especially when there is a notch present on the surface. Both the rapid loading and the presence of a notch will cause the metal's behavior to change drastically compared to how it might behave under loading conditions similar to those present in a tensile test.

Therefore, when the load is applied rapidly, the concern is with notch toughness, or impact strength. The discussion that follows will concern itself with tests that can be used to determine this particular metal property. Therefore, the various tests used to determine the notch toughness of a metal will usually use a specimen containing some type of machined notch and the load will be applied in a very rapid manner. Another important factor in impact testing is test temperature. The temperature of the specimen has a drastic effect on



ASTM standard dimensions for the Type A Charpy V-Notch specimen and the striker-anvil arrangement.

the test results. Consequently, impact testing must be performed at some prescribed temperature.

Since the advent of interest in the notch toughness of metals, numerous different tests have been developed to measure this important property. When talking about the energy absorption capabilities of a metal, it must be understood that the metal absorbs energy in steps. First, there is a certain amount of energy required

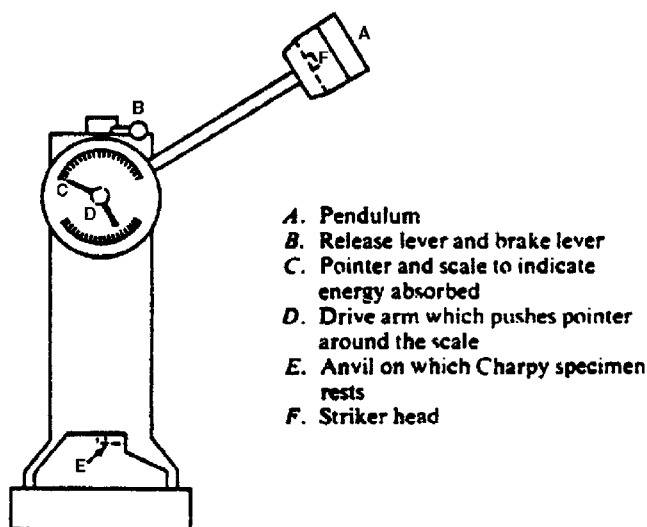
to initiate a crack. Then, some additional energy is required to cause that crack to grow, or propagate.

Some of the notch toughness tests can measure the energy of propagation separate from the energy of initiation. Other methods simply provide us with a measure of the combined energy of initiation and propagation. The engineer should specify the test method that will provide him with the desired information.

Although numerous types of notch toughness tests exist, probably the most commonly used in this country is the Charpy V-Notch test. The standard specimen used for this test is a bar 55 mm long and 10 mm by 10 mm square. One of the long sides of the specimen has a carefully machined V shaped notch 2 mm deep. The base of this notch is radiused to precisely 0.25 mm. The machining of this radius is extremely critical, since tiny inconsistencies will result in drastic variations in test results.

Once the specimen has been carefully machined, it is then cooled to the prescribed test temperature, if it is some temperature below room temperature. This can be accomplished using either a liquid or gaseous medium. After the specimen is stabilized at the required temperature, it is then removed from the low temperature bath and quickly placed in the anvil of the testing machine.

The Charpy testing machine consists essentially of a pendulum with a striker head, an anvil, a release level, and a pointer and scale. Since the goal is to measure the amount of energy that is absorbed during the fracturing of a specimen, a given amount of energy is supplied by raising the pendulum to a specified height. Upon release, the pendulum will fall and continue through its stroke until it reaches a maximum height on the opposite side of its travel.



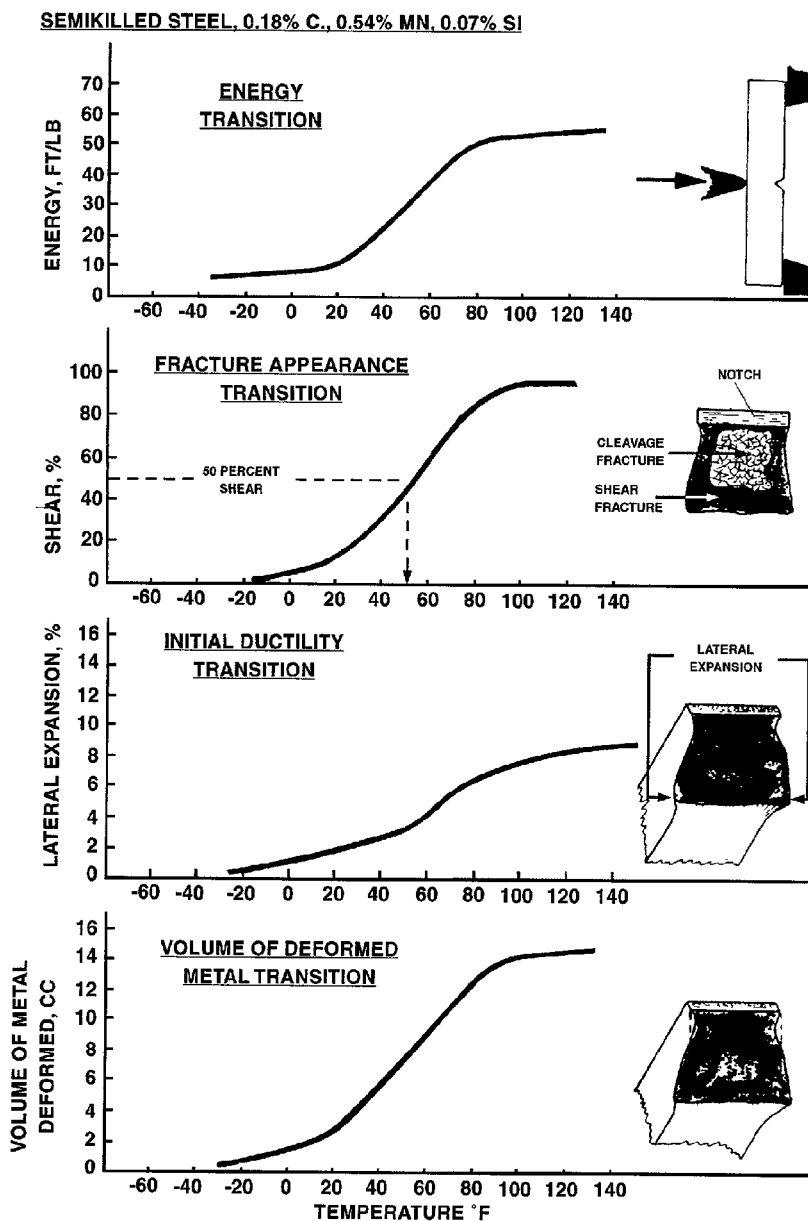
Schematic of Typical Charpy Testing Machine

If it meets no resistance, it will rise to some height that is designated as zero energy absorption. When it contacts the Charpy specimen, there is a certain amount of energy required to initiate and propagate a fracture. This causes the pendulum to rise to some level below that for zero energy absorption. The maximum height of this swing is indicated by the pointer on the scale. Since this scale is calibrated, the

amount of energy required to break the specimen can be read directly from the scale.

