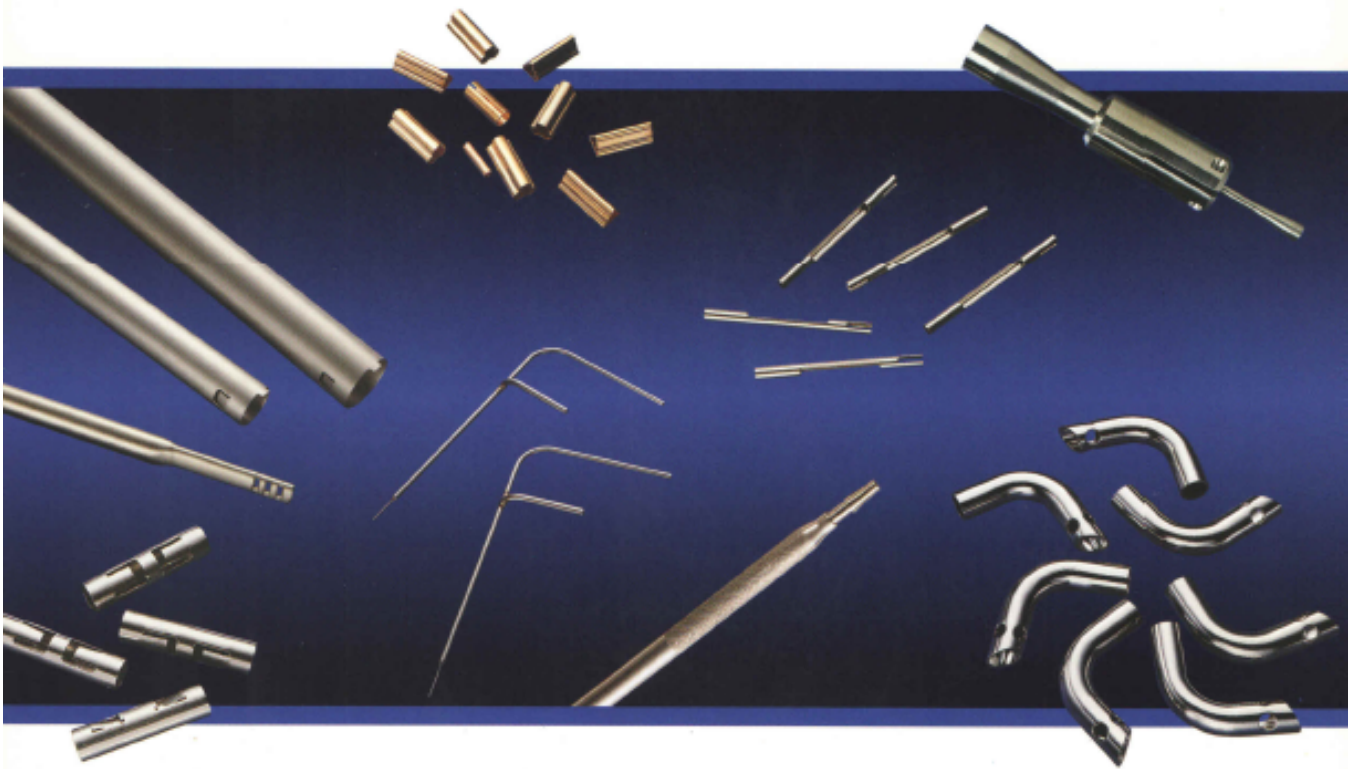




## ***FABRICATION & ALLOY SELECTION***

***A Guide for Designing with Small Metal Tubing***



## A Guide for Designing with Small Metal Tubing

Miniature metal tubing is defined as tubing with outside diameters as small as three thousandths of an inch to as large as 5/8 of an inch.

Miniature tubing, which can be provided as either seamless or welded and drawn, is produced by cold drawing in order to obtain:

1. Smooth, bright surfaces
2. Precise dimensional accuracy
3. Thin walls
4. A variety of mechanical properties and configurations

Seamless tubing is produced from pierced, extruded or drilled bar or billet which is formed into a tube hollow. The tube hollow is then progressively drawn down to finish size. Welded and drawn tubing begins as cold rolled strip which is produced in long coils, shaped into tubular form, and welded. No filler materials or flux are used in the welding operation and therefore the weld bead is of the same analysis as the parent metal. The tube is then progressively drawn down to finish size. Due to cold working and intermediate annealing, the weld zone recrystallizes and becomes homogenous with the parent metal, and becomes equivalent to the parent metal in ductility, appearance and mechanical properties. Potential benefits of welded and drawn tubing are uniform wall thickness and reduced cost.

**Cold drawing consists of pulling or drawing the tubing through a die which is smaller in diameter than the outside of the tube.**

While it passes through the die, it is usually supported on the inner surface, or I.D., by a tool called a mandrel, which controls the inside diameter, wall thickness and length of the tube. The cold drawing process is repeated until the desired tube size is reached. Cold drawing reduces ductility (pliability) of the alloy. To prevent this, the tubing is normally annealed between the drawing operations, which increases the ductility and prevents brittleness. The frequency of annealing (and subsequent cleaning and straightening operations) depends on the type of material and amount of diameter and wall reduction desired. This reduction is measured by the change in cross sectional area which takes place as the tubing passes through the die.





**The benefits of tubing define the areas where the designer should consider the use of tubular parts.**

Here are some benefit guidelines:

1. Difficult miniature shapes
2. Close tolerance
3. Elimination of expensive machining operations
4. Fewer finishing operations
5. Broad range of alloys
6. Reduction of size and weight
7. Maximize electrical and mechanical properties
8. Reduced materials cost
9. Built-in burr-free and smoother finishes
10. Potentially significant cost reduction



**Designers should recognize that tubing is available in shapes other than round.**

Small diameter precision tubing can be made square, triangular, oval, hexagonal, rectangular, trapezoidal, or tear-shaped, as well as more complex shapes. Starting with a shape other than round has, in many cases, considerably reduced the manufacturing costs of the ultimate assembly.

The information which follows on fabrication and alloys is intended as a general guide for miniature tubing and tubular parts. Other secondary operations and/or combinations thereof, closer tolerances, and finer finishes are available on application, dependent on the alloy and size.

