Steel Tube Institute
OF NORTH AMERICA

Handbook of Welded Carbon Steel Mechanical Tubing

HANDBOOK OF

WELDED CARBON STEEL MECHANICAL TUBING

STEEL TUBE INSTITUTE OF NORTH AMERICA

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2000 Ponce de Leon, Suite 600, Coral Gables, FL 33134 • Tel: (305) 421-6326
E-mail: STINA@steeltubeinstitute.org • Website: http://www.steeltubeinstitute.org

FOREWORD

It has become evident, with the growth in the knowledge of mechanics, that the tubular shape possesses distinct advantages over other shapes. Pound for pound welded steel tubing is stronger in many applications than other steel sections. It is pleasing to the eye, can be readily fabricated, and is widely available. This Handbook has been prepared for engineers, designers, and manufacturers who have used tubing, and also for those who contemplate its use. Readily accessible data are included to aid them in the selection of the proper tube for their application. Obviously it is not possible to cover all contingencies, and further information is available from any member of the Steel Tube Institute.

The data in this book apply to Electric Resistance Welded (ERW) carbon and alloy mechanical steel tubing, whether used in the as-welded condition or after further processing. Unlike pipe, mechanical tubing is not intended for the transmission of fluids, except in fluid power applications, and is produced to exact rather than nominal OD or wall dimensions, and to exacting tolerances.

Mechanical steel tubing is distinguished from steel pressure tubing by its use or application. Pressure tubing is used to contain or convey fluids under pressure and generally at other than ambient temperatures. Mechanical tubing is used in a multitude of applications not involving fluids. These include applications where strength, appearance, machinability and fabricability, resistance to torsion, and maximum strength to weight ratio are required.

It is hoped that readers will come to recognize why welded mechanical steel tubing enjoys universal acceptance, and will become aware of some of its many applications. The data will cover mechanical tubing only. Literature on carbon steel pressure tubing and structural tubing is also available from the Steel Tube Institute office or from its individual member companies.

Steel Tube Institute of North America
2500 Ponce de Leon, Suite 200
Coral Gables, FL 33134

The data contained in this Handbook reflect the general state of the art in the production of welded tubing. This material is not intended to be all inclusive, nor to be a substitute for any specific arrangements between suppliers and users of welded tubing. The data shown for properties, test procedures, tolerances, sizes and other characteristics of tubing reflect those in general use but are for reference and guidance only. Most of these data appear in public specifications and are duly referenced. Different or additional specifications and characteristics are or may be available from various tubing sources. The user of welded tubing should consult with a tubing source concerning this particular requirements.

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SECTION I — General Characteristics

Welded steel tubing has many advantages over other materials. Engineers and designers specify welded steel tubing for a progessively widening variety of applications. It may be used straight, where its strength to weight advantage is the prime requirement, or in parts requiring bending, flattening, flaring or many other types of fabrication.

Savings result from its use because the workability of welded tubing means less scrap loss and better adaptability to applications where more expensive and less reliable materials had been used. Welded tubing normally is lower in cost than seamless tubing, generally has a better surface finish, is available in lighter wall to diameter ratios, and can be manufactured from precoated steel. Its superior uniformity and concentricity allow the designer the choice of a lighter wall and thus less allowance for stock removal when the tube is to be machined.

Welded tubing is produced from flat rolled steel supplied to the tube mill in coils. The excellent surface quality on both sides of this flat rolled material results in uniform, smooth surfaces free from defects inside and out, and a uniform wall thickness.

Tubing may be cold drawn for applications requiring even better surface finish, closer tolerances, and improved tensile properties. When tubing is cold drawn over a mandrel, it is often referred to as DOM (drawn over mandrel) tubing, but when nothing is used inside the tube (drawn without mandrel), the product is referred to as sink drawn tubing.

SECTION II — Manufacturing Process

1. Raw Material

The raw material used in the production of welded tubing is flat rolled steel received from the steel mill in coils. The coiled steel is produced by the open-hearth, basic oxygen or electric furnace process. The coiled steel is killed or semi-killed (see glossary) depending on application or specifications. The tube mill specifies steel-making practice, thickness, width, edge condition, chemical analysis and in the case of cold rolled, surface finish and temper, to insure the production of tubing which meets all quality standards required. All coils are properly tagged by the producing mill, permitting identity to be maintained through all tube mill processing.

Coils may be either hot rolled (HR) or cold rolled (CR). Hot rolled steel is either without the scale removed (black) or in the pickled and oiled condition. The scale may be removed by pickling or particle blasting prior to tube manufacture. Hot rolled steel usually possesses higher tensile and yield strength properties than does cold rolled steel, which is normally annealed to facilitate forming. Cold rolled steel may be ordered with various surface finishes, closer tolerances and better control of temper and hardness, but is generally limited to the lighter gauges. Tubing made from cold rolled may be plated in the as-received condition or with surface preparation, depending on the type and quality of plating surface required. Both hot rolled and cold rolled steel are well suited for painting and, with proper procedures, a very smooth, attractive surface finish can be produced.

2. Tubing Mill Equipment

Welded steel tubing is formed, welded, sized, and cut to length in a continuous process. The flat steel is passed through consecutive matching rolls with contoured grooves which gradually form the cold steel into a tubular shape whose butted edges are welded by one of the electric resistance methods described in the next section. To facilitate uninterrupted production and consistent quality, many mills end weld coils together at the mill. This end welded section is removed at the cutoff and scrapped.

Tubing is generally welded slightly oversize with emphasis at the point of welding on weld quality rather than size. The tubing, after being welded, enters the sizing section, which consists of sets of rolls in pairs with accurate semi-circular grooves. The sizing section reduces the tube to final dimensions. The fine finish on the sizing rolls can actually improve the surface finish of the steel.

Tubing then enters the cut-off section, the forward speed of which is synchronized with the tube so that the cut-off operation is performed with accuracy at mill operating speed. Rotary head, saw, or punch cutting are generally used.

3. The Welding Process

The electric resistance method is the most common welding procedure for carbon and many alloy steels. As the name implies, heat for welding the butted edges together is generated by resistance to the flow of an electric current. The heat is confined to a narrow band along the edges, with the highest temperature at the extreme edges. The balance of the tube remains cold. Low frequency alternating current (AC), direct current (DC), and ultra high frequency alternating current are the three electric resistance welding methods being used.

In low frequency AC welding, the low voltage and high amperage current is conducted to the strip edges by a pair of rotating copper alloy discs which are insulated from each other. These are called the electrodes. Frequencies generally range from 60 to 360 Hz (cycles per second). A set of special rolls directly under the electrodes squeezes the butted edges together while they are at welding heat to produce the weld. It is important to note that no filler metal is added in the welding operation keeping the metal composition of the weld line the same as the balance of the tube.

Mills utilizing DC welding equipment have the same configuration as that described above.

A modification of the electric resistance welding process is the use of ultra high frequency (HF) electrical current with frequencies in the range of 300,000 to 500,000 Hz. Current flow along the strip edges is induced by shoes which make sliding contact with the tubing surface ahead of the butted edges, or by an encircling induction coil. At welding heat, side pressure rolls complete the weld as in low frequency welding.

4. The Weld Flash

The ERW process extrudes a small amount of metal (weld flash) on both the inside and outside of the tubing. This weld flash is removed from the outside diameter (OD) of the tube immediately after welding with a cutting or planing tool contoured to the diameter of the tube being produced. The inside diameter (ID) flash may be left in or controlled in height depending on customer requirements and application. The flash can be controlled by rolling, or by cutting with a tool contoured to the tube ID.

5. Cold Drawn and Cold Worked Tubing

Welded tubing may be further processed by cold drawing to meet specific end use requirements. The user may want OD and/or ID tolerance limits closer than can be supplied with off-the-welder tubing, a better OD or ID surface, or higher tensile properties. Cold drawing makes these possible. The drawing operation increases the yield and tensile strengths with a corresponding decrease in ductility. The drawn tube may be thermally treated to produce specific mechanical properties if desired.

The starting stock for cold drawn tubing is electric resistance welded mechanical steel tubing, either produced in-plant or purchased. Specifications require a thoroughly tested tube, and extra precautions are taken with ID weld flash removal. The flash must be cut accurately to prevent any lapping in the subsequent drawing operation. A wide variety of carbon and alloy steels up to about 0.45% carbon is drawn. If no grade is specified, Grades MT 1010 to MT 1020 may be furnished.

Preparatory to drawing the ERW tube hollow or shell is fully annealed, pickled for cleanliness, pointed, and coated with a lubricant. The pointed end of this tube is placed between jaws attached to a chain or hydraulic pulling device, which pull it through a hardened steel or carbide die with an orifice of the required dimension. If the ID tolerance and/or surface finish are important or higher tensiles are required, the tube hollow or shell is simultaneously pulled over a plug mandrel or hardened steel bar.

In drawing very small diameters, extensive use may be made of the mandrel bar drawing process. In this case a solid hardened alloy rod is inserted in the tube, and both tube and bar are drawn simultaneously through the die. The size of the bar thus controls the ID of the drawn tube. After each such draw, the tube is cross rolled to permit withdrawal of the mandrel bar.

Sink drawing (drawing without mandrel) is employed when outside diameter tolerances are the only consideration. In the smaller sizes sink drawing is often used as a final operation to bring the tube to size where final tube size is too small to use a plug or bar.

6. Thermal Treatments

When so specified carbon steel tubing whether as-welded or cold drawn is heated in temperature controlled annealing or normalizing furnaces. Stress relief annealing removes stresses induced in the cold working operation, while normalizing results in complete recrystallization of weld and base metal. This operation is usually done in an atmosphere controlled furnace. After the tubes are heated in the furnace and held at the proper temperature for the required time, they are cooled in the same atmosphere. Temperatures may range from 850 to 1750 degrees F depending on whether stress relieving, sub-critical annealing, or full normalizing is ordered.

7. Straightening

Although tubes are straight within mechanical tube tolerances as they come off the welder, special applications may demand further straightening operations. Cold drawn tubing is always straightened to specification tolerances.

8. Secondary Cutting and End Finishing

Tubes are often cut at the welder in multiples of the ordered length. For many applications final length tolerances are usually closer than can be held by cutting on the mill. In these cases secondary cutting is performed. Secondary cutting can be performed with a metal saw, single or double action shear, or a rotary lathe or disc cut-off. These operations give different end conditions which must be evaluated by the user. Punch cutting is also used, particularly where many short lengths are required and the wall thickness is comparatively light. A slow moving cold saw may be used followed by a facing operation to remove burrs and obtain a completely square end. When required, tube ends may be chamfered or brushed to remove OD or ID burr.

9. Inspection and Testing

Weld quality is checked at the welder by means of destructive and/or nondestructive tests.

Tubing ordered to a designated specification or application may be given any one or several of the following tests on the finished product:

a. Destructive Tests

1) Flattening Test. A force is applied to the tubing surface at right angles to its axis. The weld is positioned at 90 degrees or 0 degrees to the applied force. The tube is flattened to a specified amount as a check for OD or ID weld integrity.

2) Crush Test. A force is applied axially to a short length of tubing resulting in a fold which stretches outside fibers completely around the tube. This test could disclose seams or laps and also is another check for weld integrity.

3) Flare and Flange Test. A short length of tubing is expanded over a cone of predetermined included angle. A flange is produced when the tubing is flared over the cone and then placed on a flat surface under increased load. This test stresses the tubing including the weld to the extent desired.

b. Nondestructive Tests

1) Nondestructive Electric Test. The welded tubing industry has been a leader in initiating and developing new techniques for nondestructive testing. These have proven to be more sensitive to the detection of defects not generally located by pressure testing. The wide acceptance of welded tubing for many critical service applications has been due to the rapidly increasing use of these methods for testing. Some of the nondestructive techniques employed by the industry are the following:

Eddy Current (Electromagnetic). Consult ASTM E 309.
Ultrasonic. Consult ASTM E 213 and E 273.
Flux Leakage. Consult ASTM E 570.

2) Hydrostatic Test. This is an internal pressure test where the tube is filled with liquid at a specified pressure. The pressure is maintained for a specified length of time.

c. **Special Testing**

1) Hardness Testing. The Rockwell hardness test is commonly used as an indication of tensile strength or temper. The test is usually conducted on the ID of a section cut from a ring of the tube. In general, Rockwell B tests may be performed on unannealed tubing with a wall thickness of .049" min. and ID of ¼". One of the superficial Rockwell ranges should be used for thinner walled tubing. For additional information refer to "Standard Methods of Test For Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials," ASTM designation E 18.

2) Tension Testing. The tension test subjects a specimen of tube (either a full section or a longitudinal strip machined from a tube) to a measured load sufficient to cause rupture. For additional information see "Mechanical Testing of Steel Products," ASTM designation A 370, sections 5 to 13.

3) Surface Finish Measurement. Drawn over mandrel tubing can be furnished to known surface smoothness in accordance with the following table. This table lists the ID surface microinch readings shown as supplementary requirements in ASTM A 513 for "special smooth" inside surface tubing. This consideration would be of value for such applications as hydraulic cylinder tubing. For other microinch determinations consult a tubing source.

Table 1
Microinch Readings — I.D. Surface

Outside Diameter, in[A]	Tubing Wall Thickness, in.[A] 0.065 and Under	Over 0.065 to 0.150, incl	Over 0.150 to 0.187, incl	Over 0.187 to 0.225, incl	Over 0.225 to 0.312, incl
1 to 2½, incl	40	45	50	55	70
Over 2½ to 4½, incl	40	50	60	70	80
Over 4½ to 5½, incl	...	55	70	80	90
Over 5½ to 7, incl	...	55	70	80	90

[A] 1 in. = 25.4 mm.

Measuring Microinch Finish

X1.1 The procedure for making microinch readings on interior surfaces of cold worked tubing (not polished or ground) ½ in. (12.7 mm) inside diameter and larger is as follows:

X1.1.1 Measurements on tubing with longitudinal or no predominant lay should be circumferential on the inside surface of the straight tube, prior to any fabrication, on a plane approximately perpendicular to the tube axis. Measurements on tubing with circumferential lay should be longitudinal.

X1.1.2 Measurements should be made not less than 1 in. (25.4 mm) from the end.

X1.1.3 Measurements should be made at four positions approximately 90 deg apart or over a complete circumference if the trace should otherwise overlap.

X1.1.4 The length of trace should be in accordance with Section 4.5 of American National Standard B46.1, latest revision (not less than 0.600 in. (15.24 mm) long).

X1.1.5 A minimum of three such measurements should be made spaced not less than ¼ in. (6.4 mm) apart along the longitudinal axis.

X1.1.6 The numerical rating shall be the arithmetical average microinch of all readings taken. Each reading to be averaged should be the mean position of the indicator during the trace; any momentary meter excursions occupying less than 10% of the total trace should be ignored.

X1.1.7 A deviation in numerical rating in various parts of a tube may be expected. Experience to date indicates that a variation of about ±35% is normal.

X1.2 Instruments should meet the specifications given in American National Standard B46.1 latest revision.

X1.3 Mechanical tracing is preferred. If hand tracing is used, the speed of trace should not vary by more than ±20% from the required to give the appropriate cutoff. The 0.030-in. roughness width cutoff should be used.

X1.4 Microinch determinations only refer to roughness of areas that do not contain a defect, injurious or otherwise. Such defects as seams, slivers, pits, laps, etc., are subject to ordinary visual inspection in accordance with applicable specifications or trade customs, and have no relationship to roughness.

Ref.: ASTM A 513-85

SECTION III — Data on Commonly Produced Sizes of Round, Square, Rectangular and Shaped Tubing

The American Society for Testing and Materials has issued ASTM A 513 "Standard Specification for Electric Resistance Welded Carbon and Alloy Steel Mechanical Tubing." This specification covers round, square, rectangular and special shaped tubing and contains all the requirements applicable to mechanical tubing. The major requirements of A 513 are included in this Handbook as a service to the reader.

1. Round Tubing

The following tables, pages 8 to 17 cover specifications and data on round tubing. Data on cylinder and special surface tubing which apply to these grades only and which are included in A 513 as Supplementary Requirements are listed on pages 7 and 22.

Table 2
Available Sizes, Round Tubing

Size of Tube	24ga. .022"	22ga .028"	21ga .032"	20ga .035"	19ga .042"	18ga .049"	17ga .058"	16ga .065"	15ga .072"	14ga .083"	13ga .095"	12ga .109"	11ga .120"	10ga .134"	9ga .148"	.156"	8ga .165"	7ga .180"	6ga .203"	5ga .220"
.375"	O	O																		
.500"	O	O	O	O	O	O	O	O												
.625"	O	O	O	O	O	O	O	O	O	O										
.750"	O	O	O	O	O	O	O	O	O	O	O	O	O							
.875"	O	O	O	O	O	O	O	O	O	O	O	O	O							
1.000"	O	O	O	O	O	O	O	O	O	O	O	O	O	O						
1.125"	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O					
1.250"		O	O	O	O	O	O	O	O	O	O	O	O	O	O					
1.375"		O	O	O	O	O	O	O	O	O	O	O	O	O	O					
1.500"		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O		
1.625"		O	O	O	O	O	O	O	O	O	O	O	O	O	O		O	O		
1.750"		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O		
1.875"		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O		
2.000"		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
2.125"				O	O	O	O	O	O	O	O	O	O	O	O		O	O		
2.250"				O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
2.375"				O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
2.500"				O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
2.625"					O	O	O	O	O	O	O	O	O	O	O	O	O	O		
2.750"					O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
2.875"					O	O	O	O	O	O	O	O	O	O	O		O	O	O	O
3.000"					O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
3.125"						O	O	O	O	O	O	O	O	O	O		O	O	O	O
3.250"						O		O	O	O	O	O	O	O	O	O	O	O	O	O
3.500"					O	O		O	O	O	O	O	O	O	O	O	O	O	O	O
3.750"						O		O		O	O	O	O	O	O	O	O	O	O	O
4.000"					O	O		O	O	O	O	O	O	O	O	O	O	O	O	O
4.250"								O		O	O	O	O	O	O	O	O	O	O	O
4.500"								O		O	O	O	O	O	O	O	O	O	O	O
4.625"								O		O	O	O	O	O	O		O	O	O	O
4.750"								O		O	O	O	O	O	O		O	O	O	O
5.000"						O		O		O	O	O	O	O	O	O	O	O	O	O
5.500"								O		O	O	O	O	O	O	O	O	O	O	O
5.750"								O		O	O	O	O	O	O		O	O	O	O
6.000"								O		O	O	O	O	O	O	O	O	O	O	O
6.125"																				
6.500"														O	O	O	O	O	O	O
6.625"															O		O	O	O	O
6.875"																				
7.000"										O	O	O	O	O	O	O	O	O	O	O
7.500"																	O	O	O	O
8.000"										O	O	O	O	O	O	O	O	O	O	O
8.625"																			O	O
8.750"																				
10.000"																			O	O
10.750"																				O
11.250"																				
12.500"																				

Size of Tube	4ga. .238″	.250″	3ga .259″	2ga .284″	1ga .300″	.312″	.320″	.344″	.360″	.375″	.380″	.400″	.425″	.450″	.500″	.525″	.563″	.580″	.625″
.375″																			
.500″																			
.625″																			
.750″																			
.875″																			
1.000″																			
1.125″																			
1.250″																			
1.375″																			
1.500″																			
1.625″																			
1.750″																			
1.875″																			
2.000″																			
2.125″																			
2.250″																			
2.375″	O																		
2.500″	O	O																	
2.625″																			
2.750″	O	O																	
2.875″	O																		
3.000″	O	O		O	O	O													
3.125″	O																		
3.250″	O	O		O	O	O													
3.500″	O	O		O	O	O	O	O	O	O	O	O	O						
3.750″	O	O		O	O	O	O	O	O	O									
4.000″	O	O		O	O	O	O	O	O	O	O	O	O						
4.250″	O	O		O	O	O	O	O	O	O									
4.500″	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O			
4.625″	O	O																	
4.750″	O	O																	
5.000″	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	
5.500″	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
5.750″	O	O																	
6.000″	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
6.125″									O	O	O	O	O	O	O	O	O	O	O
6.500″	O	O		O	O	O	O	O	O	O									
6.625″	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
6.875″									O	O	O	O	O	O	O	O	O	O	O
7.000″	O	O		O	O	O	O	O	O	O									
7.500″	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
8.000″	O	O																	
8.625″	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
8.750″					O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
10.000″	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
10.750″	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
11.250″					O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
12.500″							O	O	O	O	O	O	O	O	O	O	O	O	O

Note: Many other sizes and gages are available. Tubing with wall thickness lighter than 15 gage is commonly available only in cold rolled steel. Tubing with wall thickness heavier than 10 gage is commonly available only in hot rolled steel.

Table 3
Tolerances, Diameter — As-Welded, Cold Rolled
Note — Measurements for diameter are to be taken at least 2 in.[A] from the ends of the tubes.

Outside Diameter Range, in.[A]	Wall Thickness		Flesh-in-Tubing[B]	Flash Controlled to 0.010 in. mex Tubing[C]	Flash Controlled[D] to 0.005 in. mex Tubing	
	Bwg[E]	in.[A]	Outside Diameter Plus and Minus	Outside Diemater Plus end Minus	Outside Diametar Plus and Minus	Inside Diameter Plus and Minus
			Tolerancas, in[F]			
3/8 to 5/8, incl	22 to 16	0.028 to 0.065	0.003	. . .	. . .	. . .
Over 5/8 to 1 1/8, incl	22 to 20	0.028 to 0.035	0.0035	0.0035	0.0035	0.013
Over 5/8 to 1 1/8, incl	18	0.049	0.0035	0.0035	0.0035	0.015
Over 5/8 to 1 1/8, incl	16 to 14	0.065 to 0.083	0.0035	0.0035	0.0035	0.019
Over 3/4 to 1 1/8, incl	13	0.095	0.0035	0.0035	0.0035	0.019
Over 7/8 to 1 1/8, incl	12 to 11	0.109 to 0.120	0.0035	0.0035	0.0035	0.021
Over 1 1/8 to 2, incl	22 to 18	0.028 to 0.049	0.005	0.005	0.005	0.015
Over 1 1/8 to 2, incl	16 to 13	0.065 to 0.095	0.005	0.005	0.005	0.019
Over 1 1/8 to 2, incl	12 to 10	0.109 to 0.134	0.005	0.005	0.005	0.022
Over 2 to 2 1/2, incl	20 to 18	0.035 to 0.049	0.006	0.006	0.006	0.016
Over 2 to 2 1/2, incl	16 to 13	0.065 to 0.095	0.006	0.006	0.006	0.020
Over 2 to 2 1/2, incl	12 to 10	0.109 to 0.134	0.006	0.006	0.006	0.023
Over 2 1/2 to 3, incl	20 to 18	0.035 to 0.049	0.008	0.008	0.008	0.018
Over 2 1/2 to 3, incl	16 to 13	0.065 to 0.095	0.008	0.008	0.008	0.022
Over 2 1/2 to 3, incl	12 to 10	0.109 to 0.134	0.008	0.008	0.008	0.025
Over 3 to 3 1/2, incl	20 to 18	0.035 to 0.049	0.009	0.009	0.009	0.019
Over 3 to 3 1/2, incl	16 to 13	0.065 to 0.095	0.009	0.009	0.009	0.023
Over 3 to 3 1/2, incl	12 to 10	0.109 to 0.134	0.009	0.009	0.009	0.026
Over 3 1/2 to 4, incl	20 to 18	0.035 to 0.049	0.010	0.010	0.010	0.020
Over 3 1/2 to 4, incl	16 to 13	0.065 to 0.095	0.010	0.010	0.010	0.024
Over 3 1/2 to 4, incl	12 to 10	0.109 to 0.134	0.010	0.010	0.010	0.027
Over 4 to 6, incl	16 to 13	0.065 to 0.095	0.020	0.020	0.020	0.034
Over 4 to 6, incl	12 to 10	0.109 to 0.134	0.020	0.020	0.020	0.037
Over 6 to 8, incl	14 to 13	0.083 to 0.095	0.025	0.025	0.025	0.039
Over 6 to 8, incl	12 to 10	0.109 to 0.134	0.025	0.025	0.025	0.042

[A] 1 in. = 25.4 mm.
[B] Flash-In-Tubing is produced to outside diameter tolerances and wall thickness tolerances only, and the height of the inside welding flash does not exceed the wall thickness or 3/32 in., whichever is less.
[C] Flash Controlled to 0.010 in. max tubing consists of tubing over 5/8 in. outside diameter which is commonly produced to outside diameter tolerances and wall thickness tolerances only, in which the height of the remaining inside welding flash is controlled not to exceed 0.010 in.
[D] Flash Controlled to 0.005 in. max tubing is produced to outside diameter tolerances and wall thickness tolerances, inside diameter tolerances and wall thickness tolerances, or outside diameter tolerances and inside diameter tolerances, in which the height of the remaining inside welding flash is controlled not to exceed 0.005 in. Any remaining flash is considered to be part of the applicable inside diameter tolerances.
[E] Birmingham Wire Gage.
[F] The ovality shall be within the tolerances except when the wall thickness is less than 3 percent of the outside diameter. In such cases the ovality may be 50 per cent greater than the outside tolerances, but the mean outside diameter shall be within the specified tolerance.
Ref.: ASTM A 513-85

Table 4
Tolerances, Diameter — As-Welded, Hot Rolled
Note — Measurements for diameter are to be taken at least 2 in.[A] from the ends of the tubes.

Outside Diameter Range, in.[A]	Wall Thickness		Flash-in-Tubing[B,C]	Flash Controlled to 0.010 in. max Tubing[C,E]	Flash Controlled to 0.005 in. max Tubing[D,E]	
	Bwg[F]	in.[A]	Outside Diameter Plus and Minus	Outside Diameter Plus and Minus	Outside Diameter Plus and Minus	Inside Diameter Plus and Minus
			Tolerances, in.[A,G]			
¾ to 1⅛, incl	16 to 10	0.065 to 0.134	0.0035		0.0035	0.020
Over 1⅛ to 2, incl	16 to 14	0.065 to 0.083	0.005	0.005	0.005	0.021
Over 1⅛ to 2, incl	13 to 7	0.095 to 0.180	0.005	0.005	0.005	0.025
Over 1⅛ to 2, incl	6 to 5	0.203 to 0.220	0.005	0.005	0.005	0.029
Over 1⅛ to 2, incl	4 to 3	0.238 to 0.259	0.005	0.005	0.005	0.039
Over 2 to 2½, incl	16 to 14	0.065 to 0.083	0.006	0.006	0.006	0.022
Over 2 to 2½, incl	13 to 5	0.095 to 0.220	0.006	0.006	0.006	0.024
Over 2 to 2½, incl	4 to 3	0.238 to 0.259	0.006	0.006	0.006	0.040
Over 2½ to 3, incl	16 to 14	0.065 to 0.083	0.008	0.008	0.008	0.024
Over 2½ to 3, incl	13 to 5	0.095 to 0.220	0.008	0.008	0.008	0.026
Over 2½ to 3, incl	4 to 3	0.238 to 0.259	0.008	0.008	0.008	0.040
Over 2½ to 3, incl	2 to 0.320	0.284 to 0.320	0.010	0.010	0.010	0.048
Over 3 to 3½, incl	16 to 14	0.065 to 0.083	0.009	0.009	0.009	0.025
Over 3 to 3½, incl	13 to 5	0.095 to 0.220	0.009	0.009	0.009	0.027
Over 3 to 3½, incl	4 to 3	0.238 to 0.259	0.009	0.009	0.009	0.043
Over 3 to 3½, incl	2 to 0.360	0.284 to 0.360	0.012	0.012	0.012	0.050
Over 3½ to 4, incl	16 to 14	0.065 to 0.083	0.010	0.010	0.010	0.026
Over 3½ to 4, incl	13 to 5	0.095 to 0.220	0.010	0.010	0.010	0.028
Over 3½ to 4, incl	4 to 3	0.238 to 0.259	0.010	0.010	0.010	0.044
Over 3½ to 4, incl	2 to 0.500	0.284 to 0.500	0.015	0.015	0.015	0.053
Over 4 to 5, incl	16 to 14	0.065 to 0.083	0.020	0.020	0.020	0.036
Over 4 to 5, incl	13 to 5	0.095 to 0.220	0.020	0.020	0.020	0.045
Over 4 to 5, incl	4 to 3	0.238 to 0.259	0.020	0.020	0.020	0.054
Over 4 to 5, incl	2 to 0.500	0.284 to 0.500	0.020	0.020	0.020	0.058
Over 5 to 6, incl	16 to 10	0.065 to 0.134	0.020	0.020	0.020	0.036
Over 5 to 6, incl	9 to 5	0.148 to 0.220	0.020	0.020	0.020	0.040
Over 5 to 6, incl	4 to 3	0.236 to 0.259	0.020	0.020	0.020	0.054
Over 5 to 6, incl	2 to 0.500	0.284 to 0.500	0.020	0.020	0.020	0.058
Over 6 to 8, incl	11 to 10	0.120 to 0.134	0.025	0.025	0.025	0.043
Over 6 to 8, incl	9 to 5	0.148 to 0.220	0.025	0.025	0.025	0.045
Over 6 to 8, incl	4 to 3	0.238 to 0.259	0.025	0.025	0.025	0.059
Over 6 to 8, incl	2 to 0.500	0.284 to 0.500	0.025	0.025	0.025	0.063

[A] 1 in. = 25.4 mm.

[B] Flash-In-Tubing is produced only to outside diameter tolerances and wall thickness tolerances and inside diameter welding flash does not exceed the wall thickness or 3/32 in., whichever is less.

[C] Flash Controlled to 0.010 in. max tubing consists of tubing over 1⅛ in. outside diameter which is commonly produced only to outside diameter tolerances and wall thickness tolerances, in which the height of the remaining welding flash is controlled not to exceed 0.010 in.

[D] Flash Controlled to 0.005 in. max tubing is produced to outside diameters and wall thickness tolerances, inside diameter and wall thickness tolerances, or outside diameters and inside diameter tolerances, in which the height of the remaining flash is controlled not to exceed 0.005 in. Any remaining flash is considered to be part of the applicable inside diameter tolerances.

[E] No Flash tubing is further processed for closer tolerances with mandrel-tubing produced to outside diameter and wall, inside diameter and wall, or outside diameter and inside diameter to tolerances with no dimensional indication of inside diameter flash. This condition is available in mandrel drawn and special smooth inside diameter tubing.

[F] Birmingham Wire Gage.

[G] The ovality shall be within the tolerances except when the wall thickness is less than 3 percent of the outside diameter. In such cases the ovality may be 50 per cent greater than the outside tolerances, but the mean outside diameter shall be within the specified tolerance.

Ref.: ASTM A 513-85

Table 5
Tolerences, Wall Thickness — As-Welded, Cold Rolled

Wall Thickness		Outside Diameter, in.[A]											
in.[A]	Bwg[B]	3/8 to 7/8, incl		Over 7/8 to 1 7/8, incl		Over 1 7/8 to 3 3/4, incl		Over 3 3/4 to 5, incl		Over 5 to 8, incl		Over 6 to 8, incl	
		Wall Thickness Tolerences, in.,[A] Plus and Minus											
		Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus
0.028	22	0.001	0.005	0.001	0.005	...	...	...	...	...	...	...	...
0.035	20	0.002	0.005	0.001	0.005	0.001	0.005	...	...	...	...	...	...
0.049	18	0.003	0.006	0.002	0.006	0.002	0.006	...	...	...	...	...	...
0.065	16	0.005	0.007	0.004	0.007	0.004	0.007	0.004	0.007	0.004	0.007	...	...
0.083	14	0.006	0.007	0.005	0.007	0.004	0.007	0.004	0.007	0.004	0.008	0.004	0.008
0.095	13	0.006	0.007	0.005	0.007	0.004	0.007	0.004	0.007	0.004	0.008	0.004	0.008
0.109	12	...	...	0.006	0.008	0.005	0.008	0.005	0.008	0.005	0.009	0.005	0.009
0.120	11	...	...	0.007	0.008	0.006	0.008	0.005	0.008	0.005	0.009	0.005	0.009
0.134	10	...	...	0.007	0.008	0.006	0.008	0.005	0.008	0.005	0.009	0.005	0.009

[A] 1 in. = 25.4 mm.
[B] Birmingham Wire Gage.
Ref.: ASTM A 513-85

Table 6
Tolerances, Well Thickness — As-Welded, Hot Rolled

Well Thickness		Outside Diemeter, in.[A]											
in.[A]	Bwg[B]	3/4 to 1, incl		Over 1 to 1 15/16, incl		Over 1 15/16 to 3 3/4, incl		Over 3 3/4 4 1/2, incl		Over 4 1/2 to 6, incl		Over 8 to 8, incl	
		Well Thickness Tolerences, in., Plus end Minus											
		Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus
0.065	16	0.005	0.009	0.004	0.010	0.003	0.011	0.002	0.012	0.002	0.012	...	...
0.072	15	0.005	0.009	0.004	0.010	0.003	0.011	0.002	0.012	0.002	0.012	...	...
0.083	14	0.006	0.010	0.005	0.011	0.004	0.012	0.003	0.013	0.003	0.013	...	...
0.095	13	0.006	0.010	0.005	0.011	0.004	0.012	0.003	0.013	0.003	0.013	...	...
0.109	12	0.006	0.010	0.005	0.011	0.004	0.012	0.003	0.013	0.003	0.013	0.003	0.013
0.120	11	0.006	0.010	0.005	0.011	0.004	0.012	0.003	0.013	0.003	0.013	0.003	0.013
0.134	10	0.006	0.010	0.005	0.011	0.004	0.012	0.003	0.013	0.003	0.013	0.003	0.013
0.148	9	...	...	0.006	0.012	0.005	0.013	0.004	0.014	0.004	0.014	0.004	0.014
0.165	8	...	...	0.006	0.012	0.005	0.013	0.004	0.014	0.004	0.014	0.004	0.014
0.180	7	...	...	0.006	0.012	0.005	0.013	0.004	0.014	0.004	0.014	0.004	0.014
0.203	6	...	...	...	...	0.007	0.015	0.006	0.016	0.005	0.017	0.005	0.017
0.220	5	...	...	...	...	0.007	0.015	0.006	0.016	0.005	0.017	0.005	0.017
0.238	4	...	...	...	...	0.012	0.020	0.011	0.021	0.010	0.022	0.010	0.022
0.259	3	...	...	...	...	0.013	0.021	0.012	0.022	0.011	0.023	0.011	0.023
0.284	1	...	...	...	...	0.014	0.022	0.013	0.023	0.012	0.024	0.012	0.024
0.300	1	...	...	...	...	0.015	0.023	0.014	0.024	0.013	0.025	0.013	0.025
0.320	...	...	...	...	...	0.016	0.024	0.015	0.025	0.014	0.026	0.014	0.026
0.344	...	...	...	...	...	0.017	0.025	0.016	0.028	0.015	0.027	0.015	0.027
0.360	...	...	...	...	...	0.017	0.025	0.016	0.028	0.015	0.027	0.015	0.027
0.375	...	...	...	...	...	...	...	0.016	0.026	0.015	0.027	0.015	0.027
0.406	...	...	...	...	...	...	...	0.017	0.027	0.016	0.028	0.016	0.028
0.438	...	...	...	...	...	...	...	0.017	0.027	0.016	0.028	0.016	0.028
0.489	...	...	...	...	...	...	...	...	...	0.016	0.028	0.016	0.028
0.500	...	...	...	...	...	...	...	...	...	0.016	0.028	0.016	0.028

[A] 1 in. = 25.4 mm.
[B] Birmingham Wire Gage.
Ref.: ASTM A 513-85

Table 7
Tolerances, Diameter, Mandrel Drawn, Sink Drawn, Special Smooth ID
Note — Measurements for diameter are to be taken at least 2 in. from the ends of the tubes.

Outside Diameter Range, in.[A]	Wall % of OD	Types 3, 4, Sink Drawn[A,B] and 5, 6, Mandrel Drawn[B,C] OD, in.		Types 5 and 6 Mandrel Drawn[B,C] ID in.	
		Over	Under	Over	Under
Up to 0.499	all	0.004	0.000	. . .	. . .
0.500 to 1.699	all	0.005	0.000	0.000	0.005
1.700 to 2.099	all	0.006	0.000	0.000	0.008
2.100 to 2.499	all	0.007	0.000	0.000	0.007
2.500 to 2.899	all	0.008	0.000	0.000	0.008
2.900 to 3.299	all	0.009	0.000	0.000	0.009
3.300 to 3.899	all	0.010	0.000	0.000	0.010
3.700 to 4.099	all	0.011	0.000	0.000	0.011
4.100 to 4.499	all	0.012	0.000	0.000	0.012
4.500 to 4.899	all	0.013	0.000	0.000	0.013
4.900 to 5.299	all	0.014	0.000	0.000	0.014
5.300 to 5.549	all	0.015	0.000	0.000	0.015
5.550 to 5.999	under 6	0.010	0.010	0.010	0.010
	6 and over	0.009	0.009	0.009	0.009
6.000 to 6.499	under 6	0.013	0.013	0.013	0.013
	6 and over	0.010	0.010	0.010	0.010
6.500 to 6.999	under 6	0.015	0.015	0.015	0.015
	6 and over	0.012	0.012	0.012	0.012
7.000 to 7.499	under 6	0.018	0.018	0.018	0.018
	8 and over	0.013	0.013	0.013	0.013
7.500 to 7.999	under 6	0.020	0.020	0.020	0.020
	6 and over	0.015	0.015	0.015	0.015
8.000 to 8.499	under 6	0.023	0.023	0.023	0.023
	6 and over	0.016	0.016	0.016	0.016
8.500 to 8.999	under 6	0.025	0.025	0.025	0.025
	6 and over	0.017	0.017	0.017	0.017
9.000 to 9.499	under 6	0.028	0.028	0.028	0.028
	6 and over	0.019	0.019	0.019	0.019
9.500 to 9.999	under 8	0.030	0.030	0.030	0.030
	6 and over	0.020	0.020	0.020	0.020
10.000 to 10.999	all	0.034	0.034	0.034	0.034
11.000 to 11.999	all	0.035	0.035	0.035	0.035
12.000 to 12.999	all	0.036	0.036	0.036	0.036
13.000 to 13.999	all	0.037	0.037	0.037	0.037
14.000 to 14.999	all	0.038	0.038	0.038	0.038

[A] Tubing, flash in or flash controlled which is further processed without mandrel to obtain tolerances closer than those shown in Tables 3 and 4.

[B] The ovality shall be within the above tolerances except when the wall thickness is less than 3 per cent of the outside diameter. In such cases the additional ovality shall be as follows but the mean outside diameter shall be within the specified tolerance:

Outside Diameter, in. (mm)	Additional Ovality Tolerance, in. (mm)
Up to 2 (50.8), incl	0.010 (0.25)
Over 2 to 3 (50.8 to 76.2), incl	0.015 (0.38)
Over 3 to 4 (76.2 to 101.6), incl	0.020 (0.51)
Over 4 to 5 (101.6 to 127.0), incl	0.025 (0.64)
Over 5 to 6 (127.0 to 152.4), incl	0.030 (0.76)
Over 6 to 7 (152.4 to 177.8), incl	0.035 (0.89)
Over 7 to 8 (177.8 to 203.2), incl	0.040 (1.02)
Over 8 to 9 (203.2 to 228.6), incl	0.045 (1.14)
Over 9 to 10 (228.6 to 254.0), incl	0.050 (1.27)
Over 10 to 11 (254.0 to 279.4), incl	0.055 (1.40)
Over 11 to 12 (279.4 to 304.8), incl	0.060 (1.52)
Over 12 to 12.500 (304.8 to 317.5), incl	0.065 (1.65)

[C] Tubing produced to outside diameter and wall thickness, or inside diameter and wall thickness, or outside diameter and inside diameter, with mandrel to obtain tolerances closer than those shown in Tables 3 and 4 and no dimensional indication of inside diameter flash.