This value, referred to as breaking energy, is the primary piece of information gained from the Charpy impact test. This energy is expressed in terms of foot-pounds of energy. While most Charpy results are expressed in terms of footpounds of energy absorption, there are other means of describing the notch toughness of a

metal. They are determined by measuring various features of the failed Charpy specimen. These values are: lateral expansion and percent shear. Lateral expansion is a measure of the amount of lateral deformation produced during the fracturing of the specimen. It is measured in terms of mils, or thousandths of an inch. Percent shear is an expression for the amount of the fracture surface that failed in a ductile, or shearing, fashion. values change with temperature. No matter which of these methods of measurement are employed, the usual concern is with the results from a whole series of tests. Once a number of specimens have been tested at various temperatures, it is possible to determine how the values change with metal temperature. If these values are plotted versus temperature, the result will be a curve having upper and lower horizontal shelves. For each category, there is some temperature at which the values drop rather abruptly. These are referred to as transition temperatures, meaning, the behavior of the metal changes from ductile to brittle at that temperature. The designer then knows that the metal should behave satisfactorily above that temperature.



Relation between energy transition and fracture appearance transition in Charpy V-Notch impact specimens with changes in temperature

Besides the Charpy test there are others that can be employed for various applications. Other tests that may be used to measure a metal's notch toughness include: drop-weight nil-ductility, explosion bulge, dynamic tear, and crack tip opening displacement (CTOD). These tests employ different types of ways of applying the load to the specimen.

Soundness Testing

These groups of tests are designed to aid in the determination of the metal's soundness, or its freedom from imperfections. Soundness tests are routinely used for the qualification of welding procedures and welders. After a test plate has been welded, specimens are removed and then subjected to some soundness test to determine if the weld contained any imperfections or defects.

There are three general types of soundness tests: bend, nick-break and fillet break. Bend testing can be performed in a number of different ways. This is probably the most common test used to judge the adequacy of a welder's qualification test coupon.

There are several different types of bend tests, depending on the orientation of the weld with respect to the bending action. There are three types of transverse weld bend specimens: face, root and side bends. With these three types, the weld lies across the longitudinal axis of the specimen and its name refers to the side of the weld that is placed in tension during the test. That is, the face of the weld is stretched in a face bend, the root of the weld is stretched in a root bend, and the side of a cross section of the weld is stretched in a side bend.

Bend tests are normally performed using some type of bend jig. There are three basic types: guided-bend, roller-equipped guided-bend, and wraparound guided-bend. The standard guided bend test jig consists of a plunger (also referred to as mandrel or ram) and a matching die that forms the previously straight bend specimen into a U shape.

To perform a bend test, the specimen is placed across the shoulders of the die with the side to be placed in tension facing down toward the inside of the die. The plunger is then situated over the area of interest and forced toward the die causing the specimen to be bent 180° and become U-shaped. The specimen is then removed and evaluated.

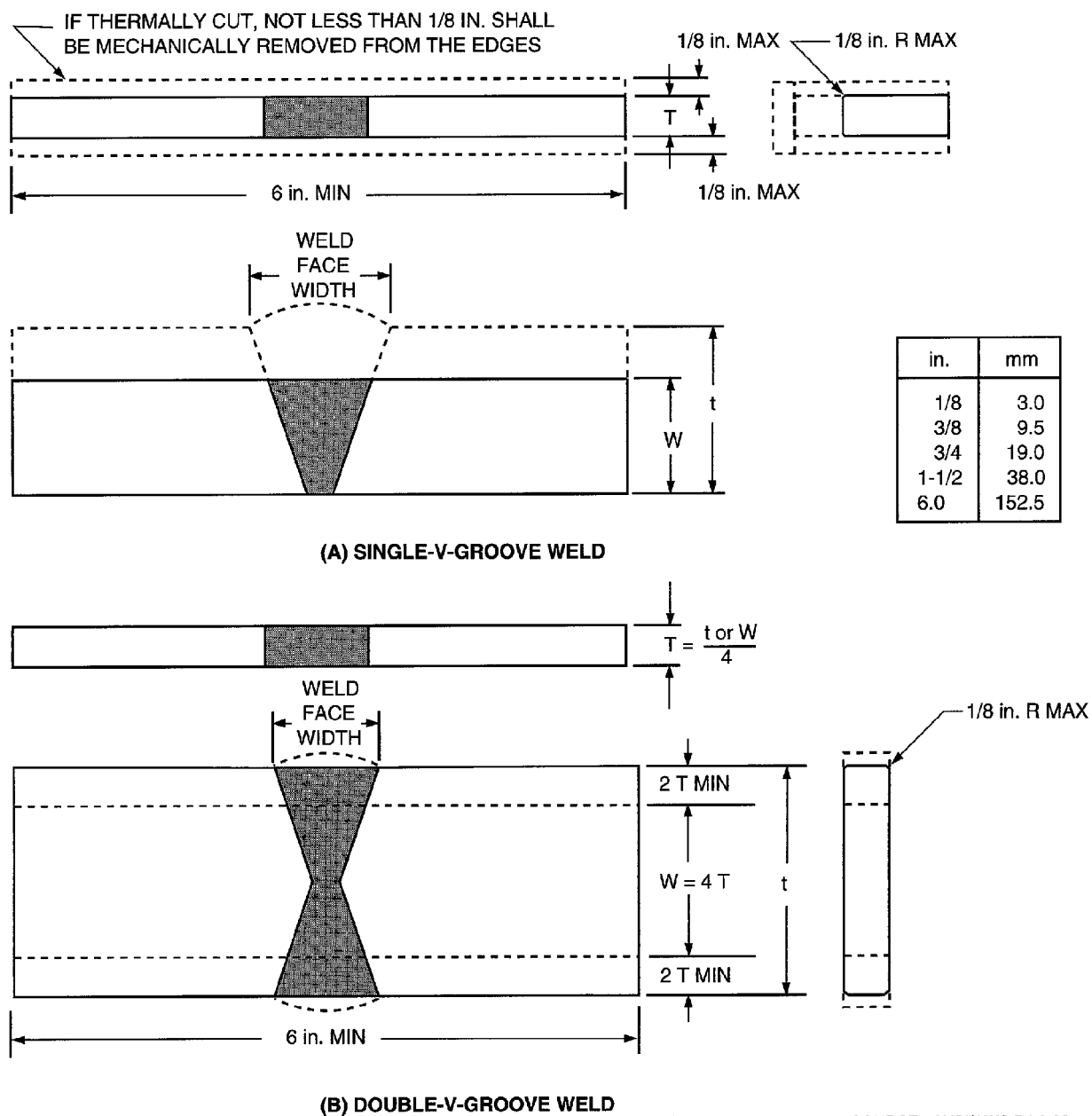
The second type of guided-bend test jig is similar to the standard guided-bend jig, except it is equipped with rollers instead of hardened shoulders on the die portion. This reduces the friction against the specimen allowing for lower loads to achieve the bending.

