AIRCRAFT TUBING DATA

Consulting Editor

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Price $1.50

($2.00 with Ring Binder)

SUMMERILL TUBING COMPANY

BRIDGEPORT · MONTG. CO. · PENNSYLVANIA

INTRODUCTION

In this new edition of Aircraft Tubing Data we have tried to incorporate most of the suggestions received since the last edition.

While some of the information given here is repeated from other sources, it is with the hope of making this publication more useful by having available in one book the essential references for aircraft design.

In the *first* section we have covered information on tubing—its manufacture—Government specifications—Tolerances—Special Shapes—what the tubing mill can supply.

In the *second* section we have added original text on various phases of interest to the aircraft manufacturing personnel. We especially call attention to the articles on welding. No matter how good the structural material may be, its full worth cannot be realized unless joining and fabrication are equally good. It is our belief that we still have a great deal to learn about welding aircraft steels.

In *third* section we have made the Tables of Tube Properties more complete. The column curves have been increased to cover all standard sizes. All curves have been refigured on the new formulae for steel tubing.

In section *four* are some of the more frequently used reference data.

Most of all we wish to acknowledge the enthusiastic assistance received from many men in the industry. We especially want to thank here all the authors indicated for their valued contributions; for suggestions and photographs. Space has permitted using only a few of the latter. The list includes the following:

Rex B. Beisel	*Vought-Sikorsky Aircraft*
Don R. Berlin	*Curtiss-Wright Corp.*
O. G. Blocher	*Stinson Aircraft Div.*
A. P. Fontaine	*Stinson Aircraft Div.*
James A. Broadston	*North American Aviation, Inc.*
Archibald M. Brown, Jr.	*Fairchild Aircraft Div.*
Norman Davidson	*Consolidated Aircraft Corp.*
Robert R. Dexter	*Inst. of Aeronautical Sci's Inc.*
G. J. Donahue	*Vultee Aircraft, Inc.*
Hall L. Hibbard	*Lockheed Aircraft Corp.*
A. N. Kugler	*Air Reduction Sales Company*
Harold Mansfield	*Boeing Aircraft Co.*
H. M. Poyer	*Bell Aircraft Corp.*
J. M. Ryder	*Civil Aeronautic Authority*
A. M. Rochlen	*Douglas Aircraft Company*
A. K. Seemann	*Linde Air Products Co.*
E. W. P. Smith	*Lincoln Electric Co.*
W. E. Thomas	*Magnaflux Corporation*
J. B. Wassall	*Vega Airplane Company*
E. E. Watts	*Glenn L. Martin Corp.*
T. A. Wells	*Beech Aircraft Corp.*
Wm. L. Wilson	*Republic Aviation Corp.*

And the many individuals from the Air Corps and Bureau of Aeronautics whose names we are not permitted to publish.

In continuing the publication of Aircraft Tubing Data we have as before tried to keep it free from all "sales talk." To those who might wish detailed information on Summerill tubing for aircraft or other uses, we will welcome direct inquiries.

J. P. D.

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REVISED AND NEW PAGES

MAY 1943

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MANUFACTURE OF SEAMLESS STEEL AIRCRAFT TUBING

A. J. WILLIAMSON, *Chief Metallurgist,*

SUMMERILL TUBING COMPANY

THE equipment and various steps in the processing of seamless steel tubing are practically the same for all sizes and grades of steel. In this article we will, however, deal more specifically with tubing for aircraft uses and especially with what is now coming to be known as "aircraft quality."

To meet the exacting requirements of aircraft quality it is necessary to control all steps in the manufacture—starting with the making of the steel and all succeeding operations.

Melting Practice: Because of the punishment the steel must withstand in the hot piercing and rolling operations, the steel itself must be of the best quality obtainable. Because of highly stressed parts and the premium on light weight and high strength for aircraft structures, the steel must be as free from inclusions and other internal stress raisers as is commercially available. In steel phraseology, it must be not only a clean steel but of homogeneous structure.

For better weldability and to reduce welding crack tendency, Summerill has developed a rather exacting specification in which both the sulphur and phosphorus are held to the lowest possible minimum. To meet these requirements, practically all manufacturers of aircraft tubing have adopted electric furnace steel in preference to basic open hearth steel. The only possibility of change might be the limiting capacity of electric furnace production under conditions facing the industry in 1941.

The electric furnace process permits close control during the steel making mainly because of small heats and better control of each heat. The electric furnace gives precise control of the slag, the degree of deoxidation, and permits maintaining of much closer limits of the alloying elements. The long quiescent period in the furnace allows the non-metallic inclusions to rise through the bath, where they are readily discarded with the slag, and obviously this produces a uniformly cleaner steel than generally available by the open hearth process.

Aircraft quality has come to be an identifying term signifying the best in steel. Cleanliness, uniformity, and general freedom from defects are tied up with "Aircraft Quality." Specially selected scrap, special melting practice and a thorough checking of samples throughout the whole manufacture of steels for aircraft are part of every steel mill's routine. Nearly all aircraft steels are now made in the electric furnace with particular attention being paid to deoxidation. SAE X4130 for aircraft is being manufactured in the electric furnace with the deoxidation such that it results in a "fine grained" steel as determined by measuring the Austenitic grain after carburizing at 1700° F. for eight hours.

It has been found that "fine grained" steels have less hardenability than coarser grained steels and give better welding results. Each heat of steel for Summerill Aircraft Tubing must be approved as to grain size, cleanliness and chemical analysis before piercing. To add to the weldability of the steel, Summerill has put maximum limits on the sulphur plus phosphorus contents.

Ninety percent (90%) of the steel used in aircraft tubing structures is made from SAE X4130 of the following analysis:

C	— .27 — .33%	S	— .050% Max.
Mn	— .40 — .60%	Cr	— .80 — 1.10%
P	— .040% Max.	Mo	— .15 — .25%

Hot Mill Practice:

After the steel has been refined and cast into ingots, it is subsequently rolled into blooms and billets, and it is the latter which as rounds are used for piercing. The rounds are checked as to uniformity of structure and freedom from defects at this point.

Piercing:

In the Mannesmann process, the solid round is heated to rolling temperature and then cross rolled between barrel-shaped rolls, which exert a great amount of pressure, thereby causing internal fracture of the steel. The tube is forced over a piercing point, which is fastened on the end of a long rod.

Let us digress for a moment and observe how this hole is formed. If one will take an ordinary pencil eraser and roll it between two flat surfaces, the center of the eraser will begin to crumble and show

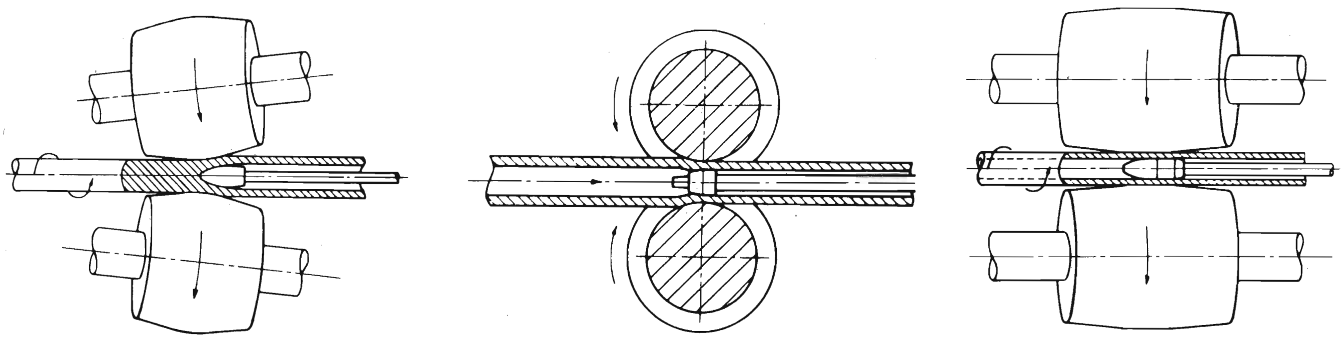


Figure 1. **Views showing the steps in the formation of a tube from the solid. All operations are done at rolling heat.**

a void. This is exactly what takes place in the Mannesmann process, excepting that the steel does not crumble, but the center fibers actually separate. As a matter of fact, we could obtain a tube without the piercing point; however, the piercing point does act as a guide and a sizing unit.

Figure I shows a series of diagrammatic drawings depicting the stages in the manufacture of a hot finished tube. Figure IA exhibits the barrel-shaped rolls, the longitudinal axes of which are set at an angle so as to impart to the tube a forward motion. Material leaving this part of the operation is then further rolled over a plug as depicted in Figure IB. In this operation the tube is smoothed out, and the wall thickness and the inside and outside diameters are further reduced. Figure IC shows the reeling operation, where the tube is rolled on a long plug, between longer barrel-shaped rolls, which evens out the wall and gives the tubing a burnish. The last operation of the hot working process is the sinking or sizing, whereby the tube is reduced on the outside and inside diameter, but not necessarily in wall thickness, to the required dimensions.

Figure II shows a longitudinal section of a round billet in the process of being pierced. One will note that the inside is opening up, before it even approaches the piercing point and this opening occurs at the point of maximum pressure between the barrel-shaped rolls.

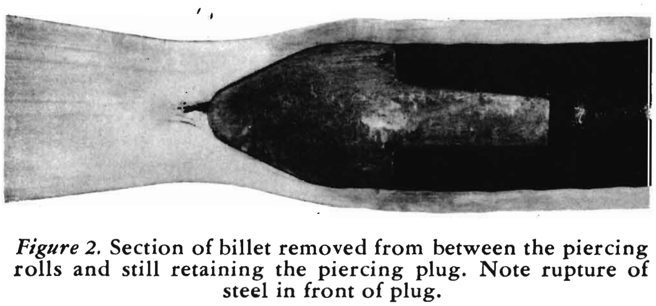


Figure 2. **Section of billet removed from between the piercing rolls and still retaining the piercing plug. Note rupture of steel in front of plug.**

The Elongator or Diescher Process:

The latest process of hot finishing tubing is the Diescher Mill. The rough tube, as it comes off the piercing rolls, is fed over a solid mandrel and then the tubing and mandrel are rolled down through a set of barrel rolls and disc guides. The barrel-shaped rolls used in this mechanism are such that they offer a long contact with the tube, thereby tending to even out the wall, etc. The large cross rolls determine the outside and inside diameters, while the distance between the mandrel and the lips of the disc guides determine the uniformity of wall.

Any cross rolling such as the elongator process is an expanding operation and if it were not for the action of the steel disc guides traveling at a faster speed than the tube, the latter would come off the mill looking very irregular. However, the discs slip on the tube and transfer any bulging or expansion of the tube into elongation.

One of the big assets of the Diescher process is its ability to produce more concentric tubes. The reason for this is explained by the fact that an eccentric tube from the piercing rolls when rolled down on a bar mandrel would vibrate and naturally set up quite a resistance going through the rolls. In so doing, the heavy wall portions find difficulty in going through the clearance allotted. However, it is a well known fact that heavy walls deform more easily than lighter walls. The resistance caused by the flow of the heavy walls is so great that the temperature is increased, causing the steel to be more plastic, thus allowing it to be elongated.

The Diescher process eliminates the rolling on the short plugs, which operation frequently is the cause of inside defects, and these defects are very difficult to remove by any later finishing operation. The tubing coming from this type of mill appears to be more concentric and freer from inside defects such as laps, seams, etc., than tubing from most other type mills.

Other Methods:

Since the first discovery of the piercing of solids by the Mannesmann Brothers in 1883, other methods of hot piercing have been developed, such as the Stiefel mill; and in England, the hydraulic plunger type. A more recent innovation is the extrusion process. However, the Mannesmann process is the most widely used in this country and, for the sizes used to produce cold drawn tubes especially for aircraft, is practically universal.

Tube Sizes:

The smallest tubes which can be produced off the hot mills are approximately 1½″ outside diameter, although there are some instances where smaller diameters are produced. Although the tubes coming from hot mills have been produced to meet certain mechanical tolerances, these requirements are generally not sufficient to meet the demand of the aircraft tubing user, so that in order to produce the required tubing it is necessary to resort to cold drawing. Cold drawn tubing has the following advantages over hot finished tubing:

1. Better surface finish.
2. Smaller sizes and lighter walls.
3. Closer tolerances.
4. A variety of shapes.
5. Improved physical properties.

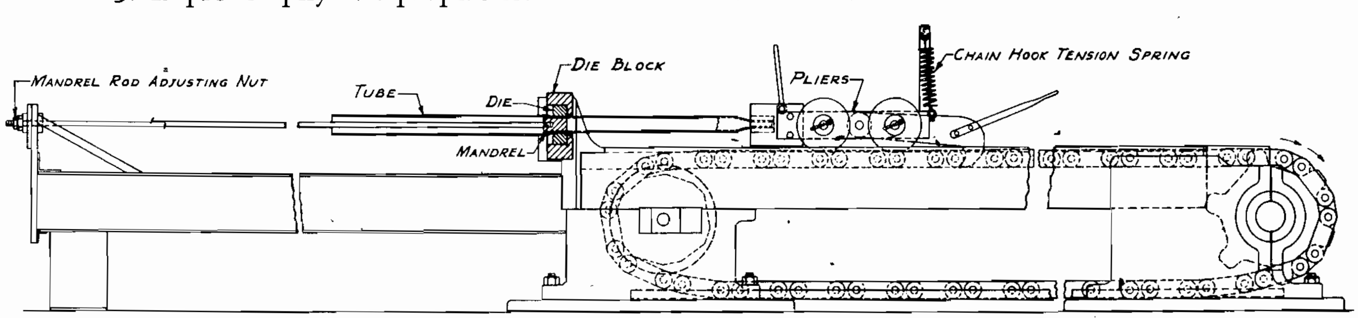
Cold Drawing:

Before cold drawing can be resorted to, the hot finished tube must be put in the proper condition. If the hardness of the material is too high, so that the material will not flow readily in the cold condition, the tubing must be annealed or softened to certain hardness limits. After annealing the tubing is pickled in a dilute solution of sulphuric acid to remove the scale, after which the tubing is rinsed free of acid and some type of grease lubricant applied to the inside and outside surfaces of the tube. Only after tubing has been prepared in a satisfactory manner is it capable of being satisfactorily cold drawn.

The cold drawing process is a cycle of operations, including—

(a) Pointing
(b) Cold Drawing
(c) Annealing
(d) Pickling

Principles in Cold Drawing: The tube to be drawn through the dies is in an annealed low strength condition, and the power must be an amount sufficient to exceed the yield point of the tube being drawn. After being pulled through a die and reduced in size, the metal in this reduced section has been cold worked and its physical properties have been increased considerably. In other words, the material coming out of the die is much stronger than that going into the die. This allows the drawing to continue for if it were not for the fact that the material hardens up, it would probably break off because of the great amount of friction in the drawing operation. In general, it can be said that the increase in physical properties, such as yield point and ultimate strength, is proportional to the percentage of the reduction of the cross sectional area.



Draw Bench Assembly Showing Seamless Tube in the Process of Drawing

Figure 3

Drawing Tools and Equipment: Although tool steel is still used for many dies, tungsten carbide is used for nearly all difficult shapes and for all popular size rounds. The tungsten carbide material is much harder than the ordinary tool steel and appears to have a self lubricating quality because of the high polish which is obtainable on this type of material. Most of the men in the mill would trade a hundred steel dies for one of the tungsten carbide. The same tube which, when drawn, is scratched with a steel die, may be satisfactorily drawn with a tungsten carbide die.

Most of the plugs used are made from hardened tool steel, the surface of which has been hard chromium plated.

The success of any cold drawing operation is dependent on the proper preparing of the tube surface, the correct annealing methods, the proper shape dies, hardness of the tools in general, the speed of the draw benches, and several other incidental features, which creep in from time to time. The defects occurring on the tube from cold drawing operations are usually scratches or gouges, caused by a pick-up on the tools.

A draw bench is shown in Figure III in schematic view.

Annealing:

Because of the fact that the metal hardens up after a cold drawing operation, it is necessary to soften it again before subjecting it to a further reduction. This softening is accomplished by heat treating and is known as annealing.

The cold drawn tube is heated to just below its lower critical temperature, but just above the recrystallization temperature at which point all the cold working strains are relieved and the material is in such a state that it can be further processed. The annealing temperature for Chromium Molybdenum steel tubing is approximately 1350° F. Most of the annealing at Summerill is done in continuous furnaces.

Normalizing:

Aircraft tubing is of course manufactured to meet the requirements of the Army and Navy Specifications, unless otherwise specified by a customer. To obtain the physical requirements, two methods are permitted by the specification:

A. *Normalizing:* This requires heating the tubing above the upper critical temperature and cooling in still air.* As X4130, X4135 and X4340 are all air hardening steels, the proper normalizing treatment will produce the desired physical properties. Normalizing also removes all the effects of cold working.

B. *Strain Relieving:* By this method the tubing after the last cold drawn pass is put through the furnace at a low annealing or "strain relieving" temperature. This will not materially reduce the tensile strength produced by cold drawing, but will lower the yield point to meet the elongation required.

Sometimes a combination of these two methods is used.

All normalizing and annealing at Summerill is done in continuous furnaces, where the temperatures are automatically controlled. A specially prepared atmosphere surrounds the material as it passes through the furnaces and cooling chambers. This prepared atmosphere has a high carbon-monoxide content, thereby preventing any oxidation; and because this atmosphere has been relieved of its water vapor contents, there is practically no decarburization. As the tube emerges from the end of the cooling chamber, it is cold and free of any scale or oxide film.

Heat Treated Material:

There is a great deal of X4130 tubing used in the heat treated condition, where ultimate strength as high as 200,000 psi. is required. It is our practice to quench this material from 1650° F. into oil and temper back to the physical properties required. It should be emphasized that Chromium Molybdenum steels require a higher tempering temperature to achieve the same high physical properties, as compared to other steels. This higher tempering temperature allows a better relief of the quenching stresses and consequently increases the toughness. It is also interesting to note Chromium Molybdenum steel is very sluggish in heat reactions, and consequently requires longer soaking periods than most steels in order to achieve the maximum properties from a quenching operation.

*For more details on normalizing and other heat treatment, see text under Heat Treatment, with Charts.

SPECIFICATIONS

IN the following digest of Aircraft Tubing specifications no attempt is made to give all paragraphs as covered by each separate specification; however, all essentials covering chemical analysis, mechanical properties and size tolerances are shown.

These details are published by authority of and arrangement with Government agencies under the following conditions:

"The U. S. Government issue of the specification from which these requirements were extracted applies for Government procurement of aeronautical material, and is subject to change. Copies of the latest Government issue are available to bidders and contractors upon application to the Government Procuring Agency concerned."

All Army and Navy Aeronautical Specifications for tubing are now identified as the "AN" series, and are in use by both the Bureau of Aeronautics and the Army Air Forces.

The Technical Committee of the aircraft engine manufacturers has prepared its own specifications known as Aeronautical Material Specifications. These are identified as AMS Specifications and are available by writing the Society of Automotive Engineers, 29 West 39th Street, New York City.

DEFINITIONS

A—AIRCRAFT OR AIRFRAME TUBING

This term designates a tube with size, analysis, mechanical properties, and surface finish suitable for use in fuselage or airframe construction. Seamless tubes for this purpose are always furnished Cold Drawn, and Electric Welded Tubing, for this application is made only from cold rolled strip. Special processes and quality selection have been established for the manufacture of aircraft tubing. It is supplied either annealed, normalized or specially heat treated and is commonly used in the condition as supplied by the manufacturer. However, in some cases, tubes may be deformed, partially machined, ground or heat treated by the user.

Aircraft tubing is usually ordered to Government Specifications (AN) or specifications promulgated by generally recognized agencies.

B—AIRCRAFT MECHANICAL TUBING

This term designates a Cold Drawn or Hot Rolled tube of analysis and internal steel qualities suitable for use in the Aircraft Industry in manufacturing axles, shock absorbers, landing gear struts, motor parts or other similar applications. Magnetic aircraft quality steel is recommended for the manufacture of these parts by the tube mill. However, both magnetic aircraft quality and commercial steel grades are being widely used.

Such tubes will have a relatively wide tolerance range, will be furnished with commercial surfaces, and special processing or selection is not required because the outside surface or the inside surface or both surfaces are *completely machined* by the user. Regular commercial standards of processing in effect for ordinary usages are employed by the tube mill. AMS (Aeronautical Material Specifications) for this class of tubing are AMS-6371 for 4130; AMS-6381 for 4140; and AMS-6413 for 4335.

C—AIRCRAFT ENGINE TUBING

Practically all tubing used by engine manufacturers is ordered to Aeronautical Material Specifications (AMS) issued by the Society of Automotive Engineers. The uses cover low carbon steels for oil lines to various alloys for push rods and other highly stressed parts. Although quite similar to many Standard SAE and Government Specifications, the carbon range, and other elements, is in some instances held closer than for the airframe requirements. There are special quality clauses which apply specifically to this type of tubing.

MATERIAL AND WORKMANSHIP

Material: The steel shall be manufactured by the open hearth, electric furnace, or crucible process.

Workmanship: The tubing shall have a good workmanlike finish conforming to the best practice for high quality aircraft material. It shall be smooth, clean, and free from heavy scale or oxide, burrs, seams, tears, grooves, laminations, slivers, pits, and other injurious defects. Surface imperfections such as handling marks, straightening marks, light mandrel and die marks, shallow pits, and scale pattern will not be considered as injurious defects, provided the imperfections are removable within the tolerances specified herein for diameter and wall thickness. The removal of surface imperfections is not required.

Quality: The steel shall be of a quality satisfactory for the fabrication of parts which may be subjected to any method of inspection, acceptable to the Government, which will disclose injurious defects.

Grain Size

Carbon Grade shall be fine and uniform for all parts of the tubing.

Alloy Grades: The austenitic grain size of the steel used for this tubing shall be predominantly No. 5 or finer, with grains as large as No. 3 permissible; as determined on a billet before piercing, hot working, or cold drawing.

Mechanical Properties: After the last cold-draw pass, the tubing shall be normalized, stress relieved, or otherwise heat treated to develop the mechanical properties specified.

Length Tolerances: Unless otherwise specified, tubing shall be furnished in random lengths of not less than five feet. When exact lengths are specified, a variation of plus 1/8, minus 0 inch, will be permitted.

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1025—CARBON TUBING—AN-WW-T-846. Amend't 1 Mar. 21, 1942.

CHEMICAL COMPOSITION

Carbon Percent	Manganese Percent	Phosphorus[1] Maximum Percent	Sulphur Maximum Percent
0.20–0.30	0.30–0.60	0.045	0.055

Note (1)—Maximum of 0.05 percent permitted when acid steel is specified.

MECHANICAL PROPERTIES

Tensile Strength	Yield Strength at Extension Indicated		Elongation in 2 Inches
Minimum Lb. per Sq. In.	Minimum Lb. per Sq. In.	Extension Under Load Inch per Inch	Minimum Percent
55,000	36,000	0.0042	22[a]

Note (a)—For each 2000 pounds per square inch in excess of 55,000 pounds per square inch tensile strength, a reduction in elongation of one percent to a minimum elongation of 10 percent will be allowed.

Mechanical Properties—Shall be as specified for material in the as furnished condition, and for material normalized by heating to 1625-1675° F. and cooling in still air.

AMS-5075: Generally similar to above specification except carbon range is 0.21—0.29.

1010—CARBON TUBING—AMS-5050A—March 1943.

Aeronautical Material Specification. A low carbon analysis of special manufacture generally used for engine oil lines, hydraulic lines, intake tubes, etc.

