EO 105-10-1

ROYAL CANADIAN AIR FORCE

HANDBOOK

ALUMINUM ALLOYS

"REVISION"
NOTICE

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FOREWORD

Aluminum alloy shapes stocked by the RCAF are procured to various specifications and since these specifications are frequently amended or superseded it would be impractical to list their chemical compositions, mechanical properties and limits of fabrication. Therefore the information presented in this Engineering Order is of a general nature and lists the chemical composition and limits of fabrication of Mill Standard alloys only. For detailed information on any of the alloys reference should be made to the procurement specification of the alloy.

The design mechanical properties at normal (room) temperature for various aluminum alloys shown in this Engineering Order are the minimum values to be expected for the specification listed. Such values may be applied to any other approved specification if the minimum requirements of such specifications do not fall below the values herein quoted.

Tensile and compressive strengths have been given in both longitudinal and transverse directions to the direction of rolling, extruding, drawing or forging. Shear and bearing strengths have been given without reference to direction and may be assumed to be the same in all directions. In those instances where the direction in which the material will be used is not known, the lesser of the applicable longitudinal or transverse properties should be used.

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SECTION 1

PROPERTIES OF ALUMINUM ALLOYS GENERAL

1 Aluminum of very high purity is a soft, light, ductile metal having a high electrical and thermal conductivity and an excellent resistant to corrosion. These are the basic properties of the metal from which the aluminum alloys are obtained.

2 While the properties of aluminum alloys are many and varied, in general, the use of an alloy in any application is governed by its ability to provide two or more particular properties. To satisfy such combinations, a wide range of alloys has been developed. In the aluminum alloys certain properties of pure aluminum are altered to a considerable extent. Strength is greatly improved but the property of lightness is practically unchanged while the electrical conductivity is reduced to an appreciable extent except in those alloys used for electrical applications.

3 All aluminum alloys are not equally resistant to corrosive attack and in some alloys this property can be considerably reduced by improper heat treating technique. While the normal surface of aluminum alloys offer sufficient protection for many applications, even greater protection can be afforded by chemical and electro-chemical treatments to increase the thickness of the natural protective oxide coating. These processes have made the aluminum alloys more adaptable to the aircraft industry.

SECTION 2

FABRICATION AND FOUNDRY PRACTICES

1 Aluminum alloys lend themselves to be formed and cast into the most diversified shapes and assemblies. Generally speaking, the same types of equipment as are used in handling other metals may be used. However, there are certain differences in the working and casting characteristics of aluminum which should be observed to obtain the best results. These characteristics are discussed under separate Parts in this Engineering Order.

SECTION 3

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NOMENCLATURE

1 The aluminum alloys are divided into two main groups: wrought alloys and casting alloys. Wrought alloys are those in which cast metal is mechanically worked by processes such as rolling, drawing, extruding, or forging, while casting alloys are those in which the metal is cast to its final form.

2 High purity aluminum 1S, has a tensile strength of only about 9000 psi while the small amounts of iron and silicon present in what is called commercially pure aluminum, 2S, increase the strength in the annealed condition, by about 45%. The alloy 3S, which contains 1.25% manganese in addition to the impurities iron and silicon, has a strength 75% greater than the annealed pure metal while the strength of alloy 52S containing 2.5% magnesium, in the annealed condition, is approximately 3 times that of the pure metal. Cold working of any of these alloys increases the strength with a sacrifice of ductility.

3 The improvement in the casting qualities of the aluminum alloys as compared with the pure metal is perhaps even greater than the improvement in their mechanical properties. The commercial casting alloys contain varying percentages of one or more alloying elements and have been developed to combine good qualities from the standpoint of foundry operations. Some of the alloys are subjected to heat-treating operations to further improve their mechanical properties.

WROUGHT ALLOYS

4 The aluminum alloys fall into several groups, each group is distinguished by one main alloying constituent. The wrought alloys are designated by numbers followed by the letter "S" (e.g. 17S) while the cast alloys are designated only by a number. Sometimes when an alloy has been developed by modifying the composition of an existing alloy, it may be designated by the same number preceded by a letter, such as A17S or B195. Symbols are used following the alloy designation to describe the various tempers resulting from cold working, heat-treating or a combination of both.

5 The Aluminum Company of Canada and the Aluminum Company of America employ the following symbols for the various groups of wrought alloys:-

99.5% - 99.69% Pure Aluminum Group	1S
99.0% - 99.49% Commercial Pure Aluminum Group	2S
Manganese Group	3S-9S
Copper Group	10S-29S
Silicon Group	30S-49S
Magnesium and Magnesium Silicide Group	50S-69S
Zinc Group	70S-79S

6 The wrought aluminum alloys are further divided into two general classes, namely, the "non-heat-treatable alloys" and the "heat-treatable alloys."

NON-HEAT-TREATABLE ALLOYS

7 The "non-heat-treatable" alloys contain elements that remain substantially in solid solution or form constituents that are insoluble. This group includes the high-purity alloys and the alloys 2S, 3S, 52S and 56S.

8 Strength of these alloys depends on the amount of cold work introduced after the last annealing operation. The properties so obtained are destroyed by subsequent heating and cannot be restored except by additional cold work. In the non-heat-treatable alloys five tempers are used to designate the Canadian products and a range of tempers are used by the American mills.

9 The five tempers, with symbols to describe them, used by Canadian mills are as follows:-

O .... Fully annealed

1/2H .... One-half hard

3/4H............ Three-quarters hard

H............... Fully hard

F............... As fabricated

10 The tempers used by the American mills range from the soft or annealed temper designated by the symbol "O" to the extra-hard temper designated as "H18" in 2S and 3S, and "H-38" in 52S alloy. In addition, there is the "as fabricated" or "F" temper produced by a variable amount of strain-hardening in the fabricating process.

11 When the temper is produced by cold working the material to the desired extent, the first digit is 1. The second digit depends on the amount of cold-working after the last process anneal and, when this cold-working has been such as to produce the hardest commercially-practical temper the number is 8. Thus, the temper designation for the commercially-hard temper is H18. For material cold-worked to a tensile strength approximately midway between the "O" and the "H18" tempers, the designation is H14. Similarly, material with a strength midway between O and the H14 is designated H12 and that with a strength midway between the H14 and H18 is known as H16.

12 It also is possible to obtain a given level of strength in the strain-hardened alloys by cold-working to a harder temper and then reducing the strength to the desired level by partially annealing the material. To designate the tempers produced by this means the digit 2 is used following the letter H. The numbers 2 through 8 are used for the second digit in the same manner as for the H1 series described above.

13 In the case of the alloys 4S, B50S, 52S and 56S, the strength developed by cold-work decreases slightly, and elongation increases, when the material is held at room temperature for a long time. These changes can be brought to practical completion by heating the material for a short time at a slightly elevated temperature. Such a stabilizing treatment is usually given to the intermediate and hard tempers of commercial products of these alloys and, to indicate such treatment the number 3 is used as the first digit after the "H" in the temper designation. Thus, for cold-worked and stabilized material, the temper designations are H32, H34, H36, and H38.

HEAT-TREATABLE ALLOYS

14 The heat-treatable alloys are those in which the mechanical properties may be improved by heat treatment. In contrast to the non-heat treatable alloys the increased strength is obtained with little sacrifice of ductility. Heat-treatable alloys have the further advantage that they can be re-heat treated after annealing to restore their original properties.

CANADIAN TEMPER DESIGNATIONS

15 There are eight tempers in which the heat-treatable alloys are supplied by the Canadian mills, but each alloy or product is not always supplied in all tempers. The symbols

following the alloy numbers that are used to describe these tempers are as follows:-

O	....	Fully annealed
W	....	Solution heat-treated
T	....	Solution heat-treated and aged
RW	....	Solution heat-treated and cold-worked
RT	....	Solution heat-treated, aged and cold-worked
F	....	As fabricated
Q	....	Quenched
A33	....	Quenched and aged

16 The "W" temper is produced by a "solution heat-treatment" which consists of heating the alloy to a temperature below the melting point, at which the alloying constituents will be taken into solid solution, followed by a quench to retain this condition.

17 The "T" temper is produced by the "age-hardening" of an alloy that has been heat-treated to the "W" condition. Aging may require heating at a relatively low temperature during which the dissolved constituents are precipitated in extremely fine particles. This is known as a "precipitation heat-treatment." Certain alloys, notably 17S and 24S, age-harden spontaneously at room temperature, obtaining their maximum properties four or five days after solution heat-treatment. These alloys are said to "age naturally" since no secondary heating is required to effect the precipitation.

18 The "RT" temper is produced by a controlled amount of cold-work applied to an alloy which has previously been heat-treated to the "T" temper. If the cold-work is applied to the "W" temper, the resulting temper is described as the "RW" temper.

19 The "A33" temper is available only in certain alloys. This temper is produced in extrusions only by quenching at the die followed by the precipitation heat-treatment. The "Q" temper is obtained when extrusions are quenched at the die.

AMERICAN TEMPER DESIGNATIONS

20 For heat-treated materials supplied by American mills, the temper designations consist of the letter "T" followed by a number of from one to three digits. The basic designations are as follows:-

T2	....	Annealed-castings only
T3	....	Solution heat-treated and then cold-worked
T4	....	Solution heat-treated
T5	....	Artificially aged only
T6	....	Solution heat-treated and then artificially aged
T7	....	Solution heat-treated and then stabilized
T8	....	Solution heat-treated, cold-worked and then artificially aged
T9	....	Solution heat-treated, artificially aged and then cold-worked
T10	....	Artificially aged and then cold-worked

21 The first numeral following the letter "T" shows the type of treatment. The actual conditions will usually be different for different alloys and may be varied for a single alloy to produce certain desired results. In this case, the tempers, other than the one usually considered standard, or the first one used, are designated by a second numeral following the one which shows the type of heat-treatment. Here, also, there is no attempt to have this numeral indicate any specific set of conditions. Just as the actual temperatures and times required to produce 61S-T6 are different from those required for 18S-T6 or 19S-T6, so are those used for 61S-T61 different from those required for 18S-T61. The numeral "1" following the "6" merely designates properties different from those developed by the standard "T-6" treatment for the respective alloys because there has been some modifications of the conditions but not of the type of treatment.

22 The condition that results from quenching an alloy from the solution heat-treatment

temperature is unstable, since age-hardening commences immediately. This unstable condition is designated by the letter "W" and since the properties vary continuously with time, it is necessary to indicate the length of aging period in order to convey the temper. For example 24S-W (20 minutes) represents a condition in which the alloy can be subjected to relatively severe forming operations, rivets can be headed and fairly deep drawing accomplished. The term 24S-W (4 days) would not be used as in this length of time the hardening that takes place at room temperature would be almost complete, and the alloy would be in the stable 24S-T4 temper. With the 75S alloy, the room temperature aging is more gradual and 75S-W (2 months) is not yet in a stable condition and, for most operations is still more workable than 75S-T6.

23 The numeral 3 immediately following the letter T designates the temper produced by strain-hardening after solution-heat-treatment. This temper is developed in sheet that has been rolled to produce the necessary degree of flatness. Material heat-treated by the user or supplied by the producer in coils is designated T4, indicating the solution-heat-treatment has been followed by natural aging only.

24 The numeral 5 indicates the material has been artificially aged without previous solution-heat-treatment. Certain fabricating processes cause the retention of sufficient alloying constituents in solid solution to permit substantial improvement in mechanical properties by artificial aging alone. Extruded shapes, castings and particularly permanent-mould castings are examples of products to which this type of heat-treatment is applied. Since the precipitation of alloying constituents from solid solution causes a change in volume of the alloy, this type of heat-treatment is used with castings, not only to improve the mechanical properties but also to stabilize dimensions and relieve casting strains.

25 Solution heat-treatment, followed by artificial aging, is designated T6, provided any cold-working of the material between the two processes does not cause a sufficiently greater response to artificial aging so that higher mechanical properties can be guaranteed. When cold-working between the solution-heat treatment and artificial aging does produce higher properties in the aged material than are attained by only the aging treatment, the designation becomes T8. Artificially aged 24S-T36 sheet becomes 24S-T86 while 24S-T3 flat sheet, stretched about 1% during the flattening process, becomes 24S-T81 when artificially aged. In the case of 61S, cold-working between solution treating and aging has no significant effect on the properties of the aged material, so the designation is T6.

26 The numeral 7 is applied to materials that have been solution-heat-treated and then stabilized under conditions of temperature and time such that the aging is carried beyond that required to produce maximum strength and hardness in order to control growth and distortion resulting from a casting or quenching strain. This type of heat-treatment is used with castings and forgings for high-temperature service.

SECTION 4

CHOICE OF AN ALLOY

1 The choice of an alloy for a particular product depends upon which of the qualities is most essential for the intended use. Thus the determining factor may be maximum mechanical properties, resistance to corrosion, ease of machining, welding or forming, or a minimum cost of material, whichever the case may be. The following description of the alloy groups will serve as a guide.

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DESCRIPTION OF ALLOY GROUPS

WROUGHT ALLOYS

1 The alloy designations used below are Alcan designations. Relevant designations and specifications are listed in Table 3 of this Engineering Order.

2 The pure aluminum group 1S, is used mainly for food, beverage, and by the chemical industry because of its excellent resistance to corrosion and ease of fabrication. Commercially pure aluminum, 2S, exhibits the same general characteristics as 1S with slightly higher strength values.

3 Manganese increases the strength to a moderate degree with only a slight reduction in ductility. This alloy, 3S, is employed where a non-heat-treatable alloy with greater strength or rigidity than 2S is required together with high resistance to corrosion.

ALUMINUM-MAGNESIUM GROUP

4 There are two alloys of this class, 56S and 57S. 56S alloy possesses the highest mechanical properties among non-heat-treatable alloys. Its workability, however, is inferior when compared with other alloys of this group. Its principal applications are for rivets and special wire products.

5 57S alloy possesses superior resistance to corrosion, particularly by sea water as well as being stronger without a material sacrifice in ductility, than the other non-heat-treatable

alloys. A further property is its resistance to fatigue stresses illustrated by the higher endurance limit that the alloy develops in all tempers. The alloy may be readily formed, particularly in the annealed temper, although it work-hardens more rapidly than 2S or 3S.

ALUMINUM-COPPER-MAGNESIUM-MANGANESE GROUP

6 This is the general classification of the "dural" type alloys and includes 17S, 24S and 26S, in all of which copper is the main alloying constituent with varying percentages of magnesium and manganese. These alloys are all of the heat-treatable group although heat-treating conditions vary with composition. The tempers obtainable also vary with the alloy as certain compositions are relatively stable in the "W" temper at ordinary temperatures, while others are unstable and age harden rapidly to the stable "T" temper. Certain of these alloys are fabricated into all or nearly all types of wrought products, while others find application only in special fields. The 16S alloy also is included in this group, although it does not contain manganese, because it exhibits the characteristics of this group; 16S is used primarily for rivets.

