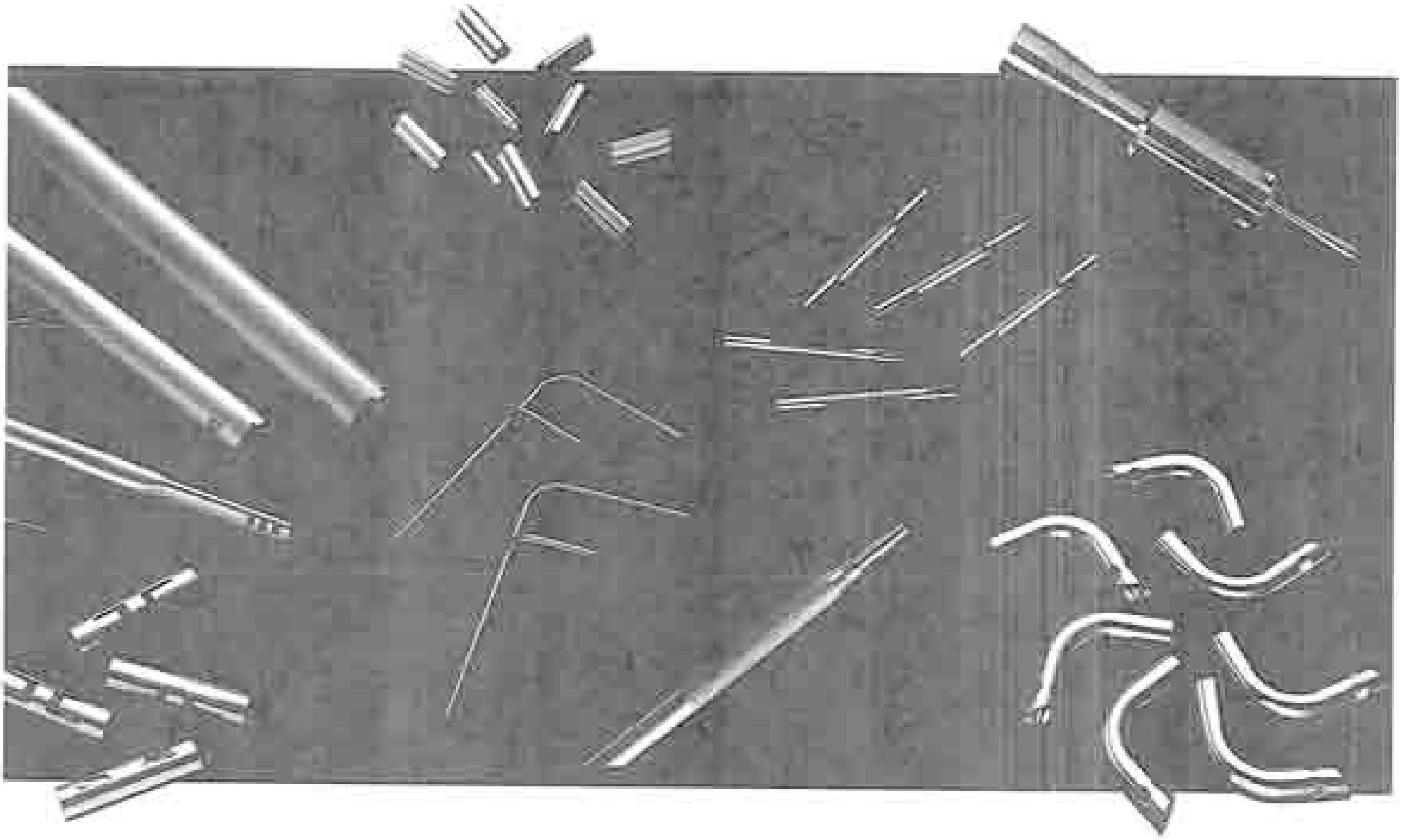
FABRICATION & ALLOY SELECTION

A Guide for Designing with Small Metal Tubing



accellent

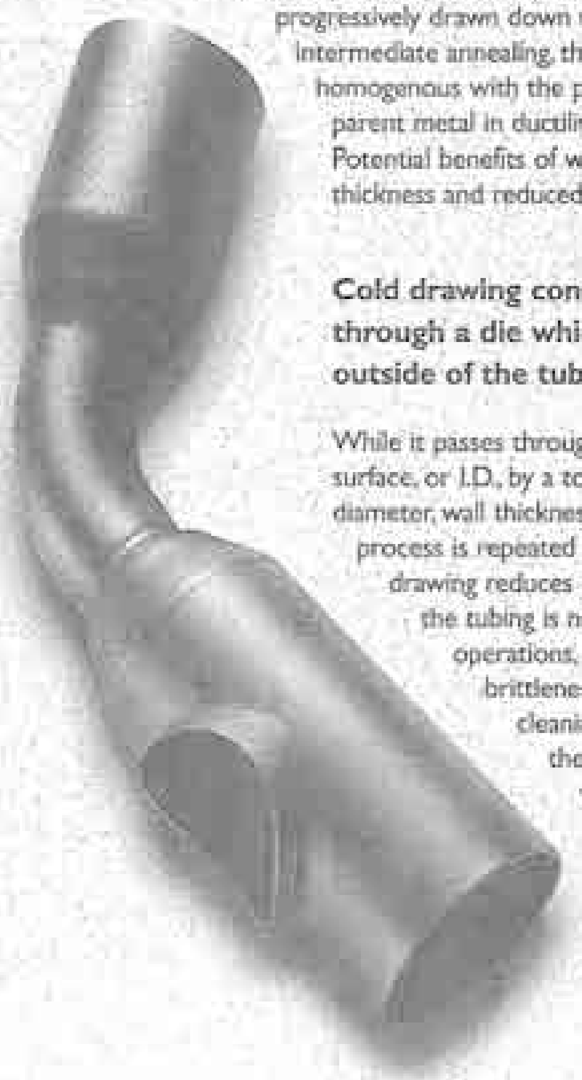
A Guide for Designing with Small Metal Tubing

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.

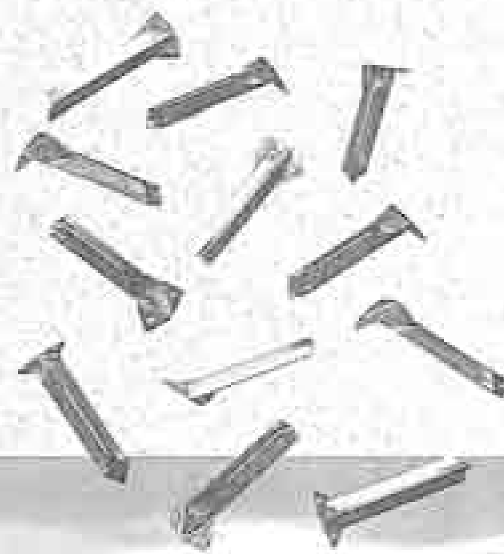
The benefits of tubing define the areas where the designer should consider the use of tubular parts.