Ref: ASTM A 513-85

Table 8
Tolerances, Wall Thickness — Cold Drawn Ovar Mandrel

Wall Thickness		Outside Diamatar, in.[A]							
in.[A]	Bwg[B]	$\frac{3}{8}$ to $\frac{7}{8}$, incl		Ovar $\frac{7}{8}$ to $1\frac{7}{8}$, incl		Ovar $1\frac{7}{8}$ to $3\frac{3}{4}$, incl		Over $3\frac{3}{4}$ to 15, incl	
		Wall Thickness Tolerances, in.,[A] Plus and Minus							
		Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus
0.035	20	0.002	0.002	0.002	0.002	0.002	0.002	...	...
0.049	18	0.002	0.002	0.002	0.003	0.002	0.003	...	...
0.065	16	0.002	0.002	0.002	0.003	0.002	0.003	0.004	0.004
0.083	14	0.002	0.002	0.002	0.003	0.003	0.003	0.004	0.005
0.095	13	0.002	0.002	0.002	0.003	0.003	0.003	0.004	0.005
0.109	12	0.002	0.003	0.002	0.004	0.003	0.003	0.005	0.005
0.120	11	0.003	0.003	0.002	0.004	0.003	0.003	0.005	0.005
0.134	10	...	...	0.002	0.004	0.003	0.003	0.005	0.005
0.148	9	...	...	0.002	0.004	0.003	0.003	0.005	0.005
0.165	8	...	...	0.003	0.004	0.003	0.004	0.005	0.006
0.180	7	...	...	0.004	0.004	0.003	0.005	0.006	0.006
0.203	6	...	...	0.004	0.005	0.004	0.005	0.006	0.007
0.220	5	...	...	0.004	0.006	0.004	0.006	0.007	0.007
0.238	4	...	...	0.005	0.006	0.005	0.006	0.007	0.007
0.259	3	...	...	0.005	0.008	0.005	0.006	0.007	0.007
0.284	2	...	...	0.005	0.006	0.005	0.006	0.007	0.007
0.300	1	...	...	0.006	0.006	0.006	0.006	0.008	0.008
0.320	...	...	...	0.007	0.007	0.007	0.007	0.008	0.008
0.344	...	...	...	0.008	0.008	0.008	0.008	0.009	0.009
0.375	...	...	...	...	...	0.009	0.009	0.009	0.009
0.400	...	...	...	...	...	0.010	0.010	0.010	0.010
0.438	...	...	...	...	...	0.011	0.011	0.011	0.011
0.460	...	...	...	...	...	0.012	0.012	0.012	0.012
0.480	...	...	...	...	...	0.012	0.012	0.012	0.012
0.531	...	...	...	...	...	0.013	0.013	0.013	0.013
0.563	...	...	...	...	...	0.013	0.013	0.013	0.013
0.580	...	...	...	...	...	0.014	0.014	0.014	0.014
0.600	...	...	...	...	...	0.015	0.015	0.015	0.015
0.625	...	...	...	...	...	0.016	0.016	0.016	0.016
0.650	...	...	...	...	...	0.017	0.017	0.017	0.017

[A] 1 in. = 25.4 mm.
[B] Birmingham Wire Gage.
Ref: ASTM A 513-85

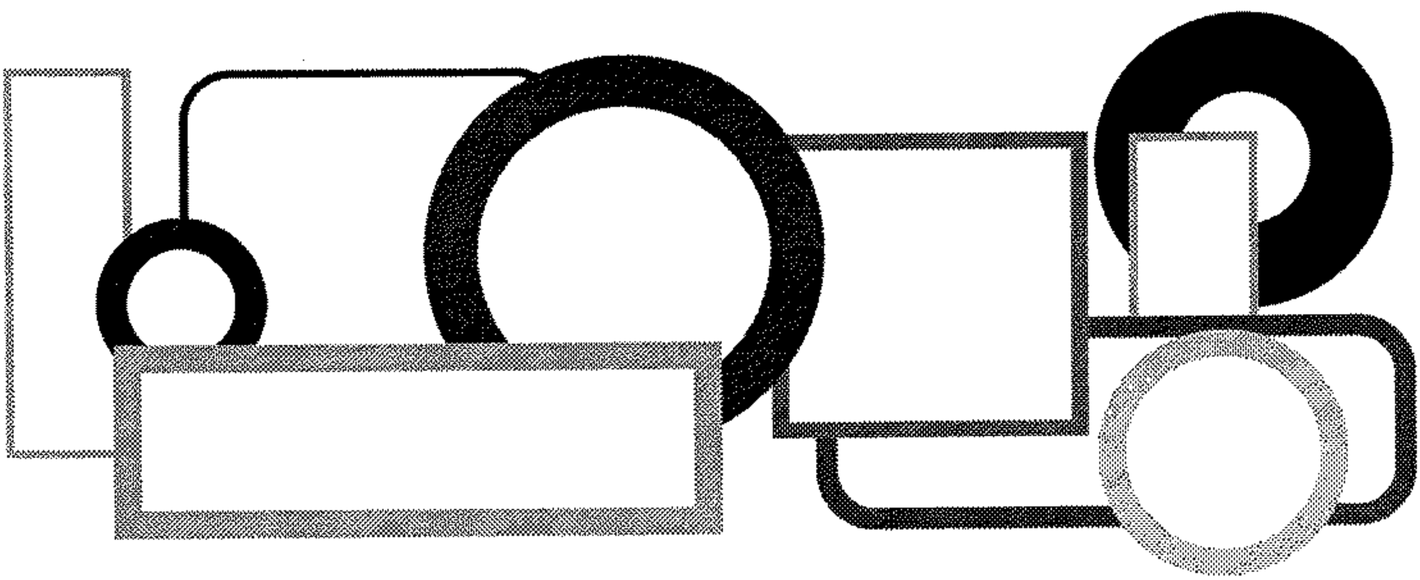


Table 9
Diameter Tolerances for Metallic-Coated Round Tubing

Outside Diameter Range, in.[A]	Wall Thickness		Tubing with Any Inside Flash Condition	Flash-Controlled to 0.005 in. Tubing Only[E]
	Bwg[B]	in.[A]	Outside[C,D] Diameter, Plus and Minus	Inside Diameter, Plus and Minus
			Tolerances, in.[F]	
1/2 to 1 1/8, incl	22 to 16	0.028/0.065	0.0035	0.019
1 1/8 to 2, incl	22 to 14	0.028/0.083	0.005	0.021
1 1/8 to 2, incl	13 to 10	0.095/0.134	0.005	0.027
2 to 2 1/2, incl	20 to 14	0.035/0.083	0.006	0.023
2 to 2 1/2, incl	13 to 10	0.095/0.134	0.006	0.029
2 1/2 to 3, incl	20 to 14	0.035/0.083	0.008	0.025
2 1/2 to 3, incl	13 to 10	0.095/0.134	0.008	0.031
3 to 3 1/2, incl	20 to 14	0.035/0.083	0.009	0.026
3 to 3 1/2, incl	13 to 10	0.095/0.134	0.009	0.032
3 1/2 to 4, incl	20 to 14	0.035/0.083	0.010	0.027
3 1/2 to 4, incl	13 to 10	0.095/0.134	0.010	0.033
4 to 5, incl	16 to 14	0.065/0.083	0.020	0.037
4 to 5, incl	13 to 10	0.095/0.134	0.020	0.043
5 to 6, incl	16 to 14	0.065/0.083	0.020	0.037
5 to 6, incl	13 to 10	0.095/0.134	0.020	0.043
6 to 8, incl	14 to 10	0.083/0.134	0.025	0.048

[A] 1 in. = 25.4 mm.
[B] Birmingham Wire Gage.
[C] Flash-in tubing is produced to outside diameter tolerances and wall thickness tolerances only, and the height of the inside welding flash does not exceed the wall thickness or 3/32 in., whichever is less.
[D] Flash controlled to 0.010 in. maximum tubing consists of tubing over 5/8 in. outside diameter which is commonly produced to outside diameter tolerances and wall thickness tolerances only, in which the height of the remaining inside welding flash is controlled not to exceed 0.010 in.
[E] Flash controlled to 0.005 in. maximum tubing is produced to outside diameter tolerances and wall thickness tolerances, inside diameter tolerances and wall thickness tolerances, or outside diameter tolerances and inside diameter tolerances, in which the height of the remaining inside welding flash is controlled not to exceed 0.005 in. Any remaining flash is considered to be part of the applicable inside diameter tolerances.
[F] The ovality shall be within the above tolerances except when the wall thickness is less than 3% of the outside diameter. When the tube wall thickness is less than 3% of the tube outside diameter the ovality may be 50% greater than the outside diameter tolerances, but the mean diameter (average of maximum outside diameter and minimum outside diameter) shall be within the specified tolerance.

Ref.: ASTM A 787-84b

Table 10
Wall Thickness Tolerance for Premetallic Coated As-welded Tubing[A]

Wall Thickness		Outside Diameter, In.											
		1/2 to 1 Incl		Over 1 to 1 15/16, Incl		Over 1 15/16 to 3 3/4, Incl		Over 3 3/4 to 4 1/2, Incl		Over 4 1/2 to 6, Incl		Over 6 to 8, Incl	
		Wall Thickness Tolerances, Inches, Plus and Minus											
In.	Bwg	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus
.028	22	.002	.006	.002	.006	...	...	...	...	...	...	...	...
.035	20	.003	.009	.002	.006	.002	.009	...	...	...	...	...	...
.049	18	.004	.007	.003	.008	.003	.008	...	...	...	...	...	...
.065	16	.005	.007	.004	.008	.003	.009	.003	.009	.002	.010	...	...
.083	14	.006	.008	.006	.008	.005	.009	.005	.009	.004	.010	.004	.010
.095	13	.008	.010	.008	.010	.007	.011	.007	.011	.009	.012	.006	.012
.109	12	.008	.010	.008	.010	.007	.011	.007	.011	.009	.012	.006	.012
.120	11	.009	.011	.009	.011	.008	.012	.008	.012	.007	.013	.007	.013
.134	10	.009	.011	.009	.011	.008	.012	.008	.012	.007	.013	.007	.013

[A] Special manufacturing practices allow for post-hot dipped galvanizing of welded tubing. If this product is desired, wall thickness tolerances shall be determined by agreement between the producer and purchaser.
[B] Birmingham Wire Gage
[C] 1 in. = 25.4 mm.

Ref.: ASTM A 787-84b

Table 11
Tolerances, Cut Length — Lathe Cut

Outside Diameter Size, in.[A]	Length			
	6 in. and under 12 in.	12 in. and under 48 in.	48 in. and under 10 ft.	10 ft. to 24 ft. incl.[B]
3/8 to 3 incl	± 1/64 in.	± 1/32 in.	± 3/64 in.	± 1/8 in.
Over 3 to 6, incl	± 1/32 in.	± 3/64 in.	± 1/16 in.	± 1/8 in.
Over 6 to 9, incl	± 1/16 in.	± 1/16 in.	± 1/8 in.	± 1/8 in.
Over 9 to 12, incl	± 3/32 in.	± 3/32 in.	± 1/8 in.	± 1/8 in.

[A] 1 in. = 25.4 mm.
[B] For each additional 10 ft. or fraction thereof over 24 ft., an additional allowance should be made of plus or minus 1/16 in.

Ref.: ASTM A 513-85

Punch, Saw, or Disc Cut

Length of Tube	Cut Length Tolerance
1 to 3 ft, incl	± 1/16 in.
Over 3 to 12 ft, incl	± 3/32 in.
Over 12 to 20 ft, incl	± 1/8 in.
Over 20 to 30 ft, incl	± 3/16 in.

Table 12
Tolerance (Inch), for Squareness of Cut (Either End) When Specified for Round Tubing[A,B]

Length of Tube, ft[C]	Outside Diameter, in.[D]				
	Under 1	1 to 2, incl	Over 2 to 3, incl	Over 3 to 4, incl	Over 4
Under 1	0.006	0.008	0.010	0.015	0.020
1 to 3, incl	0.008	0.010	0.015	0.020	0.030
Over 3 to 6, incl	0.010	0.015	0.020	0.025	0.040
Over 8 to 9, incl	0.015	0.020	0.025	0.030	0.040

[A] Actual squareness normal to length of tube, not parallelness of both ends.
[B] Values given are "go" value of feeler gage. "No go" value is 0.001 in. greater in each case.
[C] 1 ft. = 0.3 m.
[D] 1 in. = 25.4 mm.

Ref. ASTM A 513-85

Table 13
Tolerance, Straightness

The straightness tolerance for round tubing is 0.030 in./3 ft. (0.76 mm/1 m) lengths to 8.000 in. (203 mm) outside diameter. For 8.000 in. outside diameter and above, straightness tolerance is 0.060 in./3 ft. (1.52 mm/1 m) lengths. For lengths under 1 ft. the straightness tolerance shall be agreed upon between the purchaser and producer.

Ref.: ASTM A 513-85

a. Methods of Checking Tolerances on Round Tubing

Experience in checking tolerances of round tubing indicates that the methods described below can be expected to obtain the most accurate and consistent results.

1) Measuring O.D.
Normal method for measuring the outside diameter of tubing is by use of a micrometer with flat anvils. Measurements should be taken at least 2" from either end of the tube.

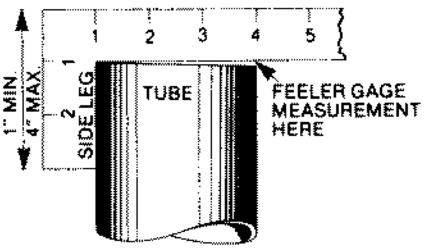
2) Measuring I.D.
The inside diameter is ordinarily measured with plug gauges. Methods other than plug gauging can be used; consult a tubing source.

3) Measuring Wall Thickness or Gauge
Gauge measurement is usually made with ball pointed gauge micrometers having a radius of the anvil of 5/32" (± 1/64") to insure correct registering of the thickness.

4) Measuring Height of Inside Weld Flash
The height of the inside weld flash is the difference between the thickness of the tube wall at the point of the flash and the thickness of the tube wall at a point near the flash, using a ball micrometer having a radius of the anvil or ball point of 5/32" (± 1/64").

5) Measuring Straightness
Straightness tolerance is checked by placing a 3' straightedge against the tube on a neutral axis. The point of maximum deflection of the tube from the straightedge should not be more than allowed in Table 13 when measured with a feeler gage.

6) Measuring Squareness of End Cut
Experience indicates measurements should be made with use of an "L" square and feeler gauge, side leg of square to be equal to tube diameter except minimum length of 1" and maximum length of 4". Outside diameter burr to be removed for measurement.



b. Tensile Properties

Welded tubing is available in a wide range of diameters and wall thicknesses. Tensile properties of the as-welded tube will vary somewhat with grade and size. These properties are shown in the following tables taken from ASTM A 513.

When hardness properties are specified on the order the tubing shall conform to the hardness limits specified in Tables 14–18 unless "Tensile Properties Required" is specified in the purchase order. When "Tensile Properties Required" is specified in the purchase order, the tubing shall conform to the tensile requirements and not necessarily the hardness limits shown in Tables 14–18. For grades not shown in Tables 14–18, tensile or hardness limits shall be upon agreement between the manufacturer and the purchaser.

Table 14
Mechanical Properties, As-Welded Tubing[A]

Type of Steel	Yield Strength, ksi (MPa), min	Ultimate Strength ksi (MPa), min	Elongation in 2 in. or 50 mm, %, min	RB min	RB max
1010	32 (221)	45 (310)	15	55	. . .
1015	35 (241)	48 (331)	15	58	. . .
1020	38 (262)	52 (359)	12	62	. . .
1025	40 (276)	58 (386)	12	65	. . .
1030	45 (310)	62 (427)	10	70	. . .
1035	50 (345)	66 (455)	10	75	. . .

Ref.: ASTM A 513-85

Table 15
Mechanical Properties, Normalized Tubing[A]

Type of Steel	Yield Strength, ksi (MPa), min	Ultimate Strength ksi (MPa), min	Elongation in 2 in. or 50 mm, %, min	RB min	RB max
1010	25 (172)	40 (276)	30	. . .	65
1015	30 (207)	45 (310)	30	. . .	70
1020	35 (241)	50 (345)	25	. . .	75
1025	37 (255)	55 (379)	25	. . .	80
1030	40 (276)	60 (414)	25	. . .	85
1035	45 (310)	65 (448)	20	. . .	88

Table 16
Mechanical Properties, Sink Drawn Tubing[A]

Type of Steel	Yield Strength, ksi (MPa), min	Ultimate Strength ksi (MPa), min	Elongation in 2 in. or 50 mm, %, min	RB min	RB max
1010	40 (276)	50 (345)	8	65	. . .
1015	45 (310)	55 (379)	8	67	. . .
1020	50 (345)	60 (414)	8	70	. . .
1025	55 (379)	65 (448)	7	72	. . .
1030	62 (427)	70 (483)	7	78	. . .
1035	70 (483)	80 (552)	7	82	. . .

Table 17
Mechanical Properties, Mandrel Drawn Tubing[A]

Type of Steel	Yield Strength, ksi (MPa), min	Ultimate Strength ksi (MPa), min	Elongation in 2 in. or 50 mm, %, min	RB min	RB max
1010	50 (345)	60 (414)	5	73	. . .
1015	55 (379)	65 (448)	5	77	. . .
1020	60 (414)	70 (483)	5	80	. . .
1025	65 (448)	75 (517)	5	82	. . .
1030	75 (517)	85 (586)	5	87	. . .
1035	80 (552)	90 (621)	5	90	. . .

Table 18
Mechanical Properties, Mandrel Drawn Stress Relieved Tubing[A,B]

Type of Steel	Yield Strength, kei (MPa), min	Ultimate Strength ksi (MPa), min	Elongation in 2 in. or 50 mm, %, min	RB min	RB max
1010	45 (310)	55 (379)	12	68	. . .
1015	50 (345)	60 (414)	12	72	. . .
1020	55 (379)	65 (448)	10	75	. . .
1025	60 (414)	70 (483)	10	77	. . .
1030	70 (483)	80 (552)	10	81	. . .
1035	75 (517)	85 (586)	10	85	. . .

Notes: Tables 14–18[A] For longitudinal strip tests, the width of the gage section shall be 1 in. (25.4 mm) and a deduction of 0.5 percentage points from the basic minimum elongation for each 1/32 in. (0.8 mm) decrease in wall thickness under 5/16 in. (7.9 mm) in wall thickness shall be permitted.

[B] These values are based on normal mill stress relieving temperatures. For particular applications, properties may be adjusted by negotiation between purchaser and producer.

Ref.: ASTM A 513-85

Table 19
Chemical Compoaition of Carbon Steela

Type of Steel	Caet or Heat Chemical Compoaition[A] Limits, %			
	C	Mn	P, max.	S, max.
1006	0.08 max.	0.45 max.	0.040	0.050
1008	0.10 max.	0.50 max.	0.040	0.050
1009	0.15 max.	0.60 max.	0.040	0.050
1010	0.08-0.13	0.30-0.60	0.040	0.050
1012	0.10-0.15	0.30-0.60	0.040	0.050
1015	0.12-0.18	0.30-0.60	0.040	0.050
1016	0.12-0.18	0.60-0.90	0.040	0.050
1017	0.14-0.20	0.30-0.80	0.040	0.050
1018	0.14-0.20	0.80-0.90	0.040	0.050
1019	0.14-0.20	0.70-1.00	0.040	0.050
1020	0.17-0.23	0.30-0.60	0.040	0.050
1021	0.17-0.23	0.60-0.90	0.040	0.050
1022	0.17-0.23	0.70-1.00	0.040	0.050
1023	0.19-0.25	0.30-0.60	0.040	0.050
1025	0.22-0.28	0.30-0.60	0.040	0.050
1026	0.22-0.28	0.60-0.90	0.040	0.050
1030	0.27-0.34	0.60-0.90	0.040	0.050
1033	0.29-0.36	0.70-1.00	0.040	0.050
1035	0.31-0.38	0.60-0.90	0.040	0.050
1040	0.38-0.44	0.60-0.90	0.040	0.050

[A] These steels may be produced by the basic open hearth, the basic oxygen, or the basic electric steelmaking process (see SAE J411, Carbon and Alloy Steels). Where silicon is required, the following limits and ranges are commonly used: for steel designations up to and including SAE 1025: 0.10% max, or ranges of 0.10 to 0.25% or 0.15 to 0.35%; for over SAE 1025: ranges of 0.10 to 0.25% or 0.15 to 0.35%. Rimmed or capped steels are characterized by a lack of uniformity in their chemical composition, especially for the elements carbon, phosphorus, and sulfur, and for this reason product analysis is not considered appropriate for these elements unless misapplication is clearly indicated.

Ranges to left are based on cast or heat analysis. Product analysis may vary over and under in accordance with the limits shown in Table 21 (Tolerances for Product Analysis).

Low-Alloy, High-Strength Steels are available in a wide range of analyses.

Table 20
Chemical Composition of Alloy Steels

Type of Steel	Ladle Chemical Composition[A] Limits, %							
	C	Mn	P Max.	S Max.	Si	Ni	Cr	Mo
1330	0.28-0.33	1.60-1.90	0.035	0.040	0.15-0.35	...	...	...
4012	0.09-0.14	0.75-1.00	0.035	0.040	0.15-0.35	...	...	0.15-0.25
4023	0.20-0.25	0.70-0.90	0.035	0.040	0.15-0.35	...	...	0.20-.030
4118	0.18-0.23	0.70-0.90	0.035	0.040	0.15-0.35	...	0.40-0.60	0.08-0.15
4130	0.28-0.33	0.40-0.60	0.035	0.040	0.15-0.35	...	0.80-1.10	0.15-0.25
4615	0.13-0.18	0.45-0.65	0.035	0.040	0.15-0.35	1.65-2.00	...	0.20-0.30
4617	0.15-0.20	0.45-0.65	0.035	0.040	0.15-0.35	1.65-2.00	...	0.20-0.30
4620	0.17-0.22	0.45-0.65	0.035	0.040	0.15-0.35	1.65-2.00	...	0.20-0.30
4718	0.16-0.21	0.70-0.90	...	...	...	0.90-1.20	0.35-0.55	0.30-0.40
4720	0.17-0.22	0.50-0.70	0.035	0.040	0.15-0.35	0.90-1.20	0.35-0.55	0.15-0.25
4815	0.13-0.18	0.40-0.60	0.035	0.040	0.15-0.35	3.25-3.75	...	0.20-0.30
4820	0.18-0.23	0.50-0.70	0.035	0.040	0.15-0.35	3.25-3.75	...	0.20-0.30
5015	0.12-0.17	0.30-0.50	0.035	0.040	0.15-0.35	...	0.30-0.50	...
5115	0.13-0.18	0.70-0.90	0.035	0.040	0.15-0.30	...	0.70-0.90	...
6118	0.16-0.21	0.50-0.70	0.035	0.040	0.15-0.35	...	0.50-0.70	0.10-0.15(V)[B]
8115	0.13-0.18	0.70-0.90	0.035	0.040	0.15-0.35	0.20-0.40	0.30-0.50	0.08-0.15
8615	0.13-0.18	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25
8620	0.18-0.23	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25
8625	0.23-0.28	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25
8630	0.28-0.33	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25
8720	0.18-0.23	0.70-0.90	0.035	0.040	0.15-0.35	0.40-0.70	0.40-0.60	0.20-0.30

[A] For standard variations in composition limits, see Table 4 of SAE J409. Small quantities of certain elements which are not specified or required may be found in alloy steels. These elements are to be considered as incidental and are acceptable to the following maximum amount: copper to 0.35%, nickel to 0.25%, chromium to 0.20%, and molybdenum to 0.06%.

[B] Vanadium.

Table 21
Product Analysis, Tolerances for Product Analysis, Welded Carbon Steel Tubing

Element	Limit or Max. of Specified Element, %	Variation % over Max. Limit or under Min. Limit: Under Min. Limit	Over Max. Limit
Carbon	To 0.15 incl	0.02	0.03
	Over 0.15 to 0.40 incl	0.03	0.04
	Over 0.40 to 0.80 incl	0.03	0.05
	Over 0.80	0.03	0.06
Manganese	To 0.60 incl	0.03	0.03
	Over 0.60 to 1.15 incl	0.04	0.04
	Over 1.15 to 1.65 incl	0.05	0.05
Phosphorus	...	...	0.01
Sulfur	...	...	0.01
Silicon	To 0.30 incl	0.02	0.03
	Over 0.30 to 0.60	0.05	0.05
Copper	For copper bearing steel	0.02	...
Lead[A]	0.15 to 0.35 incl	0.03	0.03

[A] Product analysis tolerance for lead applies both over and under a range of 0.15-0.35% lead.

c. High Strength Low Alloy Steels

Most steel producers make available many different grades and types of high strength low alloy steels which may be fabricated into tubing to produce a product with higher yield and tensile strengths than are available with the more common straight low carbon varieties. In some cases, depending on alloy, they show added resistance to atmospheric corrosion. They are not intended to be quenched and tempered as supplied. They achieve these high strengths through the addition of very small amounts of elements such as copper, nickel, chromium, columbium, vanadium, titanium, molybdenum, nitrogen, and zirconium.

These steels are available in minimum yield strengths from 50,000 psi to over 100,000 psi. The tubing producer should be consulted for the proper analysis for a particular application.

2. Squares and Rectangles

Welded tubing is produced in large volume in square and rectangular form. Due to the ease of fabrication, square and rectangular tubing finds wide usage in such items as van bodies, racks and many other mechanical assemblies. It is usually produced directly on the welder by converting the round tube into the desired shape through a section of roll stands (commonly called turksheads) at the exit end of the sizing stands. The tubes are straight as they emerge from the turksheads and normally no further straightening is required.

3. Special Shapes

Electric resistance welded tubing may also be produced in shapes other than squares and rectangles. Normal practice is to weld a round tube and produce the desired shape by forming it with a turkshead or by rolling or drawing it. The figure below shows some typical shapes that have been produced.

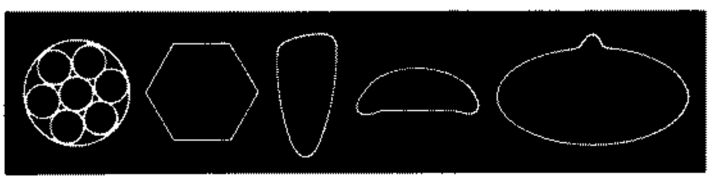


Table 22
Typical Rectangular Tubing Sizes

Rectangular Sizes, inches	Wall Thickness Range	
	Bwg.	Inches
3/8 x 5/8	22-14	(.028-.083)
3/8 x 3/4	22-16	(.028-.065)
3/8 x 1	22-13	(.028-.095)
3/8 x 1 1/8	20-13	(.035-.095)
3/8 x 1 1/2	22-11	(.028-.120)
3/8 x 2 5/8	20-9	(.035-.148)
1/2 x 3/4	22-14	(.028-.083)
1/2 x 1	22-11	(.028-.120)
1/2 x 1 1/8	22-12	(.028-.109)
1/2 x 1 1/4	22-12	(.028-.109)
1/2 x 1 1/2	22-12	(.028-.109)
1/2 x 2	20-14	(.035-.083)
5/8 x 1	22-12	(.028-.109)
5/8 x 1 1/2	20-10	(.035-.134)
5/8 x 2	20-9	(.035-.148)
3/4 x 1	22-13	(.028-.095)
3/4 x 1 1/4	20-16	(.035-.085)
3/4 x 1 3/8	20-10	(.035-.134)
3/4 x 1 1/2	22-9	(.028-.148)
3/4 x 2	20-11	(.035-.120)
7/8 x 1	16	(.065)
7/8 x 1 1/8	20-9	(.035-.148)
7/8 x 1 7/8	20-9	(.035-.148)
1 x 1 1/8	20-9	(.035-.148)
1 x 1 1/4	20-9	(.035-.148)
1 x 1 3/8	20-9	(.035-.148)
1 x 1 1/2	20-9	(.035-.148)
1 x 2	20-9	(.035-.148)
1 x 2 1/8	20-8	(.035-.165)
1 x 2 1/2	20-8	(.035-.165)
1 x 3	19-8	(.042-.165)
1 x 3 1/2	19-8	(.042-.165)
1 1/8 x 2	20-8	(.035-.165)
1 1/4 x 1 1/2	20-9	(.035-.148)
1 1/4 x 1 3/4	20-9	(.035-.148)
1 1/4 x 2	20-8	(.035-.165)
1 1/4 x 2 1/2	19-8	(.042-.165)
1 1/4 x 3	19-8	(.042-.165)
1 3/8 x 2 1/2	14	(.083)
1 3/8 x 2 1/4	19-8	(.042-.165)
1 3/8 x 6 3/8	16-8	(.065-.165)
1 1/2 x 2	19-8	(.042-.165)
1 1/2 x 2 1/2	19-8	(.042-.165)
1 1/2 x 3	18-4	(.049-.238)
1 1/2 x 3 1/2	16-4	(.065-.238)
1 1/2 x 4	16-3	(.065-.259)
1 3/4 x 3	18-8	(.049-.165)
1 7/8 x 1 5/8	16	(.065)
2 x 3	16-5	(.065-.220)
2 x 3 1/2	16-3	(.065-.259)
2 x 4	16-6	(.065-.203)
2 x 5	16-7	(.065-.180)
2 x 5 1/2	16-3	(.065-.259)
2 x 6	14-3	(.083-.259)
2 1/8 x 2 5/8	18-8	(.049-.165)
2 1/4 x 4	16-6	(.065-.203)
2 1/2 x 3	16-5	(.065-.220)
2 1/2 x 3 1/2	16-4	(.065-.250)
2 1/2 x 4	16-4	(.065-.250)
2 1/2 x 5	16-4	(.065-.250)
2 1/2 x 6	16-4	(.065-.250)
3 x 4	16-4	(.065-.250)
3 x 4 1/2	16-4	(.065-.250)
3 x 5	16-4	(.065-.250)
3 x 6	14-4	(.083-.250)
4 x 5	16-4	(.065-.250)
4 x 5 1/4	16-4	(.065-.250)
4 x 6	8-4	(.165-.250)
4 x 8	8-4	(.165-.250)

These are some commonly available sizes. Others are available.

Table 23
Typical Square Tubing Sizes

Square Sizes, inches	Wall Thickness Range	
	Bwg.	Inches
3/8	22-16	.028-.065
1/2	22-14	.028-.083
5/8	22-14	.028-.083
3/4	22-11	.028-.120
7/8	22-11	.028-.120
1	22-11	.028-.120
1 1/8	22-10	.028-.134
1 1/4	22-9	.028-.148
1 3/8	22-9	.028-.148
1 1/2	22-8	.028-.165
1 5/8	20-8	.035-.165
1 3/4	20-8	.035-.165
1 7/8	20-8	.035-.165
2	19-4	.042-.238
2 1/8	19-8	.042-.165
2 1/4	19-8	.042-.165
2 3/8	19-8	.042-.165
2 1/2	18-3	.049-.259
3	16-4	.065-.250
3 1/2	16-4	.065-.250
4	16-4	.065-.250
5	8-4	.165-.250
6	8-4	.165-.250

Approximate diagonal dimensions of square or rectangular tubes can be computed by the following formula:

$$D = 2r + \sqrt{(a-2r)^2 + (b-2r)^2}$$

D = Diagonal
a = Length of short side of rectangle or one side of square.
b = Length of long side of rectangle or one side of square.
r = Average radius of corner.

Table 24
Tolerances, Outside Dimensions[A] — Squares and Rectangles

Largest Nominal Outside Dimension, in.[B]	Wall Thickness, in.[B]	Outside Tolerance at All Sides at Corners ± in.[B]
3/16 to 5/8, incl	0.020 to 0.083, incl	0.004
Over 5/8 to 1 1/8, incl	0.025 to 0.156, incl	0.005
Over 1 1/8 to 1 1/2, incl	0.025 to 0.192, incl	0.006
Over 1 1/2 to 2, incl	0.032 to 0.192, incl	0.008
Over 2 to 3, incl	0.035 to 0.259, incl	0.010
Over 3 to 4, incl	0.049 to 0.259, incl	0.020
Over 4 to 6, incl	0.065 to 0.259, incl	0.020
Over 6 to 8, incl	0.185 to 0.259, incl	0.025

[A] Measured at corners at least 2 in. from the cut end of the tubing.

Convexity and concavity: Tubes having two parallel sides are also measured in the center of the flat sides for convexity and concavity. This tolerance applies to the specific size determined at the corners, and is measured on the following basis:

Largest Nominal Outside Dimension, in.	Tolerance Plus and Minus, in.
2 1/2 and under	0.010
Over 2 1/2 to 4	0.015
Over 4 to 8	0.025

[B] 1 in. = 25.4 mm.

Ref.: ASTM A 513-85

Table 25
Squareness of Sides, Squares and Rectangles

Permissible variations for squareness shall be determined by the following equation:

$$\pm b = c \times 0.006 \text{ in.}$$

where:

b = tolerance for out-of-square, and

c = largest external dimension across flats.

The squareness of sides is commonly determined by one of the following methods:

A square with two adjustable contact points on each arm, is placed on two sides. A fixed feeler gauge is then used to measure the maximum distance between the free contact point and the surface of the tubing, *or*

A square equipped with a direct reading vernier, may be used to determine the angular deviation which, in turn, may be related to distance in inches.

Ref.: ASTM A 513-85

Table 26
Tolerances, Twist — Squares and Rectangles

Largest Dimension, in.[A]	Twist Tolerance in 3 ft[B], in.[A]
1/2 and under	0.032
Over 1/2 to 1 1/2, incl	0.050
Over 1 1/2 to 2 1/2, incl	0.062
Over 2 1/2 to 4, incl	0.075
Over 4 to 6, incl	0.087
Over 6 to 8, incl	0.100

[A] 1 in. = 25.4 mm.

[B] 1 ft. = 0.3 m.

Twist tolerances are shown in the table above. The twist in square and rectangular tubing may be measured by holding one end of the tubing on a surface plate and noting the height of either corner of the opposite end of same side above the surface plate. Twist may also be measured by the use of a beveled protractor equipped with a level, and noting the angular deviation on opposite ends, or at any point throughout the length.

Ref.: ASTM A 513-85

Table 27
Tolerance, Straightness — Squares and Rectangles

The straightness tolerance is 1/16 in. in 3 ft. (1.7 mm/m).

Ref.: ASTM A 513-85

Table 28
Tolerances, Cut Lengths — Squares and Rectangles

Lengths, ft[A]	Tolerances, in[B]
1 to 3, incl	± 1/16
Over 3 to 12, incl	± 3/32
Over 12 to 20, incl	± 1/8
Over 20 to 30, incl	± 3/16
Over 30 to 40, incl	± 3/8

[A] 1 Ft = 0.3 m.

[B] 1 in = 25.4 mm.

Ref.: ASTM A 513-85

Table 29
Radii of Corners — Squares and Rectangles[A]

Squares and Rectangles Made from Tubes of the Following Diameter Ranges, in.[B]	Wall Thickness in Bwg and in[B]	Radius Tolerances, in[C]
1/2 to 1 1/2, incl	22 (0.028)	1/32 to 1/16
1/2 to 2 1/2, incl	20 (0.035)	1/32 to 1/16
1/2 to 4, incl	18 (0.049)	3/64 to 5/64
1/2 to 4 1/8, incl	16 (0.065)	1/16 to 7/64
3/4 to 4 1/8, incl	14 (0.083)	5/64 to 1/8
Over 4 1/8 to 6, incl	14 (0.083)	3/16 to 5/16
1 to 4 1/8, incl	13 (0.095)	3/32 to 5/32
Over 4 1/8 to 6, incl	13 (0.095)	3/16 to 5/16
1 1/4 to 4, incl	12 (0.109)	1/8 to 13/64
Over 4 to 6, incl	12 (0.109)	3/16 to 5/16
1 1/4 to 4, incl	11 (0.120)	1/8 to 7/32
Over 4 to 6, incl	11 (0.120)	7/32 to 7/16
2 to 4, incl	10 (0.134)	5/32 to 9/32
Over 4 to 6, incl	10 (0.134)	7/32 to 7/16
2 to 4, incl	9 (0.148)	3/16 to 5/16
Over 4 to 8, incl	9 (0.148)	7/32 to 7/16
2 to 8, incl	8 (0.165)	1/4 to 1/2
2 to 8, incl	7 (0.180)	1/4 to 1/2
2 1/2 to 4, incl	6 (0.203)	5/16 to 9/16
Over 4 to 8, incl	6 (0.203)	5/16 to 9/16
2 1/2 to 8, incl	5 (0.220)	3/8 to 5/8
2 1/2 to 8, incl	4 (0.238)	3/8 to 5/8
2 1/2 to 8, incl	3 (0.259)	3/8 to 5/8

[A] This table establishes a standard radius. The purchaser and producer may negotiate special radii. Slight radius flattening is more pronounced in heavier wall tubing.

[B] 1 in. = 25.4 mm.

[C] These radius tolerances apply to grades of steel covered in Table 30. The purchaser and producer may negotiate tolerances on other grades of steel.

Ref.: ASTM A 513-85

Table 30
Chemical Requirements for Standard Low-Carbon Steels[A]

	Composition, %			
Grade Designation	Carbon	Manganese	Phosphorus, max.	Sulfur, max.
MT[B] 1010	0.05-0.15	0.30-0.60	0.040	0.050
MT 1015	0.10-0.20	0.30-0.60	0.040	0.050
MT X 1015	0.10-0.20	0.60-0.90	0.040	0.050
MT 1020	0.15-0.25	0.30-0.60	0.040	0.050
MT X 1020	0.15-0.25	0.70-1.00	0.040	0.050

[A] Rimmed or capped steels which may be used for the above grades are characterized by a lack of uniformity in their chemical composition, and for this reason product analysis is not technologically appropriate unless misapplication is clearly indicated.

[B] The letters MT under grade designation indicate Mechanical Tubing.

Ref.: ASTM A 513-85

SECTION IV — Product Types

1. As-Welded Hot Rolled or Cold Rolled Flash-In

The ID flash is not removed in this type of tubing. This type is used where the height of the ID weld flash is not important.

2. As-Weldad Hot Rolled or Cold Rolled Flash-Controlled or Removed

For this product type, the ID weld flash is removed by scarfing or controlled by rolling to one of two different specifications.

a. Flash Controlled or Removed — ID flash is removed by scarfing or controlled by rolling to a maximum of .010".
b. Flash Controlled or Removed — ID flash is removed by scarfing or controlled by rolling to a maximum of .005".

3. Sink Drawn

Sink drawn tubing is produced by drawing the welded tube through a die with only the OD being controlled. This operation is performed when closer tolerances or a better surface might be required on the OD only and for enhanced mechanical properties. Sink drawn tubing can be produced from either hot rolled or cold rolled steel, and ID flash can be any of the conditions described above.

4. Drawn over Mendrel (DOM)

This product type is produced by drawing the welded tubing through a die and over a mandrel, improving surface finish and controlling the OD and ID, OD and wall, or ID and wall to closer tolerances, and/or for enhanced mechanical properties. DOM's superior concentricity is important when OD or ID machining is involved.

5. Special Smooth ID

Special Smooth ID (SSID) is a cold drawn welded tube that must meet special standards of surface in the ID. The finish must be within the microinch limits established by the governing specification, ASTM A 513. Table 1 shows these requirements. SSID tubing attains its high quality ID finish through careful selection of starting material, special processing, and extremely critical inspection at all stages of production. By taking these steps, guaranteed microinch finishes can be obtained. SSID tubing is usually furnished in the as-drawn condition, as any annealing may harm the smoothness and cleanliness of the surface.

6. Coeted Tubing

This special product is produced from pre-coated, flat rolled steel, or the coating may be applied to the tube in-line immediately after welding. The weld zone of pre-coated material may be remetallized immediately after welding. Either galvanized or aluminum coatings are available and provide extra corrosion protection. The coating is an excellent base for a long lasting painted surface where desired.

SECTION V — Special Applications

1. Hydreulic Line Tubing

Hydraulic line tubing is one of the highest quality products made by the ERW industry. It is normally produced to ANSI Standard B93.4-latest revision but also meets all the requirements of NFPA, SAE, and JIC Standards. Normalizing after welding, cold drawing, and full annealing as a final heat treatment assure ductility for severe flaring and bending. A pressure or electric test and extensive expansion, flattening, and reverse flattening tests demonstrate the tube's soundness. Typical applications would be in the hydraulic harnesses of earthmovers, machine tools, trucks, buses, cranes, etc.

Table 31
Welded Steel Hydreulic Fluid Line Tubing — Chemicel Composition, Mechanical Properties, and Dimensional Tolerances

Chamical Composition (Percentaga by Walght)

Carbon	0.18 max.
Manganese	0.30-0.60
Phosphorus	0.04 max.
Sulfur	0.05 max.

Mechenical Properties

Tensile Strength	45,000 psi. min.
Yield Strength	25,000 psi. min.
Elongation in 2"	35% min.[A]
Rockwell Hardness	B65 max.[B]

[A] For tubes with O.D. of ⅜" or less or wall thickness of .035" or less a minimum elongation of 25% is permitted.
[B] The hardness requirement does not apply to tubes with less than .065 in. wall thickness. Such tubes shall meet all other mechanical properties and all mechanical tests of this recommended standard.