7 This group is of major importance in structural applications where high mechanical properties are desired.

8 In sheet form certain of the alloys are used as Alclad. Alclad sheet consists of an alloy core coated on each side with high purity aluminum or corrosion-resistant aluminum alloy in order to provide maximum corrosion resistance. The high purity aluminum or corrosion-resistant aluminum alloy coating not only protects the core which it covers but also provides cathodic protection to the core at the sheared edges. The tensile strengths of Alclad sheet are naturally somewhat lower than the corresponding values for the uncoated alloy.

ALUMINUM-MAGNESIUM-SILICON GROUP

9 This group of heat-treatable alloys contains magnesium silicide as a hardening constituent and is being used more widely of late. Of slightly lower strength than the aluminum-copper-magnesium-manganese group, these alloys are more readily formed and fabricated and offer superior resistance to corrosion. A characteristic of the group is the stable "W" temper of all the alloys and the excellent formability in this temper. Formed parts may be given a low temperature aging treatment to develop the "T" temper without distortion.

10 The principal alloys in this group are 50S, 55S and 65S; 65S alloy has slightly lower mechanical properties than the aluminum-copper-magnesium-manganese group, but is more readily formed and fabricated, and offers superior resistance to corrosion. It is widely used in extruded sections and tubing; 55S alloy is used primarily for the manufacture of rivets.

ALUMINUM-MAGNESIUM-ZINC GROUP

11 High mechanical properties, particularly endurance strength, are characteristic of this group; 75S alloy, which is produced as sheet, extrusions, forgings and tubing is included in this group.

OTHER ALLOYS

12 The 5% silicon alloy, 33S, is used extensively for welding rod and C35S is used primarily as a brazing filler material. Alloy 28S, usually used in the "RW" temper, was specially developed for its free machining characteristics.

SECTION 6

CASTING ALLOYS

1 Castings of aluminum may be produced as sand castings, permanent-mould castings or pressure die-castings. The type of alloy most suitable for a casting depends on the shape and size of the casting and the desired dimensional accuracy.

ALUMINUM-SILICON GROUP

2 The aluminum-silicon group of alloys possess excellent casting characteristics for all types of casting processes, high resistance to corrosion and leak-proof qualities. When used with other alloying elements the aluminum-silicon group respond to heat-treatment and develop higher tensile properties.

ALUMINUM-COPPER GROUP

3 This group of alloys is susceptible to heat-treatment and possesses high strength and good machining qualities. This group is not suitable for pressure-die casting nor in some cases permanent-mould casting and the corrosion resistance is inferior to that of the aluminum-silicon group.

ALUMINUM-MAGNESIUM GROUP

4 Aluminum alloys of this group combine excellent resistance to salt water attack, high strength and ductility, good machinability and finishing characteristics. Those containing high percentages of magnesium may be heat-treated.

SECTION 7

CHEMICAL COMPOSITION OF WROUGHT ALLOYS

1 Table 1 lists the chemical composition of mill standard alloys. These chemical compositions may vary slightly from the chemical compositions of materials procured to a specific specification.

CHEMICAL COMPOSITION WROUGHT ALUMINUM ALLOYS

Alcan Alloy Number	Cu%		Fe%		Mg%		Mn%		Si%		Ti%		Zn%		Cr%		% Other Elem.	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Each	Total
1S																	0.05	0.15
2S	0.2						0.05						0.1				0.05	0.15
3S	0.2		0.7				1.5	1.0	0.6				0.1				0.05	0.15
16S	3.0	2.2	0.7		0.5	0.2	0.2		0.7		0.15		0.1		0.1		0.05	0.15
17S	4.5	3.5	0.7		0.8	0.4	0.8	0.4	0.8		0.15		0.1		0.1		0.05	0.15
24S	4.9	3.8	0.5		1.8	1.2	0.9	0.3	0.5				0.1		0.1		0.05	0.15
26S	5.0	3.9	1.0		0.8	0.2	1.2	0.4	1.2	0.5	0.15		0.1		0.1		0.05	0.15
28S	6.0	5.0	0.7		0.2		0.2		0.7				0.1				0.05	0.15
50S	0.1		0.5		0.9	0.5	0.1		0.6	0.2	0.15		0.1		0.1		0.05	0.15
55S	0.1		0.35		1.4	1.1							0.1		0.35	0.15	0.05	0.15
56S	0.1		0.3		5.4	4.5	0.2	0.05	0.3						0.2	0.05	0.05	0.15
57S	0.1				2.8	2.2	0.1						0.1		0.35	0.15	0.05	0.15
61S	0.35		1.0		0.8	0.45	0.2		1.2	0.6	0.15		0.1		0.35	0.15	0.05	0.15
65S	0.4	0.15	0.7		1.2	0.8	0.15		0.8	0.4	0.15		0.1		0.35	0.15	0.05	0.15
C65S	0.4	0.15	0.7		1.2	0.8	0.15		0.8	0.4	0.1		0.1		0.1		0.05	0.15
75S	2.0	1.2	0.7		2.9	2.1	0.3		0.5		0.2		6.1	5.1	0.4	0.18	0.05	0.15

__NOTE:__ This Table lists alloying ingredients only; the remainder is aluminum.

Table 1

CHEMICAL COMPOSITION LIMITS OF ALUMINUM CASTING ALLOYS

Alcan Alloy	Cu% Max.	Cu% Min.	Fe% Max.	Fe% Min.	Mg% Max.	Mg% Min.	Mn% Max.	Mn% Min.	Si% Max.	Si% Min	Ti% Max.	Ti% Min.	Zn% Max.	Zn% Min	Cr% Max.	Cr% Min.	Others Each	Others Total
100 (1)																		
A111	2.0	1.0	1.4	0.8	0.2	0.05			1.5	0.8	2.8	1.5	0.25	0.05			0.05	0.15
M116	0.08		0.25		2.7	2.1	0.15				3.8	3.2	0.16	0.08			0.03	0.10
117	4.0	2.0	0.8		0.15		0.7	0.3	0.35		6.0	3.0	0.2		0.2		0.10	0.30
123	0.1		0.8				0.1				6.0	4.5	0.2				0.05	0.15
125	1.5	1.0	0.5		0.6	0.4	0.1				5.5	4.5	0.2				0.05	0.15
127	4.5	3.5	0.8		0.1		0.3		0.5		5.5	4.5	0.2		1.0		0.05	0.20
135	0.2		0.5		0.4	0.2	0.1				7.5	6.5	0.2				0.05	0.15
143	4.0	3.0	1.0				0.1				8.0	8.0	0.2		0.1		0.05	0.15
160-N	0.1		0.6				0.3				13.0	10.0	0.2		0.1		0.05	0.15
160-X	0.1		0.6				0.3				13.0	10.0	0.2		0.1		0.05	0.15
162	1.5	0.5	0.6		1.3	0.7			3.0	2.0	13.0	11.0	0.2				0.05	0.15
225	5.0	4.0	0.8		0.03		0.3				1.2		0.2				0.05	0.15
236	8.0	6.5	1.5	0.95	0.3		0.5		0.2		3.0	1.0	0.2		0.1		0.05	0.20
250	10.7	9.2	1.5		0.35	0.15	0.1				0.6		0.2				0.05	0.25
A320	0.05		0.4		4.35	3.35	0.05				0.65	0.35	0.2				0.05	0.15
340	0.1		0.7		8.5	7.5	0.2				0.5						0.05	0.10
350	0.15		0.3		10.6	9.5	0.1				0.2		0.2		0		0.05	0.15

(1) Aluminum 99.5% min.

(2) This Table lists alloying elements only; the remainder is aluminum.

Table 2

RELEVANT SPECIFICATIONS

ALCAN ALLOY	TYPE	ALCOA ALLOY
1S	Sheet, Tubing, Wire, Bar and Rod	
2S	Sheet, Wire, Bar and Rod	2S
3S	Sheet	3S
16S	Wire, Bar and Rod	A17S
17S	Wire, Bar and Rod	17S
24S	Sheet, Extrusion, Tubing, Wire, Bar and Rod	24S
24S Alclad	Sheet	24S Alclad
26S	Extrusion, Wire, Rod, Bar and Forging	14S
28S	Wire, Rod and Bar	11S
50S	Extrusion, Tubing, Wire, Bar and Rod	63S
55S	Wire, Rod and Bar	53S
56S	Wire, Rod and Bar	56S
57S	Sheet, Tubing, Wire, Bar and Rod	52S
61S	Forgings	A51S
65S	Sheet, Extrusion, Tubing, Wire, Bar and Rod	61S
75S	Sheet, Extrusion, Wire, Bar, Rod and Forging	75S
75S Alclad	Sheet	75S Alclad
A111	Casting Sand	
117	Casting Sand	
123	Casting Sand	43
125	Casting Sand	355
135	Casting Sand	356
225	Casting Sand	195
236	Casting Sand	
250	Casting Sand	122
A320	Casting Sand	
350	Casting Sand	220
117	Casting Permanent Mould	
123	Casting Permanent Mould	
125	Casting Permanent Mould	355
135	Casting Permanent Mould	356
162	Casting Permanent Mould	A132
236	Casting Permanent Mould	
250	Casting Permanent Mould	122
160X	Casting Die	
340	Casting Die	

The specifications listed above have similar chemical compositions; the mechanical property requirements may differ. For interchangeability and substitution listings reference is to be made to EO 105-1-3C.

Table 3

PART 2

SHEET AND PLATE

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SHEET FINISH CLASSIFICATION

1 Aluminum alloy sheet is produced in the heat-treatable and non-heat-treatable alloys in the tempers listed below. The alloys 24S and 75S are also available in Canada in the Alclad form. Alclad is produced by applying a coating metal of aluminum or aluminum alloy to both side of the ingot which becomes alloyed with the base alloy during hot working and subsequent fabricating operations. The thickness of each surface layer varies with the base alloy and may form 2% to 15% of the composite thickness.

MILL STANDARD ALLOYS - SHEET

ALCAN ALLOY	TEMPER						
	F	O	1/2H	3/4H	H	W	T
1S		X	X	X	X		
2S		X-1	X-1	X	X-1		
3S		X	X	X	X		
24S	X	X					X
24S Alclad	X	X					X-1
57S		X-1	X-1	X	X-1		
65S	X	X				X	X
75S	X	X					X
75S Alclad	X	X					X-1

(a) Alloys marked "X" are mill standard alloys and tempers.
(b) Alloys marked "X-1" are alloys and tempers stocked by the RCAF.
(c) Alloys stocked by the RCAF are mill standard finish and "as - rolled" flatness.

Table 4

2 Relevant specifications for sheet are listed in Table 3 of this Engineering Order.

3 Requirements for non-clad 24S or 75S alloys for anodizing purposes are to be demanded by units on the "as required" basis.

4 57S alloy of the same thickness and temper is to be used in lieu of 3S alloy where such alloy is called up in drawings or repair schemes.

5 24S and 75S alloys in the "O" temper are to be demanded only where severe forming operations are to be carried out and where approved heat-treating facilities are available to heat-treat the alloy to its "T" temper after the forming has been completed.

DIMENSIONAL LIMITS - MILL STANDARD SHEET

6 The dimensions listed in Tables 5 and 6 are mill standard. The width dimensions stocked by the RCAF are 36" under 0.032" and over 0.125" thick and 36" or 48" for remainder. The sheet lengths stocked by the RCAF are 96" for thicknesses under 0.128" and 72" for thickness of 0.128" and over.

MILL STANDARD ALLOYS - PLATE

7 Aluminum alloy plate is produced in the heat-treatable and non-heat-treatable alloys in the tempers listed in Table 7. Alloys marked with an "X" are mill standard. See Table 3 for relevent specifications. Aluminum alloy plate is not stocked by the RCAF.

DIMENSIONAL LIMITS - 1S, 2S, 3S MILL STANDARD SHEET

ALCAN ALLOY AND TEMPER	MAXIMUM WIDTH, INCHES							MAXIMUM LENGTH, INCHES
	THICKNESS, INCHES							THICKNESS, INCHES
	.006 to .015	.016 to .022	.023 to .027	.028 to .035	.036 to .125	.126 to .175	.176 to .200	.006 - .200
1S-O	36	48	48	48	48	48	48	192
1S-1/2H	36	40	40	48	48			192
1S-3/4H	36	36	36	48	48			192
1S-H	36	48	48	48	48	48	48	192
2S-O	36	48	48	48	48	48	48	192
2S-1/2H	36	48	48	48	48			192
2S-3/4H	36	48	48	48	48			192
2S-H	36	48	48	48	48	48	48	192
3S-O	36	48	48	48	48	48	48	192
3S-1/2H	36	36	36	36	48			192
3S-3/4H	36	36	36	48	48			192
3S-H	36	48	48	48	48	48		192

Table 5

DIMENSIONAL LIMITS 57S, 65S, 24S, 75S MILL STANDARD SHEET

ALCAN ALLOY	MAXIMUM WIDTH INCHES									MAXIMUM LENGTH, INCHE
	THICKNESS INCHES									
	.006 to .015	.016 to .019	.020 to .024	.020 to .050	.020 to .063	.025 to .031	.032 to .050	.051 to .249	.064 to .249	
57S	16	32			48				60	Below .016" - 144" Above .015" - 192"
65S		36		48				60		All thicknesses - 192'
24S			36			42	48	60		Below .032" - 144" Above .031" - 192"
24S Alclad			36			42	48	60		Below .032" - 144" Above .031" - 192"
75S			36			42	48	60		Below .032" - 144" Above .031" - 192"
75S Alclad			36			42	48	60		Below .032" - 144" Above .031" - 192"
H TEMPER IN 57S ALLOY IS NOT OBTAINABLE ABOVE 0.145 INCHES										

Table 6

MILL STANDARD ALLOY - PLATE

ALLOY	TEMPER			
	F	O	W	T
Alcan 1S	X			
Alcan 2S	X			
Alcan 3S	X			
Alcan 24S	X	X		
Alcan 57S	X			
Alcan 65S	X	X	X	X
Alcan 75S	X	X		

Table 7

DIMENSIONAL LIMITS - MILL STANDARD PLATE

WIDTH	THICKNESS - IN. —— LENGTH - IN.		
INCHES	0.250 - 0.500	0.501 - 0.625	0.625 - 0.750
12	216	216	216
18	216	216	216
24	216	216	216
30	216	216	216
36	216	216	216
42	216	216	216
48	216	216	204
54	216	216	184
60	216	216	166

Table 8

SECTION 2

DESIGN MECHANICAL PROPERTIES OF SHEET AND PLATE

1 The design mechanical properties of sheet and plate are listed on Tables 9 to 14. Reference is to be made to the Foreword of this Engineering Order. The tempers for the various alloys stocked by the RCAF are listed in Table 4 and the relevant specifications in Table 3.