Here are some benefit guidelines:

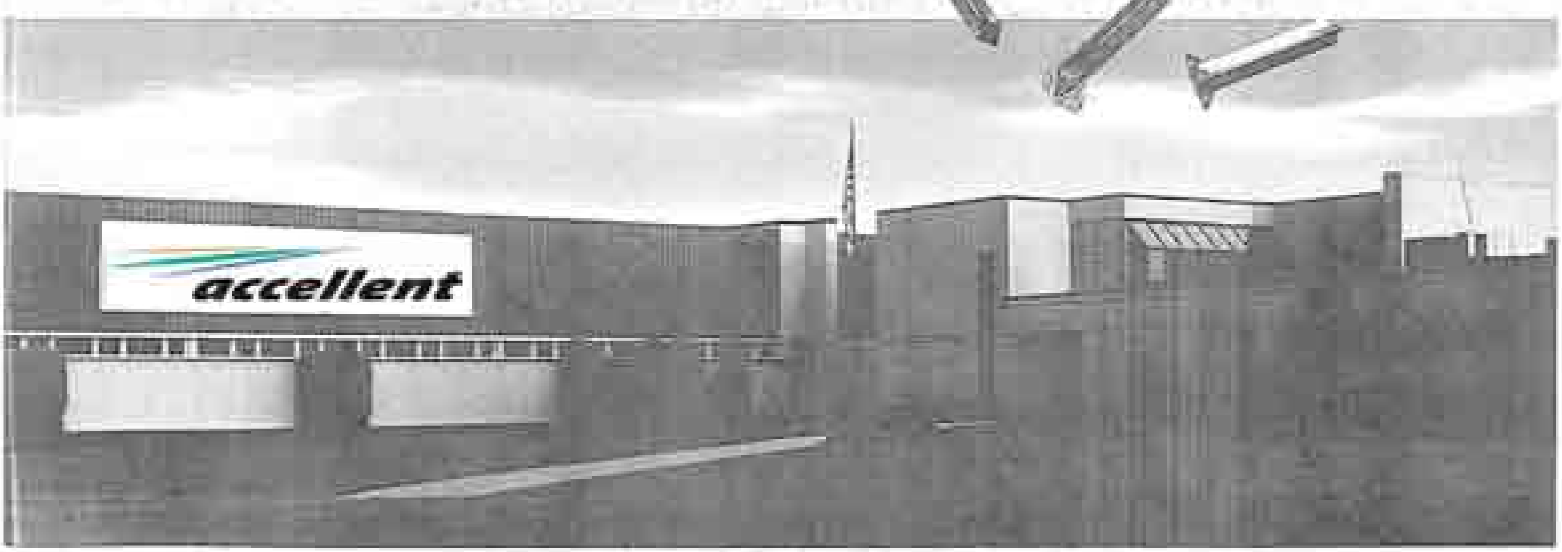
1. Difficult miniature shapes
2. Close tolerance
3. Elimination of expensive machining operations
4. Fewer finishing operations
5. Broad range of alloys
6. Reduction of size and weight
7. Maximize electrical and mechanical properties
8. Reduced materials cost
9. Built-in burr-free and smoother finishes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

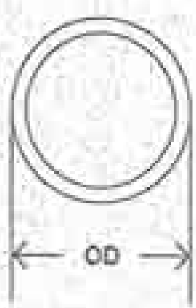


Fabricating Fine Tubing

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



Minimum: .003" Maximum: .625"

Normal Tolerances:

<.03"	.03"-.09"	.09"-.25"	>.25"
±.00025"	±.0005"	±.00075"	±.001"

Normal Surface Finish: 32 microinch

Inside Diameters

Minimum: .002"

Normal Tolerances:

<.03"	.03"-.09"	.09"-.25"	>.25"
±.00025"	±.0005"	±.001"	±.0015"

Normal Surface Finish: 63 microinch

Concentricity

Seamless - normally, within ±10% of wall thickness.

Welded & Drawn - normally, within ±5% of wall thickness.

Wall Thickness

Minimum: .0005" Maximum: .049"

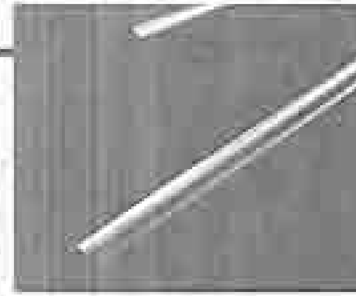
Normal Tolerances:

<.010"	.010"-.020"	>.020"
±10%	±.001"	±.0015"

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

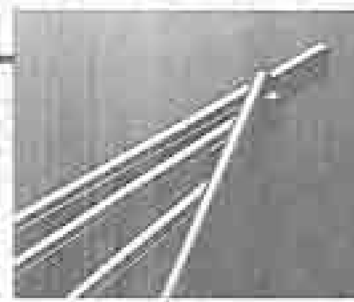
Method of Cutting	Length (inches) Max.	Min.	Tolerance ± (inches)	Rate pcs/hr.	Need to deburr
Screw Machines	6	.05	.001	50/3500	yes
Shear	6-12	.02	.003	500/20,000	no
Radial Saw	6-12	.2	.010	500/1200	yes
ECM	6-12	.2	.005	500/6000	no
Score	6-12+	.2	.010	500/1200	no

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. = .25 x 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.

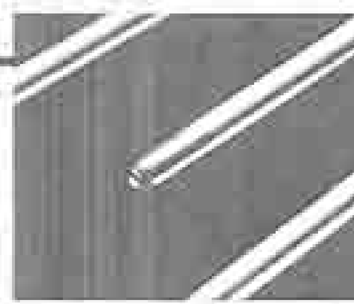


Closing

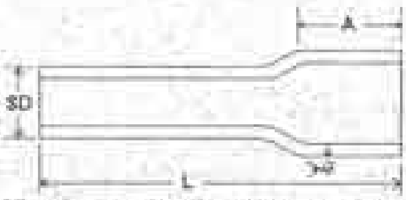
.250 Max. O.D.

$\frac{\text{OD}}{\text{WALL}}$ = 10 to 20 – Depending on Alloy

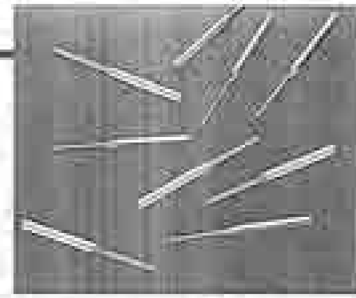
The closure and its shape can be varied depending on its application. As a general guideline, hermetic closures can be achieved depending on wall thickness and alloy.



Reducing/Expanding

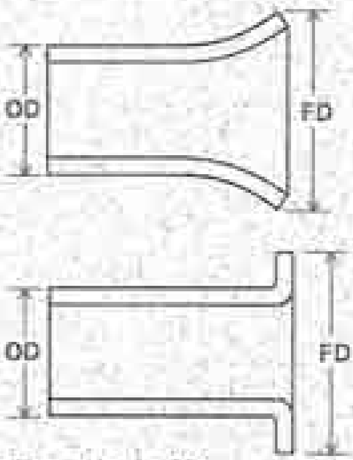


Reducing and/or expanding is a geometry that has application in a wide degree of markets. Parameters are as indicated.



$\frac{SD}{LD}$ Depends upon LD, Wall and Alloy, can be .5 or less
cc nom. = 12 L Tol. = ±.010 A Tol. = ±.010

Flaring & Flanging



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.

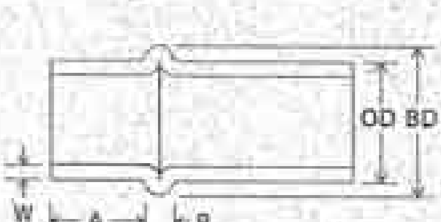
Differentiating from a normal flare which has a radiused contour is a set *flare* which has a specific conical configuration. The purpose is for definite sealing — the cone fitting into a corresponding matching part.

FD max. = 1.4 x OD
Tol. = ±.005
Internal and external corners will be rounded.

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



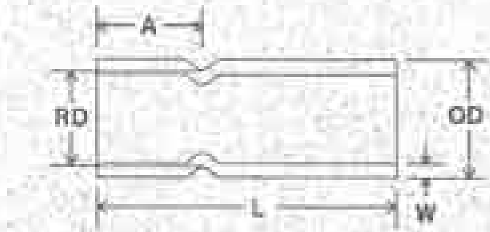
Tubular parts are frequently bulged to provide a stop for another part with which it comes in contact. The illustration indicates potential bulging/beading parameters.

B = 2 x W Tol. = ±.002
BD max. = 1.4 x OD Tol. = ±.003
A min. = .03 Tol. = ±.003

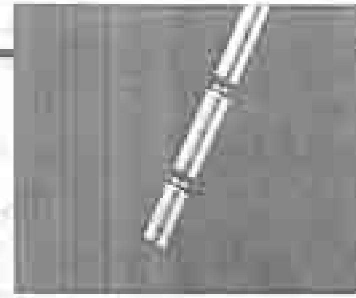
L	.12 - 1.25	1.25 - 6.00
Tol.	±.003	±.005

Internal & external bulge corners will be rounded.