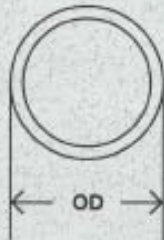
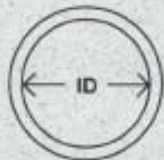





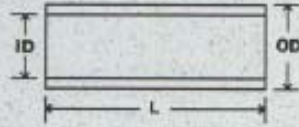
## Fabricating Fine Tubing

The designer has a host of options when considering precision small diameter tubing. There is little in the way of fabrication that cannot be achieved in spite of the miniaturization involved. The following pages give some indication of operations which can be performed individually or in various combinations on miniature tubing.

Included in the line drawings are helpful engineering parameters which are normally obtainable. Parameters shown can sometimes be exceeded with a corresponding cost increase due to any special operations involved.

Outside Diameters	Inside Diameters	Wall Thickness																						
																								
Minimum: .003" Normal Tolerances:	Minimum: .002" Normal Tolerances:	Minimum: .0005" Normal Tolerances:																						
<table style="width: 100%; border: none;"> <tr> <td style="text-align: center; border: none;">&lt;.03"</td> <td style="text-align: center; border: none;">.03"-.09"</td> <td style="text-align: center; border: none;">.09"-.25"</td> <td style="text-align: center; border: none;">&gt;.25"</td> </tr> <tr> <td style="text-align: center; border: none;"><math>\pm .00025"</math></td> <td style="text-align: center; border: none;"><math>\pm .0005"</math></td> <td style="text-align: center; border: none;"><math>\pm .00075"</math></td> <td style="text-align: center; border: none;"><math>\pm .001"</math></td> </tr> </table>	<.03"	.03"-.09"	.09"-.25"	>.25"	$\pm .00025"$	$\pm .0005"$	$\pm .00075"$	$\pm .001"$	<table style="width: 100%; border: none;"> <tr> <td style="text-align: center; border: none;">&lt;.03"</td> <td style="text-align: center; border: none;">.03"-.09"</td> <td style="text-align: center; border: none;">.09"-.25"</td> <td style="text-align: center; border: none;">&gt;.25"</td> </tr> <tr> <td style="text-align: center; border: none;"><math>\pm .00025"</math></td> <td style="text-align: center; border: none;"><math>\pm .0005"</math></td> <td style="text-align: center; border: none;"><math>\pm .001"</math></td> <td style="text-align: center; border: none;"><math>\pm .0015"</math></td> </tr> </table>	<.03"	.03"-.09"	.09"-.25"	>.25"	$\pm .00025"$	$\pm .0005"$	$\pm .001"$	$\pm .0015"$	<table style="width: 100%; border: none;"> <tr> <td style="text-align: center; border: none;">&lt;.010"</td> <td style="text-align: center; border: none;">.010"-.020"</td> <td style="text-align: center; border: none;">&gt;.020"</td> </tr> <tr> <td style="text-align: center; border: none;"><math>\pm 10\%</math></td> <td style="text-align: center; border: none;"><math>\pm .001"</math></td> <td style="text-align: center; border: none;"><math>\pm .0015"</math></td> </tr> </table>	<.010"	.010"-.020"	>.020"	$\pm 10\%$	$\pm .001"$	$\pm .0015"$
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<.010"	.010"-.020"	>.020"																						
$\pm 10\%$	$\pm .001"$	$\pm .0015"$																						
Maximum: .825" Normal Surface Finish: 32 microinch	Normal Surface Finish: 63 microinch <b>Concentricity</b> Seamless - normally, within $\pm 10\%$ of wall thickness. Welded & Drawn - normally, within $\pm 5\%$ of wall thickness.	Maximum: .049" Normal Tolerances:																						

## Cutting



L	<2"	2" - 6"	6" - 18"	18" - 36"
Tol.	±.003	±.005	±.010	±.016

OD & ID Burr — Burr free to .001 max.  
 Can deburr to slight radius,  
 OD & ID Distortion — None to .001 max.

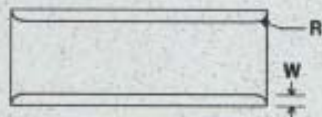
**Cutting** — is the first and perhaps the primary technique, and from the standpoint of accuracy and rate, cutting has great value in manufacturing methods. Depending on dimensions and material to be cut, there are several employable methods which affect both quality and cost. The table below provides a general summary.



CUTTING					
Method of Cutting	Length (inches)		Tolerance ± (inches)	Rate pcs/hr.	Need to deburr
	Max.	Min.			
Screw Machines	6	.05	.001	50/3500	yes
Shear	6-12	.02	.003	500/20,000	no
Radial Saw	6-12	.2	.010	500/1200	yes
ECM	6-12	.2	.005	500/6000	no
Score	6-12+	.2	.010	500/1200	no

**Method of Cutting** — note that there are similarities in end result, but also note the differences in rate and deburring requirements. Of the five methods described for cutting, only three yield essentially burr-free ends. If either of the other two methods are used, an additional operation is necessary to remove the burr which adds to the cost. In the case of very fine tubing, where the I.D. is .250" or less, removing I.D. burrs becomes more difficult. The cut tube, independent of cutting methods, serves as the basis of all further forming operations.

## ID Radius

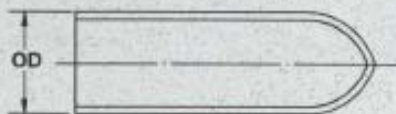


R max.  $\approx .25 \times W$   
 Coined radius will be smooth and free of burrs or serrations.

Ends of shear cut tubes can be coined as indicated in the illustration to permit unrestricted assembly of mating components, or to insure burr-free configuration. ECM provides a slight inside radius, which is inherent to the process.



## Closing

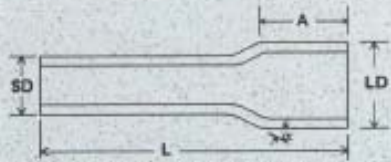


.250 Max. O.D.  
 $\frac{OD}{WALL} = 10 \text{ to } 20$  - Depending on Alloy

The closure and its shape can be varied depending on its application. As a general guideline, hermetic closures can be achieved depending on wall thickness and alloy.



## Reducing/Expanding

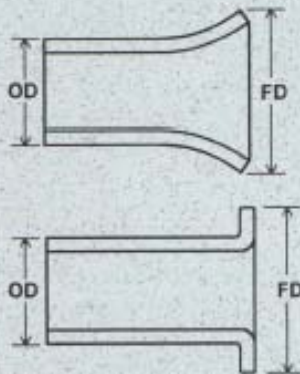


SD Depends upon LD, Wall and Alloy, can be .5 or less  
 LD  $\propto$  nom.  $\approx 13$  L Tol.  $\approx \pm .010$  A Tol.  $\approx \pm .010$

Reducing and/or expanding is a geometry that has application in a wide degree of markets. Parameters are as indicated.