DESIGN MECHANICAL PROPERTIES OF BARE 24S SHEET AND PLATE (PSI)

TYPE	BARE - 24S SHEET AND PLATE (4)											COILED SHEET
SPECIFICATION	AN-A-12											
CONDITION	HEAT TREATED BY USER (3)					HEAT TREATED					HEAT TREATED AND ROLLED	HEAT TREATED
THICKNESS	<.250	.250 to .500	.5-1	1-2	2-3	<.250	.250 to .500	.5-1	1-2	2-3	<.500	<.250
ULTIMATE TENSILE STRENGTH L (1)	62,000	64,000	62,000	60,000	56,000	65,000	65,000	63,000	61,000		70,000	62,000
ULTIMATE TENSILE STRENGTH T	62,000	64,000	62,000	60,000	56,000	64,000	64,000	62,000	60,000	56,000	69,000	62,000
TENSILE YIELD STRENGTH .002" PERMANENT SET L	40,000	38,000	38,000	38,000	38,000	48,000	46,000	44,000	42,000		60,000	40,000
TENSILE YIELD STRENGTH .002" PERMANENT SET T	40,000	38,000	38,000	38,000	38,000	42,000	40,000	40,000	40,000	40,000	52,000	40,000
COMPRESSIVE YIELD STRENGTH L	40,000	38,000	38,000	38,000	38,000	40,000	38,000	38,000	38,000		49,000	40,000
COMPRESSIVE YIELD STRENGTH T	40,000	38,000	38,000	38,000	38,000	45,000	43,000	43,000	42,000		56,000	40,000
ULTIMATE STRENGTH IN PURE SHEAR	37,000	38,000	37,000	36,000	34,000	40,000	40,000	38,000	36,000		43,000	37,000
ULTIMATE BEARING STRESS (e/D = 1.5) (2)	93,000	96,000	93,000	90,000	84,000	98,000	98,000	95,000	92,000		105,000	93,000
ULTIMATE BEARING STRESS (e/D = 2.0)	118,000	122,000	118,000	114,000	106,000	124,000	124,000	120,000	116,000		133,000	118,000
YIELD BEARING STRESS (e/D = 1.5)	56,000	53,000	53,000	53,000	53,000	69,000	64,000	62,000	60,000		84,000	56,000
YIELD BEARING STRESS (e/D = 2.0)	64,000	61,000	61,000	61,000	61,000	79,000	74,000	70,000	68,000		96,000	64,000
MODULUS OF ELASTICITY IN TENSION	10,500											
MODULUS OF ELASTICITY IN COMPRESSION	10,700											
COMMERCIAL DESIGNATION	24S-T4		24S-T42			24S-T3		24S-T4			24S-T36	24S-T4

(1) L = LONGITUDINAL (width grain); T = TRANSVERSE (cross grain)
(2) D = HOLE DIAMETER, e = edge distance measured from the hole centerline in the direction of stressing. Use value e/D = 2.0 for all larger values of edge distance.
(3) HEAT TREATED by user refers to all material supplied in the annealed temper and heat treated by user and to all material re-heat treated by user regardless of temper in which the material was supplied.
(4) PLATE is material which is greater than 0.249" thick.

Table 9

DESIGN MECHANICAL PROPERTIES OF CLAD 24S SHEET AND PLATE (PSI)

TYPE		CLAD - 24S SHEET AND PLATE (4)														COILED SHEET	
SPECIFICATION		AN-A-13															
CONDITION		HEAT TREATED BY USER (3)						HEAT TREATED						HEAT TREATED AND ROLLED		HEAT TREATED	
THICKNESS		<.064	.064 .249	.250 .499	.5-1	1-2	2-3	.010 .063	.064 .249	.250 .499	.5-1	1-2	2-3	.019 .063	.064 .500	.012 .063	<.064
ULTIMATE TENSILE STRENGTH	L (1)	58,000	61,000	62,000	60,000	58,000	54,000	60,000	63,000	63,000	61,000	59,000		63,000	67,000	58,000	61,000
	T	58,000	61,000	62,000	60,000	58,000	54,000	59,000	62,000	62,000	60,000	58,000	54,000	62,000	66,000	58,000	61,000
TENSILE YIELD STRENGTH .002" PERMANENT SET	L	37,000	38,000	38,000	36,000	36,000	36,000	45,000	46,000	46,000	42,000	40,000		55,000	58,000	37,000	38,000
	T	37,000	38,000	38,000	36,000	36,000	36,000	39,000	40,000	40,000	38,000	38,000	38,000	48,000	50,000	37,000	38,000
COMPRESSIVE YIELD STRENGTH	L	37,000	38,000	38,000	36,000	36,000	36,000	37,000	38,000	38,000	36,000	36,000		46,000	48,000	37,000	38,000
	T	37,000	38,000	38,000	36,000	36,000	36,000	42,000	43,000	43,000	41,000	40,000		51,000	54,000	37,000	38,000
ULTIMATE STRENGTH IN PURE SHEAR		35,000	37,000	37,000	36,000	35,000	32,000	38,000	40,000	40,000	37,000	35,000		40,000	42,000	35,000	37,000
ULTIMATE BEARING STRESS	(e/D = 1.5)(2)	87,000	92,000	93,000	90,000	87,000	81,000	90,000	95,000	95,000	92,000	89,000		95,000	101,000	87,000	92,000
	(e/D = 2.0)	110,000	116,000	118,000	114,000	110,000	103,000	114,000	120,000	120,000	116,000	112,000		120,000	127,000	110,000	116,000
YIELD BEARING STRESS	(e/D = 1.5)	52,000	53,000	53,000	50,000	50,000	50,000	64,000	64,000	64,000	59,000	56,000		77,000	81,000	52,000	53,000
	(e/D = 2.0)	59,000	61,000	61,000	58,000	58,000	58,000	73,000	74,000	74,000	67,000	64,000		88,000	93,000	59,000	61,000
MODULUS OF ELASTICITY IN TENSION		10,500						10,500						10,500			
MODULUS OF ELASTICITY IN COMPRESSION		10,700						10,700						10,700			
COMMERCIAL DESIGNATION		24S-T4		24S-T42				24S-T3		24S-T4				24S-T36		24S-T4	

(1) L = Longitudinal (with grain); T = Transverse (cross grain)
(2) D = Hole Diameter; e = edge distance measured from the hole centerline in the direction of stressing.
Use value e/D = 2.0 for all larger values of edge distance.
(3) Heat treated by user refers to all material supplied in the annealed temper and heat treated by user, and to all material re-heat treated by user regardless of temper in which the material was supplied.
(4) Plate is material which is greater than 0.249" thick.

Table 10

DESIGN MECHANICAL PROPERTIES OF CLAD 24S SHEET (PSI)

TYPE	CLAD - 24S SHEET							
SPECIFICATION	AN-A-42							
CONDITION	HEAT TREATED AND AGED		HEAT TREATED COLD WORKED AND AGED					
THICKNESS	<.064	>.064	<.064	>.064	<.064	>.064	<.064	>.064
ULTIMATE TENSILE STRENGTH L (1)	60,000	62,000	64,000	67,000	67,000	70,000	70,000	72,000
T	60,000	62,000	62,000	65,000			66,000	70,000
TENSILE YIELD STRENGTH .002" PERMANENT SET L	47,000	49,000	57,000	59,000	63,000	66,000	66,000	69,000
T	47,000	49,000	54,000	56,000			62,000	66,000
COMPRESSIVE YIELD STRENGTH L	47,000	49,000	55,000	57,000	62,000	65,000	63,000	66,000
T	47,000	49,000	55,000	57,000			63,000	66,000
ULTIMATE STRENGTH IN PURE SHEAR	36,000	37,000	38,000	39,000	39,000	40,000	40,000	41,000
ULTIMATE BEARING STRESS (e/D = 1.5)(2)	90,000	93,000	96,000	100,000	100,000	105,000	105,000	106,000
(e/D = 2.0)	114,000	118,000	122,000	127,000	127,000	133,000	133,000	135,000
YIELD BEARING STRESS (e/D = 1.5)	66,000	69,000	78,000	83,000	88,000	92,000	91,000	95,000
(e/D = 2.0)	75,000	78,000	90,000	94,000	101,000	106,000	104,000	109,000
TANGENT MODULUS	10,500							
MODULUS OF ELASTICITY IN COMPRESSION	10,700							
COMMERCIAL DESIGNATION	24S-T6		24S-T81		24S-T84		24S-T86	

(1) L = Longitudinal (with grain); T = Transverse (cross grain)

(2) D = Hole diameter; e = edge distance measured from the hole centerline in the direction of the stressing. Use value e/D = 2.0 for all larger values of edge distance.

Table 11

DESIGN MECHANICAL PROPERTIES OF 75S SHEET AND PLATE (PSI)

TYPE	BARE 75S SHEET AND PLATE (3)					CLAD 75S SHEET AND PLATE				
SPECIFICATION	AN-A-9					AN-A-10				
CONDITION	HEAT TREATED AND AGED									
THICKNESS	.016 .039	.040 .249	.250 .500	.501 1.000	1-2	.016 .039	.040 .249	.250 .499	.500 1.000	1-2
ULTIMATE TENSILE STRENGTH L (1) T	76,000 76,000	77,000 77,000	77,000 77,000	79,000 77,000	79,000 77,000	70,000 70,000	72,000 72,000	72,000 72,000	74,000 72,000	74,000 72,000
TENSILE YIELD STRENGTH .002" PERMANENT SET L T	66,000 65,000	67,000 66,000	67,000 66,000	69,000 66,000	69,000 66,000	61,000 60,000	63,000 62,000	63,000 62,000	64,000 62,000	64,000 62,000
COMPRESSIVE YIELD STRENGTH L T	67,000 70,000	68,000 71,000	69,000 69,000	69,000 69,000	69,000 69,000	62,000 64,000	64,000 66,000	64,000 64,000	64,000 64,000	64,000 64,000
ULTIMATE STRENGTH IN PURE SHEAR	46,000	46,000	46,000	47,000	47,000	42,000	43,000	43,000	44,000	44,000
ULTIMATE BEARING STRESS (e/D = 1.5)(2) (e/D = 2.0)	114,000 144,000	116,000 146,000	116,000 146,000	119,000 150,000	119,000 150,000	105,000 133,000	108,000 137,000	108,000 137,000	111,000 141,000	111,000 141,000
YIELD BEARING STRESS (e/D = 1.5) (e/D = 2.0)	92,000 106,000	94,000 107,000	94,000 107,000	97,000 110,000	97,000 110,000	85,000 98,000	88,000 101,000	88,000 101,000	90,000 102,000	90,000 102,000
MODULUS OF ELASTICITY IN TENSION	10,300					10,300				
MODULUS OF ELASTICITY IN COMPRESSION	10,500					10,500				
COMMERCIAL DESIGNATION	75S-T6					ALCLAD 75S-T6				

(1) L = Longitudinal (with grain); T = Transverse (cross grain)
(2) D = Hole diameter; e = edge distance measured from hole centerline in the direction of the stressing.
Use value e/D = 2.0 for all larger values of edge distance.
(3) Plate is material which is greater than 0.249" thick.

Table 12

DESIGN MECHANICAL PROPERTIES OF CLAD 14S SHEET AND PLATE (PSI)

TYPE	SHEET (FLAT AND COILED) AND PLATE				FLAT SHEET AND PLATE (4)				COILED SHEET		SHEET (FLAT AND COILED) AND PLATE		
SPECIFICATION	AN-A-22												
CONDITION	HEAT TREATED BY USER (3)				HEAT TREATED						HEAT TREATED AND AGED		
THICKNESS	<.039	.040 .249	.250 .499	.500 1	<.039	.040 .249	.250 .499	.500 1	<.039	.040 .128	<.039	.040 .499	.500 1
ULTIMATE TENSILE STRENGTH L (1) T	55,000 55,000	57,000 57,000	57,000 57,000	55,000 55,000	56,000 55,000	58,000 57,000	58,000 57,000	56,000 55,000	55,000 55,000	57,000 57,000	64,000 63,000	65,000 64,000	65,000 64,000
TENSILE YIELD STRENGTH L .002" PERMANENT SET T	32,000 32,000	34,000 34,000	34,000 34,000	32,000 32,000	40,000 35,000	41,000 36,000	41,000 36,000	37,000 34,000	32,000 32,000	34,000 34,000	56,000 55,000	58,000 57,000	57,000 56,000
COMPRESSIVE YIELD STRENGTH L T	32,000 32,000	34,000 34,000	34,000 34,000	32,000 32,000	33,000 38,000	34,000 39,000	34,000 39,000	32,000 36,000	32,000 32,000	34,000 34,000	56,000 57,000	58,000 59,000	57,000 58,000
ULTIMATE STRENGTH IN PURE SHEAR	33,000	34,000	34,000	33,000	35,000	37,000	37,000	34,000	33,000	34,000	39,000	39,000	39,000
ULTIMATE BEARING STRESS (e/D = 1.5) (2) (e/D = 2.0)	83,000 105,000	86,000 108,000	86,000 108,000	83,000 105,000	84,000 106,000	87,000 110,000	87,000 110,000	84,000 106,000	83,000 105,000	86,000 108,000	96,000 122,000	98,000 124,000	98,000 124,000
YIELD BEARING STRESS (e/D = 1.5) (e/D = 2.0)	45,000 51,000	48,000 54,000	48,000 54,000	45,000 51,000	56,000 64,000	57,000 66,000	57,000 66,000	52,000 59,000	45,000 51,000	48,000 54,000	78,000 90,000	81,000 93,000	80,000 91,000
MODULUS OF ELASTICITY IN TENSION	10,400												
MODULUS OF ELASTICITY IN COMPRESSION	10,600												
COMMERCIAL DESIGNATION	R301-T4 ALCLAD 14S-T4		R301-T42 ALCLAD 14S-T42		R301-T3 ALCLAD 14S-T3		R301-T4 ALCLAD 14S-T4		R301-T4 ALCLAD 14S-T4		R301-T6 ALCLAD 14S-T6		

(1) L = Longitudinal (with grain); T = Transverse (cross grain)
(2) D = Hole diameter; e = edge distance measured from the hole centerline in the direction of stressing. Use value e/D = 2.0 for all larger values of edge distance.
(3) Heat treated by user refers to all material supplied in the annealed temper and heat treated by user, and to all material re-heat treated by user regardless of temper in which material was supplied.
(4) Plate is material which is greater than 0.249" thick.