Dimensional Tolerences

When tubing is specified by outside diameter and inside diameter, the tolerances shown in the table below apply.

Nominal Outside Diameter	O.D. Inches	I.D. Inches
Up to ⅜", inclusive	±0.002	±0.005
Over ⅜" to ⅝", inclusive	±0.0025	±0.0025
Over ⅝" to 2", inclusive	±0.003	±0.003
Over 2" to 2½", inclusive	±0.004	±0.004
Over 2½" to 3", inclusive	±0.005	±0.005
Over 3" to 4", inclusive	±0.006	±0.006

When tubing is specified by the outside diameter (or the inside diameter) and the nominal wall thickness, the above tolerances apply for the specified diameter, and the allowable wall thickness variation is ±10% for tubes ⅜" diameter and over, and ±15% for tubes under ⅜" O.D.

Ref.: NFPA STD T3.15.67.1, approved as ANSI Standard B93.4-1981

Extracted from American National Standard Electric Resistance Welded Mandrel Drawn Hydraulic Line Tubing (ANSI B93.4-1981) with the permission of the publisher, The National Fluid Power Association, Inc.

2. Hydraulic Cylinder Tubing

Hydraulic cylinder tubing is, as the name implies, used to produce hydraulic cylinders. It is available in two grades, regular DOM and Special Smooth IO (SSIO). OOM is not furnished with an ID of cylinder quality. The ID is sometimes surface finished by the buyer but can also be furnished in that condition by the mill or steel service center. SSIO tubing is an excellent choice for certain types of hydraulic cylinders where no further finishing of the ID is desired or required.

Honing is used to modify the inside surface of tubing used for hydraulic cylinders to meet the cylinder manufacturers' requirements for surface finish (microinch) and ovality. The process uses honing stones, held on a rotating shaft. The honing head is passed through the tube ID in a helical pattern. Honing pressure, stone grit and number of passes control the final ID dimensions of the tubing.

3. Propeller Shaft Tubing

Wall thickness uniformity inherent in welded tubing in either the as-welded or cold drawn condition provides a well balanced tube especially suited for propeller or drive shafts in automotive vehicles.

This application of welded tubing demands rigid requirements. Well balanced tubing for propeller and drive shaft applications differs from regular mechanical tubing in tolerances and often in mechanical properties.

The following evaluations, affecting the dimensions and processing of the tubing supplied for this application, will need to be considered by the design engineer:

(1) Torque rating of engine.

(2) Low or reverse gear ratio, whichever is greater.

(3) Distance between bearing points.

(4) Maximum speed of shaft in r.p.m.

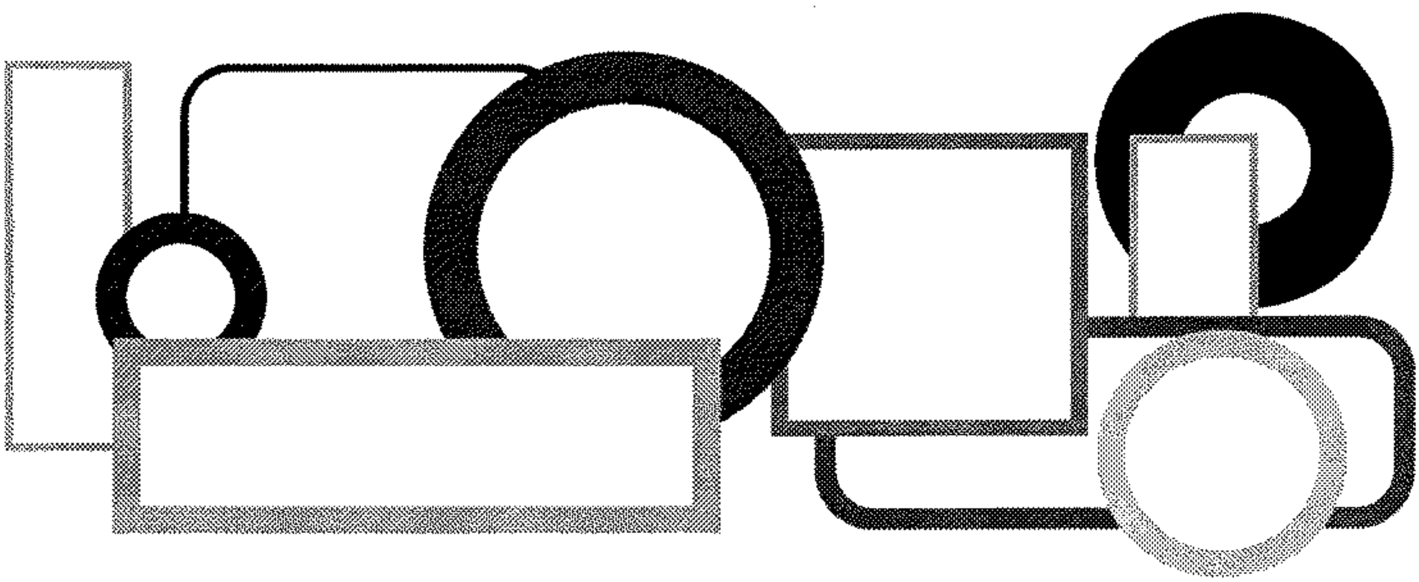
(5) Method used to attach splines to tube.

Table 32
Minimum Inside Diameter Stock Allowance on Oiemeter[A] for Removal of Inside-Surface Imperfectione by Honing Operation (Mandrel-Orawn Tubing)

Outside Oiameter, in.[B]	Well Thicknese, in.[B]							
	0.085 end under	Over 0.065 to 0.125, incl	Over 0.125 to 0.180, incl	Over 0.180 to 0.230, incl	Over 0.230 to 0.360, incl	Ovar 0.360 to 0.460, incl	Over 0.460 to 0.583, incl	Over 0.563
Up to and incl 1½	0.010	0.011	0.013	0.015	0.018	. . .	. . .	. . .
Over 1½ to 3 incl	0.010	0.012	0.014	0.016	0.018	0.021	0.023	. . .
Over 3 to 4 incl	0.011	0.013	0.015	0.017	0.019	0.021	0.023	0.025
Over 4 to 4¾ incl	. . .	0.014	0.016	0.018	0.020	0.022	0.024	0.026
Over 4¾ to 6 incl	. . .	0.015	0.017	0.019	0.021	0.023	0.025	0.027
Over 6 to 8 incl	. . .	0.016	0.018	0.020	0.022	0.024	0.026	0.028
Over 8 to 10½ incl	. . .	. . .	. . .	0.021	0.023	0.025	0.027	0.029
Over 10½ to 12½ incl	. . .	. . .	. . .	0.022	0.024	0.026	0.028	0.030
Over 12½ to 14 incl	. . .	. . .	. . .	0.024	0.025	0.027	0.029	0.031
Over 14 to 15 incl	. . .	. . .	. . .	0.025	0.026	0.028	0.030	0.032

[A] If a specific size is desired, these allowances plus normal size tolerances must be considered in calculating size to be ordered.
[B] 1 in. = 25.4 mm.

Ref.: ASTM A 513-85



SECTION VI — Fabrication

This section covers the many processing, fabricating, and manipulating operations which the welded tubing user may perform on the tubing. Limitations including bending radii, width of flange and maximum size of bead have been included to illustrate the excellent ductility of welded tubing. These data are based on past performance and represent normal practice. However, it should be pointed out that a change in chemical analysis or an anneal prior to fabrication may alter these figures and can result in further improvement in ductility. (It should again be stressed that any limitations are not due to the weld but solely to the inherent properties of the steel from which the tube is made.)

There have been many instances in which the fabricator, because of his advanced methods, has been able far to exceed the anticipated ductility of the welded tubing, and manufacture parts which otherwise would not appear to be feasible. The uniformity of welded tubing is, of course, the prime consideration, but condition of the equipment and fabricating techniques play a vital role in any fabricating operation.

1. Cutting

Any of the conventional cutting methods, e.g., punch, saw, disc, supported shear, or lathe, can be used on welded steel tubing. Selection of the proper method to use depends on the necessary or desired accuracy of length and end condition.

A punch cut is normally performed with a single cut die, which leaves a small dimple in the tube. However, a double cut die can be utilized when it is necessary to punch cut tubing without leaving a dimple. In either case, a punch cut leaves a slight cutting burr on the end of the tube.

Saw cutting can be accomplished using a high-speed, hot rotary saw or a low-speed, cold rotary saw. The high-speed saw, or friction cut off device, generally produces a burr which is hard and brittle, and tube ends may be discolored due to the amount of heat generated. The low-speed saw, similar to a milling cutter or a hack saw, leaves a slight burr in addition to a hanging burr on one end which is easily removed.

Disc or roller cutting tends to restrict the tube opening slightly, in addition to hardening the end to a small degree due to cold working. This operation leaves an ID burr which may be heavy at times.

Supported shear cutting is a high production cutting method utilizing no blades, wheels, or cutters. It holds fairly close length tolerances and leaves a square, relatively burr-free face.

A lathe cutting operation utilizes a cutting tool and thus provides the greatest length accuracy of any of these cutting methods. Tubes cut using this method usually have smooth ends and some OD and ID burr.

The additional operation of end chamfering is often performed when the end of a tube is to be fabricated, especially if it is to be flared or expanded. This operation usually produces a square cut face with a slight chamfer on the OD and ID to remove all burrs.

Any cutting operation which results in a hard end as in disc cutting or a heavy burr as in high speed cutting, or in the formation of irregularity or roughness due to notches will interfere with any subsequent operation on the end of the tube, such as flaring or flanging, and may cause cracking or splitting. This can be taken care of by filing, end facing, grinding or deburring after cutting, to remove the burr or roughness, and it may be more economical to use this procedure than lathe cutting. Annealing the end also improves it for fabrication by increasing ductility.

2. Bending

As stated earlier, welded tubing is ideal for any bending operation because of its uniformity and ductility. It is used in widely diversified service and equipment including hydraulic lines, automobile and truck exhaust pipes which frequently have several bends in different planes, heat exchangers wherein tubes may be bent 180°, tubular furniture and boiler tubes. Diameters and wall thicknesses may vary greatly, according to the application.

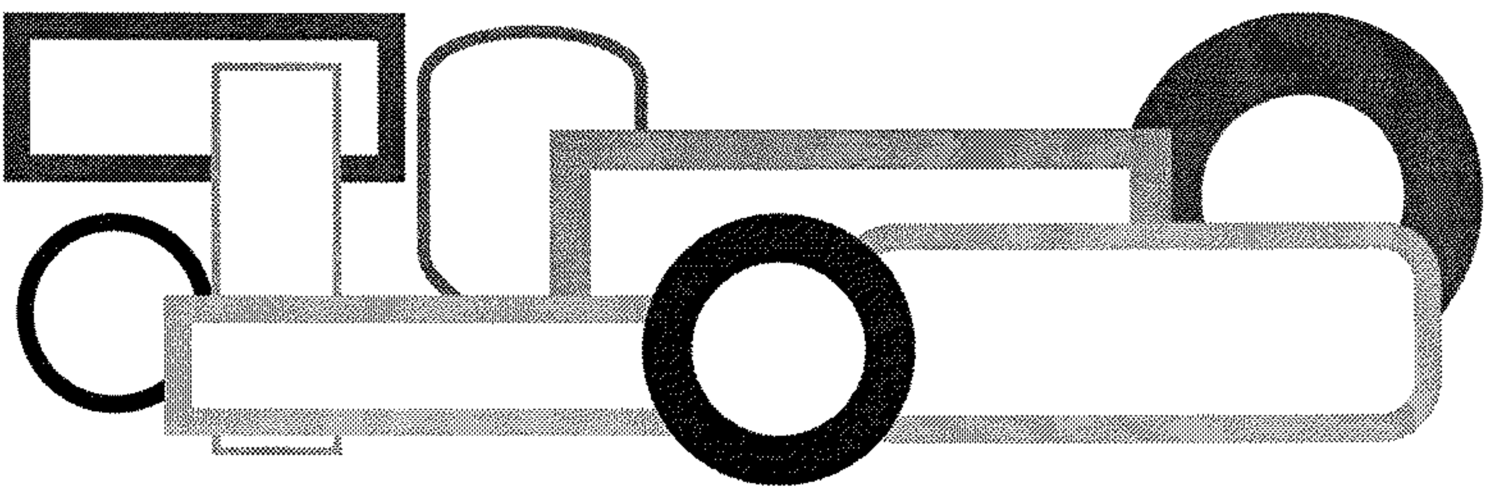
The low carbon steels are obviously best adapted for bending because they have maximum ductility. The higher carbons have lower ductility, are harder and cannot be bent on as small radii. Annealing is sometimes employed if the required bend is very severe. Tubes should be free from abrasive dust, chips and dirt if the tubing is to be bent over a mandrel.

In bending, the steel is stressed beyond its yield strength. Its ductility determines the amount of stretch or elongation the steel will take before it fractures.

The quality of bend desired, the amount of flattening, smoothness required and number of bends per piece all influence bending procedure and whether an internal support or mandrel should be used.

There are several basic methods of bending. Press bending or bending on a ram automatic machine is similar to bending a piece of tubing by hand over the knee. A die or roll is pressed against the tube supported on a pair of dies or rolls. The amount of flattening depends upon the tube diameter and wall thickness.

Rotary automatic bending machines come in a large range of types and sizes. The tube is clamped to a bending die which has a groove corresponding to the tube diameter. A shoe is



then clamped against the tube. The die encompasses 180 degrees of the tube circumference and the shoe which has a corresponding groove surrounds the other half. In one procedure the die and tube rotate around the shoe and in the other the shoe is wiped against the tube. A mandrel held stationary and accurately positioned in the tube supports the inner wall if smooth bends with a minimum of flattening are desired. These machines are generally hydraulically operated.

Manually operated machines cover a wide range of types, from the bender for conduit to complicated designs similar to the hydraulic machines except that they are hand powered. They are best suited to relatively light wall and small diameter tubing.

Roll bending employs three rolls with grooves, offset so the tube is bent when passed through them. It is frequently used to form coils or large radius bends.

Roll extrusion forming is suitable for bending tubing from approximately 5" OD to 12" OD by applying pressure to a segment of the inside diameter. Applied by a roller, the force extrudes a segment of the wall, and the tube bends to relieve the re-rolling stress. Any radius from 3 × outside diameter and larger can be produced by the same tooling. The method is applicable in medium to heavy wall material with low production requirements.

a. Bending Round Tubing

1) Bends Without Mandrel

The dies used in making a bend without a mandrel have a contour somewhat smaller than the tube diameter to support the metal and reduce tendency to wrinkle, so that there is a reduction in cross section at the bend. Table 33 indicates minimum bend radii for various tube sizes using the following formula:

$$L = \frac{.2468\,\pi\,D^2 - d^2}{t}$$

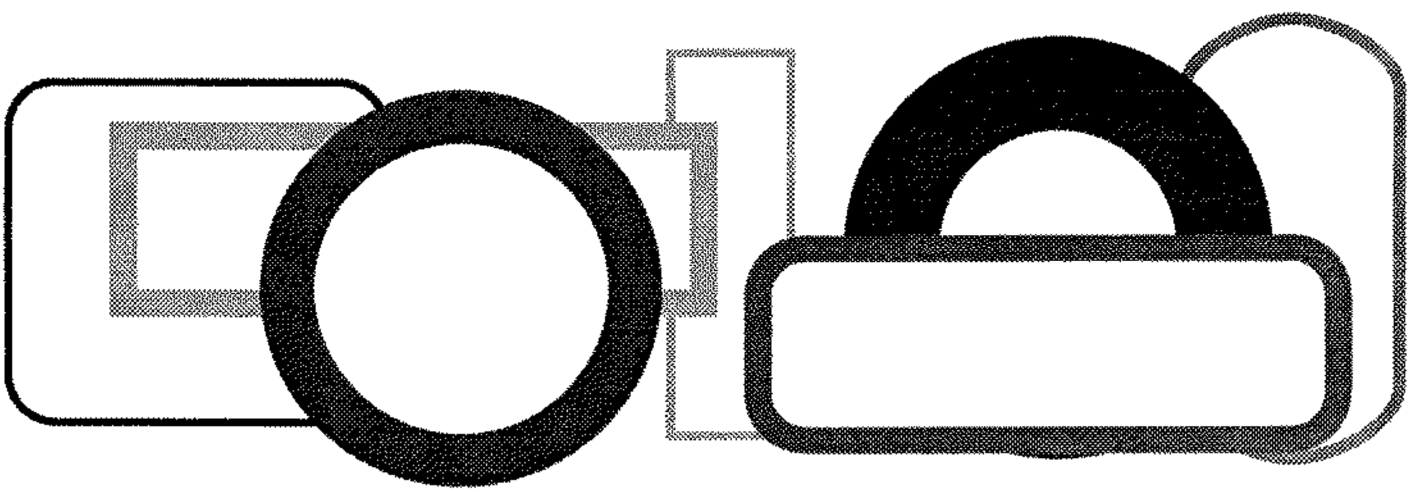
L = Center line radius of bend
D = Outside diameter of tube
d = Inside diameter of tube
t = Wall thickness
π = 3.1418

The above figures are applicable when the angle of bend does not exceed 90° for outside diameters not exceeding 2½" and 75° over 2½". Smaller radii, closer than recommended, and larger angles of bend, also other limitations mentioned later, may be produced or exceeded but this increases cost and can result in higher scrap loss.

Table 33
Bends Without Mandrel Minimum Bend Radius

Diamatar of Tuba	14 Geuge[A] (Radius)	16 Gauge (Radius)	16 Gauge (Radlua)	20 Gauge (Redius)	22 Gauga (Radiua)
½"	1¼"	1¼"	1½"	1½"	1½"
¾"	2"	2"	2¼"	2¼"	2¼"
1"	2¾"	3"	3"	3"	3"
1¼"	3½"	3¾"	3¾"	3¾"	3¾"
1½"	4½"	4½"	4½"	4½"	4½"
1¾"	5¼"	5¼"	5¼"	5¼"	5¼"
2"	6"	6"	6"	6"	.....
2¼"	6¾"	6¾"	6¾"	6¾"	.....
2½"	7½"	7½"	7½"	7¾"	.....
2¾"	8¼"	8¼"	8½"	8½"	.....
3"	9"	9"	9¼"	9¼"	.....
3¼"	9¾"	10"	10"	.....	.....
3½"	10½"	10¾"	10¾"	.....	.....
3¾"	11½"	11½"	.....	.....	.....
4"	12¼"	12¼"	.....	.....	.....

[A]Birmingham Wire Gage.
These are examples. Any intermediate size can be computed by the formula.



2) Mandrel Bends
Minimum bend radii are indicated in Table 34. In the light gauges and for smaller radii, it is difficult to make mandrel bends that are wholly free from wrinkle "shadows." Smaller radii can be supplied on all sizes in the Table but without definite assurance that the tube will be free from wrinkles on the inside of the bend.

Mandrels come in several designs. The simplest, a solid piece with a stub or curved end, is used with heavier walls and for simple bends. The flexible type which has a series of balls or discs at the end is used for lighter walls because it gives support of the inside wall past the bend. The balls are pivoted so that the mandrel can be removed from the bend by withdrawal of the straight section. Positioning of the mandrel during the bending operation is very important. If it does not enter sufficiently, it will not support the tube and if inserted too far it will tend to pinch the tube against the die or form and will cause breakage or extreme wall thickness reduction. Filling the tube with sand, rosin or a low melting alloy (the latter two are melted and poured into the tube) is sometimes done. The tube must be heated after bending to let the alloy or rosin run out.

Table 34
Mandrel Bends Minimum Bend Radius

O.D.	Bwg.[A]	Minimum Radius
½" to ⅞"	16	1½ × O.D.
½" to ⅞"	18	2 × O.D.
½" to ⅞"	20	2½ × O.D.
1" to 2¼"	14	1½ × O.D.
1" to 2¼"	16	2 × O.D.
1" to 2¼"	18	2½ × O.D.
1" to 2¼"	20	3 × O.D.
2⅜" to 3"	14	2 × O.D.
2⅜" to 3"	16	2½ × O.D.
2⅜" to 3"	18	3 × O.D.
3⅛" to 4"	14	2½ × O.D.
3⅛" to 4"	16	3 × O.D.

[A]Birmingham Wire Gage.

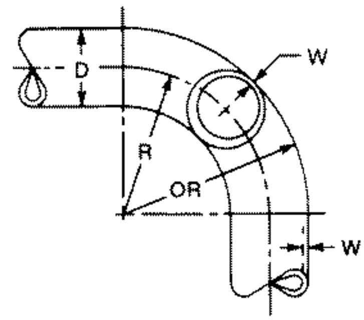
3) General Instructions For Bending & Bent Parts

Minimum Distance Between Bends
Bends in the same plane 2 × OD
Bends in different planes 3 × OD

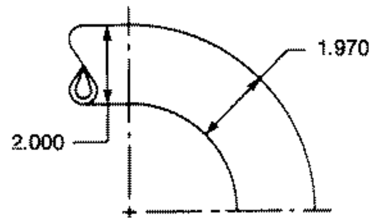
Distance of Bends From End of Tube
In order to maintain a true diameter of the tube at the ends, the distance between the theoretical end of the bend and the end of the tube should be 2 × OD.

Sized Ends
When sizing the ends of a fabricated part for either outside or inside diameter or both, the tolerances to be maintained should correspond to either the OD or the ID as shown under "Flash Controlled to 0.005" Max.," Tables 3 or 4.

Wall Displacament Incurred in Banding
Some wall displacement occurs in all bending of tubular products. It is most noticeable in mandrel bending when the attempt is made to eliminate wrinkles. The amount of displacement will vary, depending on the equipment used and the chemistry and physical properties of the tube involved.



When tubing is bent, the wall thickness increases on the inside and decreases on the outside.



In addition to outer wall thinning, there is a slight OD flattening in a bend.

As an example of what may happen in a particular lot of carben steel tubing, the following was taken from a production run of 1010 steel, 2⅜" OD × .035" wall, annealed finish.

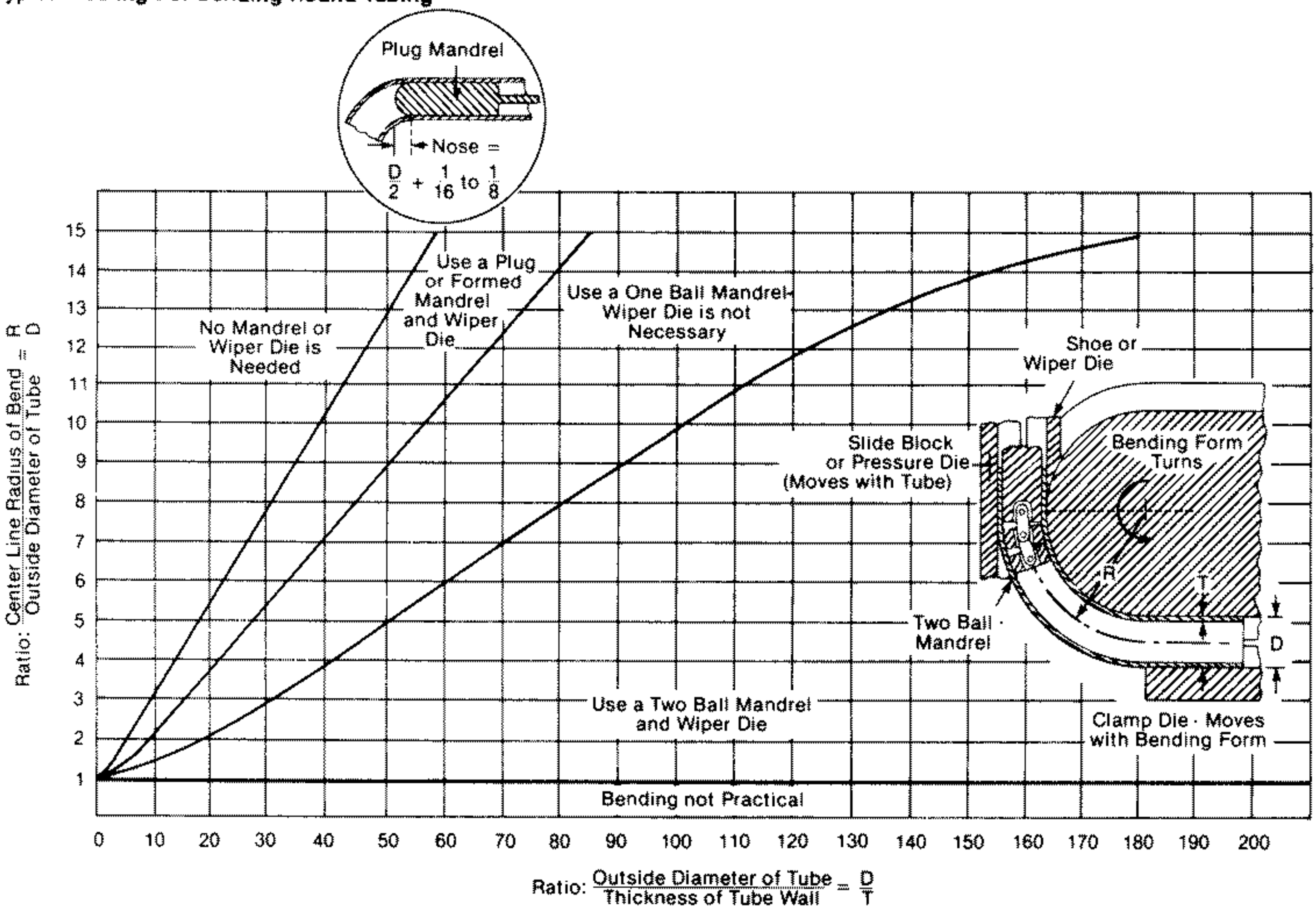
A tube having a 90° bend was checked in the plane of the bend at a point 45° from the starting point of the bend. The inside wall of the tube showed an increase in wall thickness of 20%. The wall thickness on the center line showed an 8% decrease and the wall thickness on the outside of the bend was decreased 30%. The ratio of the outside diameter of the tube to the radius of the bend was 1:1⅓.

4) Mandrel Types and Guide For Use

The data from which the chart below was drawn were developed for carbon steel tubing.

Factors which affect the simplicity or difficulty of bending a particular size of tubing to a required radius are, primarily, the outside diameter of the tube and its wall thickness. Large bend radii are easier to form than small ones. Large diameter tubing has greater differential in stretch between the inside and outside fibers and hence increased probability of thinning and flattening in sharp bends. Thin wall tubes tend to wrinkle. The most difficult bends are on large thin tubes bent to a relatively short radius. Compensation for difficulties due to thin wall or large diameter are made in the tooling, primarily by supporting the tube walls by more or less complex mandrels. The bending of tubing still requires experience and skill; therefore, the chart should be used as a guide rather than to indicate the absolute limits of what can be done with any given support.

Typical Tooling For Bending Round Tubing



b. Bending Squere end Rectanguler Tubing

Square and rectangular tubing is generally bent using an inside mandrel since the walls have a tendency to collapse during bending if no mandrel is used. Bending radii on shaped tubing are greater (larger) than for the equivalent round size because the steel, particularly in the corners, is harder due to the cold working. Controlled annealing can improve this condition. Split dies are employed almost exclusively when bending shapes because use of this type die permits the tubes to be placed on the mandrel more easily before bending and facilitates tube removal after bending. The bending mandrel, usually of the link type, should closely fit the inside of the tube. Tables 35 and 36 indicate minimum bend radii for square and rectangular tubing. Wrinkle-free bends with smaller radii are possible with special tooling and good equipment.

Teble 35
Minimum Bend Redius For Squere Tubing

Size of Square	14 Gauge[A]	16 Gauge	18 Geuge	20 Gauge
½"	1⅝"	1¾"	1⅞"	2"
¾"	2⅝"	2¹³⁄₁₆"	3"	3⅜"
1"	3½"	3¾"	4"	4½"
1¼"	4¹¹⁄₁₆"	5"	5⅝"	....
1½"	5⅝"	6"	6¾"	....
1¾"	7"	7⅞"	8¾"	....
2"	8"	9"	10"	....
2½"	10"	12½"	....	....
3"	12"	15"	....	....
4"	20"	22½"	....	....
4½"	22½"	25"	....	....
5"	25"	27½"	....	....

[A]Birmingham Wire Gage.

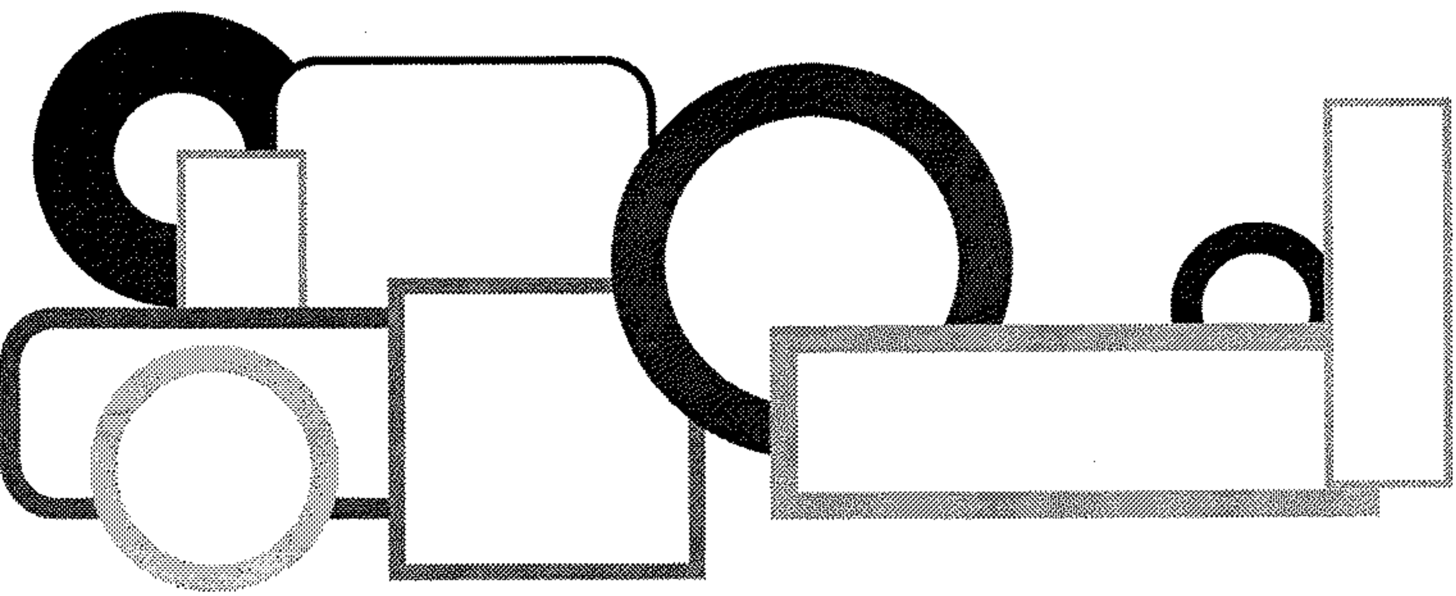
Table 36
Minimum Bend Radius For Rectangular Tubing

Size of Rectangle	Bend Located on	14 Gauge[A]	16 Gauge	18 Gauge	20 Gauge
½″ x 1″	½″ side	3½″	3¾″	4″	4½″
	1″ side	3½″	3¾″	4″	4½″
½″ x 1¼″	½″ side	4 11/16″	5″	5⅝″	....
	1¼″ side	4 11/16″	5″	5⅝″	....
½″ x 1½″	½″ side	5⅝″	6″	6¾″	....
	1½″ side	5⅝″	6″	6¾″	....
¾″ x 1″	¾″ side	4 11/16″	5″	5⅝″	....
	1″ side	3½″	3¾″	4″	....
¾″ x 1¼″	¾″ side	5⅝″	6″	6¾″	....
	1¼″ side	4 11/16″	5″	5⅝″	....
¾″ x 1½″	¾″ side	7″	7⅞″	8¾″	....
	1½″ side	5⅝″	6″	6¾″	....
¾″ x 1¾″	¾″ side	8″	9″	10″	....
	1¾″ side	7″	7⅞″	8¾″	....
¾″ x 2″	¾″ side	10″	12½″	....	....
	2″ side	8″	9″	....	....
1″ x 1¼″	1″ side	5⅝″	6″	6¾″	....
	1¼″ side	4 11/16″	5″	5⅝″	....
1″ x 1½″	1″ side	7″	7⅞″	8¾″	....
	1½″ side	5⅝″	6″	6¾″	....
1″ x 1¾″	1″ side	8″	9″	10″	....
	1¾″ side	7″	7⅞″	8¾″	....
1″ x 2″	1″ side	10″	12½″	....	....
	2″ side	8″	9″	....	....
1″ x 2½″	1″ side	12″	15″	....	....
	2½″ side	10″	12½″	....	....
1″ x 3″	1″ side	16½″	19¼″	....	....
	3″ side	12″	15″	....	....
1″ x 3½″	1″ side	20″	22½″	....	....
	3½″ side	16½″	19¼″	....	....
1¼″ x 1½″	1¼″ side	7″	7⅞″	8¾″	....
	1½″ side	5⅝″	6″	6¾″	....
1¼″ x 1¾″	1¼″ side	8″	9″	10″	....
	1¾″ side	7″	7⅞″	8¾″	....
1¼″ x 2″	1¼″ side	10″	12½″	....	....
	2″ side	8″	9″	....	....

[A]Birmingham Wire Gage.

Size of Rectangle	Bend Located on	14 Gauge[A]	16 Gauge	18 Gauge	20 Gauge
1¼″ x 2½″	1¼″ side	12″	15″	....	....
	2½″ side	10″	12½″	....	....
1¼″ x 3″	1¼″ side	16½″	19¼″	....	....
	3″ side	12″	15″	....	....
1½″ x 2″	1½″ side	10″	12½″	....	....
	2″ side	8″	9″	....	....
1½″ x 2½″	1½″ side	12″	15″	....	....
	2½″ side	10″	12½″	....	....
1½″ x 2¾″	1½″ side	16½″	19¼″	....	....
	2¾″ side	11″	13¾″	....	....
1½″ x 3″	1½″ side	20″	22½″	....	....
	3″ side	12″	15″	....	....
1½″ x 3½″	1½″ side	22½″	24¾″	....	....
	3½″ side	16½″	19¼″	....	....
1½″ x 4″	1½″ side	27½″	30″	....	....
	4″ side	20″	22½″	....	....
2″ x 3″	2″ side	16½″	19¼″	....	....
	3″ side	12″	15″	....	....
2″ x 4″	2″ side	22½″	24¾″	....	....
	4″ side	20″	22½″	....	....
2½″ x 4″	2½″ side	22½″	24¾″	....	....
	4″ side	20″	22½″	....	....
2½″ x 5″	2½″ side	24¾″	26½″	....	....
	5″ side	20″	22½″	....	....
2½″ x 6″	2½″ side	28″	30″	....	....
	8″ side	22½″	24″	....	....
3″ x 4″	3″ side	20″	22½″	....	....
	4″ side	18″	20″	....	....
3″ x 5″	3″ side	24¾″	26½″	....	....
	5″ side	13″	16″	....	....
3″ x 6″	3″ side	28″	30″	....	....
	6″ side	18″	20″	....	....
4″ x 5″	4″ side	24¾″	26½″	....	....
	5″ side	20″	22½″	....	....
4″ x 6″	4″ side	26½″	28″	....	....
	6″ side	22½″	24″	....	....

[A]Birmingham Wire Gage



3. Swaging (Cold)

a. Wall Thicknass

A reduction in diameter may yield an increase in wall thickness. No hard and fast rule can be given for the increase in wall thickness when a tube diameter is decreased by swaging. However, if necessary, the wall thickness can be controlled by swaging over a mandrel.

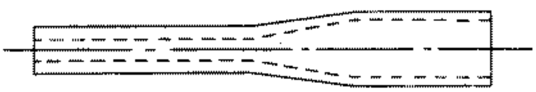
b. Hardnass Changa

Cold working generally increases the hardness and decreases the ductility of the tube. The extent to which cold working affects the hardness and ductility depends on such factors as original properties, speed of forming, resistance of tube to swaging, degree of taper and percentage of diameter reduction.

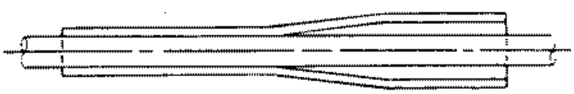
c. Tapering

Since it is extremely difficult to make abrupt tapers, the taper on each side should be limited to about 4½°, or the total included angle made 9° or less if conditions will permit.

Typical Examplas of Swaged Parts



Tapered Tube Made Without a Mandrel—
Wall Thickness Increased



Tapered Tube Made With Mandrel—
Wall Thickness Controlled

Straight Taper With or Without Mandrel

d. ID Dimensions

Swaging over a mandrel will produce controlled ID dimensions.

e. ID Finish

The ID finish of a tube is affected by the finish of the mandrel and the cleanliness of the I D of the tube.

f. Material Loss

Since the tube wall is moved from one shape to another, there is no weight loss or waste caused by the displacement.

4. Die Sizing

Die sizing is utilized when a precision tube end (± .0005") is needed, so it can be assembled. The tube end is forced into a die, thus reducing its diameter to a certain size. Although the amount of reduction for each pass into a die is limited, additional passes may be made, with certain limitations, to achieve a desired size.

A reduction in diameter may yield an increase in wall thickness. No hard and fast rule can be given for the increase in wall thickness when a tube diameter is decreased by die sizing. However, if necessary, the wall thickness can be controlled by die sizing over a mandrel.

5. Expanding

Table No. 37 following is based on use of tubing in types flash-in, flash controlled to .010" maximum, or flash controlled to .005" maximum; grades 1010 or 1015. End condition and material type both affect the extent of expansion which can be achieved.

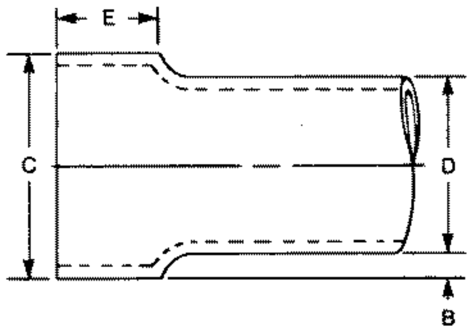


Table 37
Expanding
(All dimensions expressed in inches)

D	B	C	E
½	1/32	9/16	¼ to ½
1	1/16	1 1/8	¼ to 1
1½	3/32	1 11/16	¼ to 1½
2	1/8	2¼	¼ to 2
2½	5/32	2 13/16	½ to 2½
3	3/16	3 3/8	½ to 2½
3½	7/32	3 15/16	½ to 2½
4	¼	4½	½ to 2½
4½	9/32	5 1/16	½ to 2½
5	5/16	5 5/8	½ to 2½
5½	11/32	6 3/16	½ to 2½
6	3/8	6¾	½ to 2½

Note: If intermediate sizes are desired, use the following formula. The above table was made by assuming that the steel had an elongation of 12½%.

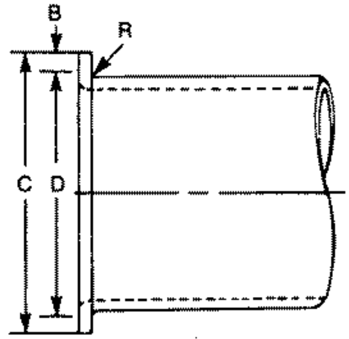
$$B = D \times \frac{.125}{2} = D \times .0625$$

D = Diameter of tube
B = Width of flange on one side

6. Flanging and Beading

The following tables are based on use of tubing in types flash-in, flash controlled to .010" maximum or flash controlled to .005" maximum; grades 1010 or 1015. End condition and material type both affect the extent of flanging end beeding which can be achieved.

Flenging 90°



Teble 38
Flanging 90°

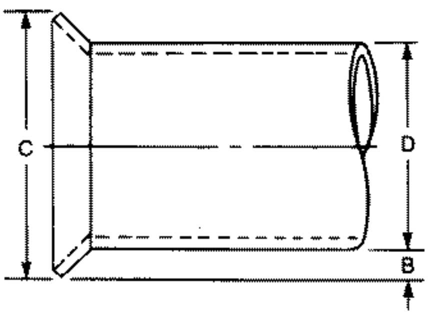
Radius R should be greeter than wall thickness.