Corseting

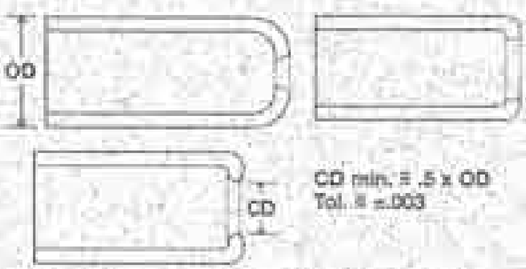


Corsets, as in bulging, provide a stop, internal in this case, again where one part is in intimate contact with another. The illustration indicates corseting parameters.



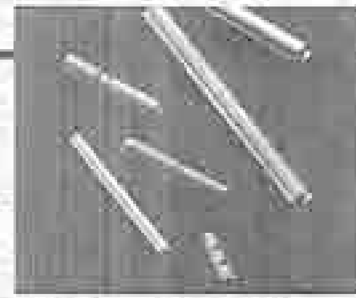
OD max. ≡ .169
RD min. ≡ .7 x OD Tol. ≡ ±.002
A min. ≡ .7 x OD Tol. ≡ ±.005
L max. ≡ 1.00 Tol. ≡ ±.005
OD/W max. ≡ 20, min. ≡ 6

Rounded End Tubes



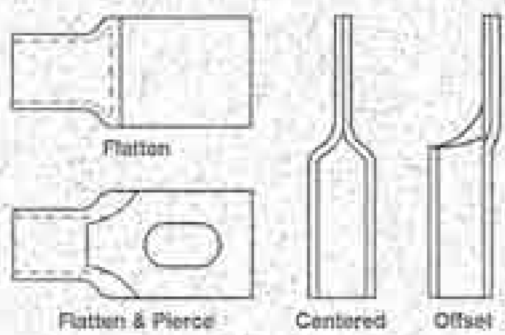
CD min. ≡ .5 x OD
Tol. ≡ ±.003

Internal and external corners will be rounded.



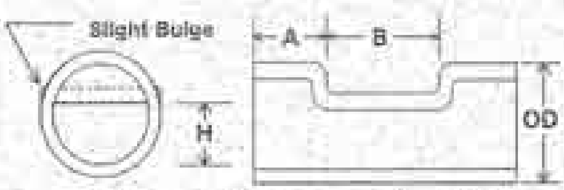
Tubes can be supplied with one or both ends rounded or tapered to close the end down to approximately 50% of the O.D. Although the preference is to have full spherical radius, smaller radii can be supplied depending on the wall thickness of the tube. The inside surface is free formed, not supported, 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



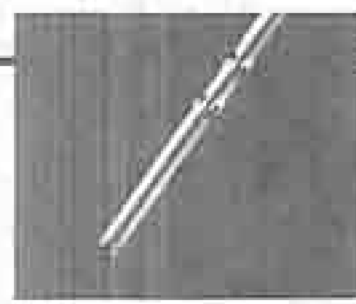
Tubular parts can be supplied with one end flattened and pierced. Pierced holes can be round or elongated. All flattening is done without restriction of material so that flat width and thickness are relative to the tubing size selected. The ends of flat tubes are not typically trimmed. The flattened 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

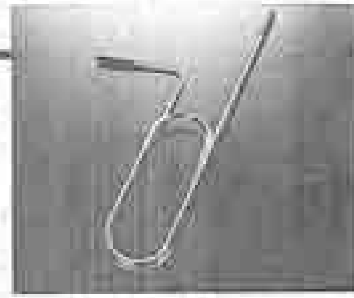


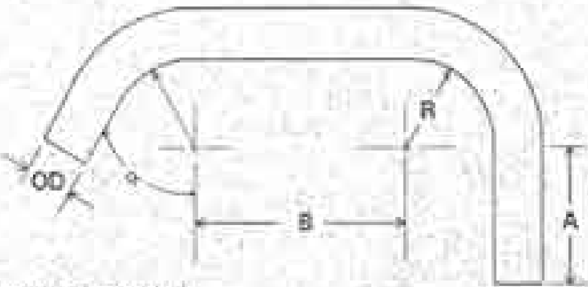
H min. ≡ .7 x OD
A Tol. ≡ ±.005
B Tol. ≡ ±.005
Tol. ≡ ±.003

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



Bending & Coiling



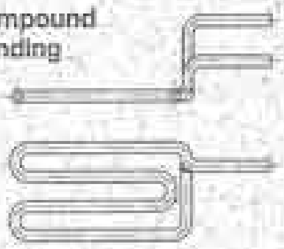


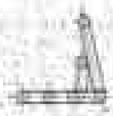
In general, a tube can be bent satisfactorily around a radius 2.5 times the O.D. of the tube without internal support. For tighter bends, a special mandrel is used to avoid kinking and collapse. This raises costs, but makes it possible to bend tubing around a radius as small as the O.D. of the tubing.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

Simple Bending

R min. = 2 x OD for <10% closure
A min. = 2 x OD to eliminate secondary trim
A Tol. = ±.005 other end = ±.010
A Tol. = ±.010
B Tol. = ±.010
α Tol. = ±1°

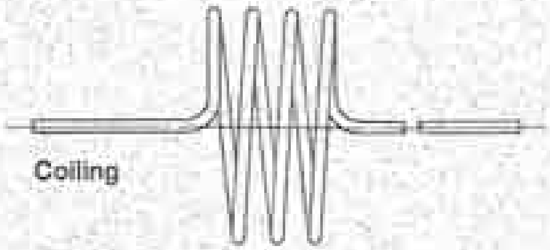
Compound Bending





Range $\frac{OD}{Wall}$ up to 20
Min. Wall - .003

Min. Bend Radius = 2 x Tube O.D.

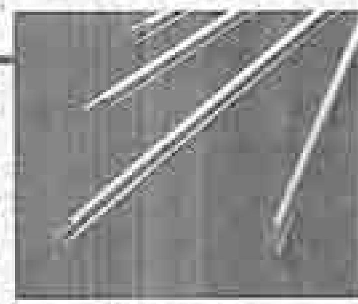


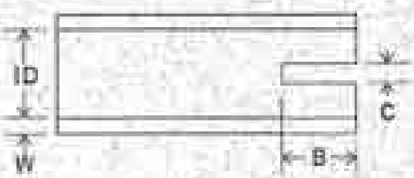
Coiling

$\frac{OD}{W}$ range Min. $\frac{20}{1}$
Min. Wall - .003

Min. Bend Radius = 2 x Tube O.D.

Slotting

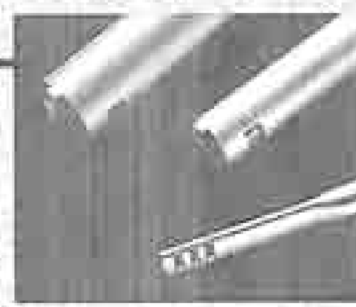


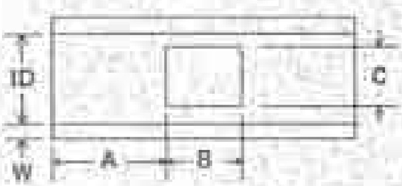


Slotting is used for a wide variety of applications, and the operation is not limited to a single slot. As an example, to affix wires in a tube, the tube is slotted and the wires are crimped in place.

C max. = ID - 4 x W
C min. = 2 x W (.005 min.) Tol. = ±.001
B Tol. = ±.005
Slot Burr - free to .001 max.
Available in multiple slot configurations with or without crimping.

Punching

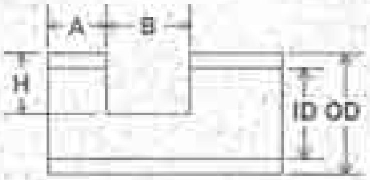




Round, square or elongated holes can be punched in a tube. Shapes and locations around tube can be varied as specified.