CHEMICAL COMPOSITION

Carbon Max. Percent	Manganese Max. Percent	Phosphorus Max. Percent	Sulphur Max. Percent
0.15	0.60	0.045	0.055

MECHANICAL CONDITION

(a) Normalized or annealed to conform to a minimum elongation of 35% in 2 in., with a full section test piece, or 25% in 2 in., with a strip test piece.

(b) Samples representing the ends of each tube will be flared over a cone of 60° included angle until the large end diameter has increased 50%. The flared ends shall be inspected and any tube revealing defects or cracks shall be rejected.

TOLERANCES—*for AMS-5050A*

Nominal Outside Diameter	Outside Dimensions Inches Plus or Minus	Wall Thickness
Less Than 1.500″ 1.500″ to 3″ inclusive Over 3″	−0.000, +0.005 −0.000, +0.010 −0.000, +0.015	0.5 in., or larger nominal inside diameter, shall not vary more than + or − 10% from thickness specified; smaller sizes may vary + or − 15%.

4130—CHROMIUM-MOLYBDENUM—AN-WW-T-850a—March 26, 1942.

CHEMICAL COMPOSITION

Carbon Percent	Manganese Percent	Phosphorus Maximum Percent	Sulphur Maximum Percent	Chromium Percent	Molybdenum Percent
0.25–0.35	0.40–0.60	0.040	0.050	0.80–1.10	0.15–0.25

AN-WW-T-850a

This specification is for Army-Navy and general use and is the one principally employed for the purchase of seamless X-4130 round, square, rectangular, oval and streamline aircraft tubing. It provides for furnishing tubes in condition A (annealed); in condition N (normalized or cold drawn and stress relieved), or heat treated to various quenched and tempered mechanical properties. Unless otherwise ordered, the tubing is supplied in condition N. See Table I.

Special operations such as bending or otherwise deforming, etc., are sometimes performed on tubes ordered to this specification. Such tubing is usually furnished in condition A (annealed) and the purchaser should furnish full information on his order when he intends to make special applications of such tubing.

AMS-6360A

Similar to AN-WW-T-850a but differs in grain size and specification details. It has been employed principally by engine manufacturers but the quantity of tubing ordered to this specification has been small when compared to that ordered to AN-WW-T-850a. Indicates magnetic testing.

AMS-6361, 6362, 6363

The above are similar to 6360A but provide for 125,000, 150,000 or 180,000 psi minimum tensile.

NE-8630—CHROMIUM-NICKEL-MOLYBDENUM—AN-T-15—Amend't-1—March 15, 1943.

This new National Emergency Steel NE-8630 is the alternate for 4130 steel and may be supplied by the tube mills when and as 4130 is not available.

CHEMICAL COMPOSITION

Element	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum
Percent..........	0.27–0.33	0.70–0.90	0.040-Max.	0.040-Max.	0.20–0.35	0.40–0.60*	0.40–0.60	0.15–0.25
Tolerance........	−0.02	±0.03	+0.005	+0.005	±0.02	±0.03	±0.03	±0.03

Note (a)—The nickel content in this analysis now specified as 0.60 as the top limit will probably be changed to 0.70 in the near future.

AMS-6530

This specification is similar to AN-T-15 for NE-8630. Supplied in condition N only.

X-4135—CHROMIUM-MOLYBDENUM—AN-WW-T-852a—March 26, 1942.

CHEMICAL COMPOSITION

Carbon Percent	Manganese Percent	Phosphorus Maximum Percent	Sulphur Maximum Percent	Chromium Percent	Molybdenum Percent
0.30–0.40	0.40–0.70	0.040	0.050	0.80–1.10	0.15–0.25

AN-WW-T-852a

Similar to AN-WW-T-850a except requires X-4135 steel and was written primarily to cover relatively heavy wall tubing.

AMS-6365

Similar to AN-WW-T-852a. Same comments apply as made regarding 6360A.

AMS-6366, 6367, 6368, 6369

Same as AMS-6365 except provision is made for 125,000, 150,000, 180,000 or 200,000 psi minimum tensile.

See Tables I and II next page for Mechanical Properties.
See Tolerance Tables beginning on Sec. I—10.

NE-8635—CHROMIUM-NICKEL-MOLYBDENUM—AN-T-22—Amend't-1—March 15, 1943.

This new National Emergency Steel NE-8635 is the alternate for 4135 Steel and may be supplied by the tube mills when and as 4135 is not available.

CHEMICAL COMPOSITION

Element	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum
Percent..........	0.33–0.38	0.75–1.00	0.040-Max.	0.040-Max.	0.20–0.35	0.40–0.60*	0.40–0.60	0.20–0.30
Tolerance........	±0.02	±0.04	+0.005	+0.005	±0.02	±0.03	±0.03	±0.03

Note (a)—The nickel content in this analysis now specified as 0.60 as the top limit will probably be changed to 0.70 in the near future.

Note (b)—The molybdenum content of this analysis is .20/.30 which would place this in the 8700 series rather than the 8600 series in which the molybdenum content is .15/.25. However, due to the overlapping by .05 points and the fact that otherwise the chemical requirements are the same except for the carbon and aircraft tubing users being more familiar with the 8600 series, we for the time being are referring to it as NE-8635.

Mechanical Properties Same as for 4135

AMS-6535—This specification is similar to AN-T-22 for NE-8635. Supplied in condition "N" only.

MECHANICAL PROPERTIES—TABLE I

For 4130—AN-WW-T-850a and NE-8630—AN-T-15

Condition and Wall Thickness	Tensile Strength (min.)	Yield Strength at 0.2% Set or at Extension Indicated		Elongation in 2 inches	
		(min.)	Extension Under Load	Full Tube (min.)	Strip (min.)
Inch	Lbs. per Sq. In.	Lbs. per Sq. In.	Inch in 2 Inches	Percent	Percent
(A)=Annealed	95,000 Max.				
(N)=Normalized or Stress relieved					
Up to 0.035 incl.	95,000	75,000	0.0090	10	5
Over 0.035 to 0.188 incl.	95,000	75,000	0.0090	12	7
Over 0.188	90,000	70,000	0.0087	15	10
(HT–125) All Walls	125,000	100,000	0.0107	12	7
(HT–150) All Walls	150,000	135,000	0.0130	10	6
(HT–180) All Walls	180,000	165,000	0.0154	8	5

MECHANICAL PROPERTIES—TABLE II

For 4135—AN-WW-T-852a and NE-8635—AN-T-22

Condition and Wall Thickness	Tensile Strength (min.)	Yield Strength at 0.2% Set or at Extension Indicated		Elongation in 2 inches	
		(min.)	Extension Under Load	Full Tube (min.)	Strip (min.)
Inch	Lbs. per Sq. In.	Lbs. per Sq. In.	Inch in 2 Inches	Percent	Percent
(A)=Annealed	100,000 Max.				
(N)=Normalized or Stress Relieved					
Up to 0.188 incl.	100,000	85,000	0.0097	12	7
Over 0.188	95,000	80,000	0.0093	15	10

Note—HT (Heat Treated) values are same as for 4130 and 8630—see Table I above.
Unless otherwise specified, tubing shall be furnished in condition (N).

X-4340—CHROMIUM-NICKEL-MOLYBDENUM

Navy Aeronautical Specification No. M-4991. Amend't-1—Aug. 29, 1942.

Condition—The tubing shall be furnished in the following conditions, as specified:

(A) Normalized.
(B) Heat treated 200,000 T.S.
(C) Heat treated 230,000 T.S.
(D) Annealed (all mechanical properties waived).

Quality—The steel shall be of aircraft quality satisfactory for the fabrication of parts which may be supplied to magnetic inspection by a process acceptable to the Bureau of Aeronautics.

CHEMICAL COMPOSITION

Carbon Percent	Manganese Percent	Sulphur Maximum Percent	Phosphorus Maximum Percent	Chromium Percent	Nickel Percent	Molybdenum Percent
0.35–0.40	0.50–0.80	0.050	0.040	0.60–0.90	1.50–2.00	0.20–0.30

MECHANICAL PROPERTIES

Condition	Ultimate Strength	Yield Point Minimum	Elongation in 2 Inch Minimum	
			Up to and including $\frac{3}{16}$ Inch Wa.	Above $\frac{3}{16}$ Inch Wa.
A	150,000 psi. (Normalized)	120,000 psi.	5%	7%
B	200,000 psi.	170,000 psi.	4%	6%
C	230,000 psi.	200,000 psi.	3%	5%
D	Annealed—Physical properties waived			

The mechanical properties of the steel shall be as specified when the steel is quenched in oil from 1500 to 1550° F., and suitably tempered. Normalizing shall be from a temperature of 1550 to 1625° F.

SIZE TOLERANCES—ROUND TUBING—TABLE III

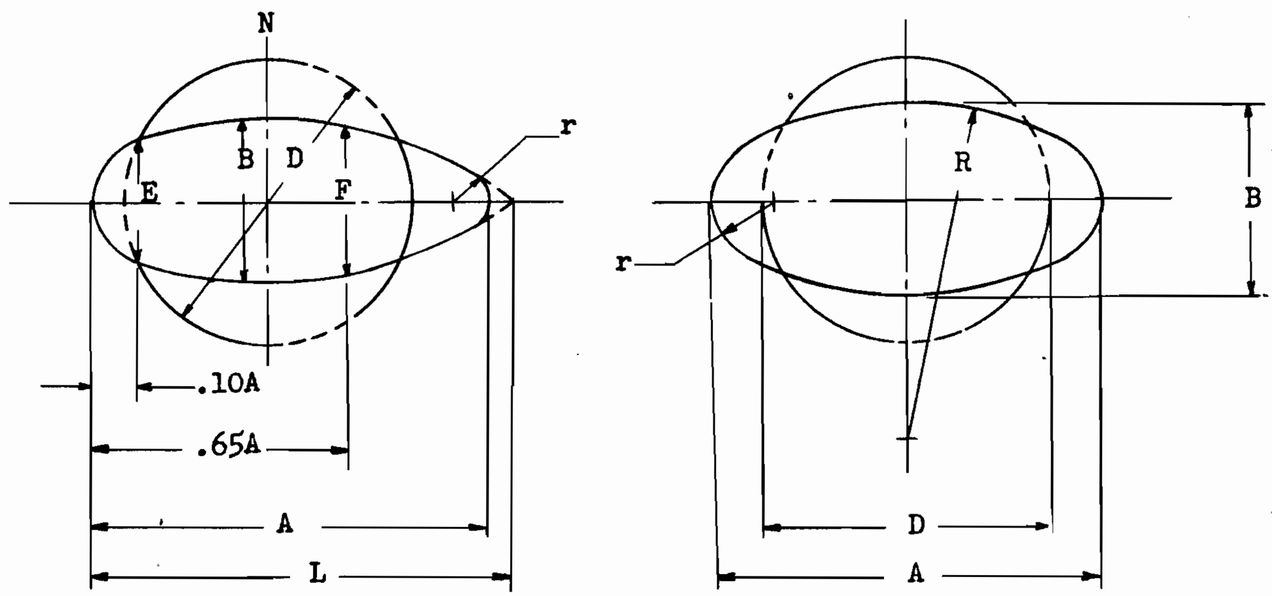
For 1025 Carbon, 4130, NE-8630, X-4135, NE-8635 and other Alloy Airframe Tubing

Outside Diameter and Wall Thickness Tolerances

Nominal Outside Diameter	Variation from Nominal		
	Outside Diameter		Wall Thickness
	Conditions (A) & (N)	HT Conditions	
Inches	Inch	Inch	Percent
Under 0.5	±0.005	±0.010	±15(*b*)
0.5 to 1.5 incl.	±0.005	±0.015	±10
Over 1.5 to 3.0 incl.	±0.010	±0.030	±10
Over 3.0 to 5.5 incl.	±0.015	±0.045	±10
Over 5.5	±0.020	±0.060	±10

Note—The above tabulated tolerances shall be allowed on the mean outside diameter and wall thickness of the tubing. (Each mean outside diameter shall be taken as the average of the maximum and minimum outside diameters of any transverse section.)

(*b*) ±15 percent for tubing with ½″ or less *inside* diameter.



FORMULAS FOR DETERMINING NOMINAL TUBING DIMENSIONS

(D = Equivalent Round Dia.)

STREAMLINE		OVAL	
Design Reference Dimensions	Inspection Reference Dimensions	Design Reference Dimensions	Inspection Reference Dimensions
N = Neutral Axis (at 0.45A) L = Construction Point (= 2.5B) r = .1085D (Approx.)	A = 1.3486D B = 0.5714D E = 0.411D F = 0.457D	$\frac{A}{B} = 2$ R = 1.10D (Approx.) r = .206D (Approx.)	A = 1.30D B = 0.65D

TABLE IV

DIMENSIONS AND TOLERANCES FOR *STREAMLINE* AND *OVAL* TUBING

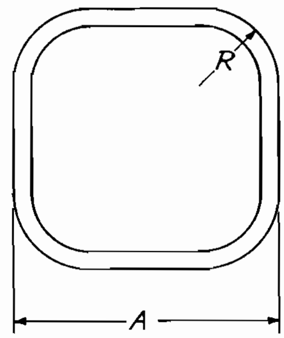
Diameter "D"	Wall Thickness (1)	Width "A" (Major Axis)		Width "B" (Minor Axis)		Width "E"	Width "F"
		Type III	Type IV	Type III	Type IV	Type III	Type III
Inches	Inch	Inches	Inches	Inches	Inches	Inches	Inches
		Tol. +.040 −.025		Tolerance +.025 −.015			
1.00	.035	1.349	1.300	0.571	0.650	0.411	0.457
1.25	.035	1.685	1.625	0.714	0.812	0.514	0.572
1.50	.035	2.023	1.950	0.857	0.975	0.617	0.686
1.75	.049	2.360	2.275	1.000	1.138	0.720	0.801
2.00	.049	2.697	2.600	1.143	1.300	0.823	0.916
2.25	.058	3.035	2.925	1.286	1.462	0.926	1.030
2.50	.058	3.372	3.250	1.429	1.625	1.029	1.145
		Tol. +.050 −.035		Tolerance +.035 −.025			
2.75	.065	3.708	3.575	1.571	1.787	1.131	1.258
3.00	.065	4.045	3.900	1.714	1.950	1.234	1.373
3.25	.083	4.383	4.225	1.857	2.113	1.337	1.487
3.50	.083	4.720	4.550	2.000	2.275	1.440	1.602
3.75	.083	5.057	4.875	2.143	2.437	1.543	1.717
		Tol. +.070 −.050		Tolerance +.055 −.040			
4.00	.083	5.394	5.200	2.285	2.600	1.645	1.830
4.25	.095	5.732	5.525	2.428	2.762	1.748	1.945
4.50	.095	6.069	5.850	2.571	2.925	1.851	2.059
4.75	.125	6.406	6.175	2.714	3.087	1.954	2.174
5.00	.125	—	6.500	—	3.250	—	—

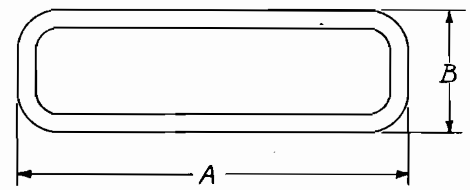
Note: For sizes other than Standard the Procuring Agency shall provide a drawing with invitations and contracts.
Note (1)—Tolerances on Wall Thickness shall be ± 10 percent. Wall Thickness as shown is the minimum thickness available.

STRAIGHTNESS TOLERANCES—TABLE V

Rounds, Rectangles, Streamlines and Ovals

Type	Condition	Tolerance for Maximum Departure from Straightness Expressed as a Proportional Part of Length	Measured From
I—Round	(A) & (N) (HT)	One part in 800 One part in 600	
II—Rectangular	(A) & (N) (HT)	One part in 800 One part in 600	
III—Streamline	(A) & (N) (A) & (N) (HT) (HT)	One part in 800 One part in 400 One part in 600 One part in 300	From plane of major axis From plane of minor axis From plane of major axis From plane of minor axis
IV—Oval	(A) & (N) (A) & (N) (HT) (HT)	One part in 800 One part in 400 One part in 600 One part in 300	From plane of major axis From plane of minor axis From plane of major axis From plane of minor axis





SQUARES and RECTANGLES

TABLE VI
OUTSIDE DIMENSION AND WALL THICKNESS TOLERANCES FOR *SQUARE* AND *RECTANGULAR* TUBING WITH ROUNDED CORNERS

Largest Nominal Outside Dimension Inches	Variation from Nominal	
	Outside Dimensions Inches Plus or Minus	Wall Thickness Percent Plus or Minus
Under 0.75	.010	10
0.75 to 1.5 incl.	.015	10
Over 1.5 to 2.5 incl.	.020	10
Over 2.5 to 3.5 incl.	.025	10
Over 3.5 to 5.5 incl.	.030	10

Notes:

1. Permissible variations on rectangular tubing are based on the largest outside dimension.
2. Permissible variations on outside dimensions include convexity or concavity.
3. Wall variations as shown in the above table do not apply at corners.
4. Unless otherwise specified, the corners may not be true radii in one section, nor throughout any one length. The corner radii will also vary depending upon the outside dimensions and wall thickness.
5. When special corners are required, detailed drawings must be submitted with inquiries or orders.
6. When square tubing is required, rectangular tubing with equal sides should be specified.

SQUARENESS OF SIDES

The squareness of rectangular tubes may vary in accordance with the following formula:

$\pm B = .006c$

Where B = Tolerance for out-of-square

C = Length of longest side

Example:

Rectangular tube two inches by 1 inch

C = 2 inches

$\pm B = (.006)(2)$

$\pm B = .012$ inch

Test for Squareness. The squareness of the tubing shall be found by placing a true try square on opposite diagonal corners and at each two foot interval along the length. If lack of contact between any side and the square edge can be measured with feelers at only the top or at only the bottom of any side exclusive of corner radii, the maximum width of the opening shall be considered the amount out of square.

Thus a two inch by one inch rectangular tube may have its sides fail to be 90 degrees to each other, by not more than $\pm$ .012 inch.

ALLOWABLE TWIST

The average twist in the full length of each rectangular tube shall not exceed $\frac{1}{32}$ inch per 3 feet of length.

Twist Test for Squares and Rectangles. The twist of each piece of rectangular or square tubing shall be determined by placing each tube on a surface plate so that the bottom side, at one end, is in contact with, and parallel to, the surface plate. The distance that either corner, at the opposite end, is above the surface plate shall be considered as the total twist for the full length of the tube.

18-8—SEAMLESS STAINLESS—AN-WW-T-855 Amendment No. 1—March 21, 1942.

Grade—Corrosion-resistant seamless steel tubing shall be furnished in one grade only.

Condition—The tubing shall be furnished in the following conditions, as specified.

Physical Conditions

(A) Annealed

(B) ¼ hard

Surface Conditions

(1) Pickled and passivated

(2) Polished 80 grit

(3) Polished 120 grit

(4) Polished 240 grit

(5) Polished 320 grit, plus buff.

CHEMICAL COMPOSITION

C (max.)	Mn	P (max.)	S (max.)	Cr (min.)	Ni (min.)	Si	Cu (max.)
Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
0.12	0.2–2.5	0.04	0.04	17.0	7.0	0.2–1.5	0.50

MECHANICAL PROPERTIES—TABLE VII

Physical Condition	Tensile Strength		Yield Strength at 0.2% set or at Extension Indicated		Elongation in 2 Inches (min.)	
	(min.)	(max.)	(min.)	Extension Under Load	Full Tube	Strip
	Lb. per Sq. In.		Lb. per Sq. In.	Inch in 2 Inches	Percent	Percent
(A)	75,000	100,000	30,000[a]	0.0063	35	30
(B)	120,000	—	75,000	0.0098	15	12

Note (a)—Value of Yield Strength for information only. Tests will not be conducted unless otherwise specified.

See Table VIII—Sec. I—11c for Size Tolerances for Stainless Tubing

18-8—STABILIZED SEAMLESS STAINLESS—AN-WW-T-858 Amendment No. 1—March 21, 1942.

CHEMICAL COMPOSITION

C (max.)	Mn	P (max.)	S (max.)	Cr (min.)	Ni (min.)	Si	Cu (max.)	Cb or Ti
Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
0.10	0.2–2.5	0.04	0.04	17.0	7.0	0.2–1.5	0.50	Note 1

Note 1. Columbium and titanium are considered to be interchangeable as the stabilizing element; and unless otherwise specified, either may be furnished, at the option of the manufacturer, in an amount not less than 8 times the carbon content for columbium or not less than 4 times the carbon content for titanium.

MECHANICAL PROPERTIES—SUPPLIED ANNEALED ONLY

Tensile Strength (max.)	Elongation in 2 Inches (min.)	
	Full Tube	Strip
Lb. per Sq. In.	Percent	Percent
100,000	35	30

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SIZE TOLERANCES FOR STAINLESS TUBING—TABLE VIII

Nominal Dimensions		Variation from Nominal		
		Outside Diameter		Wall Thickness
Outside Diameter Inches	Wall Thickness Inch	Condition (A) Inch	Condition (B) Inch	Percent
Less than 0.5	All Thicknesses	+0.010 −0.000	+0.010 −0.000	±15
0.5 to 1.5	0.065 and over Less than 0.065	+0.010 −0.000 +0.020 −0.000	+0.010 −0.000	±10
1.5 to 3.5	0.095 and over Less than 0.095	±0.010 ±0.020	±0.010	±10
3.5 to 4 incl.	0.148 and over Less than 0.148	±0.015 ±0.030	±0.015	±10

Straightness—In no portion of any piece of tubing shall the departure from straightness exceed one part in 600 parts of length.

WELDED ALLOY AIRCRAFT TUBING

1025—*WELDED* CARBON TUBING—AN-T-4, April 1, 1942.

Requirements for welded Carbon Tubing are the same as for seamless except as noted below under AN-T-3.

4130—*WELDED* CHROMIUM-MOLYBDENUM—AN-T-3—March 25, 1942.

"The Chemical Analysis, Size Tolerances and Mechanical Properties for welded 4130 Alloy, NE-8630 and 1025 Carbon Aircraft tubing are the same as for Seamless Aircraft tubing (See Tables under AN-WW-T-846 for Carbon, AN-WW-T-850a and AN-T-15 for Alloys)."

Workmanship clause is identical with requirements for seamless except the addition of the following:

"The weld shall not contain defects having lengths greater than $\frac{1}{16}$ inch, or depths greater than ½ the wall thickness."

"The maximum height of the inside welding flash shall not exceed 60 per cent of the nominal wall thickness of the tubing and in no case shall it be greater than $\frac{3}{64}$ inch."

"The tubing may be pickled or otherwise cleaned, if necessary, to meet surface conditions specified herein."

"This specification is for Army-Navy and general use and is the one principally employed for the purchase of WELDED 4130 round, square, rectangular, oval and streamlined aircraft tubing. It provides for furnishing tubes annealed, in condition N (normalized or cold drawn and stress relieved), or heat treated to various quenched and tempered mechanical properties. Unless otherwise ordered, the tubing is supplied in condition N."

"Special operations such as bending or otherwise deforming, etc., are sometimes performed on tubes ordered to this specification. Such tubing is usually furnished in condition A (annealed) and the purchaser should furnish full information on his order when he intends to make special applications of such tubing."

NE-8630—*WELDED* CHROMIUM-NICKEL-MOLYBDENUM—AN-T-33.

Requirements for this new NE steel in welded tubing are the same as for seamless except as noted under AN-T-3, opposite page.

NE-8630—*WELDED* CHROMIUM-NICKEL-MOLYBDENUM—AN-T-33, Mar. 15, 1943.

Requirements for this new NE steel in welded tubing are the same as for seamless in this analysis except as noted on opposite page under AN-T-3.

This specification covering the new National Emergency Steel is the alternate for welded 4130 steel and may be supplied by the manufacturers of welded aircraft tubing when and as 4130 is not available.