(All dimensions expressed in inches)

D	B	C
½	1/32	9/16
1	1/16	1 1/8
1½	3/32	1 11/16
2	1/8	2¼
2½	5/32	2 13/16
3	3/16	3 3/8
3½	7/32	3 15/16
4	¼	4½
4½	9/32	5 1/16
5	5/16	5 5/8
5½	11/32	6 3/16
6	3/8	6¾

For other sizes, see note.

Flanging 45°



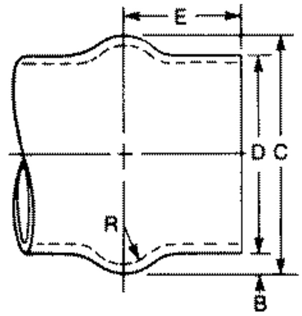
Teble 39
Flenging 45°

(All dimensions expressed in inches)

D	B	C
½	1/32	9/16
1	1/16	1 1/8
1½	3/32	1 11/16
2	1/8	2¼
2½	5/32	2 13/16
3	3/16	3 3/8
3½	7/32	3 15/16
4	¼	4½
4½	9/32	5 1/16
5	5/16	5 5/8
5½	11/32	6 3/16
6	3/8	6¾

For other sizes, see note.

Expended Bead



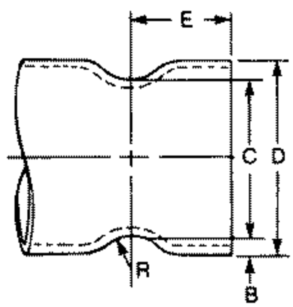
Teble 40
Expandad Bead

(All dimensions expressed in inches)

D	B	C	Min. R	E
½	1/32	9/16	1/8	¼ to ½
1	1/16	1 1/8	1/8	½ to 1
1½	3/32	1 11/16	3/16	½ to 1
2	1/8	2¼	3/16	¾ to 1½
2½	5/32	2 13/16	¼	1 to 2
3	3/16	3 3/8	¼	1½ to 2½
3½	7/32	3 15/16	¼	1½ to 3
4	¼	4½	¼	1½ to 3
4½	9/32	5 1/16	¼	1½ to 3
5	5/16	5 5/8	¼	1½ to 3
5½	11/32	6 3/16	¼	1½ to 3
6	3/8	6¾	¼	1½ to 3

For other sizes, see note.

Depressed Bead



Teble 41
Depressed Bead

(All dimensions expressed in inches)

D	B	C	Min. R	E
½	1/32	7/16	1/8	¼ to ½
1	1/16	7/8	1/8	½ to 1
1½	3/32	1 5/16	3/16	½ to 1
2	1/8	1¾	3/16	¾ to 1½
2½	5/32	2 3/16	¼	1 to 2
3	3/16	2 5/8	¼	1½ to 2½
3½	7/32	3 1/16	¼	1½ to 3
4	¼	3½	¼	1½ to 3
4½	9/32	3 15/16	¼	1½ to 3
5	5/16	4 3/8	¼	1½ to 3
5½	11/32	4 13/16	¼	1½ to 3
6	3/8	5¼	¼	1½ to 3

For other sizes, see note.

Note: If intermediate sizes are wanted, use the following formula:

$$B = D \times \frac{.125}{2} = D \times .0625$$

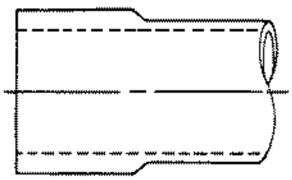
B = Width of flange, bevel or bead on one side

D = Outside diameter of tube.

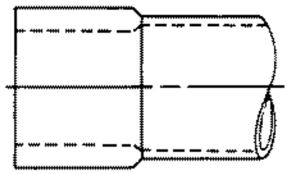
7. Upsetting

Welded steel tubing can be upset while hot by the usual methods employed for this operation. Requirements vary by size and gauge and the number of operations possible in the upsetting machine. It is possible by using a sufficient number of operations to close completely the end of a 1¼" tube for a distance of about 3" by upsetting and swaging. Ordinary upsets, in which the wall thickness is increased 50%, are readily supplied for the purpose of increasing strength and allowing for the cutting of threads.

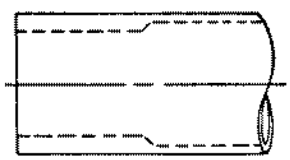
External and Internal Upsets



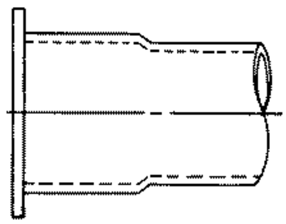
External Upset



External and Internal Upset



Internal Upset



Upset and Flanged

8. Spinning

Spinning is an operation used to close one or both ends of a tube. It is generally done hot by heating the end of the tube, rotating it at high speed and forging the end by holding a tool which is held steady or moved in an arc against the tube end. The tool is designed to force the end of the tube inward. The center of the closed end may not be gas tight because of scale trapped in the joint. The center is generally removed and a plug or fitting inserted. However, tubes have been used as spun. Welded tubes are widely used for such service. Spinning may also be done cold on light gauges of carbon steel.

9. Joining

Carbon steel tubing can be joined by virtually all welding and brazing methods and by many mechanical methods. Specific information for particular applications can be obtained from the Welded Steel Tube Institute or any of its members.

10. Polishing

For the information of users who polish tubes for plating or other end use, experience indicates that the approximate amount of stock that can be removed from the wall of a carbon steel tube by one pass of a specific grade of grit is as follows:

Grit No.	Stock Removed from Wall Per Pass
80	.0015 in.
120	.0010 in.
150	.0008 in.
180	.0007 in.
240	.0005 in.
320	.0002 in.

SECTION VII —Specifications

Several organizations have written specifications covering welded tubing usually intended for a specific end use.

These agencies and their designations are as follows:

Agency	Specification Designations
American Society for Testing and Materials	ASTM
American National Standards Institute	ANSI
National Fluid Power Association	NFPF
Society of Automotive Engineers	SAE
Aerospace Material Specifications	AMS
United States Government	Military (MIL-T)

SECTION VIII — Technical Data and Reference Tables

1. Design Dete

a. General Comments

Round tubing offers numerous advantages in structural applications. Minimum resistance to the wind is met since exposed surface area is the same in all directions. Square and rectangular tubes are ideal in structural applications because they combine the efficiency of the hollow thinwalled section with excellent appearance plus flat sides for easy, economical connecting and other fabricating operations.

Compression (axially loaded) members tend to resist failure in the direction perpendicular to the axis which has the greatest radius of gyration. Since the most efficient cross section for a compression member is, therefore, one with a relatively large radius of gyration per unit weight and with a constant radius of gyration about any axis, a round tube is the theoretical ideal. Square tubes have a constant radius of gyration about any cross-sectional axis, at some sacrifice in efficiency compared to round tubes, but may be easier to join into a structure.

The unbraced length of a column at various directions to the cross section influences the column load which can be carried. Rectangular tubes can sometimes be used to advantage when unbraced lengths in different directions to the cross section are unequal.

Round tubes resist bending stresses equally in all directions. Therefore, where beams must be designed for equal loading in any direction, tubes with a circular cross section will have the least weight for given strength and stiffness. When asymmetrical loading problems arise, however, design considerations lead to the selection of members with other cross sections; I-beams are generally used where greatest section modulus and moment of inertia are required in a single plane. Similarly, square and rectangular sections may be used when the design calls for loading primarily on two planes at right angles to each other, squares when loads are equal, rectangles when loading in one plane is dominant.

In the case of the I-beam loading discussed above, there is a condition even here where the tubular section has advantages, that is, where the compression flange of the beam is laterally unsupported for distances greater than certain specified limits. In these cases reductions in bending stress of the I-beam or frequent lateral supports are required to prevent lateral buckling of its compression flange. Because of their high torsional resistance, tubes seldom require stress reductions or frequent lateral supports.

Structural designers are assured of full continuity through joints in welded assemblies. The principle of tubular truss construction is now being applied with great success in the construction of crane booms and oil-well derricks.

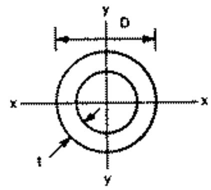
b. Elements of Sections

The following formulae are used for calculating elements of sections (See page 46 for a definition of symbols). These formulae are based on basic engineering principles such as those found in *Formulas for Stress and Strain*, by Roark and Young, 5th edition, McGraw-Hill Publishing Company, 1975, and include factors to provide for varying corner radii of squares and rectangles.

The elements of sections shown on pages 33 to 45 are based on these formulae. Corner radii used in the calculations are based on mean values allowed in ASTM A 513-85. The effects of any variations in dimensions from values shown must be taken into consideration.

When sections are to be used in building construction, reference should be made to the latest edition of the *Specification for the Design of Light Gage Cold Formed Steel Structural Members* (published by the American Iron & Steel Institute, 1000 16th St. NW, Washington, DC 20036) and the applicable building code or other regulatory provisions. For mechanical tubing see applicable specifications (ASTM A 513, for example) for permissible tolerances.

Formulae — Round Tube



D = outside diameter
t = wall thickness

Area, $A = \pi t (D - t)$

Moment of Inertia, $I_{x\text{-}x} = I_{y\text{-}y} = \dfrac{\pi [D^4 - (D - 2t)^4]}{64}$

Section Modulus, $S_{x\text{-}x} = S_{y\text{-}y} = \dfrac{2 I_{x\text{-}x}}{D}$

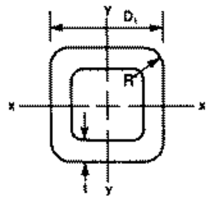
Radius of Gyration, $r_{x\text{-}x} = r_{y\text{-}y} = \sqrt{\dfrac{I_{x\text{-}x}}{A}}$

Weight in lb/ft, $W = 3.3996\,A$

Formulae — Square Tube

Area, $A = t[4D_1 - 8R + \pi(2R - t)]$

Moment of Inertia, $I_{x\text{-}x} = I_{y\text{-}y} = \dfrac{t^3(D_1 - 2R)}{6} + 2t(D_1 - 2R)\left(\dfrac{D_1 - t}{2}\right)^2$



$$+ \frac{t(D_1 - 2R)^3}{6}$$
$$+ \left(\frac{\pi}{4} - \frac{8}{4.5\pi}\right)[R^4 - (R - t)^4]$$
$$- \frac{8t\,R^2(R - t)^2}{4.5\,\pi(2R - t)}$$
$$+ \pi t(2R - t)\left[\frac{D_1}{2} - R + \frac{4\{R^3 - (R - t)^3\}}{3\pi\{R^2 - (R - t)^2\}}\right]^2$$

Section Modulus, $S_{x\text{-}x} = S_{y\text{-}y} = \dfrac{2 I_{x\text{-}x}}{D_1}$

Radius of Gyration, $r_{x\text{-}x} = r_{y\text{-}y} = \sqrt{\dfrac{I_{x\text{-}x}}{A}}$

Weight in lb/ft, $W = 3.3996\,A$

Formulae — Rectangular Tube

Area, $A = t[2(B + C) - 8R + \pi(2R - t)]$

Moment of Inertia, $I_{x\text{-}x} = \dfrac{t^3(B - 2R)}{6} + 2t(B - 2R)\left(\dfrac{C - t}{2}\right)^2$

$$+ \frac{t(C - 2R)^3}{6}$$
$$+ \left(\frac{\pi}{4} - \frac{8}{4.5\pi}\right)[R^4 - (R - t)^4]$$
$$- \frac{8t\,R^2(R - t)^2}{4.5\,\pi(2R - t)}$$
$$+ \pi t(2R - t)\left[\frac{C}{2} - R + \frac{4\{R^3 - (R - t)^3\}}{3\pi\{R^2 - (R - t)^2\}}\right]^2$$

Moment of Inertia, $I_{y\text{-}y} = \dfrac{t^3(C - 2R)}{6} + 2t(C - 2R)\left(\dfrac{B - t}{2}\right)^2$

$$+ \frac{t(B - 2R)^3}{6}$$
$$+ \left(\frac{\pi}{4} - \frac{8}{4.5\pi}\right)[R^4 - (R - t)^4]$$
$$- \frac{8t\,R^2(R - t)^2}{4.5\,\pi(2R - t)}$$
$$+ \pi t(2R - t)\left[\frac{B}{2} - R + \frac{4\{R^3 - (R - t)^3\}}{3\pi\{R^2 - (R - t)^2\}}\right]^2$$

Section Modulus, $S_{x\text{-}x} = \dfrac{2 I_{x\text{-}x}}{C}$

Section Modulus, $S_{y\text{-}y} = \dfrac{2 I_{y\text{-}y}}{B}$

Radius of Gyration, $r_{x\text{-}x} = \sqrt{\dfrac{I_{x\text{-}x}}{A}}$

Radius of Gyration, $r_{y\text{-}y} = \sqrt{\dfrac{I_{y\text{-}y}}{A}}$

Weight in lb/ft, $W = 3.3996\,A$

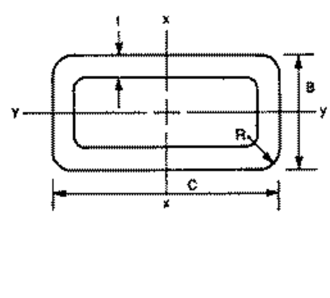


Table 42—Round Tubing

OUTSIDE DIA. (D) IN.	INSIDE DIA. (d) IN.	WALL THICKNESS (t) IN.	RATIO OD TO WALL THICKNESS (D/t)	AREA (A) SQ. IN.	WEIGHT LB./FT.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.
0.500	0.430	0.035	14.2857	0.0511	0.1738	0.0014	0.0056	0.1649
	0.402	0.049	10.2041	0.0694	0.2360	0.0018	0.0071	0.1604
	0.370	0.065	7.6923	0.0888	0.3020	0.0021	0.0086	0.1555
0.625	0.555	0.035	17.8571	0.0649	0.2205	0.0028	0.0091	0.2090
	0.527	0.049	12.7551	0.0887	0.3014	0.0037	0.0119	0.2044
	0.495	0.065	9.6154	0.1144	0.3888	0.0045	0.0145	0.1993
	0.459	0.083	7.5301	0.1413	0.4805	0.0053	0.0170	0.1939
0.750	0.680	0.035	21.4286	0.0786	0.2673	0.0050	0.0134	0.2531
	0.652	0.049	15.3061	0.1079	0.3669	0.0067	0.0178	0.2484
	0.620	0.065	11.5385	0.1399	0.4755	0.0083	0.0221	0.2433
	0.584	0.083	9.0361	0.1739	0.5913	0.0098	0.0262	0.2376
	0.532	0.109	6.8807	0.2195	0.7462	0.0116	0.0309	0.2299
0.875	0.805	0.035	25.0000	0.0924	0.3140	0.0082	0.0187	0.2972
	0.777	0.049	17.8571	0.1272	0.4323	0.0109	0.0249	0.2925
	0.745	0.065	13.4615	0.1654	0.5623	0.0137	0.0312	0.2873
	0.709	0.083	10.5422	0.2065	0.7021	0.0164	0.0374	0.2815
	0.657	0.109	8.0275	0.2623	0.8917	0.0196	0.0449	0.2736
1.000	0.930	0.035	28.5714	0.1061	0.3607	0.0124	0.0247	0.3414
	0.902	0.049	20.4082	0.1464	0.4977	0.0166	0.0332	0.3367
	0.870	0.065	15.3846	0.1909	0.6491	0.0210	0.0419	0.3314
	0.834	0.083	12.0482	0.2391	0.8129	0.0253	0.0507	0.3255
	0.782	0.109	9.1743	0.3051	1.0372	0.0307	0.0615	0.3174
	0.732	0.134	7.4627	0.3646	1.2394	0.0350	0.0700	0.3098
1.125	1.055	0.035	32.1429	0.1199	0.4074	0.0178	0.0317	0.3856
	1.027	0.049	22.9592	0.1656	0.5631	0.0240	0.0427	0.3808
	0.995	0.065	17.3077	0.2165	0.7359	0.0305	0.0542	0.3755
	0.959	0.083	13.5542	0.2717	0.9237	0.0371	0.0660	0.3696
	0.907	0.109	10.3211	0.3479	1.1828	0.0454	0.0807	0.3613
	0.857	0.134	8.3955	0.4172	1.4183	0.0521	0.0927	0.3536
1.250	1.180	0.035	35.7143	0.1336	0.4542	0.0247	0.0395	0.4297
	1.152	0.049	25.5102	0.1849	0.6285	0.0334	0.0534	0.4250
	1.120	0.065	19.2308	0.2420	0.8226	0.0426	0.0682	0.4196
	1.084	0.083	15.0602	0.3043	1.0345	0.0521	0.0833	0.4136
	1.032	0.109	11.4679	0.3907	1.3283	0.0642	0.1027	0.4052
	0.982	0.134	9.3284	0.4698	1.5972	0.0742	0.1187	0.3974
1.375	1.305	0.035	39.2857	0.1473	0.5003	0.0331	0.0481	0.4739
	1.277	0.049	28.0612	0.2041	0.6939	0.0449	0.0653	0.4691
	1.245	0.065	21.1538	0.2675	0.9094	0.0575	0.0837	0.4637
	1.209	0.083	16.5663	0.3369	1.1453	0.0706	0.1027	0.4577
	1.157	0.109	12.6147	0.4335	1.4738	0.0875	0.1273	0.4493
	1.107	0.134	10.2612	0.5224	1.7760	0.1017	0.1480	0.4413
1.500	1.430	0.035	42.8571	0.1611	0.5476	0.0432	0.0577	0.5181
	1.402	0.049	30.6122	0.2234	0.7593	0.0589	0.0785	0.5133
	1.370	0.065	23.0769	0.2930	0.9962	0.0756	0.1008	0.5079
	1.334	0.083	18.0723	0.3695	1.2561	0.0931	0.1241	0.5018
	1.282	0.109	13.7615	0.4763	1.6193	0.1159	0.1545	0.4933
	1.232	0.134	11.1940	0.5750	1.9549	0.1354	0.1806	0.4853
	1.170	0.165	9.0909	0.6920	2.3526	0.1565	0.2087	0.4756
1.625	1.555	0.035	46.4286	0.1748	0.5944	0.0553	0.0680	0.5623
	1.527	0.049	33.1633	0.2426	0.8248	0.0754	0.0928	0.5575
	1.495	0.065	25.0000	0.3188	1.0830	0.0971	0.1195	0.5520
	1.459	0.083	19.5783	0.4021	1.3669	0.1199	0.1475	0.5460
	1.407	0.109	14.9083	0.5191	1.7648	0.1499	0.1845	0.5374
	1.357	0.134	12.1269	0.6277	2.1338	0.1758	0.2164	0.5293
	1.295	0.165	9.8485	0.7568	2.5728	0.2042	0.2514	0.5195

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Table 42—Round Tubing (Continued)

OUTSIDE DIA. (D) IN.	INSIDE DIA. (d) IN.	WALL THICKNESS (t) IN.	RATIO OD TO WALL THICKNESS (D/t)	AREA (A) SQ. IN.	WEIGHT LB./FT.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.
1.750	1.680	0.035	50.0000	0.1886	0.6411	0.0694	0.0793	0.6065
	1.652	0.049	35.7143	0.2618	0.8902	0.0948	0.1083	0.6016
	1.620	0.065	26.9231	0.3441	1.1697	0.1223	0.1398	0.5962
	1.584	0.083	21.0843	0.4347	1.4777	0.1514	0.1730	0.5901
	1.532	0.109	16.0550	0.5619	1.9103	0.1900	0.2171	0.5815
	1.482	0.134	13.0597	0.6803	2.3127	0.2236	0.2555	0.5733
	1.420	0.165	10.6061	0.8216	2.7931	0.2608	0.2981	0.5634
1.875	1.805	0.035	53.5714	0.2023	0.6878	0.0857	0.0914	0.6507
	1.777	0.049	38.2653	0.2811	0.9556	0.1172	0.1251	0.6458
	1.745	0.065	28.8462	0.3696	1.2565	0.1516	0.1617	0.8403
	1.709	0.083	22.5904	0.4673	1.5885	0.1880	0.2005	0.6342
	1.657	0.109	17.2018	0.6047	2.0559	0.2367	0.2524	0.6256
	1.607	0.134	13.9925	0.7329	2.4916	0.2793	0.2980	0.6174
	1.545	0.165	11.3636	0.8884	3.0134	0.3270	0.3488	0.6074
2.000	1.930	0.035	57.1429	0.2161	0.7345	0.1043	0.1043	0.6948
	1.902	0.049	40.8163	0.3003	1.0210	0.1430	0.1430	0.6900
	1.870	0.065	30.7692	0.3951	1.3433	0.1851	0.1851	0.6845
	1.834	0.083	24.0964	0.4999	1.8993	0.2300	0.2300	0.6784
	1.782	0.109	18.3486	0.6475	2.2014	0.2904	0.2904	0.6697
	1.732	0.134	14.9254	0.7855	2.6705	0.3437	0.3437	0.6614
	1.670	0.165	12.1212	0.9512	3.2337	0.4036	0.4036	0.6514
	1.626	0.187	10.6952	1.0651	3.6209	0.4423	0.4423	0.6444
2.125	2.055	0.035	60.7143	0.2298	0.7813	0.1255	0.1181	0.7390
	2.027	0.049	43.3673	0.3196	1.0864	0.1723	0.1621	0.7342
	1.995	0.065	32.6923	0.4207	1.4301	0.2234	0.2102	0.7287
	1.959	0.083	25.6024	0.5325	1.8101	0.2780	0.2616	0.7226
	1.907	0.109	19.4954	0.6903	2.3469	0.3517	0.3311	0.7138
	1.857	0.134	15.8582	0.8382	2.8494	0.4172	0.3927	0.7055
	1.795	0.165	12.8788	1.0160	3.4540	0.4913	0.4824	0.6954
	1.751	0.187	11.3636	1.1385	3.8708	0.5395	0.5078	0.8884
2.250	2.180	0.035	64.2857	0.2436	0.8280	0.1494	0.1328	0.7832
	2.152	0.049	45.9184	0.3388	1.1518	0.2053	0.1825	0.7784
	2.120	0.065	34.6154	0.4482	1.5188	0.2665	0.2369	0.7729
	2.084	0.083	27.1084	0.5650	1.9209	0.3322	0.2953	0.7667
	2.032	0.109	20.6422	0.7331	2.4924	0.4212	0.3744	0.7579
	1.982	0.134	16.7910	0.8908	3.0283	0.5006	0.4449	0.7496
	1.920	0.165	13.6364	1.0808	3.6742	0.5910	0.5253	0.7395
	1.876	0.187	12.0321	1.2120	4.1202	0.6501	0.5778	0.7324
2.500	2.430	0.035	71.4286	0.2710	0.9214	0.2059	0.1647	0.8716
	2.402	0.049	51.0204	0.3773	1.2827	0.2834	0.2268	0.8667
	2.370	0.065	38.4615	0.4972	1.6904	0.3688	0.2950	0.8612
	2.334	0.083	30.1205	0.6302	2.1426	0.4608	0.3686	0.8550
	2.282	0.109	22.9358	0.8188	2.7834	0.5863	0.4690	0.8462
	2.232	0.134	18.6567	0.9960	3.3881	0.8992	0.5594	0.8378
	2.170	0.165	15.1515	1.2104	4.1148	0.8290	0.6632	0.8276
	2.126	0.187	13.3690	1.3588	4.6195	0.9147	0.7317	0.8204
2.750	2.652	0.049	56.1224	0.4158	1.4135	0.3793	0.2758	0.9551
	2.620	0.065	42.3077	0.5483	1.8640	0.4944	0.3595	0.9496
	2.584	0.083	33.1325	0.6954	2.3642	0.6189	0.4501	0.9434
	2.532	0.109	25.2294	0.9044	3.0745	0.7898	0.5744	0.9345
	2.482	0.134	20.5224	1.1013	3.7439	0.9445	0.6869	0.9261
	2.420	0.165	16.6667	1.3400	4.5554	1.1238	0.8173	0.9158
	2.376	0.187	14.7059	1.5057	5.1188	1.2429	0.9040	0.9086
	2.250	0.250	11.0000	1.9635	6.6751	1.5493	1.1268	0.8883

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Table 42—Round Tubing (Continued)

OUTSIDE DIA. (D) IN.	INSIDE DIA. (d) IN.	WALL THICKNESS (t) IN.	RATIO OD TO WALL THICKNESS (D/t)	AREA (A) SQ. IN.	WEIGHT LB./FT.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.
3.000	2.902	0.049	61.2245	0.4543	1.5443	0.4946	0.3298	1.0435
	2.870	0.085	46.1538	0.5993	2.0375	0.6457	0.4304	1.0379
	2.834	0.083	36.1446	0.7606	2.5858	0.8097	0.5398	1.0317
	2.782	0.109	27.5229	0.9900	3.3655	1.0357	0.6905	1.0228
	2.732	0.134	22.3881	1.2065	4.1016	1.2415	0.8277	1.0144
	2.670	0.185	18.1818	1.4696	4.9959	1.4814	0.9876	1.0040
	2.626	0.187	16.0428	1.6526	5.6181	1.6418	1.0945	0.9967
	2.500	0.250	12.0000	2.1598	7.3426	2.0586	1.3724	0.9763
3.250	3.152	0.049	66.3265	0.4928	1.6752	0.6313	0.3885	1.1319
	3.120	0.065	50.0000	0.6504	2.2111	0.8251	0.5077	1.1263
	3.084	0.083	39.1566	0.8258	2.8074	1.0360	0.6376	1.1201
	3.032	0.109	29.8165	1.0758	3.6566	1.3280	0.8173	1.1112
	2.982	0.134	24.2537	1.3118	4.4594	1.5950	0.9815	1.1027
	2.920	0.165	19.6970	1.5991	5.4365	1.9079	1.1741	1.0923
	2.876	0.187	17.3797	1.7994	6.1174	2.1182	1.3035	1.0850
	2.750	0.250	13.0000	2.3562	8.0101	2.6691	1.6425	1.0643
3.500	3.402	0.049	71.4266	0.5312	1.8060	0.7910	0.4520	1.2202
	3.370	0.065	53.8482	0.7014	2.3846	1.0349	0.5914	1.2147
	3.334	0.083	42.1687	0.8910	3.0290	1.3012	0.7435	1.2084
	3.282	0.109	32.1101	1.1612	3.9476	1.6708	0.9547	1.1995
	3.232	0.134	28.1194	1.4170	4.8172	2.0100	1.1486	1.1910
	3.170	0.165	21.2121	1.7287	5.8770	2.4093	1.3767	1.1805
	3.126	0.187	18.7166	1.9463	6.8167	2.6788	1.5308	1.1732
	3.000	0.250	14.0000	2.5525	8.8776	3.3901	1.9372	1.1524
	2.750	0.375	9.3333	3.6816	12.5158	4.5588	2.6050	1.1128
3.750	3.652	0.049	76.5306	0.5697	1.9368	0.9756	1.3086	1.3086
	3.820	0.065	57.8923	0.7525	2.5582	1.2777	0.6814	1.3030
	3.584	0.083	45.1607	0.9562	3.2506	1.6080	0.8576	1.2968
	3.532	0.109	34.4037	1.2468	4.2386	2.0879	1.1029	1.2879
	3.482	0.134	27.9851	1.5222	5.1750	2.4914	1.3288	1.2793
	3.420	0.165	22.7273	1.8583	6.3176	2.9918	1.5958	1.2688
	3.376	0.187	20.0535	2.0932	7.1160	3.3308	1.7764	1.2614
	3.250	0.250	15.0000	2.7489	9.3451	4.2307	2.2564	1.2406
	3.000	0.375	10.0000	3.9761	13.5171	5.7311	3.0566	1.2006
4.000	3.902	0.049	81.6327	0.6082	2.0677	1.1870	0.5935	1.3970
	3.870	0.065	61.5385	0.8035	2.7317	1.5557	0.7778	1.3914
	3.834	0.083	48.1928	1.0214	3.4722	1.9597	0.9799	1.3852
	3.782	0.109	36.6972	1.3324	4.5297	2.5235	1.2618	1.3762
	3.732	0.134	29.8507	1.6275	5.5328	3.0442	1.5221	1.3677
	3.670	0.165	24.2424	1.9879	6,7581	3.6614	1.8307	1.3571
	3.626	0.187	21.3904	2.2401	7.6153	4.0808	2.0404	1.3497
	3.500	0.250	16.0000	2.9452	10.0126	5.2002	2.6001	1.3288
	3.250	0.375	10.8667	4.2706	14.5183	7.0899	3.5449	1.2885
4.500	4.370	0.049	89.2308	0.9056	3.0788	2.2271	0.9898	1.5682
	4.334	0.083	54.2169	1.1517	3.9155	2.8098	1.2488	1.5619
	4.282	0.109	41.2844	1.5036	5.1117	3.6261	1.6116	1.5529
	4.232	0.134	33.5821	1.8380	6.2484	4.3835	1.9482	1.5443
	4.170	0.165	27.2727	2.2471	7.6392	5.2862	2.3494	1.5338
	4.126	0.187	24.0642	2.5338	8.6139	5.9028	2.6234	1.5263
	4.000	0.250	18.0000	3.3379	11.3477	7.5625	3.3811	1.5052
	3.750	0.375	12.0000	4.8596	16.5209	10.4217	4.6319	1.4644
	3.624	0.438	10.2740	5.5894	19.0017	11.6620	5.1831	1.4445
	3.500	0.500	9.0000	6.2832	21.3603	12.7627	5.6723	1.4252

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Table 42—Round Tubing (Continued)

OUTSIDE DIA. (D) IN.	INSIDE DIA. (d) IN.	WALL THICKNESS (t) IN.	RATIO OD TO WALL THICKNESS (D/t)	AREA (A) SQ. IN.	WEIGHT LB./FT.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.
5.000	4.902	0.049	102.0408	0.7621	2.5910	2.3355	0.9342	1.7505
	4.870	0.065	76.9231	1.0077	3.4259	3.0684	1.2274	1.7449
	4.834	0.083	60.2410	1.2821	4.3587	3.8758	1.5503	1.7387
	4.782	0.109	45.8716	1.8748	5.8938	5.0107	2.0043	1.7297
	4.732	0.134	37.3134	2.0485	6.9639	6.0675	2.4270	1.7210
	4.670	0.165	30.3030	2.5063	8.5204	7.3323	2.9329	1.7104
	4.626	0.187	26.7380	2.8275	9.6125	8.1998	3.2799	1.7029
	4.500	0.250	20.0000	3.7306	12.6827	10.5507	4.2203	1.6817
	4.250	0.375	13.3333	5.4487	18.5234	14.6647	5.8659	1.8406
	4.124	0.438	11.4155	6.2774	21.3406	16.4810	8.5924	1.6203
	4.000	0.500	10.0000	7.0686	24.0303	18.1132	7.2453	1.6008
5.500	5.370	0.065	84.6154	1.1098	3.7730	4.0986	1.4904	1.9217
	5.334	0.083	66.2651	1.4125	4.8019	5.1822	1.8844	1.9154
	5.282	0.109	50.4587	1.8461	6.2759	6.7092	2.4397	1.9064
	5.232	0.134	41.0448	2.2589	7.6795	8.1356	2.9584	1.8978
	5.170	0.165	33.3333	2.7655	9.4015	9.8483	3.5812	1.8871
	5.126	0.187	29.4118	3.1213	10.6111	11.0270	4.0098	1.8796
	5.000	0.250	22.0000	4.1233	14.0177	14.2384	5.1776	1.8583
	4.750	0.375	14.6667	6.0377	20.5259	19.9293	7.2470	1.8168
	4.624	0.438	12.5571	6.9654	23.8796	22.4771	8.1735	1.7964
	4.500	0.500	11.0000	7.8540	26.7004	24.7891	9.0142	1.7766
	4.250	0.625	8.6000	9.5720	32.5411	28.9030	10.5102	1.7377
6.000	5.870	0.065	92.3077	1.2119	4.1201	5.3369	1.7790	2.0985
	5.834	0.083	72.2892	1.5429	5.2451	6.7535	2.2512	2.0922
	5.782	0.109	55.0459	2.0173	6.8579	8.7539	2.9180	2.0831
	5.732	0.134	44.7761	2.4694	8.3951	10.6272	3.5424	2.0745
	5.670	0.165	36.3636	3.0246	10.2826	12.8829	4.2943	2.0638
	5.626	0.187	32.0856	3.4150	11.6097	14.4395	4.8132	2.0563
	5.500	0.250	24.0000	4.5160	15.3527	18.6992	6.2331	2.0349
	5.250	0.375	16.0000	6.6288	22.5284	26.3260	8.7753	1.9932
	5.124	0.438	13.6986	7.6534	26.0185	29.7791	9.9264	1.9726
	5.000	0.500	12.0000	8.6394	29.3704	32.9376	10.9792	1.9526
	4.750	0.825	9.6000	10.5538	35.8786	38.6285	12.8782	1.9132
6.625	6.295	0.165	40.1515	3.3486	11.3840	17.4793	5.2768	2.2847
	6.251	0.187	35.4278	3.7822	12.8579	19.6119	5.9206	2.2771
	6.125	0.250	26.5000	5.0069	17.0215	25.4746	7.6904	2.2556
	5.875	0.375	17.6667	7.3631	25.0316	36.0821	10.8927	2.2137
	5.749	0.438	15.1256	8.5134	28.9422	40.9397	12.3592	2.1929
	5.625	0.500	13.2500	9.6211	32.7080	45.4184	13.7112	2.1727
	5.375	0.625	10.6000	11.7810	40.0506	53.5896	16.1780	2.1328
7.000	6.834	0.083	84.3373	1.8036	6.1316	10.7883	3.0824	2.4457
	6.782	0.109	64.2202	2.3597	8.0221	14.0101	4.0029	2.4366
	6.732	0.134	52.2388	2.8904	9.8262	17.0389	4.8683	2.4280
	6.670	0.165	42.4242	3.5430	12.0448	20.7020	5.9149	2.4172
	6.626	0.187	37.4332	4.0025	13.6068	23.2404	6.6401	2.4097
	6.500	0.250	28.0000	5.3014	18.0228	30.2347	8.6385	2.3881
7.500	7.000	0.250	30.0000	5.6941	19.3578	37.4567	9.9885	2.5648
	6.750	0.375	20.0000	8.3939	28.5360	53.4130	14.2435	2.5226
	8.624	0.438	17.1233	9.7174	33.0354	60.8113	18.2163	2.5016
	6.500	0.500	15.0000	10.9956	37.3805	87.8914	18.0511	2.4812
	6.250	0.625	12.0000	13.4990	45.8913	80.4141	21.4438	2.4407
8.000	7.834	0.083	96.3855	2.0644	7.0180	16.1759	4.0440	2.7992
	7.782	0.109	73.3945	2.7021	9.1862	21.0361	5.2590	2.7902
	7.732	0.134	59.7015	3.3114	11.2573	25.6184	6.4046	2.7815
	7.670	0.165	48.4848	4.0614	13.8070	31.1783	7.7948	2.7707
	7.826	0.187	42.7807	4.5900	15.6040	35.0432	8.7608	2.7631
	7.500	0.250	32.0000	6.0868	20.6928	45.7463	11.4366	2.7415

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Table 43—Square Tubing

DIMENSIONS INCHES		WALL THICKNESS (t)	AREA (A)		MOM. OF INERTIA	SECTION MODULUS	RADIUS OF GYRATION
OUTSIDE (D,)	INSIDE (d)	IN.	SQ. IN.	WEIGHT LB./FT.	(I) IN.	(S) IN.	(r) IN.
0.375	0.305	0.035	0.0458	0.1558	0.0009	0.0046	0.1378
	0.277	0.049	0.0607	0.2064	0.0011	0.0056	0.1321
	0.245	0.065	0.0746	0.2537	0.0012	0.0062	0.1253
0.500	0.430	0.035	0.0633	0.2153	0.0023	0.0090	0.1887
	0.402	0.049	0.0852	0.2896	0.0029	0.0114	0.1829
	0.370	0.065	0.1071	0.3642	0.0033	0.0133	0.1760
	0.334	0.083	0.1299	0.4415	0.0037	0.0149	0.1692
0.625	0.555	0.035	0.0808	0.2748	0.0046	0.0149	0.2397
	0.527	0.049	0.1097	0.3729	0.0060	0.0192	0.2339
	0.495	0.065	0.1396	0.4747	0.0072	0.0230	0.2269
	0.459	0.083	0.1714	0.5826	0.0083	0.0265	0.2199
0.750	0.680	0.035	0.0983	0.3343	0.0083	0.0222	0.2907
	0.652	0.049	0.1342	0.4562	0.0109	0.0290	0.2848
	0.620	0.065	0.1721	0.5852	0.0133	0.0354	0.2778
	0.584	0.083	0.2129	0.7237	0.0156	0.0416	0.2707
	0.532	0.109	0.2590	0.8804	0.0172	0.0458	0.2577
0.875	0.805	0.035	0.1158	0.3938	0.0135	0.0309	0.3418
	0.777	0.049	0.1587	0.5395	0.0179	0.0409	0.3358
	0.745	0.065	0.2046	0.6957	0.0221	0.0506	0.3288
	0.709	0.083	0.2544	0.8648	0.0263	0.0601	0.3215
	0.857	0.109	0.3135	1.0657	0.0298	0.0682	0.3086
1.000	0.930	0.035	0.1333	0.4533	0.0206	0.0411	0.3928
	0.902	0.049	0.1832	0.6228	0.0274	0.0548	0.3868
	0.870	0.065	0.2371	0.8062	0.0342	0.0684	0.3797
	0.834	0.083	0.2959	1.0059	0.0410	0.0821	0.3725
	0.782	0.109	0.3680	1.2509	0.0476	0.0951	0.3595
1.125	1.055	0.035	0.1508	0.5128	0.0297	0.0528	0.4438
	1.027	0.049	0.2077	0.7061	0.0398	0.0708	0.4378
	0.995	0.065	0.2696	0.9167	0.0500	0.0889	0.4307
	0.959	0.083	0.3374	1.1470	0.0605	0.1075	0.4234
	0.907	0.109	0.4225	1.4362	0.0712	0.1265	0.4105
	0.857	0.134	0.4983	1.6871	0.0787	0.1398	0.3981
1.250	1.180	0.035	0.1683	0.5723	0.0412	0.0659	0.4948
	1.152	0.049	0.2322	0.7894	0.0555	0.0888	0.4888
	1.120	0.065	0.3021	1.0272	0.0701	0.1122	0.4817
	1.084	0.083	0.3789	1.2880	0.0853	0.1364	0.4744
	1.032	0.109	0.4770	1.6215	0.1016	0.1625	0.4615
	0.982	0.134	0.5633	1.9148	0.1136	0.1818	0.4491
1.375	1.305	0.035	0.1858	0.6318	0.0554	0.0805	0.5458
	1.277	0.049	0.2567	0.8727	0.0748	0.1088	0.5398
	1.245	0.065	0.3346	1.1376	0.0950	0.1381	0.5327
	1.209	0.083	0.4204	1.4291	0.1160	0.1888	0.5253
	1.157	0.109	0.5315	1.8068	0.1396	0.2030	0.5124
	1.107	0.134	0.6303	2.1426	0.1577	0.2293	0.5002
1.500	1.430	0.035	0.2033	0.6913	0.0724	0.0966	0.5969
	1.402	0.049	0.2812	0.9560	0.0982	0.1309	0.5908
	1.370	0.065	0.3671	1.2481	0.1251	0.1668	0.5837
	1.334	0.083	0.4619	1.5702	0.1534	0.2046	0.5763
	1.282	0.109	0.5860	1.9921	0.1860	0.2480	0.5634
	1.232	0.134	0.6973	2.3704	0.2118	0.2824	0.5512
	1.170	0.165	0.7982	2.7137	0.2226	0.2967	0.5280

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Table 43—Square Tubing (Continued)