## Flaring & Flanging



FD max.  $\approx 1.4 \times$  OD  
 Tol.  $\approx \pm .005$   
 Internal and external corners will be rounded.

**Flaring** — as the name connotes, is a flaring or angular expansion usually of both I.D. and O.D., one purpose being to provide a lead-in to the I.D. This assists in automatic assembly and/or for sealing. Small flared tubes can be supplied from tubing as small as .025" O.D. They are generally formed with a flaring tool which has a radius shape as opposed to an angular shape, and the flare diameter is normally 1.3 to 1.4 times the tubing diameter.

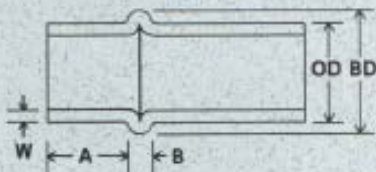
Differentiating from a normal flare which has a radiused contour is a *set flare* which has a specific conical configuration. The purpose is for definite sealing — the cone fitting into a corresponding matching part.



**Flanging** — flanged tubes are produced using forming tools which generally produce a 90 degree flange, creating a relatively accurate O.D. stop on a tube which is to be inserted into the end of another tube or part.

Flange diameters are generally 1.3 to 1.4 times the tube O.D. depending on wall thickness. There will always be at least a .005" radius under the flange. Since the flange diameter is formed, not trimmed, flange diameter tolerance must be at least plus or minus .003". Depending on alloy and O.D. size, flanged tubes can be produced from wall thickness of .005" or less to a maximum of about .020".

## Bulging/Beading



Tubular parts are frequently bulged to provide a stop for another part with which it comes in contact. The illustration indicates potential bulging/beading parameters.

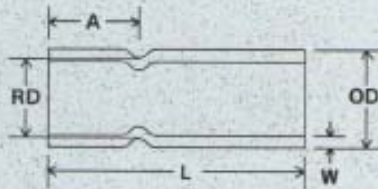
B = 2 x W  
 BD max.  $\approx 1.4 \times$  OD  
 A min.  $\approx .03$   
 L  $\frac{.12 - 1.25}{\pm .003} \quad \frac{1.25 - 6.00}{\pm .005}$

Tol.  $\approx \pm .002$   
 Tol.  $\approx \pm .003$   
 Tol.  $\approx \pm .003$

Internal & external bulge corners will be rounded.



## Corseting



OD max.  $\approx .188$   
RD min.  $\approx .7 \times OD$   
A min.  $\approx .7 \times OD$

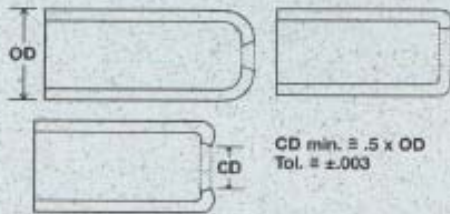
Tol.  $\approx \pm .002$   
Tol.  $\approx \pm .005$

L max.  $\approx 1.00$  Tol.  $\approx \pm .005$   
OD/W max.  $\approx 20$ , min.  $\approx 6$

Corsets, as in bulging, provide a stop, internal in this case, again where one part is in intimate contact with another. The illustration indicates corseting parameters.



## Rounded End Tubes



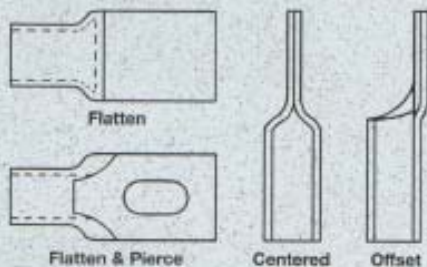
CD min.  $\approx .5 \times OD$   
Tol.  $\approx \pm .003$

Internal and external corners will be rounded.

Tubes can be supplied with one or both ends rounded or tapered to close the end down to approximately 50% of the O.D. Although the preference is to have full spherical radius, smaller radii can be supplied depending on the wall thickness of the tube. The inside surface is free formed, not supported, on production equipment, so a limited control over I.D. corner radii exists. This style part can be supplied from tubing .030" O.D. and up.



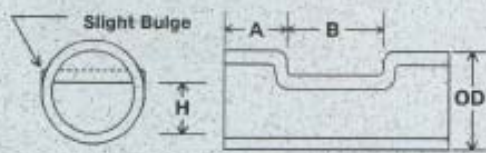
## Flatten, Flatten & Pierce



Tubular parts can be supplied with one end flattened and pierced. Pierced holes can be round or elongated. All flattening is done without restriction of material so that flat width and thickness are relative to the tubing size selected. The ends of flat tubes are not typically trimmed. The flattened section can be offset or on the center line of the tube. Illustration indicates the various alternatives for flattened ends, but keep in mind that tubes may also be flattened at locations other than the end.



## Dimpling



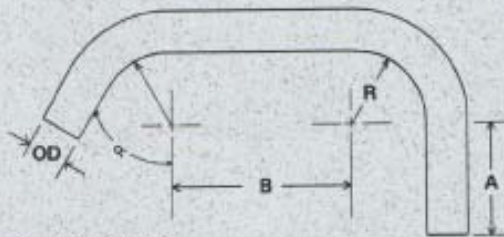
H min.  $\approx .7 \times OD$   
A Tol.  $\approx \pm .005$   
B Tol.  $\approx \pm .005$

Tol.  $\approx \pm .003$

When creating a dimple in a tube, it is important to note that a slight bulge on the O.D. will result.



## Bending & Coiling

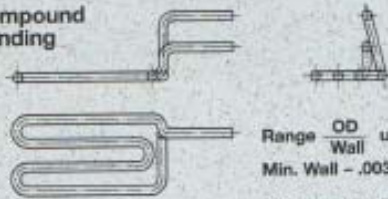


### Simple Bending

$R$  min.  $\approx 2 \times OD$  for  $<10\%$  closure  
 $A$  min.  $\approx 2 \times OD$  to eliminate secondary trim  
 $A$  Tol.  $\approx \pm .005$  other end  $\approx \pm .010$   
 $A$  Tol.  $\approx \pm .010$   
 $B$  Tol.  $\approx \pm .010$   
 $\alpha$  Tol.  $\approx \pm 1^\circ$

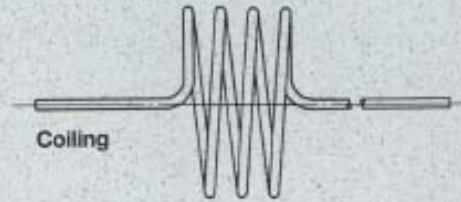
In general, a tube can be bent satisfactorily around a radius 2.5 times the O.D. of the tube without internal support. For tighter bends, a special mandrel is used to avoid kinking and collapse. This raises costs, but makes it possible to bend tubing around a radius as small as the O.D. of the tubing. Compound bending should be avoided whenever possible. Ends of tubes can be coiled to permit unrestricted assembly of mating components, or to ensure burr-free configuration.