Table 13

Part 2
Section 2

DESIGN MECHANICAL PROPERTIES OF 52S AND 61S SHEET (PSI)

TYPE	SHEET					
ALLOY	52S				61S, R361	
SPECIFICATION	QQ-A-318, 47A11				QQ-A-327	
CONDITION	1/4 HARD	1/2 HARD	3/4 HARD	FULL HARD	HEAT TREATED	HEAT TREATED AND AGED
THICKNESS	.016 - .249	.013 - .249	.013 - .162	.013 - .128	<.250	<.250
ULTIMATE TENSILE STRENGTH L (1) T	31,000 31,000	34,000 34,000	37,000 37,000	39,000 39,000	30,000 30,000	42,000 42,000
TENSILE YIELD STRENGTH L .002" PERMANENT SET T	21,000 20,000	24,000 23,000	29,000 29,000	33,000 33,000	16,000 16,000	36,000 35,000
COMPRESSIVE YIELD STRENGTH L T	20,000 21,000	23,000 24,000				35,000 36,000
ULTIMATE STRENGTH IN PURE SHEAR	19,000	20,000	22,000	23,000	20,000	27,000
ULTIMATE BEARING STRESS (e/D = 1.5) (2) (e/D = 2.0)	50,000 65,000	54,000 71,000	59,000 78,000	62,000 82,000	48,000 63,000	67,000 88,000
YIELD BEARING STRESS (e/D = 1.5) (e/D = 2.0)	29,000 34,000	34,000 38,000	41,000 46,000	46,000 53,000	22,000 26,000	49,000 56,000
MODULUS OF ELASTICITY IN TENSION	10,100				9,900	
MODULUS OF ELASTICITY IN COMPRESSION	10,200				10,100	
COMMERCIAL DESIGNATION	52S - H32	52S - H34	52S-H36	52S - H38	61S-T4; R361-T4	61S-T6; R361-T6

(1) L = Longitudinal (with grain); T = Transverse (cross grain)
(2) D = Hole diameter; e = edge distance measured from the hole centerline in the direction of stressing.
Use value e/D = 2.0 for all larger values of edge distance.

Table 14

SECTION 3

TOLERANCES

1 The tolerances listed below are applicable to all commercial mill standard sheet:-

THICKNESS TOLERANCES - SHEET

THICKNESS - IN.	TOLERANCE IN. - PLUS OR MINUS			
	MAX. WIDTH 18"	WIDTH 18" - 36"	WIDTH 36" - 54"	WIDTH 54" - 60"
0.006 - 0.010	0.001	0.0015		
0.011 - 0.017	0.0015	0.0015	0.002	
0.018 - 0.028	0.0015	0.0002	0.0025	
0.029 - 0.036	0.002	0.0025	0.0025	0.0035
0.037 - 0.045	0.002	0.0025	0.003	0.005
0.046 - 0.068	0.0025	0.003	0.004	0.006
0.069 - 0.076	0.003	0.003	0.004	0.006
0.077 - 0.096	0.0035	0.0035	0.005	0.006
0.097 - 0.108	0.004	0.004	0.005	0.007
0.109 - 0.140	0.0045	0.0045	0.005	0.007
0.141 - 0.172	0.006	0.006	0.008	0.009
0.173 - 0.203	0.007	0.007	0.010	0.011
0.204 - 0.249	0.009	0.009	0.011	0.013

Table 15

SECTION 4

BEND RADIUS FACTOR

1 The minimum permissible radius for bending varies with the nature of the forming operation, the type of forming equipment, and the design and condition of the tools. The minimum working radius for a given material or the hardest alloy and temper for a given radius can be ascertained only by actual trial under contemplated conditions of fabrication.

2 Table 16 lists the approximate bend radius factor for a 90° cold bend in the various aluminum alloys. The factor is expressed in terms of thickness of the sheet. For example, 3S-3/4H sheet 0.182" thick, has a bend radius factor of 3 which means the sheet can be cold bent 90° over a radius of approximately 3 x 0.182" or 0.546".

3 Alclad sheet can be bent over slightly smaller radii than the corresponding tempers of the bare alloy.

BEND RADIUS FACTOR FOR 90° COLD BEND - SHEET

ALLOY AND TEMPER	THICKNESS IN INCHES					
	0.258-0.183	0.182-0.129	0.128-0.065	0.064-0.033	0.032-0.016	0.015-
2S-O	0	0	0	0	0	0
2S-1/4H, H12	1	0	0	0	0	0
2S-1/2H, H14	1	1	0	0	0	0
2S-3/4H, H16	3	2	1.5	1	0	0
2S-H, H18	4	3	2	1.5	1	0
3S-O	0	0	0	0	0	0
3S-1/4H, H12	1	1	0	0	0	0
3S-1/2H, H14	1 1/2	1	1	0	0	0
3S-3/4H, H16	4	3	2	1.5	1	1
3S-H, H18	6	5	4	3	2	1
24S-O	1	1	0	0	0	0
24S-T	7	6	6	5	4	3
24S-T3	5-7	4-6	4-6	3-5	2-4	1.5-3
24S-T36	6-10	5-7	4-6	3-5	3-5	2-4
57S-O	0	0	0	0	0	0
57S-1/4H, H32	.5-1.5	0-1	0-1	0	0	0
57S-1/2H, H34	3	2	1.5	1	0	0
57S-3/4H, H16	4	3	2	1.5	1	1
57S-H, H18	6	5	4	3	2	1
65S-O	0	0	0	0	0	0
65S-W	4	3	2	1.5	1	1
65S-T	4	4	3	2	1.5	1
65S-T4	2-4	1.5-3	1-2	.5-1.5	0-1	0-1
65S-T6	2-4	2-4	1.5-3	1-2	.5-1.5	0-1
75S-O	1.5-3	1-2	.5-1.5	0-1	0	0
75S-T	6	5	4	3	3	2
75S-T6	10	7	6	5	5	4

Table 16

SECTION 5

WEIGHT OF SHEET

1 Table 17 lists the weight for 2S sheet. For other alloys, these weights should be multiplied by the following factors: 3S-1.01, 24S and 24S Alclad-1.02, 57S-.98, 65S-1.000, 75S and 75S Alclad-1.03.

WEIGHT OF SHEET

Thickness In.	Lb. per Sq. Ft.	Thickness In.	Lb. per Sq. Ft.	Thickness In.	Lb. per Sq. Ft.
0.020	0.282	0.057	0.804	0.125	1.76
0.025	0.353	0.064	0.093	0.128	1.81
0.028	0.395	0.072	1.02	0.144	2.03
0.032	0.452	0.078	1.10	0.172	2.43
0.036	0.508	0.081	1.14	0.188	2.65
0.040	0.564	0.091	1.28	0.203	2.86
0.047	0.663	0.102	1.44	0.234	3.30
0.051	0.720	0.109	1.54	0.250	3.53

Table 17

PART 3

EXTRUSIONS

SECTION 1

MILL STANDARD ALLOYS - EXTRUSIONS

1 Extrusions are produced by subjecting hot cast billets to sufficient hydraulic ram pressure to force the metal to flow plastically through a die orifice, forming a product with a cross section that conforms to the shape of the orifice. Closely controlled speed, pressures and temperatures are vital to insure uniform quality of extruded products. Uniform metal flow is obtained through a simple round or symmetrical orifice. However, where both heavy and thin sections may be present, friction on the die walls tends to produce non-uniform flow. Where a light flange adjoins a heavy flange the metal tends to flow more rapidly into the heavy flange portion.

2 This is a critical problem in designing extrusions and is controlled by suitable selection of entrance radii and length of bearing surfaces in the die.

3 The extrusion process makes possible the production of shapes which have been designed to facilitate the erection of the structure in which they are used and in which the metal is disposed more efficiently with the relation to the stresses which it must withstand than is possible in standard rolled structural shapes. The choice of the alloy depends upon the use to which the extrusion is employed. For structural applications, 75S alloy affords the highest strength. When lower stresses are to be encountered 26S alloy shapes can be employed if the minimum section thickness is 1/8" or larger. For thinner sections as well as some heavy sections 24S alloy is used. 24S and 75S alloy are extensively used in aircraft construction.

4 Extrusions for aircraft structural members are produced to number 1 finish which is not controlled for uniformity of appearance.

5 Aircraft structural extrusions procured for repair requirements are referenced under the airframe section of the specific aircraft for which they are stocked. Requirements for extrusion for aircraft repair where such extrusion is not catalogued or where nil stocks exist are to be referred to Air Materiel Command Headquarters.

MILL STANDARD ALLOYS - EXTRUSIONS

ALCAN ALLOY	TEMPER					
	F	O	Q	A-33	W	T
24S	X	X				X
26S	X	X			X	X
50S	X	X	X	X	X	X
65S	X	X			X	X
75S	X	X				X

Alloys marked "X" are Mill Standard Alloys.

Table 18

Part 3
Section 2

SECTION 2

DESIGN MECHANICAL PROPERTIES - EXTRUSIONS

1 The design mechanical properties for extrusions are included in Tables 43 and 44 of this EO. Reference is also to be made to the Foreword of this EO for information regarding the design mechanical properties.

PART 4

TUBING

SECTION 1

MILL STANDARD ALLOY - TUBING

1 Extruded tubing and pipe is produced by forcing heated blooms through a pre-determined die opening equipped with a mandrel interiorly concentric with the die and of such a diameter as to produce the desired wall thickness.

2 Drawn tubing and pipe is made from extruded tubing on a draw bench. The extruded tube is slipped over the draw bulb which, when in drawing position, is exteriorly concentric with the draw die. The leading end of the extruded tube is pointed and inserted through the draw die and is gripped by jaws which subsequently draw the tubing through the die. The interior bulb determines the degree of reduction and the wall thickness.

3 Tubing is produced in the following alloys and tempers listed in Table 19. Those alloys marked "X" are mill standard and those marked "X -1" are the alloys and tempers stocked by the RCAF.

MILL STANDARD ALLOY - TUBING

Alcan Alloy	Wall Thickness Inches	Available Tempers						
		O	F	1/2H	3/4H	H	W	T
1S	Up to 0.150	X	X	X		X		
	0.151 - 0.2000	X	X	X				
	0.201 and over		X					
57S	Up to 0.200	X-1	X	X	X	X		
	0.201 to 0.250	X	X	X	X			
	0.251 and over		X					
24S	All thicknesses	X	X					X-1
50S	All thicknesses	X	X				X	X
65S	All thicknesses	X	X				X	X-1

Table 19

MILL STANDARD ALLOYS - STANDARD AND EXTRA HEAVY PIPE

Alcan Alloys	Wall Thickness Inches	Available Tempers						
		O	F	1/2H	3/4H	H	W	T
1S	Up to 0.150	X	X	X		X		
	0.151 to 0.200	X	X	X				
	0.201 and over		X					
50S	All thicknesses	X	X				X	X
57S	Up to 0.200	X	X	X	X	X		
	0.201 to 0.250	X	X	X	X			
	0.251 and over		X					
65S	All thicknesses	X	X				X	X

Table 20

SECTION 2

MILL STANDARD TOLERANCES - TUBING AND PIPE

1 Tubing is stocked by the RCAF in ten to twelve foot straight lengths. The mill standard sizes of tubing and extra heavy pipe are listed in Tables 21 to 24.

OUTSIDE DIAMETER AND WALL THICKNESS RANGE

OUTSIDE DIAMETER INCHES	WALL THICKNESS INCHES	
	Alcan 1S Alcan 50S Alcan 65S	Alcan 57S Alcan 24S
.187-.249	.015-.040	.015-.040
.250-.311	.018-.080	.018-.080
.312-.374	.020-.100	.020-.080
.375-.499	.020-.100	.020-.100
.500-.624	.020-.150	.020-.150
.625-.749	.020-.150	.025-.150
.750-.999	.023-.200	.025-.200
1.000-1.499	.030-.300	.030-.300
1.500-1.999	.035-.300	.040-.300
2.000-2.499	.047-.300	.047-.300
2.500-2.999	.055-.300	.065-.300
3.000-3.499	.080-.300	.080-.300
3.500-3.999	.080-.300	.100-.300
4.000-4.500	.125-.200	

Table 21

WALL THICKNESS TOLERANCES - ROUND TUBING

Specified Wall Thickness Inches	Deviation from Specified Wall Thickness (Plus or Minus) on individual measurement of wall thickness		
	Heat Treatable Alloys %	Non Heat-Treatable Alloys - Inches	On Mean Wall Thickness Inches
0.010-0.035	10%	0.002	0.002
0.036-0.049	10%	0.003	0.003
0.050-0.120	10%	0.004	0.004
0.121-0.203	10%	0.005	0.005
0.204-0.300	10%	0.008	0.008
0.301-0.375	10%	0.012	0.012

Table 22

DIAMETER TOLERANCES - ROUND TUBING

Specified Diameter Inches	Deviation from Specified Diameter (Plus or Minus) inches on individual measurement of diameter		
	Heat Treatable Alloys	Non Heat-Treatable Alloys	On Mean Diameter
Up to 1/2	0.006	0.003	0.003
Over 1/2 - 1	0.008	0.004	0.004
Over 1 - 2	0.010	0.005	0.005
Over 2 - 3	0.012	0.006	0.006
Over 3 - 4 1/2	0.016	0.008	0.008

Table 23

DIAMETER TOLERANCES ON STANDARD AND EXTRA HEAVY PIPE

Standard and Extra Heavy Pipe Sizes Inches	Deviation from nominal Diameter Inches			
	Outside Diameter		Inside Diameter	
	Plus	Minus	Plus	Minus
1/8 - 1/2	0.005	0	0	0.003
Over 1/2 - 2	0.008	0	0	0.005
Over 2 - 4	0.010	0	0	0.007

Table 24

SECTION 3

DESIGN MECHANICAL PROPERTIES - TUBING

1 Table 25 lists the design mechanical properties of 24S and 61S tubing. Reference is to be made to the Foreword to this EO for information regarding the design mechanical properties.

DESIGN MECHANICAL PROPERTIES 24S AND 61S TUBING (PSI)

ALLOY SPECIFICATION	24S AN-T-80		61S WW-T-789
CONDITION	Heat Treated	Heat Treated by User	Heat Treated and Aged
THICKNESS	.018 - .500	.018 - .500	.025 - .500
ULTIMATE TENSILE STRENGTH L T	64,000	62,000	42,000
TENSILE YIELD STRENGTH L .002" PERMANENT SET T	42,000	40,000	35,000
COMPRESSIVE YIELD STRENGTH L T	42,000	40,000	35,000
ULTIMATE STRENGTH IN PURE SHEAR	39,000	39,000	27,000
ULTIMATE BEARING STRENGTH (e/D = 1.5) (e/D = 2.0)	96,000 122,000	96,000 122,000	67,000 88,000
YIELD BEARING STRENGTH (e/D = 1.5) (e/D = 2.0)	59,000 67,000	56,000 64,000	49,000 56,000
MODULUS OF ELASTICITY	10,500		9,900
MODULUS OF COMPRESSION	10,700		10,100
MODULUS OF RIGIDITY	4,000		3,800
COMMERCIAL DESIGNATION	24S-T3	24S-T4	61S-T6

L = Longitudinal (with grain); T = Transverse (cross grain)

D = Hole Diameter; e = edge distance measured from the hole centerline in the direction of stressing. Use value e/D = 2.0 for larger values of edge distance.

Table 25

SECTION 4

INTERNAL WORKING PRESSURES - TUBING

1 The internal working pressure for aluminum alloy tubing may be computed from Tables 26 and 27. The factor of safety used in compiling the table is approximately 4 at normal temperature. Table 26 shows the internal working pressure for various diameters and wall thicknesses of 1S-O tubing. By multiplying the given value for the diameter and wall thickness to be used from Table 26 by the conversion factor for the alloy being used from Table 27 the internal working pressure of the tubing may be determined.