The last common type of guided-bend jig is referred to as the wraparound jig. It bears this name because the specimen is bent by being wrapped around a stationary pin. This type is useful for bending specimens having different strengths of base and weld metal. If there is a great imbalance, there will be a tendency to bend preferentially in the weaker metal, resulting in a kink or a bend away from the area of intersection.

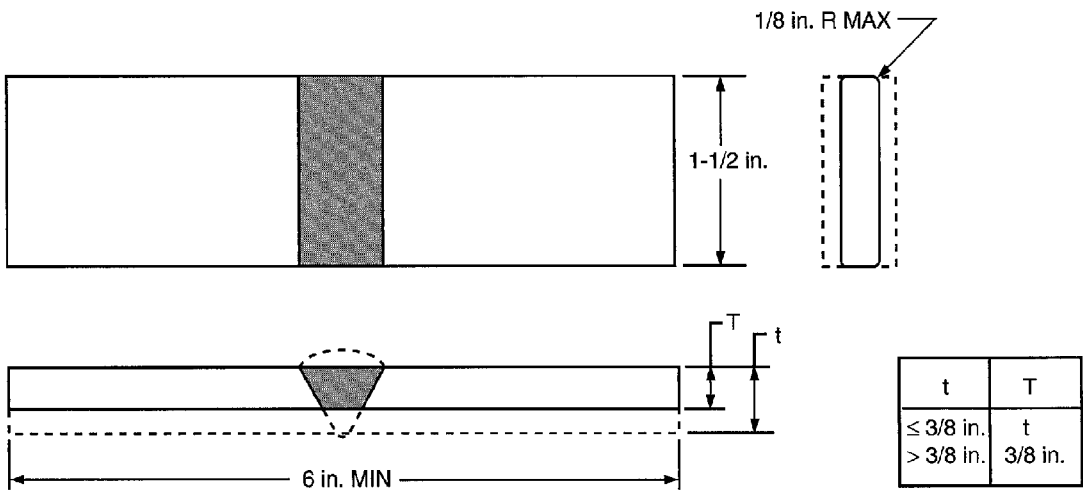
Most qualification tests for mild steel require that the specimen be bent around a mandrel having a diameter four times the thickness of the specimen. Therefore, a 3/8 inch specimen would be bent around a 1-1/2 inch diameter mandrel. This results in a 20% elongation of the outer surface of the bend specimen. If a smaller bend mandrel is used, the necessary amount of elongation would increase.

With any of these bend tests, the specimens must be carefully prepared to prevent test inaccuracies. Any grinding or sanding marks on the tension surface should be running parallel to the direction of bending so they don't provide stress raisers which could cause the specimen to fail prematurely. The corners of the specimen should be radiused to relieve that stress concentration as well. For specimens removed from pipe coupons, the side of the bend specimen against the ram may be required to be ground flat.

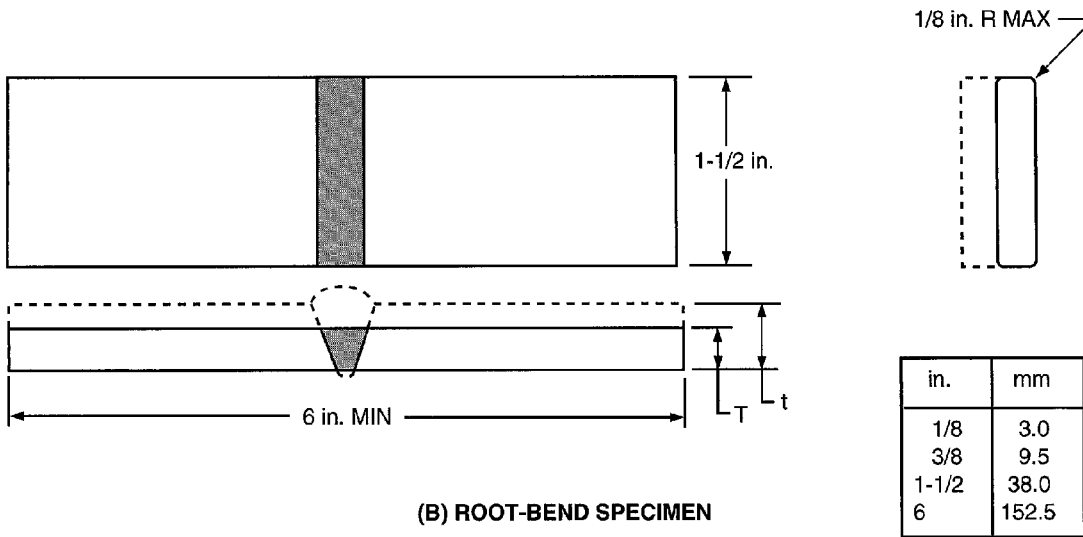
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TRANSVERSE SIDE-BEND SPECIMENS (PLATE)