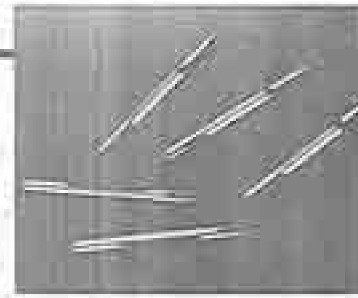
A min. = 2 x W Tol. = ±.003
B min. = 2 x W (.010 min.) Tol. = ±.001
C max. = ID - 4 x W
C min. = 2 x W (.010 min.) Tol. = ±.001
Hole Burr - Burr free to .001 max. Round, elongated, and multiple hole configurations are available.

Notching

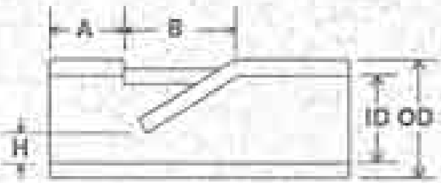


H max. ≡ .5 x OD Tol. ≡ ±.002
ID min. ≡ .06
A min. ≡ 2 x W Tol. ≡ ±.003
B min. ≡ 2 x W (.010 min.) Tol. ≡ ±.002
Available with multiple notches and notch at end of piece.

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.

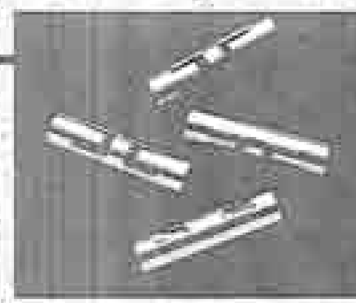


Lancing



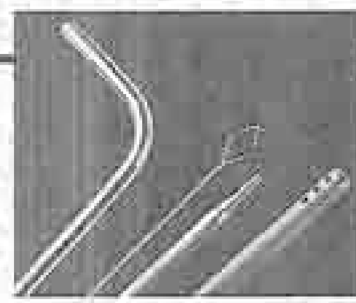
Tab Width max. ≡ ID – 4 x W Tol. ≡ ±.001
Tab Width min. ≡ 2 x W (.010 min.)
A min. ≡ 2 x W Tol. ≡ ±.003
H Tol. ≡ ±.003
Available with multiple tabs.

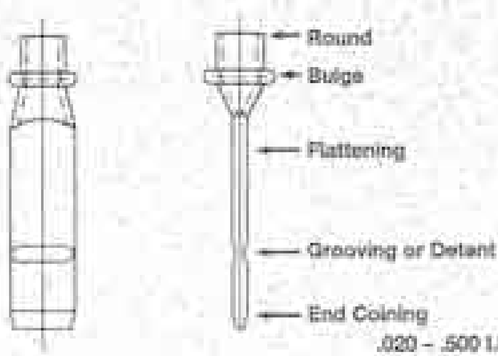
Tubes are lanced for various reasons including the creation of an internal stop. A single tab or multiple tabs can be located on a tube as required.



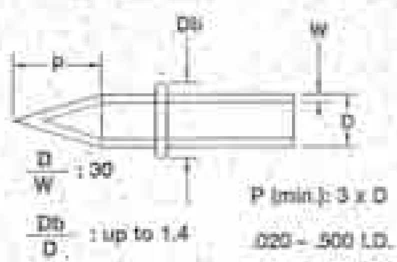
Multiple Fabrication Operations

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.