EXAMPLE

It is desired to determine the internal working pressure of a 1" OD x .035" wall tubing of 57S 1/2H aluminum alloy. From Table 26 the internal working pressure of 1" OD x .035" wall tubing of 1S-O alloy is 217 psi. The conversion factor for 57S 1/2H is 3.2. The internal working pressure then of a 1" OD x .035" wall tubing of 57S 1/2H alloy is 3.2 x 217 psi or 694.4 psi.

CAUTION

Tables 26 and 27 are not to be used to compute aircraft plumbing requirements. Surge pressures must be considered in any pressure system.

Part 4
Section 4

TYPICAL INTERNAL WORKING PRESSURES FOR 1S-O TUBING (PSI)

WALL THICKNESS INCHES	OUTSIDE DIAMETER - INCHES																					
	1/4	3/8	1/2	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	3 1/4	3 1/2	3 3/4	4
0.022	574																						
0.028	745	481	355	281	232	198	173																
0.035	951	611	449	355	293	250	217	193	173	157	143	132	122	114	107								
0.049	1381	882	644	507	417	355	308	273	245	221	203	186	173	161	151								
0.065			877	687	564	479	415	367	328	297	271	250	231	215	201	178	160						
0.083					735	622	539	475	425	384	350	322	298	277	259	230	206	187	171	157			
0.109																305	273	247	226	208			
0.134																378	339	306	280	257	239	222	208
0.165																			348	320	296	276	258

Table 26

CONVERSION FACTORS OF TYPICAL INTERNAL WORKING PRESSURES

	Alloy and Temper	Conversion Factor	Alloy and Temper	Conversion Factor	Alloy and Temper	Conversion Factor
	1S-1/2H	1.4	50S-O	1.3	65S-O	1.5
	1S-H	1.8	50S-W	2.0	65S-W	3.0
	24S-O	2.5	50S-T	2.9	65S-T	3.8
	24S-T	5.8	57S-O	2.5		
			57S-1/2H	3.2		
			57S-H	3.4		

Table 27

SECTION 5

FORMING CHARACTERISTICS OF TUBING

1 Forming aluminum alloy tubing and pipe can be accomplished by conventional methods used for other alloys. It is necessary, of course, to become thoroughly informed regarding the mechanical properties of the tubing and pipe alloys for successful bending.

2 The stretch property (elongation) of aluminum tubing is the major factor for consideration in forming. The tensile properties are also very important. An aluminum alloy having good stretch properties and reasonably high tensile strength is desirable for forming. An alloy with high stretch properties and low tensile strength, while the easiest to bend, will require careful tooling to avoid fracturing, flattening and collapse of the inner wall. Such collapse will occur if the ability of the alloy to absorb compressive stresses is exceeded.

3 The stretch and shrink properties of aluminum alloys, like other alloys, are proportionately less for thin cross-sections than for heavier ones. This means that the minimum possible bending radius will increase in proportion to a decrease in wall thickness. Thin-wall tubing is especially susceptible to fracturing or buckling unless extreme care is used to confine the shape properly in the forming tools. Naturally, the tools must be of the best design, and the actual bending must be done with generous and effective lubrication and at a steady and reasonably moderate speed.

4 It is not recommended to bend aluminum tubing hot. However, if this is necessary, the temperature of the alloy should not exceed 190°C (375°F).

5 More detailed information on beading, bending and flaring is found in EO 05-1-3 and Part 10 of this Engineering Order.

WEIGHT OF TUBING

6 Table 28 lists the weight per lineal foot of 1S tubing. For computing the weights of other alloys these weights are to be multiplied by the following factors: 24S-1.02, 57S-0.98, 50S-0.99, 65S-1.00, 75S-1.03.

WEIGHT OF TUBING

WALL THICKNESS INCHES	OUTSIDE DIAMETER - INCHES																	
	1/4	3/8	1/2	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
.284								.87	1.00	1.13	1.26	1.39	1.52	1.65	1.78	2.04	2.30	2.56
.259								.82	.94	1.06	1.17	1.29	1.41	1.53	1.64	1.88	2.11	2.35
.238								.77	.88	.99	1.10	1.21	1.31	1.42	1.53	1.74	1.96	2.17
.220								.73	.83	.93	1.03	1.13	1.23	1.33	1.43	1.63	1.83	2.03
.203						.500	.59	.68	.77	.86	.96	1.05	1.14	1.23	1.33	1.51	1.70	1.88
.180						.460	.54	.62	.71	.79	.87	.95	1.04	1.12	1.20	1.37	1.53	1.69
.165				.280	.350	.430	.50	.58	.65	.73	.80	.88	.95	1.03	1.10	1.25	1.40	1.55
.148				.260	.320	.390	.46	.53	.59	.66	.73	.80	.86	.93	1.00	1.13	1.27	1.41
.134				.240	.300	.360	.42	.48	.54	.60	.67	.73	.79	.85	.91	1.04	1.16	1.28
.120				.230	.270	.320	.38	.43	.49	.54	.60	.65	.71	.76	.82	.93	1.04	1.15
.109			.152	.190	.240	.290	.34	.39	.44	.49	.54	.59	.64	.69	.74	.84	.94	1.04
.095			.141	.184	.227	.270	.31	.35	.40	.44	.49	.53	.57	.61	.66	.74	.83	.91
.083	.051	.089	.124	.162	.201	.239	.28	.31	.35	.39	.43	.47	.51	.55	.59	.66	.74	.81
.072	.047	.080	.113	.146	.179	.212	.24	.27	.31	.34	.38	.41	.44	.47	.51	.57	.64	.70
.065	.044	.074	.104	.133	.163	.193	.22	.25	.27	.30	.33	.36	.39	.42	.45	.51	.57	
.058	.041	.067	.094	.120	.147	.173	.20	.23	.26	.28	.31	.33	.36	.39	.41	.47	.52	
.049	.036	.058	.080	.103	.125	.147	.17	.19	.21	.24	.26	.28	.30	.33	.35			
.042	.032	.051	.070	.089	.108	.127	.15	.16	.18	.20	.22	.23	.25	.27	.29			
.035	.027	.043	.059	.075	.091	.107	.12	.14	.16	.17	.18	.19	.21	.23	.25			
.032	.025	.040	.055	.069	.084	.099	.11											
.028	.023	.036	.049	.061	.074	.087	.10											
.025	.020	.031	.043	.054														
.022	.018																	

Table 28

PART 5

WIRE, BAR AND ROD

SECTION 1

MILL STANDARD ALLOYS - WIRE, BAR AND ROD

1 Aluminum alloys may be fabricated by rolling, drawing (cold finish) or extruding, or a combination of two or more of these processes to produce:-

(a) Rolled rod.

(b) Drawn wire, drawn rod, drawn bar.

(c) Extruded rod, extruded bar.

2 Wire is defined as any solid section such as round, square, rectangle, hexagon or octogon (exclusive of flattened wire) whose greatest dimension is less than 1/4". The American definition refers to sizes less than 3/8".

3 Rod is defined as any solid round section whose diameter is 1/4" or greater. The American definition refers to sizes larger than 3/8" diameter.

4 Bar is defined as any solid section other than round whose greatest dimension is 1/4" or over. The American definition refers to sizes larger than 3/8".

5 Tables 29 to 44 list the mill standard alloys, dimensional limits and tolerances of Canadian produced alloys.

MILL STANDARD ALLOYS - DRAWN WIRE

ALCAN ALLOY	F	O	1/2H	H	W	T	RW
	NON-HEAT - TREATABLE ALLOYS						
2S	X	X	X	X			
56S	X	X	X	X			
57S	X	X	X	X			
	HEAT - TREATABLE ALLOYS						
17S	X	X				X	
28S							X
50S	X	X			X	X	
65S	X	X			X	X	

Alloys and tempers marked "X" are mill standard.

Table 29

Part 5
Section 1

MILL STANDARD ALLOYS - BAR

STANDARD ALLOYS									
NON-HEAT TREATABLE			HEAT - TREATABLE						
2S	56S	57S	17S	24S	26S	28S	50S	65S	75S
DRAWN BAR									
O, F		O, F	O, F, T			RW	O, F, W, T	O, F, W, T	O, F, T
EXTRUDED BAR									
O, F		O, F	O, F, T	O, F, T	O, F, T		O, F, W (1) T(1) Q(1) A-33 (1)	O, F, W, T	O, F, T
FLATTENED BAR									
O, F 1/2H H	O, F 1/2H H	O, F 1/2H H							

(1) Alcan 50S extruded bar is available in Q and A-33 tempers where the thickness is less than 0.500".

Table 30

MILL STANDARD ALLOYS - ROD

ROD DIAMETER INCHES	MILL STANDARD TEMPERS									
	NON-HEAT TREATABLE ALLOYS			HEAT - TREATABLE ALLOYS						
	2S	56S	57S	17S	24S	26S	28S	50S	65S	75S
DRAWN ROD										
All Sizes	O, F		O, F	O, F, T			RW	O, F, W, T	O, F, W, T	O, F, T
EXTRUDED ROD										
All Sizes	O, F		O, F	O, F, T	O, F, T	O, F, T		O, F, W, T Q, A-33	O, F, W, T	O, F, T
ROLLED ROD										
3/8	O, F		O, F				F	O, F, W, T	O, F	
9/16	O, F	O, F	O, F	O, F			F	O, F, W, T	O, F	
11/16	O, F	O, F	O, F	O, F			F	O, F, W, T	O, F	
7/8	O, F	O, F	O, F	O, F			F	O, F, W, T	O, F	

Alcan 50S extruded rod is available in Q and A-33 tempers where diameter is under 0.500". W and T tempers in extruded rod over 0.500" diameter.

Table 31

DIMENSIONAL LIMITS OF DRAWN WIRE

SHAPE OF WIRE	DIMENSIONS INCHES				REMARKS
	DIAMETER		DISTANCE ACROSS FLATS		
	MIN.	MAX.	MIN.	MAX.	
ROUND	0.018	0.249			
SQUARE			0.018	0.249	SUPPLIED WITH SQUARE OR ROUND CORNERS
RECTANGULAR			0.030	0.249	SUPPLIED WITH SQUARE OR ROUND CORNERS
HEXAGON			0.156	0.249	

Table 32

Part 5
Section 1

DIMENSIONAL LIMITS OF ROD

PRODUCT	DIAMETER INCHES MIN.	DIAMETER INCHES MAX.
DRAWN ROD (STRAIGHT LENGTH)	0.250	2.500 (1)
DRAWN ROD (COILS)	0.250	0.750
ROLLED ROD	0.375	0.875
EXTRUDED ROD	0.532	13.0 (2)

(1) Diameters over 1.500" in 57S and in heat-treatable alloys other than 28S are not mill standard.

(2) Diameters over 5.750" in "T" tempers are not mill standard.

Table 33

DIMENSIONAL LIMITS OF DRAWN BAR

SHAPE OF BAR	DIMENSIONS - INCHES							
	ACROSS FLATS		THICKNESS		WIDTH		CROSS SECTIONAL AREA	
	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
SQUARE	0.250	0.625						0.390
	0.626	1.500					0.391	
RECTANGULAR			0.044	0.187	(2)	1.000(2)		0.390
			0.188	1.375	(1)	2.500	0.391 (1)	
HEXAGONAL	0.250	0.688						
	0.689	1.500						

(1) For thickness range 0.188 - 0.390 minimum width 1.001". For thickness range over 0.390 minimum cross sectional area 0.391".

(2) See Table 35.

(3) Drawn square or rectangular bar can be produced with sharp corners or 0.015" radius corners.

Table 34

DIMENSIONAL LIMITS OF EXTRUDED BAR

SHAPE OF BAR	DIMENSIONS - INCHES							
	ACROSS FLATS		THICKNESS		WIDTH		CROSS SECTIONAL AREA	
	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
SQUARE (2)	0.626	5.000						
RECTANGULAR(2)				5.000	(1)	12.000	(1)	
HEXAGONAL	0.562	5.000						

(1) For thickness range 0.188 - 0.390 minimum width 1.001".
For thickness range over 0.390 minimum cross sectional area 0.391.

(2) See Table 36.

(3) Maximum permissible radius for sharp corners 0.015".

Table 35

WIDTH LIMIT OF DRAWN RECTANGULAR BAR

THICKNESS INCHES	WIDTH INCHES MIN.	WIDTH INCHES MAX.	THICKNESS INCHES	WIDTH INCHES MIN.	WIDTH INCHES MAX.
0.044 - 0.048	0.250	0.281	0.391 - 0.500	0.391	2.500
0.049 - 0.057	0.250	0.500	0.501 - 0.625	0.501	2.250
0.058 - 0.061	0.250	0.750	0.626 - 0.750	0.626	2.250
0.062 - 0.092	0.250	1.000	0.751 - 1.000	0.752	2.000
0.093 - 0.124	0.250	1.000	1.001 - 1.125	1.002	1.875
0.125 - 0.155	0.250	1.000	1.126 - 1.250	1.127	1.750
0.156 - 0.187	0.250	1.000	1.251 - 1.375	1.252	1.500
0.188 - 0.390	0.250	2.500			

Table 36

THICKNESS LIMITS OF EXTRUDED SQUARE AND RECTANGULAR BAR

WIDTH INCHES	THICKNESS - INCHES				
	ALCAN ALLOY				
	2S, 50S MIN.	65S MIN.	26S, 17S MIN.	24S, 75S MIN.	ALL ALLOYS MAX.
0.626	.625	.625	.625	.625	.626
0.750	.520	.520	.520	.520	.750
0.875	.446	.446	.446	.446	.875
0.937	.415	.415	.415	.415	.937
1.000	.391	.391	.391	.391	1.000
OVER 1 to (NOT INCL.) 2	.125	.125	.125	.125	2.000
2.0 to (NOT INCL.) 3	.125	.125	.125	.125	3.000
3.0 to (NOT INCL.) 4	.125	.125	.125	.125	4.000
4.0 to (NOT INCL.) 5	.125	.125	.125	.187	5.000
5.0 to (NOT INCL.) 6	.125	.125	.125	.187	5.000
6.0 to (NOT INCL.) 7	.125	.125	.187	.187	4.125
7.0 to (NOT INCL.) 8	.125	.125	.187	.250	3.500
8.0 to (NOT INCL.) 9	.187	.187	.250	.250	3.125
9.0 to (NOT INCL.) 10	.187	.187	.250	.375	2.750
10.0 to (NOT INCL.) 11	.187	.187	.250	.375	2.500
11.0 to 12	.187	.187	.250	.437	2.250

Table 37

DIMENSIONAL TOLERANCES OF WIRE, BAR AND ROD

MATERIAL	DIAMETER OR DISTANCE ACROSS FLATS - INCHES	TOLERANCES IN. PLUS OR MINUS	
		ROUND	SQUARE, HEX, RECT.
ROLLED ROD	3/8	1/32	
	9/16	1/32	
	11/16	3/64	
	7/8	1/16	
DRAWN WIRE ROD AND BAR	UP TO 0.035	0.0005	
	0.036 to 0.064	0.0010	0.0015
	0.065 to 0.249	0.0015	0.0020
	0.250 to 0.500	0.0015	0.0020
	0.501 to 1.000	0.0020	0.0025
	1.001 to 1.500	0.0025	0.0030
	1.501 to 2.000	0.0040	0.0050
	2.001 to 3.000	0.0040	0.0050
EXTRUDED ROD AND BAR	UP TO 0.124	0.006	0.006
	0.125 to 0.249	0.007	0.007
	0.250 to 0.500	0.008	0.008
	0.501 to 0.750	0.009	0.009
	0.751 to 1.000	0.010	0.010
	1.001 to 1.500	0.012	0.012
	1.501 to 2.000	0.016	0.016
	2.001 to 4.000	0.024	0.024
	4.001 to 6.000	0.034	0.034
	6.001 to 8.000	0.044	0.044
	8.001 to 10.000	0.054	0.054
	10.001 to 12.000	0.064	0.064

Table 38

BEND RADIUS FACTOR FOR 180° COLD BEND OF ALUMINUM ALLOY WIRE, BAR AND ROD

ALLOY AND TEMPER	DIAMETER OR LEAST DISTANCE BETWEEN PARALLEL FACES - INCHES		
	0.018 - 0.124	0.125 - 0.374	0.375 - 1.000
2S-O	0	1	1
2S-1/2H	0	2	
2S-H	0		
17S-O	1	1	
17S-T	2	4	4
24S-O	1		
24S-T	3	6	6
55S-O	1	1	1
55S-W	3	3	3
55S-T	3	4	4
56S-O	0	1	1
56S-1/2H	2	2	
56S-H	2		
57S-O	0	1	1
57S-1/2H	0	2	
57S-H	2		
65S-O	1	2	2
65S-W	3	3	3
65S-T	4	4	4

THE BEND RADIUS REQUIRED IS THE PRODUCT OF THE THICKNESS OF THE ALLOY BEING USED AND THE FACTOR SHOWN.