(A) FACE-BEND SPECIMEN

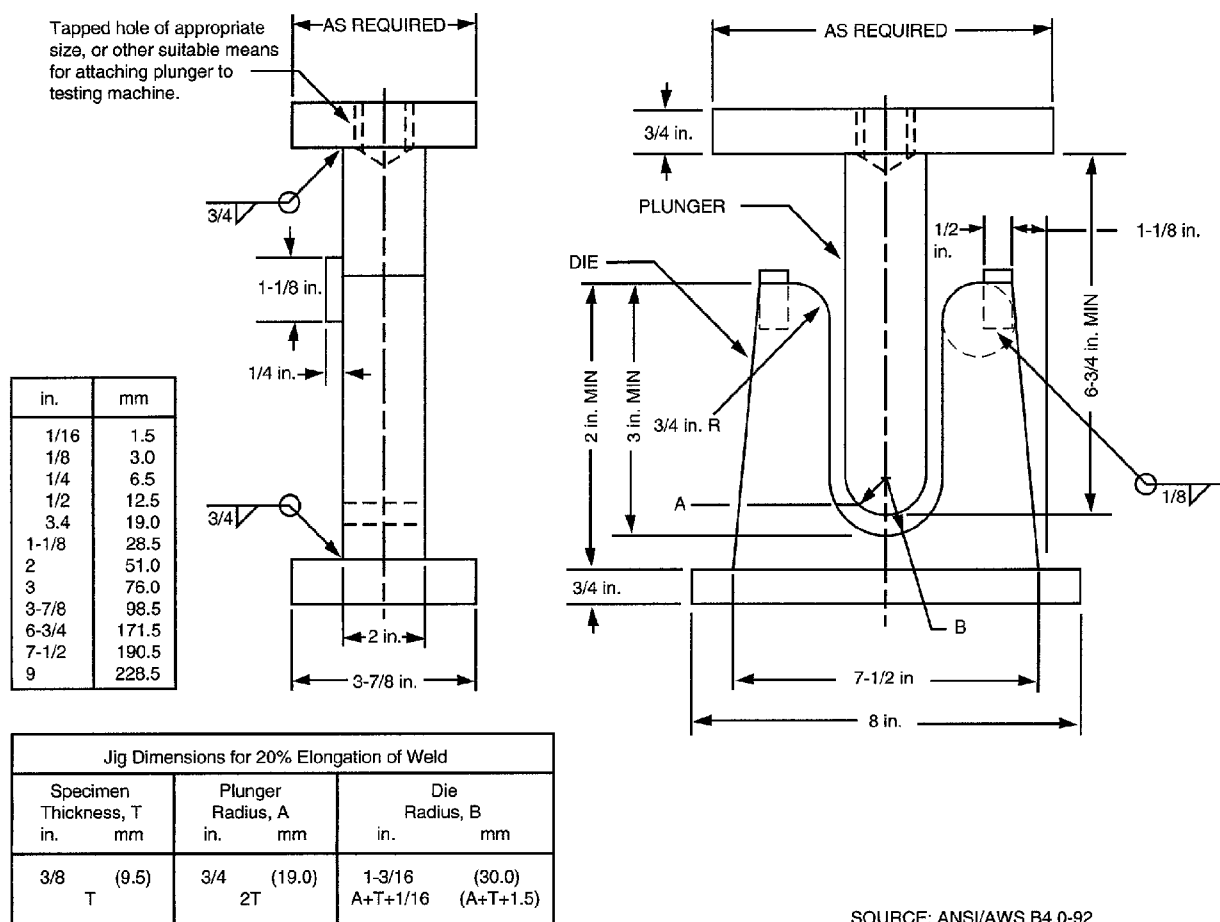


(B) ROOT-BEND SPECIMEN

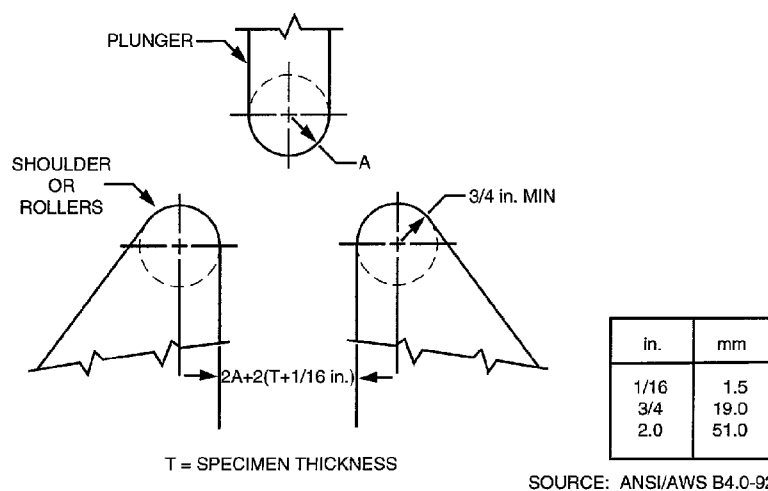
SOURCE: ANSI/AWS B4.0-92

TRANSVERSE FACE-BEND AND ROOT-BEND SPECIMENS (PLATE)

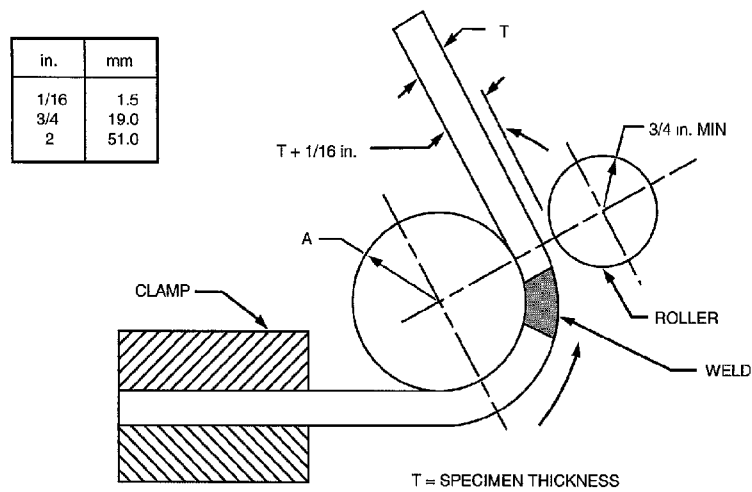
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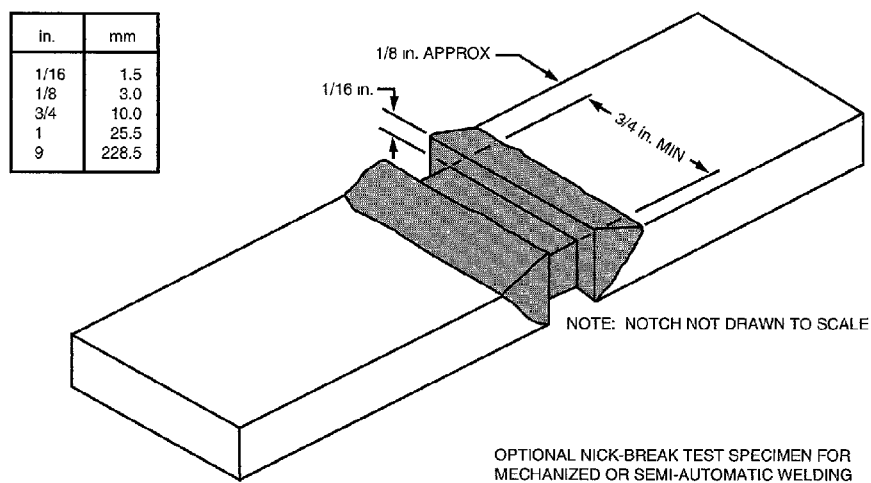
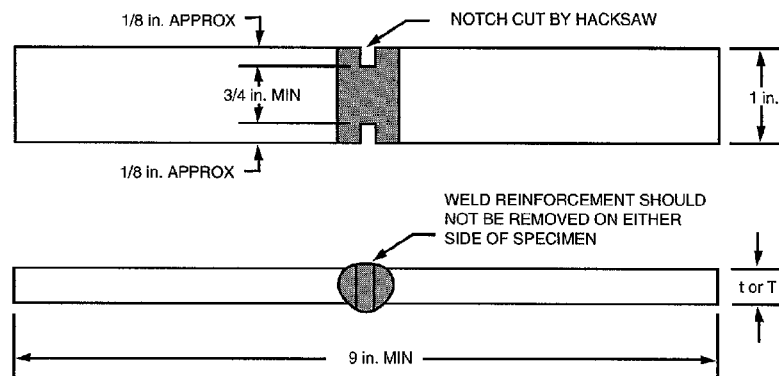
TYPICAL BOTTOM GUIDED-BEND TEST FIXTURE



TYPICAL BOTTOM EJECTING GUIDED-BEND TEST BEND FIXTURE



SOURCE: ANSI/AWS B4.0-92

ALTERNATIVE WRAP-AROUND GUIDED BEND TEST BEND FIXTURE

SOURCE: ANSI/AWS B4.0-92

NICK BREAK TEST SPECIMEN

to eliminate the bending in the direction transverse to the bending direction.