AMS-5077 *Welded* 1025 round, rectangular and square aircraft tubing.

AMS-6510 *Welded* 4130 round aircraft tubing.

USA-10245 *Welded* 1025 tubing for gliders only. Tubes are furnished as welded or cold drawn and annealed, as ordered.

18-8—*WELDED* STAINLESS—AN-WW-T-861—Amendment No. 2—June 11, 1942.

WELDED CORROSION RESISTANT STEEL TUBING

Same as AN-WW-T-858 Seamless Stabilized Stainless, except—

(1) "Supplied in the annealed condition only—no mechanical properties specified."

(2) "If beads are present at the welds on the inner surfaces of the tubing, such beads shall not be thicker than one-half of the nominal wall thickness of the tubing except that in no case shall the thickness of the bead exceed 1/64 inch. The outer surfaces of the tubing shall be free from beading or other indication of the presence of welds."

(3) "The annealing temperature shall be not less than 1900° F."

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STANDARD SIZES FOR ALLOY & CARBON SEAMLESS & WELDED AIRCRAFT TUBING (NOT STAINLESS)

Tube mills have made a thorough study, for a long period of time, of the various tube sizes which they have been asked to make. As a result of this study, it was found that the most common sizes are limited to 195 which include tubes up to and including 3″ outside diameter, and walls as heavy as ¼″.

It is recommended, therefore, that tubing users make every attempt to order aircraft tubing according to the tables of Standard Sizes, as proposed by Tubing Manufacturers as shown below.

X=SEAMLESS O=WELDED **OUTSIDE DIAMETER IN INCHES** 3/8/43.

WALL IN.	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/4	2 1/2	2 3/4	3
.022	X	X	X	X																			
.028	X	X	X	X	Ⓧ	Ⓧ	O	Ⓧ	Ⓧ	Ⓧ	X	X											
.035	X	X	X	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ		X	X	X				
.042				O	O	O	O		O	O													
.049	X	X	X	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	X	X	X				
.058		X	X	X	X	Ⓧ	O	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	X	X	X	X			
.065		X	X	X	X	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	X	X	X	X	X	X	X
.083				X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
.095			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
.120 / .125						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
.156								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
.188								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
.250									X		X	X	X		X		X	X	X	X	X	X	X

MACHINING ALLOWANCES

For tubing to be machined on both O.D. and I.D. and used for shock struts, landing gears, and other heavy wall tubes on aircraft parts

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IF a part can be finished with only one surface machined, i.e., either O.D. or I.D., the allowance for one surface only as given in the following tables will apply.

The following data have been prepared by the Technical Committee of the tubing manufacturers. At first glance some of the allowances may seem excessive to those not completely familiar with all details in tubing manufacture, but the Committee feels that, when the high quality necessary for aircraft, the methods of inspection and mill conditions, are taken into account, these allowances are fair and the net result will be better by removing the amounts specified rather than skimping and having higher rejections on a finished part.

Please note particularly that the allowances for hot finished tubing are greater than for cold drawn tubing. It is not possible to finish by hot rolling to as close tolerances or with as good a finish as obtainable by cold drawing.

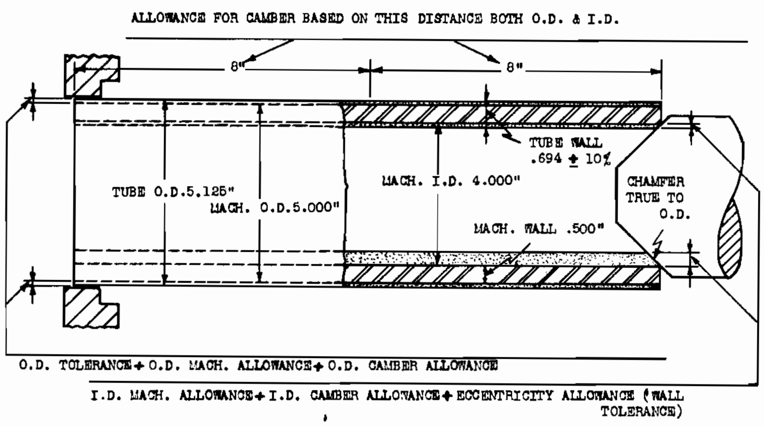

Fig. I—Tube chucked on O.D.

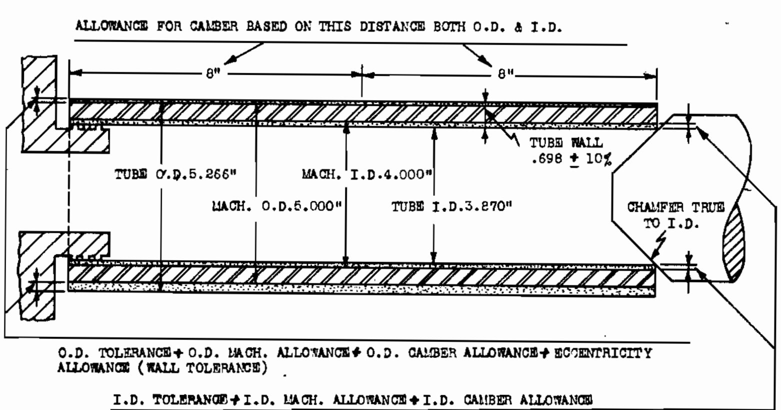

Fig. II—Tube chucked on I.D.

There are two basic chucking methods for machining of tubing—

1. By locating, i.e., chucking true to the outside surface of the tube.
2. By locating true to the inside surface of the tube, i.e., "on centers."

Therefore, the following types and methods are covered in the allowance tables.

a. Cold Drawn Tube—Machining Allowances if machined true to tube *O.D.*

b. Cold Drawn Tube—Machining Allowances if machined true to tube *I.D.*

c. Hot Finish Tube—Machining Allowances if machined true to tube *O.D.*,

d. Hot Finish Tube—Machining allowances if machined true to tube *I.D.*

MACHINING ALLOWANCES FOR COLD DRAWN TUBING

(a) For parts machined true with O.D.
(b) For parts machined true with I.D.

Size Range	(a) When machined true with O.D.		(b) When machined true with I.D.		Allowance for Wall Variation
	O.D. Mach. Allowance	I.D. Mach. Allowance	O.D. Mach. Allowance	I.D. Mach. Allowance	
Up to but not incl. 1½″ O.D.	.070″	.070″	.070″	.070″	The plus or minus 10% for wall tolerance must also be added as an additional allowance when machining requires a finished tube with uniform wall.
1½″ to but not incl. 2½″ O.D.	.075″	.075″	.075″	.075″	
2½″ to but not incl. 3½″ O.D.	.085″	.085″	.085″	.085″	
3½″ to but not incl. 4½″ O.D.	.095″	.095″	.095″	.095″	
4½″ to but not incl. 5½″ O.D.	.105″	.105″	.105″	.105″	
5½″ to but not incl. 6½″ O.D.	.120″	.120″	.120″	.120″	
6½″ to but not incl. 8″ O.D.	.135″	.135″	.135″	.135″	
8″ to but not incl. 10¾″ O.D.	.150″	.150″	.150″	.150″	

Standard tolerances for mechanical tubing as shown in Table I, Sec. I—11J for Cold Drawn Tubing will apply. When an "under" or "minus" tolerance is shown on the O.D., this amount must be added to the O.D. machining allowance given above to assure proper stock removal.

Allowance for camber (or straightness) must also be added when applicable.

If machining tolerances are furnished, use the maximum machined O.D. and the minimum machined I.D. in determining the size to which are added the allowances for camber.

MACHINING ALLOWANCES FOR HOT FINISHED TUBE

(c) Machined true with O.D.
(d) Machined true with I.D.

Size Range	(c) When machined true with O.D.		(d) When machined true with I.D.		Allowance for Wall Variation
	O.D. Mach. Allowance	I.D. Mach. Allowance	O.D. Mach. Allowance	I.D. Mach. Allowance	
Up to but not incl. 2½″ O.D.	.110″	.075″	.110″	.185″	The plus or minus 12½% for wall variation must also be added as an additional allowance when machining requires a finished tube with uniform wall.
2½″ to but not incl. 3½″ O.D.	.125″	.085″	.125″	.185″	
3½″ to but not incl. 4½″ O.D.	.135″	.095″	.135″	.185″	
4½″ to but not incl. 5½″ O.D.	.145″	.105″	.145″	.185″	
5½″ to but not incl. 6½″ O.D.	.175″	.120″	.175″	.185″	
6½″ to but not incl. 8″ O.D.	.195″	.135″	.195″	.195″	
8″ to but not incl. 10¾″ O.D.	.220″	.150″	.220″	.210″	

Standard tolerances for Hot Finished Mechanical Tubing as shown in Table II, Sec. I—11J will apply. An I.D. tolerance of plus or minus $\frac{1}{16}$″ has also been agreed on by the tube mills.

Also allowance for camber (or straightness) must be added when applicable.

If machining tolerances are furnished, use the maximum machined O.D. and the minimum machined I.D. in determining the size to which are added the allowances for camber.

CAMBER OR STRAIGHTNESS ALLOWANCE

(See Figures Sec. I—11 F)

Where the machined dimension used in calculating extends more than 3 inches from the chuck or other holding mechanism, the possibility of out-of-straightness of the tube must be taken into consideration. In such cases the following "camber allowance" must be added to the machining allowance, O.D., I.D., or both as required.

Distance from Chuck	O.D. of Machined Part	
	Up to and incl. 5″	Over 5″
Over 3″ to and incl. 6″	.010″ on dia.	.020″ on dia.
Over 6″ to and incl. 9″	.020″ on dia.	.030″ on dia.
Over 9″ to and incl. 12″	.030″ on dia.	.045″ on dia.
Over 12″ to and incl. 18″	.040″ on dia.	.060″ on dia.
Over 18″ to and incl. 24″	.050″ on dia.	.075″ on dia.
Over 24″ to and incl. 30″	.060″ on dia.	.090″ on dia.
Over 30″ to and incl. 36″	.070″ on dia.	.100″ on dia.

Note—In calculating, use the maximum machined outside diameter and the minimum machined inside diameter if machining tolerances are furnished. If only one machined dimension is furnished for each diameter, assume it to be the maximum machined O.D. and the minimum machined I.D.

CENTERLESS GRINDING

If O.D. stock is to be removed by centerless grinding instead of machining, reduce all O.D. "machining allowances" by .005″.

If machining tolerances are furnished, use the maximum machined O.D. and the minimum machined I.D. in determining the size to which are added the above allowances for camber.

EXAMPLES OF CALCULATIONS

In order to explain the method for calculating tube sizes, and also to illustrate the effect machining methods and tube finishes have on tube size, the following examples of the four methods (a, b, c, d) for arriving at a common machined size are shown:

Problem: To calculate a tube size to machine to a straight cylinder 5″ O.D. x 4″ I.D. x 16″ long.

Method a: Cold Drawn Tube—Machined True to O.D.

	Machined O.D. . . .		5.000″	
add	O.D. Mach. Allowance .		.105″	
add	Camber Allowance . .		.020″	
equals	Tube O.D.		5.125″	5.125″ Tube O.D.
	Machined I.D.		4.000″	
	I.D. Machine Allowance . .	.105″		
	Camber Allowance .	.020″		
subtract		.125″	.125″	
subtract			3.875″	3.875″
equals	twice min. wall			1.250″
divide	by two; equals minimum wall that will assure required stock removal			.625″

Table 5 (A.I. & S.I. Sect. 18) permits the wall to vary ±10% of normal wall. Therefore to obtain normal wall,

divide .625″ by 0.9—equals tube wall . .694″ Tube Wall

Tube size to specify:
Cold Drawn, O.D. 5.125″ (+.015 − .000)
Wall .695″ (±10%)

Method b: Cold Drawn Tube—Machined True to I.D.

	Machined I.D.		4.000″	
	I.D. Machine Allowance . .	.105″		
	Camber Allowance .	.020″		
	I.D. "over" tolerance . . .	.005″		
subtract	. . . .	.130″	.130″	
equals	Tube I.D.		3.870″	3.870″ Tube I.D.
	Machined O.D. . . .		5.000″	
add	O.D. Machine Allowance .		.105″	
add	Camber Allowance . .		.020″	
			5.125″	
subtract	Tube I.D.		3.870″	
equals	twice minimum wall . .		1.255″	
divide	by two; equals minimum wall that will assure required stock removal		.628″	

Table 5 (A.I. & S.I. Section 18) permits the wall to vary ±10% of normal wall. Therefore to obtain normal wall,

divide .628″ by 0.9—equals tube wall . .698″

To obtain tube O.D.

add	twice .698″ to tube I.D. . . .	1.396″
equals	Tube O.D.	5.266″ Tube O.D.

Tube size to specify:
Cold Drawn, O.D. 5.266″ (+.015″ − .000″)
I.D. 3.870″ (+.005″ − .015″)

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Method c: Hot Finish Tube—Machined True to O.D.

	Machined O.D.		5.000″	
add	O.D. Machine Allowance .		.145″	
add	Camber Allowance . .		.020″	
equals	Tube O.D.		5.165″	5.165″ Tube O.D.
	Machined I.D.			
	I.D. Machine Allowance . .	.105″		
	Camber Allowance .	.020″		
subtract		.125″	.125″	
subtract			3.875″	3.875″
equals	twice minimum wall			1.290″
divide	by two; equals minimum wall that will assure required stock removal			.645″

Table 6 (A.I. & S.I. Section 18) permits the wall to vary ± 12½% of normal wall. Therefore, to obtain normal wall,

divide	.645″ by 0.875″—equals tube wall	.737″ Tube Wall

Tube size to specify:

Hot Finish O.D. 5.165″ (±.031″) See Note
Wall .737″ (±12½%)

Note—This O.D. would have to be adjusted to roll size available, probably 5 3/16″ (5.188″) or 5¼″ (5.250″) in which case the wall would have to be increased accordingly to protect the I.D. clean up.

Method d: Hot Finish Tube—Machined True to I.D.

	Machined I.D.		4.000″	
	I.D. Machine Allowance . .	.185″		
	Camber Allowance .	.020″		
subtract		.205″	.205″	
equals	Tube I.D.		3.795″	3.795″ Tube I.D.
	Machined O.D.		5.000″	
add	O.D. Machine Allowance .		.145″	
add	Camber Allowance . . .		.020″	
			5.165″	
subtract	Tube I.D.		3.795″	
equals	twice minimum wall . .		1.370″	
divide	by two; equals minimum wall that will assure required stock removal .		.685″	

Table 6 (A.I. & S.I. Section 18) permits the wall to vary ±12½% of normal wall. Therefore, to obtain normal wall,

divide	.685″ by 0.875″—equals tube wall	.783″	
	To obtain tube O.D.		
add	twice .783″ to tube I.D.		1.566″
equals	Tube O.D.		5.361″ Tube O.D.

Tube size to specify:

Hot Finish O.D. 5.361″(±.031″) See Note
I.D. 3.795″(±1/16″)

Note—This O.D. would probably be adjusted to 5⅜″ (5.375″) to fit the mill sizing roll. The I.D. would remain the same.

TABLE I—PERMISSIBLE VARIATIONS IN THE DIAMETERS AND WALL THICKNESSES OF ROUND *COLD DRAWN SEAMLESS* MECHANICAL TUBING—(See Explanatory Notes)

Group	Size O.D., In.	Permissible Variations from: Outside Diameter, In.		Inside Diameter, In.		Wall Thickness Percent	
		Over	Under	Over	Under	Over	Under
1	3/16 to ½ excl.	0.004	0	a, b	a, b	a, b	a, b
2	½ to 1½ excl.	0.005[c]	0[c]	0[a, b]	0.005[a, b]	10[a, b]	10[a, b]
3	1½ to 3½ excl.	0.010[c]	0[c]	0[a]	0.010[a]	10[a]	10[a]
4	3½ to 5½ excl.	0.015	0[c]	0.005[a]	0.015[a]	10[a]	10[a]
5	5½ to 8 excl. when wall is less than 5% of O.D.	0.030[c]	0.030[c]	0.035[c]	0.035[c]	10	10
6	5½ to 8 excl. when wall is from 5% to 7.5% of O.D.	0.020	0.020	0.025	0.025	10	10
7	5½ to 8 excl. when wall is over 7.5% of O.D.	0.030	0	0.015[a]	0.030[a]	10[a]	10[a]
8	8 to 10¾ incl. when wall is less than 5% of O.D.	0.045[c]	0.045[c]	0.050[c]	0.050[c]	10	10
9	8 to 10¾ incl. when wall is from 5% to 7.5% of O.D.	0.035	0.035	0.040	0.040	10	10
10	8 to 10¾ incl. when wall is over 7.5% of O.D.	0.045	0	0.015[a]	0.040[a]	10[a]	10[a]

(a) For tubes with inside diameter less than 50 percent of outside diameter or with wall thickness more than 25 percent of outside diameter, or with wall thickness over 1¼ in., or weighing more than 90 lb. per ft. which cannot be successfully drawn over a mandrel, the inside diameter may vary over or under by an amount equal to 10 percent of the wall thickness. The wall thickness may vary 12½ percent over or under that specified.

(b) For tubes with inside diameter less than ½ in. (or less than ⅝ in. when the wall thickness is more than 20 percent of the outside diameter), which cannot be successfully drawn over a mandrel, the wall thickness may vary 15 percent over or under that specified and the inside diameter will be governed by the outside diameter and wall thickness variations.

(c) Tubing having a wall thickness less than 3 per cent of the outside diameter cannot be straightened properly without a certain amount of distortion. Consequently such tubes, while having an average outside diameter and inside diameter within the tolerances shown in Table V, will require an ovality tolerance of ½ percent over or under the nominal outside diameter and inside diameter, this being in addition to the tolerances indicated in the table.

TABLE II—PERMISSIBLE VARIATIONS IN OUTSIDE DIAMETERS AND WALL THICKNESSES OF ROUND *HOT-FINISHED* MECHANICAL TUBING

Group	Specified Size, Outside Diameter, In.	Ratio of Wall Thickness to Outside Diameter	Permissible Variations from Diameter and Wall Thickness: Outside Diameter, In.		Wall Thickness, Percent: .109″ and Under		Over .109″ to .172″ Incl.		Over .172″ to .203″ Incl.		Over .203″	
			Over	Under	Over	Under	Over	Under	Over	Under	Over	Under
1	Under 3	All wall thicknesses	0.023	0.023	16.5	16.5	15	15	14	14	12.5	12.5
2	3 to 5½ excl.	All wall thicknesses	.031	.031	16.5	16.5	15	15	14	14	12.5	12.5
3	5½ to 8 excl.	All wall thicknesses	.047	.047					14	14	12.5	12.5
4	8 to 10¾ incl.	5% and over	.047	.047							12.5	12.5
5	8 to 10¾ incl.	Under 5%	.063	.063							12.5	12.5

Note 1. These tolerances apply to carbon and alloy steel tubes as defined on page 7 furnished in the "as rolled" or "soft annealed" condition. For tubes furnished heat treated by quenching in air or liquids, tolerances should be subject to agreement between the manufacturer and purchaser.

Note 2. The recognized standard range of sizes of hot-finished tubes is 1½ in. to and including 10¾ in. outside diameter. The wall thickness may not be less than 0.095 in. (No. 13 BWG) and must be 3 per cent or more of the outside diameter. For sizes under 1½ in. or over 10¾ in. outside diameter the permissible variations are to be agreed upon by the purchaser and the manufacturer.

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AIRCRAFT SIZE TOLERANCES

As outlined in the preceding article on the manufacture of tubing, the emphasis has been placed on quality rather than size accuracy. For most requirements where the tubular structures are welded together at various points, fittings have only recently come into use. Therefore accuracy to size has not been of major importance.

With increased production there is an increase in the use of fittings. Some of these are designed to go inside the tube requiring reasonably close accuracy on the inside diameter of the tube, and some are to fit on the outside of the tube. It is obvious that if the fittings are to be produced under production conditions, it is necessary that the dimension of both the tube and the fitting should be reasonably close—closer than available on standard aircraft tubing.

Ground Finish

Grinding the OD to obtain closer size accuracy includes removing a sufficient amount of the outside surface all around the tube to insure what a steel man refers to as "cleaning up the surface," i.e., removing all surface imperfections to obtain as near perfect surface as possible. This requires a tube finished by cold drawing at least .010″ over the size specified for smaller sizes and up to as much as .030″ for larger sizes.

In other words, a tube to have a ground finish must be produced with special oversize to allow for this extra material and size. It is not practical to take a stock size 1″ OD x .065″ wall and grind to an accuracy on OD of plus or minus .001″ and still leave the proper wall and obtain the clean surface required.

This of course may mean extra time for delivery in order to manufacture the special tubing required before grinding.

Size Accuracy

The following limits for size accuracy will apply within the range of sizes shown for all average wall requirements. For very thin walls, or thick walls, it may not be possible to maintain these limits under all conditions. Length, heat treatment and ratio of wall to outside diameter may affect what is practical to obtain under production conditions.

1. *Outside Diameter*

The following size accuracy can be obtained by centerless grinding on sizes up to and including 1½″.

For sizes larger than 1½″ OD, it is possible to finish by cold drawing to closer tolerances than specified for standard aircraft material. The following table will serve as a guide as to what can be obtained under regular production conditions. If closer accuracy than indicated here is required, it should be taken up with the tube mill first.

2. *Inside Diameter*

The following accuracy on ID's can be obtained by cold drawing. Any other method of obtaining close accuracy on the ID of small diameter tubing is generally too expensive for most commercial requirements.

The extra charge for obtaining close accuracy varies with the size relative to standard tolerances, etc.

Summerill is not at this time equipped to grind sizes over 1½″ OD.

Closest OD Accuracy Available by Grinding		Closest ID Accuracy Available by Cold Drawing	
OD Size	Total Tol.	ID Size	Total Tol.
⅛″ (.125″) up to and incl. ½″ (.500″)	± .0005″	1/16″ (.0625″) up to and incl. ⅜″ (.375″)	± .001″
Over ½″ up to and incl. 1¼″ (1.250″)	± .001″	13/32″ (.4062) up to and incl. ⅞″ (.875″)	± .0015″
Over 1¼″ (1.250″) up to and incl. 1½″ (1.500″)	± .001″	29/32″ (.9062″) up to and incl. 1½″ (1.500″)	± .002″
Closest Accuracy regularly available by Cold Drawing for either OD or ID			
Over 1½″ up to and incl. 2½″	± .0025″	Over 1½″ up to and incl. 2½″	± .0025″
Over 2½″ up to and incl. 3½″	± .004″	Over 2½″ up to and incl. 3½″	± .004″

Size Tolerances

Reference to the size tolerance tables for aircraft tubing shows the variation from nominal size in outside diameters for sizes ½″ OD up to 1½″ OD is plus or minus .005″, and for each group of larger sizes the allowable variation is proportionately larger and also the wall thickness may vary plus or minus 10% and still come within specification regulations.