DIMENSIONS INCHES OUTSIDE (D,)	INSIDE (d)	WALL THICKNESS (t) IN.	AREA (A) SQ. IN.	WEIGHT LB./FT.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.
1.625	1.555	0.035	0.2208	0.7507	0.0927	0.1141	0.6479
	1.527	0.049	0.3057	1.0393	0.1259	0.1550	0.6419
	1.495	0.065	1.3996	1.3586	0.1610	0.1982	0.6347
	1.459	0.083	0.5034	1.7113	0.1981	0.2438	0.6273
	1.407	0.109	0.6405	2.1773	0.2418	0.2976	0.6144
	1.357	0.134	0.7643	2.5982	0.2772	0.3411	0.6022
	1.295	0.165	0.8807	2.9942	0.2957	0.3640	0.5794
1.750	1.680	0.035	0.2383	0.8102	0.1164	0.1331	0.6989
	1.652	0.049	0.3302	1.1225	0.1585	0.1812	0.6929
	1.620	0.065	0.4321	1.4691	0.2032	0.2323	0.6858
	1.584	0.083	0.5449	1.8524	0.2507	0.2865	0.6783
	1.532	0.109	0.6950	2.3626	0.3077	0.3517	0.6654
	1.482	0.134	0.8313	2.8259	0.3547	0.4054	0.6532
	1.420	0.165	0.9632	3.2746	0.3833	0.4380	0.6308
1.875	1.805	0.035	0.2558	0.8697	0.1439	0.1535	0.7499
	1.777	0.049	0.3547	1.2058	0.1963	0.2094	0.7439
	1.745	0.065	0.4646	1.5796	0.2522	0.2690	0.7368
	1.709	0.083	0.5864	1.9935	0.3119	0.3327	0.7293
	1.657	0.109	0.7495	2.5479	0.3847	0.4104	0.7165
	1.607	0.134	0.8983	3.0537	0.4455	0.4752	0.7042
	1.545	0.165	1.0457	3.5551	0.4866	0.5190	0.6821
2.000	1.902	0.049	0.3792	1.2891	0.2396	0.2396	0.7949
	1.870	0.065	0.4971	1.6901	0.3085	0.3085	0.7878
	1.834	0.083	0.6279	2.1345	0.3823	0.3823	0.7803
	1.782	0.109	0.8040	2.7332	0.4735	0.4735	0.7675
	1.732	0.134	0.9653	3.2815	0.5506	0.5506	0.7553
	1.670	0.165	1.1282	3.8356	0.6068	0.6068	0.7334
	1.626	0.187	1.2657	4.3030	0.6670	0.6670	0.7259
2.125	2.027	0.049	0.4037	1.3724	0.2889	0.2719	0.8460
	1.995	0.065	0.5296	1.8006	0.3727	0.3507	0.8388
	1.959	0.083	0.6694	2.2756	0.4626	0.4354	0.8313
	1.907	0.109	0.8585	2.9184	0.5751	0.5413	0.8185
	1.857	0.134	1.0323	3.5093	0.6711	0.6316	0.8063
	1.795	0.165	1.2107	4.1160	0.7453	0.7015	0.7846
2.250	2.152	0.049	0.4282	1.4557	0.3445	0.3062	0.8970
	2.120	0.065	0.5621	1.9111	0.4451	0.3957	0.8898
	2.084	0.083	0.7109	2.4167	0.5534	0.4920	0.8823
	2.032	0.109	0.9130	3.1037	0.6902	0.6135	0.8695
	1.982	0.134	1.0993	3.7370	0.8079	0.7182	0.8573
	1.920	0.165	1.2932	4.3965	0.9034	0.8030	0.8358
2.500	2.402	0.049	0.4772	1.6223	0.4763	0.3810	0.9990
	2.370	0.065	0.6271	2.1320	0.6170	0.4936	0.9919
	2.334	0.083	0.7939	2.6989	0.7693	0.6154	0.9844
	2.282	0.109	1.0220	3.4743	0.9646	0.7717	0.9715
	2.232	0.134	1.2333	4.1926	1.1351	0.9081	0.9594
	2.170	0.165	1.4582	4.9574	1.2835	1.0268	0.9382
	2.126	0.187	1.6397	5.5745	1.4197	1.1357	0.9305
	2.000	0.250	2.0890	7.1019	1.6899	1.3519	0.8994
3.000	2.902	0.049	0.5752	1.9554	0.8326	0.5551	1.2031
	2.870	0.065	0.7571	2.5740	1.0830	0.7220	1.1960
	2.834	0.083	0.9599	3.2632	1.3558	0.9038	1.1885
	2.782	0.109	1.2400	4.2154	1.7137	1.1425	1.1756
	2.732	0.134	1.5013	5.1037	2.0322	1.3548	1.1635
	2.670	0.165	1.7882	6.0793	2.3351	1.5567	1.1427
	2.626	0.187	2.0137	6.8459	2.5936	1.7291	1.1349
	2.500	0.250	2.5890	8.8017	3.1559	2.1039	1.1041

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Teble 43—Square Tubing (Continued)

DIMENSIONS INCHES OUTSIDE (D_t)	INSIDE (d)	WALL THICKNESS (t) IN.	AREA (A) SQ. IN.	WEIGHT LB./FT.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.
3.500	3.370	0.065	0.8871	3.0159	1.7390	0.9937	1.4001
	3.334	0.083	1.1047	3.7557	2.1184	1.2105	1.3848
	3.282	0.109	1.4419	4.9019	2.7265	1.5580	1.3751
	3.232	0.134	1.7441	5.9293	3.2322	1.8469	1.3613
	3.170	0.165	2.1182	7.2012	3.8441	2.1966	1.3471
	3.126	0.187	2.3877	8.1174	4.2822	2.4470	1.3392
	3.000	0.250	3.0890	10.5015	5.2893	3.0225	1.3085
4.000	3.870	0.065	1.0171	3.4579	2.6176	1.3088	1.6042
	3.834	0.083	1.2707	4.3200	3.2086	1.6043	1.5890
	3.782	0.109	1.6599	5.6430	4.1402	2.0701	1.5793
	3.732	0.134	2.0121	6.8404	4.9321	2.4660	1.5858
	3.670	0.165	2.4482	8.3230	5.8930	2.9465	1.5515
	3.626	0.187	2.7617	9.3888	6.5791	3.2896	1.5434
	3.500	0.250	3.5890	12.2013	8.2151	4.1076	1.5129
5.000	4.670	0.165	3.1082	10.5668	11.9406	4.7762	1.9600
	4.626	0.187	3.5097	11.9317	13.3716	5.3488	1.9519
	4.500	0.250	4.5890	15.6009	16.9439	6.7776	1.9215
6.000	5.670	0.165	3.7682	12.8105	21.1378	7.0459	2.3684
	5.626	0.187	4.2577	14.4746	23.7190	7.9063	2.3603
	5.500	0.250	5.5890	19.0005	30.3422	10.1141	2.3300

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

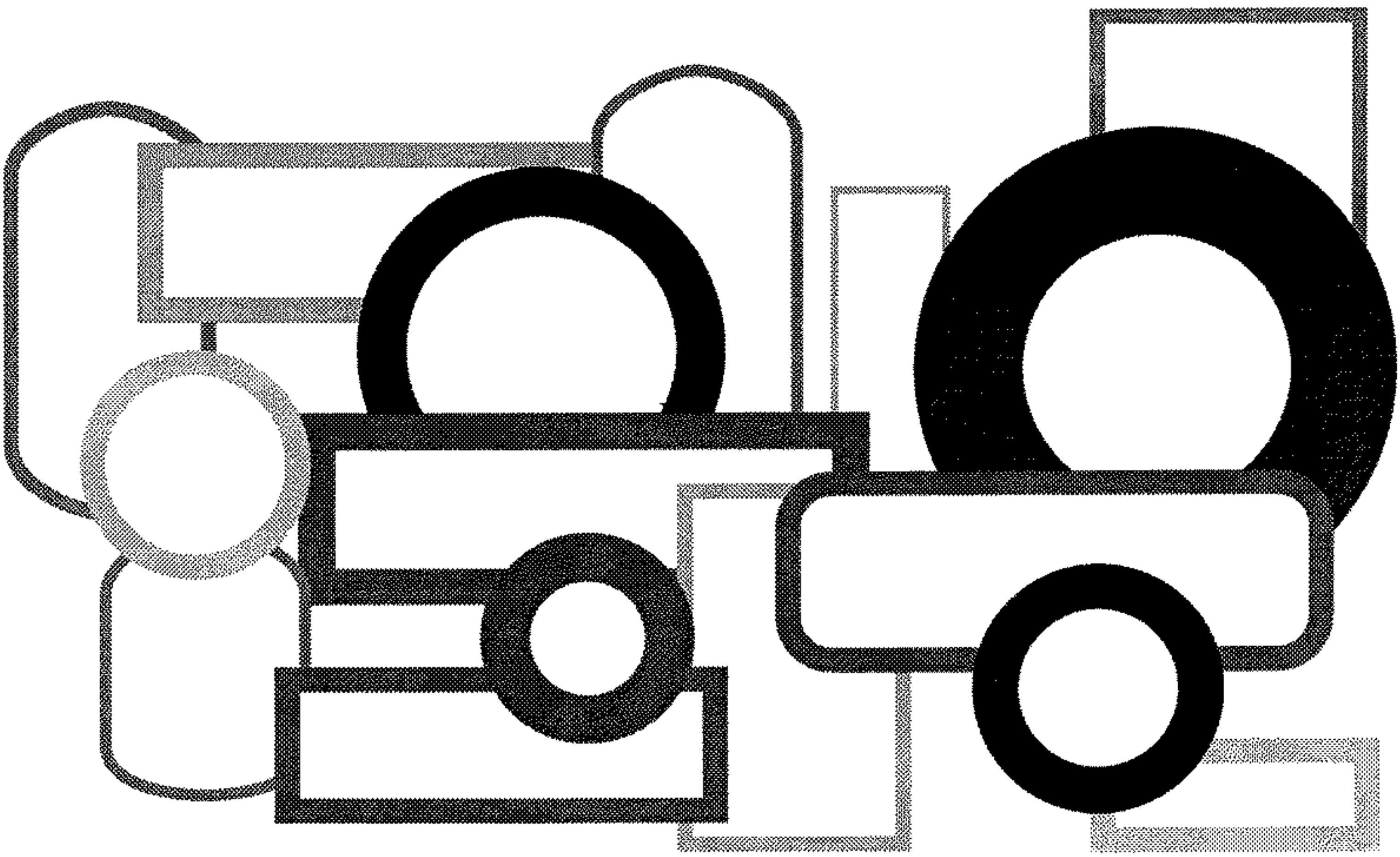


Table 44—Rectangular Tubing

SIZE INCHES	WALL THICKNESS (t) INCH	AREA (A) SQ. IN.	WEIGHT LB./FT.	MAJOR AXIS (X-X) MOM. OF INERTIA (I) IN.	MAJOR AXIS (X-X) SECTION MODULUS (S) IN.	MAJOR AXIS (X-X) RADIUS OF GYRATION (r) IN.	MINOR AXIS (Y-Y) MOM. OF INERTIA (I) IN.	MINOR AXIS (Y-Y) SECTION MODULUS (S) IN.	MINOR AXIS (Y-Y) RADIUS OF GYRATION (r) IN.
0.375 x 0.625	0.035	0.0633	0.2153	0.0031	0.0100	0.2223	0.0014	0.0074	0.1485
	0.049	0.0852	0.2896	0.0040	0.0128	0.2163	0.0018	0.0094	0.1439
	0.065	0.1071	0.3642	0.0047	0.0150	0.2089	0.0021	0.0110	0.1389
	0.083	0.1299	0.4415	0.0053	0.0169	0.2019	0.0024	0.0126	0.1347
0.375 x 0.750	0.035	0.0721	0.2451	0.0050	0.0132	0.2624	0.0017	0.0068	0.1515
	0.049	0.0974	0.3313	0.0064	0.0170	0.2560	0.0021	0.0112	0.1469
	0.065	0.1234	0.4195	0.0076	0.0203	0.2481	0.0025	0.0133	0.1421
0.375 x 1.000	0.035	0.0896	0.3045	0.0104	0.0208	0.3405	0.0022	0.0116	0.1557
	0.049	0.1219	0.4146	0.0136	0.0271	0.3336	0.0028	0.0148	0.1511
	0.065	0.1559	0.5300	0.0165	0.0329	0.3249	0.0033	0.0178	0.1464
	0.083	0.1921	0.6532	0.0193	0.0385	0.3168	0.0039	0.0208	0.1425
0.375 x 1.125	0.035	0.0983	0.3343	0.0141	0.0251	0.3789	0.0024	0.0130	0.1572
	0.049	0.1342	0.4582	0.0185	0.0330	0.3718	0.0031	0.0167	0.1526
	0.065	0.1721	0.5852	0.0226	0.0403	0.3627	0.0038	0.0201	0.1479
	0.083	0.2129	0.7237	0.0287	0.0475	0.3541	0.0044	0.0235	0.1440
0.375 x 1.500	0.035	0.1246	0.4235	0.0302	0.0402	0.4922	0.0032	0.0171	0.1604
	0.049	0.1709	0.5812	0.0401	0.0535	0.4846	0.0041	0.0221	0.1557
	0.065	0.2209	0.7509	0.0498	0.0664	0.4748	0.0050	0.0269	0.1511
	0.083	0.2751	0.9353	0.0596	0.0795	0.4656	0.0060	0.0318	0.1471
	0.109	0.3407	1.1583	0.0672	0.0896	0.4441	0.0069	0.0368	0.1424
0.375 x 2.625	0.035	0.2033	0.6913	0.1383	0.1054	0.8248	0.0055	0.0295	0.1649
	0.049	0.2812	0.9560	0.1874	0.1428	0.8163	0.0072	0.0384	0.1601
	0.065	0.3671	1.2481	0.2382	0.1815	0.8054	0.0089	0.0473	0.1554
	0.083	0.4619	1.5702	0.2921	0.2225	0.7952	0.0106	0.0564	0.1513
	0.109	0.5860	1.9921	0.3489	0.2658	0.7716	0.0127	0.0677	0.1472
	0.134	0.6973	2.3704	0.3910	0.2979	0.7488	0.0148	0.0791	0.1458
0.500 x 0.750	0.035	0.0808	0.2748	0.0061	0.0162	0.2744	0.0032	0.0129	0.1998
	0.049	0.1097	0.3729	0.0079	0.0211	0.2685	0.0042	0.0167	0.1948
	0.065	0.1396	0.4747	0.0095	0.0254	0.2613	0.0050	0.0200	0.1892
	0.083	0.1714	0.5826	0.0111	0.0296	0.2545	0.0058	0.0232	0.1841
0.500 x 1.000	0.035	0.0983	0.3343	0.0124	0.0249	0.3556	0.0042	0.0167	0.2063
	0.049	0.1342	0.4562	0.0164	0.0327	0.3491	0.0054	0.0218	0.2013
	0.065	0.1721	0.5652	0.0200	0.0401	0.3412	0.0066	0.0264	0.1959
	0.083	0.2129	0.7237	0.0237	0.0474	0.3336	0.0078	0.0310	0.1908
	0.109	0.2590	0.8804	0.0260	0.0520	0.3169	0.0086	0.0346	0.1828
0.500 x 1.250	0.035	0.1158	0.3938	0.0218	0.0350	0.4343	0.0051	0.0206	0.2107
	0.049	0.1587	0.5395	0.0290	0.0464	0.4275	0.0067	0.0269	0.2057
	0.065	0.2046	0.6957	0.0359	0.0575	0.4190	0.0082	0.0329	0.2003
	0.083	0.2544	0.8648	0.0429	0.0687	0.4108	0.0097	0.0388	0.1953
	0.109	0.3135	1.0657	0.0484	0.0774	0.3928	0.0111	0.0442	0.1878
0.500 x 1.500	0.035	0.1333	0.4533	0.0349	0.0485	0.5115	0.0061	0.0244	0.2139
	0.049	0.1832	0.6228	0.0466	0.0621	0.5044	0.0080	0.0320	0.2088
	0.065	0.2371	0.8062	0.0582	0.0778	0.4954	0.0098	0.0393	0.2035
	0.083	0.2959	1.0059	0.0701	0.0935	0.4869	0.0116	0.0466	0.1984
	0.109	0.3680	1.2509	0.0805	0.1074	0.4678	0.0135	0.0539	0.1913
0.500 x 2.000	0.035	0.1683	0.5723	0.0740	0.0740	0.5630	0.0080	0.0320	0.2182
	0.049	0.2322	0.7894	0.0997	0.0997	0.6554	0.0105	0.0422	0.2130
	0.065	0.3021	1.0272	0.1260	0.1260	0.6458	0.0130	0.0521	0.2077
	0.083	0.3789	1.2880	0.1536	0.1536	0.6366	0.0155	0.0622	0.2025
0.625 x 1.000	0.035	0.1071	0.3640	0.0145	0.0289	0.3677	0.0070	0.0223	0.2550
	0.049	0.1464	0.4979	0.0191	0.0383	0.3615	0.0091	0.0292	0.2498
	0.065	0.1884	0.6405	0.0236	0.0473	0.3541	0.0112	0.0359	0.2440
	0.063	0.2336	0.7942	0.0281	0.0562	0.3470	0.0133	0.0425	0.2383
	0.109	0.2862	0.9730	0.0318	0.0631	0.3321	0.0150	0.0480	0.2289

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Table 44—Rectangular Tubing (Continued)

				MAJOR AXIS (X-X)			MINOR AXIS (Y-Y)		
SIZE INCNES	WALL TNICKNESS (t) INCN	AREA (A) SO. IN.	WEIGHT LB./FT.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.
0.625 x	0.035	0.1421	0.4830	0.0398	0.0528	0.5278	0.0100	0.0321	0.2657
1.500	0.049	0.1954	0.6644	0.0531	0.0708	0.5211	0.0133	0.0424	0.2605
	0.065	0.2534	0.8614	0.0666	0.0888	0.5127	0.0165	0.0526	0.2548
	0.083	0.3166	1.0764	0.0806	0.1075	0.5046	0.0197	0.0629	0.2491
	0.109	0.3952	1.3438	0.0939	0.1252	0.4874	0.0229	0.0733	0.2407
	0.134	0.4628	1.5732	0.1025	0.1366	0.4705	0.0252	0.0807	0.2334
0.625 x	0.035	0.1771	0.6020	0.0825	0.0825	0.8824	0.0131	0.0419	0.2720
2.000	0.049	0.2444	0.8310	0.1114	0.1114	0.6751	0.0174	0.0556	0.2667
	0.065	0.3184	1.0824	0.1413	0.1413	0.6661	0.0217	0.0694	0.2810
	0.083	0.3996	1.3586	0.1727	0.1727	0.6574	0.0260	0.0833	0.2552
	0.109	0.5042	1.7141	0.2056	0.2056	0.6386	0.0308	0.0986	0.2471
	0.134	0.5968	2.0287	0.2297	0.2297	0.6204	0.0345	0.1104	0.2404
0.750 x	0.035	0.1158	0.3938	0.0165	0.0330	0.3776	0.0106	0.0282	0.3023
1.000	0.049	0.1587	0.5395	0.0219	0.0439	0.3717	0.0140	0.0373	0.2969
	0.065	0.2046	0.6957	0.0272	0.0544	0.3647	0.0173	0.0461	0.2907
	0.083	0.2544	0.8648	0.0326	0.0651	0.3578	0.0206	0.0550	0.2847
0.750 x	0.035	0.1333	0.4533	0.0283	0.0453	0.4608	0.0128	0.0342	0.3102
1.250	0.049	0.1832	0.6228	0.0379	0.0606	0.4546	0.0170	0.0454	0.3049
	0.065	0.2371	0.8062	0.0474	0.0758	0.4471	0.0212	0.0585	0.2989
0.750 x	0.035	0.1508	0.5128	0.0443	0.0590	0.5418	0.0151	0.0402	0.3162
1.500	0.049	0.2077	0.7061	0.0595	0.0794	0.5354	0.0201	0.0535	0.3108
	0.065	0.2696	0.9167	0.0750	0.1000	0.5274	0.0251	0.0668	0.3049
	0.083	0.3374	1.1470	0.0911	0.1215	0.5197	0.0301	0.0804	0.2989
	0.109	0.4225	1.4362	0.1072	0.1430	0.5038	0.0354	0.0944	0.2895
	0.134	0.4963	1.6871	0.1184	0.1578	0.4884	0.0392	0.1046	0.2812
0.750 x	0.035	0.1858	0.6318	0.0909	0.0909	0.6994	0.0196	0.0522	0.3245
2.000	0.049	0.2567	0.8727	0.1231	0.1231	0.6925	0.0261	0.0697	0.3191
	0.085	0.3346	1.1376	0.1565	0.1565	0.6639	0.0328	0.0875	0.3132
	0.083	0.4204	1.4291	0.1918	0.1918	0.6755	0.0396	0.1057	0.3071
	0.109	0.5315	1.8068	0.2301	0.2301	0.6580	0.0473	0.1260	0.2982
0.875 x 1.000	0.065	0.2209	0.7509	0.0308	0.0616	0.3734	0.0250	0.0571	0.3363
1.000 x	0.035	0.1508	0.5128	0.0348	0.0557	0.4802	0.0247	0.0494	0.4046
1.260	0.049	0.2077	0.7061	0.0467	0.0748	0.4743	0.0331	0.0661	0.3990
	0.065	0.2696	0.9167	0.0589	0.0942	0.4673	0.0416	0.0831	0.3926
	0.083	0.3374	1.1470	0.0715	0.1144	0.4603	0.0503	0.1006	0.3861
	0.109	0.4225	1.4362	0.0845	0.1352	0.4472	0.0594	0.1188	0.3750
	0.134	0.4963	1.6871	0.0938	0.1501	0.4347	0.0660	0.1320	0.3647
1.000 x	0.035	0.1683	0.5723	0.0537	0.0716	0.5847	0.0288	0.0575	0.4134
1.500	0.049	0.2322	0.7894	0.0725	0.0966	0.5586	0.0386	0.0773	0.4079
	0.065	0.3021	1.0272	0.0918	0.1224	0.5512	0.0487	0.0975	0.4018
	0.083	0.3789	1.2880	0.1121	0.1494	0.5439	0.0592	0.1183	0.3951
	0.109	0.4770	1.6215	0.1339	0.1786	0.5299	0.0706	0.1411	0.3846
	0.134	0.5633	1.9148	0.1602	0.2003	0.5165	0.0792	0.1583	0.3749
1.000 x	0.035	0.2033	0.8913	0.1078	0.1078	0.7282	0.0369	0.0739	0.4262
2.000	0.049	0.2812	0.9560	0.1464	0.1484	0.7216	0.0498	0.0995	0.4207
	0.065	0.3871	1.2481	0.1870	0.1870	0.7137	0.0631	0.1261	0.4145
	0.083	0.4619	1.5702	0.2301	0.2301	0.7058	0.0769	0.1538	0.4080
	0.109	0.5860	1.9921	0.2792	0.2792	0.6902	0.0928	0.1857	0.3981
	0.134	0.6973	2.3704	0.3180	0.3180	0.6754	0.1055	0.2110	0.3890
1.000 x	0.035	0.2383	0.8102	0.1874	0.1499	0.8866	0.0451	0.0902	0.4351
2.500	0.049	0.3302	1.1225	0.2556	0.2045	0.8798	0.0609	0.1218	0.4295
	0.065	0.4321	1.4691	0.3281	0.2625	0.8713	0.0774	0.1548	0.4233
	0.083	0.5449	1.8524	0.4058	0.3247	0.8630	0.0946	0.1893	0.4167
	0.109	0.6950	2.3626	0.4977	0.3981	0.8462	0.1151	0.2303	0.4070
	0.134	0.8313	2.8259	0.5730	0.4584	0.8303	0.1318	0.2637	0.3982
	0.185	0.9632	3.2746	0.6086	0.4869	0.7949	0.1422	0.2844	0.3842

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Table 44—Rectangular Tubing (Continued)

SIZE INCHES	WALL THICKNESS (t) INCH	AREA (A) SO. IN.	WEIGHT LB./FT.	MAJOR AXIS (X-X) MOM. OF INERTIA (I) IN.	MAJOR AXIS (X-X) SECTION MODULUS (S) IN.	MAJOR AXIS (X-X) RAOIUS OF GYRATION (r) IN.	MINOR AXIS (Y-Y) MOM. OF INERTIA (I) IN.	MINOR AXIS (Y-Y) SECTION MODULUS (S) IN.	MINOR AXIS (Y-Y) RADIUS OF GYRATION (r) IN.
1.000 x 3.000	0.049	0.3792	1.2891	0.4060	0.2706	1.0347	0.0720	0.1441	0.4359
	0.065	0.4971	1.6901	0.5232	0.3488	1.0258	0.0918	0.1835	0.4296
	0.083	0.6279	2.1345	0.6497	0.4331	1.0172	0.1124	0.2247	0.4230
	0.109	0.8040	2.7332	0.8030	0.5354	0.9994	0.1374	0.2748	0.4134
	0.134	0.9653	3.2815	0.9319	0.6212	0.9826	0.1582	0.3163	0.4048
	0.165	1.1282	3.8356	1.0083	0.6722	0.9454	0.1732	0.3464	0.3918
1.000 x 3.500	0.049	0.4282	1.4557	0.6038	0.3450	1.1875	0.0832	0.1664	0.4408
	0.065	0.5621	1.9111	0.7804	0.4460	1.1783	0.1061	0.2122	0.4344
	0.083	0.7109	2.4167	0.9721	0.5555	1.1694	0.1301	0.2602	0.4278
	0.109	0.9130	3.1037	1.2089	0.6908	1.1507	0.1597	0.3194	0.4182
	0.134	1.0993	3.7370	1.4114	0.8065	1.1331	0.1845	0.3690	0.4097
	0.165	1.2932	4.3965	1.5492	0.8852	1.0945	0.2042	0.4084	0.3974
1.125 x 2.000	0.035	0.2121	0.7210	0.1163	0.1163	0.7404	0.0480	0.0853	0.4756
	0.049	0.2934	0.9976	0.1581	0.1581	0.7340	0.0648	0.1153	0.4700
	0.065	0.3834	1.3034	0.2022	0.2022	0.7263	0.0824	0.1466	0.4637
	0.083	0.4826	1.6407	0.2492	0.2492	0.7186	0.1008	0.1793	0.4571
	0.109	0.6132	2.0847	0.3037	0.3037	0.7037	0.1224	0.2176	0.4468
	0.134	0.7308	2.4843	0.3475	0.3475	0.6896	0.1397	0.2484	0.4373
	0.165	0.8395	2.8539	0.3645	0.3645	0.6589	0.1485	0.2640	0.4206
1.250 x 1.500	0.035	0.1858	0.6318	0.0631	0.0841	0.5826	0.0477	0.0764	0.5068
	0.049	0.2567	0.8727	0.0854	0.1138	0.5767	0.0645	0.1031	0.5011
	0.065	0.3346	1.1376	0.1086	0.1448	0.5697	0.0818	0.1309	0.4945
	0.083	0.4204	1.4291	0.1331	0.1774	0.5626	0.1000	0.1600	0.4878
	0.109	0.5315	1.8068	0.1606	0.2141	0.5497	0.1206	0.1930	0.4764
	0.134	0.6303	2.1426	0.1821	0.2428	0.5375	0.1367	0.2187	0.4657
1.250 x 1.750	0.035	0.2033	0.6913	0.0907	0.1037	0.6680	0.0542	0.0867	0.5163
	0.049	0.2812	0.9560	0.1232	0.1408	0.6619	0.0733	0.1173	0.5106
	0.065	0.3671	1.2481	0.1573	0.1798	0.6546	0.0933	0.1493	0.5042
	0.083	0.4619	1.5702	0.1935	0.2211	0.6472	0.1143	0.1829	0.4975
	0.109	0.5860	1.9921	0.2353	0.2689	0.6336	0.1387	0.2219	0.4865
	0.134	0.6973	2.3704	0.2686	0.3070	0.6207	0.1582	0.2531	0.4763
1.250 x 2.000	0.035	0.2208	0.7507	0.1247	0.1247	0.7515	0.0607	0.0971	0.5241
	0.049	0.3057	1.0393	0.1698	0.1698	0.7452	0.0822	0.1315	0.5185
	0.065	0.3996	1.3586	0.2175	0.2175	0.7377	0.1048	0.1677	0.5121
	0.083	0.5034	1.7113	0.2684	0.2684	0.7302	0.1286	0.2057	0.5054
	0.109	0.6405	2.1773	0.3282	0.3282	0.7159	0.1567	0.2508	0.4947
	0.134	0.7643	2.5982	0.3770	0.3770	0.7023	0.1796	0.2874	0.4848
	0.165	0.8807	2.9942	0.3998	0.3998	0.6737	0.1924	0.3078	0.4674
1.250 x 2.500	0.049	0.3547	1.2058	0.2924	0.2339	0.9079	0.0999	0.1599	0.5307
	0.065	0.4646	1.5796	0.3763	0.3011	0.9000	0.1277	0.2044	0.5244
	0.083	0.5864	1.9935	0.4666	0.3733	0.8920	0.1571	0.2514	0.5176
	0.109	0.7495	2.5479	0.5759	0.4607	0.8766	0.1929	0.3086	0.5073
	0.134	0.8983	3.0537	0.6674	0.5339	0.8620	0.2226	0.3561	0.4978
	0.165	1.0457	3.5551	0.7221	0.5777	0.8310	0.2432	0.3891	0.4822
1.250 x 3.000	0.049	0.4037	1.3724	0.4593	0.3062	1.0667	0.1176	0.1882	0.5398
	0.065	0.5296	1.8006	0.5932	0.3955	1.0583	0.1507	0.2411	0.5334
	0.083	0.6694	2.2756	0.7381	0.4921	1.0501	0.1857	0.2971	0.5267
	0.109	0.8585	2.9184	0.9172	0.6115	1.0337	0.2290	0.3664	0.5165
	0.134	1.0323	3.5093	1.0700	0.7134	1.0181	0.2655	0.4248	0.5071
	0.165	1.2107	4.1160	1.1752	0.7835	0.9852	0.2940	0.4704	0.4928
1.375 x 2.250	0.049	0.3424	1.1642	0.2408	0.2140	0.8385	0.1127	0.1640	0.5737
	0.065	0.4484	1.5243	0.3096	0.2752	0.8309	0.1443	0.2099	0.5673
	0.083	0.5656	1.9229	0.3834	0.3408	0.8233	0.1777	0.2585	0.5605
	0.109	0.7222	2.4552	0.4726	0.4201	0.8089	0.2183	0.3175	0.5497
	0.134	0.8648	2.9398	0.5470	0.4862	0.7953	0.2519	0.3665	0.5398
	0.165	1.0045	3.4149	0.5913	0.5256	0.7672	0.2745	0.3992	0.5227
1.375 x 2.500	0.083	0.6071	2.0640	0.4970	0.3976	0.9047	0.1952	0.2839	0.5670

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Table 44—Rectangular Tubing (Continued)

SIZE INCHES	WALL THICKNESS (t) INCH	AREA (A) SQ. IN.	WEIGHT LB./FT.	MAJOR AXIS (X-X) MOM. OF INERTIA (I) IN.	MAJOR AXIS (X-X) SECTION MODULUS (S) IN.	MAJOR AXIS (X-X) RADIUS OF GYRATION (r) IN.	MINOR AXIS (Y-Y) MOM. OF INERTIA (I) IN.	MINOR AXIS (Y-Y) SECTION MODULUS (S) IN.	MINOR AXIS (Y-Y) RADIUS OF GYRATION (r) IN.
1.500 x 2.000	0.049	0.3302	1.1225	0.1931	0.1931	0.7648	0.1242	0.1655	0.6132
	0.065	0.4321	1.4691	0.2480	0.2480	0.7575	0.1590	0.2120	0.6066
	0.083	0.5449	1.8524	0.3068	0.3066	0.7502	0.1960	0.2613	0.5997
	0.109	0.6950	2.3626	0.3773	0.3773	0.7368	0.2407	0.3209	0.5885
	0.134	0.8313	2.8259	0.4359	0.4359	0.7241	0.2777	0.3702	0.5780
	0.165	0.9632	3.2746	0.4703	0.4703	0.6988	0.3011	0.4015	0.5591
1.500 x 2.500	0.049	0.3792	1.2891	0.3292	0.2634	0.9318	0.1500	0.2000	0.6289
	0.065	0.4971	1.6901	0.4246	0.3396	0.9241	0.1926	0.2568	0.6224
	0.083	0.6279	2.1345	0.5274	0.4219	0.9165	0.2379	0.3172	0.6156
	0.109	0.8040	2.7332	0.6541	0.5233	0.9020	0.2940	0.3920	0.6048
	0.134	0.9653	3.2815	0.7617	0.6094	0.8883	0.3414	0.4552	0.5947
	0.165	1.1282	3.8356	0.8357	0.6686	0.8607	0.3769	0.5025	0.5780
1.500 x 3.000	0.049	0.4282	1.4557	0.5127	0.3418	1.0942	0.1759	0.2345	0.6408
	0.065	0.5621	1.9111	0.6633	0.4422	1.0862	0.2262	0.3016	0.6343
	0.083	0.7109	2.4167	0.8266	0.5510	1.0783	0.2799	0.3732	0.6275
	0.109	0.9130	3.1037	1.0314	0.6876	1.0629	0.3474	0.4632	0.6169
	0.134	1.0993	3.7370	1.2082	0.8055	1.0484	0.4051	0.5401	0.6071
	0.165	1.2932	4.3965	1.3421	0.8948	1.0187	0.4527	0.6035	0.5916
	0.187	1.4527	4.9388	1.4862	0.9908	1.0115	0.4977	0.6636	0.5853
1.500 x 3.600	0.065	0.6271	2.1320	0.9723	0.5556	1.2451	0.2598	0.3464	0.6436
	0.083	0.7939	2.6989	1.2146	0.6941	1.2369	0.3218	0.4291	0.6367
	0.109	1.0220	3.4743	1.5229	0.8702	1.2207	0.4008	0.5344	0.6262
	0.134	1.2333	4.1926	1.7921	1.0241	1.2055	0.4688	0.6251	0.6166
	0.165	1.4582	4.9574	2.0102	1.1487	1.1741	0.5284	0.7046	0.6020
	0.187	1.6397	5.5745	2.2316	1.2752	1.1666	0.5816	0.7754	0.5955
1.600 x 4.000	0.065	0.6921	2.3530	1.3597	0.6798	1.4016	0.2934	0.3912	0.6511
	0.083	0.8769	2.9810	1.7019	0.8510	1.3932	0.3638	0.4850	0.6441
	0.109	1.1310	3.8448	2.1421	1.0710	1.3762	0.4542	0.6055	0.6337
	0.134	1.3673	4.6481	2.5302	1.2651	1.3604	0.5325	0.7100	0.6241
	0.165	1.6232	5.5184	2.8605	1.4303	1.3275	0.6042	0.8056	0.6101
	0.187	1.8267	6.2102	3.1820	1.5910	1.3198	0.6654	0.8872	0.6035
	0.250	2.3390	7.9518	3.8206	1.9103	1.2780	0.7938	1.0584	0.5825
1.750 x 3.000	0.049	0.4527	1.5390	0.5661	0.3774	1.1182	0.2474	0.2828	0.7393
	0.065	0.5946	2.0215	0.7334	0.4889	1.1105	0.3193	0.3649	0.7327
	0.083	0.7524	2.5578	0.9150	0.6100	1.1028	0.3963	0.4529	0.7258
	0.109	0.9675	3.2890	1.1456	0.7638	1.0882	0.4944	0.5650	0.7148
	0.134	1.1663	3.9648	1.3464	0.8976	1.0745	0.5790	0.6618	0.7046
	0.165	1.3757	4.6770	1.5090	1.0060	1.0473	0.6517	0.7448	0.6883
2.000 x 3.000	0.065	0.6271	2.1320	0.8034	0.5356	1.1318	0.4309	0.4309	0.8289
	0.083	0.7939	2.6989	1.0034	0.6689	1.1242	0.5363	0.5363	0.8219
	0.109	1.0220	3.4743	1.2598	0.8399	1.1103	0.6715	0.6715	0.8106
	0.134	1.2333	4.1926	1.4846	0.9897	1.0972	0.7894	0.7894	0.8001
	0.165	1.4582	4.9574	1.6759	1.1173	1.0720	0.8938	0.8938	0.7829
	0.187	1.6397	5.5745	1.8594	1.2396	1.0649	0.9876	0.9876	0.7761
2.000 x 3.500	0.065	0.6921	2.3530	1.1642	0.6632	1.2969	0.4919	0.4919	0.8430
	0.083	0.8769	2.9810	1.4572	0.8327	1.2891	0.6128	0.6128	0.8360
	0.109	1.1310	3.8448	1.8369	1.0496	1.2744	0.7696	0.7696	0.8249
	0.134	1.3673	4.6481	2.1729	1.2417	1.2607	0.9073	0.9073	0.8146
	0.165	1.6232	5.5184	2.4712	1.4121	1.2339	1.0349	1.0349	0.7985
	0.187	1.8267	6.2102	2.7480	1.5703	1.2265	1.1446	1.1446	0.7916
	0.260	2.3390	7.9518	3.3180	1.8960	1.1910	1.3769	1.3769	0.7672
2.000 x 4.000	0.065	0.7571	2.5740	1.6114	0.8057	1.4589	0.5529	0.5529	0.8545
	0.083	0.9599	3.2632	2.0206	1.0103	1.4509	0.6893	0.6893	0.8474
	0.109	1.2400	4.2154	2.5553	1.2776	1.4355	0.8677	0.8677	0.8365
	0.134	1.5013	5.1037	3.0321	1.5160	1.4212	1.0251	1.0251	0.8263
	0.165	1.7882	6.0793	3.4695	1.7347	1.3929	1.1761	1.1761	0.8110
	0.187	2.0137	6.8459	3.8650	1.9325	1.3854	1.3015	1.3015	0.8039

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Table 44—Rectangular Tubing (Continued)