The acceptability of bend test specimens is normally judged based on the size and/or number of defects that appear on the tension surface. The governing code or specification will dictate the exact acceptance/rejection criteria.

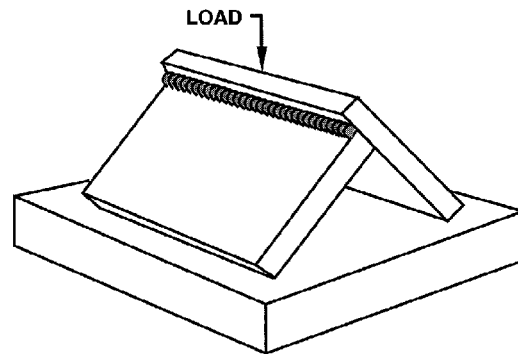
The next type of soundness test to be discussed is the nick-break test. This test is used almost exclusively by the pipeline industry as described in API 1104. This method judges the soundness of the weld by fracturing the specimen through the weld so that the fracture surface can be analyzed for the presence of discontinuities. The fracture is localized in the weld zone with saw cuts along two or three surfaces.

Once the specimen has been saw cut, it is then broken by pulling in a tensile machine, hitting the center with a hammer while supporting the ends or hitting one end with a hammer while the other end is held in a vise. The method of breaking is not significant because you are not interested in how much effort is required to fail the specimen. The sole purpose is to fail the specimen through the weld zone so it can be determined if any imperfections are present. The fracture surface is then examined for evidence of any areas of slag inclusions, porosity or incomplete fusion. If present, they are measured and accepted or rejected based on the code limitations.

The last soundness test to be mentioned here is the fillet weld break test. Like the other two types, this soundness test is used primarily in the qualification of welders. This is the only test required for the qualification of tackers in accordance with AWS D1.1, *Structural Welding Code- Steel*.

To perform this test, a welder places a fillet weld on one side of a T-joint. Once complete, the specimen is placed in a press and bent to produce a fracture at or near the weld. Again, the interest is not how much load is required for failure, but rather the condition of the fracture surface, with respect to the presence of discontinuities.

With this test, the inspector is looking for a weld having satisfactory surface appearance. Further, he inspects the fracture surface to assure that the weld has evidence of fusion to the root and that there are no areas of incomplete fusion to the base metal or porosity larger than 3/32" inches in their greatest dimension.



Method of testing fillet weld break specimen

These soundness tests are used routinely in many different industries. Their application and evaluation appear to be quite straightforward. However, the welding inspector should be aware that the evaluation of these tests may not be as simple as the various codes and' specifications might imply. For this reason, it is important that the inspector actually spend some time performing these tests to become familiar with their performance and interpretation.

Destructive Tests for Chemical Properties

The tests that have been previously discussed are used to determine the mechanical properties of a metal. However, there is also interest in the various chemical properties of a metal. In fact, the chemical makeup of a metal determines to a great degree the mechanical properties of that metal. Therefore, it is often necessary to determine the chemical composition of a metal. The three most common methods are: *spectrographic*, *combustion*, and *wet chemical analysis*.

The welding inspector will rarely be required to perform chemical analysis. However, he may have to review the results of these analysis to

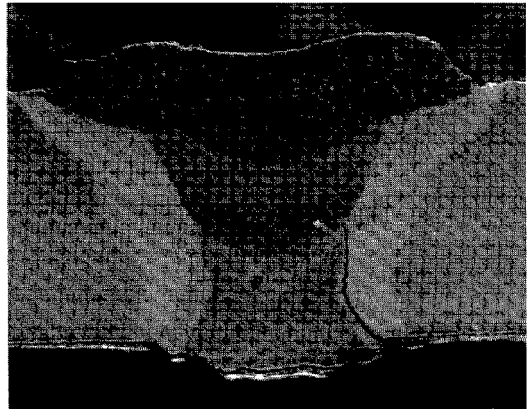
determine if a metal complies with a particular specification. For more information regarding chemical analysis of metals, refer to the ASTM specifications that cover this subject. The particular methods used for steel are listed in ASTM A751.

Another group of tests that can generally be classified as chemical tests are corrosion tests. These are specific tests designed to determine the corrosion resistance of a metal or combination of metals. Losses from corrosion of metals cost industry tens of billions of dollars annually. Therefore, designers are very concerned about how a metal will behave in a particular corrosive environment. The tests used to determine the degrees of corrosion resistance are designed to simulate as closely as possible the actual conditions that the metal will encounter during its service. Some of the considerations that must be addressed when setting up a corrosion test are: chemical composition, corrosive environment, temperature, presence of moisture, presence of oxygen, presence of other metals, and amount of stress. If any of these features are ignored, the corrosion test may yield invalid results.

Metallographic Testing

Another way in which the characteristics of a metal can be determined is through the use of various metallographic tests. These tests basically consist of removing a section of a metal or a weld and polishing it to some degree. Once prepared, the specimen can then be evaluated with the unaided eye or with the use of magnification.

Metallographic testing is generally classified as either macroscopic or microscopic. They differ in the amount of magnification that is utilized. Macro tests are generally performed using magnifications of 10X or lower. Micro tests, on the other hand, use magnifications greater than 10X.



Typical Weld Photomicrograph (Crack adjacent to the weld)

A number of different features can be observed on a typical macro specimen. Often the cross section of a weld can be examined to determine such things as: depth of fusion, depth of penetration, effective throat, weld soundness, degree of fusion, presence of weld discontinuities, weld configuration, number of weld passes, etc. A picture of a macro specimen is referred to as a photomacrograph.

Micro tests can be used to determine various features as well. Included are: microstructural constituents, presence of inclusions, presence of microscopic defects, nature of cracking, etc. Similarly, pictures of micro specimens are called photomicrographs.

These various metallographic tests can be very helpful in such matters as failure analysis, weld procedure and welder qualification, and process control testing.

The two types of specimens also differ in the amount of preparation required. Some macro specimens need only be rough ground, whereas micro specimens require fine grinding and even polishing to produce a mirror finish.

There is so much information which can be gained about the properties of a metal by making simple macro and micro evaluations that metallographic testing is an important tool for both the welding inspector and the engineer.