Analyzing or interpreting this for a specific size the tubing manufacturer might, if the extreme limits are taken advantage of, ship tubing having variable dimensions, such as—

Using 1″ OD x .065″ wall as an example, the theoretical limits are as follows:

Possible Wall Variation of ± 10%	OD Variation ± .005″
.065″ Nominal Wall	1.000″ Nominal OD
.0715″ Max. Wall N + 10%	1.005″ Max. OD
.0585″ Min. Wall N − 10%	.995″ Min. OD

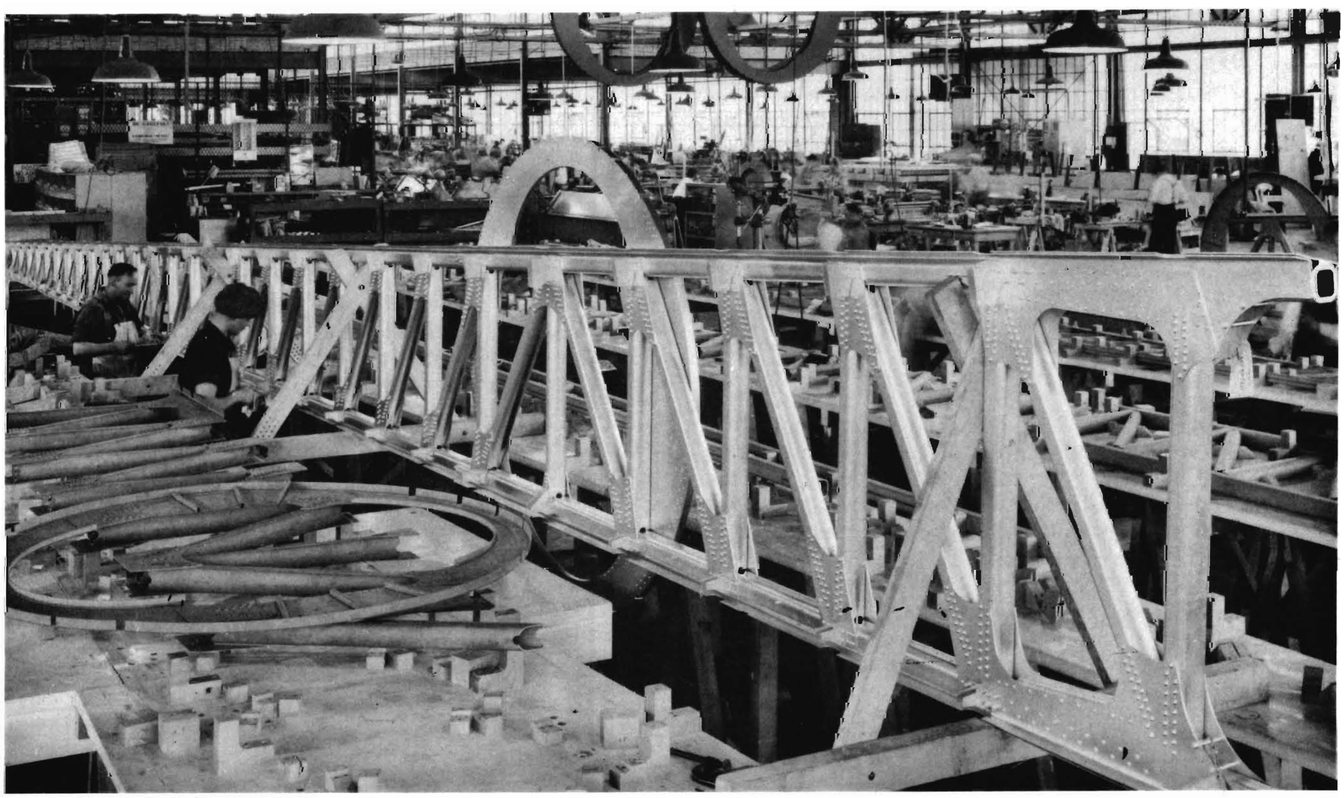
To obtain the minimum and maximum ID, we double the walls and subtract from OD—

Nominal Size	Minimum ID	Maximum ID
1.000″ OD	.995″ = Min. OD	1.005″ = Max. OD
.130″ (2 x .065)	.143″ = (2 x Max. Wall)	.117″ = (2 x Min. Wall)
.870″ ID	.852″ = Min. ID	.888″ = Max. ID
		.852″ = Min. ID
		.036″ = possible variation in ID

These variations of course are much too wide where a manufacturer wishes to apply end fittings with minimum machine work either for ID or OD fittings.

To meet this condition we suggest buying tubing to exact cut lengths with either the OD or ID specified to as close size tolerance as the tube mill will accept. The extra for these close tolerances is reasonable and much less than required for machine work.

As a guide to what may be expected for tolerances closer than standard, the table on preceding page will be of assistance.



Wing-spar for a Boeing Clipper. This shiny assembly is the front spar for the main left-hand wing-panel for a Boeing 314 Clipper. The ring in the center of the picture marks the location of the outboard engine nacelle. Both the upper and lower spar chords are square steel tubes.

USE OF THE PHYSICAL PROPERTIES CHARTS

The following pages of graphs depicting the physical properties obtained with different steels by quenching and tempering are given as a sort of guide as to what may be expected with the different steels. Some people may find that they will obtain some variation from the data in these curves.

In the heat treating and normalizing of S.A.E. X4130, X4340, and other Molybdenum steels, it is extremely important that sufficient soaking time be given to the material at the high temperature to insure the complete solution of all the Carbides, so that the maximum physical properties are obtained. The Summerill laboratory has drawn up a set of curves showing the relation between the wall thickness and the time necessary in the furnace, so that these maximum physical properties may be obtained. It is by the use of this Time Control Chart that the Physical Properties Charts were developed. It might be added that the correlation between wall thickness and the time in the furnace has been drawn up as a result of years of experience. The Physical Properties Charts themselves are simple to understand, and are more or less self-explanatory. In most cases the analyses of the samples tested are indicated and it is reasonable to expect that with some variation in analysis, the properties obtained will vary. As has been pointed out before, the most effective element in the hardening of steels is Carbon. The higher the Carbon, the higher will be the physical properties, generally speaking. In other words, if at one time we are working with a steel whose composition is at the high side of the range of the S.A.E. analysis, we will find appreciably higher physical properties than with a steel whose analysis is on the low side of the range.

In order to obtain more uniform physical properties, the Summerill Tubing Company has adopted a specification whereby the Carbon and other hardenable elements such as Chromium and Molybdenum are held to a very narrow range. To improve weldability both the sulphur and phosphorus are required to have maximum considerably lower than ordinarily specified.

SOME HEAT TREATING TERMS AND DATA

In the heat treating of metals there is always some terminology associated with the practice which at first may seem confusing, but with an explanation of these terms the heat treater will better understand the general subject.

The hardness which is capable of being developed in a piece of steel is generally a function of the Carbon content. In other words, as the Carbon content increases, the hardness increases upon very rapid cooling from a high temperature. Alloying elements in addition to the Carbon do not increase the hardness; however, they do increase the depth of hardening. In other words, a thin section such as $\frac{1}{16}$ of an inch with a .50% Carbon content will harden throughout on quenching. Now if the section is increased to 1 inch, the maximum hardness may be developed only to a depth of perhaps $\frac{3}{32}$ of an inch, measuring from the surface inward. The center of the 1 inch piece will be considerably softer than the surface. However, if alloying elements such as Chromium and Molybdenum are added to a steel with the same Carbon content, the surface layers will still reach the same hardness as the plain Carbon steel, but it is likely that the center of the piece will now have very nearly the same hardness as the surface. Such is the effect of alloying elements. It is possible by proper additions of alloying elements to obtain nearly the same hardness at the center of a 5 inch solid round as on the surface.

Critical Temperatures: In the heating or cooling of steel through a range of temperatures, there are certain changes in structure as well as physical properties which result. The temperatures at which these changes occur are known as critical temperatures or critical points. It happens that steel, when being heated up, has two such critical points known as the lower (Ac_1) and the upper (Ac_3.) The range of temperatures between these points is known as the critical range, in which there is a gradual change which takes place. Before any heat treating can be done on steel, it is necessary to know the critical temperatures and to make sure that the temperatures at which these changes have taken place have been recognized. The higher the Carbon the lower is the upper critical temperature, and naturally the lower will be the hardening or normalizing temperature. The critical temperatures vary with different alloy steels; however, in any one steel the lower critical temperature remains constant and only the upper critical temperature changes with increasing or decreasing Carbon content.

Steels existing below the critical temperatures are composed of Iron (ferrite) plus Iron Carbide. If steel is heated to just above its lower critical, thus into the critical range, the Iron Carbide begins to dissolve and form grains of solid solution. As the temperature is raised to the upper critical temperature, more and more solid solution grains form and absorb the surrounding ferrite and Iron Carbide. As the upper critical temperature is reached, the material is now all solid solution where all the Carbon is dissolved and the structure at this temperature is called Austenite.

Before the hardening of any steel can be accomplished, it must be put into this solid solution state with all the Carbides in solution.

Hardening: As has been pointed out, it is necessary to get the steel into a solid solution by heating to above the critical range, at which point the steel is quenched into either oil or water. This rapid cooling causes the solid solution to break up, and thereby causing the Carbides to precipitate and cause hardening.

It is important that sufficient soaking time be given to a piece of steel in the hardening operation so that all the Carbides are absorbed prior to quenching. Some steels, especially Molybdenum bearing steels, need longer soaking periods than steels which are not Molybdenum bearing. This is because of the fact that Molybdenum Carbides are quite stable, and are reluctant to go into solid solution.

Tempering: The tempering operation is one of reheating after rapid cooling such as quenching. This tempering is done to relieve the severe stresses which are set up during the hardening operation, and also to improve the ductility, thereby increasing the toughness of the hardened steel. In general, tempering results in reduced hardness, but with a general improvement of physical properties. Sometimes tempering is used after normalizing to reduce physical properties.

It is best to relieve the severe stresses set up in quenching immediately so as to avoid cracking of the material. In view of this it is desirable to temper as soon after quenching as possible.

Annealing: The term annealing may be split up into two types:

I. *Full Annealing*. When full annealing, the material is heated to above the critical range and allowed to cool very slowly, usually in a furnace. Full annealing is employed when very soft material is desired, with uniformity of grain.

II. *Process Annealing*. In this type of annealing the material is heated to just below the critical range to remove effects of cold work, so that further cold reduction may take place. This type of annealing may also be used to merely obtain a softer material.

Normalizing: Normalizing is the heating of steel to above its critical range, and after sufficient soaking to insure homogeneity, the steel is allowed to cool in still air. Normalizing is generally done at approximately 100° F. above the critical range.

The purposes of normalizing are several:

(1) To obtain a uniform and homogeneous micro-structure.
(2) To reduce internal stresses, to remove the directional properties of previous cold work.
(3) To refine the grain.
(4) To obtain desired physical properties in air hardening steels.
(5) Sometimes employed to improve machinability.

Stress Relieving: Stress relieving is heating of metals to some temperature sufficient to remove the various stresses which it may contain, caused either by welding, cold working, etc. In steel, the stresses may be readily removed by heating the material to approximately 1100° F. In many cases, stress relieving is desirable on cold worked material just prior to machining; because the removal of these stresses will eliminate the tendency of the piece to distort after machining. In some steels it is desirable to stress relieve prior to hardening after cold work, to prevent cracking.

Quenching: Materials may be either quenched in water or in oil; however, there are instances where brine solutions are used. For high strength aircraft steels, it is recommended that all quenching be done in oil. This will tend to reduce distortion and also minimize tendency to cracking.

There are many different kinds of quenching oils sold on the market, and in lots of cases the type of oil used varies in different plants. In general, however, it is desirable to use an oil which will not break down by repeated use, and also to use an oil which has fairly good heat extracting power. It is desirable to use an oil which has its maximum fluidity at the lowest possible temperature. Experience at Summerill has shown that the use of an oil at approximately 125° F. has considerable fluidity and the constancy of operation for the heat treating of S. A. E. X4130. In some cases the oil temperature may rise to 200° F. without interfering with the results of the quench.

Scaling: It is important in all heat treating operations to keep the scale or oxidation at a minimum. Even a thin skin of scale on the surface of a piece of steel will interfere with the effect of quenching. Even in normalizing scale will act as an insulator so that the maximum properties are not obtained.

Wherever possible, it is desirable to use a controlled atmosphere furnace, of which there are many on the market. Sometimes it is desirable to use retorts, either of the same Carbon content, or higher than the material being heat treated. If the Carbon content of the retort is lower, decarburization will result. The burning of a cup of oil at the mouth of the retort will greatly eliminate any scaling.

There are some copper paints on the market, which, when applied to the surface of the steel, will decrease the tendency to scale.

Decarburization: All Molybdenum steels are very susceptible to the loss of Carbon at the surface. Obviously, the loss of Carbon in heat treating will result in lowered physical properties. This is another good reason for using controlled atmospheres, in which the atmosphere is kept highly reducing. The loss of Carbon is one of the most difficult things to control when heat treating Chromium Molybdenum steels, and all kinds of care should be taken.

PHYSICAL TESTING TERMS

Aircraft tubing users are mainly interested in the tensile properties of aircraft tubing. In order to give a clearer understanding of the subject, the standard definitions for the most frequently used terms in physical testing are outlined.

Modulus of Elasticity: As long as steel is in the elastic state it will show the same deformation with the same load whether the steel is heat treated, cold drawn, annealed, etc. In other words, if we apply a certain load and measure the extension of the steel on the test by some delicate means such as an extensometer, it will record a certain extension. However, upon release of this load, the extension will go back to zero. This ratio of the applied stress to the extension is known as the modulus of elasticity when the measurements are taken in the elastic range.

Stress: The stress is the applied load in pounds divided by the cross-sectional area of the specimen. The stress will then be expressed in pounds per square inch.

Strain: The strain is the extension or elongation caused by a particular load and is recorded in inches per inch.

Proportional Limit: The proportional limit is defined as the limit at which the increase in strain is not proportional to the increase in stress. This phenomenon can be observed from a stress-strain curve, and the point where the curve deviates from a straight line is known as the proportional limit.

Elastic Limit: The elastic limit is the point where the greatest load per unit area will not produce a measurable permanent set after the load has been released. Obviously, this point is slightly beyond the proportional limit.

Proof Stress: The proof stress is that stress at which a material will not show a permanent deformation of more than a specified amount after the complete release of the load.

Yield Strength: Yield strength is the stress at which a material shows a definitely specified deformation under load. For instance, in the Army and Navy specifications, the point at which there is a .2% permanent set is known as the yield strength. There are several methods of determining the yield strength, all of which are fully covered in the Army and Navy specifications, and Federal Specification QQ-M-151, Inspection of Metals.

Yield Point: The yield point is defined as the stress at which a marked increase in deformation occurs without increase of load. The drop of the beam method is sometimes employed, and also the divider method is used; however, both of these are done more or less by eye.

Tensile Strength: The tensile strength or ultimate strength is the maximum load divided by the original cross-sectional area which the material is capable of withstanding.

Percentage of Elongation: The percentage of elongation is the difference in a specified gauge length before and after the specimen has been pulled, and is expressed in percentage of the original gauge length.

MACHINABILITY

There are a great many instances where Chromium Molybdenum and other Molybdenum steels are machined after heat treating. It appears that Molybdenum steels, in general, are capable of being machined at much higher hardness than one would normally expect. This, of course, is quite an advantage because it allows accurate parts to be made after all heat treatment is accomplished.

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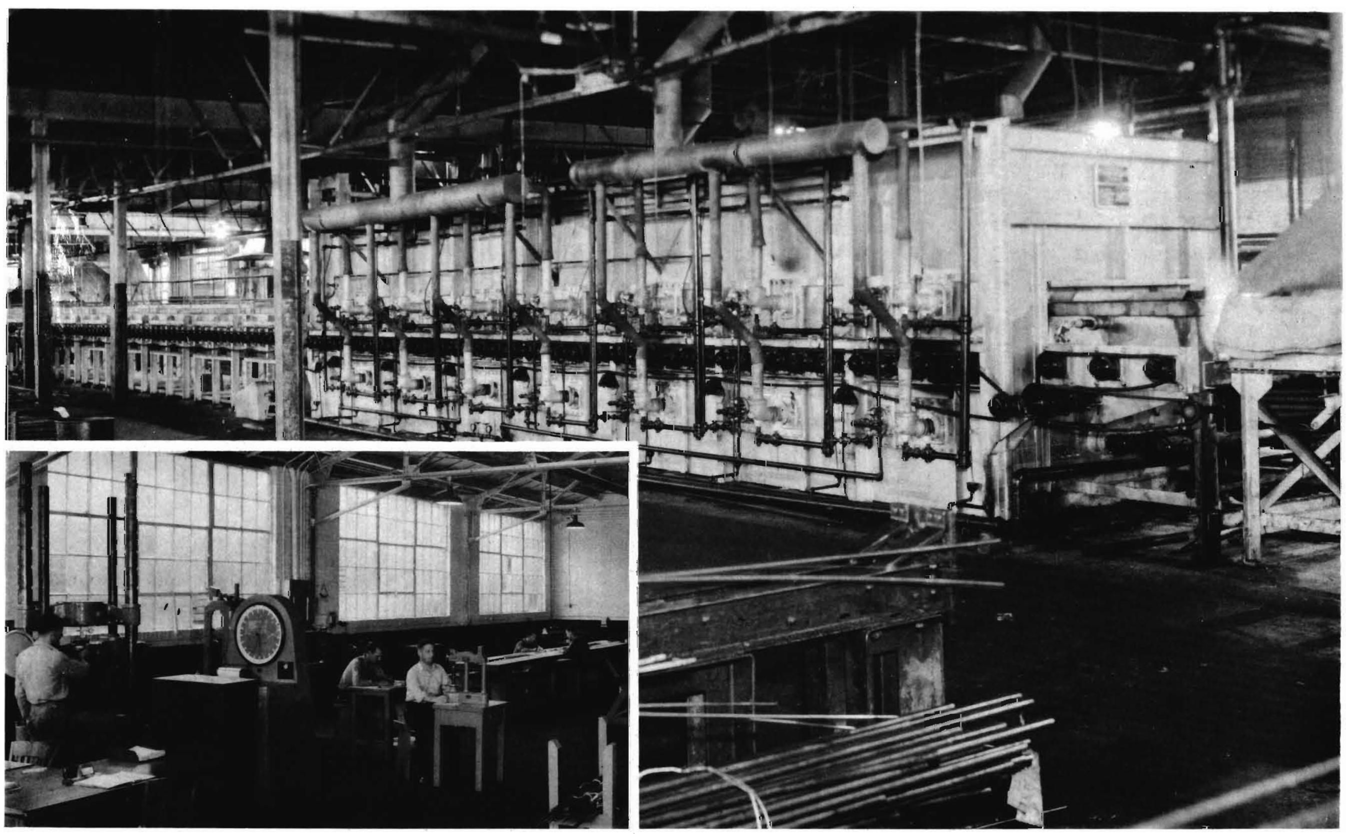


One of the four continuous annealing and normalizing furnaces at SUMMERILL with small insert showing a corner of the Laboratory with part of the physical testing and inspection equipment.

DECARBURIZATION ON HEAT TREATED AIRCRAFT TUBING

THE effects of decarburization as applied to quenched and tempered tubing, particularly S.A.E. X4130 Aircraft Steel, are apparently not clear to many users of this material. With a view to a better understanding, the Summerill Laboratory has prepared the following information covering the subject with a table of allowances for decarburization.

Decarburization means the loss of carbon in the steel and occurs during annealing and heat treatment. The steel analyses containing molybdenum have a tendency to lose carbon during various types of heat treatment more readily than some other analyses.

If the effects of decarburization are clearly understood and accepted by the engineering, production and inspection personnel in customers' plants, a great deal of misunderstanding and correspondence will be avoided and better results will be obtained in the use of heat treated tubing.

The decarburized zones are on the surface of the tubing—both outside and inside surfaces. Below these decarburized zones, as shown on the accompanying chart, the composition of the steel, i. e., chemical analysis, is not materially changed. It is evident, therefore, if the zones affected by heat are removed, the base metal, i. e., the original composition of the steel, will be intact.

Steel tubing is heat treated to obtain desired physical properties such as tensile strength, yield strength and elongation. For most heat treated parts, it is necessary to check the results of the heat treatment to be sure that every part meets the physical requirements. When actual physical "pull tests" are possible, ordinary surface decarburization does not materially affect the results of such tests. However, such "pull tests" are on "test pieces" and, for a great deal of production, many structures and thousands of parts, it would be wholly impractical to make a "pull test" for each size or each part.

In many cases it is mandatory to have the maximum hardness at the surfaces for hard chromium plating for wearing parts, and in this case the full removal of decarburization is necessary.

Allowable Limits for Decarburization

1. On wall thicknesses .187″ and over, an allowance of 10% of wall thickness on both OD and ID is necessary.
2. On wall thicknesses lighter than .187″, an allowance of 15% of wall thickness on the OD and 10% on the ID is necessary.

In other words, in order to obtain accurate hardness readings, a sufficient amount of metal must be removed from the surface to equal the percentage indicated for varying wall thicknesses.

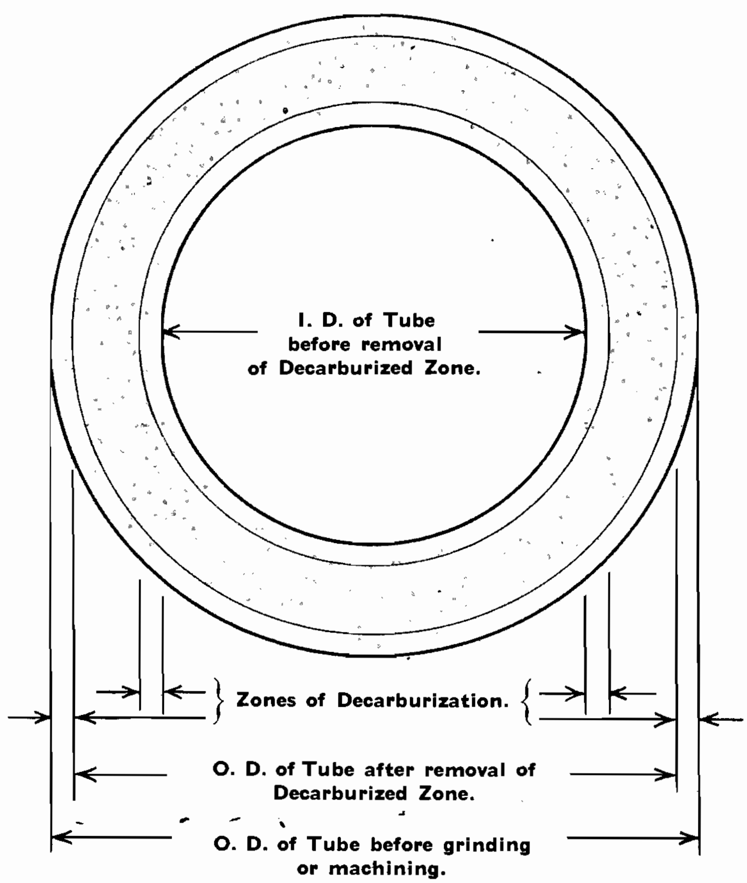


Diagram showing the nature of the Decarburized Zones, the removal of which is necessary to insure full surface hardness. In many cases it is not necessary to remove the I. D. decarburization.

The depth of the Decarburized Zones will vary with wall thickness and to a certain degree with the outside diameter. Note in the figure above that the Decarburized Zones include both the partial and complete areas of decarburization.

The tolerances set up in this table include the zone of total decarburization (that zone which is practically free ferrite and devoid of carbon) plus the zone of partial decarburization (that zone which is a gradation from the layer of ferrite to the full carbon content of the metal).

Generally the effects of decarburization, i. e., the depth of the decarburized zone, is not as deep on the ID as on the OD of the tube. This is due to the heat of the furnace being in more direct contact with the surface of the tube on the OD. This is indicated in the above for heavy wall tubes. No allowance is made on lighter walls as it is rarely necessary to remove decarburized zones on the inside surface for lighter wall tubing.

Hardness Readings. As a substitute for the "pull test" it has been common practice to check the physical properties of steel by "hardness tests." On tubing, the Rockwell method is generally used on light walls and the Brinell method on heavy walls. By many thousands of check tests, a table of hardness numbers or readings has been developed and correlated to give corresponding Tensile Strength. See Table Sec. IV-8.