				MAJOR AXIS (X-X)			MINOR AXIS (Y-Y)		
SIZE INCHES	WALL THICKNESS (t) INCH	AREA (A) SQ. IN.	WEIGHT LB./FT.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.
2.000 x 5.000	0.065	0.8871	3.0159	2.7980	1.1192	1.7759	0.6748	0.6748	0.8722
	0.083	1.1047	3.7557	3.3852	1.3541	1.7505	0.8211	0.8211	0.8621
	0.109	1.4419	4.9019	4.3705	1.7482	1.7410	1.0478	1.0478	0.8525
	0.134	1.7441	5.9293	5.1727	2.0691	1.7222	1.2354	1.2354	0.8416
	0.165	2.1182	7.2012	6.1571	2.4629	1.7049	1.4583	1.4583	0.8297
2.000 x 5.500	0.065	0.9521	3.2369	3.5536	1.2922	1.9319	0.7358	0.7358	0.8791
	0.083	1.1877	4.0378	4.3118	1.5679	1.9053	0.8976	0.8976	0.8693
	0.109	1.5509	5.2724	5.5737	2.0268	1.8958	1.1459	1.1459	0.8596
	0.134	1.8781	6.3848	6.6121	2.4044	1.8763	1.3533	1.3533	0.8489
	0.165	2.2832	7.7621	7.8878	2.8683	1.8587	1.5995	1.5995	0.8370
	0.187	2.5747	8.7531	8.8196	3.2071	1.8508	1.7723	1.7723	0.8297
	0.250	3.3390	11.3514	10.9421	3.9790	1.8103	2.1738	2.1738	0.8069
2.000 x 6.000	0.083	1.2707	4.3200	5.3870	1.7957	2.0590	0.9742	0.9742	0.8758
	0.109	1.6599	5.6430	8.9708	2.3236	2.0493	1.2440	1.2440	0.8657
	0.134	2.0121	6.8404	8.2863	2.7621	2.0293	1.4711	1.4711	0.8551
	0.165	2.4482	8.3230	9.9039	3.3013	2.0113	1.7406	1.7406	0.8432
	0.187	2.7617	9.3888	11.0837	3.6916	2.0033	1.9293	1.9293	0.8358
	0.250	3.5890	12.2013	13.8135	4.6045	1.9618	2.3730	2.3730	0.8131
2.250 x 4.000	0.065	0.7896	2.6845	1.7373	0.8687	1.4833	0.7176	0.6379	0.9533
	0.083	1.0014	3.4043	2.1799	1.0899	1.4754	0.8965	0.7969	0.9462
	0.109	1.2945	4.4007	2.7619	1.3810	1.4607	1.1318	1.0060	0.9350
	0.134	1.5883	5.3314	3.2830	1.6415	1.4469	1.3408	1.1918	0.9246
	0.165	1.8707	6.3598	3.7739	1.8870	1.4203	1.5445	1.3729	0.9086
	0.187	2.1072	7.1638	4.2065	2.1032	1.4129	1.7125	1.5222	0.9015
2.500 x 3.000	0.065	0.6921	2.3530	0.9435	0.6290	1.1676	0.7140	0.5712	1.0157
	0.083	0.8769	2.9810	1.1802	0.7868	1.1602	0.8919	0.7135	1.0085
	0.109	1.1310	3.8448	1.4882	0.9922	1.1471	1.1234	0.8987	0.9966
	0.134	1.3673	4.6481	1.7610	1.1740	1.1349	1.3279	1.0624	0.9855
	0.165	1.6232	5.5184	2.0097	1.3398	1.1127	1.5172	1.2137	0.9668
	0.187	1.8267	6.2102	2.2326	1.4884	1.1055	1.6826	1.3461	0.9597
2.500 x 3.500	0.065	0.7571	2.5740	1.3560	0.7749	1.3383	0.8105	0.6484	1.0346
	0.083	0.9599	3.2632	1.6997	0.9713	1.3307	1.0134	0.8107	1.0275
	0.109	1.2400	4.2154	2.1509	1.2291	1.3170	1.2798	1.0239	1.0159
	0.134	1.5013	5.1037	2.5537	1.4592	1.3042	1.5167	1.2133	1.0051
	0.165	1.7882	6.0793	2.9323	1.6756	1.2805	1.7443	1.3955	0.9878
	0.187	2.0137	6.8459	3.2644	1.8654	1.2732	1.9360	1.5488	0.9805
	0.250	2.5890	8.8017	3.9859	2.2777	1.2408	2.3578	1.8863	0.9543
2.500 x 4.000	0.065	0.8221	2.7950	1.8632	0.9318	1.5054	0.9070	0.7256	1.0503
	0.083	1.0429	3.5454	2.3392	1.1696	1.4977	1.1349	0.9079	1.0432
	0.109	1.3329	4.5313	2.9044	1.4522	1.4761	1.4112	1.1290	1.0290
	0.134	1.6101	5.4737	3.4331	1.7165	1.4602	1.6658	1.3327	1.0172
	0.165	1.9532	8.6402	4.0784	2.0392	1.4450	1.9715	1.5772	1.0047
	0.187	2.2007	7.4817	4.5479	2.2740	1.4375	2.1893	1.7515	0.9974
	0.250	2.8390	9.6516	5.5940	2.7970	1.4037	2.8820	2.1456	0.9720
2.500 x 5.000	0.065	0.9521	3.2369	3.1939	1.2776	1.8315	1.1000	0.8800	1.0748
	0.083	1.1877	4.0378	3.8871	1.5548	1.8091	1.3446	1.0757	1.0640
	0.109	1.5509	5.2724	5.0230	2.0092	1.7997	1.7241	1.3793	1.0544
	0.134	1.8781	6.3848	5.9671	2.3869	1.7825	2.0433	1.6347	1.0431
	0.165	2.2832	7.7621	7.1237	2.8495	1.7663	2.4258	1.9406	1.0307
	0.187	2.5747	8.7531	7.9636	3.1854	1.7587	2.6961	2.1569	1.0233
	0.250	3.3390	11.3514	9.9081	3.9624	1.7224	3.3305	2.6644	0.9987
2.500 x 6.000	0.065	1.0821	3.6788	5.0007	1.6669	2.1497	1.2929	1.0344	1.0931
	0.083	1.3537	4.6022	6.1138	2.0379	2.1251	1.5877	1.2701	1.0830
	0.109	1.7889	6.0135	7.9171	2.6390	2.1156	2.0369	1.8295	1.0731
	0.134	2.1461	7.2959	9.4402	3.1467	2.0973	2.4208	1.9366	1.0621
	0.165	2.6132	8.8840	11.3106	3.7702	2.0804	2.8801	2.3041	1.0498
	0.187	2.9487	10.0246	12.6667	4.2222	2.0726	3.2029	2.5623	1.0422
	0.250	3.8390	13.0512	15.8877	5.2959	2.0343	3.9789	3.1831	1.0181

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

				MAJOR AXIS (X-X)			MINOR AXIS (Y-Y)		
SIZE INCHES	WALL THICKNESS (t) INCH	AREA (A) SQ. IN.	WEIGHT LB./FT.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.	MOM. OF INERTIA (I) IN.	SECTION MODULUS (S) IN.	RADIUS OF GYRATION (r) IN.
3.000 x 4.000	0.065	0.8871	3.0159	2.1149	1.0575	1.5440	1.3639	0.9093	1.2399
	0.083	1.1047	3.7557	2.5730	1.2865	1.5261	1.6630	1.1086	1.2269
	0.109	1.4419	4.9019	3.3176	1.6588	1.5169	2.1374	1.4249	1.2175
	0.134	1.7441	5.9293	3.9350	1.9675	1.5021	2.5332	1.6888	1.2052
	0.185	2.1182	7.2012	4.6873	2.3436	1.4876	3.0110	2.0074	1.1923
	0.187	2.3877	8.1174	5.2309	2.6155	1.4801	3.3522	2.2348	1.1849
	0.250	3.0890	10.5015	6.4808	3.2404	1.4484	4.1429	2.7619	1.1581
3.000 x 4.500	0.065	0.9521	3.2389	2.7929	1.2413	1.7127	1.5040	1.0027	1.2568
	0.083	1.1877	4.0378	3.4068	1.5141	1.6936	1.8398	1.2265	1.2446
	0.109	1.5509	5.2724	4.3996	1.9554	1.6843	2.3658	1.5772	1.2351
	0.134	1.8781	6.3848	5.2309	2.3248	1.6689	2.8096	1.8731	1.2231
	0.165	2.2832	7.7621	6.2461	2.7760	1.6540	3.3448	2.2299	1.2103
	0.187	2.5747	8.7531	6.9794	3.1020	1.6464	3.7254	2.4836	1.2029
	0.250	3.3390	11.3514	8.6937	3.8639	1.6136	4.6233	3.0822	1.1767
3.000 x 5.000	0.065	1.0171	3.4579	3.5898	1.4359	1.8786	1.6441	1.0961	1.2714
	0.083	1.2707	4.3200	4.3891	1.7556	1.8585	2.0167	1.3444	1.2598
	0.109	1.6599	5.6430	5.6755	2.2702	1.8491	2.5942	1.7294	1.2501
	0.134	2.0121	6.8404	6.7615	2.7046	1.8331	3.0860	2.0573	1.2384
	0.165	2.4482	8.3230	8.0902	3.2361	1.8178	3.8786	2.4524	1.2258
	0.187	2.7617	9.3888	9.0498	3.6199	1.8102	4.0986	2.7324	1.2182
	0.250	3.5890	12.2013	11.3241	4.5296	1.7763	5.1038	3.4025	1.1925
3.000 x 6.000	0.065	1.1471	3.8998	5.5733	1.8578	2.2042	1.9244	1.2829	1.2952
	0.083	1.4367	4.8843	6.8405	2.2802	2.1820	2.3704	1.5802	1.2845
	0.109	1.8779	6.3841	8.8635	2.9545	2.1725	3.0510	2.0340	1.2746
	0.134	2.2801	7.7515	10.5942	3.5314	2.1555	3.6387	2.4258	1.2633
	0.165	2.7782	9.4449	12.7173	4.2391	2.1395	4.3482	2.8974	1.2507
	0.187	3.1357	10.6603	14.2497	4.7499	2.1317	4.8450	3.2300	1.2430
	0.250	4.0890	13.9011	17.9619	5.9873	2.0959	6.0648	4.0432	1.2179
4.000 x 5.000	0.065	1.1471	3.8998	4.3816	1.7526	1.9544	3.1220	1.5610	1.8497
	0.083	1.4367	4.8843	5.3930	2.1572	1.9374	3.8476	1.9238	1.6365
	0.109	1.8779	6.3841	6.9806	2.7922	1.9280	4.9704	2.4852	1.6269
	0.134	2.2801	7.7515	8.3504	3.3402	1.9137	5.9426	2.9713	1.6144
	0.165	2.7782	9.4449	10.0234	4.0093	1.8994	7.1230	3.5815	1.6012
	0.187	3.1357	10.6603	11.2223	4.4689	1.8918	7.9628	3.9814	1.5935
	0.250	4.0890	13.9011	14.1600	5.6640	1.8609	10.0276	5.0138	1.5660
4.000 x 5.250	0.065	1.1796	4.0103	4.9095	1.8703	2.0401	3.2478	1.6239	1.6593
	0.083	1.4782	5.0254	6.0477	2.3039	2.0227	4.0069	2.0035	1.8464
	0.109	1.9324	6.5694	7.8322	2.9837	2.0132	5.1770	2.5885	1.6368
	0.134	2.3471	7.9792	9.3762	3.5719	1.9987	6.1935	3.0968	1.6244
	0.165	2.8807	9.7254	11.2635	4.2909	1.9843	7.4274	3.7137	1.6113
	0.187	3.2292	10.9782	12.6183	4.8062	1.9766	8.3042	4.1521	1.6038
	0.250	4.2140	14.3261	15.9462	6.0747	1.9453	10.4710	5.2355	1.5763
4.000 x 6.000	0.165	3.1082	10.5668	15.5307	5.1769	2.2353	8.3406	4.1704	1.6381
	0.187	3.5097	11.9317	17.4156	5.8052	2.2276	9.3287	4.6643	1.8303
	0.250	4.5890	15.6009	22.1104	7.3701	2.1950	11.8011	5.9005	1.6036
4.000 x 8.000	0.165	3.7682	12.8105	31.3727	7.8432	2.8854	10.7785	5.3882	1.6911
	0.187	4.2577	14.4748	35.2540	8.8135	2.8775	12.0606	6.0303	1.6830
	0.250	5.5890	19.0005	45.1447	11.2862	2.8421	15.3479	7.6740	1.6571

These elements of sections are calculated using the formulae on p.28 and are based on the exact size shown and on corner radii as specified on p.28. Any variation in dimensions from those shown will affect the values calculated for these elements of sections.

Definition of Symbols

A —Area of cross section, $in.^2$

α —Angle of twist, radians

B —Outside dimension, short side across flat, in. (rectangle)

b —Width of section, in.

Bwg. —Birmingham Wire Gauge

C —Outside dimension, long side across flat, in. (rectangle)

c —Distance of extreme fiber from neutral axis, in.

D —Outside diameter, in.

D_1 —Outside dimension, square, across flat side, in.

d —Inside diameter, in.

Δ_x —Deflection of beam at distance x, in.

Δ max. —Maximum deflection of beam, in.

E —Modulus of elasticity; 29,500,000 psi. for steel

F_a —Maximum allowable average axial stress in compression, psi.

f —Bending stress, (+) for tension and (−) for compression, psi.

f_x —Maximum unit stress in beam section at distance x from origin, psi.

$$f_x = \frac{M_x c}{I} = \frac{M_x}{S}$$

f_y —Specified minimum yield point, psi.

G —Shear modulus of elasticity, psi. (approx. 12,000,000 psi. for steel)

I — Moment of inertia of area of cross section about the neutral axis, $in.^4$

I_p —Polar moment of inertia of area of cross section about axis through the center of gravity, $in.^4$

$I_{x\text{-}x}$ —Moment of inertia with axis parallel to short side, $in.^4$

$I_{y\text{-}y}$ —Moment of inertia with axis parallel to long side, $in.^4$

l —Length of beam span or unbraced length of column, in.

M —Bending moment, in.-lb.

M_1, M_2 —Bending moments at fixed ends, in.-lb.

M_x —Resisting bending moment at section distance x from origin, in.-lb.

N —Number of revolutions per minute

P —Force or concentrated load, lb.

p —Hydrostatic pressure, psi.

π —Ratio of circumference of a circle to its diameter, equals 3.1416...

Q —Form factor, i.e., stress and/or area factor used to modify beam and column loads

R —Outside corner radius, in.

R_1, R_2 —Reaction forces, lb.

r —Radius of gyration, in.

$r_{x\text{-}x}$ —Radius of gyration with axis parallel to short side, in.

$r_{y\text{-}y}$ —Radius of gyration with axis parallel to long side, in.

S —Section modulus, $in.^3$

S_1 —Fiber stress, psi.

S_p —Polar section modulus, $in.^3$

$S_{x\text{-}x}$ —Section modulus with axis parallel to short side, $in.^3$

$S_{y\text{-}y}$ —Section modulus with axis parallel to long side, $in.^3$

T —Applied torque, in.-lb.

t —Wall thickness, in.

τ —Shear stress, psi.

V —Maximum shear load, lb.

V_x —Shear load at section distance x from origin, lb.

v —Average shear stress in beam, psi.

W —Weight, lb./ft.

w —load per unit length, lb./in.

x —Distance from origin to section, in.

y —Distance from neutral axis to fiber, in.

c. Columns

The formulae which follow apply to carbon steel and are for the determination of the maximum allowable average axial stress in compression, F_a, or P/A, in which P is the working or service column load and A is the gross cross-sectional area of the column member.

The American Iron and Steel Institute Formulae:
The AISI column formulae are intended for design of structural members cold-formed to shape from sheet or strip steel. The 1968 Edition of the Specification for the Design of Cold-Formed Steel Structural Members provides the following formulae for columns, adapted to the symbols used herein:

For effective slenderness ratios, $\frac{KL}{r}$ less than $\frac{C_c}{\sqrt{Q}}$:

$$F_a = .522\,Qf_y - \left(\frac{Q\,f_y\,KL/r}{47250}\right)^2$$

For effective slenderness ratios, $\frac{KL}{r}$ equal to or greater than $\frac{C_c}{\sqrt{Q}}$:

$$F_a = \frac{151{,}900{,}000}{\left(\frac{KL}{r}\right)^2}$$

In the above,

$C_c = \sqrt{2\pi^2 E/f_y}$

K — effective length factor

The form factor, Q, can be taken as unity for cylindrical tubular members provided the mean diameter-to-thickness ratio does not exceed $3{,}300{,}000/f_y$. For cylindrical tubular members with a mean diameter-to-thickness ratio larger than $3{,}300{,}000/f_y$, but not greater than $13{,}000{,}000/f_y$, the allowable compression stress, F_a, shall not exceed:

$$\frac{662{,}000}{D/t - 1} + .399\,f_y$$

Square and rectangular tubular members should be checked for effectiveness of their full cross sections. Use of effective cross sectional properties in determining Q may become necessary. (See Sections 2.3 and 3.6 of the AISI Specification.)

d. Beams

Frequently used formulae
The formulae given below are frequently required in structural designing. They are included herein for the convenience of those engineers who have infrequent use for such formulae and hence may find reference necessary.

Flexural stress at extreme fiber:
$f = Mc/I = M/S$, in psi.
Flexural stress at any fiber:
$f = My/I$, in psi.
Average vertical shear (for maximum see below):
$v = V/A$, in psi.
Horizontal shearing stress at any section A-A:
$v = VQ/Ib$, in psi.

Q — moment of area about the neutral axis of the entire section of that portion of the cross-section lying outside of section A-A, in in.³

b — width at section A-A, in in.

(Intensity of vertical shear is equal to that of horizontal shear acting normal to it at the same point and both are usually a maximum at mid-height of beam.)

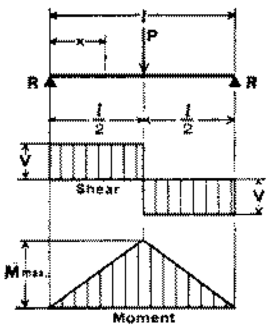
Slope and deflection at any point:

$$EI\frac{d^2y}{dx^2} = M$$

"x" and "y" are abscissa and ordinate respectively of a point on the neutral axis, referred to axes of rectangular coordinates through a selected point of support.

e. Beam Diagrams

1) Simple Beam/Concentrated Load at Center



$R = V \ldots\ldots = \frac{P}{2}$

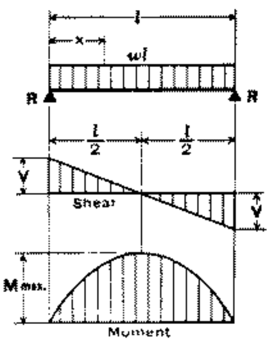
M max. (at point of load) $\ldots = \frac{Pl}{4}$

M_x (when $x < \frac{l}{2}$) $\ldots = \frac{Px}{2}$

Δmax. (at point of load) $\ldots = \frac{Pl^3}{48EI}$

Δ_x (when $x < \frac{l}{2}$) $\ldots = \frac{Px}{48EI}(3l^2 - 4x^2)$

2) Simple Beam/Uniformally Distributed Load



$R = V \ldots\ldots = \frac{wl}{2}$

$V_x \ldots\ldots = w\left(\frac{l}{2} - x\right)$

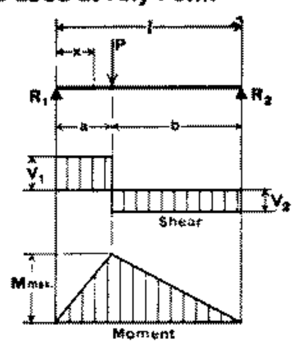
M max. (at center) $= \frac{wl^2}{8}$

$M_x \ldots\ldots = \frac{wx}{2}(l - x)$

Δmax. (at center) $. = \frac{5wl^4}{384\,EI}$

$\Delta x \ldots\ldots = \frac{wx}{24\,EI}(l^3 - 2lx^2 + x^3)$

3) Simple Beam/Concentrated Load at Any Point



$R_1 = V_1$ (max. when $a < b$) $\ldots = \frac{Pb}{l}$

$R_2 = V_2$ (max. when $a > b$) $\ldots = \frac{Pa}{l}$

M max. (at point of load) $\ldots = \frac{Pab}{l}$

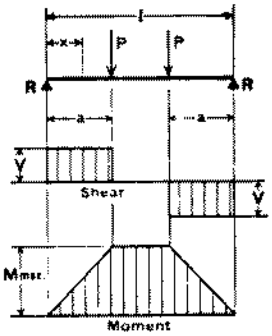
M_x (when $x < a$) $\ldots = \frac{Pbx}{l}$

Δmax. (at $x = \sqrt{\frac{a(a+2b)}{3}}$ when $a > b$) $= \frac{Pab\,(a+2b)\sqrt{3a\,(a+2b)}}{27\,EI\,l}$

Δa (at point of load) $\ldots = \frac{Pa^2b^2}{3EIl}$

Δx (when $x < a$) $\ldots = \frac{Pbx}{6EIl}(l^2 - b^2 - x^2)$

4) Simple Beam/Two Equal Concentrated Loads Symmetrically Placad



$R = V$ .... = P

M max. (between loads) ...... = Pa

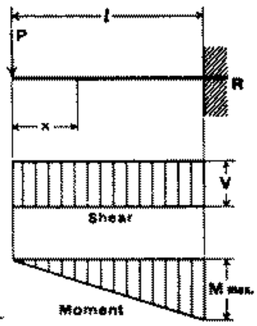
M_x (when $x < a$) .... = Px

Δmax. (at center) .... = $\frac{Pa}{24EI}(3l^2 - 4a^2)$

Δx (when $x < a$) .... = $\frac{Px}{6EI}(3la - 3a^2 - x^2)$

Δx (when $x > a$ and $< (l - a)$ .... = $\frac{Pa}{6EI}(3lx - 3x^2 - a^2)$

5) Cantilever Beem/Concentrated Load at Free End



$R = V$ .... = P

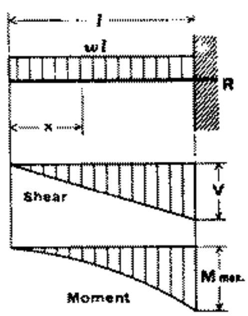
M max. (at fixed end) .... = Pl

M_x .... = Px

Δmax. (at free end) .... = $\frac{Pl^3}{3EI}$

Δ_x .... = $\frac{P}{6EI}(2l^3 - 3l^2x + x^3)$

6) Centilevar Beem / Uniformly Distributad Load



$R = V$ .... = wl

V_x .... = wx

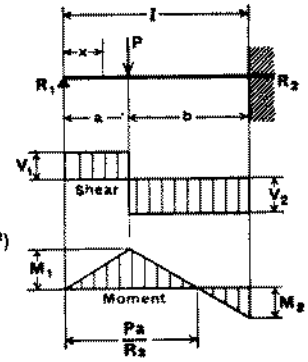
M max. (at fixed end) .... = $\frac{wl^2}{2}$

M_x .... = $\frac{wx^2}{2}$

Δmax. (at free end) .... = $\frac{wl^4}{8EI}$

Δ_x .... = $\frac{w}{24EI}(x^4 - 4l^3x + 3l^4)$

7) Beam Fixed et One End, Supported et Othar / Concentrated Loed at Any Point



$R_1 = V_1$ .... = $\frac{Pb^2}{2l^3}(a + 2l)$

$R_2 = V_2$ .... = $\frac{Pa}{2l^3}(3l^2 - a^2)$

M_1 (at point of load) = R_1a

M_2 (at fixed end) ... = $\frac{Pab}{2l^2}(a + l)$

M_x (when $x < a$) .... = R_1x

M_x (when $x > a$) .... = $R_1x - P(x - a)$

Δmax. $\left(\text{when } a < .414l \text{ at } x = l\frac{l^2 + a^2}{3l^2 - a^2}\right)$. = $\frac{Pa}{3EI}\frac{(l^2 - a^2)^3}{(3l^2 - a^2)^2}$

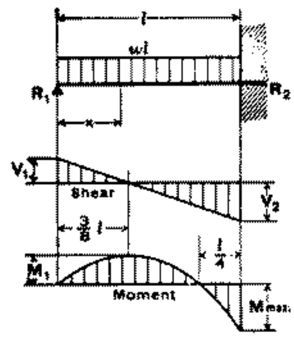
Δmax. $\left(\text{when } a > .414l \text{ at } x = l\sqrt{\frac{a}{2l + a}}\right)$ = $\frac{Pab^2}{6EI}\sqrt{\frac{a}{2l + a}}$

Δa (at point of load) .... = $\frac{Pa^2b^3}{12EIl^3}(3l + a)$

Δx (when $x < a$) .... = $\frac{Pb^2x}{12EIl^3}(3al^2 - 2lx^2 - ax^2)$

Δx (when $x > a$) .... = $\frac{Pa}{12EIl^3}(l\text{-}x)^2(3l^2x\text{-}a^2x\text{-}2a^2l)$

8) Beam Fixed at One End, Supported et Other / Uniformly Distributad Loed



$R_1 = V_1$ .... = $\frac{3wl}{8}$

$R_2 = V_2$ max. .... = $\frac{5wl}{8}$

V_x .... = $R_1 - wx$

M max. .... = $\frac{wl^2}{8}$

M_1 (at $x = \frac{3}{8}l$) .... = $\frac{9}{128}wl^2$

M_x .... = $R_1x - \frac{wx^2}{2}$

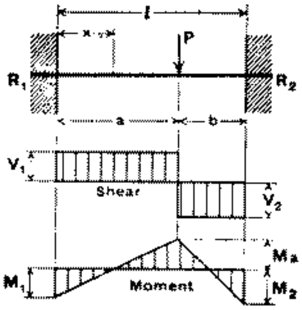
Δmax. $\left(\text{at } x = \frac{l}{16}(1 + \sqrt{33}) = .4215l\right)$ ..... = $\frac{wl^4}{185EI}$

Δx .... = $\frac{wx}{48EI}(l^3 - 3lx^2 + 2x^3)$

Beam Diagrams Courtesy of American Institute of Steel Construction, Inc.

Ref.: Manual of Steel Construction, Eighth Edition © 1980

9) Beam Fixed at Both Ends / Concantrated Load at Any Point



$R_1 = V_1$ (max. when a<b) .... $= \frac{Pb^2}{l^3}(3a + b)$

$R_2 = V_2$ (max. when a>b) .... $= \frac{Pa^2}{l^3}(a + 3b)$

M_1 (max. when a<b) .... $= \frac{Pab^2}{l^2}$

M_2 (max. when a>b) .... $= \frac{Pa^2b}{l^2}$

Ma (at point of load) .... $= \frac{2Pa^2b^2}{l^3}$

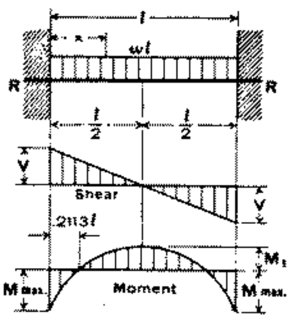
M_x (when x<a) .... $= R_1x - \frac{Pab^2}{l^2}$

Δmax. $\left(\text{when } a > b \text{ at } x = \frac{2al}{3a+b}\right)$ .... $= \frac{2Pa^3b^2}{3EI(3a + b)^2}$

Δa (at point of load) .... $= \frac{Pa^3b^3}{3EIl^3}$

Δx (when x<a) .... $= \frac{Pb^2x^2}{6EIl^3}(3al - 3ax - bx)$

10) Beam Fixed at Both Ends / Uniformly Distributed Loads



R = V .... $= \frac{wl}{2}$

V_x .... $= w\left(\frac{l}{2} - x\right)$

M max. (at ends) .... $= \frac{wl^2}{12}$

M_1 (at center) .... $= \frac{wl^2}{24}$

M_x .... $= \frac{w}{12}(6lx - l^2 - 6x^2)$

Δmax. (at center) .... $= \frac{wl^4}{384EI}$

Δx .... $= \frac{wx^2}{24EI}(l - x)^2$

f. Torsion

1) Torsional Stress

If a twisting moment is applied to a round tubular shaft with one end fixed, the fibers of the shaft are subjected to a shearing stress. The yield strength in shear due to torsion is usually assumed to be 57% of the yield strength measured in a tension test. The magnitude of the stress is given by

$$\tau = \frac{TD}{2I_p} = \frac{T}{S_p}$$

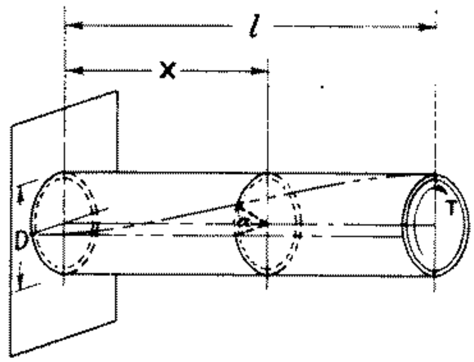
2) Angle of Twist

In the figure below, a round tubular shaft has a torque T applied throughout its length, l.

A section at distance x from the fixed end of the shaft is rotated through an angle which is proportional to the distance from the fixed end and the applied torque.

The angle α in radians is:

$$\alpha = \frac{Tx}{GI_p}$$



3) Torsional Moment and Power Transmitted by Round Tubular Shafts

For a given shearing stress the torque which a shaft can transmit is

$$T = \frac{2\tau I_p}{D} = \tau S_p$$

The relationship between torque and horsepower is

$$H.P. = \frac{2\pi NT}{12 \times 33000} \text{ or } H.P. = \frac{\pi N \tau I_p}{99000D}$$

which represents the horsepower a shaft of diameter D, turning N revolutions per minute can transmit if its shearing stress is τ pounds per square inch.

Table 45
Tubing Weights — Round Tubing Pound Weight Per Lineal Foot (Calculated) — Weight 1 Cubic Inch = .2833 Pound

O.D. Inches	.028″ Bwg[A] 22	.035″ Bwg. 20	.049″ Bwg. 18	.065″ Bwg. 16	.083″ Bwg. 14	.095″ Bwg. 13	.109″ Bwg. 12	.120″ Bwg. 11	.134″ Bwg. 10	.148″ Bwg. 9	.165″ Bwg. 8
1/4	.0664	.0804	.1052	.1284	....	....	....	....	....	....	....
3/8	.1038	.1271	.1706	.2152	.2588	....	....	....	....	....	....
1/2	.1411	.1738	.2360	.3020	.3696	....	....	....	....	....	....
5/8	.1785	.2205	.3014	.3888	.4805	.5377	....	....	....	....	....
3/4	.2159	.2673	.3668	.4755	.5913	.6646	.7462	.8074	....	....	....
7/8	.2533	.3140	.4323	.5623	.7021	.7914	.8917	.9676	....	....	....
1	.2907	.3607	.4977	.6491	.8129	.9182	1.0372	1.1278	1.2393	....	....
1 1/8	.3280	.4074	.5631	.7359	.9237	1.0450	1.1827	1.2880	1.4182	1.5443	....
1 1/4	.3654	.4542	.6285	.8226	1.0345	1.1719	1.3283	1.4482	1.5971	1.7419	1.9120
1 3/8	.4028	.5009	.6939	.9094	1.1453	1.2987	1.4738	1.6084	1.7760	1.9394	2.1323
1 1/2	.4402	.5476	.7593	.9962	1.2561	1.4255	1.6193	1.7686	1.9549	2.1370	2.3525
1 5/8	.4776	.5943	.8248	1.0830	1.3669	1.5523	1.7648	1.9288	2.1338	2.3346	2.5728
1 3/4	....	.6411	.8902	1.1697	1.4777	1.6792	1.9103	2.0890	2.3127	2.5322	2.7931
1 7/8	....	.6878	.9556	1.2565	1.5885	1.8060	2.0558	2.2492	2.4916	2.7298	3.0134
2	....	.7345	1.0210	1.3433	1.6993	1.9328	2.2014	2.4094	2.6705	2.9273	3.2336
2 1/8	....	.7812	1.0864	1.4301	1.8101	2.0596	2.3469	2.5696	2.8494	3.1249	3.4539
2 1/4	....	.8280	1.1518	1.5168	1.9209	2.1865	2.4924	2.7298	3.0282	3.3225	3.6742
2 3/8	....	.8747	1.2172	1.6036	2.0317	2.3133	2.6379	2.8900	3.2071	3.5201	3.8945
2 1/2	....	.9214	1.2827	1.6904	2.1425	2.4401	2.7834	3.0502	3.3860	3.7177	4.1147
2 5/8	....	.9681	1.3481	1.7772	2.2533	2.5669	2.9289	3.2104	3.5649	3.9152	4.3350
2 3/4	....	1.0149	1.4135	1.8639	2.3641	2.6938	3.0744	3.3706	3.7438	4.1128	4.5553
2 7/8	....	1.0616	1.4789	1.9507	2.4749	2.8206	3.2200	3.5308	3.9227	4.3104	4.7756
3	....	....	1.5443	2.0375	2.5857	2.9474	3.3655	3.6910	4.1018	4.5080	4.9958
3 1/8	....	....	1.6097	2.1243	2.6966	3.0742	3.5110	3.8512	4.2805	4.7056	5.2161
3 1/4	....	....	1.6751	2.2110	2.8074	3.2011	3.6565	4.0114	4.4594	4.9031	5.4364
3 3/8	....	....	1.7406	2.2978	2.9182	3.3279	3.8020	4.1716	4.6383	5.1007	5.6567
3 1/2	....	....	1.8060	2.3846	3.0290	3.4547	3.9475	4.3318	4.8171	5.2983	5.8769
3 5/8	....	....	1.8714	2.4714	3.1398	3.5815	4.0930	4.4920	4.9960	5.4959	6.0972
3 3/4	....	....	1.9368	2.5581	3.2506	3.7084	4.2386	4.6522	5.1749	5.8935	6.3175
3 7/8	....	....	2.0022	2.6449	3.3614	3.8352	4.3841	4.8124	5.3538	5.8910	6.5378
4	....	....	2.0676	2.7317	3.4722	3.9620	4.5296	4.9726	5.5327	6.0886	6.7580
4 1/8	....	....	....	2.8185	3.5830	4.0888	4.6751	5.1328	5.7116	8.2862	6.9783
4 1/4	....	....	....	2.9052	3.6938	4.2157	4.8206	5.2930	5.8905	6.4838	7.1986
4 3/8	....	....	....	2.9920	3.8046	4.3425	4.9661	5.4532	6.0694	6.6814	7.4189
4 1/2	....	....	....	3.0788	3.9154	4.4693	5.1117	5.6134	6.2483	6.8789	7.8391
4 5/8	....	....	....	3.1656	4.0262	4.5961	5.2572	5.7736	6.4272	7.0765	7.8594
4 3/4	....	....	....	3.2523	4.1370	4.7230	5.4027	5.9338	6.6060	7.2741	8.0797
4 7/8	....	....	....	3.3391	4.2478	4.8498	5.5482	6.0940	8.7849	7.4717	8.3000
5	....	....	....	3.4259	4.3586	4.9766	5.6937	6.2542	6.9638	7.6693	8.5202
5 1/4	....	....	....	....	....	....	....	6.5746	7.3216	8.0644	8.9608
5 1/2	....	....	....	3.7730	4.8018	5.4839	6.2758	6.8950	7.8794	8.4596	9.4013
5 3/4	....	....	....	3.9465	5.0235	5.7376	6.5688	7.2154	8.0372	8.8547	9.8419
6	....	....	....	4.1201	5.2451	5.9912	6.8578	7.5358	8.3949	9.2499	10.2824
6 1/4	....	....	....	....	....	....	....	....	8.7527	9.6451	10.7230
6 1/2	....	....	....	....	....	....	....	....	9.1105	10.0402	11.1635
6 3/4	....	....	....	....	....	....	....	....	....	....	11.6041
7	....	....	....	....	....	....	....	....	....	10.8305	12.0446
7 1/4	....	....	....	....	....	....	....	....	....	....	....
7 1/2	....	....	....	....	....	....	....	....	....	....	12.9257

The different grades of stainless steel permit considerable variations in weight. The ferritic stainless steels may be about 5% less, and the austenitic stainless steels about 2% greater than the values shown in this table, which are based on weights for carbon steel.

[A]Birmingham Wire Gauge.

Table 45—(Continued)
Round Tubing Pound Weight Per Lineal Foot (Calculeted) — Weight 1 Cubic Inch = .2833 Pound

O.D. Inches	.180" Bwg. 7	.203" Bwg. 8	.220" Bwg. 5	.238" Bwg. 4	.259" Bwg. 3	.264" Bwg. 2	.300" Bwg. 1	.320"	.340"	.360"	.375"
1/4	....	....	....	....	....	....	....	....	....	....	....
3/8	....	....	....	....	....	....	....	....	....	....	....
1/2	....	....	....	....	....	....	....	....	....	....	....
5/8	....	....	....	....	....	....	....	....	....	....	....
3/4	....	....	....	....	....	....	....	....	....	....	....
7/8	....	....	....	....	....	....	....	....	....	....	....
1	....	....	....	....	....	....	....	....	....	....	....
1 1/8	....	....	....	....	....	....	....	....	....	....	....
1 1/4	....	....	....	....	....	....	....	....	....	....	....
1 3/8	2.2973	....	....	....	....	....	....	....	....	....	....
1 1/2	2.5378	....	....	....	....	....	....	....	....	....	....
1 5/8	2.7779	3.0830	....	....	....	....	....	....	....	....	....
1 3/4	3.0182	3.3540	3.5949	....	....	....	....	....	....	....	....
1 7/8	3.2585	3.6250	3.8886	4.1610	....	....	....	....	....	....	....
2	3.4988	3.8960	4.1823	4.4787	....	....	....	....	....	....	....
2 1/8	3.7391	4.1670	4.4760	4.7965	5.1616	....	....	....	....	....	....
2 1/4	3.9794	4.4380	4.7697	5.1142	5.5073	....	....	....	....	....	....
2 3/8	4.2197	4.7090	5.0634	5.4319	5.8531	6.3423	....	....	....	....	....
2 1/2	4.4600	4.9800	5.3571	5.7496	6.1989	6.7214	7.0488	....	....	....	....
2 5/8	4.7003	5.2510	5.8508	8.0674	6.5446	....	....	....	....	....	....
2 3/4	4.9406	5.5220	5.9445	6.3851	6.8904	7.4797	7.8498	8.3048	....	....	....
2 7/8	5.1809	5.7930	6.2382	6.7028	7.2362	7.8568	8.2503	8.7320	....	....	....
3	5.4212	6.0640	8.5319	7.0206	7.5819	8.2380	8.6508	9.1592	9.6590	....	....
3 1/8	5.6615	8.3350	6.8258	7.3383	7.9277	....	....	....	....	....	....
3 1/4	5.9018	6.6060	7.1193	7.6560	8.2735	8.9962	9.4518	10.0136	10.5668	11.1115	11.5144
3 3/8	6.1421	6.8770	7.4130	7.9738	8.6192	....	....	....	....	....	....
3 1/2	8.3824	7.1480	7.7067	8.2915	8.9650	9.7545	10.2528	10.8680	11.4746	12.0727	12.5156
3 5/8	6.6227	7.4190	8.0004	8.6092	9.3108	....	....	....	....	....	....
3 3/4	6.8630	7.6900	8.2941	8.9269	9.6565	10.5128	11.0638	11.7224	12.3824	13.0339	13.5169
3 7/8	7.1033	7.9610	8.5878	9.2447	10.0023	....	....	....	....	....	....
4	7.3436	8.2320	8.8815	9.5824	10.3481	11.2711	11.8548	12.5768	13.2902	13.9951	14.5181
4 1/8	7.5839	8.6031	9.1752	9.8801	10.6938	....	....	....	....	....	....
4 1/4	7.8242	8.7741	9.4689	10.1979	11.0396	12.0294	12.6558	13.4312	14.1980	14.9563	15.5194
4 3/8	8.0645	9.0451	9.7826	10.5158	11.3853	....	....	....	....	....	....
4 1/2	8.3048	9.3161	10.0563	10.8333	11.7311	12.7876	13.4568	14.2856	15.1058	15.9175	16.5206
4 5/8	8.5451	9.5871	10.3500	11.1511	12.0769	....	....	....	....	....	....
4 3/4	8.7854	9.8581	10.6437	11.4888	12.4226	13.5459	14.2578	15.1400	16.0136	16.8787	17.5219
4 7/8	9.0257	10.1291	10.9374	11.7865	12.7684	....	....	....	....	....	....
5	9.2660	10.4001	11.2311	12.1042	13.1142	14.3042	15.0588	15.9944	16.9214	17.8399	18.5231
5 1/4	9.7466	10.9421	11.8185	12.7397	13.8057	15.0625	15.8598	16.8488	17.8292	18.8011	19.5244
5 1/2	10.2272	11.4841	12.4059	13.3752	14.4972	15.8208	16.6608	17.7032	18.7370	19.7623	20.5256
5 3/4	10.7078	12.0261	12.9933	14.0106	15.1888	16.5790	17.4618	18.5576	19.6448	20.7235	21.5269
6	11.1864	12.5681	13.5807	14.6461	15.8883	17.3373	18.2628	19.4120	20.5526	21.6847	22.5281
6 1/4	11.6690	13.1101	14.1881	15.2815	16.5718	18.0956	19.0638	20.2664	21.4604	22.6459	23.5294
6 1/2	12.1496	13.6521	14.7555	15.9170	17.2634	18.8539	19.8648	21.1208	22.3682	23.8071	24.5306
6 3/4	12.6302	14.1942	15.3429	16.5525	17.9549	19.8122	20.6658	21.9752	23.2750	24.5683	25.5319
7	13.1108	14.7362	15.9303	17.1879	18.6464	20.3704	21.4668	22.8296	24.1838	25.5295	26.5331
7 1/4	....	15.2782	16.5177	17.8234	19.3379	21.1287	22.2678	23.6840	25.0916	26.4907	27.5344
7 1/2	14.0720	15.8202	17.1051	18.4588	20.0295	21.8870	23.0688	24.5384	25.9994	27.4519	28.5358

The weights on this and the preceeding page were calculated according to the formula:

$$W = 10.68\,(D - t) \times t$$

where

W = the weight, in pounds, of one foot of tubing,
D = the outside diameter of the tube in inches,
and
t = the wall thickness in inches.

This formula involves the density of the pipe or tubing material, in this case figured on the basis of one cubic inch of steel = .2833 lb.