Selection of Destructive Testing Samples

Another important factor related to these various destructive tests, as well as the nondestructive test methods to be mentioned later, is the number of tests that will be required for a particular situation. That is, will all welds be subjected to a certain test or will only a few be selected for evaluation? Sampling is the selection of some of the welds, weldments or materials from a production run. Conclusions about the quality of welding in the entire production run are drawn from the results of these inspections.

The welding inspector is often the key person responsible for this activity. The purpose of sampling is presumably acceptance inspection. This is an examination performed for the buyer of weldments to satisfy him that what he is offered meets the purchasing specifications. To reach that decision, the complete lot (100 percent sampling) or a portion of the lot (partial sampling) must be examined. The welding inspector will also sample the shop output if acting as a fabricator's inspector, as part of his quality assurance program.

It is hoped that the purchaser and the fabricator have noted at the outset the impossibility of obtaining 100 percent assurance from partial sampling. The reason for this is twofold.

Primarily, the tests will be nondestructive examinations because destructive testing becomes nonproductive when it approaches 10 percent. Destructive tests of the mechanical reliability of a few out of many welds permits only a statistical judgment as to how many of the remaining welds not tested may meet specifications. The assurance is less than 100 percent reliable because of the inherent variability of welding.

Secondly, complete testing by nondestructive examination methods provides only indirect evidence of weld soundness. One hundred percent nondestructive examination will never provide assurance that all the welds are perfect. In fact, statisticians recognize that 100 percent inspection of any item, even by simple go/no-go tests, is

seldom 100 percent efficient. It should be realized how easily the inspector tires and how often his attention wanders. The monotony of testing dulls the mind. The purchaser must understand that there will always be an uncertainty in the resulting conclusions.

The engineers must consider whatever final testing and examinations are required in the specifications for the job. The welding inspector does only as directed, of course. Actual specification of the percentage, order, and frequency of sample selection is well outside the welding inspector's normal inspection function.

Summary of Sampling Plans

Sampling welds for evaluation tests or for acceptance testing is one of the welding inspector's important functions. Acceptance inspection is the usual purpose. The number of welds or weldments to be sampled and the tests to be applied should be designated in the purchase specifications or the applicable code.

The welding inspector will use complete sampling where weldments of the highest quality are required for critical services. One or more methods of nondestructive or destructive testing, above and beyond visual inspection, will probably be specified for the critical joints (such as complete penetration welds in butt joint).

The less important welds may require less critical inspection. For the average job, the inspection will generally involve a combination of complete visual inspection plus random partial sampling. The random partial sampling will usually be inspected by one or more of the various methods of nondestructive examination or destructive testing.

Complete 100 percent sampling and testing is usually restricted to critical joints in critical weldments. It must be recognized, however, that the detection of defects by 100 percent inspection is inherently less than 100 percent reliable.

<u>Units Pertaining to Welding</u>		
<u>Property</u>	<u>Unit</u>	<u>Symbol</u>
area dimensions	square millimeter	mm ²
current density	ampere per square millimeter	A/mm ²
deposition rate	kilogram per hour	kg/h
electrical resistivity	ohm meter	Ω · m
electrode force	newton	N
flow rate (gas and liquid)	liter per minute	L/min
fracture toughness	meganeutron meter ^{-3/2}	MN · m ^{-3/2}
impact strength	joule	J = N · m
linear dimensions	millimeter	mm
power density	watt per square meter	W/m ²
pressure (gas and liquid)	kilopascal	kPa = 1000 N/m ²
pressure (vacuum)	pascal	Pa = N/m ²
tensile strength	megapascal	MPa = 1000 000 N/m ²
thermal conductivity	watt per meter kelvin	W / (m · K)
travel speed	millimeter per second	mm/s
volume dimensions	cubic millimeter	mm ³
wire feed speed	millimeter per second	mm/s

decimal place is always moved to where there is only one number appearing to its left. The number of spaces which the decimal place was moved becomes the power of ten in the scientific notation expression. If the decimal point was moved in the opposite direction, as would be the case for a number less than one, then the power of ten becomes a negative number. The examples below show how scientific notation is used.

Metric Conversions

In recent years, there has been an effort to convert our American system of measurement to an international system referred to as the *International System of Units* (In French, "*Le Systeme Internationale d'Unites*") or *SI*. Consequently, the welding inspector may have occasion to inspect parts or interpret specifications having these SI units. He may then be asked to convert those units into more familiar units.

This is part of the job math which the welding inspector may be required to perform. As a minimum, he will be asked to perform some of these conversions on the AWS CWI examination. The following discussion is meant to provide a basis for the welding inspector to understand how these conversions are performed.

Before actually looking at the conversion process, it is important to understand some of the notations which will be used to express different numeric values. One of the techniques used to express numbers which may be very large or very small, is called scientific notation. What this method does is reduce some number to an expression which includes a number multiplied by some power of ten. For example, the number 234,567 would be expressed as 2.34567×10^5 in scientific notation.

It should be obvious that the same digits are used but the decimal place has been moved. The

Scientific Notation Examples

$$234 = 2.34 \times 10^2$$

$$0.0234 = 2.34 \times 10^{-2}$$

$$5.678 \times 10^3 = 5,678$$

$$5.67 \times 10^{-4} = 0.000567$$

From this exercise, it is evident that movements of the decimal point one space is equivalent to multiplying or dividing by ten, depending on the direction in which it is moved.

Another type of notation with which the welding should become familiar are the various prefixes which are used to indicate powers of ten. These are simply abbreviations to reduce the number of digits required. As an example, "kilo" means 1000, so a kilometer is 1000 meters. Similarly, "milli" means one-thousandth, so a millimeter is one-thousandth of a meter or there are 1000 millimeters in one meter. Some examples of the use of these prefixes appear below.

Examples of Prefixes for Powers of Ten

$$456,000,000 \text{ Pa} = 456 \text{ MPa}$$

$$56 \text{ km} = 56,000 \text{ m}$$

$$234,000 \text{ mm} = 234 \text{ m}$$

$$456 \text{ g} = 0.456 \text{ kg}$$

With this background, it is now possible to begin a discussion of how to actually perform numeric conversions from US to SI and SI to US.

SI Prefixes (Source: ANSI/AWS A1.1)			
Exponential Expression	Multiplication Factor	Prefix	Symbol
10^{18}	1 000 000 000 000 000	exa	E
10^{15}	1 000 000 000 000 000	peta	P
10^{12}	1 000 000 000 000	tera	T
10^9	1 000 000 000	giga	G
10^6	1 000 000	mega	M
10^3	1 000	kilo	k
10^2	100	hecto*	h
10	10	deka*	da
10^{-1}	0.1	deci*	d
10^{-2}	0.01	centi*	c
10^{-3}	0.001	milli	m
10^{-6}	0.000 001	micro	μ
10^{-9}	0.000 000 001	nano	n
10^{-12}	0.000 000 000 001	Pico	p
10^{-15}	0.000 000 000 000 001	femto	f
10^{-18}	0.000 000 000 000 000 001	atto	a

*Nonpreferred. Prefixes should be selected in steps of 103 so that the resultant number before the prefix is between 0.1 and 1000. These prefixes should not be used for units of linear measurement, but may be used for higher order units. For example, the linear measurement, decimeter, is nonpreferred, but square decimeter is acceptable.