As "hardness readings" are taken on the surface of the tube, it is therefore essential to "true readings" to *remove the "decarburized surface"* to obtain readings on the base metal.

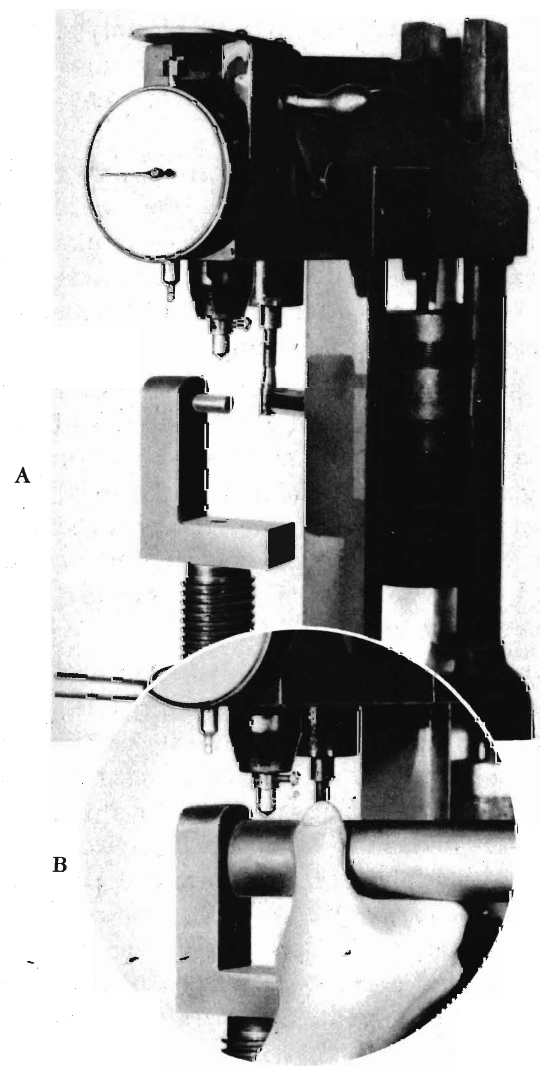
In addition to being a non-destructive test, permitting readings on each part rather than test pieces, this method of checking physicals is fast and in the hands of an experienced operator with proper equipment gives wholly satisfactory results.

ROCKWELL TESTING

In taking hardness readings on tubes having average and lighter wall thicknesses, it is important that these readings are taken on the wall of the tube with the anvil on the inside of the tube wall.

The accompanying illustrations show how, with a small auxiliary fixture on the Rockwell Machine, it is possible to do this. For all tubes having an ID dimension of ½″ and larger, a uniform anvil is used. For tubes having an ID smaller than ½″, the anvil is changed to permit taking readings on tubes with the ID as small as ¼″.

If hardness readings are taken across the OD of the tube on average and light wall tubing, there is a certain amount of spring in the tube which eliminates accurate readings. On tubes with heavy walls, or those having a wall thickness at least 25% of the OD, it is possible to take readings across the OD by the Rockwell method. This is because the heavy wall tubes are strong enough across the outside diameter to permit taking hardness readings without affecting the accuracy of such readings.



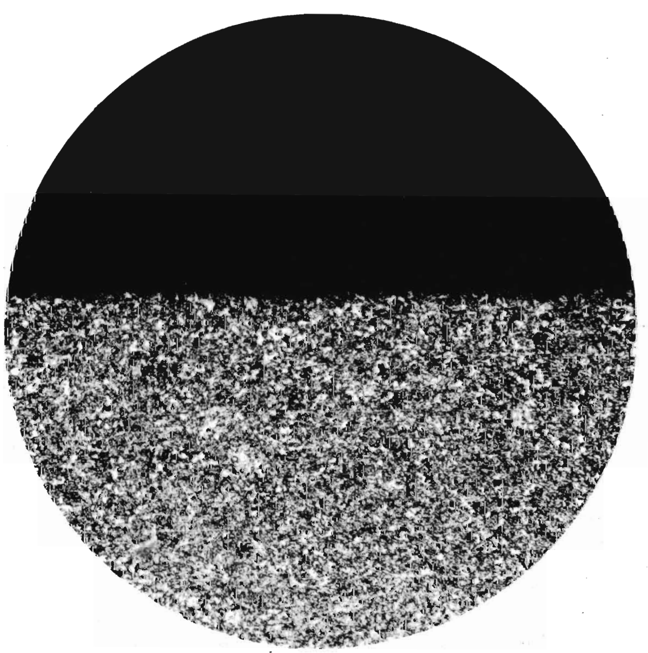
Illustrations showing the special "Anvil Fixture" for a Rockwell Machine as used at Summerill for taking readings on tubing.

A. Shows the fixture with Anvil. The latter can be changed to different sizes when required to fit tubes having a small ID.

B. This is the same set-up with tube in position.

SURFACE DEFECTS ON SEAMLESS TUBING

Reproduction of decarburized surface of X4130 normalized steel tubing. (Magnification X100.)



Reproduction of surface of X4130 normalized steel tubing showing absence of decarburization. Full hardness readings can be obtained on such a surface. (Magnification X100.)

SURFACE DEFECTS

The manufacturing processes in the production of seamless steel tubing—starting with the hot piercing operation on through the hot rolling, reeling, and later cold drawing and annealing—produce a surface condition which requires the removal of surface metal for many aircraft parts. This is necessary to insure a sound base metal surface free from superficial defects.

The table showing allowances for decarburization should not be confused or used to cover allowances for surface defects. Tubing which is to be machined or ground in order to clean up the surface or true up the wall due to eccentricity and ovality should be ordered sufficiently oversize to allow for removal of stock in accordance with the following table. This table for removal of surface may be greater or less than the amount indicated for decarburization. Eccentricity allowances are covered in adjoining text.

Table for Removal of Material on OD or ID to Eliminate Surface Defects

Under ½″ OD	remove	.032″	of OD or ID Minimum
½″ to 1″ OD	"	.065″	" " " " "
1″ to 2″ OD	"	.094″	" " " " "
2″ to 4″ OD	"	.125″	" " " " "
4″ to 6″ OD	"	.156″	" " " " "

Note—The effect of the above is to reduce the wall thickness by one-half the indicated amount for the OD removed.

> *For example*, if a given application requires a 1¾″ OD tube x .125″ wall finished on the OD to have perfect surface, the tubing should be ordered oversize to a minimum of 1.844″ minimum OD x .172″ minimum wall. After machining and grinding to finished dimension, removing the .094″ minimum OD or .047″ on the wall, it will insure obtaining a clean base metal surface free from so-called "surface defects."

If the wall thickness is such that the decarburization may be deeper than recommended in the above table, then the removal of more material may be necessary to obtain full surface hardness for Rockwell or Brinell readings.

The question of surface defects must be treated seriously and one must take into account the allowance set up for surface defects in the Air Corps Specifications for X4130 and X4135 Aircraft Tubing: "A surface imperfection will not be considered injurious nor require removal provided the defect can be removed by filing or machining and the tube still come within the tolerances of Table III" (OD and Wall Thickness).

ECCENTRICITY

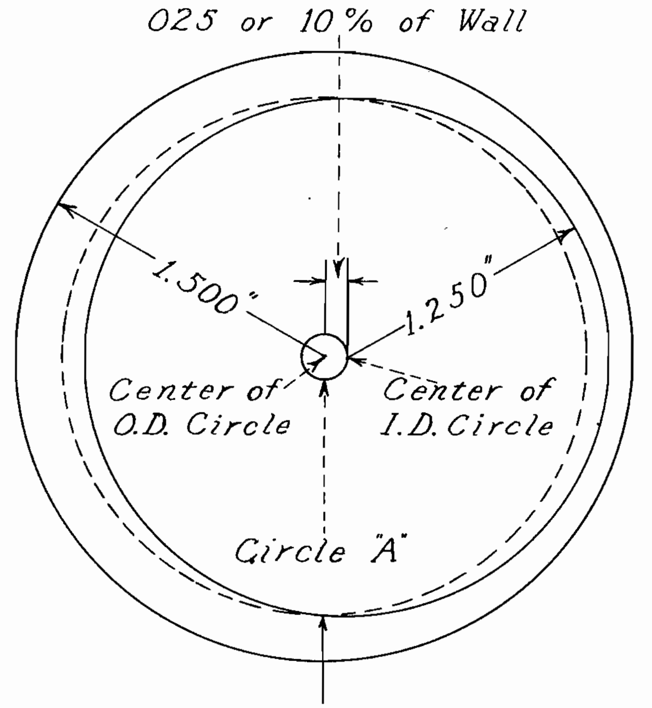
ECCENTRICITY—WALL VARIATION

Although real strides have been made in recent years to minimize wall variation on seamless tubing, the hot piercing process still does not permit obtaining a seamless tube billet with an absolutely uniform wall. In other words, it has not been possible to hold or guide the material during the piercing operation in a manner to insure absolute wall uniformity. Although the solid billet is held in position between the two piercing rolls with top and bottom guides, and better equipment is all the time producing better results, nonetheless the solid billet and resulting tube round rotate rather freely during the piercing operation.

The result is indicated on the accompanying drawing in an exaggerated manner. Standard tolerances on wall variation for seamless tubing are still plus or minus 10% of the nominal or specified wall.

New hot finishing equipment, such as the Diescher and Foren mills, reduces, i. e. minimizes, the wall variation. Also the so-called Rockrite or tube reducing machines for cold operations are still further tending to minimize wall variation on sizes available from tube billets which have been processed by the Diescher Mill and later tube reducers. It is now possible to obtain a wall accuracy frequently as close as plus or minus .001″. This, however, is ordinarily not available in sizes over 1″ OD.

When finished parts require absolute wall uniformity or very close limits, it is therefore generally necessary to resort to machining or grinding, or both, to obtain the required results.



Dotted Circle Indicates I.D. Circle of Concentric Tube

In order to true up the wall it is necessary to chuck the tube on ID and machine the OD, or the reverse, i. e., chuck the tube on the OD and machine or grind the ID. The former, of course, is the simpler type of operation.

MAGNETIC INSPECTION

More and more tubing is being ordered to meet the requirements of magnetic inspection, i. e., the tubing is subject to rejection based on magnetic inspection. Whenever this type of inspection is required, the surface condition of seamless steel tubing in the "as rolled" or "as drawn" condition must be taken into account.

Because of the surface defects inherent in seamless steel tubing as outlined in the accompanying text, magnetic inspection will show up many minute hair-line surface indications. Generally it is difficult and frequently impossible for the inspector to distinguish between minor defects and serious flaws in the tubing if these surface defects have not been removed.

When ordering tubing subject to rejection based on magnetic inspection, the tube mill will generally require that such inspection must be made after sufficient surface on the tube has been removed to eliminate inherent surface defects.

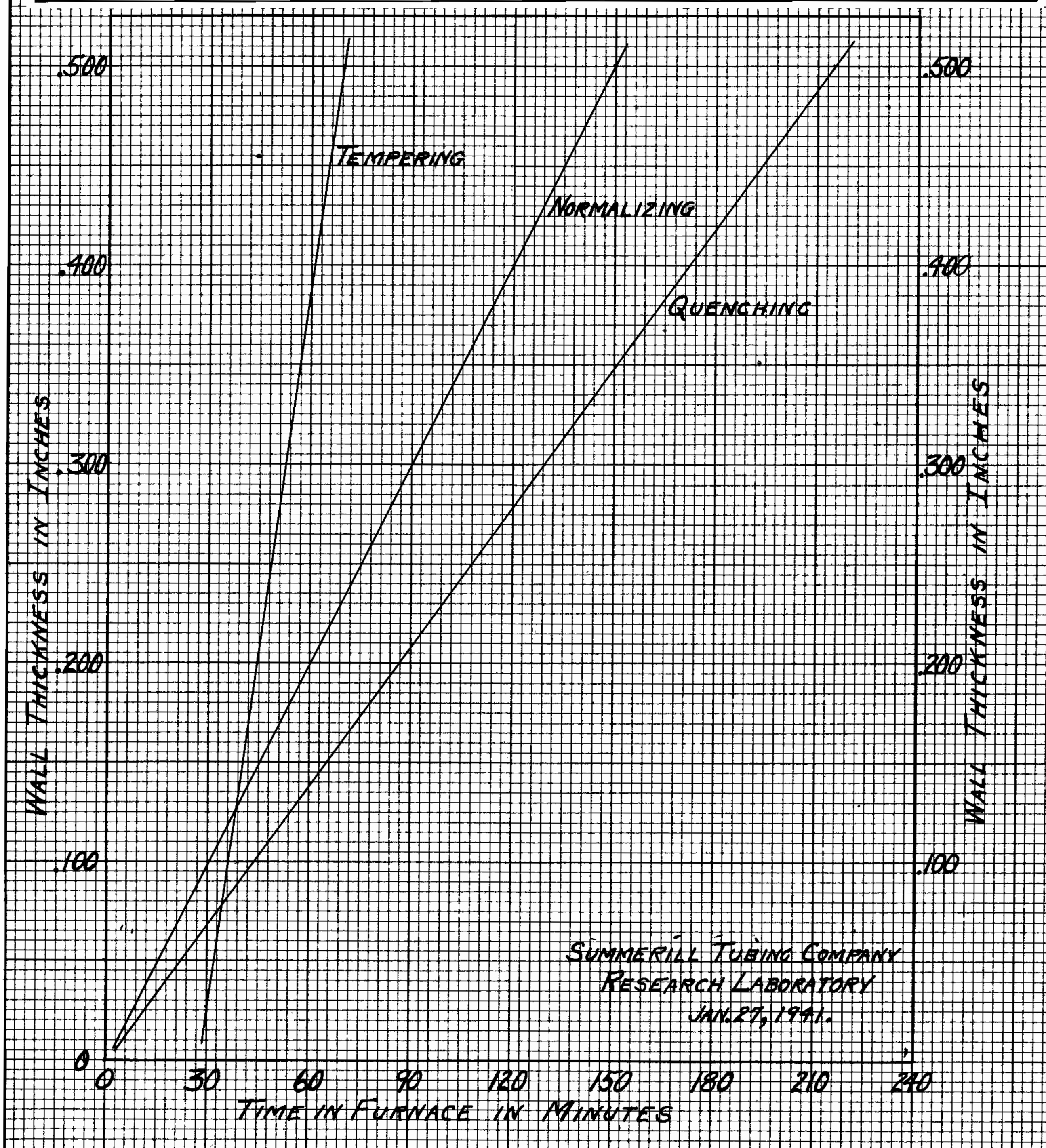
Magnetic quality does not mean the steel will be absolutely free from non-metallic inclusions. In commercial practice it is impossible to produce steel of this quality. It does, however, mean that the defects present are within certain specified limits. By removal of the surface as above mentioned, the operator and inspector can more readily determine the quality of each piece as there will be little doubt when serious defects are indicated.

TIME CONTROL CHART

S.A.E. X4130, X4135 & X4340—TUBING

Curves showing the relation between wall thickness and necessary time in the furnace for Normalizing, Quenching and Tempering so as to obtain the maximum properties for each type of heat treatment.

Normalizing and Quenching temperatures are 1650° F. Tempering as desired. (See Physical Properties Chart for S.A.E. X4130.)



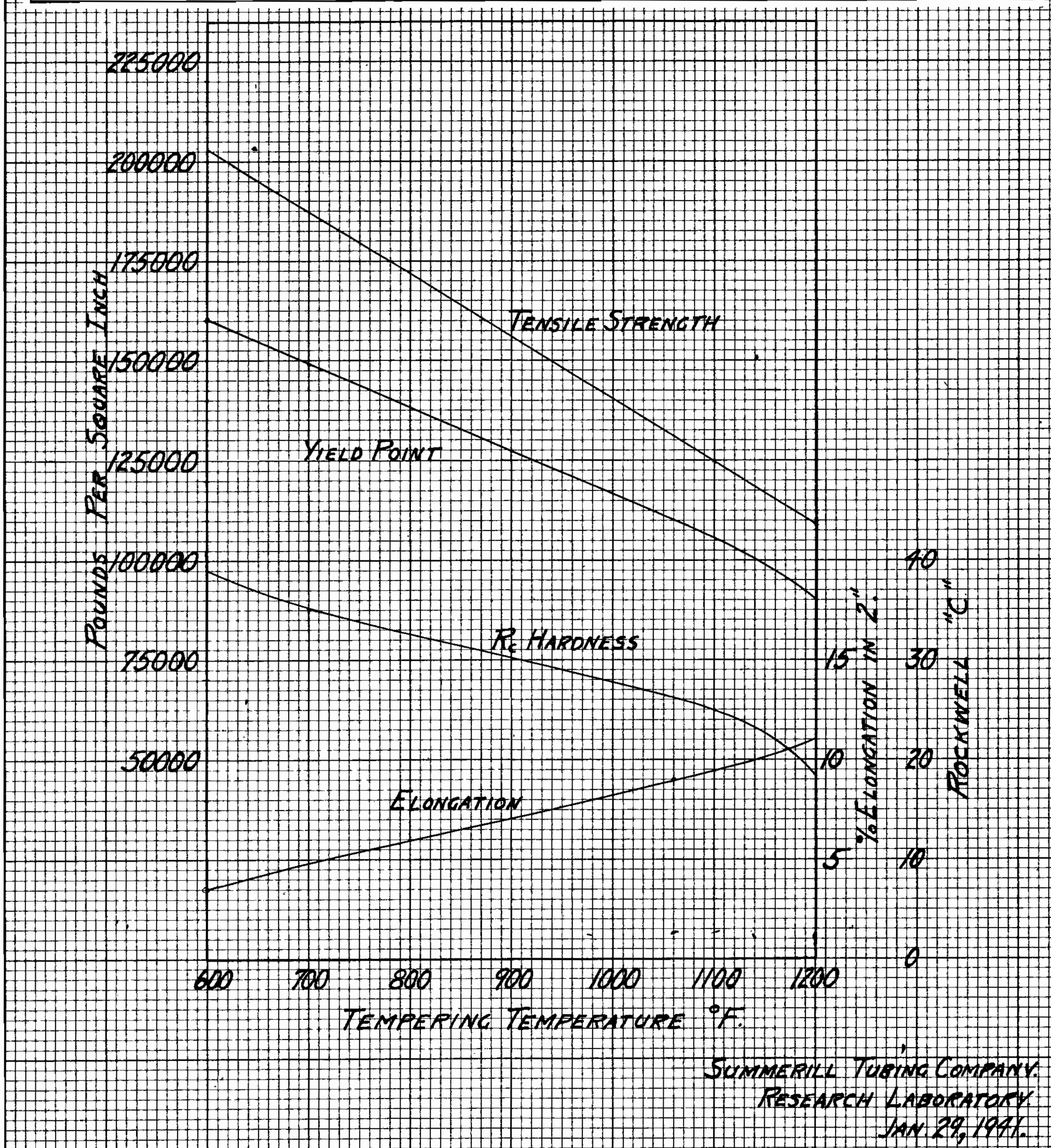
The time in the furnace should be determined by the heaviest part of the piece to be heat treated—i. e., thickness of wall or forging.

PHYSICAL PROPERTIES CHART

S.A.E. X4130—TUBING

Data Accumulated from all sizes of Specimens. Oil Quenched from 1650° F. Tempered as Indicated.

S.A.E. Analysis.	Analysis of Specimen.	As Normalized from 1650° F.	Approximate Critical Points.
C - .28/.33%	The curves cover whole	See Specification 57-180-2D	Ac1 - 1380° F.
Mn- .40/.60%	range of S.A.E. analysis.	and 44T18C INT.	Ac3 - 1475° F.
Cr- .80/1.10%			Ar1 - 1250° F.
Mo- .15/.25%			
S - .050 Max. %			
P - .040 Max. %			



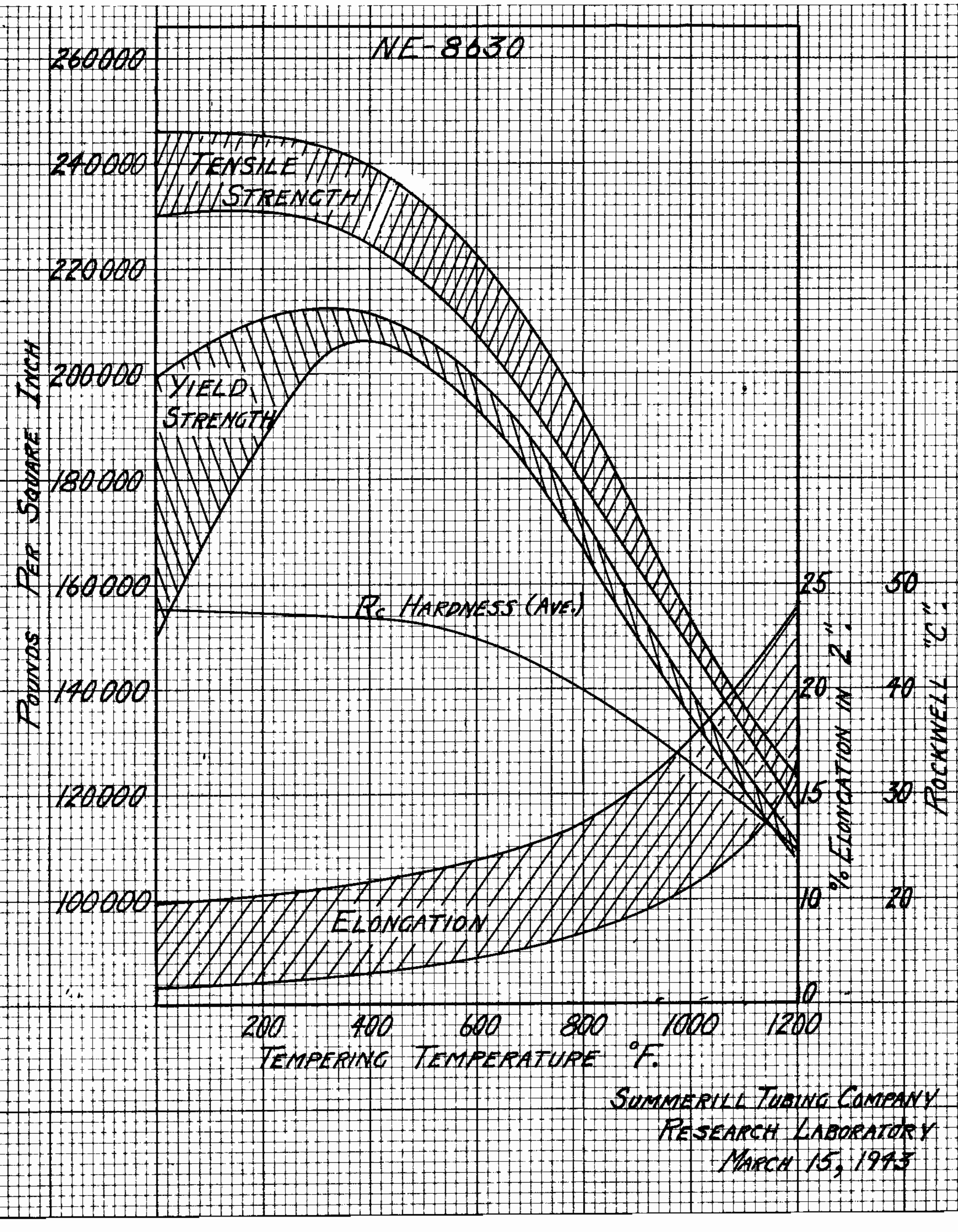
The time in the furnace should be determined by the heaviest part of the piece to be heat treated—
i. e., thickness of wall or forging. See Time Control Chart Page 17, this Section.