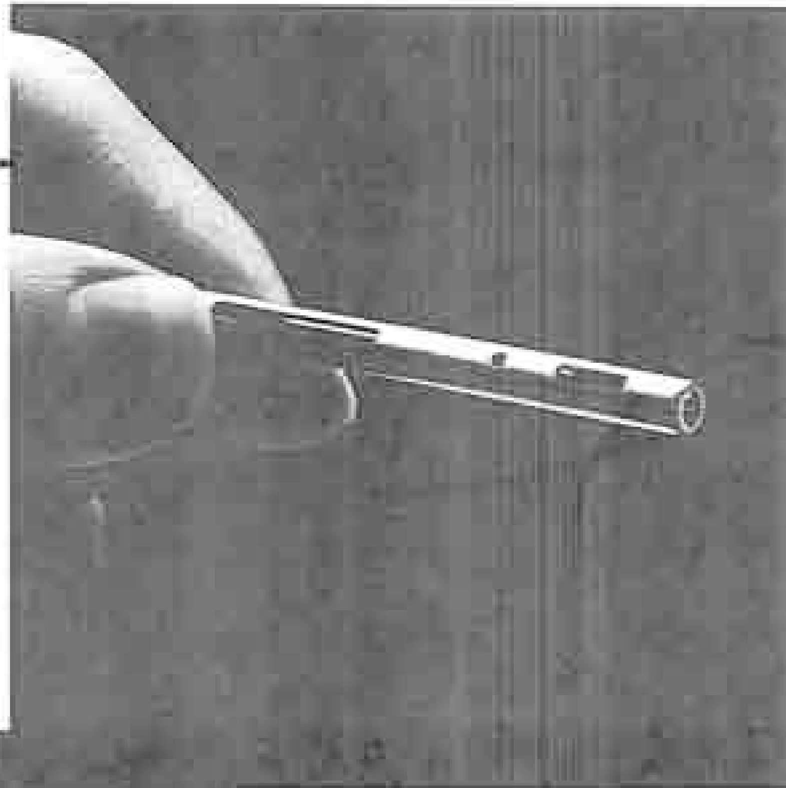


Multiplicity of Secondary Operations

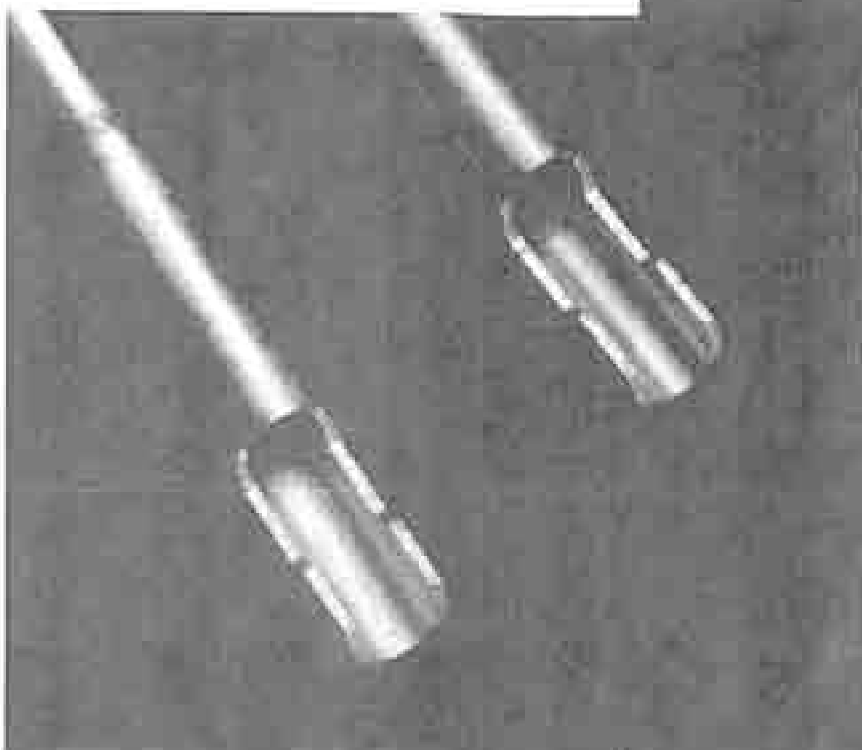


Bulging, Tapering and Closing

EDM

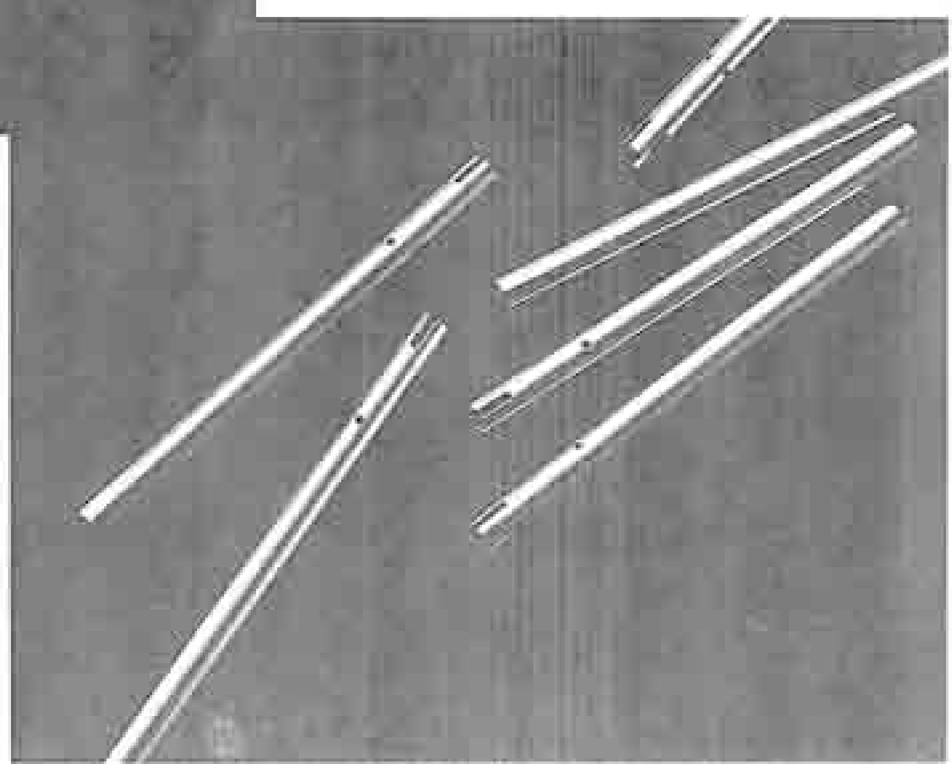


Electrical Discharge Machining (EDM) removes metal through the action of high-energy electrical discharges on the surface of the workpiece. It is applicable to materials which are good electrical conductors and since there is virtually zero force between the tool and the workpiece, very delicate and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

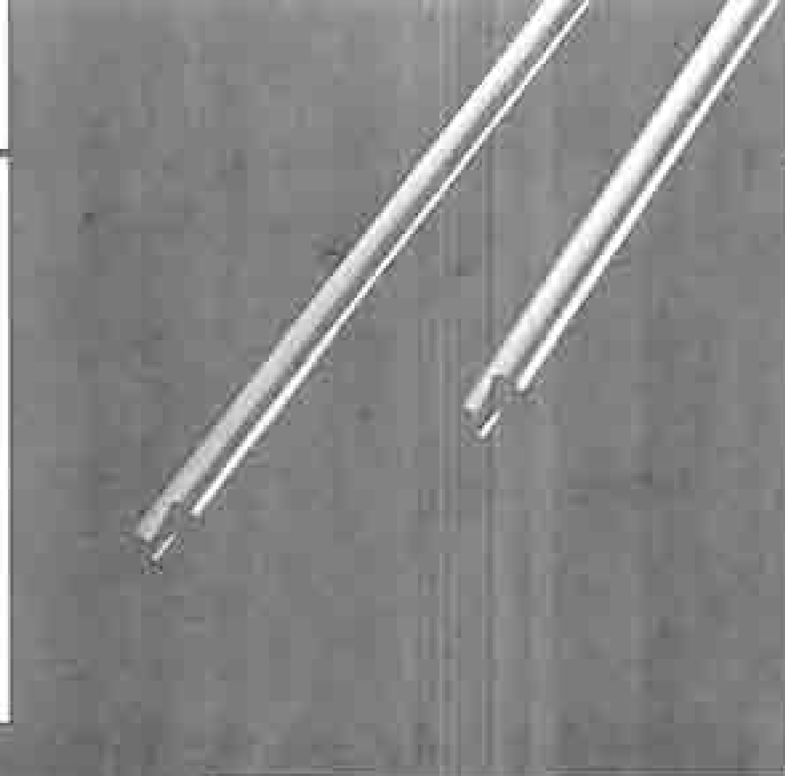


Profiles and slots can be produced using either wire or electrode plunge type machines. These processes provide a sharp, burr-free edge. Very smooth surfaces can be achieved through the use of a fine finishing pass.

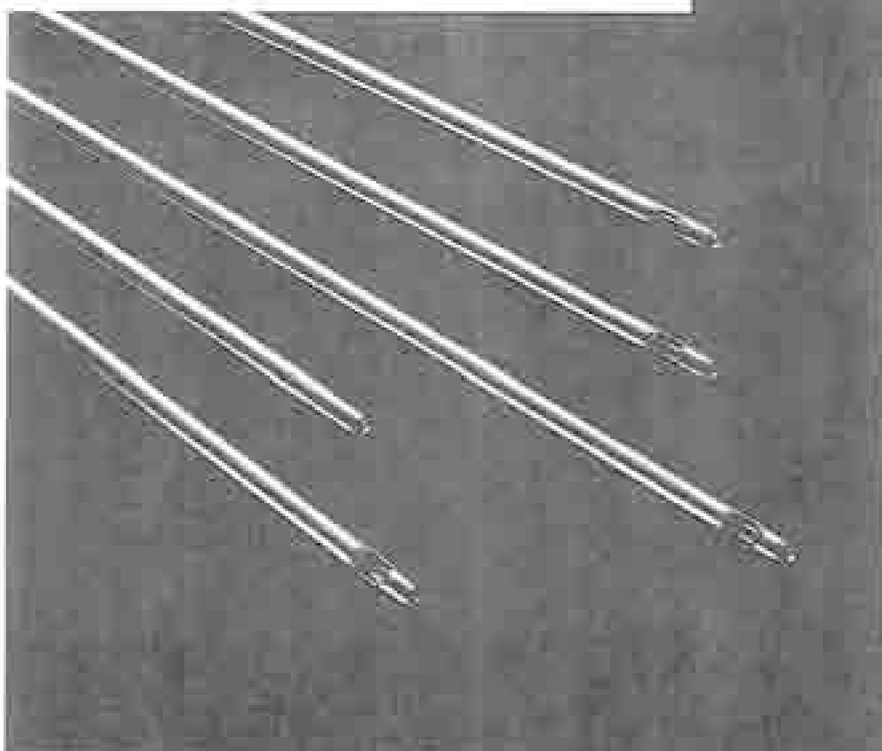
Circular and shaped holes can be produced using EDM drilling type machines. This process can produce holes as small as 0.006" diameter. Hole quality will be slightly lower than the electrode plunge, however production rates are higher.



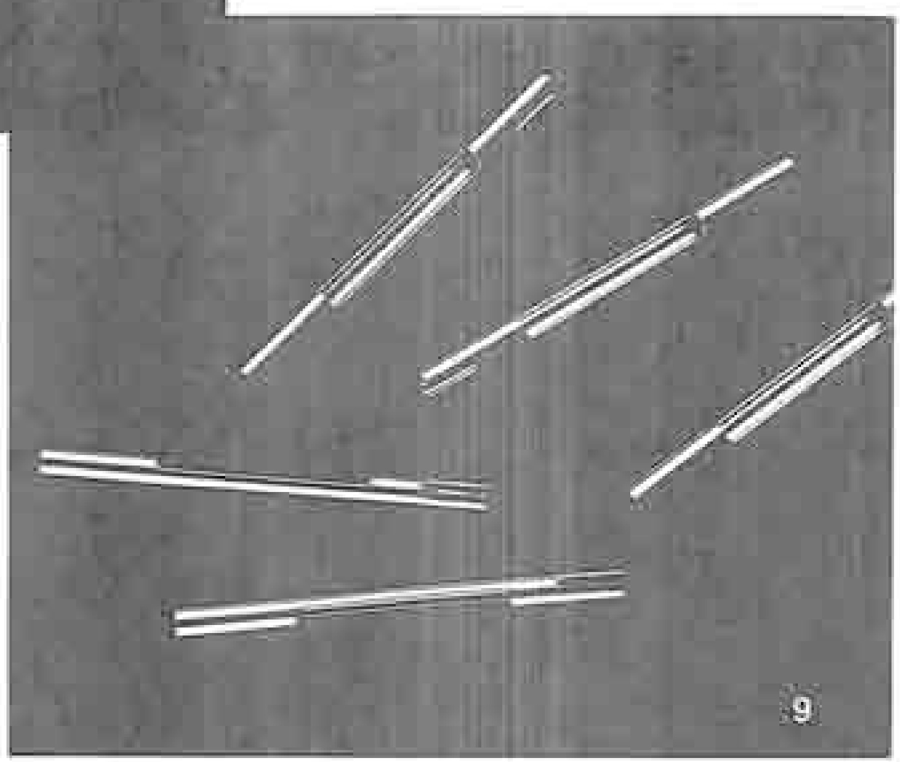
ECM/ECG



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.