The initial point to understand is that the welding inspector is not intended to memorize all of the conversion factors. Every factor which will be needed for the AWS CWI examination will be provided. The CWI candidate must simply be capable of manipulating the numbers to arrive at some solution.

A listing of some of the more common conversion factors is provided here to illustrate how these conversion factors will be noted on the CWI examination. You see that the table on the facing page is arranged in four columns, entitled: "Property," "To convert From," "To," and "Multiply by." These columns will be used in the same order as they are listed.

For any conversion exercise, the first step is to decide what particular property is described by the units which are to be converted. Once the proper category has been chosen from the "Property" column, look at the second column ("To convert from") and locate the line which contains the unit that is given in the exercise. This is the unit which will be converted. Moving straight across to the right, look for the unit that matches the unit to which the conversion will be made. When the line which contains both the known and desired units is located, the value

found in the last column ("Multiply by") is the appropriate conversion factor. At this point, simply multiply the number of the known units by this conversion factor. The result is the number of desired units. Several examples appear below to show how to use this table to perform typical conversions.

Conversion Example 1: An oxygen gage shows a pressure of 550 kPa. That is how many psi?

- 1) Property = pressure (gas and liquid)
- 2) Known unit= 550 kPa
- 3) Desired unit= psi
- 4) Conversion factor = 1.450×10^{-1}
Solution: $550 \text{ kPa} \times .1450 = ? \text{ psi}$
 $550 \text{ kPa} = 79.75 \text{ psi}$

Conversion Example 2: A tensile specimen was pulled and displayed an ultimate tensile strength of 655 MPa. This corresponds to how many psi?

- 1) Property = tensile strength
- 2) Known unit = 655 MPa
- 3) Desired unit = psi
- 4) Conversion factor = 1.450×10^2
Solution: $655 \text{ MPa} \times 145.0 = ? \text{ psi}$
 $655 \text{ MPa} = 94,975 \text{ psi}$

Conversion Example 3: What is the diameter in millimeters of a 5/32 inch electrode?

- 1) Property = linear measurements
- 2) Known unit = 5/32 inch (0.156 in)
- 3) Desired unit = mm
- 4) Conversion factor = 2.540×10
Solution: $0.156 \text{ in} \times 25.4 = ? \text{ mm}$
 $0.156 \text{ in} = 3.96 \text{ mm}$

Conversion Example 4: Welding parameters were adjusted to produce a weld metal deposition rate of 7.3 kg/h. What is that deposition rate in terms of lb/h?

- 1) Property = deposition rate
- 2) Known unit = 7.3 kg/h
- 3) Desired unit = lb/h
- 4) Conversion factor = 2.2
Solution: $7.3 \text{ kg/h} \times 2.2 = ? \text{ lb/h}$
 $7.3 \text{ kg/h} = 16.06 \text{ lb/h}$

Conversions for Common Welding Terms* (Source ANSI/AWS A1.1-)

Property	To Convert From	To	Multiply by
area dimensions (mm ²)	in ²	mm ²	6.451 600 x 10 ²
	mm ²	in ²	1.550 003 x 10 ⁻³
current density (A/mm ²)	A/in ²	A/mm ²	1.550 003 x 10 ⁻³
	A/mm ²	A/in ²	6.451 600 x 10 ²
disposition rate** (kg/h)	lb/h	kg/h	0.45**
	kg/h	lb/h	2.2**
electrical resistivity (Ω · m)	Ω · cm	Ω · m	1.000 000 x 10 ⁻²
	Ω · m	Ω · cm	1.000 000 x 10 ²
electrical force (N)	pound-force	N	4.448 222
	kilogram-force	N	9.806 650
	N	lbf	2.248 089 x 10 ⁻¹
flow rate (L/min)	ft ³ /h	L/min	4.719 475 x 10 ⁻¹
	gallon per hour	L/min	6.309 020 x 10 ⁻²
	gallon per minute	L/min	3.785 412
fracture toughness (MN · m ^{-3/2})	ksi · in ^{1/2}	MN · m ^{-3/2}	1.098 855
	MN · m ^{-3/2}	ksi · in ^{1/2}	0.910 038
heat input (J/m)	J/in	J/m	3.937 008 x 10
	J/m	J/in	2.540 000 x 10 ⁻²
impact energy	foot pound force	J	1.355 818
linear measurements (mm)	in.	mm	2.540 000 x 10
	ft	mm	3.048 000 x 10 ²
	mm	in.	3.937 008 x 10 ⁻²
	mm	ft	3.280 840 x 10 ⁻³
power density (W/m ²)	W/in ²	W/mm ²	1.550 003 x 10 ³
	W/m ²	W/in ²	6.451 600 x 10 ⁻⁴
pressure (gas and liquid) (kPa)	psi	kPa	6.894 757
	lb/ft ²	kPa	4.788 026 x 10 ⁻²
	N/mm ²	kPa	1.000 000 x 10 ³
pressure (gas and liquid) (kPa)	kPa	psi	1.450 377 x 10 ⁻¹
	kPa	lb/ft ²	2.088 543 x 10
	kPa	N/mm ²	1.000 000 x 10 ⁻³
pressure (vacuum) (Pa)	torr (mm Hg at 0°C)	Pa	1.333 220 x 10 ²
	micron (μ m Hg at 0°C)	Pa	1.333 220 x 10 ⁻¹
	Pa	torr	7.500 640 x 10 ⁻³
	Pa	micron	7.500 640
	bar	psi	1.450 377 x 10 ¹
tensile strength (MPa)	psi	MPa	6.894 757 x 10 ⁻³
	lb/ft ²	MPa	4.788 026 x 10 ⁻⁵
	N/mm ²	MPa	1.000 000
	MPa	psi	1.450 377 x 10 ²
	MPa	lb/ft ²	2.088 543 x 10 ⁴
	MPa	N/mm ²	1.000 000
thermal conductivity (W/[m · K])	cal/(cm · s° · C)	W/(m · K)	4.184 000 x 10 ²
travel speed,	in./min	mm/s	4.233 333 x 10 ⁻¹
wire feed speed (mm/s)	mm/s	in/min	2.362 205