MECHANICAL PROPERTIES CHART

NE-8630 TUBING

Size of Specimens Tested: 1-1/8" O.D. x .120" wa.; 5/8" O.D. x .049" wa.; 3/4" O.D. x .065" wa.; 1/2" O.D. x .035" wa. Oil quenched from 1650° F. Tempered as indicated. These curves represent the range of properties obtained with above size specimens.

NE Analysis.	Analysis of Specimens	Normalized from 1700° F. 3/4" O.D. x .065" Wall.		Tempered at 900° F. after Normalizing	Approximate Critical Points
C - .28/.33%	.30	Ultimate Strength	113,000 psi.	107,000 psi.	Ac_1 - 1335° F.
Mn- .70/.90%	.77	Yield Strength	75,000 psi.	85,500 psi.	Ac_3 - 1470° F.
Cr- .40/.60%	.50	Elongation in 2"	21%	22%	Ar_1 - 1220° F.
Ni- .40/.70%	.51				
Mo- .15/.25%	.19				
S - .040 max.	.018				
P - .040 max.	.016				



The time in the furnace should be determined by the heaviest part of the piece to be heat treated—i. e., thickness of wall or forging. See Time Control Chart Page 17, this Section.

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NATIONAL EMERGENCY STEELS

With Special Reference to NE-8630

The establishing of National Emergency (NE) steels was made necessary by the critical shortages of vital alloying elements, such as nickel and chromium. The scarcity of virgin nickel and the difficulty of receiving chromium imports made it mandatory to turn to such elements as manganese and molybdenum.

Unlike in the last war, the manganese situation is relatively good, thanks to the ingenuity of steel mill metallurgists. Molybdenum is the one element which is produced almost entirely in the U. S.; hence, its supply was thought unlimited. So many steels were turned over to molybdenum bearing, that today molybdenum is perhaps the most critical element. Its demand far exceeds its production plus the reserve. It is thus necessary that as many plain carbon steels be used as is possible.

In airplane manufacture it is not as easy to substitute a lower strength or carbon steel for an alloy steel; hence, it is necessary to obtain a steel with equal hardenability and strength. The only way this can be done is to balance the available necessary elements in the steel, to give maximum benefits.

Sometime ago, a group of technical men from the American Iron and Steel Institute, Society of Automotive Engineers, and others interested met and arrived at a series of substitutes for the chromium bearing, chromium-molybdenum, and chromium-nickel-molybdenum bearing steels. 4130 aircraft steel falls into the category of a chromium-molybdenum steel for which an alternate was necessary to save chromium.

The analyses arrived at were based upon the available supply and a projected foresight into the future of the steel scrap situation. Steel scrap can be and is a large reservoir and source of supply for many alloying elements, especially nickel and to some extent molybdenum. In some localities the scrap analysis is such that large percentages of nickel exist—nickel is impossible to remove from the steel melt; the only way it can be controlled is to dilute it.

So, in an effort to utilize the scrap to a maximum, and to use as little virgin metal as possible, the NE-8600 series was evolved as an alternate for the 4100 series.

Obviously the complete testing of each alternate analysis would have been impossible in a relatively short time—so the agreed upon analyses were subjected to the Jominy *End Quench Hardenability Tests*, which were a quick way of determining behavior and served as an excellent basis for comparison.

NE-8630 was picked as the alternate for 4130 and it was decided that extensive testing should be done to determine its adaptability, etc. This was in early 1942. Mechanical testing, hardenability, weldability, toughness, model testing, etc., had to be investigated in the aircraft field to make sure that any move would be the correct one; when the change was mandatory.

Many investigations on NE-8630 were made by the Army Air Forces, Aircraft companies, Tube Mills, etc.—because of the fact that this steel was to be used for tubing and sheet in relatively light gauges —and where weldability is of prime importance. All reports, almost without exception, have proven NE-8630 to be an excellent alternate for 4130 and in all instances the weldability is superior. The response of the yield strength upon tempering after normalizing is of considerable interest.

Among the advantages of NE-8630 over 4130 are,

1. Availability in view of the scrap situation.
2. Utilizing the nickel in the scrap as part of the alloy content rather as an uncontrolled residual.
3. Better heat treating control with all effective elements being known and controlled quantities.
4. Better weldability.
5. The possibility of using higher carbon contents—hence higher properties with good weldability.

NE-8630 can be welded to 4130 and heat treated similarly.

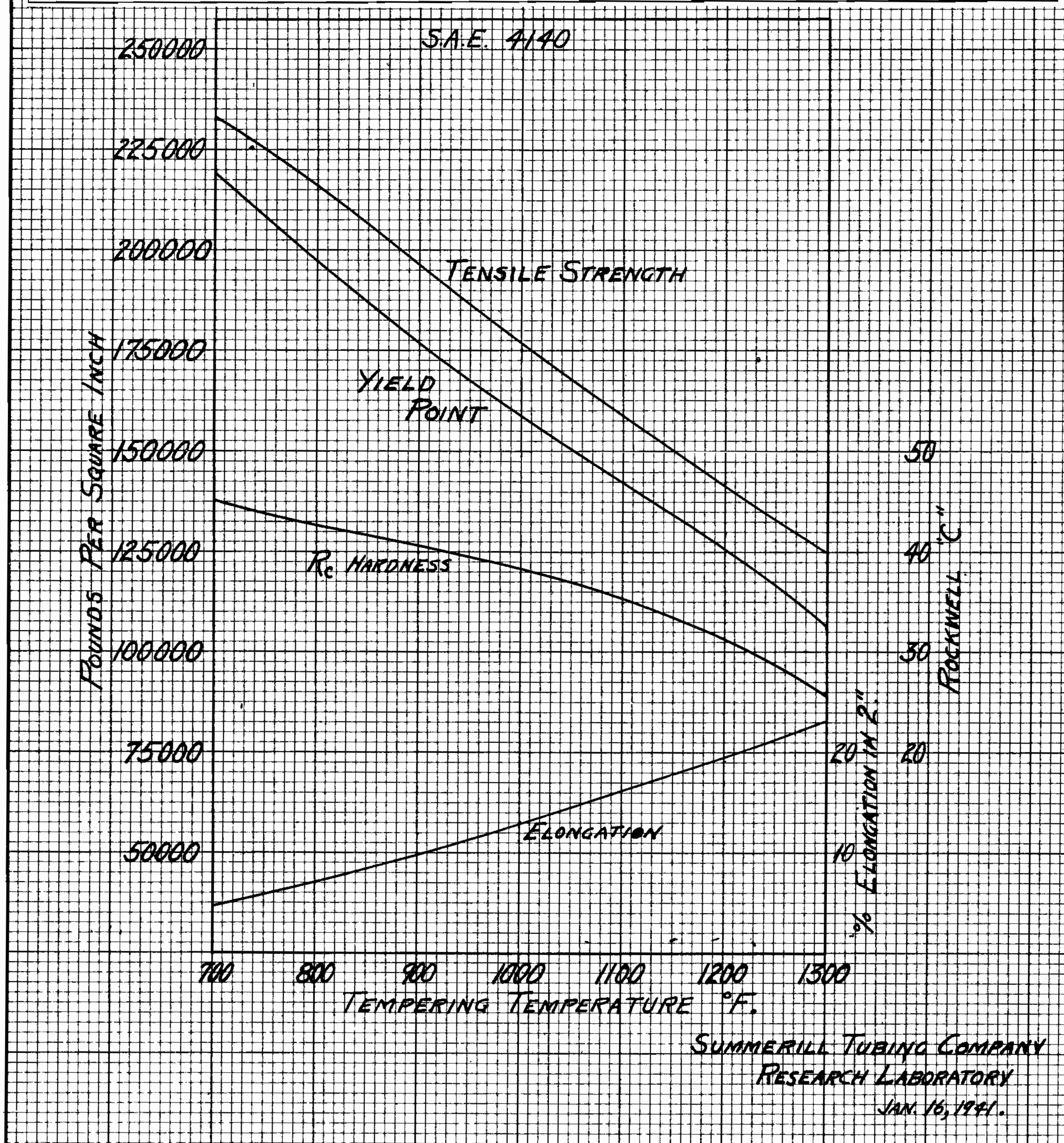
The use of NE steels, especially the 8600 and 8700 series, is a MUST if we are to obtain and use every pound of steel produced. The best justification for their use is the steel scrap situation. Scrap is being used as a source for some alloys—as well as a necessity in the open hearth and electric furnaces. It may seem strange to use nickel—when it is so scarce—but it is existent automatically in the scrap—so we might as well make use of its presence—we can't get it out.

PHYSICAL PROPERTIES CHART

S.A.E. 4140—TUBING

Size of Specimen: - 1" O.D. x .095 Wall. Oil Quenched from 1575° F. Tempered as Indicated

S.A.E. Analysis.	Analysis of Specimen.	As Normalized from 1700° F.	Approximate Critical Points.
C - .35/.45%	.41%	Yield Point -113,400 psi.	Ac_1 - 1380°F.
Mn- .60/.80%	.75%	Ultimate Strength-143,000 psi.	Ac_3 - 1460°F.
Cr- .80/1.10%	1.04%		Ar_1 - 1280°F.
Mo- .15/.25%	.21%		
S - .050%	.020%		
P - .040%	.016%		



The time in the furnace should be determined by the heaviest part of the piece to be heat treated—
i. e., thickness of wall or forging. See Time Control Chart Page 17, this Section.

PHYSICAL PROPERTIES CHART

S.A.E. X4340—TUBING

Size of Specimen: - 1" O.D. x .058" Wall. Oil Quenched from 1575° F. Tempered as Indicated.

S.A.E. Analysis.	Analysis of Specimen.
C - .35/.45%	.38%
Mn- .50/.80%	.71%
Cr- .60/.90%	.74%
Ni- 1.50/2.00%	1.72%
Mo- .20/.30%	.24%
S - .050% Max.	.016%
P - .040% Max.	.017%

As Normalized from 1700° F.

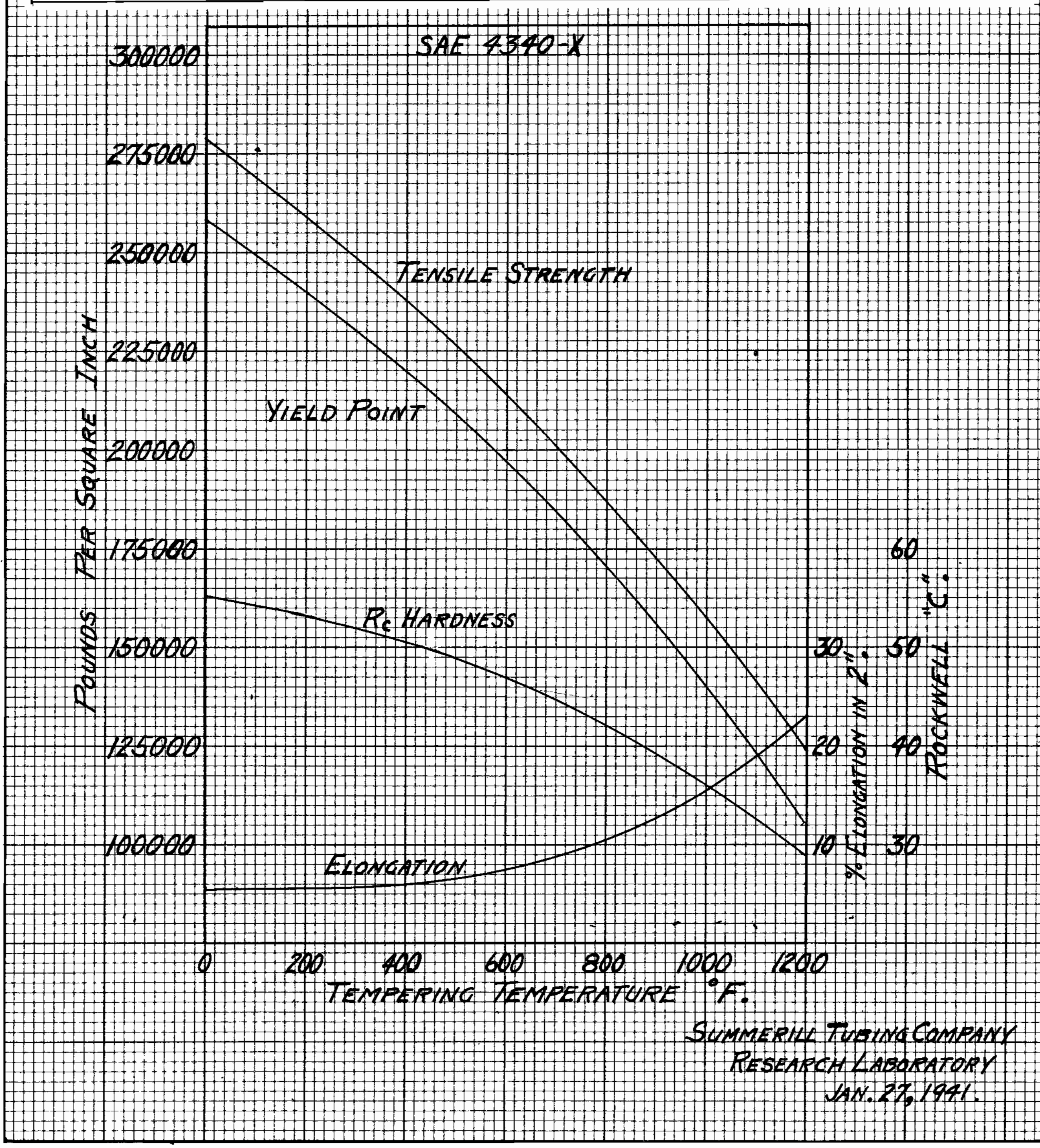
Yield Point - 120,000 psi.
Ultimate Strength - 172,000 psi.

As Quenched Hardness

Rc - 55

Approximate Critical Points.

Ac1 - 1340° F.
Ac3 - 1475° F.
Ar1 - 750° F.



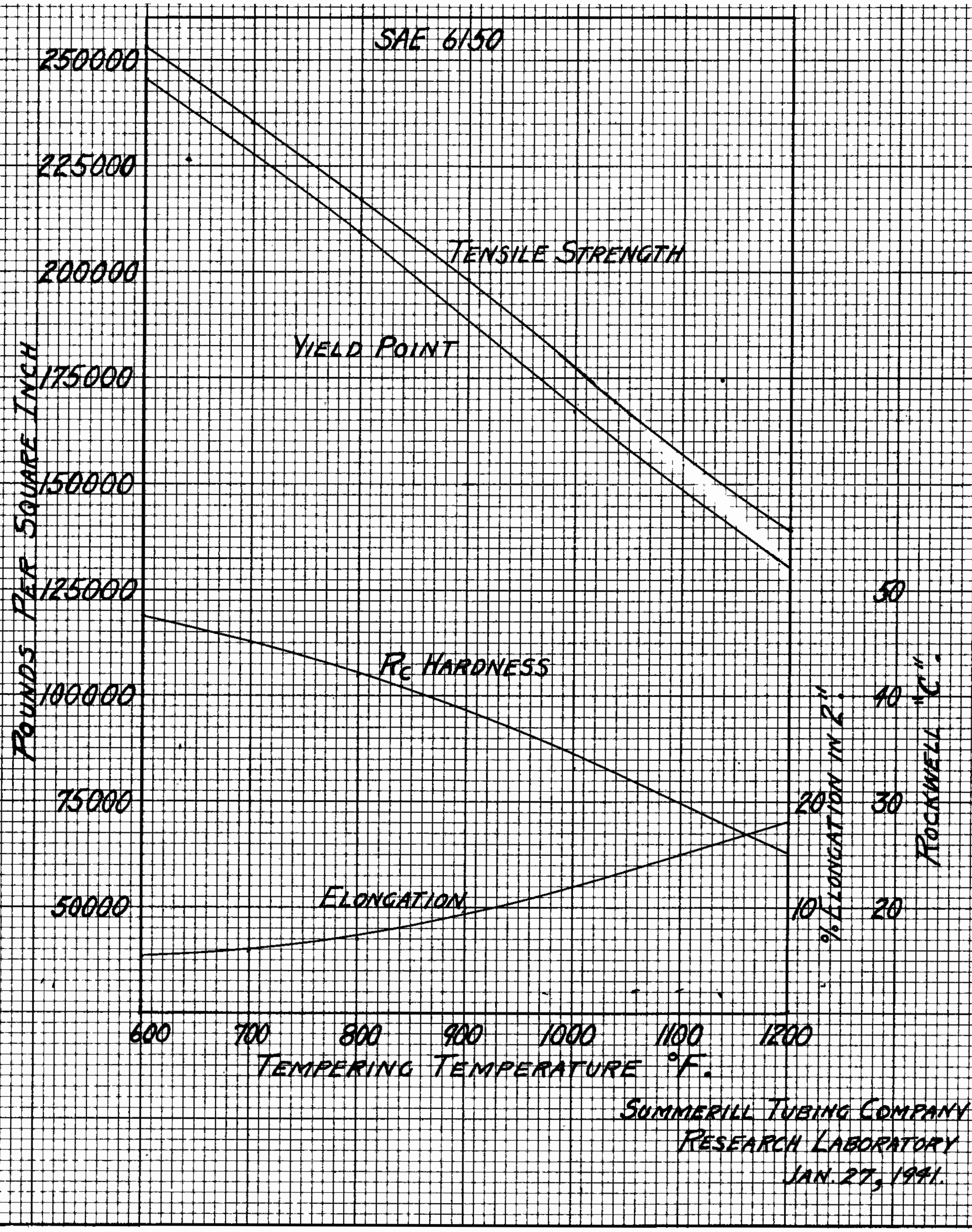
The time in the furnace should be determined by the heaviest part of the piece to be heat treated—i. e., thickness of wall or forging. See Time Control Chart Page 17, this Section.

PHYSICAL PROPERTIES CHART

S.A.E. 6150—TUBING

Size of Specimen: - .890" O.D. x .080" Wall. Oil Quenched from 1575° F. Tempered as Indicated.

S.A.E. Analysis.	Analysis of Specimen.	As Normalized from 1700° F.	Approximate Critical Points.
C - .45/.55%	.52%	Yield Point - 108,000 psi.	Ac_1 - 1390° F.
Mn- .60/.90%	.72%	Ultimate Strength - 148,000 psi.	Ac_3 - 1450° F.
Cr- .80/1.10%	1.00%		Ar_1 - 1290° F.
V - .15% Min.	.18%		
S - .050% Max.	.018%	**As Quenched Hardness.**	
P - .040% Max.	.015%	Rc - 53	



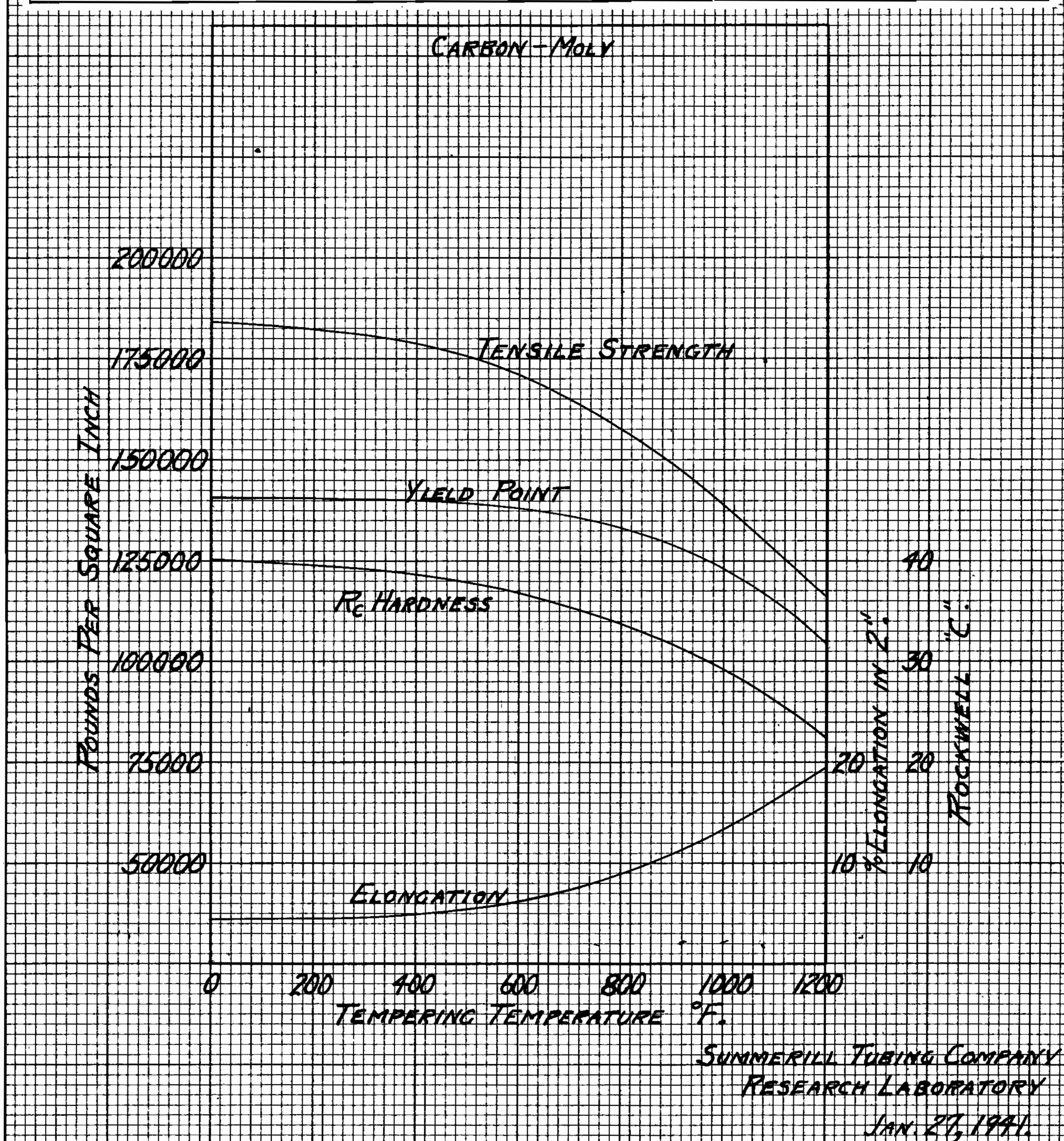
The time in the furnace should be determined by the heaviest part of the piece to be heat treated—
i. e., thickness of wall or forging. See Time Control Chart Page 17, this Section.

PHYSICAL PROPERTIES CHART

CARBON-MOLYBDENUM STEEL—TUBING

Size of Specimen: - 1-1/16" O.D. x .058" Wall. Oil Quenched from 1700° F. Tempered as Indicated.