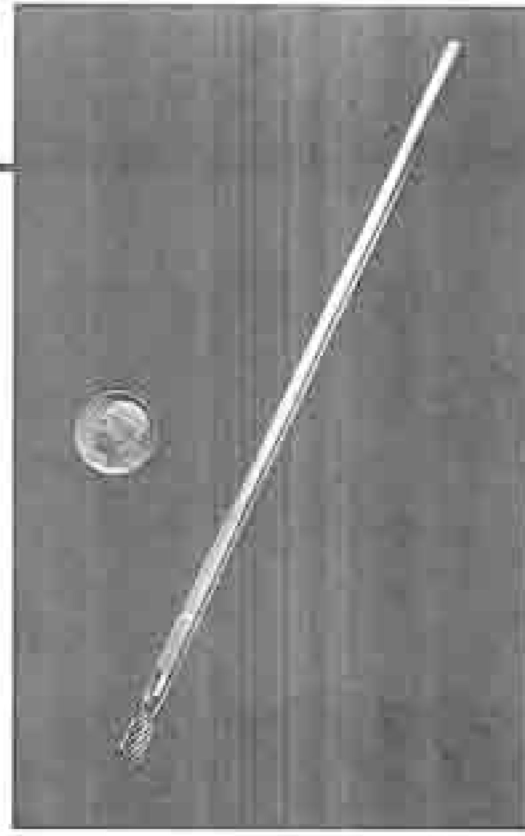
Electrochemical cut-off is a high speed tube cut-off process for producing burr-free straight cut tubular blanks. Blank lengths range from 0.25 inch to 44 inches. Tube outside diameters range from 0.010 inch to 0.625 inch. Length tolerances of +/- 0.003" and perpendicularity tolerances of 1/2 degree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

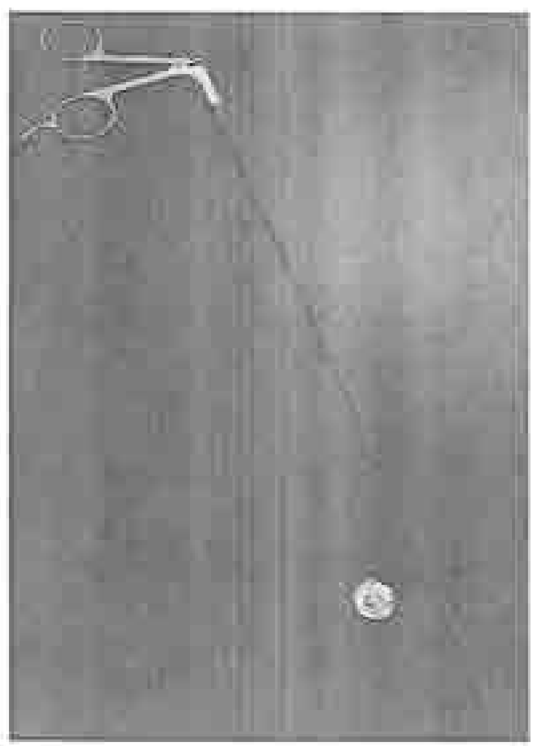
Tubular assemblies are found in a limitless number of applications. Assembly techniques such as Snap, Captive, and Interference or Shrink fits are a cost effective method of joining. Brazing, Soldering, Welding and Adhesive bonding are also methods commonly used. Employing the full range of fabrication 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.

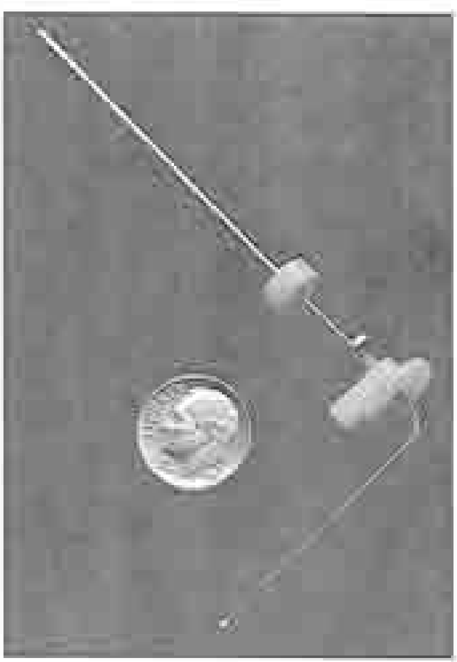


Burr assembly used in arthroscopic surgery

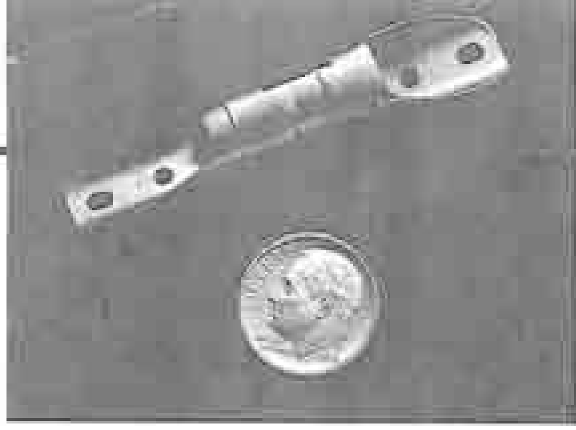
Tubular assembly for critical lighting application