* Preferred units are given in parenthesis

** Approximate conversion.

REVIEW -**CHAPTER 7
DESTRUCTIVE TESTING**

- Q7-1** Which property cannot be determined from a tensile test?
- a. ultimate tensile strength
 - b. percent elongation
 - c. percent reduction of area
 - d. impact strength
 - e. yield strength
- Q7-2** The property which describes the ability of a metal to deform or resist some applied load is:
- a. strength
 - b. toughness
 - c. hardness
 - d. ductility
 - e. none of the above
- Q7-3** The point at which a metal's behavior changes from elastic to plastic (onset of permanent deformation) is referred to as:
- a. yield strength
 - b. ultimate tensile strength
 - c. modulus of elasticity
 - d. Young's modulus
 - e. none of the above
- Q7-4** Which of the following is an expression for a metal's ductility?
- a. percent elongation
 - b. percent reduction of area
 - c. proportional limit
 - d. a and b above
 - e. b and c above

- Q7-5** What is the percent elongation of a specimen whose original gage length was inches and final gage length was 2.5 inches?
- a. 30%
 - b. 25%
 - c. 50%
 - d. 40%
 - e. none of the above
- Q7-6** The property of metals which describes their resistance to indentation is called:
- a. strength
 - b. toughness
 - c. hardness
 - d. ductility
 - e. none of the above
- Q7-7** The metal property test which is greatly affected by the surface condition of the part is:
- a. tensile strength
 - b. hardness
 - c. fatigue strength
 - d. impact strength
 - e. all of the above
- Q7-8** The type of strength which is related to a metal's behavior when the load is applied in a cyclic manner is:
- a. tensile
 - b. compressive
 - c. torsional
 - d. impact
 - e. fatigue
- Q7-9** The family of hardness tests which uses both a minor and major load is called:
- a. Brinell
 - b. Vickers
 - c. Rockwell
 - d. Knoop
 - e. none of the above

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- Q7-10** Which of the following tests are referred to as microhardness tests?
- a. Rockwell
 - b. Vickers
 - c. Knoop
 - d. a and b above
 - e. b and c above
- Q7-11** What type of test uses a weighted pendulum which strikes a notched test specimen?
- a. Brinell test
 - b. fatigue test
 - c. tensile test
 - d. crack opening displacement (COD)
 - e. Charpy impact test
- Q7-12** Endurance limit is an expression used for what type of testing?
- a. fatigue
 - b. hardness
 - c. soundness
 - d. tension
 - e. none of the above
- Q7-13** Which of the following is not considered a soundness test?
- a. tensile
 - b. face bend
 - c. fillet break
 - d. root bend
 - e. nick-break
- Q7-14** The type of testing used to evaluate the type of microstructure present in a metal is called:
- a. tensile
 - b. hardness
 - c. toughness
 - d. metallographic
 - e. none of the above

- Q7-15** A 50 lb can of welding electrodes weighs approximately how many kg?
- a. 227 kg
 - b. 2.3 kg
 - c. 22.7 kg
 - d. 23,000 kg
 - e. none of the above
- Q7-16** Which two metal properties are directly related for many steels?
- a. impact strength and fatigue strength
 - b. tensile strength and ductility
 - c. tensile strength and hardness
 - d. toughness ad fatigue strength
 - e. none of the above
- Q7-17** What is the wire feed speed which is measured to be 175 in./min.
- a. .125 m/s
 - b. 74 mm/s
 - c. 7.4 mm/s
 - d. a and b above
 - e. b and c above
- Q7-18** The property of metals which describes their ability to carry some type of load is:
- a. strength
 - b. toughness
 - c. hardness
 - d. ductility
 - e. none of the above
- Q7-19** Generally, as strength increases, the ductility:
- a. increases
 - b. stays the same
 - c. decreases
 - d. depends on the type of metal
 - e. none of the above

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- Q7-20** The ability of a metal to absorb energy is called:
- a. strength
 - b. ductility
 - c. hardness
 - d. toughness
 - e. none of the above
- Q7-21** A weld joint is measured and found to be 345 mm long. How long is that joint in terms of inches?
- a. 135.8 in
 - b. 13.58 in
 - c. 8760 in
 - d. 876 in
 - e. none of the above
- Q7-22** Which of the following tests are used to verify the soundness of a weld?
- a. nick break
 - b. fillet break
 - c. bend test
 - d. radiographic test
 - e. all of the above
- Q7-23** With the SAW process we can achieve a deposition rate of 19.7 kg/h. How many lb/h is this?
- a. 434 lb/h
 - b. 43.4 lb/h
 - c. 87.5 lb/h
 - d. 8.9 lb/h
 - e. none of the above
- Q7-24** Ultimate tensile strength can be determined using which of the following tests?
- a. tensile
 - b. bend
 - c. Charpy
 - d. nick break
 - e. nil-ductility drop-weight

- Q7-25** Calculation of percent elongation is determined after measuring the change in
- percent reduction of area
 - depth of indentation
 - diameter of indentation
 - cross sectional area
 - length between gage marks
- Q7-26** With the GMAW process we use a wire feed speed of 170 mm/s. How many in./min. is this?
- 40.16 in/min
 - 53.7 in/min
 - 401.6 in/min
 - 537 in/min
 - none of the above
- Q7-27** With the GTAW process flow rates are measured at 22 L/min. How many ft³/h is this?
- 10.4 ft³/h
 - 1.39 ft³/h
 - 46.6 ft³/h
 - 83.2 ft³/h
 - none of the above
- Q7-28** Calculation of tensile strength is accomplished by dividing the tensile load by
- cross sectional area
 - percent elongation
 - percent reduction of area
 - gage length
 - none of the above
- Q7-29** The metal property describing its freedom from imperfections is
- tensile strength
 - soundness
 - impact strength
 - toughness
 - ductility

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- Q7-30** If a metal exhibits a great deal of elongation prior to falling when a tensile load is applied is said to have high:
- tensile strength
 - hardness
 - impact strength
 - toughness
 - ductility
- Q7-31** A specimen approximately 2" long with a V-notch machined in the center of one of its sides is used for which of the following tests?
- tensile
 - nil-ductility drop-weight
 - Charpy
 - bend
 - tuck break
- Q7-32** A heat input of 1,500,000 J/m is how many J/in.?
- 381 J/in.
 - 3,810 J/in.
 - 38,100 J/in
 - 381,000 J/in
 - none of the above
- Q7-33** Which of the following properties can be determined from a tensile test?
- ultimate tensile strength, yield strength, ductility
 - yield strength, ductility, toughness
 - ductility only
 - toughness only
 - all of the above
- Q7-34** The heat capacity of a furnace is listed as 120,000 Btu. What is that in terms of Joules?
- 29,000J
 - 502,000J
 - 130J
 - 290J
 - 13,000J

- Q7-35** The force required to bend a steel bar is measured to be 890 N. That is how many lbf?
- a. 200.3 lbf
 - b. 2003 lbf
 - c. 20 lbf
 - d. 550 lbf
 - e. none of the above
- Q7-36** A coating was removed from a SMAW electrode. After weighing, it was found to have a mass of 2.4 oz. That is how many grams?
- a. 68 g
 - b. 6.8 g
 - c. 0.008 g
 - d. 0.8 g
 - e. none of the above