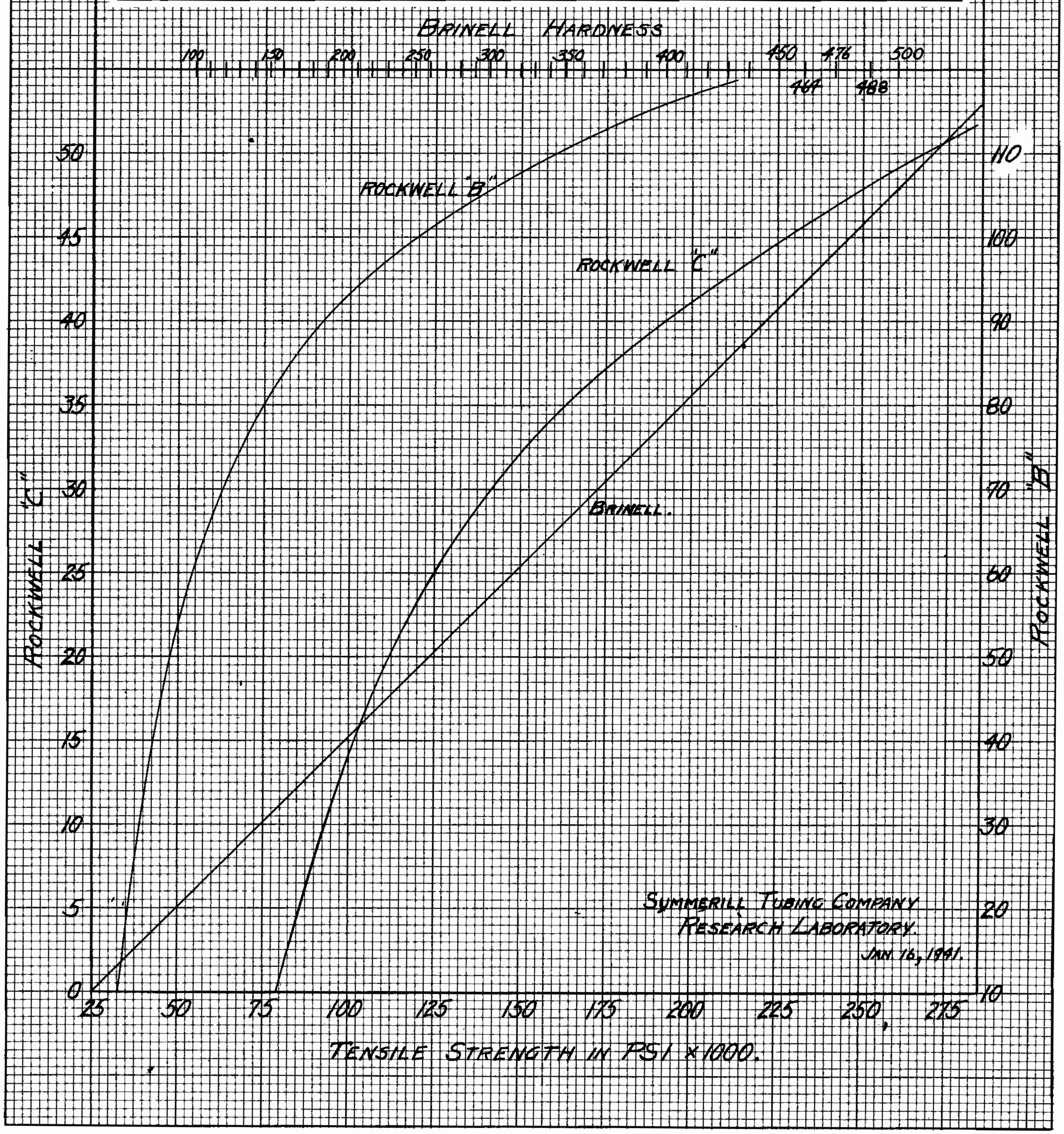
Analysis of Specimen.	As Normalized from 1700° F.	As Quenched Hardness.
C - .19%	Yield Point - 62,700 psi.	Rc - 40
Mn- .69%	Ultimate Strength - 88,800 psi.	
Mo- .58%		
P - .018%		
S - .025%		



The time in the furnace should be determined by the heaviest part of the piece to be heat treated—i. e., thickness of wall or forging. See Time Control Chart Page 17, this Section.

HARDNESS AND TENSILE STRENGTH COORDINATION FOR STEEL

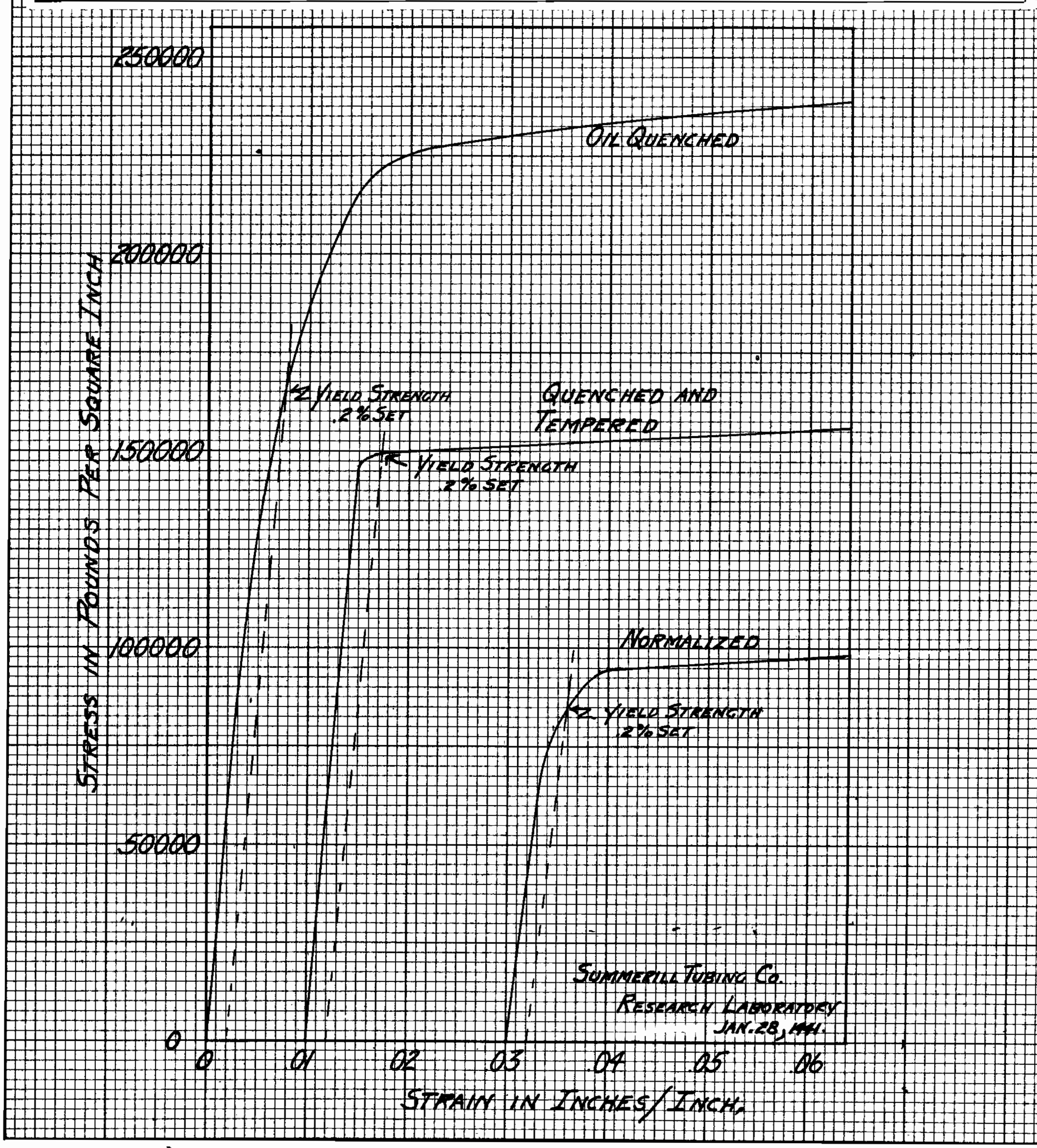
BRINELL, ROCKWELL B AND C



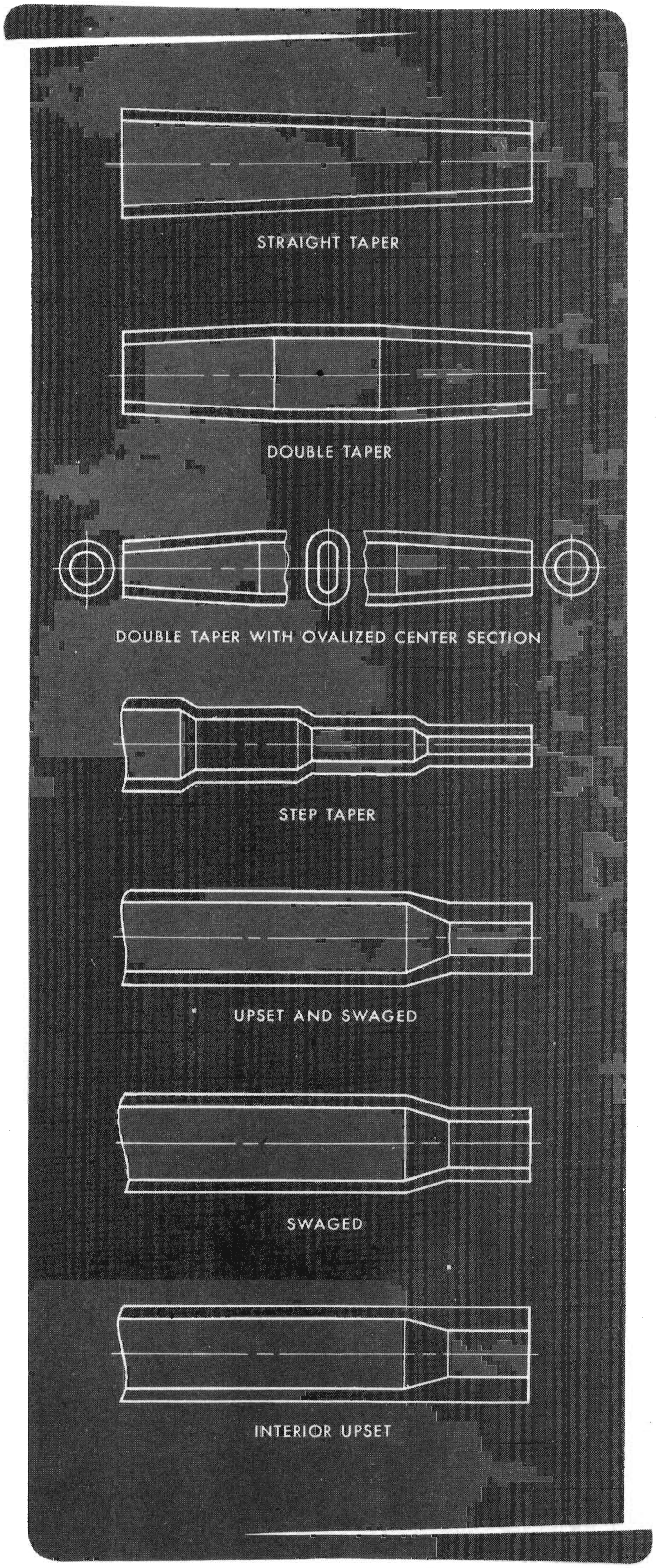
TYPICAL STRESS-STRAIN CURVES
S.A.E. X4130—TUBING

S.A.E. Analysis.	Oil Quenched from 1700° F.	Quenched and Tempered at 900° F. for 1/2 hour.	Normalized.
C - .25/.35% Mn- .40/.60% Cr- .80/1.10% Mo- .15/.25% S - .050% Max. P - .040% Max.	Yield Strength - 165,000 psi.* Ultimate Strength - 255,000 psi.	Yield Strength - 149,500 psi.* Ultimate Strength - 157,000 psi.	Yield Strength - 84,400 psi.* Ultimate Strength - 132,950 psi.

*Note - Yield Strength determined according to Federal Specification QQ-M-151a.



TAPERED AND FORMED TUBES



THE demand by engineers and designers throughout industry for tapered, formed, swaged and upset tubing has resulted in extensive technical development in this field. Ways and means have been devised to produce such work in a constantly increasing range of shapes and sizes and new developments are being made almost daily. Consequently, the aircraft industry is thinking more and more in terms of relying upon the tube mill to produce such special tubes to answer design problems.

Size limitations for tapering, upsetting and swaging are largely a matter of equipment. Tube mills and other tube fabricators are installing equipment for tapering and forming larger sizes as rapidly as the demands justify.

There are several basic methods by which tapered tubing is made, including *spinning*, *drawing* and *swaging*. Each process has its advantages and its limitations, but excellent work is produced by them all. The specifications and requirements of each individual job usually dictate the process to be used.

In the spinning process a base tube is spun and shaped without the use of an inside mandrel. Control of wall thickness to aircraft specifications is possible, and straight, curved or step tapers, single or multiple, can be produced on tubes ranging up to 20 feet in length. Obviously this process is used to produce only round sections, but in some cases, secondary shaping, such as ovalizing, can be done after spinning.

The drawing process makes use of a die and mandrel and offers a wide latitude of step tapers and other such work as the nature of the drawing process will permit. Although most products of the drawing process are round in section, shapes such as squares, ovals, etc., are also produced. This process permits particularly accurate control of wall thicknesses and diameters.

It is impractical to attempt to define the size and wall thickness limitations for tapering, swaging or forming, as what may have been impossible to produce yesterday would be quite feasible to produce today. In general, however, these operations

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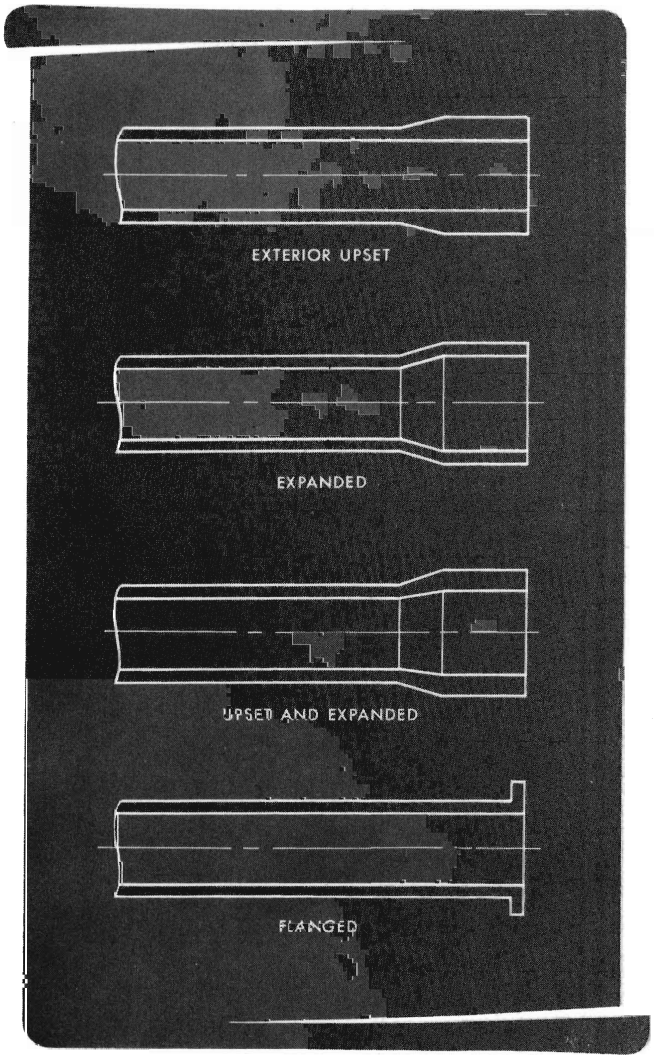


can be performed, within reasonable limits, on tubing of practically any wall thickness. Upsetting is usually limited to those tubes whose diameter-thickness ratio does not exceed 20 to 25.

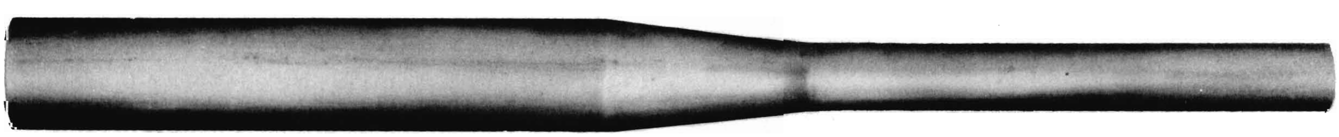
As a further guide to preliminary investigation, the following general statements may prove useful:

Tubes may be upset to a length equal to their diameter without great difficulty. In many cases, 1½ to 2 times the tube diameter is practicable, but this depends to some extent on the degree of wall thickening required. The wall may be thickened to 1½ to 2 times the base tube wall thickness with comparative ease and where the length of the upset is nominal, greater increases in wall thicknesses are possible.

Swaging or tapering to reduction of 25% in base tube diameter is normally possible and greater reductions can be made in many instances.

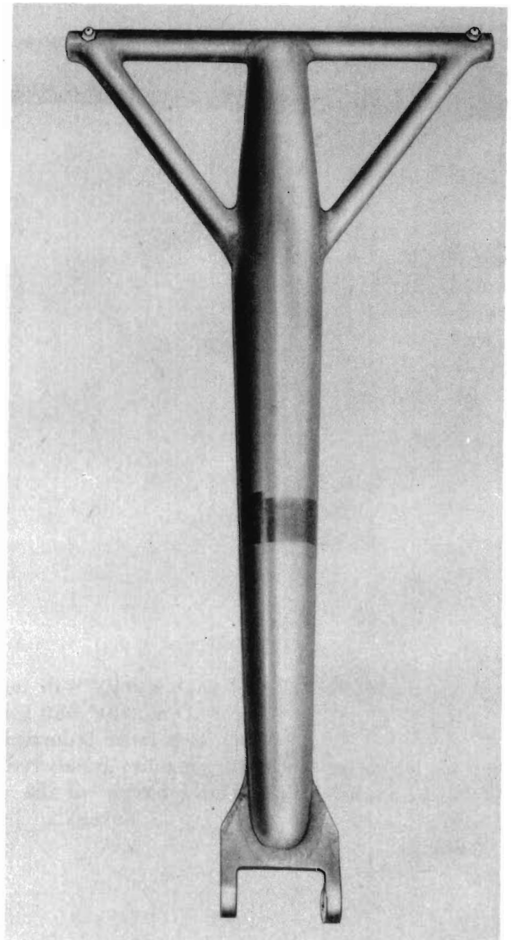
Expanding, flaring or flanging to 1½ times the base tube diameter can usually be accomplished and greater deformation can frequently be made.

Engineers and designers will find the tube mills ready to cooperate in the solution of problems relating to all types of special tubing. A constantly growing fund of information as well as an expanding range of production experience is available to the aircraft industry.



A tapered tube, 3½″ O.D. x .065″ wall tapered to 2″ x .083″ wall. This part was formerly made by welding two tubes together with a long "fish mouth" joint. As previously made, welding costs alone were greater than cost of this finished taper.

Double straight tapers on a 3¼″ O.D. x .156″ wall tube. Tapers reduced ends to 2″ x .180″ wall.



Tail wheel drag strut made from double tapered tube. Structural advantage of this use of tapered tubing is plainly evident.

SPUN-TAPERED TUBES

Outside Diameters—range up to 4″ and new production equipment is being developed which should soon increase permissible O.D.

Wall Thicknesses—of base tubes (i.e., tubing from which tapered sections are spun) are shown below. These thickness limitations should not be considered as inflexible, however, as it is sometimes possible to expand them when degree of taper and other factors permit.

O.D. up to 2″	.035″ to .083″
O.D. of 2″ to 3″	.049″ to .125″
O.D. of 3″ to 4″	.065″ to .170″

Lengths—range up to 20 feet.

Reductions—of base tube diameter can be made on one end, both ends, as well as anywhere on the tube length. Permissible degree of reduction depends upon factors such as analysis, O.D. and wall thickness, but generally speaking, the low and

Another type of double end straight taper having a parallel wall section on each end.

Long, straight, uniform taper. 2¼″ O.D. x .042″ wall tapered to 1¼″ O.D. x .042″ wall. This particular unit is for a control tube application.

Double taper symmetrical with a straight center section. Base tube is 3″ O.D. x .095″ wall with ends tapered to 2″ O.D. x .100″ wall. After spinning, center section is ovalized to a major axis of 3⁹⁄₁₆″ and minor axis of 2⅛″.

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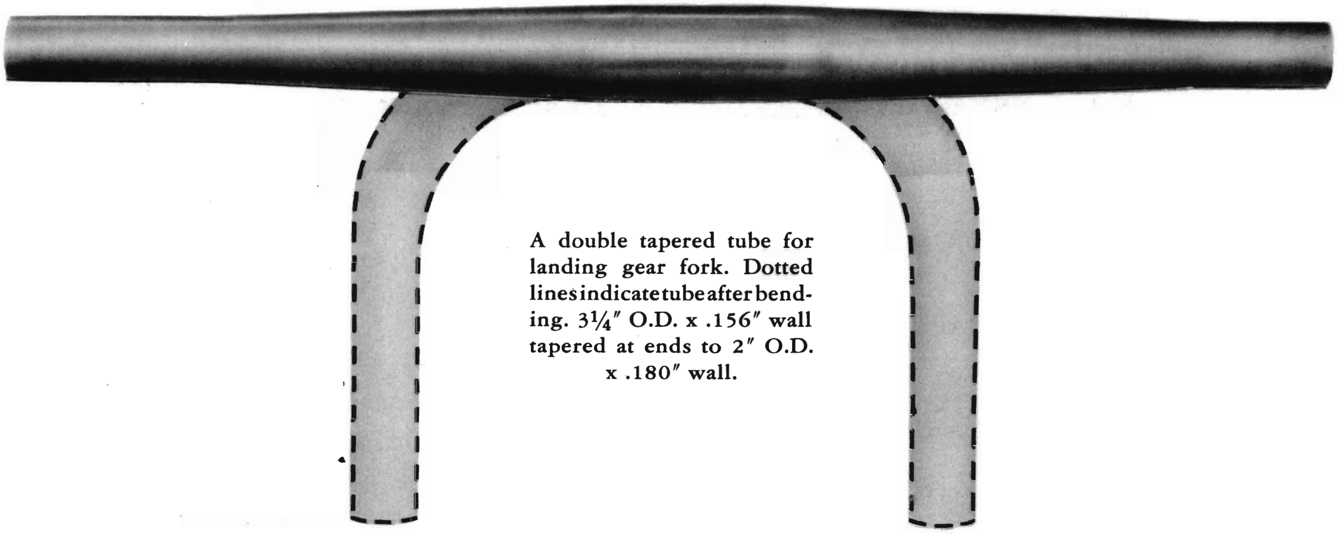
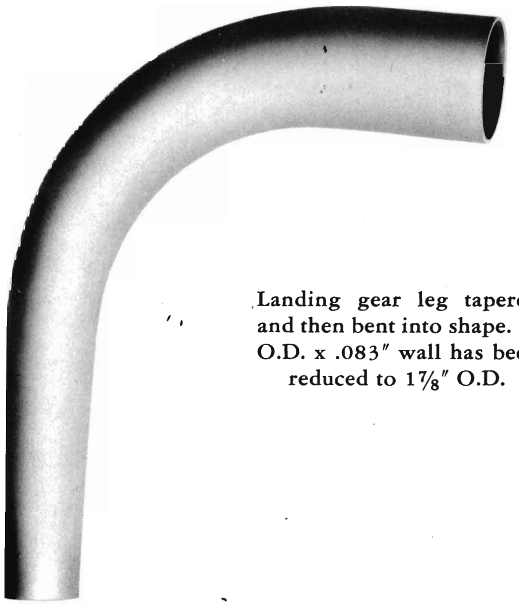


A double tapered tube for landing gear fork. Dotted lines indicate tube after bending. 3¼″ O.D. x .156″ wall tapered at ends to 2″ O.D. x .180″ wall.

3¾″ O.D. x .049″ wall tapered to 2⅜″ O.D. x .049″ wall for torque tube. This large reduction at end of torque tubes greatly reduces the size and weight of the required fittings.



Landing gear leg tapered and then bent into shape. 3″ O.D. x .083″ wall has been reduced to 1⅞″ O.D.