### Compound Bending



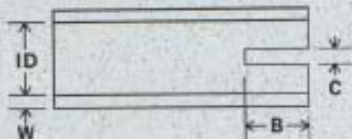
Range  $\frac{OD}{Wall}$  up to 20  
 Min. Wall - .003  
 Min. Bend Radius =  $2 \times$  Tube O.D.

### Coiling



$\frac{OD}{W}$  range Min.  $\frac{20}{1}$   
 Min. Wall - .003  
 Min. Bend Radius =  $2 \times$  Tube O.D.

## Slotting

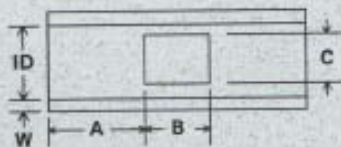


$C$  max.  $\approx ID - 4 \times W$   
 $C$  min.  $\approx 2 \times W$  (.006 min.)  
 $B$  Tol.  $\approx \pm .005$   
 Tol.  $\approx \pm .001$   
 Slot Burr - free to .001 max.  
 Available in multiple slot configurations with or without crimping.

Slotting is used for a wide variety of applications, and the operation is not limited to a single slot. As an example, to affix wires in a tube, the tube is slotted and the wires are crimped in place.



## Punching

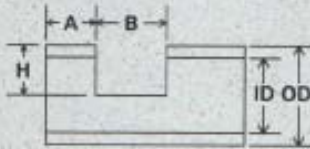


$A$  min.  $\approx 2 \times W$   
 $B$  min.  $\approx 2 \times W$  (.010 min.)  
 $C$  max.  $\approx ID - 4 \times W$   
 $C$  min.  $\approx 2 \times W$  (.010 min.)  
 Tol.  $\approx \pm .003$   
 Tol.  $\approx \pm .001$   
 Tol.  $\approx \pm .001$   
 Tol.  $\approx \pm .001$   
 Hole Burr - Burr free to .001 max. Round, elongated, and multiple hole configurations are available.

Round, square or elongated holes can be punched in a tube. Shapes and locations around tube can be varied as specified.



## Notching



H max.  $\approx .5 \times OD$   
 ID min.  $\approx .06$   
 A min.  $\approx 2 \times W$   
 B min.  $\approx 2 \times W$  (.010 min.)

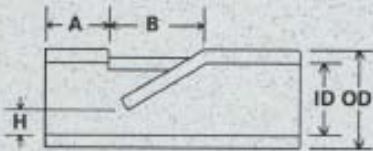
Tol.  $\approx \pm .002$   
 Tol.  $\approx \pm .003$   
 Tol.  $\approx \pm .002$

Available with multiple notches and notch at end of piece.

Single or multiple notching is frequently required. Tubes can be notched at the end of the unit or as close to the end as needed by creating a notch and then shear cutting the tube so that the notch is burr-free.



## Lancing



Tab Width max.  $\approx ID - 4 \times W$   
 Tab Width min.  $\approx 2 \times W$  (.010 min.)  
 A min.  $\approx 2 \times W$   
 H Tol.  $\approx \pm .003$

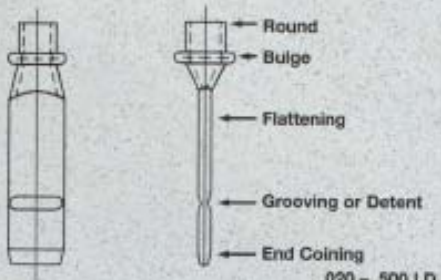
Tol.  $\approx \pm .001$   
 Tol.  $\approx \pm .003$

Available with multiple tabs.

Tubes are lanced for various reasons including the creation of an internal stop. A single tab or multiple tabs can be located on a tube as required.



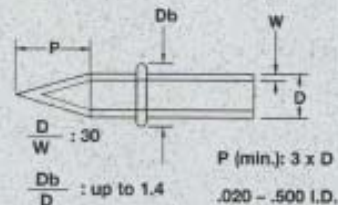
## Multiple Fabrication Operations



Multiplicity of Secondary Operations

Frequently, designs call for a combination of fabrication operations. Multiple practical combinations can be provided. Illustration shows a part that was bulged, flattened, tapered, corseted, and end-coined.

Shown also are the geometries of a bulged, tapered, and closed part.



Bulging, Tapering and Closing



## **EDM**

Electrical Discharge Machining (EDM) removes metal through the action of high-energy electrical discharges on the surface of the workpiece. It is applicable to materials which are good electrical conductors and since there is virtually zero force between the tool and the workpiece, very delicate and intricate parts may be produced from this method.



Profiles and slots can be produced using either wire or electrode plunge type machines. These processes provide a sharp, burr-free edge. Very smooth surfaces can be achieved through the use of a fine finishing pass.

Circular and shaped holes can be produced using EDM drilling type machines. This process can produce holes as small as 0.006" diameter. Hole quality will be slightly lower than the electrode plunge, however production rates are higher.



## **ECM/ECG**

Electrochemical machining (ECM) removes material through a combination of abrasion and electrochemical action. An electrical circuit is established between the power supply, the cut-off-wheel and the workpiece through an electrolyte which is directed at the wheel-workpiece interface. This process provides burr-free machining with considerably less cutting wheel wear.



Electrochemical cut-off is a high speed tube cut-off process for producing burr-free straight cut tubular blanks. Blank lengths range from 0.25 inch to 44 inches. Tube outside diameters range from 0.010 inch to 0.625 inch. Length tolerances of  $\pm 0.003$ " and perpendicularity tolerances of 1/2 degree are possible.

Electrochemical grinding (ECG) is a surface profile forming process. An inverse profile is "dressed" into the grinding wheel and as the wheel is passed over the tubular part the desired profile is produced burr-free on the part. Edge condition can be specified as being sharp to slightly radiused. Tolerances are typical of traditional form grinding.