Table 39

WEIGHT OF ALUMINUM WIRE

DIAMETER		AREA OF CROSS SECTION SQ. IN.	WEIGHT PER LINEAL FOOT POUNDS	FEET PER POUND OF WEIGHT
FRACTIONS IN.	DECIMALS IN.			
	0.0179	0.00025	0.00029	3383
	0.0201	0.00032	0.00038	2660
	0.0226	0.00042	0.00049	2053
	0.0253	0.00050	0.00059	1704
	0.0285	0.00064	0.00075	1333
1/32	0.0313	0.00077	0.00090	1111
	0.0320	0.00080	0.00094	1064
	0.0359	0.0010	0.0012	851
	0.0403	0.0013	0.0015	667
	0.0453	0.0016	0.0019	532
3/64	0.0469	0.0017	0.0020	501
	0.0508	0.0020	0.0023	426
	0.0571	0.0026	0.0031	327
1/16	0.0625	0.0031	0.0036	275
	0.0641	0.0032	0.0038	266
	0.0720	0.0041	0.0048	208
5/64	0.0781	0.0048	0.0056	177
	0.0808	0.0051	0.0064	167
	0.0907	0.0065	0.0076	132
3/32	0.0938	0.0069	0.0081	122
	0.1019	0.0082	0.0096	104
7/64	0.1094	0.0094	0.0110	91
	0.1144	0.0103	0.0121	83
1/8	0.1250	0.0123	0.0145	69
	0.1285	0.0129	0.0152	66
9/64	0.1406	0.0155	0.0182	55
	0.1443	0.0163	0.0193	52
5/32	0.1562	0.0192	0.0225	44
	0.1620	0.0206	0.0242	41
11/64	0.1719	0.0232	0.0272	37
	0.1819	0.0260	0.0305	33
3/16	0.1875	0.0276	0.0324	31
13/64	0.2031	0.0324	0.0381	26
	0.2043	0.0328	0.0385	26
7/32	0.2188	0.0376	0.0442	23
	0.2294	0.0413	0.0485	21
15/64	0.2344	0.0431	0.0506	20

THE WEIGHTS IN THE ABOVE TABLE ARE FOR 2S WIRE.
FOR OTHER ALLOYS THESE WEIGHTS SHOULD BE MULTIPLIED/DIVIDED BY THE FOLLOWING FACTORS: 1S - 1.00, 16S - 1.01, 17S - 1.03, 55S - 0.99, 56S - 0.97, 57S - 0.98.

Table 40

WEIGHT OF ALUMINUM BAR

THICKNESS INCHES		AREA OF CROSS SECTION SQUARE INCH			WEIGHT PER LINEAL FOOT POUNDS		
FRACTION	DECIMAL	ROUND	SQUARE	HEXAGON	ROUND	SQUARE	HEXAGON
1/4	.250	.0491	.0625	.0542	.0577	.0729	.0631
9/32	.281	.0620	.0789	.0684	.0728	.0927	.0803
5/16	.3125	.0767	.097	.0840	.0901	.114	.099
11/32	.344	.0928	.118	.102	.109	.139	.120
3/8	.375	.110	.141	.122	.130	.165	.143
13/32	.406	.130	.165	.143	.152	.194	.168
7/16	.438	.150	.192	.166	.177	.225	.195
15/32	.469	.173	.220	.191	.203	.258	.224
1/2	.500	.196	.250	.216	.231	.294	.254
17/32	.531	.222	.282	.244	.260	.332	.288
9/16	.563	.249	.316	.274	.292	.372	.322
19/32	.594	.277	.353	.306	.325	.414	.358
5/8	.625	.307	.391	.339	.360	.459	.398
21/32	.656	.338	.431	.374	.397	.506	.439
11/16	.688	.371	.473	.410	.436	.555	.482
23/32	.719	.406	.517	.448	.477	.607	.527
3/4	.750	.442	.563	.487	.519	.661	.573
25/32	.781	.479	.612	.530	.563	.707	.621
13/16	.831	.519	.660	.572	.609	.775	.672
27/32	.844	.559	.712	.617	.657	.836	.725
7/8	.875	.601	.766	.664	.706	.899	.779
29/32	.906	.645	.821	.712	.758	.965	.834
15/16	.938	.690	.879	.761	.811	1.032	.894
31/32	.969	.737	.939	.814	.866	1.103	.953
1	1.000	.785	1.000	.866	.923	1.175	1.018
1 1/8	1.125	.994	1.266	1.096	1.168	1.487	1.288
1 1/4	1.250	1.227	1.562	1.353	1.442	1.835	1.589
1 3/8	1.375	1.485	1.891	1.638	1.745	2.222	1.924
1 1/2	1.500	1.767	2.250	1.948	2.08	2.64	2.29
1 5/8	1.625	2.074	2.641	2.287	2.44	3.10	2.69
1 3/4	1.750	2.405	3.062	2.652	2.83	3.60	3.12
1 7/8	1.875	2.761	3.516	3.045	3.24	4.13	3.58
2	2.000	3.142	4.000	3.464	3.69	4.70	4.07
2 1/8	2.125	3.547	4.516	3.911	4.17	5.30	4.59
2 1/4	2.250	3.976	5.062	4.384	4.67	5.95	5.15
2 3/8	2.375	4.430	5.641	4.885	5.20	6.63	5.74
2 1/2	2.500	4.909	6.250	5.412	5.77	7.34	6.36
2 5/8	2.625	5.412	6.891	5.967	6.36	8.10	7.02
2 3/4	2.750	5.940	7.562	6.549	6.97	8.88	7.69
2 7/8	2.875	6.492	8.266	7.158	7.63	9.71	8.41
3	3.000	7.069	9.000	7.794	8.30	10.57	9.15
3 1/4	3.250	8.296	10.564	9.148	9.76	12.40	10.76
3 1/2	3.500	9.620	12.250	10.608	11.32	14.40	12.48
3 3/4	3.750	11.044	14.064	12.180	12.96	16.52	14.32
4	4.000	12.566	16.000	13.856	14.76	18.80	16.28
4 1/4	4.250	14.186	18.064	15.644	16.68	21.20	18.36
4 1/2	4.500	15.904	20.250	17.536	18.68	23.80	20.60
4 3/4	4.750	17.720	22.564	19.540	20.80	26.52	22.96
5	5.000	19.636	25.000	21.650	23.08	29.40	25.44

THE WEIGHTS ABOVE ARE FOR 2S ALLOY. FOR OTHER ALLOYS THESE WEIGHTS ARE TO BE MULTIPLIED BY THE FOLLOWING FACTORS: 17S - 1.03, 24S - 1.02, 26S - 1.03, 28S - 1.04, 50S - 0.99, 65S - 1.00, 75S - 1.03.

Table 41

DESIGN MECHANICAL PROPERTIES OF ROLLED BAR, ROD AND SHAPES (PSI)

ALLOY	14S	17S	24S	53S	61S	75S
SPECIFICATION		QQ-A-351	QQ-A-354	QQ-A-331	QQ-A-325	
CONDITION	HEAT TREATED AND AGED	HEAT TREATED		HEAT TREATED AND AGED		
THICKNESS	>3/16 <36 sq. ins.	<3.000	<3.000	<3.000	<3.000	<3.000
ULTIMATE TENSILE STRENGTH L (1) T (1)	65,000 62,000	55,000	62,000 50,000	32,000	42,000	77,000 70,000
TENSILE YIELD STRENGTH AT PERMANENT SET OF 0.002" L (1) T (1)	55,000 53,000	32,000	40,000 37,000	25,000	35,000	66,000 60,000
COMPRESSIVE YIELD STRENGTH L (1) T (1)	55,000 53,000	32,000	40,000 37,000	25,000	35,000	66,000 60,000
ULTIMATE STRENGTH IN PURE SHEAR	38,000	33,000	37,000	19,000	25,000	46,000
ULTIMATE BEARING STRESS (e/D = 1.5) (2) (e/D = 2.0) (2)	98,000 124,000	83,000 105,000	93,000 118,000	51,000 67,000		100,000 123,000
YIELD BEARING STRESS (e/D = 1.5) (2) (e/D = 2.0) (2)	77,000 88,000	45,000 51,000	56,000 64,000	35,000 40,000		86,000 92,000
MODULUS OF ELASTICITY IN TENSION	10,500	10,400	10,500	9,900	9,900	10,300
MODULUS OF ELASTICITY IN COMPRESSION	10,700	10,600	10,700	10,100	10,100	10,500
MODULUS OF RIGIDITY	4,000	3,950	4,000	3,800	3,800	3,900

(1) L = Longitudinal (with grain); T = Transverse (cross grain)
(2) D = Hole diameter; e = edge distance measured from the hole centerline in direction of stressing.
Use value of e/D = 2.0 for larger values of edge distance. (Refer to the Foreword page i of this EO).

Table 42

DESIGN MECHANICAL PROPERTIES OF 14S AND 75S EXTRUDED BAR, ROD AND SHAPES (PSI)

ALLOY	14S					75S				
SPECIFICATION	AN-A-8					AN-A-11				
CONDITION	HEAT TREATED AND AGED				HEAT TREAT AND AGED BY USER (3)	HEAT TREATED AND AGED				
THICKNESS AND CROSS SECTIONAL AREA	.125 to .499	.500 to .749	>.750 <25 sq.ins.	>.750 >25 <32 sq.ins.	>.125 <32 sq.ins.	>.249	.250 to 2.999	3 to 4 <20 sq.ins.	3 to 5 >20 <32 sq.ins.	4.5 to 5 < 32 sq. ins.
ULTIMATE TENSILE STRENGTH L (1) / T (1)	60,000 54,000	64,000 58,000	68,000 61,000	68,000	60,000 54,000	78,000 66,000	80,000 66,000	80,000 64,000	78,000 62,000	78,000
TENSILE YIELD STRENGTH AT PERMANENT SET OF .002" L (1) / T (1)	53,000 48,000	58,000 52,000	60,000 54,000	58,000	53,000 48,000	70,000 58,000	72,000 58,000	70,000 56,000	70,000 53,000	68,000
COMPRESSIVE YIELD STRENGTH L (1) / T (1)	55,000 53,000	60,000 57,000	62,000 57,000		43,000 48,000	70,000 70,000	72,000 65,000			
ULTIMATE STRENGTH IN PURE SHEAR	35,000	37,000	39,000		35,000	43,000	44,000			
ULTIMATE BEARING STRESS (e/D = 1.5) (2) / (e/D = 2.0) (2)	90,000 114,000	96,000 122,000	90,000 114,000			101,000 125,000	96,000 128,000			
YIELD BEARING STRESS (e/D = 1.5) (2) / (e/D = 2.0) (2)	74,000 85,000	81,000 93,000	78,000 84,000			91,000 98,000	79,000 101,000			
MODULUS OF ELASTICITY IN TENSION	10,500					10,300				
MODULUS OF ELASTICITY IN COMPRESSION	10,700					10,500				
MODULUS OF RIGIDITY	4,000					3,900				

(1) L = Longitudinal (with grain); T = Transverse (cross grain)
(2) D = Hole diameter; e = edge distance measured from the hole centerline in direction of stressing. Use value of e/D = 2.0 for large values of edge distance.
(3) Heat treat by user refers to all material supplied in the annealed temper and heat treated by user, and to all material re-heat treated by user regardless of temper in which material was supplied. (Refer to the Foreword page i of this EO.)

Table 43

DESIGN MECHANICAL PROPERTIES OF 24S AND 61S EXTRUDED SHAPES (PSI)

ALLOY	24S					61S
SPECIFICATION	QQ-A-354					QQ-A-325
CONDITION	HEAT TREATED				HEAT TREAT BY USER	HEAT TREATED AND AGED
THICKNESS AND CROSS SECTIONAL AREA	<.250	.250 to .749	.750 to 1.499	> 1.500 <25 sq.in.	>.250 <.32 sq.in.	<3.000
ULTIMATE TENSILE STRENGTH L (1)	57,000	60,000	65,000	70,000	57,000	38,000
T (1)	51,000	51,000	51,000	51,000	51,000	36,000
TENSILE YIELD STRENGTH AT PERMANENT SET OF .002" L (1)	42,000	44,000	46,000	52,000	38,000	35,000
T (1)	36,000	36,000	37,000	39,000	36,000	33,000
COMPRESSIVE YIELD STRENGTH L (1)	38,000	39,000	44,000	50,000	38,000	35,000
T (1)	38,000	39,000	42,000	42,000	38,000	35,000
ULTIMATE STRENGTH IN PURE SHEAR	30,000	32,000	34,000	37,000	30,000	24,000
ULTIMATE BEARING STRESS (e/D = 1.5) (2)	85,000	85,000	85,000	85,000	85,000	61,000
(e/D = 2.0) (2)	108,000	108,000	108,000	108,000	108,000	80,000
YIELD BEARING STRESS (e/D = 1.5) (2)	59,000	60,000	61,000	62,000	53,000	49,000
(e/D = 2.0) (2)	67,000	69,000	71,000	73,000	61,000	56,000
MODULUS OF ELASTICITY IN TENSION	10,500					9,900
MODULUS OF ELASTICITY IN COMPRESSION	10,700					10,100
MODULUS OF RIGIDITY	4,000					3,800

(1) L = Longitudinal (with grain); T = Transverse (cross grain)
(2) D = Hole diameter; e = edge distance measured from the hole centerline in direction of stressing. Use value of e/D = 2.0 for large values of edge distance.
(3) Heat treat by user refers to all material supplied in the annealed temper and heat treated by user, and all material re-heat treated by user regardless of temper in which material was supplied. (Refer to the Foreword page i of this EO.)