Table 46
Comparison Of Standard Weight Pipe Sizes And Welded Tubing

Pipe Size	Standard Weight Pipe — Diameter — OD Inches	ID Inches	Wall Thickness Inches	Size of Commonly Produced Welded Tube — OD Inches	Wall Thickness Bwg.[A] & Inch	Nearest Fractional Size of Welded Tube — OD Inches	Wall Thickness Bwg. & Inch
1/8	.405	.269	.068	1/2	16 (.065)	13/32	16 (.065)
1/4	.540	.364	.088	1/2	14 (.083)	17/32	14 (.083)
3/8	.675	.493	.091	5/8	13 (.095)	21/32	13 (.095)
1/2	.840	.622	.109	7/8	12 (.109)	27/32	12 (.109)
3/4	1.050	.824	.113	1	12 (.109)	1 1/16	12 (.109)
1	1.315	1.049	.133	1 1/4	11 (.120)	1 5/16	10 (.134)
1 1/4	1.660	1.380	.140	1 5/8	9 (.148)	1 5/8	9 (.148)
1 1/2	1.900	1.610	.145	1 7/8	9 (.148)	1 7/8	9 (.148)
2	2.375	2.067	.154	2 3/8	9 (.148)	2 3/8	9 (.148)
2 1/2	2.875	2.469	.203	2 7/8	6 (.203)	2 7/8	6 (.203)
3	3.500	3.068	.216	3 1/2	5 (.220)	3 1/2	5 (.220)
3 1/2	4.000	3.548	.226	4	4 (.238)	4	4 (.238)

[A]Birmingham Wire Gauge

Table 47
Dimensions Of Steel Pipe[A]

Nominal Pipe Size, in.	Outside Diameter, in.	Nominal Wall Thickness, in. — Schedule 5[B]	Schedule 10[B]	Schedule 40	Schedule 80
1/8	0.405	. . .	0.049	0.068	0.095
1/4	0.540	. . .	0.065	0.088	0.119
3/8	0.875	. . .	0.065	0.091	0.126
1/2	0.840	0.065	0.083	0.109	0.147
3/4	1.050	0.065	0.083	0.113	0.154
1	1.315	0.065	0.109	0.133	0.179
1 1/4	1.660	0.065	0.109	0.140	0.191
1 1/2	1.900	0.065	0.109	0.145	0.200
2	2.375	0.065	0.109	0.154	0.218
2 1/2	2.875	0.083	0.120	0.203	0.276
3	3.500	0.083	0.120	0.218	0.300
3 1/2	4.000	0.083	0.120	0.226	0.318
4	4.500	0.083	0.120	0.237	0.337

The decimal thicknesses listed for the respective pipe sizes represent their nominal or average wall dimensions.

[A]These do not conform to ASA B36.10.

[B]Schedule 5 and 10 wall thicknesses do not permit threading in accordance with ASA B2.1.

Ref.: Taken from ANSI B36.19-1965 (R 1971)

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Table 48
Nominal Weights Of Steel Pipe[A,B]

Nominal Pipe Size, in.	Weight of Steel Pipe, Plain Ends — Schedule 5	Schedule 10	Schedule 40	Schedule 80
1/8	. . .	0.19	0.24	0.31
1/4	. . .	0.33	0.42	0.54
3/8	. . .	0.42	0.57	0.74
1/2	0.54	0.67	0.85	1.09
3/4	0.69	0.86	1.13	1.47
1	0.87	1.40	1.68	2.17
1 1/4	1.11	1.81	2.27	3.00
1 1/2	1.28	2.09	2.72	3.63
2	1.61	2.64	3.65	5.02
2 1/2	2.48	3.53	5.79	7.66
3	3.03	4.33	7.58	10.25
3 1/2	3.48	4.97	9.11	12.51
4	3.92	5.61	10.79	14.98

[A]Weights are given in pounds per linear foot and are for carbon steel pipe with plain ends.

[B]The different grades of stainless steel permit considerable variations in weight. The ferritic stainless steels may be about 5 per cent less, and the austenitic stainless steels about 2 per cent greater than the values shown in this table which are based on weights for carbon steel.

Ref.: Taken from ANSI B36.19-1965 (R 1971)

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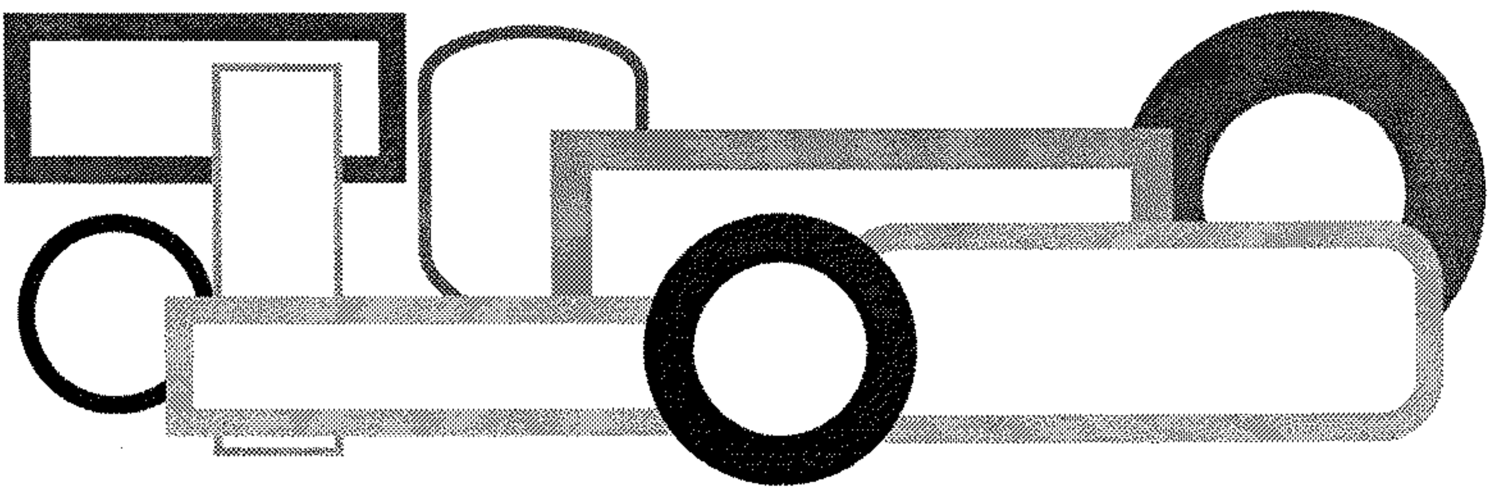

Table 49
Decimal Equivalents Of Birmingham Wire Gaugas And Fractions Of An Inch

Bwg.[A] Numbers	Fractions of an Inch	Decimal Equivalent—Inch	Bwg. Numbers	Fractions of an Inch	Decimal Equivalent—Inch
30	...	.012	...	5/16	.3125
29	...	.013	...	21/64	.3281
28	...	.014	0	...	.340
..	1/64	.0156	...	11/32	.3438
27	...	.016	...	23/64	.3594
26	...	.018	...	3/8	.375
25	...	.020	00	...	.380
24	...	.022	...	25/64	.3906
23	...	.025	...	13/32	.4063
22	...	.028	...	27/64	.4219
..	1/32	.0313	000	...	.425
21	...	.032	...	7/16	.4375
20	...	.035	...	29/64	.4531
19	...	.042	0000	...	.454
..	3/64	.0469	...	15/32	.4688
18	...	.049	...	31/64	.4844
17	...	.058	00000	1/2	.500
..	1/16	.0625	...	33/64	.5156
16	...	.065	...	17/32	.5313
15	...	.072	...	35/64	.5469
..	5/64	.0781	...	9/16	.5625
14	...	.083	...	37/64	.5781
..	3/32	.0934	...	19/32	.5938
13	...	.095	...	39/64	.6094
12	...	.109	...	5/8	.625
..	7/64	.1094	...	41/64	.6406
11	...	.120	...	21/32	.6563
..	1/8	.125	...	43/64	.6719
10	...	.134	...	11/16	.6875
..	9/64	.1408	...	45/64	.7031
9	...	.148	...	23/32	.7188
..	5/32	.1562	...	47/64	.7344
8	...	.165	...	3/4	.750
..	11/64	.1719	...	49/64	.7656
7	...	.180	...	25/32	.7813
..	3/16	.1875	...	51/64	.7969
6	...	.203	...	13/16	.8125
..	13/64	.2031	...	53/64	.8281
..	7/32	.2188	...	27/32	.8438
5	...	.220	...	55/64	.8594
..	15/64	.2344	...	7/8	.875
4	...	.238	...	57/64	.8906
..	1/4	.250	...	29/32	.9063
3	...	.259	...	59/64	.9219
..	17/64	.2656	...	15/16	.9375
..	9/32	.2813	...	61/64	.9531
2	...	.284	...	31/32	.9688
..	19/64	.2969	...	63/64	.9844
1	...	.300	...	1.00	1.000

[A]Birmingham Wire Gauge.

Table 50
Decimal Equivalants Of Various Gauges
The usual gauge designation for welded steel tube is Bwg. (Birmingham Wire Gauge).

Gauge Numbers	Birmingham (or Stubs Iron) Wire Gauge (Bwg.)	Brown and Sharpe	Manufacturers' Standard Gauge for Steel Sheet
000	.425	.4096	...
00	.380	.3648	...
0	.340	.3249	...
1	.300	.2893	...
2	.284	.2578	...
3	.259	.2294	.2391
4	.238	.2043	.2242
5	.220	.1819	.2092
6	.203	.1620	.1943
7	.180	.1443	.1793
8	.165	.1285	.1644
9	.148	.1144	.1495
10	.134	.1019	.1345
11	.120	.0907	.1196
12	.109	.0808	.1046
13	.095	.0720	.0897
14	.083	.0641	.0747
15	.072	.0571	.0673
16	.065	.0508	.0598
17	.058	.0453	.0538
18	.049	.0403	.0478
19	.042	.0359	.0418
20	.035	.0320	.0359
21	.032	.0285	.0329
22	.028	.0253	.0299
23	.025	.0226	.0289
24	.022	.0201	.0239
25	.020	.0179	.0209
26	.018	.0159	.0179
27	.016	.0142	.0164
28	.014	.0126	.0149
29	.013	.0113	.0135
30	.012	.0100	.0120
31	.010	.0089	...
32	.009	.0080	...
33	.008	.0071	...
34	.007	.0063	...
35	.005	.0056	...
36	.004	.0050	...
37	...	.0045	...
38	...	.0040	...

NOTE: Always use decimals when specifying the gauge or wall thickness so that there will be no confusion in gauge numbers.

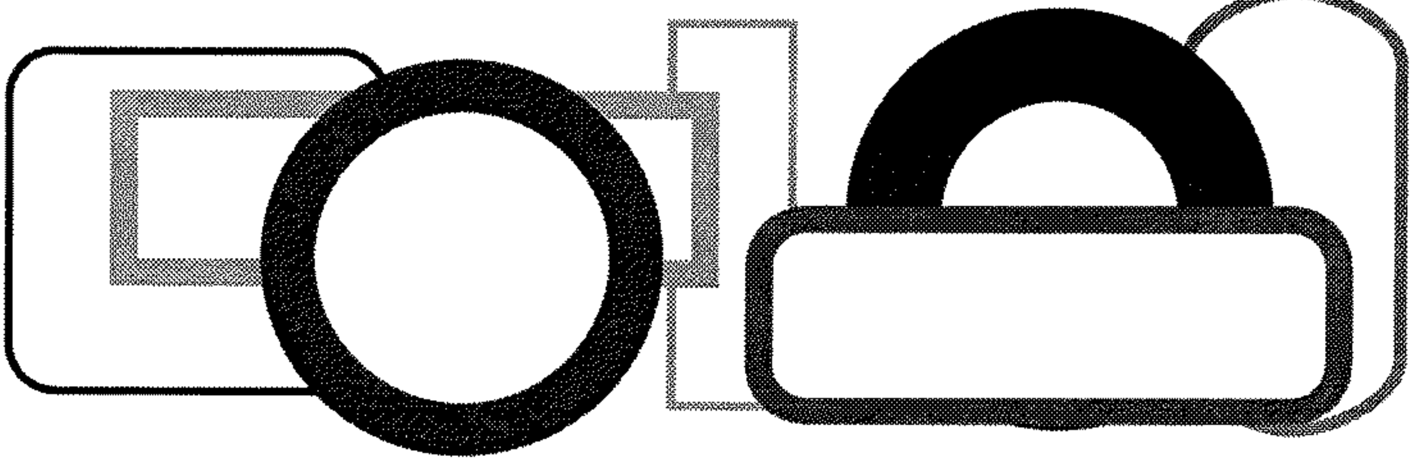

Table 51
Hardness Conversion Numbers For Soft Steel

B 100kg. 1/16" Ball — Rockwell Hardness Tester	F 60kg. 1/16" Ball — Rockwell Hardness Tester	G 150kg 1/16" Ball — Rockwell Hardness Tester	15-T 15kg. 1/16" Ball — Rockwell Superficial Hardness Tester	30-T 30kg. 1/16" Ball — Rockwell Superficial Hardness Tester	45-T 45kg. 1/16" Ball — Rockwell Superficial Hardness Tester	E 100kg. 1/8" Ball — Rockwell Hardness Tester	K 150kg. 1/8" Ball — Rockwell Hardness Tester	A 60kg. "Brale" — Rockwell Hardness Tester	Knoop Hardness 500 Gr. & Over — Knoop Elongated Diamond	Brinell Hardness 500 kg. 10mm Ball — Standard Brinell	Brinell Hardness 3000 kg. D.P.H. 10kg — Square Base Diamond Pyramid — 136° Apex Angle	Tensile Strength Approx. Only — Thousand lbs. per square inch
100	—	82.5	93.0	82.0	72.0	—	—	61.5	251	201	240	116
99	—	81.0	92.5	81.5	71.0	—	—	61.0	246	195	234	112
98	—	79.0	—	81.0	70.0	—	—	60.0	241	189	228	109
97	—	77.5	92.0	80.5	69.0	—	—	59.5	236	184	222	106
96	—	76.0	—	80.0	68.0	—	—	59.0	231	179	216	103
95	—	74.0	91.5	79.0	67.0	—	—	58.0	226	175	210	101
94	—	72.5	—	78.5	66.0	—	—	57.5	221	171	205	98
93	—	71.0	91.0	78.0	65.5	—	—	57.0	216	167	200	96
92	—	69.0	90.5	77.5	64.5	—	100	56.5	211	163	195	93
91	—	67.5	—	77.0	63.5	—	99.5	56.0	206	160	190	91
90	—	66.0	90.0	76.0	62.5	—	98.5	55.5	201	157	185	89
89	—	64.0	89.5	75.5	61.5	—	98.0	55.0	196	154	180	87
88	—	62.5	—	75.0	60.5	—	97.0	54.0	192	151	176	85
87	—	61.0	89.0	74.5	59.5	—	96.5	53.5	188	148	172	83
86	—	59.0	88.5	74.0	58.5	—	95.5	53.0	184	145	169	81
85	—	57.5	—	73.5	58.0	—	94.5	52.5	180	142	165	80
84	—	56.0	88.0	73.0	57.0	—	94.0	52.0	176	140	162	78
83	—	54.0	87.5	72.0	56.0	—	93.0	51.0	173	137	159	77
82	—	52.5	—	71.5	55.0	—	92.0	50.5	170	135	156	75
81	—	51.0	87.0	71.0	54.0	—	91.0	50.0	167	133	153	74
80	—	49.0	86.5	70.0	53.0	—	90.5	49.5	164	130	150	72
79	—	47.5	—	69.5	52.0	—	89.5	49.0	161	128	147	
78	—	46.0	86.0	69.0	51.0	—	88.5	48.5	158	126	144	
77	—	44.0	85.5	68.0	50.0	—	88.0	48.0	155	124	141	
76	—	42.5	—	67.5	49.0	—	87.0	47.0	152	122	139	
75	99.5	41.0	85.0	67.0	48.5	—	86.0	46.5	150	120	137	
74	99.0	39.0	—	66.0	47.5	—	85.0	46.0	147	118	135	
73	98.5	37.5	84.5	65.5	46.5	—	84.5	45.5	145	116	132	
72	98.0	36.0	84.0	65.0	45.5	—	83.5	45.0	143	114	130	
71	97.5	34.5	—	64.0	44.5	100	82.5	44.5	141	112	127	
70	97.0	32.5	83.5	63.5	43.5	99.5	81.5	44.0	139	110	125	
69	96.0	31.0	83.0	62.5	42.5	99.0	81.0	43.5	137	109	123	
68	95.5	29.5	—	62.0	41.5	98.0	80.0	43.0	135	107	121	
67	95.0	28.0	82.5	61.5	40.5	97.5	79.0	42.5	133	106	119	
68	94.5	26.5	82.0	60.5	39.5	97.0	78.0	42.0	131	104	117	
65	94.0	25.0	—	60.0	38.5	96.0	77.5	—	129	102	116	
64	93.5	23.5	81.5	59.5	37.5	95.5	76.5	41.5	127	101	114	
63	93.0	22.0	81.0	58.5	36.5	95.0	75.5	41.0	125	99	112	
62	92.0	20.5	—	58.0	35.5	94.5	74.5	40.5	124	98	110	
61	91.5	19.0	80.5	57.0	34.5	93.5	74.0	40.0	122	96	108	
60	91.0	17.5	—	56.5	33.5	93.0	73.0	39.5	120	95	107	
59	90.5	16.0	80.0	56.0	32.0	92.5	72.0	39.0	118	94	106	
58	90.0	14.5	79.5	55.0	31.0	92.0	71.0	38.5	117	92	104	
57	89.5	13.0	—	54.5	30.0	91.0	70.5	38.0	115	91	103	
56	89.0	11.5	79.0	54.0	29.0	90.5	69.5	—	114	90	101	
55	88.0	10.0	78.5	53.0	28.0	90.0	68.5	37.5	112	89	100	
54	87.5	8.5	—	52.5	27.0	89.5	68.0	37.0	111	87	—	
53	87.0	7.0	78.0	51.5	26.0	89.0	67.0	36.5	110	86	—	
52	86.5	5.5	77.5	51.0	25.0	88.0	66.0	36.0	109	85	—	
51	86.0	4.0	—	50.5	24.0	87.5	65.0	35.5	108	84	—	
50	85.5	2.5	77.0	49.5	23.0	87.0	64.5	35.0	107	83	—	

Even for steel, tensile strength relation to hardness is inexact, unless determined for specific material.

Table 51—(Continued)
Hardness Conversion Numbers For Soft Steel

B 100kg. 1/16" Ball	F 60kg. 1/16" Ball	15-T 15kg. 1/16" Ball	30-T 30kg. 1/16" Ball	45-T 45kg. 1/18" Ball	E 100kg. 1/8" Ball	H 60kg. 1/8" Ball	K 150kg. 1/8" Ball	A 60kg. "Brale"	Knoop Hardness 500 Gr & Over	Brinell Hardness 500kg. 10mm Ball
Rockwell Hardness Tester	Rockwell Hardness Tester	Rockwell Superficial Hardness Tester	Rockwell Superficial Hardness Tester	Rockwell Superficial Hardness Tester	Rockwell Hardness Tester	Rockwell Hardness Tester	Rockwell Hardness Tester	Rockwell Hardness Tester	Knoop Elongated Diamond	Standard Brinell
50	85.5	77.0	49.5	23.0	87.0	—	64.5	35.0	107	83
49	85.0	76.5	49.0	22.0	86.5	—	63.5	—	106	82
48	84.5	—	48.5	20.5	85.5	—	62.5	34.5	105	81
47	84.0	76.0	47.5	19.5	85.0	—	61.5	34.0	104	80
46	83.0	75.5	47.0	18.5	84.5	—	61.0	33.5	103	—
45	82.5	—	46.0	17.5	84.0	—	60.0	33.0	102	79
44	82.0	75.0	45.5	16.5	83.5	—	59.0	32.5	101	78
43	81.5	74.5	45.0	15.5	82.5	—	58.0	32.0	100	77
42	81.0	—	44.0	14.5	82.0	—	57.5	31.5	99	76
41	80.5	74.0	43.5	13.5	81.5	—	56.5	31.0	98	75
40	79.5	73.5	43.0	12.5	81.0	—	55.5	—	97	—
39	79.0	—	42.0	11.0	80.0	—	54.5	30.5	96	74
38	78.5	73.0	41.5	10.0	79.5	—	54.0	30.0	95	73
37	78.0	72.5	40.5	9.0	79.0	—	53.0	29.5	94	72
36	77.5	—	40.0	8.0	78 5	100	52.0	29.0	93	—
35	77.0	72.0	39.5	7.0	78.0	99.5	51.5	28.5	92	71
34	76.5	71.5	38.5	6.0	77.0	99.0	50.5	28.0	91	70
33	75.5	—	38.0	5.0	76.5	—	49.5	—	90	69
32	75.0	71.0	37.5	4.0	76.0	98.5	48.5	27.5	89	—
31	74.5	—	36.5	3.0	75.5	98.0	48.0	27.0	88	68
30	74.0	70.5	36.0	2.0	75.0	—	47.0	26.5	—	67
29	73.5	70.0	35.5	1.0	74.0	97.5	46.0	26.0	—	—
28	73.0	—	34.5	—	73.5	97.0	45.0	25.5	—	66
27	72.5	69.5	34.0	—	73.0	96.5	44.5	25.0	85	—
26	72.0	69.0	33.0	—	72.5	—	43.5	24.5	—	65
25	71.0	—	32.5	—	72.0	96.0	42.5	—	—	64
24	70.5	68.5	32.0	—	71.0	95.5	41.5	24.0	—	—
23	70.0	68.0	31.0	—	70.5	—	41.0	23.5	82	63
22	69.5	—	30.5	—	70.0	95.0	40.0	23.0	—	—
21	69.0	67.5	29.5	—	69.5	94.5	39.0	22.5	—	62
20	68.5	—	29.0	—	68.5	—	38.0	22.0	—	—
19	68.0	67.0	28.5	—	68.0	94.0	37.5	21.5	79	61
18	67.0	66.5	27.5	—	67.5	93.5	36.5	—	—	—
17	66.5	—	27.0	—	67.0	93.0	35.5	21.0	—	60
16	66.0	66.0	26.0	—	66.5	—	35.0	20.5	—	—
15	65.5	65.5	25.5	—	65.5	92.5	34.0	20.0	76	59
14	65.0	—	25.0	—	65.0	92.0	33.0	—	—	—
13	64.5	65.0	24.0	—	64.5	—	32.0	—	—	58
12	64.0	64.5	23.5	—	64.0	91.5	31.5	—	—	—
11	63.5	—	23.0	—	63.5	91.0	30.5	—	73	—
10	63.0	64.0	22.0	—	62.5	90.5	29.5	—	—	57
9	62.0	—	21.5	—	62.0	—	29.0	—	—	—
8	61.5	63.5	20.5	—	61.5	90.0	28.0	—	71	—
7	61.0	63.0	20.0	—	61.0	89.5	27.0	—	—	56
6	60.5	—	19.5	—	60.5	—	26.0	—	—	—
5	60.0	62.5	18.5	—	60.0	89.0	25.5	—	69	55
4	59.5	62.0	18.0	—	59.0	88.5	24.5	—	—	—
3	59.0	—	17.0	—	58.5	88.0	23.5	—	—	—
2	58.0	61.5	16.5	—	58.0	—	23.0	—	68	54
1	57.5	61.0	16.0	—	57.5	87.5	22.0	—	—	—
0	57.0	—	15.0	—	57.0	87.0	21.0	—	67	53

NOTE: Data supplied by Wilson Instrument Division, American Chain & Cable Company, Inc., copyrighted 1975, reprinted by permission.

Table 52
Hardness Conversion Numbers for Steel

Rockwell C Hardness Number	Diamond Pyramid Hardness Number	Brinell Hardness Number[A] 10-mm Standard Ball, 3000-kg Load	10-mm Hultgren Ball, 3000-kg Load	10-mm Carbide Ball, 3000-kg Load	Rockwell Hardness Number A Scale, 60-kg Load, Diamond Cone Penetrator	D Scale, 100-kg Load, Diamond Cone Penetrator	Rockwell Superficial Hardness Number 15-N Scale, 15-kg Load, Superficial Diamond Cone Penetrator	30-N Scale, 30-kg Load, Superficial Diamond Cone Penetrator	45-N Scale, 45-kg Load, Superficial Diamond Cone Penetrator	Rockwell C Hardness Number
68	940	...	...	...	85.6	76.9	93.2	84.4	75.4	68
67	900	...	...	...	85.0	76.1	92.9	83.6	74.2	67
66	865	...	...	...	84.5	75.4	92.5	82.8	73.3	66
65	832	...	...	**739**	83.9	74.5	92.2	81.9	72.0	65
64	800	...	...	**722**	83.4	73.8	91.8	81.1	71.0	64
63	772	...	...	**705**	82.8	73.0	91.4	80.1	69.9	63
62	746	...	...	**688**	82.3	72.2	91.1	79.3	68.8	62
61	720	...	...	**670**	81.8	71.5	90.7	78.4	67.7	61
60	697	...	**613**	**654**	81.2	70.7	90.2	77.5	66.6	60
59	674	...	**599**	**634**	80.7	69.9	89.8	76.6	65.5	59
58	653	...	**587**	615	80.1	69.2	89.3	75.7	64.3	58
57	633	...	**575**	595	79.6	68.5	88.9	74.8	63.2	57
56	613	...	**561**	577	79.0	67.7	88.3	73.9	62.0	56
55	595	...	**546**	560	78.5	66.9	87.9	73.0	60.9	55
54	577	...	**534**	543	78.0	66.1	87.4	72.0	59.8	54
53	560	...	**519**	525	77.4	65.4	86.9	71.2	58.6	53
52	544	**500**	**508**	512	76.8	64.6	86.4	70.2	57.4	52
51	528	**487**	494	496	76.3	63.8	85.9	69.4	56.1	51
50	513	**475**	481	481	75.9	63.1	85.5	68.5	55.0	50
49	498	**464**	469	469	75.2	62.1	85.0	67.6	53.8	49
48	484	451	455	455	74.7	61.4	84.5	66.7	52.5	48
47	471	442	443	443	74.1	60.8	83.9	65.8	51.4	47
46	458	432	432	432	73.6	60.0	83.5	64.8	50.3	46
45	446	421	421	421	73.1	59.2	83.0	64.0	49.0	45
44	434	409	409	409	72.5	58.5	82.5	63.1	47.8	44
43	423	400	400	400	72.0	57.7	82.0	62.2	46.7	43
42	412	390	390	390	71.5	56.9	81.5	61.3	45.5	42
41	402	381	381	381	70.9	56.2	80.9	60.4	44.3	41
40	392	371	371	371	70.4	55.4	80.4	59.5	43.1	40
39	382	362	362	362	69.9	54.6	79.9	58.6	41.9	39
38	372	353	353	353	69.4	53.8	79.4	57.7	40.8	38
37	363	344	344	344	68.9	53.1	78.8	56.8	39.6	37
36	354	336	336	336	68.4	52.3	78.3	55.9	38.4	36
35	345	327	327	327	67.9	51.5	77.7	55.0	37.2	35
34	336	319	319	319	67.4	50.8	77.2	54.2	36.1	34
33	327	311	311	311	66.8	50.0	76.6	53.3	34.9	33
32	318	301	301	301	66.3	49.2	76.1	52.1	33.7	32
31	310	294	294	294	65.8	48.4	75.6	51.3	32.5	31
30	302	286	286	286	65.3	47.7	75.0	50.4	31.3	30
29	294	279	279	279	64.7	47.0	74.5	49.5	30.1	29
28	286	271	271	271	64.3	46.1	73.9	48.6	28.9	28
27	279	264	264	264	63.8	45.2	73.3	47.7	27.8	27
26	272	258	258	258	63.3	44.6	72.8	46.8	26.7	26
25	266	253	253	253	62.8	43.8	72.2	45.9	25.5	25
24	260	247	247	247	62.4	43.1	71.6	45.0	24.3	24
23	254	243	243	243	62.0	42.1	71.0	44.0	23.1	23
22	248	237	237	237	61.5	41.6	70.5	43.2	22.0	22
21	243	231	231	231	61.0	40.9	69.9	42.3	20.7	21
20	238	226	226	226	60.5	40.1	69.4	41.5	19.6	20

[A] The Brinell hardness numbers in boldface type are outside the range recommended for Brinell hardness testing in Section 5(c) of the Method of Test for Brinell Hardness of Metallic Materials (ASTM Designation: E 10)

Ref.: ASTM E 140-84

SECTION IX — Glossary

Acid Brittleness—Brittleness induced in steel, when it is pickled in dilute acid to remove scale, or during electroplating. Commonly attributed to absorption of hydrogen.

Acid Steel—Steel made in a furnace or converter lined with siliceous (acid) refractory material. In the open hearth and electric furnaces employing the acid process, the hearth or bottom consists of fritted (burned in) silica sand. The acid bessemer converter usually is lined with a kind of sandstone called "firestone." Raw materials for acid steel must be low in phosphorus and sulfur.

Additions—Materials which are added to the molten bath of steel or to the molten steel in the ladle to produce the chemical composition required for the specific steel order.

Age Hardening—Aging—In a metal or alloy, a change in properties that generally occurs slowly at room temperature and more rapidly at higher temperatures, 500° to 900°F. Hardness and strength are increased and ductility generally lowered. Usually follows cold working.

Aircraft Quality—Denotes material for important or highly stressed parts of aircraft and for other similar purposes; such materials are of extremely high quality requiring closely controlled, restrictive and special practices in their manufacture.

Alloy—A substance that has metallic properties and is composed of two or more chemical elements of which at least one is a metal.

Alloy Scrap—Scrap steel which contains one or more alloying metals, such as nickel, chromium, tungsten, molybdenum. Such scrap must be very carefully classified according to composition and kept separate from other kinds of scrap.

Alloy Steel—Steel is classified as alloy when the maximum of the range given for the content of alloying elements exceeds one or more of the following: manganese, 1.65 pct.; silicon, 0.60 pct.; copper, 0.60 pct.; or in which a definite range or a definite minimum quantity of any of the following elements is specified or required within the limits of the recognized field of constructional alloy steels: aluminum, boron, chromium up to 3.99 pct., cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium, or any other alloying element added to obtain desired alloying properties.

Alloying Elements—Chemical elements added for improving the properties of the finished products. Chief alloying elements in alloy steels are: nickel, chromium, manganese, molybdenum, vanadium, silicon, copper.

Alpha Iron—The form of iron that is stable below Ac_3 (1670°F., e.g., the temperature at which a change in phase occurs). See also Austenite, Ferrite and Gamma Iron.

Annealing—A process involving heating and cooling, usually applied to induce softening. The term also refers to treatments intended to alter mechanical or physical properties, produce a definite microstructure, or remove gases.

Annealing (Bright)—A process of annealing usually carried out in a controlled furnace atmosphere so that surface oxidation is reduced to a minimum and the surface remains relatively bright.

Annealing (Full Annealing)—A softening process in which a ferrous alloy is heated to a temperature above the transformation range and after being held for a sufficient time at this temperature, is cooled slowly to a temperature below the transformation range. The alloy is ordinarily allowed to cool slowly in the furnace, although it may be removed and cooled in some medium that insures a slow rate of cooling.

Annealing (Graphitizing)—A heating and cooling process for cast iron or steel by which the combined carbon is transformed, wholly or partly, to graphitic or free carbon.

Annealing (Malleablizing)—A process of annealing white cast iron in such a way that the combined carbon is wholly or partly transformed to graphitic or free carbon or, in some instances, part of the carbon is removed completely.

Annealing (Normalizing)—A process in which a steel is heated to a suitable temperature above the transformation range and is subsequently cooled in still air at room temperature.

Annealing (Patenting)—Heating iron base alloys above the critical temperature range followed by cooling to below that range in air or in molten lead maintained at a temperature of about 700°F.

Annealing (Process Annealing)—A process by which a ferrous alloy is heated to a temperature close to, but below, the lower limit of the transformation range and is subsequently cooled. This process is applied in order to soften the metal for cold working.

Annealing (Spheroidizing)—Any process of heating and cooling that produces a rounded or globular form of carbide in steel. Spheroidizing methods frequently used are:

1. Prolonged holding at a temperature just below Ac_1.
2. Heating and cooling alternately between temperatures that are just above and just below Ac_1.
3. Heating to a temperature above Ae_1, or Ae_3, and then cooling very slowly in the furnace, or holding at a temperature just below Ac_1.
4. Cooling at a suitable rate from the minimum temperature at which all carbide is dissolved, to prevent the reformation of a carbide network, and then reheating in accordance with method 1 or 2 above (applicable to hypereutectoid steel containing a carbide network).

Annealing (Tempering)—A process of reheating quench-hardened or normalized steel to a temperature below the transformation range, and then cooling at any rate desired.

Austenite—A solid solution formed when carbon and certain alloying elements dissolve in gamma iron. Gamma iron is formed when carbon or constructional alloy steel is heated above the so-called critical range, and the ferrite (alpha iron, with a body-centered crystal structure) is transformed to a face-centered crystal structure. Austenite does not exist in most ordinary steels at room temperature.

Austenitic Grain Size—As used in this publication, the grain structure established by a standardized heat treatment procedure.

Austenitizing—The process of forming austenite by heating a ferrous alloy to temperatures in the transformation range (partial austenitizing) or above the transformation range (complete austenitizing).

Banded Structure—A segregated microstructure of nearly parallel planes aligned in the direction of hot working. In steels, the bands tend to contain a higher concentration of carbon.

Basic Bottom and Lining—In a melting furnace, the inner lining and bottom composed of either crushed burned dolomite, magnesite, magnesite bricks or basic slag. These materials have a basic reaction in the melting process.

Basic Material—A chemical expression meaning the opposite of acid. Basic and acid materials, when brought together so that they can react, neutralize each other, forming salts or slags. In such reactions, the base becomes the positive part of the salt and the acid the negative. Examples of basic materials: limestone (or lime, CaO), magnesite (MgO), dolomite (containing both CaO and MgO). Examples of acid materials: quartzite or silica (SiO_2) and the various clays, oxides of sulfur, etc. In metallurgy, the terms, "bases" and "acids," are applied to refractories, fluxes, and slags. Slags are said to be basic when the bases in them are greater than the acids; or to be acid when the acids in them are greater than the bases.

Basic Oxygen Furnace—A steel refining furnace which uses top blow oxygen to heat the molten iron, melt scrap and alloy additions, and reduce the carbon level.

Basic Steel—Steel melted in a furnace that has a basic bottom and lining, and under a slag that is dominantly basic.

Beading—Raising or depressing a ridge, of specified contour, on a section of tubing.

Beam—Any of a series of structural steel sections, such as the H, I, and wide flange members. When used in structural applications, tubing can also be considered a beam.

Bend Radius—The radius corresponding to the curvature of a bent specimen or bent area of a formed part, measured on the inside of a bend or on the centerline of the tube, as defined.

Bend Tests—Tests used to determine the ductility and/or other characteristics of steel or tubing. The number of bends and the radius and degree of bends are generally determined by the applicable specifications.

Blowhole—An internal cavity in steel produced during the solidification of the metal by evolved gas which, in failing to escape, is held in pockets.

Blue Brittleness—Brittleness occurring in steel when heated in the temperature range of 400° to 650°F., or when cold after being worked within this temperature range.

Box Annealing—A process of annealing a ferrous alloy in a suitable closed metal container with or without packing material in order to minimize oxidation. The charge is usually heated slowly to a temperature below the transformation range, but sometimes above or within it, and is then cooled slowly. This process is also called "close annealing" or "pot annealing."

Brazing—Joining metals by fusion of nonferrous alloys that have melting points above 800°F. but lower than those of the metals being joined. This may be accomplished by means of a torch (torch brazing), in a furnace (furnace brazing) or by dipping in a molten flux bath (dip or flux brazing). The filler metal is ordinarily in rod form in torch brazing; whereas in furnace and dip brazing the work material is first assembled and the filler metal may then be applied as wire, washers, clips, bands, or may be integrally bonded, as in brazing sheet.

Brazing Sheet—A clad type of sheet product, coated on one or both surfaces with an alloy that has a melting point lower than the melting point of the core alloy. During brazing, only the coating melts and flows to form fillets in the preassembled article.

Bright Dip—An acid solution into which articles are dipped to obtain a clean, bright surface.

Brittleness—A tendency to fracture without appreciable deformation.

Bulging—Local expansion of tubes or shells by internal hydraulic pressure or by compression of a rubber cylinder.

Burned Steel—Steel which has been heated in an oxidizing atmosphere at a sufficiently high temperature to result in penetration of the oxides formed into the grain boundaries and under the steel surface.

Burnishing—Plastic smearing such as may occur on metallic surfaces during buffing. Also used as a surface finishing operation on hydraulic cylinder tubing.

Burr—A rough or sharp edge left on metal by a cutting tool.

Butt Welding—Joining two edges or ends by placing one against the other and welding them.

Camber—Amount of longitudinal curvature or deviation from straightness. In flat rolled steels, it is due to difference in length between the two edges.

Camber of Rolls—The increased diameter at the middle of rolls, designed to counterbalance the bending of the rolls when they are subjected to high pressures during rolling.

Camber of Sheet—Deviation from edge straightness. See Camber.

Carbide—A compound of carbon with one or more metallic elements.

Carbon Steel—Steel which owes its properties chiefly to various percentages of carbon without substantial amounts of other alloying elements; also known as straight carbon steel, or plain carbon steel. Steel is classified as carbon steel when no minimum content of elements other than carbon is specified or required to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.20 pct.; or the maximum content for the following does not exceed the percentages noted: manganese, 1.65; silicon, 0.60; copper, 0.60.

Carbonitriding—A process in which a ferrous alloy is case-hardened by first being heated in a gaseous atmosphere of such composition that the alloy absorbs carbon and nitrogen simultaneously, and then being cooled at a rate that will produce desired properties.

Carburizing—To introduce carbon:

1. While steel is molten by adding carbonaceous material, coke, coal, electrode scrap, etc.
2. While steel is in the solid state by heating it in contact with carbonaceous matter.

Case-Hardening—A process of hardening a ferrous alloy so that the surface layer or case is made substantially harder than the interior or core. Typical case-hardening processes are carburizing and quenching, cyaniding, carbonitriding, nitriding, induction hardening and flame hardening.

Chamfer—To cut at an angle or bevel.

Chipping—A method for removing seams and other surface defects with chisel or gouge so that such defects will not be worked into the finished product. Chipping is often employed also to remove metal that is excessive but not defective. Removal of defects by gas cutting is known as "deseaming" or "scarfing."

Chrome Pickle—A chemical treatment for magnesium in a nitric acid, sodium dichromate solution. The treatment gives some protection against corrosion by producing a film that is also a base for paint.

Chromium—An alloying element added to alloy steel (in amounts up to around 1.50 pct.) to increase hardenability. Chromium content of 5 pct. or more confers special ability to resist corrosion. Steels containing more than 10.5 pct. chromium are called "Stainless Steel."

Cladding—A process for covering one metal with another and generally establishing a metallurgical bond between them.

Coating—The process of covering steel with another material, primarily for corrosion resistance.

Cold Drawing—The process of pulling or pushing a tube through a hardened steel or carbide die to reduce its diameter and obtain closer OD tolerances. Process can also be carried out by pulling the tube over a mandrel as it progresses through the die, thereby more closely controlling inside diameter. Higher tensile properties are obtained because the operation is performed at room temperature or in isolated cases at elevated temperatures but considerably under the lower critical temperature.

Cold Drawn—Refers to tubing drawn in the cold state through a hardened steel or carbide die, either with or without a mandrel on the inside.

Cold Heading—Cold heading consists in forcing metal to flow cold into dies to form thicker sections and more or less intricate shapes. The operation is performed with specialized machines where the metal, in the form of wire or bar stock, may be upset or headed in certain sections to a larger size and, if desired, may be extruded in other sections to a smaller diameter than the stock wire. Although cold heading was developed for the production of bolts, screws and rivets and is used largely for these parts, the process is applicable to a wide variety of special parts that have somewhat similar form.

Cold Rolled Products—Flat-rolled products which have been finished by rolling the piece without heating (at approximately room temperature).

Cold Work—Plastic deformation at such temperatures and rates that substantial increases occur in the strength and hardness of the metal. Visible structural changes include changes in grain shape and, in some instances, mechanical twinning or banding.

Cold Working—Deforming a metal plastically at such a temperature and rate that strain hardening occurs. The upper limit of temperature for this process is the recrystallization temperature.

Collapsing Pressure—A pressure which, when applied to the outside of a tube, causes it to cave in or to fail by bending or buckling inwardly.

Columbium—A metal which is added to steels to increase its strength after hot rolling through precipitation of carbides. One of several typical additives for high strength low alloy or microalloyed steel.

Combined Carbon—The carbon that is combined with iron or alloying elements to form carbide in cast iron or steel.

Compression Teat (Tubing)—Test made on a section of tube applying compressive force perpendicular to the diameter of the tube, also called Crush Test.

Concentricity—The relationship between the center of the inside diameter and the center of the outside diameter. Concentricity is related to the variation in the wall thickness of any one circumference of a tube.

Conduit Pipa — Product used for protection and routing of electrical conductors.

Conatant-Load Test—A stress-corrosion-cracking or mechanical test in which the specimen is stressed by applying a dead load.