## Assembly Products

Tubular assemblies are found in a limitless number of applications. Assembly techniques such as Snap, Captive, and Interference or Shrink fits are a cost effective method of joining. Brazing, Soldering, Welding and Adhesive bonding are also methods commonly used. Employing the full range of fabrication possibilities can reduce both the number of components and the number of joinings within the assembly. Examples of these different assembly methods are illustrated below and on the opposite page.



**Burr assembly used in arthroscopic surgery**



**Tubular assembly for critical lighting application**

**Minimally invasive surgical instrument used for biopsy procedures**



**Diagnostic aspiration probe**





**Hinge assembly for a  
laptop computer**



**Complex assembly used  
in prostate surgery**



**Bi-tubular  
device for  
sinus surgery**

**Metering probe**



**Metering  
probe**



## Alloys

Selecting the proper alloy for your particular application is important in order to achieve maximum performance and price benefits. When selecting the proper alloy many factors must be taken into consideration, including electrical and mechanical properties such as ultimate strength, electrical conductivity, specific weight, useful temperature range, modulus of elasticity, and corrosion resistance.

ALLOY	CHEMICAL COMPOSITION (%)	PHYSICAL PROPERTIES			
		Melting Range (°F)	Density (lb/in <sup>3</sup> ) @ 68°F	Thermal Expansion (in/in/°F x 10 <sup>6</sup> )	Electrical Resistivity (ohms/cir mil/ft.) 68°F
<b>Nickel Alloys</b>					
Nickel 200, "A" Nickel	Ni 99.5; C 0.06; Mn 0.25; Fe 0.15; S 0.005; Si 0.05; Cu 0.05	2615-2635	0.321	7.9 (68-572°F)	57
Nickel 201, Low-Carbon Nickel	Ni 99.5; C 0.01; Mn 0.20; Fe 0.15; S 0.005; Si 0.05; Cu 0.05	2615-2635	0.321	7.8 (68-572°F)	50
Nickel 205, "A" Nickel (electronic grade)	Ni 99.5; C 0.06; Mn 0.20; Fe 0.10; S 0.005; Si 0.05; Cu 0.05; Ti 0.02; Mg 0.04	2615-2635	0.321	7.9 (70-500°F)	57
Monel <sup>®</sup> Alloy 400**	Ni 66.0; C 0.12; Mn 0.90; Fe 1.35; S 0.005; Si 0.15; Cu 31.5	2370-2460	0.319	8.7 (70-300°F)	307
Monel <sup>®</sup> Alloy 404	Ni 55.0; C 0.06; Mn 0.01; Fe 0.05; S 0.005; Si 0.02; Cu 44.0; Al 0.02	2370-2460	0.321	8.5 (70-500°F)	300
Monel <sup>®</sup> Alloy K-500, "K" Monel	Ni 65.0; C 0.15; Mn 0.60; Fe 1.00; S 0.005; Si 0.15; Cu 29.5; Al 2.80; Ti 0.50	2400-2460	0.306	8.2 (70-500°F)	370
Inconel <sup>®</sup> Alloy 600	Ni 76.0; C 0.04; Mn 0.20; Fe 7.20; S 0.007; Si 0.20; Cu 0.10; Cr 15.8	2500-2600	0.304	7.8 (70-500°F)	620
Inconel <sup>®</sup> Alloy 601	Ni 60.5; Cr 23.0; Fe 14.0; Al 1.35; Cu 0.5; Mn 0.5; Si 0.25; S 0.007; C 0.05	2375-2495	0.291	7.6 (80-200°F) 9.3 (80-1500°F)	717

Over 90 alloy options are available. Many of the most commonly required alloys are detailed below. Consult UT for availability of specific alloys.



A	65	15	45	B65	Combines good mechanical and electrical properties with corrosion and oxidation resistance. Retains much of its strength at high temperatures and is tough and ductile at subzero temperatures.
H/2	85	55	15	B75	
H	100	90	6	B95	
A	65	15	45	B65	Specified over Nickel 200 for exposure to temperatures above 600°F. Stable in oxidizing atmospheres to 2000°F. Used as thermocouple sheaths in molten salt baths at temperatures to 1200°F. Frequently used in electronic components requiring severe bending, flaring, expanding or flanging.
H/2	85	55	15	B75	
H	100	90	6	B95	
A	65	15	45	B65	Specified for electrical and electronic parts. Elasticity and dampening factors are sufficiently high to minimize vibrational and microphonic effects. Has sufficient strength at normal bombardment temperatures to prevent deformation during outgassing. Has high curie temperature and magneto-striction coefficient.
H/2	85	55	15	B75	
H	100	90	6	B95	
A	75	40	40	B70	Excellent corrosion resistance and high mechanical strength at temperatures to 1200°F. Specified for surgical instruments and for critical instrument parts exposed to salt water.
H/2	95	65	20	B85	
H	120	100	6	O20	
A	75	40	40	B70	Low magnetic permeability and excellent brazing characteristics. Good strength at outgassing temperatures.
H/2	95	65	20	B85	
H	120	100	6	C20	
A	90	50	35	B85	Non-magnetic temperatures below -210°F. Retains strength, toughness, and ductility down to -423°F.
H/2	115	80	15	B95	
H	140	100	6	C20	
A	90	40	40	B85	Resists oxidation to 2150°F. Resists stress corrosion cracking. Excellent mechanical properties at subzero or high temperatures.
H/2	115	75	20	B95	
H	145	120	6	C30	
A	100	40	40	B90	Resists oxidation and scaling to 2300°F. Used for furnace parts, heat treating fixtures, and thermocouple protection tubes.
H/2	120	70	20	B95	
H	145	120	6	C30	