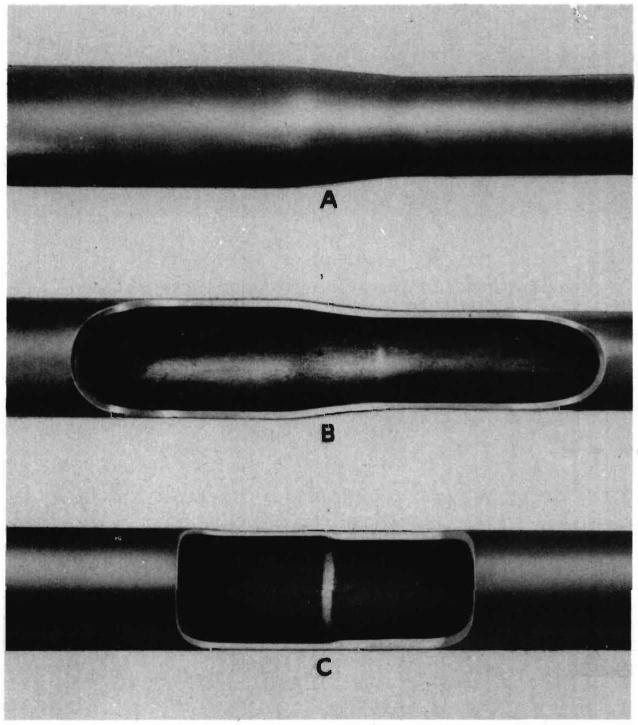
medium carbon steels can be reduced to approximately 60% of base tube diameter, while alloy steels can be reduced to approximately 65 or 70% of base tube diameter.

Wall Thickness—on reduced diameter can, in most cases, be made either *greater* than, the *same* as, or *less* than that of the base tube.

Tolerances—of spun tubing will, unless otherwise specified, be the same as those for standard aircraft tubing, which is normally used for the base tube. (See "Size Tolerance Table for Round Tubing" in this section.) Individual requirements as to tolerances, etc., are always analyzed by the mill and agreement arrived at with the purchaser in case of unusual tolerance requirements.

Heat Treatment—can be made at the mill on practically any spun-tapered tube. When heat treatment is required, wider tolerances should be allowed, as shown in the Size Tolerance Table.

STEP-TAPERED TUBES



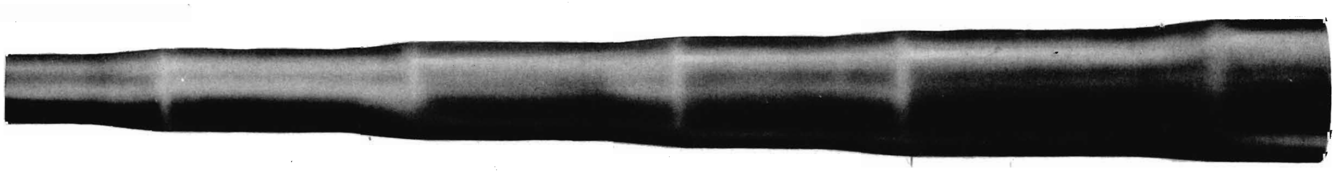
Illustrations of step-tapered tube with section cutaway. Note the absence of sharp corners and that change in diameter is accomplished with smooth curves. The wall thickness on the tapered section is actually slightly heavier than that on the large diameter.

Inside step taper resulting in change of wall thickness with uniform O.D.

The term step taper is generally used to identify those tapered tubes which have two or more steps and three or more parallel wall tube diameters. Usually made from a base tube of the maximum step diameter, step-tapered tubes can be produced by spinning, drawing, swaging or pushing into a die. The swaging operation is the method generally used on heavy walls and the pushing into a die is particularly useful for short tapers.

Although step-tapered tubing was produced and used before the long straight taper was available, there are still many applications in which step-tapered tubing is of particular use. Since it is possible to control the wall thicknesses to closer tolerances in a drawn step taper, and the walls of each diameter are parallel, the problem of joints and fittings is somewhat simplified. Also, step-tapered tubes in shapes other than round can be drawn for special requirements.

Steps—in a step-tapered tube occur at the points of change in diameter and the length of those steps



5/8", O.D. x .156" wall tapered in five steps to 2½" O.D. x .100" wall. Note the long, smooth tapers at each step.

An unusually long step-tapered tube having eight steps and nine diameters. Twenty-two feet in length, this tube is reduced from 3" O.D. x .095" wall to 13/16" x .058" wall.

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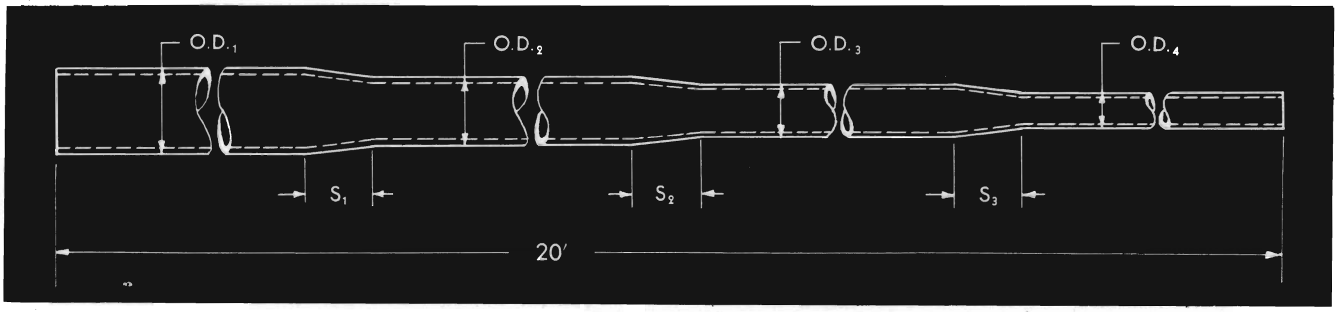
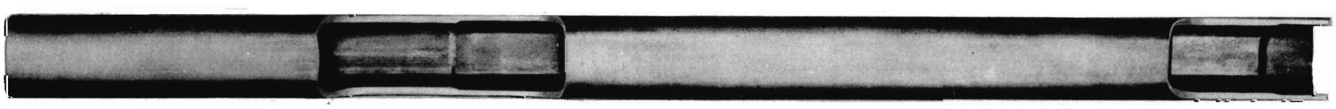


General limitations on step tubes are difficult to give, but the above drawing might prove helpful. O.D.$_1$ is the outside diameter of a base tube and O.D.$_2$, O.D.$_3$, etc., are the diameters of the various reduced sections. Number of steps is controlled by the amount of reduction required and changes in O.D. are usually held to 3/8″ maximum and preferably to no more than 1/4″ at any one step. The length of steps themselves (S_1, S_2, S_3, etc.) can usually be made from 1 to 3″ depending on various factors. The distance between steps can range from a few inches to many feet. Overall length of step-tapered tubes range up to more than 20 feet.

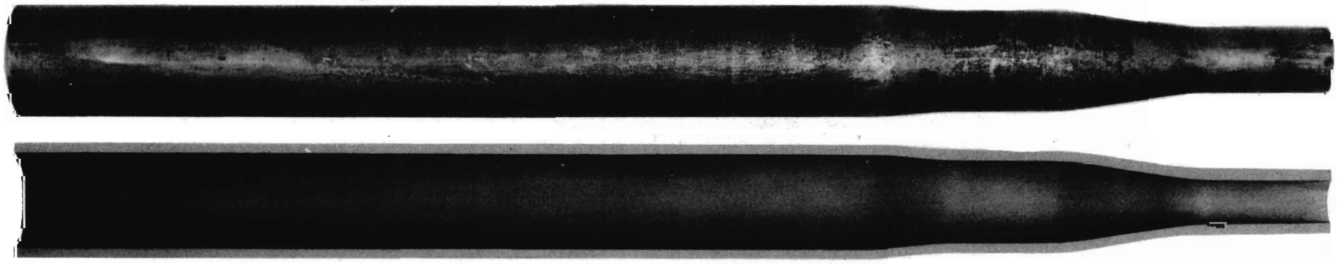
can vary according to customer requirements from extremely short steps up to approximately 3″ in length, in which cases the absence of a sharp shoulder eliminates points of concentrated stress.

Outside Diameters—range up to approximately 4″ for the base tube. Generally speaking, the required amount of reduction controls the number of steps and the permissible reduction will vary somewhat with the size of the tubing. In the drawing process, common practice indicates a maximum limit of 1/4″ reduction on the O.D. in one pass. In some cases, however, this can be increased. For example, if a 2″ base tube is to be reduced to 1″ on the small end, it may require only 3 passes and a like number of steps. Of course, the distance between steps can be almost any dimension, as required.

Lengths—of step-tapered tubes are normally limited to 26 feet for normalized tubes, and 20 feet for heat-treated tubes.



Cutaway view showing inside step taper of 2½″ O.D. square with 3/16″ wall on the heavy end reduced to .095″ wall on light end. This reduction is made in two steps.



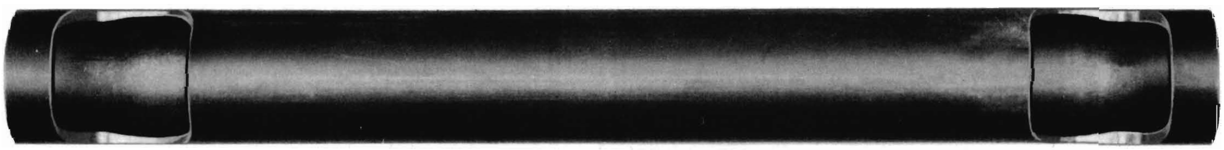
View and section showing double step-tapered tube which is later machined to provide a thin wall on the largest O.D.

Tolerances—of step-tapered tubing will, unless otherwise specified, be the same as those for standard aircraft tubing which is normally used for the base tube. The tolerances on reduced diameters and wall thicknesses can also be maintained within limits of standard Government specifications. Where heat treatment is required, wider tolerances should be allowed.

Straightness Tolerances—for step-tapered tubes will be to Government specification, i.e., one part in 600 for each diameter and the overall straightness.

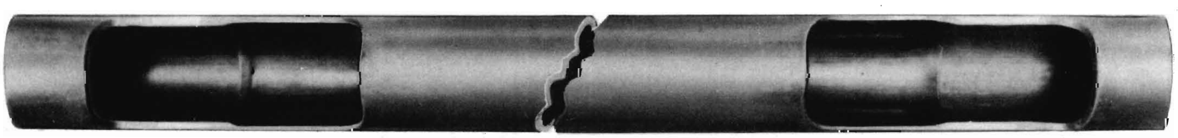
UPSET END TUBES

The aircraft industry frequently requires tubes which are light in wall thickness for most of the length, but with one or both ends upset to provide strength and metal for threading or other method of attachment to fittings. Due to the relatively light walls of most aircraft tubing, it has in the past been difficult to produce these heavy ends by either hot

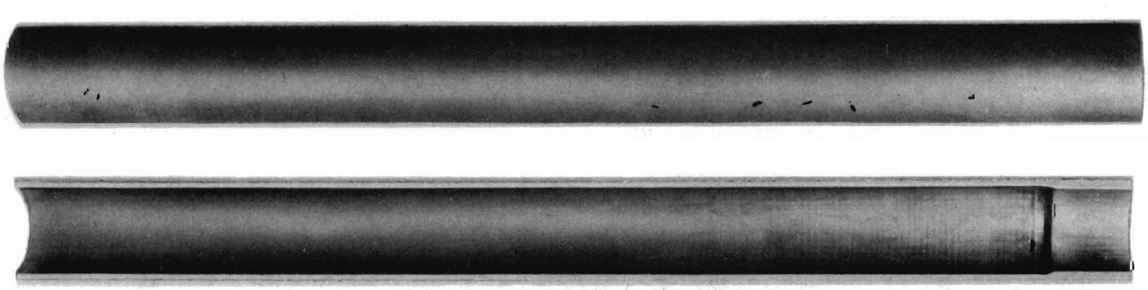


Short section of tubing upset at both ends with cutaway views to show increase in wall thickness.

This tube has an outside upset on one end and an inside upset on the other end. Due to relatively light wall for major length of tube, this particular piece has been produced by a combination of swaging and machining.



$1\frac{1}{4}''$ O.D. x .065″ wall with both ends upset to increase thickness to .110″ wall.



This piston tube has a uniform outside diameter but one end has been upset to provide increased wall thickness for attachment. Section shows relatively short length of upset end.

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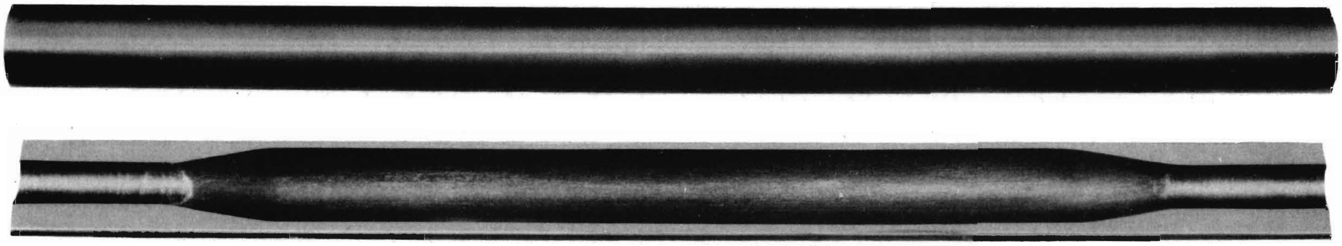


Shown above is a short tube with both ends upset. Outside surface has been machine finished.

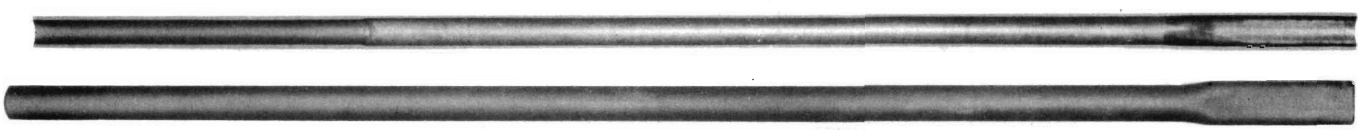
or cold upsetting. The metal tended to fold back rather than increase in thickness, but tube manufacturers have solved a number of the problems attendant to this operation.

The minimum wall thickness generally required for upsetting is 1/8″, but the length and the amount of upset is a controlling factor. For example, it is easier to upset a 1/8″ wall tube to a thickness of 3/16″ and a length of 1″ than it is to upset the same base tube to a thickness of 1/4″ and a length of 3″.

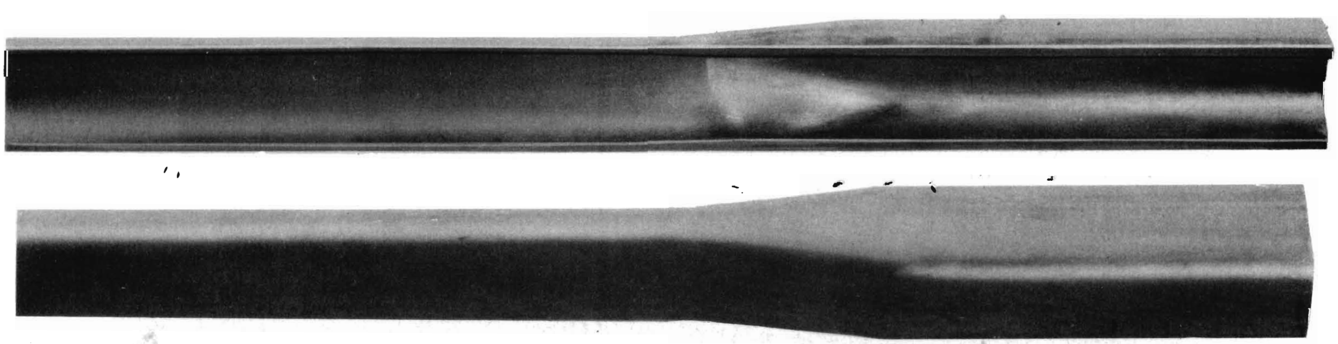
Shapes of tubing which can be upset include round, square and oval.

Outside Diameters—range up to 4″ and in some cases even larger.

Wall Thicknesses—of tubes which are to be upset range from light walls up to and including heavy walls. On light or average wall thicknesses, the increase in thickness of the upset end can be made up to 75% to 90% increase over base tube wall thickness. On walls of 1/8″ or heavier, larger increases in the heavy ends are possible. In most cases an increase of 100% in wall thickness will answer requirements.



Special upset end tube with rectangular section at one end. This tube is round for most of its length with a .095″ wall. Rectangular end is 6″ long and has a .156″ wall. The opposite end is round in section but has a wall thickness of .125″ for a length of 12″. The rectangular end is used for the attachment of a hinged fitting.



Shown above is an enlarged view and section of rectangular end on the round tube described above. This section shows the increase in wall thickness as well as the unusual rectangular shape required for attachment of fitting.

SWAGED TUBES

Where tubing is required with one or both ends reduced in size for a relatively short distance, it can usually be produced by swaging. Applications for swaged end tubes include "push-pull" control tubes, torque tubes, landing gear braces, controls and similar uses.

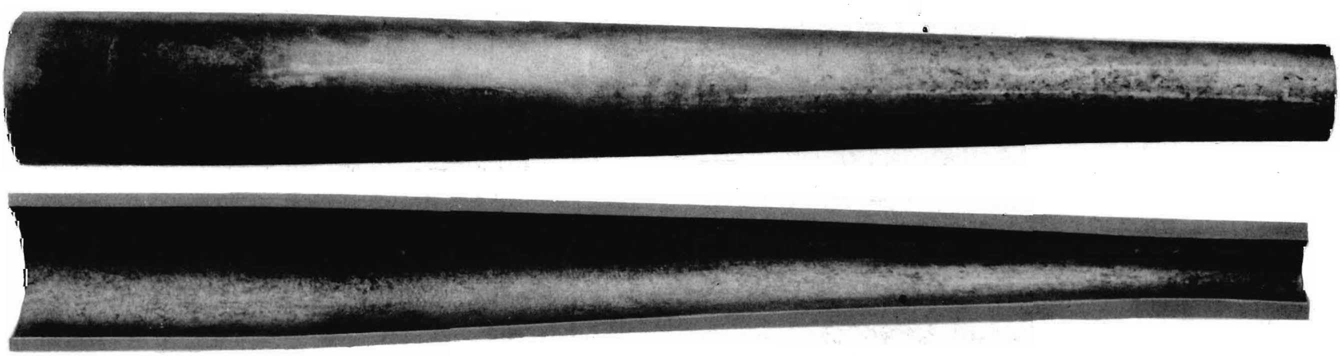
Various methods are used to produce swaged ends depending upon sizes, wall thicknesses, etc. Swaging may be done hot or cold and frequently such ends are produced by drawing and pushing into a die. Such reductions by means of a die are normally made without the use of a mandrel and consequently, the I.D. is not held to close tolerance. In many cases the I.D. is produced smaller than required and then machine-finished to the proper I.D.

Light wall and average weight tubing are normally reduced cold, while heavy wall tubes must be reduced hot. Where heat treatment is required, wider tolerances should be allowed.

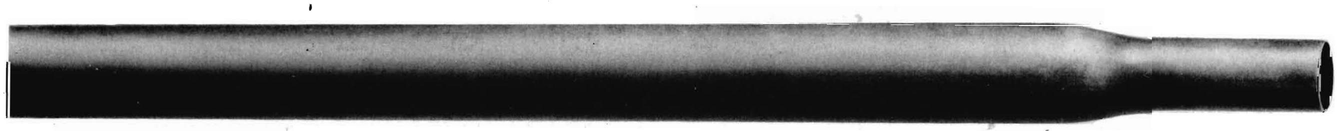
Outside Diameters—have up to the present been limited to sizes of 4″ O.D. and smaller.

Wall Thicknesses—on base tubes with swaged ends have ranged up to .375″ and in some cases slightly heavier.

Lengths—of tubes with swaged ends normally range from 12″ up to 5 feet, but longer tubes can be produced in many cases.



A hot swaged main landing gear leg before machining. 4½″ O.D. x ⅜″ wall reduced to 2″ O.D. x 9/16″ wall. Note rapid thickening of wall towards the small end, which is typical of hot swaging.



1⅛″ O.D. reduced on one end to ¾″ O.D. by swaging. This operation is frequently done on push-pull control tubes for the attachment of fittings.

Small hot swaged tube, to be machined as landing wheel axle for a glider.

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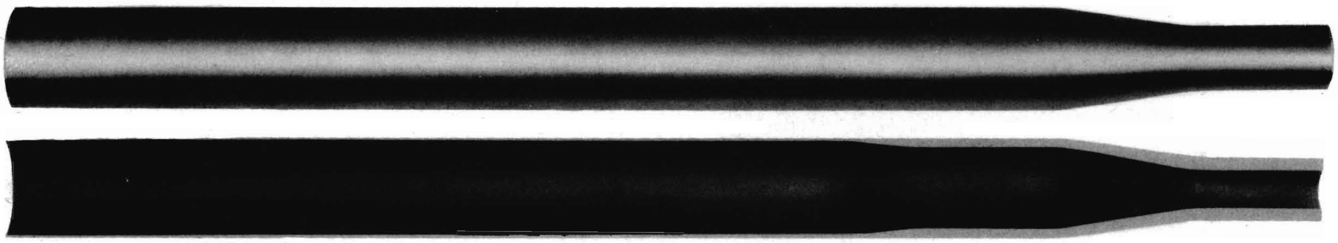
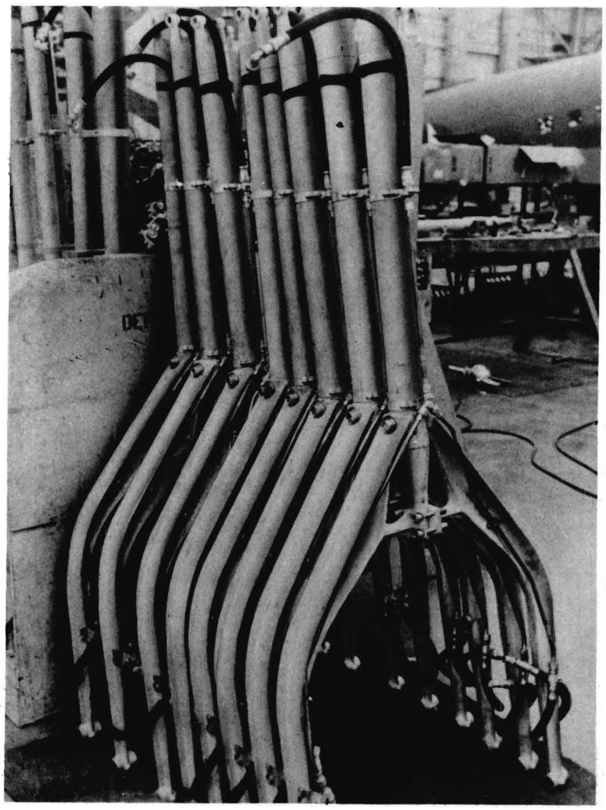


Shown above is the $3\frac{1}{2}''$ O.D. x $\frac{3}{8}''$ wall two-step taper (as illustrated under "Tapered Tubes") after machining. Note heavy wall for wheel fork and cross brace shown attached in photo at left. By outside machining to .095″ wall for major length of the tube, the weight is greatly reduced, yet all stress requirements are fully answered.



Completely assembled landing gear braces ready for installation. Vertical tube is shown in illustrations at top of this page.

FINISHING AND MACHINING

Most tube mills will do a certain amount of finishing or machining on special formed tubes as required. This means that complete units can be finished in many cases. Such machine work includes surface grinding, polishing, special tolerances, turning and bending.

In all inquiries for machined or finished special tubing, complete drawings must be submitted for engineering analyses by the tube mills.

Shown above is a small selection of various tapered, step-tapered, swaged and formed tubes. These examples are merely representative of some of the special tubing being produced for the aircraft industry.

$1\frac{1}{4}''$ O.D. axle tubes swaged and then threaded and slotted on one end while the opposite end is machined for fitting.