Continuous Casting — A casting technique in which a slab or billet, or other shape is continuously solidified while it is being poured, so that its length is not determined by mold dimensions.

Controlled Cooling—A process of cooling from an elevated temperature in a predetermined manner, to avoid hardening, cracking or internal damage, or to produce a desired microstructure. This cooling usually follows the final hot forming operation.

Cooling Stressea—Stresses developed by uneven contraction of external constraint of metal during cooling; also those stresses resulting from localized plastic deformation during cooling, and retained.

Corrosion—Gradual chemical or electro-chemical attack on a metal by atmosphere, moisture or other agents.

Corroaion Embrittlament—The embrittlement caused in certain alloys by exposure to a corrosive environment. Such material is usually susceptible to the intergranular type of corrosion attack.

Corroaion Fatigua—The repeated cyclic stressing of a metal in a corrosive medium, resulting in more rapid deterioration of properties than would be encountered as a result of either cyclic stressing or of corrosion alone.

Coupling—A threaded sleeve used to connect two pipes. Commercial couplings are threaded inside to suit exterior thread of pipe.

Craep—The long term deformation of metals under a constant load or a constant stress, usually at elevated temperatures. Loading times are generally in excess of 100,000 hours.

Critical Strain—The percentage strain or amount of cold work at which large grain growth occurs during annealing at a specific temperature.

Crop—The end or ends of an ingot that contain the pipe or other defects to be cut off and discarded; also termed "crop end" and "discard."

Crush Test—Same as Compression Test.

Cryatallization—The formation of a crystal lattice by atoms during solidification from a liquid, such as in ingot freezing. Crystallization is not a long term embrittlement of metal.

Cup Fracture—The type of fracture in which the exterior portion is extended and the interior is relatively depressed, resembling a cup. This type of fracture is a good indication of a ductile material. When only a part of the exterior is extended, the term "half-cupped" or "quarter-cupped" is used.

Cyaniding—A process of case hardening a ferrous alloy by heating in a molten cyanide, thus causing the alloy to absorb carbon and nitrogen simultaneously. Cyaniding is usually followed by quenching to produce a hard case.

Decarburization—The loss of carbon from the surface of a ferrous alloy as a result of heating in a medium that reacts with the carbon.

Deep Drawing—Forming shaped articles or shells by forcing sheet metal into a die.

Deep Etching—Macro-etching; etching, for examination at a low magnification in a reagent that attacks the metal to a much greater extent than normal for microscopic examination. Gross features may be developed: abnormal grain size, segregation, cracks or grain flow.

Descaling—As related to tubing, the process of cleaning the steel surface after oxidation. Generally pickling or shot or sand blasting are used.

Diffusion Zone—In the clad type of products, the zone between coating and core, in which diffusion between the two has occurred.

Dimensions of Tubing—(The dimensions for tubing should not be confused with the nominal dimensions for pipe, which are standardized and set by the applicable specifications.)

1. A round tube section has three dimensions, any two of which may be varied. The three dimensions are outside diameter (OD), inside diameter (ID), and wall thickness or gauge (t).

a. OD: OUTSIDE DIAMETER—Specified in inches and fractions of an inch, or in inches and decimals of an inch.

b. ID: INSIDE DIAMETER—Specified in same terms as the OD.

c. WALL: WALL THICKNESS OR GAUGE—Specified in either fractions of an inch, decimals of an inch or by a "Wire Gauge" number. In the United States the standard wire gauge used for tubing is the "Birmingham" iron wire gauge, designated "Bwg." or "B.W.G."

2. *Nominal* as applied to any of these dimensions refers to the theoretical or stated single value of that dimension. The dimensions ordinarily specified by the customer are termed "nominal."

3. *Maximum and Minimum* referring to the greatest and least values of any dimension as agreed upon, constitute the limits within which all such dimensions must fall.

4. *Average* dimensions are those secured by averaging a series of micrometer readings of sufficient number to assure that all parts of the tube are within the maximum and minimum dimensions specified.

Drawing Quality Steel—Rimmed or Aluminum Killed steel held to low impurity levels and manufactured by special rolling and processing operations to produce a material which can stand extreme cold deformation without creating defects.

Dry Cyaniding—Synonymous with carbonitriding.

Ductility—The property that permits permanent deformation before fracture by stress in tension.

Elastic Constant—The ratio of load to extension in the elastic region of metal deformation. Otherwise known as Hookes Law, Young's Modulus or the elastic modulus and is considered a constant for steels at 30,000,000 psi.

Elastic Deformation—Temporary changes caused in dimensions by stress. The material returns to the original dimensions after removal of the stress.

Elastic Hysteresis—Energy absorbed by reversed deformation, represented by the closed loop of stress-strain curves in the elastic range, formed by curves for loading and unloading.

Elastic Limit—The maximum stress which a material is capable of sustaining without any measurable permanent extension remaining after complete release of the applied force.

Electrical Metallic Tubing—Referred to as EMT, an electrical conduit of lighter wall thickness than rigid conduit pipe and joined by some type of threadless fitting.

Elongation—The amount of permanent extension in the vicinity of the fracture in the tension test; usually expressed as a percentage of the original gauge length, as 25% in 2 in. Elongation may also refer to the amount of extension at any stage in any process that elongates a body continuously, as in rolling.

Endurance Limit—The maximum stress that a metal will withstand without failure during a specified large number of cycles of stress. If the term is employed without qualification, the cycles of stress are usually such as to produce complete reversal of flexural stress.

Endurance Ratio—The ratio of the endurance limit for cycles of reversed flexural stress to the tensile strength.

Erosion—The abrasion of metal or other material by liquid or gas, usually accelerated by pressure of solid particles of matter in suspension, and sometimes by corrosion.

Etch Tests—Tests used to detect inclusions in steel. A common method of making such tests is to dip the sample into acid which reacts with the inclusions and discloses their presence. See Macroetch.

Etching—In metallography, the process of revealing structural details by the preferential attack of reagents on a metal surface.

Extrusion—Shaping metal into a chosen continuous form by forcing it through a die of appropriate shape.

Fabricator, Steel—One who forms, manufactures or builds. His operations are to punch, cut, shear, drill, bend, flange or weld plates and shapes.

Fatigue—The tendency for a metal to break under conditions of repeated cyclic stressing considerably below the ultimate tensile strength.

Fatigue Crack or Failure—A fracture starting from a nucleus where there is an abnormal concentration of cyclic stress and propagating through the metal. The surface is smooth and frequently shows concentric (sea shell) markings with a nucleus as a center.

Fatigue Limit—The maximum stress that a metal will withstand without failure for a specified large number of cycles of stress. Usually synonymous with endurance limit.

Ferrite—A solid solution in which alpha iron is the solvent, and which is characterized by a body-centered cubic crystal structure. See also Austenite, Alpha Iron, Gamma Iron.

Ferroalloy—An iron-bearing product, not within the range of those called steels, which contains a considerable amount of one or more alloying elements, such as manganese, silicon, phosphorus, vanadium, chromium. Some of the more common ones are ferrochromium, ferromanganese, ferrophosphorus, ferrosilicon, ferrovanadium. The chief use of these alloys is for making additions of their respective alloying elements to molten steel.

Ferrous Metallurgy—That branch of metallurgy dealing with iron and steels.

Fiber, Fibre—

1. A characteristic of wrought metal that indicates directional properties and is revealed by the etching of a longitudinal section or is manifested by the fibrous or woody appearance of a fracture. Fiber is caused chiefly by the extension of the constituents of the metal, both metallic and nonmetallic, in the direction of working.

2. The pattern of preferred orientation of metal crystals after a given deformation process (usually wiredrawing).

Fiber Stress—Local stress at a point or line on a section over which stress is not uniform, such as on the cross section of a beam under a bending load.

Finish—In the steel industry, refers to the type of surface condition desired or existing in the finished product.

Finished Steel—Steel that is ready for the market without further work or treatment. Blooms, billets, slabs, sheet bars, and wire rods are termed "semifinished."

Finishing Temperature—The temperature at which hot mechanical working of metal is completed.

Flame Annealing—A process of softening a metal by the application of heat from a high-temperature flame.

Flame Cutting—

1. Severing a piece of steel by burning a portion out by means of an oxyacetylene torch, or

2. Removing a part of the surface by means of the burning torch, as in conditioning (more properly called scarfing).

Flame Hardening—A process of hardening a ferrous alloy by heating it above the transformation range by means of a high-temperature flame, and then cooling as required.

Flange—The projecting annular rim formed at right angles to the tube. As a test, used to evaluate tube weld quality and overall soundness. Used in testing the tube and for Van Stone joints.

Flare Test—The tapered expansion of a welded tube over a cone having various degrees and of various lengths.

Flash—A thin fin of metal formed at the sides of a forging or weld when a small portion of metal is forced out between the edges of the forging or welding dies.

Flattening Test—A test for either or both the tube base metal and weld line where a ring from the tube or crop end is flattened. The weld line is positioned 0° or 90° to the applied force and the ring flattened to a specified height. Examination is made during the test for signs of cracking.

Floating Plug—A plug that locates itself inside a tube during drawing, in such a way that the tube is reduced in thickness between the plug and the die.

Flow Stress—The shear stress required to cause plastic deformation of solid metals.

Fog Quenching—A method of quenching in which a fine vapor or mist is used as the quenching medium.

Forming—To shape or fashion with the hand or tools or by a shape or mold.

Forming Properties—Those physical and mechanical properties that allow a steel to be formed without injury to the steel in the finished product.

Fracture Stress—The maximum principal true stress (fracture load divided by fracture area).

Fracture Test—Breaking a piece of metal for the purpose of examining the fractured surface to determine the structure or carbon content of the metal or to detect the presence of internal defects.

Frequency—As applied to electric current, the number of alternations per second divided by two, in the direction of flow of the alternating current.

Full Annealing—A softening process in which a ferrous alloy is heated to a temperature above the transformation range and, after being held for a sufficient time at this temperature, is cooled slowly to a temperature below the transformation range. The alloy is ordinarily allowed to cool slowly in the furnace, although it may be removed and cooled in some medium that insures a slow rate of cooling.

Galvanizing—The process of applying a coating of zinc to the steel. The coating is applied by hot dipping or electrolytic deposition.

Galvannealed—An extra tight coat of galvanizing metal (zinc) applied to a soft steel sheet, after which the sheet is passed through an oven at about 1200°F. The resulting coat is dull gray without spangle especially suited for subsequent painting.

Gamma Iron—Allotropic form of pure iron, stable in the temperature range of 1670° to 2535°F., having a face-centered cubic crystal structure.

Gamma Loop—Refers to the boundaries of the gamma or austenite field of the iron—chromium constitutional diagram. Chromium influences the ferritic form of the iron so that increasing additions move the delta ferrite temperature range downward and the alpha ferrite range upward until the two fields meet, thus enclosing the austenite field as a "loop" beyond which all alloys richer in chromium are permanently ferritic. Iron base alloys with such elements as columbium, molybdenum, tungsten, and others, also form a gamma loop.

Gas Cutting—Cutting material with gas torch rather than by shearing. This operation may set up undesirable stresses in the material near the cut edges due to thermal effects; such stresses can be relieved by suitable heat treatment. Same as Flame Cutting.

Gas Cyaniding—Synonymous with Carbonitriding.

Gauge—A measurement of thickness. There are various standard gauges such as United States Standard Gauge (USS), Galvanized Sheet Gauge (GSG), Birmingham Wire Gauge (BWG, Bwg. or B.W.G.). Birmingham Wire Gauge is commonly used by the welded tube industry.

Gauge, Working—The gauge used by the workman in inspecting the product. Tested periodically by the reference gauge.

Grain Size—The average size of the individual crystals in metals expressed as:

1. The ASTM grain size number
2. The austenitic grain size
3. The number of grains per unit area as viewed metallographically or
4. Some average dimensional value of the grains.

Grains—Individual crystals in metals.

Graphitizing—A heating and cooling process by which the combined carbon in cast iron or steel is transformed, wholly or partly, to graphitic or free carbon.

Hand Tight—Couplings tightened by hand with such effort as an average man can continuously exert. It does not refer to such forcings as can be done by a man picked for his strength.

Hardenability—In a ferrous alloy, the property that determines the depth and distribution of hardness induced by quenching.

Hardness—A mechanical property of metals related to the tensile strength, and thereby roughly to ductility or formability. Hardness is usually expressed in terms of the method of measurement, such as:

1. The resistance to penetration or indentation as in the Rockwell, Brinell, Vickers, and Knoop tests
2. Stiffness of temper of wrought products
3. Machinability characteristics.

Heat Analysis—The term applied to the chemical analysis representative of a heat or blow of steel and is the analysis reported to the purchaser. It is determined by analyzing (for such elements as have been specified) a test ingot sample obtained from part of the heat or blow during the pouring of the steel from a ladle.

Heat Treating Film—A thin oxide coating or film formed on the surface of metals during thermal treatments.

Heat Treatment—A combination of heating and cooling operations, timed and applied to a metal or alloy in the solid state in a way that will produce desired properties. Heating for the sole purpose of hot working is excluded from the meaning of this definition.

High Strength Steels—Low alloy steels forming a specific class in which enhanced mechanical properties and, in most cases, good resistance to atmospheric corrosion are obtained by the incorporation of moderate proportions of one or more alloying elements other than carbon. The preferred terminology is now "high-strength, low-alloy steels."

Homogeneous—Usually defined as having identical characteristics throughout. However, physical homogeneity may require only an identity of lattice type throughout while chemical homogeneity requires uniform distribution of alloying elements.

Homogenizing Treatment—A heat treatment, usually for a long time at a high temperature, designed to make metal chemically homogeneous.

Hot Forming—Working operations, such as bending and drawing sheet and plate, forging, pressing, and heading, performed on metal heated to temperatures above room temperature.

Hot Quenching—A process of quenching in a medium at a temperature substantially higher than atmospheric temperature.

Hot Shortness—Brittleness in hot metal.

Hot Working—Plastic deformation of metal at such a temperature and rate that strain hardening does not occur. The lower limit of temperature for this process is the recrystallization temperature.

Impact Extrusion—A cold forming process in which the metal is forced by impact to flow around the punch, forming a tube with a solid bottom.

Impact Test—A test to determine the energy absorbed in fracturing a test bar at high velocity. The test may be in tension or in bending, or it may properly be a notch test if a notch is present, creating multiaxial stresses.

Inclusions—Particles of nonmetallic impurities, usually oxides, sulfides, silicates, and such, which are mechanically held in steel during and after solidification.

Indentation Hardness—The resistance of a material to indentation. This is the usual type of hardness test, in which a pointed or rounded indenter is pressed into a surface under a substantially static load.

Indirect Extrusion (Inverted)—An extrusion process in which the metal is forced back inside a hollow ram that pushes the die.

Induction Hardening—A process of hardening a ferrous alloy by heating it above the transformation range by means of electrical induction, and then cooling as required.

Induction Heating—A process of heating by electrical induction.

Initial Creep—The early part of the time-elongation curve for creep, in which extrusion increases at a rapid rate.

Intercrystalline Cracking—Cracks or fractures that follow along grain boundaries in the microstructure of metals and alloys.

Intergranular Corrosion—A type of electrochemical corrosion that progresses preferentially along the grain boundaries of an alloy, usually because the grain boundary regions contain material anodic to the central regions of the grain.

Internal Soundness—Refers to condition of inside of material—lack of defects, pipe, segregation, nonuniformity of composition.

Interrupted Quenching—A process of quenching in which the metal object being quenched is removed from the quenching medium while the object is at a temperature substantially higher than that of the quenching medium.

Intracrystalline Cracking—Fractures across the grains in metal.

Isothermal Annealing—A process in which a ferrous alloy is heated to produce a structure partly or wholly austenitic, and is then cooled to and held at a temperature that causes transformation of the austenite to a relatively soft ferrite-carbide aggregate.

Killed and Semi-Killed Steel — The factors governing steel ingot structures are influenced in degree or extent by various conditions singly or in combination, some of which are temperature and chemical composition of both metal and slag, rate of pouring, and size and shape of ingot molds. The control of such interrelated conditions has been the object of extended research and experimental work.

The manufacture of steel from raw materials is an oxidizing process, and the molten metal as it comes from the furnace contains more or less oxygen in the form of dissolved oxides, the amount varying with the composition desired, and with certain conditions of steel making.

If certain elements such as manganese, silicon or aluminum are added in sufficient amounts to molten metal in the furnace, in the ladle, or in the ingot mold, the metal will solidify quietly without evolution of gases.

1. Killed Steel—Steel deoxidized with a strong deoxidizing agent such as silicon or aluminum in order to reduce the oxygen content to a minimum so that no reaction occurs between carbon and oxygen during solidification.
2. Semi-Killed Steel—Steel incompletely deoxidized, to permit evolution of sufficient carbon monoxide to offset solidification shrinkage.

Laminations—Defects resulting from the presence of blisters, seams or nonmetallic inclusions aligned parallel to the worked surface of a metal.

Lap—A surface defect appearing as a seam caused from folding over, during hot rolling, fins or sharp corners and then rolling or forging, but not welding, them into the surface.

Lap Wald—A term applied to a weld formed by lapping two pieces of metal and then pressing or hammering, and applied particularly to the longitudinal joint produced by a welding process for tubes or pipe, in which the edges of the skelp are beveled or scarfed so that when they are over-lapped they can be welded together.

Longitudinal Diraction—The direction in a wrought metal product parallel to the direction of working (drawing, extruding, rolling).

Longitudinal Tast—This term should be used only in connection with test specimens, both tension and bend, and to indicate that their longitudinal axis is parallel to the direction of greatest extension of the material from which they are cut. The stresses applied to both the tension and bend test specimens will be in the direction of their longitudinal axis. In speaking of bending flat-rolled products longitudinally, it is understood that the bend or fold runs parallel to the direction of greatest extension of the material in rolling (i.e., with the grain). This means, of course, that the direction of this bend is at right angles to the fold in a longitudinal bend specimen.

Machining—In general, the cutting away of the surface of a metal by means of power driven machinery. Specifically, a method of conditioning steel by machining away the surface.

Macroetch—A testing procedure for revealing porosity, pipe, inclusions, gross nonmetallics, segregation, etc. Surface of the test piece should be reasonably smooth or even polished. After applying a suitable etching solution, the structure developed by the action of the reagent may be observed.

Macrograph—A photographic reproduction of any object that has not been magnified more than ten times.

Macroscopic—Visible either with the naked eye or under low magnification (as great as about 10 diameters).

Macroscopic Strasses—Residual stresses of such scope that relatively large areas of the material or the whole specimen are involved. These stresses are accompanied by strain measurable with ordinary extensometers under appropriate test conditions.

Macrostructure—The structure and internal condition of metals are revealed on a ground or polished (and usually etched) sample, by either the naked eye or under low magnification (up to about 10 diameters).

Magnaflux—An inspection given to important or highly stressed parts of quality steel. It consists in suitably magnetizing the material and applying a prepared magnetic powder which adheres to it along lines of flux leakage. The existence of surface and subsurface discontinuities can be shown.

Malleability—The property that determines the ease of deforming a metal when the metal is subjected to rolling or hammering. The more malleable metals can be hammered or rolled into thin sheet more easily than others.

Malleablizing—A process of annealing white cast iron in such a way that the combined carbon is wholly or partly transformed to graphitic or free carbon or, in some instances, part of the carbon is removed completely.

Mandral—

1. A rod used to retain the cavity in hollow metal products during working.
2. A metal bar around which other metal may be cast, bent, formed or shaped.

Martempering—The process of quenching an austenitized ferrous alloy in a medium maintained at a temperature in the upper portion of the temperature range of martensite formation, or slightly above that range, and holding in the medium until the temperature throughout the alloy is substantially uniform. The alloy is then allowed to cool in air through the temperature range of martensite formation.

Martansita—An unstable constituent in quenched steel, formed without diffusion and only during cooling below a certain temperature. The structure is characterized by its acicular appearance on the surface of a polished and etched specimen. Martensite is the hardest of the transformation products of austenite. In most steels as-quenched martensite must be tempered to make it suitable for use.

Machanical Matallurgy—The science concerned with the relationships among the measured mechanical properties of metals and their mechanical behavior in service, and with the way these properties and service characteristics vary with chemical composition, structure and temperature. The field also includes mechanical processing such as rolling, drawing and the like.

Mechanical Propertias—Those properties of a material that reveal the elastic and inelastic reaction when force is applied, or that involve the relationship between stress and strain; for example, the modulus of elasticity, tensile strength and fatigue limit. These properties have often been designated as "physical properties," but the term "mechanical properties" is much to be preferred. See Physical Properties.

Mechanical Tubing—Used for a variety of mechanical and structural purposes as opposed to pressure tubing which is used for the conduction of fluids under pressure. It is commonly manufactured to consumer specifications covering chemical analysis, mechanical properties and often to special dimensional tolerances. It is used for such a variety of purposes that it is impractical to subdivide it into classifications such as are used for other classes of tubing.

Mechanical Working—Subjecting metal to pressure exerted by rolls, dies, presses, or hammers, to change its form or to affect the structure and consequently the mechanical properties.

Matallography—The science concerning the constitution and structure of metals and alloys as revealed by the microscope.

Metallurgy—The science which deals with the extraction of metals from their ores and the adaptation and application of these metals to the uses for which they are intended.

Microclaanliness—Refers to the extent or quantity of nonmetallic inclusions observed by examination under a microscope.

Microscopic Tests—Tests used in studying inclusions, segregation and structure. Microscopic studies may be supplemental and coordinated with other tests.

Mill Finish—A surface finish produced on sheet and plate, characteristic of the ground finish on the rolls used in fabrication.

Milling—The mechanical treatment of material, as in a ball mill, to produce particles or alter their size or shape, or to coat one component of a powder mixture with another.

Modulus of Elasticity—The slope of the elastic portion of the stress-strain curve in mechanical testing. The stress is divided by the unit elongation. The tensile or compressive elastic modulus is called "Young's modulus"; the torsional elastic modulus is known as the "shear modulus," or "modulus of rigidity."

Modulus of Rigidity—In a torsion test, the ratio of the unit shear stress to the displacement caused by its per unit length in the elastic range. This modulus corresponds to the modulus of elasticity in the tension test.

Molybdanum—An alloying element commonly used in low alloy and other steels to increase hardenability; commonly called moly.

Momant of Inartie—It is not practical to provide an adequate definition of this term within the scope of this Handbook. A recognized engineering handbook or textbook should be consulted for a proper definition.

Necking Down—The narrowing, or constricting to a smaller cross-sectional area, which occurs at a localized place on a tensile test piece while it is being pulled.

Nitriding—A process of case hardening in which a ferrous alloy, usually of special composition, is heated in an atmosphere of ammonia or in contact with nitrogenous material to produce surface hardening by the absorption of nitrogen, without quenching.

Nominel OD, ID and Well—See Dimensions of Tubing.

Normalize—The normalizing process which is commonly applied to steel articles of heavy section consists of heating to a temperature about 100°F. above the critical range and cooling in still air.

Normalizing—An annealing process which consists of transforming a ferrous article fully to austenite and then cooling in still air.

Notch Brittleness—Susceptibility of a material to brittleness in areas containing a groove, scratch, sharp fillet or notch.

Notch Sensitivity—The reduction in nominal strength, impact or static, by the presence of a stress concentration. See Notch Brittleness.

Oiling—Application of a suitable oil to final product to retard rusting. Where surface is a consideration, it is also desirable in reducing friction scratches that may develop in transit. The oil coating is not intended to serve as a lubricant for subsequent fabrication.

Opereting Stress—The stress to which a structural unit is subjected during service.

Ovality—The difference between the maximum and minimum diameters of any one section of round tube, by actual measurement.

Overbending—Allowance for springback when bending metal to a desired angle.

Overheeted—A term applied when, after exposure to an excessively high temperature, a metal develops an undesirably coarse grain structure but is not permanently damaged. Unlike a burnt structure, the structure produced by overheating can be corrected by suitable heat treatment, by mechanical work, or by a combination of the two.

Overstressing—Permanently deforming a metal by subjecting it to stresses that exceed the elastic limit.

Oxida—Usually refers in the steel industry to oxide of iron, of which there are three principal ones: FeO, Fe_3O_4, Fe_2O_3. In addition, there are many mixtures of these oxides which form on the surface of steel at different temperatures and give the steel different colors, such as yellow, brown, purple, blue and red. Oxides must be thoroughly removed from the surface of steel objects which are to be coated. See Scale.

Oxygan Staal—Steel made with the use of an oxygen blast as an alternate or adjunct with air to oxidize impurities in the melting process. Increases rapidity of the process.

Pass—
1. Movement of a piece of steel through a stand of rolls.
2. The open space between two grooved rolls through which is rolled the steel which is being processed.

Pessivating—Immersion of steel in an acid bath to remove surface impurities and to render the surface passive.

Permenent Set—Plastic deformation.

Photomicrograph—A photographic reproduction of any object magnified more than 10 diameters. The term micrograph may be used.

Physical Properties—Those properties familiarly discussed in physics, exclusive of those described under mechanical properties; for example, density, electrical conductivity, coefficient of thermal expansion. This term has often been used to describe mechanical properties, but this usage is not recommended. See Mechanical Properties.

Physicel Testing—Testing methods by which physical properties are determined. This term is also used inadvisedly to mean the determination of the mechanical properties.

Pickle—Chemical or electrochemical removal of surface oxides.

Pipe—
1. A cavity formed by contraction in metal (especially ingots) during solidification of the last portion of liquid metal.
2. A tubular form of steel, generally of heavier wall thickness than tubing and made to a "nominal" outside diameter, e.g., 2" pipe is 2⅜" outside diameter.

Pit—A sharp depression in the surface of metal.

Plastic Deformation—Permanent distortion of a material under the action of applied stresses.

Plasticity—The ability of a metal to be deformed extensively without rupture.

Plog—A rod or mandrel that fills a tube as it is drawn through a die.

Pressure Tubes—As distinguished from pressure piping are used to conduct fluids under pressure or at elevated temperatures or both and are suitable for the external application of heat. Subdivisions of this classification include boiler tubes, superheater tubes, oil still tubes, heat exchanger and condenser tubes.

Principal Stresses—Normal stresses along rectilinear coordinates that are so chosen in direction that shearing stresses are zero.

Process Anneeling—A process by which a ferrous alloy is heated to a temperature close to, but below, the lower limit of the transformation range and is subsequently cooled. This process is applied in order to soften the metal for cold working.

Proof Stress—In a tensile test, the stress that will cause a specified permanent deformation in a material, usually 0.01 pct. or less.

Proof Test—Any type of test to indicate that the material or structure is suitable for the purpose intended.

Proportional Limit—The greatest stress a material is capable of sustaining without a deviation from the law of proportionality of stress and strain. If the load is removed for any stress up to this point, the material will spring back, or assume its original dimensions.

Quality—The ability of a material, process or article to meet specified requirements for which it is intended.

Quench Hardening—A process of hardening a ferrous alloy of suitable composition by heating within or above the transformation range and cooling at a rate sufficient to increase the hardness substantially. The process usually involves the formation of martensite.

Quenching—A process of rapid cooling from an elevated temperature by contact with liquids, gases or solids.

Quenching Crack—A fracture resulting from thermal stresses induced during rapid cooling or quenching. Frequently encountered in alloys that have been overheated and liquated and are thus "hot short."

Radioactive Metals—A group of metals with high atomic weights and with atomic nuclei that decompose slowly, giving off continual radiations of positively charged alpha particles, which are relatively slow; negatively charged beta particles, which are faster and lighter; and gamma rays. The gamma rays are similar to X-rays but are more penetrating and are used for radiography of very thick sections. Bombardment by neutrons can make any metal radioactive and small concentrations of such metals are used as "tracers" in the study of diffusion and other phenomena.

Radius of Gyration—It is not practical to provide an adequate definition of this term within the scope of this Handbook. A recognized engineering handbook or textbook should be consulted for a proper definition.

Range—The term range as used in connection with chemical or physical properties, lengths, tolerances, etc., is the numerical difference between the maximum and minimum of the given limits. Thus carbon 0.15 to 0.25 per cent is considered to be a ten-point range.

Reamed—Having the burr removed from inside, at ends, by a slight countersinking.

Recessed—Counterbored for a short distance when applied to couplings.

Reduction Area—In a tensile test the difference between the original cross-sectional area and that of the smallest area at the point of rupture; usually stated as a percentage of the original area; also called "contraction of area."

Refining Temperature—A temperature, usually just higher than the transformation range, employed in the heat treatment of steel to refine the structure, in particular, the grain size.

Residual Stress—Macroscopic stresses that are set up within a metal as the result of non-uniform plastic deformation. This deformation may be caused by cold working or by drastic gradients of temperature from quenching or welding.

Resilience—The tendency of a material to return to its original shape after the removal of a stress that has produced elastic strain.

Resistance Welding—A type of welding process in which the work pieces are heated by the passage of an electric current through the contact. Such processes include spot welding, seam or line welding and percussion welding.

Roll Forming (as applied to tube manufacture)—A process of coiling flat-rolled material into cylinders (tubes).

Roller Straightening—A process involving a series of staggered rolls, between which rod, tubing and shapes are passed for the purpose of straightening. The process consists of a series of bending operations.

Salt Spray Test—An accelerated corrosion test in which the metal specimens are exposed to a fine mist of salt water solution either continuously or intermittently.

Sampling—The cutting or baring of samples for testing.

Scab (Scabby)—A blemish caused on a casting by eruption of gas from the mold face, or by uneven mold surfaces; or occurring where the skin from a blowhole has partly burned away and is not welded. They also result from splashing of molten metal on mold walls during teeming.

Scale—An oxide of iron which forms on the surface of hot steel.

Scarfing—Cutting surface areas of metal objects, ordinarily by using a gas torch. The operation permits surface defects to be cut from ingots, billets or the edges of plate that are to be beveled for butt welding. See Chipping.

Schedule Number—An arbitrary method of designating wall thickness of pipe. Wall thickness of each schedule number varies with nominal diameter.

Seam—On the surface of metal, a crack that has been closed but not welded; usually produced by some defect either in casting or in working, such as blowholes that have become oxidized or folds and laps that have been formed during working. Seam also refers to lap joints, as in seam welding.

Secondary Hardening—Tempering certain alloy steel at certain temperatures so that a hardness is obtained greater than that resulting from the tempering of the same steel at some lower temperature for the same time.

Section Modulus—It is not practical to provide an adequate definition of this term within the scope of this Handbook. A recognized engineering handbook or textbook should be consulted for a proper definition.

Segregation—The result of the natural phenomenon in the solidification of a steel ingot in which various components of the steel having the lowest freezing point are concentrated in parts of the ingot last to solidify.

Semi-Killed Steel—See Killed, Semi-Killed.

Shielded-Arc Welding—Electric-arc welding in which the metal is protected from the air atmosphere. An inert gaseous atmosphere or flux-coated electrodes may be used.

Shortness—Brittleness in metal.

Silver Solders—Alloys of silver, copper, zinc and other metals, melting between 600° and 1600°F. used for making strong joints that resist corrosion.

Sink Drawing—Drawing tubing through a die without use of an interior tool.

Skelp — A heavy gauge hot rolled strip product basically used in the production of continuous buttweld pipe. Is sometimes used in the production of heavy wall tubing.

Soak—To hold an ingot, slab, bloom, billet or other piece of steel in a hot chamber or pit to secure uniform temperature throughout. Freshly stripped ingots are hottest in the interior, whereas a cold object which is being heated is hottest at the surface. The term is used in connection with heating of steel whether for forging or rolling or for heat treatment.

Soldering—Joining metals by fusion of alloys that have relatively low melting points — most commonly, lead-base or tin-base alloys, which are the soft solders. Hard solders are alloys that have silver, copper, or nickel bases and use of these alloys with melting points higher than 800°F. is generally termed brazing.

Solution Heat Treatment—A process in which an alloy is heated to a suitable temperature, is held at this temperature long enough to allow a certain constituent to enter into solid solution and is then cooled rapidly to hold the constituent in solution. The metal is left in a super-saturated, unstable state and may subsequently exhibit age hardening.

Spectrograph—An optical instrument for determining the presence or concentration of metallic constituents in a material by indicating the presence and intensity of specific wave lengths of radiation when the material is thermally or electrically excited.

Stainless—
1. A trade name given to alloy steel that is corrosion and heat resistant. The chief alloying elements are chromium, nickel, molybdenum and silicon in various combinations with a possible small percentage of titanium, vanadium, etc.
2. By AISI definition, a steel is called "Stainless" when it contains 10.5 pct. or more chromium.

Straightening—The removal of sweep and camber by roller straightening or by use of the gag press.

Streamline Tubing—Extruded or drawn tubing of which the cross section is shaped like a teardrop.

Stress—The load per unit of area. Ordinarily stress-strain curves do not show the true stress (load divided by area at that moment) but a fictitious value obtained by always using the original area.

Stress Relieving—A process of reducing residual stresses in a metal object by heating the object to a suitable temperature and holding for a sufficient time. This treatment may be applied to relieve stresses induced by casting, quenching, normalizing, machining, cold working or welding.

Stretcher Straightening—A process for straightening rod, tubing and shapes by the application of tension at the ends of the stock. The products are elongated a definite amount to remove warpage.

Stripping—Removing coated or electrolytically deposited metal or oxides from the base.

Structural Tubing—Tubing used primarily for structural applications and produced in rounds, squares, rectangles, and shapes.

Surface Checking—General breaking and cracking of the surface, which may result from a variety of causes, such as overrolling, overforming, or atmospheric attack at grain boundaries.

Surface Inspection—The inspection of the surface of products for defects such as ingot cracks, scabs, seams, burned steel, laps, twist, guide marks, etc.

Swager—A machine used to reduce diameter or taper tubing. A pair of dies with grooves corresponding to the desired diameter or taper hammer of the tube. These dies are actuated by a number of horizontal rolls in a revolving cage and the impact causes the dies to revolve and thereby work the tube diameter to the desired size or contour.

Temper—A condition produced in a metal or alloy by mechanical or thermal treatment and having characteristic structure and mechanical properties. A given alloy may be in the fully softened or annealed temper, or it may be cold worked to the hard temper, or further to spring temper. Intermediate tempers produced by cold working (rolling or drawing) are called "quarter-hard," "half-hard" and "three-quarters hard," and are determined by the amount of cold reduction and the resulting tensile properties. In addition to the annealed temper, conditions produced by thermal treatment are the solution heat treated temper and the heat treated and artificially aged temper. Other tempers involve a combination of mechanical and thermal treatments and include that temper produced by cold working after heat treating, and that produced by artificial aging of alloys that are as-cast, as-extruded, as-forged and heat treated, and worked.

Tempering—A process of reheating quench-hardened or normalized steel to a temperature below the transformation range, and then cooling at any rate desired.

Tensile Strength—The value obtained by dividing the maximum load observed during tensile straining until breakage occurs by the specimen cross-sectional area before straining. Also called "ultimate strength."

Terneplate—Steel sheet, hot dip coated with terne metal (10-15 pct. tin, 85-90 pct. lead).

Thermal Stresses—Stresses in metal, resulting from non-uniform distribution of temperature.

Thermal Treatment—Any treatment listed under annealing or heat treating.

Torsion—Strain created in a material by a twisting action. Correspondingly, the stress within the material resisting the twisting.

Transformation Range or Transformation Temperature Range—The temperature interval within which austenite forms while ferrous alloys are being heated. Also the temperature interval within which austenite disappears while ferrous alloys are being cooled. The two ranges are distinct, sometimes overlapping but never coinciding. The limiting temperatures of the ranges depend on the composition of the alloy and on the rate of change of temperature, particularly during cooling.

Transformation Temperature—The temperature at which a change in phase occurs. The term is sometimes used to denote the limiting temperature of a transformation range.

Transverse Test—This term should be used only in connection with test specimens, both tension and bend, and to indicate that their longitudinal axis is perpendicular to the direction in which the material from which they are cut is most drawn out. Although the stress applied to the transverse specimens will be in the direction of their longitudinal axis, this stress is at right angles to the longitudinal axis of the material. In speaking of bending flat-rolled products transversely it is understood that the bend or fold runs crosswise of the direction in which the material is most drawn out (i.e., across the grain).

Tube Reducer—A machine in which a pair of rolls is used for cold rolling tubing and rod. These rolls have a tapered groove around part of their surface, corresponding to the intended change in outside dimension of the tube or rod. The stock is rotated between working strokes. This process is somewhat different from the Pilger process in that the stock moves in the same direction, as rolling proceeds; the axes of the rolls move back and forth parallel to the stock; and the direction of rotation of the rolls changes between the forward working stroke and the backward return stroke. A fixed mandrel is used in rolling tubing.

Tubing—A non-standardized hollow shaped product with a relatively uniform wall thickness, generally round, square, or rectangular, and manufactured to specified requirements for dimensions, chemical analysis, mechanical properties and other characteristics (such as surface) required for applications in aircraft, sanitary, mechanical, pressure, ornamental or structural uses. It is generally specified to two dimensions, i.e., OD (Outside Diameter) and wall, ID (Inside Diameter) and wall, or OD and ID It is not primarily designed for use with standard threaded pipe couplings or for applications where standard or heavy wall pipe is normally used.

Ultimete Strength—The greatest load per square inch of original cross-sectional area carried during a tension test to failure. The term "ultimate strength" is preferred to "tensile strength."

Upset—The product of any cold or hot forming of material in which the metal is thickened by being forced back into itself. It is usually done at a red heat by hammering or press forging. Upset tubes are those whose ends have their walls so thickened for a short distance, usually to such an extent that the threading leaves as great a thickness of metal below roots of threads as in main body of tubes. Upset tubes are much used as stay tubes; they are sometimes called stove tubes.

Viscosity—The resistance of fluid substance to flowing, quantitatively characteristic for each individual substance at a given temperature and under other definite external conditions.

Weld Bead—The built-up portion of a weld, formed either from the filler metal or from the parent metal.

Welding—A process used to join metals by the application of heat. Fusion welding, which includes gas, arc and thermit welding, requires that the parent metals be melted. This distinguishes fusion welding from brazing. In pressure or resistance welding, joining is accomplished by the use of heat and pressure without melting. The parts that are being welded are pressed together and heated simultaneously, so that recrystallization occurs across the interface.

Welding, Arc—The method of uniting metals by use of an electric arc to raise the metal temperature to the fusion point.

Welding, Electric Resistence—The method of uniting metals by passage of an electric current through the metal, whereby the resistance of the metal results in a temperature increase at the abutting surfaces sufficient to effect union. Pressure is generally applied to insure intimate contact of the surfaces to be welded.

Welding, Fusion—Joining of metals by heating the adjoining parts to the melting point. The molten puddle formed becomes the joint. Arc, gas and thermit welding are examples of fusion welding.

Welding, Ges—The use of acetylene or other suitable gas to raise the metal temperature sufficiently to effect complete union.

Walding, Induction—A form of electric resistance welding wherein the welding heat is generated within the metal by resistance to the flow of an electric current induced in the metal by means of a circumferential or tangent coil.

Welding, Inert Arc—Arc welding in an atmosphere of an inert gas which serves to protect the molten puddle from contamination and oxidation by preventing air from coming in contact with the metal while it is at elevated temperatures.

Welding, Plasme Arc—The plasma arc process concentrates a jet stream of gas on a restricted weld area, providing more control and uniformity of the weld than was before possible. Used to produce welded stainless steel pipe and tubing in the heavier wall thicknesses.

Welding Stress—The stress resulting from localized heating and cooling of metal during welding.

Woody Fracture—A descriptive term for fracture of sound, though dirty steel, frequently also reedy or conchoidal in appearance, and often containing discernible slag particles. Woody fractures sometimes contain many small slivery areas, too numerous and small to be correctly termed "flakes" and of a different nature.

Work Hardness—Hardness developed in metal as a result of cold working. See Cold Working.

Workability—The characteristic or group of characteristics that determines the ease of forming a metal into desired shapes.

Wrought Iron—A commercial iron produced by the Aston process or in a puddling furnace. It contains little carbon and a considerable amount of included slag that, due to subsequent working, gives a fibrous structure to the iron.

Yield Point—In mild or medium-carbon steel, the stress at which a marked increase in deformation occurs without increase in load. In other steels and in nonferrous metals this phenomenon is not observed. See Yield Strength.

Yield Strength—The stress at which a material exhibits a specified limiting deviation from proportionality of stress to strain. An offset of 0.2 pct. is used for many metals such as steel, aluminum base, and magnesium base alloys while a 0.5 pct. total elongation under load is frequently used for copper alloys.

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