ALLOY	CHEMICAL COMPOSITION (%)	PHYSICAL PROPERTIES			
		Melting Range (°F)	Density (lb/in <sup>3</sup> ) @ 68°F	Thermal Expansion (in/in/°F x 10 <sup>3</sup> )	Electrical Resistivity (ohms/cir mil/ft.) 68°F
<b>Nickel Alloys (cont.)</b>					
Inconel® Alloy 625	Ni 61.0; Cr 21.5; Mo 9.0; Fe 2.5; Si 0.25; Mn 0.25; Al 0.2; Ti 0.2; S 0.008; C 0.05; Cb 3.6	2350-2460	0.305	7.1 (70-200°F) 8.8 (70-1600°F)	776
Inconel® Alloy 718	Ni 52.5; Cr 19.0; Cb 5.1; Mo 3.1; Ti 0.9; Al 0.5; C 0.08; Balance Fe	2300-2440	0.296	7.2 (70-200°F) 9.5 (70-1600°F)	753
Inconel® Alloy X-750, Inconel "X"	Ni 73.0; C 0.04; Mn 0.70; Fe 6.75; S 0.007; Si 0.30; Cu 0.05; Cr 15.0; Al 0.80; Ti 2.50; Cb 0.85	2540-2600	0.298	7.5 (80-600°F)	731
Nichrome V	Ni 90.0; Cr 20.0	2550	0.304	7.9 (70-500°F)	650
Hastelloy® C-22 Alloy	Ni 56; Cr 22; Mo 13; Fe 3; W 3; Co 2.5; Mn 0.5; V 0.5; Si 0.08; C 0.01	2475-2550	0.314	7.0 (75-600°F)	685
Hastelloy® X Alloy	Ni 47; Cr 22; Fe 18; Mo 9; Co 1.5; W 0.6; C 0.10; Mn 1.0; Si 1.0; B 0.008	2300-2470	0.297	8.6 (79-1200°F)	712
<b>Ferrous Alloys</b>					
Type 304 Austenitic Stainless Steel	Cr 19.0; Ni 10.0; Balance Fe. Allowable maximums: C 0.08; Mn 2.0; Si 1.0; P 0.045; S 0.030	2550-2650	0.286	9.6 (32-212°F)	433
Type 304L Austenitic Stainless Steel	Cr 19.0; Ni 10.0; Balance Fe. Allowable maximums: C 0.03; Mn 2.0; Si 1.0; P 0.045; S 0.030	2550-2650	0.286	9.6 (32-212°F)	433
Type 305 Austenitic Stainless Steel	Cr 18.0; Ni 12.0; Balance Fe. Allowable maximums: C 0.12; Mn 2.0; Si 1.0; P 0.045; S 0.030	2550-2650	0.286	9.6 (32-212°F)	440
Type 310 Austenitic Stainless Steel	Cr 25; Ni 20; Balance Fe Allowable Maximums: C 0.08; Mn 2.00; Si 1.50; P 0.045; S 0.030	2550-2650	0.285	8.5 (0-600°F)	470
Type 316L Austenitic Stainless Steel	Cr 17; Ni 13; Mo 2.5; Balance Fe Allowable Maximums: C 0.03; Mn 2.00; Si 1.00; P 0.045; S 0.030	2500-2550	0.284	9.0 (0-600°F)	445
Type 316L Austenitic Stainless Steel Medical Grade	Cr 17; Ni 13; Mo 2.5; Balance Fe Allowable Maximums: C 0.03; Mn 2.00; N 0.1; Si 1.00; P 0.045; S 0.030	2500-2550	0.284	9.0 (0-600°F)	445
Type 321 Austenitic Stainless Steel	Cr 18; Ni 10; Ti 0.40; Balance Fe Allowable Maximums: C 0.08; Mn 2.00; Si 1.00; P 0.045; S 0.030	2550-2600	0.286	9.2 (0-600°F)	433



TYPICAL MECHANICAL PROPERTIES*					APPLICATIONS AND CHARACTERISTICS
Temper	Ultimate Tensile Strength (psi x 10 <sup>3</sup> )	Yield Strength (psi x 10 <sup>3</sup> )	Elongation (%)	Hardness	
A H/2 H	125 150 200	70 110 150	40 20 5	B95 C30 C40	Combines high strength, excellent fabricability and outstanding corrosion resistance. Used for chemical processing, combustion systems, and marine applications.
A H/2 H	140 160 200	75 120 150	30 15 5	B100 C30 C40	
A H/2 H	120 165 200	50 110 150	45 20 5	B90 C30 C40	
A H/2 H	100 120 150	50 100 120	45 20 5	B80 B95 C25	Resists oxidation to 2100°F. High electrical resistance at elevated temperatures in heating elements and cathode support sleeves.
A H/2 H	116 151 192	59 127 174	57 23 9	B90 C33 C40	Excellent resistance to oxidizing aqueous media including wet chlorine and mixtures of nitric acid or oxidizing acids with chlorine ions. High resistance to fretting, crevice corrosion and stress corrosion cracking.
A H/2 H	110 145 170	55 120 150	44 15 8	B90 C31 C37	Exceptional combination of oxidation resistance, fabricability and high-temperature strength.
A H/2 H*	85 125 140	40 105 130	50 20 12	B85 C25 C30	Offers good corrosion and heat resistance. Mechanical properties good down to -300°F and up to 1650°F.
A H/2 H*	85 125 140	40 105 130	50 20 8	B85 C25 C30	Weldments for corrosive conditions where intergranular carbide precipitation must be avoided. Nuclear components.
A H/2 H*	85 120 160	40 90 130	50 25 8	B85 B95 C30	Applications involving severe forming—fasteners, anodes, grid cups and other electrical components.
A H/2 H*	85 125 165	40 95 135	50 25 8	B85 C20 C30	Used for components requiring good heat resistance. Resists scaling in continuous service to 2100°F. Often used in processing equipment, thermocouple protective tubing and special fuel and conduit lines.
A H/2 H*	85 120 135	40 95 120	50 25 8	B85 C25 C30	Has highest creep strength of stainless steels and resists acid corrosion best. Used in pressure gages and other instruments exposed to chemicals, foods and pharmaceuticals.
A H/2 H*	85 120 135	40 95 120	50 25 8	B85 C25 C30	High strength and excellent corrosion resistance. Closely controlled chemistry for medical applications including body implants.
A H/2 H**	85 125 140-180	40 95 125-160	50 20 12	B85 C25 C30	Stabilized with titanium. Used in weldments for corrosive service in the 800° to 1650°F range.

\*The mechanical properties listed are averaged values and are to be used as informational guidelines. Specific requirements must be indicated if necessary.

\*\* Temper value is a function of O.D., wall, and the type of tube drawing process specified.