Minimally invasive surgical instrument used for biopsy procedures

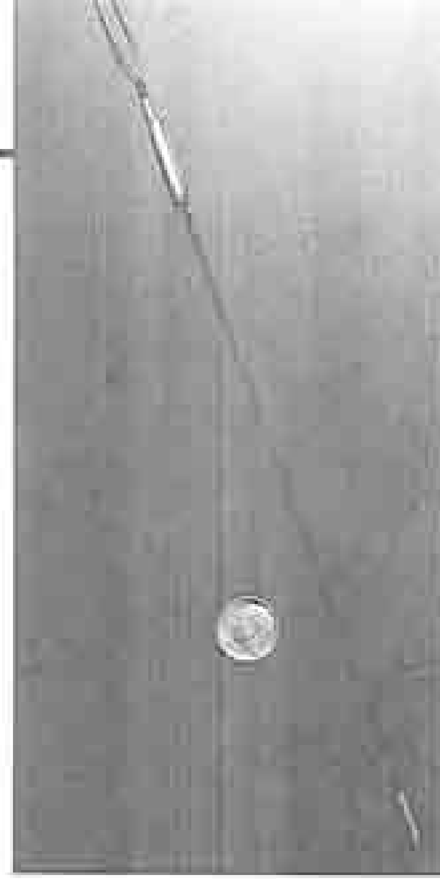




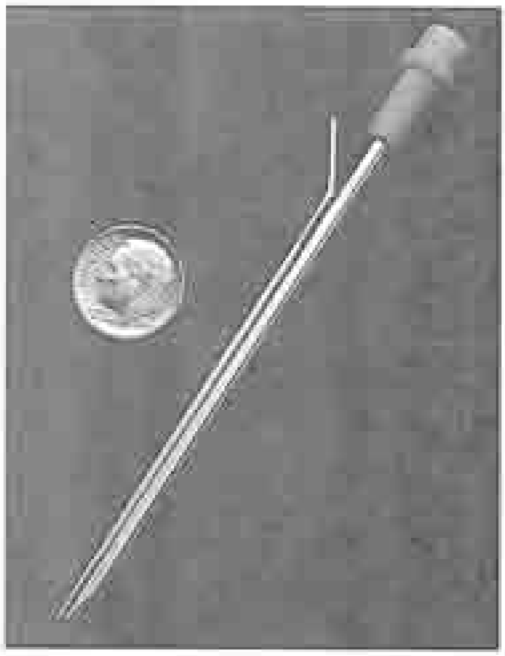
Diagnostic aspiration probe



Hinge assembly for a laptop computer

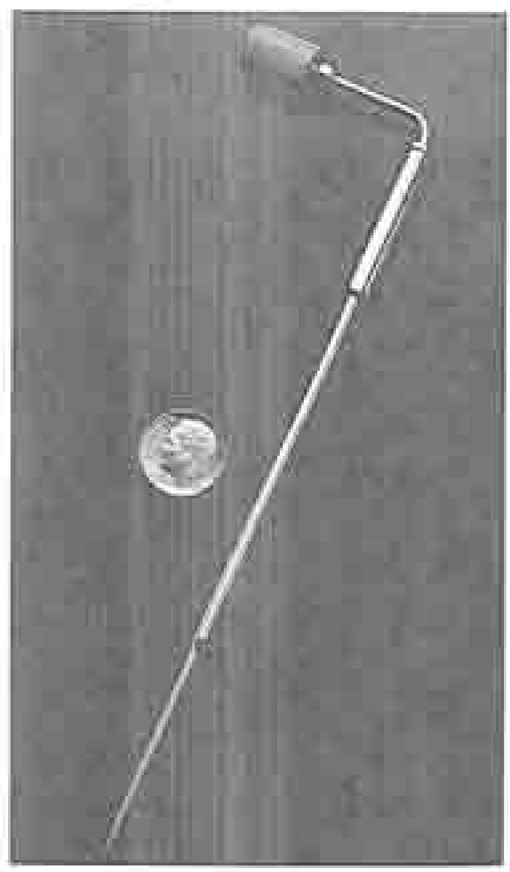


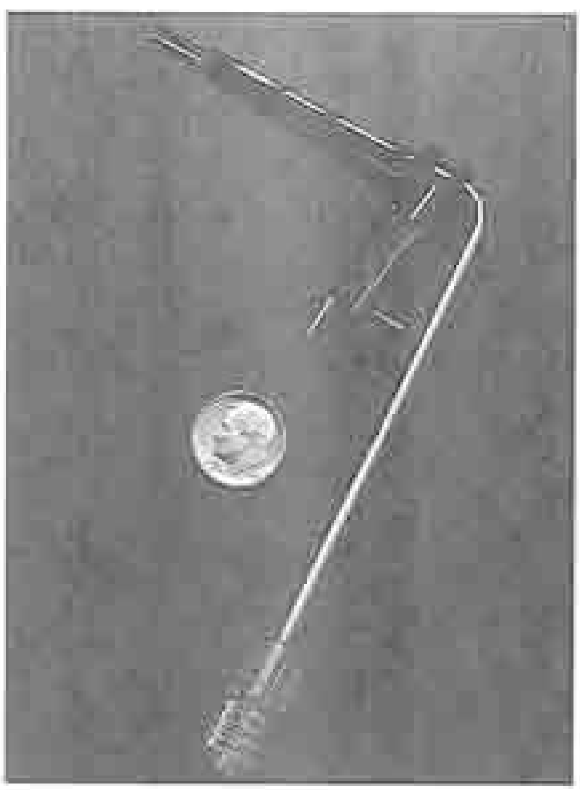
Complex assembly used in prostate surgery



Bi-tubular devise for sinus surgery

Metering probe





Metering probe

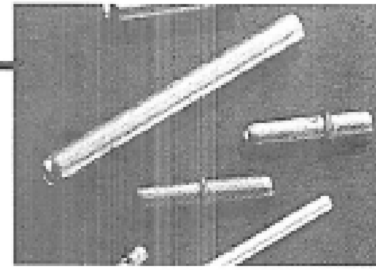
Alloys

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^3) @ 68°F	Thermal Expansion (in/in/ °F x 10^6)	Electrical Resistivity (ohms/cir mil/ft.) 68°F
Nickel Alloys					
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® 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 (70-500°F)	307
Monel® 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® 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® 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	7.6 (70-500°F)	620
Inconel® 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

**"Monel" Alloy is a Registered Trademark of Inco Alloys International, Inc.

Over 90 alloy options are available. Many of the most commonly required alloys are detailed below.



TYPICAL MECHANICAL PROPERTIES*

Temper	Ultimate Tensile Strength (psi x10³)	Yield Strength (psi x10³)	Elongation (%)	Hardness	APPLICATIONS AND CHARACTERISTICS
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	C20	
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	

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

ALLOY	CHEMICAL COMPOSITION (%)	PHYSICAL PROPERTIES			
		Melting Range (°F)	Density (lb/in³) @ 68°F	Thermal Expansion (in/in/°F x 10⁶)	Electrical Resistivity (ohms/cir mil/ft.) 68°F
Nickel Alloys (cont.)					
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 80.0; 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
Ferrous Alloys					
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 0.08; 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

† Inconel† is a Registered Trademark of Inco Alloys International, Inc.

TYPICAL MECHANICAL PROPERTIES*

Temper	Ultimate Tensile Strength (psi x10³)	Yield Strength (psi x10³)	Elongation (%)	Hardness	APPLICATIONS AND CHARACTERISTICS
A	125	70	40	B95	Combines high strength, excellent fabricability and outstanding corrosion resistance. Used for chemical processing, combustion systems, and marine applications.
H/2	150	110	20	C30	
H	200	150	5	C40	
A	140	75	30	B100	Excellent high temperature strength and oxidation resistance in the age hardened condition. Used in aircraft turbine engine parts, rocket motors, and pumps.
H/2	160	120	15	C30	
H	200	150	5	C40	
A	120	50	45	B90	Offers high creep-rupture strength and oxidation and corrosion resistance to 1500°F. Strong and ductile to -423°F. Non-magnetic.
H/2	165	110	20	C30	
H	200	150	5	C40	
A	100	50	45	B80	Resists oxidation to 2100°F. High electrical resistance at elevated temperatures in heating elements and cathode support sleeves.
H/2	120	100	20	B95	
H	150	120	5	C25	
A	116	59	57	B90	Excellent resistance to oxidizing aqueous media including wet chlorine and mixtures of nitric acid or oxidizing acids with chlorine ions. High resistance to pitting, crevice corrosion and stress corrosion cracking.
H/2	151	127	23	C33	
H	192	174	9	C40	
A	110	55	44	B90	Exceptional combination of oxidation resistance, fabricability and high-temperature strength.
H/2	145	120	15	C31	
H	170	150	8	C37	
A	85	40	50	B85	Offers good corrosion and heat resistance. Mechanical properties good down to -300°F and up to 1650°F.
H/2	125	105	20	C25	
H*	140	130	12	C30	
A	85	40	50	B85	Weldments for corrosive conditions where intergranular carbide precipitation must be avoided. Nuclear components.
H/2	125	105	20	C25	
H*	140	130	8	C30	
A	85	40	50	B85	Applications involving severe forming—fasteners, anodes, grid cups and other electrical components.
H/2	120	90	25	B95	
H*	160	130	8	C30	
A	85	40	50	B85	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.
H/2	125	95	25	C20	
H*	165	135	8	C30	
A	85	40	50	B85	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.
H/2	120	95	25	C25	
H*	135	120	8	C30	
A	85	40	50	B85	High strength and excellent corrosion resistance. Closely controlled chemistry for medical applications including body implants.
H/2	120	95	25	C25	
H*	135	120	8	C30	
A	85	40	50	B85	Stabilized with titanium. Used in weldments for corrosive service in the 800° to 1650°F range.
H/2	125	95	20	C25	
H**	140-180	125-160	12	C30	