Table 44

PART 6

FORGINGS

SECTION 1

FORGING ALUMINUM ALLOYS

1 Aluminum alloy forgings are employed where better strength, soundness or finish are required than can be obtained by the casting processes. In forging, the metal is worked to the desired shape by applying heavy blows or pressure, either with or without the use of special dies. Such working produces a fine, close grain structure with the grain flow following the contour of the part. Forging provides maximum mechanical properties in the direction needed and the ability to withstand adverse conditions of loading, such as sudden shock or frequent reversal of stress.

2 Either rolling or extrusion may be used to produce aluminum alloy forging stock. Forging shapes are usually extruded, but forging rod is generally rolled while forging bar may be rolled or extruded. Material produced by either method may be cold finished to obtain close tolerances and to control the surface condition, or the material may be supplied hot finished, depending on requirements. In all cases the forging stock must be carefully conditioned to ensure surfaces suitable for the exacting requirements of forging.

3 Aluminum alloys commonly used for forging are 14S-T6 where high strength is required or 14S-T4 for those parts previously made from 17S alloy. 25S, A51S and 61S alloys provide ease of forging while 18S and 32S alloys offer good performance at elevated temperatures. When higher strength than obtained from 14S-T6 is required 75S-T6 may be used, however the strength of this alloy is affected by the rate of quenching after heat-treatment and the forging section thickness should not exceed 3". Where strength requirements are not severe, the 2S and 3S alloys offer ease of forging.

4 Proper forging temperatures vary with the equipment and the process being employed. The recommended maximum forging temperatures are:-

32S	427°C (800°F)
18S	438°C (820°F)
14S, 17S	449°C (840°F)
25S	460°C (860°F)
A51S, 61S	471°C (880°F)

DESIGN MECHANICAL PROPERTIES 14S AND 75S HAND FORGED STOCK (PSI)

TYPE	HAND FORGED STOCK (Length not over 2 1/2 times width or diameter, or all Lengths of Rectangles having Width Greater than 4 Times the Thickness										PARTS From Hand-Forged Stock					
ALLOY	14S										75S					
CONDITION	HEAT TREATED AND AGED										PARTS HEAT TREATED AND AGED BY USER					
SHAPE	Rounds, Squares and Rectangles (Width < 1 1/4 Times Thickness)					Rectangles (Width > 1 1/4 times Thickness)					Any Part < 3" Thickness Cut From Square or Rectangle Forged Stock					
CROSS SECTIONAL AREA IN SQ. IN.	< 36	> 36 < 100	> 100 < 144	> 144 < 196	> 196 < 256	< 36	> 36 < 100	> 100 < 144	> 144 < 196	> 196 < 256	< 9	> 9 < 16	> 16 < 36	> 36 < 64	> 64 < 100	> 100 < 144
ULTIMATE TENSILE STRENGTH L (1) T	65,000 62,000	63,000 60,000	62,000 60,000	61,000 58,000	60,000 58,000	65,000 62,000	63,000 60,000	63,000 60,000	62,000 60,000	62,000 60,000	75,000 75,000	74,000 72,000	73,000 71,000	72,000 70,000	71,000 69,000	68,000 60,000
TENSILE YIELD STRENGTH .002" PERMANENT SET L T	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	65,000 65,000	64,000 62,000	62,000 60,000	61,000 59,000	60,000 58,000	58,000 50,000
COMPRESSIVE YIELD STRENGTH L T	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000	50,000 50,000						
ULTIMATE STRENGTH IN PURE SHEAR	40,000	39,000	39,000	38,000	37,000	40,000	39,000	39,000	38,000	38,000						
ULTIMATE BEARING STRENGTH (e/D = 1.5)(2) (e/D = 2.0)	98,000 124,000	95,000 120,000	93,000 118,000	92,000 116,000	90,000 114,000	98,000 124,000	95,000 120,000	95,000 120,000	93,000 118,000	93,000 118,000						
YIELD BEARING STRENGTH (e/D = 1.5) (e/D = 2.0)	70,000 80,000	70,000 80,000	70,000 80,000	70,000 80,000	70,000 80,000	70,000 80,000	70,000 80,000	70,000 80,000	70,000 80,000	70,000 80,000						
MODULUS OF ELASTICITY IN TENSION	10,500					10,500					10,300					
MODULUS OF ELASTICITY IN COMPRESSION	10,700					10,700					10,500					
MODULUS OF RIGIDITY	4,000					4,000					3,900					

(1) L = Longitudinal (with grain); T = Transverse (cross grain)
(2) D = Hole diameter; e = edge distance measured from the Hole centerline in the direction of stressing.
Use value e/D = 2.0 for all larger values of edge distance.

Table 45

PART 7

CASTINGS

SECTION 1

ALUMINUM ALLOY CASTINGS - GENERAL

1 Aluminum alloy castings are obtainable in three different types, according to the adopted founding method; sand castings, permanent-mould castings, and pressure-die castings.

2 The selection of the particular type of casting is dependent on the quantities involved, finish required, dimensional accuracy and the mechanical properties required.

3 The cost of metal dies for permanent-mould and die castings is relatively high in comparison to the cost of pattern equipment for sand castings unless large numbers are to be produced. However usually smoother surfaces and closer dimensional tolerances are obtainable from metal moulds and generally in these respects, die castings are superior to permanent mould castings.

4 The rapid rate of solidification introduced in a permanent mould casting usually results in higher mechanical properties than those from the same alloy cast in sand.

5 Table 46 lists the general characteristics and typical uses of aluminum casting alloys.

6 Where pressure tightness is a requirement of castings in the finished condition, this should be noted on the drawing or enquiry, indicating the medium exerting the pressure and the maximum pressure exerted in pounds per square inch.

7 Relevant Alcoa specifications for castings are listed in Table 3 of this Engineering Order.

GENERAL CHARACTERISTICS AND TYPICAL USES OF ALUMINUM CASTING ALLOYS

Alcan Alloy	GENERAL CHARACTERISTICS				Casting Process	Typical Uses
	Heat Treatable	Castability	Corrosion Resistance	Machinability		
100	No	Fair	Excellent	Fair	Sand	Very malleable. Fittings for electrical, food and beverage industry.
A111	Yes	Good	Fair	Good	Sand	For uses requiring good mechanical properties and strength at elevated temperatures.
117	No	Excellent	Fair	Good	Sand, Perm. Mould	General purpose, moderate strength for medium stress castings.
123	No	Excellent	Excellent	Fair	Sand, Perm. Mould	For thin-walled castings and castings subject to atmospheric attack.
125	Yes	Excellent	Fair	Good	Sand, Perm.Mould	Stressed castings of intricate shape with good mechanical properties.
135	Yes	Excellent	Excellent	Good	Sand, Perm. Mould	Used where requirements include high strength, corrosion resistance, pressure tightness and dimensional stability on temperature variation.
143	No	Very Good	Fair	Good	Die	General purpose, good mechanical properties.
160X	No	Excellent	Good	Fair	Die	For intricate parts with thin sections, instrument cases, etc.
162	Yes	Good	Good	Good	Perm. Mould	Low co-efficient thermal expansion, good wear resistance and good strength at elevated temperatures. Excellent piston alloy.
225	Yes	Good	Fair	Very Good	Sand	Stressed castings requiring high strength and ductility. Machine parts.
236	No	Good	Fair	Very Good	Sand, Perm. Mould	For medium stressed castings requiring good machining.
250	Yes	Good	Fair	Good	Sand, Perm.Mould	For engine parts requiring good strength at elevated temperatures, good wear resistance and greater hardness.
A320	No	Good	Excellent	Excellent	Sand	Good finishing characteristics and corrosion resistance. Marine and ornamental.
340	No	Good	Excellent	Excellent	Die	Excellent strength, ductility, corrosion resistance and good finishing.
350	Yes	Good	Excellent	Excellent	Sand	This alloy has the highest combination of mechanical properties, corrosion resistance and machinability of any sand cast. alloy.

Table 46

DESIGN MECHANICAL PROPERTIES OF ALUMINUM ALLOY CASTINGS (PSI)

TYPE	SAND CASTINGS					PERMANENT MOULD CASTINGS			
ALLOY	40E	195-T4	195-T6	220-T4	356-T6	B195-T4	B195-T6	355-T6	356-T6
SPECIFICATION	AN-A-17	AN-A-35		AN-A-33	AN-A-39	AN-A-36		AN-A-41	AN-A-34
CONDITION	AGED	HEAT TREATED CLASS 1	HEAT TREATED AND AGED CLASS 2	HEAT TREATED	HEAT TREATED AND AGED	HEAT TREATED CLASS 1	HEAT TREATED AND AGED CLASS 2	HEAT TREATED AND AGED	
ULTIMATE TENSILE STRENGTH	32	29	32	42	30	33	35	37	33
TENSILE YIELD STRESS .002" PERMANENT SET	20	13	20	22	20	20	22	23	22
COMPRESSIVE YIELD STRESS		14	21	23	20	20	22	23	22
ULTIMATE STRESS IN PURE SHEAR	27	22	24	30	25	25	26	26	25
ULTIMATE BEARING STRESS (e/D = 1.5) (1) (e/D = 2.0)		46 61	51 67	67 88	48 63				
YIELD BEARING STRESS (e/D = 1.5) (e/D = 2.0)		22 26	34 40	37 44	34 40				
MODULUS OF ELASTICITY IN TENSION					10,300				
MODULUS OF ELASTICITY IN COMPRESSION					10,300				
MODULUS OF RIGIDITY					3,850				
COMMERCIAL DESIGNATION	40E	195-T4	195-T6	220-T4	356-T6	B195-T4	B195-T6	355-T6	356-T6

Reference should be made to the specific requirements of the procuring or certifying agency in regard to the use of the above values in the design of castings.

(1) D = Hole diameter; e = edge distance measured from the hole centerline in the direction of the stressing. Use value e/D = 2.0 for all large values.

Table 47

PART 8

HEAT TREATMENT

SECTION 1

GENERAL

1 In Part 1, Section 3, it was explained that the wrought aluminum alloys were divided into two general classes, the non-heat-treatable alloys and the heat-treatable alloys. The strength of the non-heat-treatable alloys depends on the amount of cold work introduced after the last annealing process. The properties so obtained are destroyed by subsequent heat treating and cannot be restored except by additional cold work. The strength of the heat-treatable alloys on the other hand is increased primarily by heat treating and the effects of annealing can be overcome by subsequent heat treatment.

2 There are three different heat treatments that may be employed to alter or improve the properties of the aluminum alloys, namely: annealing, solution heat treatment and precipitation heat treatment. Annealing may be employed to remove the effects of plastic deformation (cold work) or to soften solution heat treated and aged material. The solution heat treatment is used to strengthen the heat-treatable alloys as well as to adapt them to mild forming within a short time after the heat treatment. The precipitation heat treatment is an aging treatment and is employed on the heat-treatable alloys to stabilize them by an artificial or "speeded-up" aging process.

3 In order to understand the various heat treatments and soaking times for the various alloys, it is necessary to understand the elementary metallurgy involved in the science of heat treating.

SECTION 2

TABLE OF CONTENTS

THEORY OF METALLURGY

1 Combinations of metals like those found in the aluminum alloys have exceedingly complex structures. A molten aluminum alloy may be composed of six to nine different metals, some dissolved in others (like ink in water) and some not dissolved but just mixed (like oil and water). As the molten alloy is allowed to cool, it will reach a point where solidification begins. At this point "crystals" begin to form and with continued cooling, additional crystals form, building up on the first crystals to produce "grains". For the purpose of discussion, let it be assumed that the solidified metal is composed of grains, which in turn are composed of crystals.

2 In addition, certain compounds are formed by the various combinations of metals. These compounds may solidify out separately, either between the grains along the grain boundaries, or in the grains between the crystals. Also, certain other elements may separate out during cooling to room temperature. Obviously, the resulting structure is quite complex, as previously mentioned.

WORK HARDENING

3 Adjoining crystals can "slip" against each other in many different directions; that is they are said to have many different "slip planes" A metal in which slippage of the crystals has not occurred is called soft.

4 Application of mechanical force will cause crystals to slip along any given slip plane only a certain amount. When soft metal is cold worked (hammered, stretched, formed or has its dimensions changed mechanically by any other method of applying force at room temperature), the adjoining crystals move along a slip plane. Because only a certain amount of slippage can occur along any one slip plane, the limit of movement on that plane is quickly reached and further working then requires slippage along other planes.

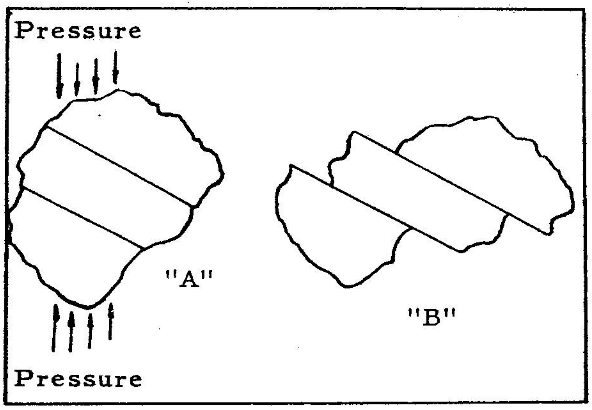

Figure 8-1 Deformation Along Slip Planes

5 However, the planes along which subsequent slippage occurs may not be so favourably positioned with respect to the applied force. The result is that the application of the same amount of force as before produces much less change in shape, or to produce the same amount of change in shape, much more force must be applied. As further work is done on the piece of metal, the resistance to change increases greatly and the metal is said to "work harden". Additional working will in time cause the metal to rupture.

6 Figure 8-1 is a graphic description of a metal showing force being applied in the direction of the arrows in "A". "B" shows the resultant movement of the crystals along the slip planes.

ANNEALING

7 The original workability of the metal can be restored by producing a "fresh" set of crystals having an entirely new set of slip planes. This is done by heating the previously worked metal to a point where a new crystal structure is produced. This temperature is called "recrystallization" point or "temperature of recrystallization". Aluminum alloys require comparatively low recrystallization temperatures 177°-399°C. (350°-750°F.). This operation is easy to control and reliable results can be had with little difficulty on most of the aluminum alloys. The detailed operation is described in Section 3 and the specific treating cycle is shown in Part 9.