ALLOY	CHEMICAL COMPOSITION (%)	PHYSICAL PROPERTIES			
		Melting Range (°F)	Density (lb/in <sup>3</sup> ) @ 68°F	Thermal Expansion (in/in/°F x 10 <sup>6</sup> )	Electrical Resistivity (ohms/cir mil/ft.) 68°F
<b>Ferrous Alloys (cont.)</b>					
Type 347 Austenitic Stainless Steel	Same as for Type 321 except no titanium; instead Cb & Ta at 10 times minimum carbon	2550-2600	0.286	9.4 (0-600°F)	440
Type 410 Martensitic Stainless Steel	Cr 12; Balance Fe Allowable Maximums: C 0.15; Mn 1.00; Si 0.75; P 0.040; S 0.030	2700-2790	0.279	6.5 (32-1200°F)	342
Type 446 Ferritic Stainless Steel	Cr 27; N added 0.10-0.25; Balance Fe Allowable Maximums: C 0.20; Mn 1.50; Si 1.00; P 0.04; S 0.030	2550-2750	0.273	5.5 (0-600°F)	342
Type AM 350 Semi-Austenitic Stainless Steel	Cr 16.5; Ni 4.3; Mo 2.8; N 0.1; Balance Fe	2560-2625	0.282	6.3 (70-200°F)	475
Type 1020 Low-Carbon-Steel	C 0.20; Mn 0.45; Balance Fe	2750-2775	0.283	8.4	86
17-4 PH	C .07; Mn 1.00; Si 1.00; Cr 15.0-17.5; Ni 3.0-5.0; P .04; S .03; Cu 3.0-5.0; Nb 0.15-0.45	2560-2625	0.28	6.0 (212°F)	600
17-7 PH	C .09; Mn 1.00; Si 1.00; Cr 15.0-17.5; Ni 6.0-8.0; Al 1.0	2560-2625	0.28	6.0 (212°F)	600
<b>Reactive/Refractory Metals &amp; Alloys</b>					
Columbium	Cb	4474	0.31	3.82 (70°F)	79
Columbium + 1.0% Zirconium	Zr 0.8-1.2; Balance Cb	4350	0.31		
Titanium, Commercially Pure, Grade 2	Ti 98.6-99.3	3030-3040	0.164	5.8 (68-1650°F)	331
Titanium 6Al-4V	Al 5.5-6.75; V 3.5-4.5; Fe <.25	3000	0.161	5.3	758
Titanium 3Al - 2.5V	Al 2.5 - 3.5; V 2.0 - 3.0; Fe <.31	3100	.162	5.3 (32-1000°F)	758
Tantalum	Ta	5425	0.60	3.6 (70°F)	75
Zirconium	Zr	3350	0.237	3.1 (212°F)	240



TYPICAL MECHANICAL PROPERTIES*					APPLICATIONS AND CHARACTERISTICS
Temper	Ultimate Tensile Strength (psi x10 <sup>3</sup> )	Yield Strength (psi x10 <sup>3</sup> )	Elongation (%)	Hardness	
A H/2 H**	85 125 150-185	40 95 130-170	50 20 12	B85 C25 C30	Stabilized with columbium. Used for weldments in vibrating or corrosive services in the 800 to 1500°F range.
A H/2 H** HT	75 90 110-135 180	40 75 100-125 150	30 20 7 10	B85 B95 C20 C43	Low-cost, high-strength steel used in turbines, Bourdon springs, medical instruments, bushings, guided missiles, rocket components and high-pressure torque tubes. Excellent spring properties but poor impact resistance at low temperatures.
A H/2 H**	75 105 125-145	60 80 95-130	30 15 5	B85 B95 C25	Has greatest heat and electrical resistance of stainless steels. Resists corrosion well. Excellent for glass-to-metal seals. See Data Sheet 1064.
A H/2 H	140 160 200	60 110 160	30 15 5	B95 C30 C40	An age hardenable alloy also used where combination of high strength and corrosion resistance is required.
A H/2 H	55 68 90	40 58 75	35 15 5	B65 B78 B90	For structural tubular parts.
A H/2 H HT	150 180 210 240	125 150 185 225	20 17 14 6	C36 C42 C46 C52	Precipitation hardening stainless steel that exhibits high strength, excellent corrosion resistance and high temperature resistance. Common applications are aircraft, marine and chemical processing.
A H/2 H HT	150 175 200 230	125 150 175 225	20 17 14 6	C36 C42 C46 C52	Precipitation hardening stainless steel that exhibits high strength, excellent corrosion resistance and high temperature resistance. Frequently called for in aircraft and medical applications.
A H	40 80	35 70	30 5	55 (VHN) 120 (VHN)	Used in nuclear reactors and in high-temperature heat exchangers. Retains much of its strength at temps to 2000°F.
A H	48 90	40 80	30 5	65 (VHN) 140 (VHN)	Used for nuclear reactors, missiles and aircraft. Has good strength at high temps and is more easily welded than Cb.
A H/2 H	70 85 105	40 65 85	28 15 8	B60 B80 B90	Aircraft and processing equipment parts requiring good strength-to-weight ratio or excellent corrosion resistance.
A H/2 H	115 125 135	85 95 110	15 10 3	C32 C42 C50	An alpha-beta titanium alloy with a high strength to weight ratio and excellent corrosion resistance. The alloy is stable over the temperature range of -423°F to +1000°F, and has excellent fatigue properties and fracture toughness.
A H/2 H	115 120 135	8 95 110	15 10 3	C27 C37 C45	An alpha-beta titanium alloy with a high strength to weight ratio and excellent corrosion resistance. Useful properties and long life span to temperatures as high as 600°F.
A H	60 100	50 90	40 10	80 (VHN) 155 (VHN)	Used in capacitors, chemical plant equipment, electronic rectifiers, surgical implants, nuclear reactors, spacecraft. Resists all acids except hydrofluoric.
A H/2 H	65 75 90	40 60 80	25 15 5	B80 B88 B62	Chemical plant equipment.

\* The mechanical properties listed are averaged values and are to be used as informational guidelines. Specific requirements must be indicated if necessary.  
 \*\* Temper value is a function of O.D., wall, and the type of tube drawing process specified.



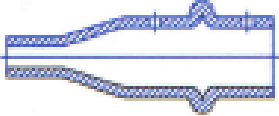
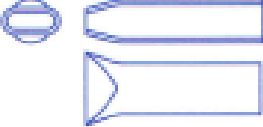