* 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^3) @ 68°F	Thermal Expansion (in/in/ °F x 10^6)	Electrical Resistivity (ohms/cir mil/ft.) 68°F
Ferrous Alloys (cont.)					
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
Reactive/Refractory Metals & Alloys					
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 A40	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*

Temper	Ultimate Tensile Strength (psi x10³)	Yield Strength (psi x10³)	Elongation (%)	Hardness	APPLICATIONS AND CHARACTERISTICS
A	85	40	50	B85	Stabilized with columbium. Used for weldments in vibrating or corrosive services in the 800 to 1500°F range.
H/2	125	95	20	C25	
H**	150-185	130-170	12	C30	
A	75	40	30	B85	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.
H/2	90	75	20	B95	
H**	110-135	100-125	7	C20	
HT	180	150	10	C43	
A	75	60	30	B85	Has greatest heat and electrical resistance of stainless steels. Resists corrosion well. Excellent for glass-to-metal seals. See Data Sheet 1064.
H/2	105	80	15	B95	
H**	125-145	95-130	5	C25	
A	140	60	30	B95	An age hardenable alloy also used where combination of high strength and corrosion resistance is required.
H/2	160	110	15	C30	
H	200	160	5	C40	
A	55	40	35	B65	For structural tubular parts.
H/2	68	58	15	B78	
H	90	75	5	B90	
A	150	125	20	C36	Precipitation hardening stainless steel that exhibits high strength, excellent corrosion resistance and high temperature resistance. Common applications are aircraft, marine and chemical processing.
H/2	180	150	17	C42	
H	210	185	14	C46	
HT	240	225	6	C52	
A	150	125	20	C36	Precipitation hardening stainless steel that exhibits high strength, excellent corrosion resistance and high temperature resistance. Frequently called for in aircraft and medical applications.
H/2	175	150	17	C42	
H	200	175	14	C46	
HT	230	225	6	C52	
A	40	35	30	55 (VHN)	Used in nuclear reactors and in high-temperature heat exchangers. Retains much of its strength at temps to 2000°F.
H	80	70	5	120 (VHN)	
A	48	40	30	65 (VHN)	Used for nuclear reactors, missiles and aircraft. Has good strength at high temps and is more easily welded than Cb.
H	90	80	5	140 (VHN)	
A	70	40	28	B60	Aircraft and processing equipment parts requiring good strength-to-weight ratio or excellent corrosion resistance.
H/2	85	65	15	B80	
H	105	85	8	B90	
A	115	85	15	C32	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.
H/2	125	95	10	C42	
H	135	110	3	C50	
A	115	8	15	C27	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.
H/2	120	95	10	C37	
H**	135	110	3	C45	
A	60	50	40	80 (VHN)	Used in capacitors, chemical plant equipment, electronic rectifiers, surgical implants, nuclear reactors, spacecraft. Resists all acids except hydrofluoric.
H	100	90	10	155 (VHN)	
A	65	40	25	B80	Chemical plant equipment.
H/2	75	60	15	B88	
H	90	80	5	B62	

* 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.

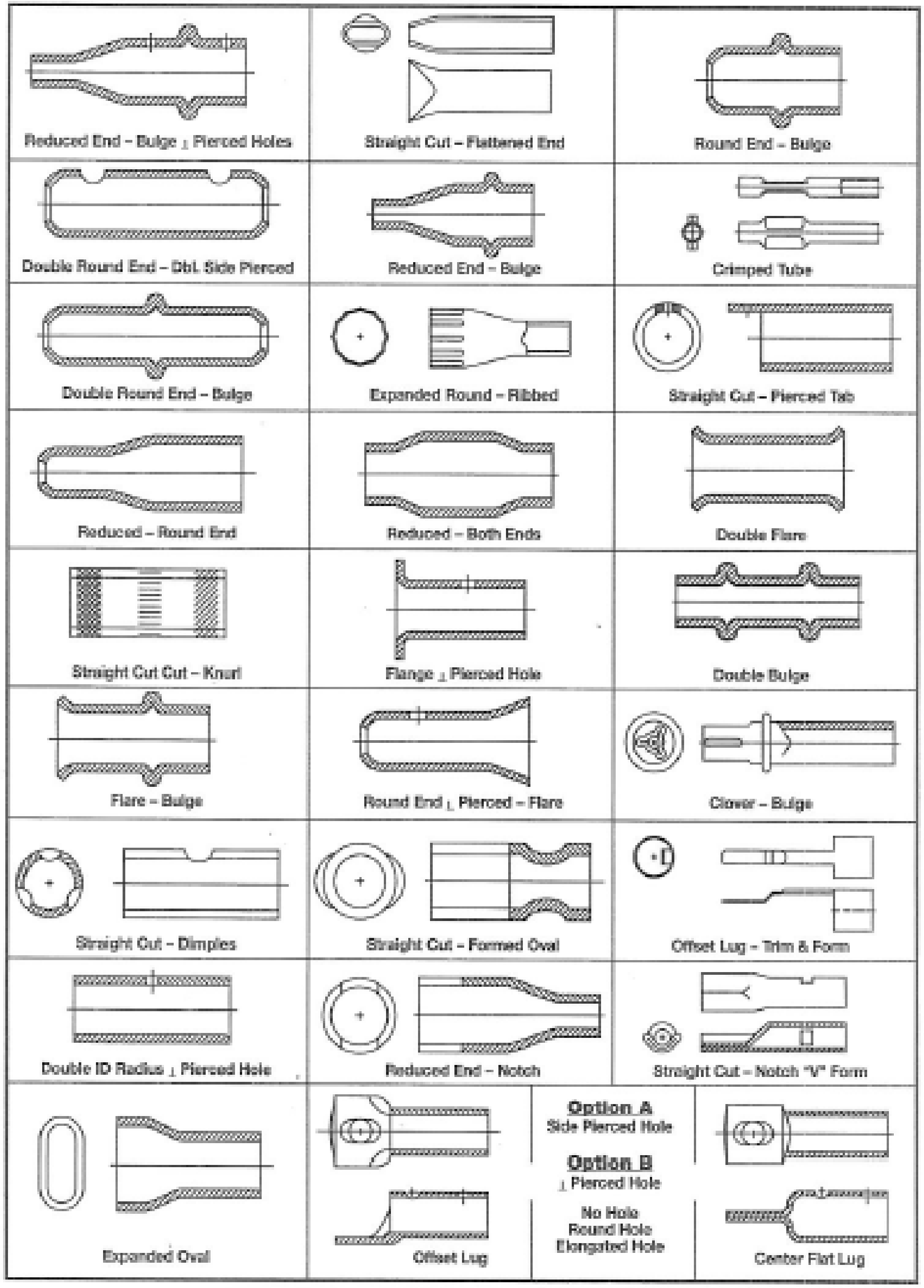
ALLOY	CHEMICAL COMPOSITION (%)	PHYSICAL PROPERTIES Melting Range (°F)	Density (lb/in³) @ 68°F	Thermal Expansion (in/in/°F x 10⁶)	Electrical Resistivity (ohms/cir mil/ft.) 68°F
Reactive/Refractory Metals & Alloys (cont.)					
Zircaloy 2	Sn 1.5; Fe 0.13; Cr 0.10; Ni 0.05; Balance Zr	3300	0.237	3.6 (212°F)	445
Precious Metals					
Gold	Au	1945	0.698	7.9	13.2
Fine Silver	Ag	1761	0.379	10.9	8.85
Coin Silver	Ag 90; Cu l0	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
Shape Memory/Superelastic Alloys					
Nitinol	Ni 55.8; Ti 44.2	2390	0.234	6.1	493
Controlled Expansion and Glass Sealing Alloys					
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 004; Si 1.00; Co 0.20	2650-2700	0.293	4.5 (-50 - +150°F)	611
Cobalt High Temperature Alloys					
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)	589
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*

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

* 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



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