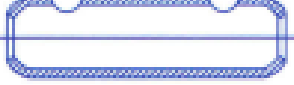




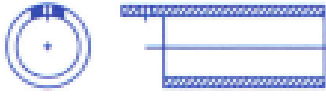



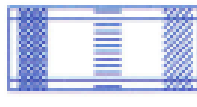



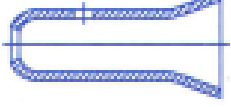

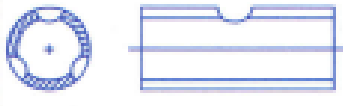

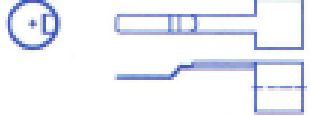



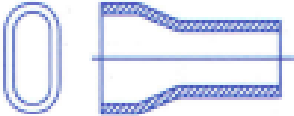
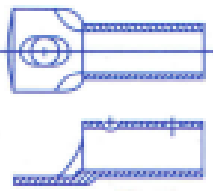
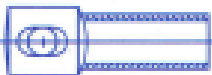
ALLOY	CHEMICAL COMPOSITION (%)	PHYSICAL PROPERTIES			
		Melting Range (°F)	Density (lb/in <sup>3</sup> ) @ 68°F	Thermal Expansion (in/in/°F x 10 <sup>6</sup> )	Electrical Resistivity (ohms/cir mil/ft.) 68°F
<b>Reactive/Refractory Metals &amp; Alloys (cont.)</b>					
Zircaloy 2	Sn 1.5; Fe 0.13; Cr 0.10; Ni 0.05; Balance Zr	3300	0.237	3.6 (212°F)	445
<b>Precious Metals</b>					
Gold	Au	1945	0.698	7.9	13.2
Fine Silver	Ag	1761	0.379	10.9	8.85
Coin Silver	Ag 90; Cu 10	1420-1620	0.371	—	11.9
Platinum	Pt	3224	0.775	5.1 (68°F-212°F)	59.2
Palladium	Pd	2826	0.434	6.5 (68°F)	64.9
<b>Shape Memory/Superelastic Alloys</b>					
Nitinol	Ni 55.8; Ti 44.2	2390	0.234	6.1	493
<b>Controlled Expansion and Glass Sealing Alloys</b>					
52 Alloy	Ni 51.0; Fe 49.0	2600	0.298	5.4 (70-1050°F)	281
Fe Ni Co	Ni 29, Co 17, Mn 0.3, Balance Fe	2606	0.302	2.9	294
42 Alloy	Ni, Co & Cu 40.25-41.75, C 0.05 max.; Mn 1.00 max; Si 0.10-0.40; Balance Fe	2606	0.293	3.18 (0-200°F)	421
36% Nickel-Iron Alloy Invar (TN The International Nickel Co.)	Ni, Co & Cu 34.50-36.50; C 0.10 max., Mn 0.50 max. Si 0.20-0.35; Balance Fe	2600	0.291	0.7 (0-200°F)	487
Ni-Span-C (TN The International Nickel Co.)	Ni 42; Cr 5.4; Ti 2.4; Fe 48.5; Al 0.65 Allowable Maximums: C 0.06; Mn 0.80 S 0.04; P 0.04; Si 1.00; Co 0.20	2650-2700	0.293	4.5 (-50 - +150°F)	611
<b>Cobalt High Temperature Alloys</b>					
L-605 Alloy (Haynes® 25 Alloy)	Co 51; Cr 20; W 15; Ni 10; Mn 1.5; C 0.10; Fe 3.0; Si 0.40	2425-2570	0.330	8.0 (70-1000°F)	540
Elgiloy®	Co 40; Cr 20; Ni 15; Mo 7.0; Mn 2.0; C 0.15; Be 0.10; Fe Bal	Approx. 2600	0.300	8.6 (70-900°F)	599
MP35N	Ni 35.0; Co 35.0; Cr 20.0; Mo 10.0	2400-2600	0.304	8.7 (70-1000°F)	615



TYPICAL MECHANICAL PROPERTIES*					APPLICATIONS AND CHARACTERISTICS
Temper	Ultimate Tensile Strength (psi x 10 <sup>3</sup> )	Yield Strength (psi x 10 <sup>3</sup> )	Elongation (%)	Hardness	
A H/2 H	70 85 105	50 75 95	25 15 5	B85 B90 B95	Nuclear Reactors.
A H	19 32	— 30	45 4		Chemical equipment, spacecraft and jewelry.
A H	22 54	8 44	40 5		Electrical components.
A H	40 65	20 55	40 5		Higher strength and better wearing properties than Fine Silver.
A H	18 35	— —	35 2	40(VHN) 95(VHN)	Electrical contacts, catalysts.
A H	27 54	— —	30 3	41 (VHN) 105 (VHN)	Electrical contacts, catalysts.
S.E.	167	65	10		Superelastic alloy.
A H/2 H	80 95 115	35 55 80	40 20 5	B75 B90 C20	Glass-to-metal seals. See Data Sheet 1064.
A H/2 H	70 95 115	50 70 80	30 10 5		Glass-to-metal seals. See Data Sheet 1064.
A H/2 H	80 100 130	35 55 85	35 20 6	B80 B90 C25	Glass-to-metal seals. See Data Sheet 1064.
A H/2 H	80 90 110	50 70 90	35 15 5	B80 B90 C25	Composite tubing for thermostatic controls. Sometimes used for glass-to-metal sealing.
A H/2 H	90 120 130	40 115 125	40 20 6	B75 B95 C25	Pressure-sensitive devices.
A H/2 H	144 175 230	65 145 180	55 25 14	C24 C40 C44	High temperature strength with good resistance to oxidizing environments up to 1800°F.
A H/2 H	120 160 210	40 120 170	35 15 5	B90 C35 C40	High temperature corrosion resistance with excellent fatigue life. Bio-compatible for use as surgical implements.
A H/2 H	140 165 200	65 130 180	50 25 5	B90 C25 C45	Provides excellent combination of high strength, ductility and corrosion resistance, and the alloy is resistant to most mineral acids and sea water.

\* The mechanical properties listed are averaged values and are to be used as informational guidelines. Specific requirements must be indicated if necessary.

## Specialty Fabrication Operations

 Reduced End - Bulge $\perp$ Pierced Holes	 Straight Cut - Flattened End	 Round End - Bulge
 Double Round End - Dbl. Side Pierced	 Reduced End - Bulge	 Crimped Tube
 Double Round End - Bulge	 Expanded Round - Ribbed	 Straight Cut - Pierced Tab
 Reduced - Round End	 Reduced - Both Ends	 Double Flare
 Straight Cut Cut - Keurl	 Flange $\perp$ Pierced Hole	 Double Bulge
 Flare - Bulge	 Round End $\perp$ Pierced - Flare	 Clover - Bulge
 Straight Cut - Dimples	 Straight Cut - Formed Oval	 Offset Lug - Trim & Form
 Double ID Radius $\perp$ Pierced Hole	 Reduced End - Notch	 Straight Cut - Notch "V" Form
 Expanded Oval	 Offset Lug	<p><b>Option A</b> Side Pierced Hole</p> <p><b>Option B</b> <math>\perp</math> Pierced Hole</p> <p>No Hole Round Hole Elongated Hole</p>  Center Flat Lug