8 For practical purposes, suppose a deep drawn cup is being formed from a flat circle Instead of attempting to produce the cup from the flat in a single forming operation, the final shape may be attained in steps or stages, annealing the part between successive operations whenever necessary to overcome the work hardening. In this manner, it is possible to keep each step within the practical working limits of the material and not draw the sheet beyond the point where excessive work hardening would cause rupture of the metal in the form of cracks or breaks. This is why many articles formed from aluminum alloy sheet involve a sequence of press operations with a series of intermediate annealing treatments.

TIME ELEMENT

9 It is important to understand the influence of time in heat treating metals. For example, if in the above described annealing process, the work is not held above the recrystallization temperature long enough, the new crystals will not have a chance to form completely. It takes a certain amount of time to form the new grain structure of the metal.

10 Time is also required for the heat to soak thoroughly throughout all portions of the metal piece being treated. This is necessary in order that sufficient temperature rise will occur in all sections to provide the change in the metallurgical structure that is desired. While a fast treatment in a furnace operated at a higher temperature may bring the interior of the work up to the desired temperature in less time, it would certainly heat the outside edges and corners of the work to excessive temperatures and probably damage these portions.

11 For the above mentioned reasons, allowance for the correct length of time at the detailed temperature is essential in any heat treating operation.

12 The time element enters into heat treatment in another important manner. Because a certain period of time is required for structural or metallurgical changes (such as solid diffusion, paragraphs 35 to 38) to reach a completed or stable stage, it is possible to quickly change the temperature of the metal by quenching and thereby obtain at room temperature certain desired types of structures that could not otherwise be had at room temperature.

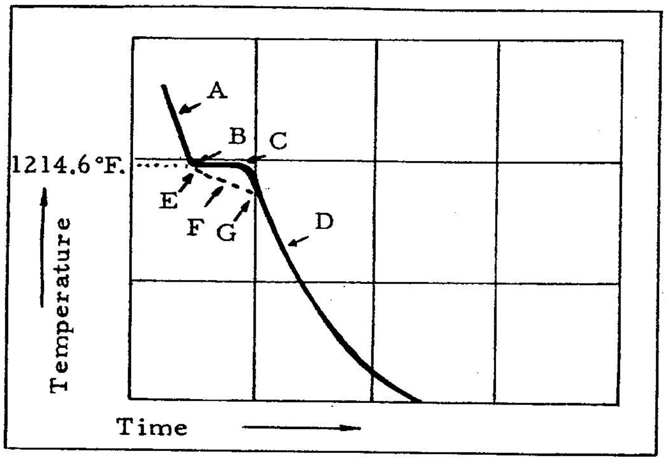

Figure 8-2 Time VS Temperature for a Pure Metal

13 Before going on to the heat treating cycles and structures of aluminum alloys, let a pure metal, for the sake of simplicity, be observed to see how this time element influences its structure. Figure 8-2 indicates the relation between time and temperature as a pure metal is allowed to cool from the molten state, represented by point "A". As its temperature falls, it reaches point "B" where the metal begins to solidify or freeze. For pure aluminum, this freezing point is 657°C.(1214.6°F.).

14 The curve on the graph indicates that the metal remains at this temperature for a period of time. This is because the change from a liquid to a solid is accompanied by the release of heat, the mechanism of the operation being such that enough heat is released to balance that being lost, thus retaining the temperature of the metal constant during the period in which this solidification is taking place. It will be noted that the portion of the curve "B" to "C" is level.

15 As soon as the metal has completely solidified, its temperature again falls gradually as it is allowed to cool, represented by the sloping line "D".

16 It should be understood that only pure metal follows this type of curve and that each different metal has a different solidification or freezing point; that is, the level portion of the curve will fall at a different temperature.

17 Now observe the results of two pure metals, aluminum and copper, which have been melted together and allowed to cool. A curve of entirely different shape develops because the combination of the two metals has a freezing "range" instead of a freezing "point"; that is, the material begins to freeze at one temperature and continues to freeze while the temperature falls to a lower value before all of it has solidified. This is shown by the dotted curve at "F" in Figure 8-2 where the curve slopes from "E" to "G"

18 The combination of aluminum and copper does not freeze or solidify completely at a single temperature because the mixture formed by the two metals behaves in an entirely different manner than a pure metal like aluminum or copper (above). Let this freezing action be considered by tracing the new curve on Figure 8-2.

DIFFERENTIAL FREEZING

19 At "E", Figure 8-2, the crystals forming out as the metal is just beginning to solidify will consist of an alloy of almost pure aluminum. As the temperature falls, crystals with appreciable amounts of copper will begin forming. With continued dropping temperature, the crystals forming will contain more and more copper. Thus at "E", the alloy particles freezing out may contain 99.9% aluminum and 0.1% copper. Similarly, particles containing 98% aluminum and 2% copper will freeze out at a lower temperature, and so on.

20 Accordingly as the temperature falls, the material freezing out of solution at any particular moment corresponds to the alloy of aluminum and copper that freezes at that particular temperature. This accounts for the fact that as the temperature curve, Figure 8-2, traverses the "F" portion of the chart, the alloy crystals forming out of the molten metal contain more and more copper. At "G" the entire mass becomes solidified and the temperature drops along the same type of curve as before.

21 When the molten metal contains more than two elements, this curve changes considerably and the freezing action becomes increasingly complicated. It is evident, that in an aluminum alloy containing six to nine different elements, the action may be extremely

complicated when it is considered that the many different elements in turn form various mixtures or compounds which may behave in still different ways.

PRECIPITATION

22 One of the complications resulting from having these many different elements in the aluminum alloy is that certain combinations of elements may form mixtures or compounds which may freeze out of solution or separate out in small independent particles before or even after most of the other metal has solidified.

23 These particles may be extremely small and may exist between the surfaces of adjoining crystals in such a manner as to "lock" the crystals by hindering them from sliding and thereby increasing the resistance to mechanically working the material. This in turn may make the material hard, tough, brittle, etc. Depending upon the circumstances, the results may be desirable or undersirable.

24 This precipitation or separating out from the molten metal can be demonstrated as follows. Place several spoonfuls of salt in a glass of boiling water, adding salt until no more will dissolve and some remains on the bottom even after repeated stirring. Pour this solution into another glass, leaving behind the undissolved salt. The second glass will now contain a "saturated" solution of salt in water.

25 Place this glass in a basin of cold water and stir the solution. As it cools, the temperature will drop to a point where the water cannot hold all the salt in solution. The glass now holds a "supersaturated" solution in which the extra salt will immediately form salt crystals as it precipitates out of solution.

26 The same thing happens when a molten aluminum alloy is allowed to cool. Various elements and combination of elements will precipitate out of the molten alloy as the temperature falls to a point where they can no longer be held in solution. In many cases, the alloy does not have to be molten, for certain compounds may precipitate out of the metal after it has solidified.

27 When a constituent precipitates out, it may accumulate between the grains alongthe grain boundaries, or in the form of minute particles between crystals inside the grains. These particles, then, may be present in the slip planes between adjacent crystals. If the same particle is partially imbedded in both surfaces of adjoining crystals, it is evident that it will tend to lock those surfaces together and prevent them from sliding freely on one another. Thus such particles will tend to increase the resistance to slippage between crystals because of this "keying" effect.

28 With slippage made more difficult, the metal acts like it had fewer slip planes, is harder to work and may be considerably stronger. So the end result may be that the mechanical properties of the metal are greatly improved. As will be seen, this is the aim of certain heat-treating cycles.

29 It must be borne in mind that not only solids precipitate out of a liquid (the molten metal) but also solids precipitate out of solids, because just as a solid metal can diffuse into another solid metal (described under "homogenizing" paragraphs 35-38), so can a solid precipitate out from another solid. To illustrate this latter action, however, there is no simple analogy like that of salt and water previously mentioned.

30 At this point, the picture becomes increasingly difficult to follow and a study of some of the other factors will help to clarify the action.

SEGREGATION

31 When molten aluminum alloys are poured into moulds and allowed to cool to form ingots (castings), the surfaces of the ingot that contact the mould naturally cool faster, So the first crystals to be formed are in the ingot surfaces contacting the mould walls. As the temperature of the metal continues to fall and more crystals are formed, the new ones form on the inner side of the older ones, causing the metal grains to "grow" toward the centre of the ingot in a direction at right angles to the mould walls.

32 At the same time the rapid extraction of heat through the mould walls is causing the grains to grow inwardly from the ingot surface, the temperature difference existing between the

solidifying outer layers of the ingot and the still molten inner portion produces another important action.

33 It has been shown how certain constituents of the metal may precipitate or separate out from the remainder as the temperature drops. Now with uneven temperatures throughout the ingot, it becomes evident that precipitation will occur unevenly. This in return results in uneven distribution of the precipitate (the material that precipitates out).

34 Since the precipitates may have an exceptionally important influence on the characteristics of the metal, it is essential that they be uniformly distributed throughout the entire body of the metal. This is done by mechanically working or "kneading" the ingot, supplemented by the heat treatment called "homogenizing".

HOMOGENIZING

35 Referring back to where all the metal had just solidified, paragraph 19, it is to be recalled that the crystals forming first were almost pure aluminum and that succeeding crystals contained more and more copper in the form of a richer copper-aluminum alloy. Thus the grains in the solidified metal have what is termed a "cored" structure; that is, the inside crystals near the core are much different than the outer crystals of a grain. As the metal freezes and cools to room temperature, the resultant "cast" metal possesses this undesirable cored structure. So it becomes necessary to change this structure to a more desirable one.

36 To accomplish this, the metal is subjected to "solid diffusion" - a term used to denote the diffusion or spreading out or dissolving of one metal into another when both are in a solid state. It is well known that some liquids will readily dissolve into water and certain liquids will readily dissolve certain solids, as water dissolves salt. However, it is not so well known that certain solids can dissolve other solids.

37 This phenomenon may be proved by pressing tightly together the carefully cleaned surfaces of a gold and a silver block. The dividing line will gradually disappear as the two metals blend or dissolve into one another. While this action will occur at room temperature, it is greatly speeded by heating both metals.

38 In a similar manner, the copper is caused to diffuse throughout the metal structure by heating the metal to a temperature just under its melting point, followed by slow cooling. This treatment is known as "homogenizing". For many aluminum alloys, it is carried out in the temperature range of 482°-538° C. (900°-1000° F.). By this means, it is possible to overcome the tendency of certain constituents to segregate or separate to form thin and dense areas. Homogenizing thus is an aid in bringing about uniform distribution of the alloying elements and other constituents, and so helps in producing the desired homogeneous structure.

STRENGTHENING ALUMINUM ALLOYS BY HEAT TREATMENT

39 As was explained in paragraphs 22 to 30, it is possible to strengthen the aluminum alloys by causing certain constituents to precipitate out inside the grains along the crystal boundaries or in the slip planes between crystals in such a manner as to lock or key the crystals, thus hindering slippage and so producing a "harder" and stronger metal.

40 Also resistance to slippage can be increased by controlling the material that is precipitated between crystals so that it acts like a "sharp grit" instead of like a "ball bearing". It is evident that a material that tends to aid free movement of one crystal on another will produce a softer, weaker alloy, whereas a precipitate that tends to prevent such movement will in turn produce a harder and stronger structure.

41 Sections 4 and 5 detail the process and Part 9 shows the specific treating cycle to develop the above requirement. Of course the different aluminum alloys require slightly different treatments because of the cumulative effect of the different combinations of elements in them.

42 Reference to Figure 8-3 "Constitution Diagram for Copper - Aluminum Alloys" will show why these particular temperature ranges are required and to find out about the "aging" treatment, either natural or artificial, that is

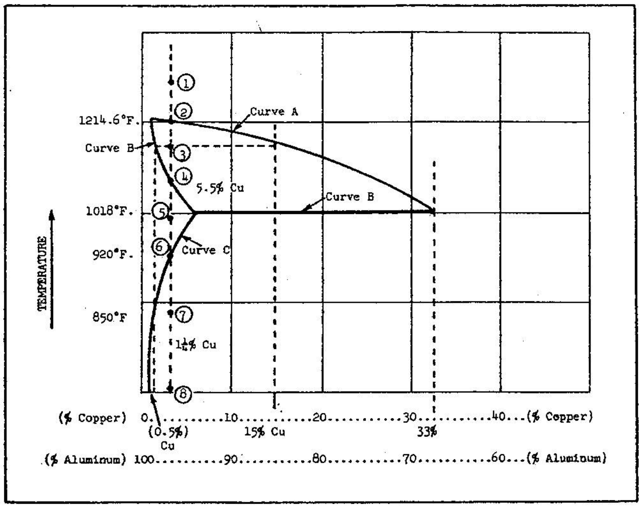

Figure 8-3 Constitution Diagram for Copper-Aluminum Alloys

necessary to develop maximum strength in the aluminum alloys.

43 The vertical scale in Figure 8-3 represents the temperature going up from a low temperature at the bottom to above the melting point of the aluminum alloys at the top. Because the alloys being discussed have aluminum and copper as the principal constituents, the horizontal scale at the base can be used to show the percentages of both aluminum and copper. Since the information plotted on the chart was obtained from tests upon a series of alloys with different compositions of aluminum and copper it is possible to determine exactly how much copper is contained in the aluminum-copper alloy that is solidifying out of solution and also to determine now much copper remains in the still molten alloy.

44 The transformations of a 3% copper 97% aluminum alloy are shown on the chart as it is heated to 704.4°C. (1300°F.) (Point 1). At this temperature all the metal is molten and the copper has dissolved into the aluminum. Now the metal is allowed to cool to 643.3°C. (1190°F.) (Point 2) which falls on curve "A". Curve "A" represents the temperature at which the molten metal starts to solidify. The 657°C. (1214.6°F.) shown is the temperature at which pure aluminum starts to solidify and 643.3°C. (1190°F.) is the temperature at which the 3% aluminum-copper alloy starts to solidify. The first crystals that start to form at this temperature will be almost pure aluminum. These crystals will serve as the nuclei or centre points around which the grains will form by solidification of other crystals on them as cooling continues.

SOLID SOLUTION

45 The alloy is now allowed to cool to 626.6° C. (1160° F.) (Point 3). Since the solidification began at point 2, the material is now partly solidified and partly molten. Because the aluminum has been crystallizing out of solution with very little copper, the copper content of the still molten alloy is increasing.

46 Curve "B" represents the temperature at which freezing is completed for the different compositions. From the point where a horizontal line from point 3 intersects curve "B", run a vertical line to the base. The copper content of the alloy freezing out at 626.6°C. (1160°F.) is shown to be 1 1/4% on the copper scale.

47 To determine the copper content of the still molten alloy, run a horizontal line from point 3 to curve "A" and from this point of intersection, drop a vertical line to the base. The copper scale will show that the still molten alloy contains about 15% copper.

48 At lower temperatures (between points 3 and 4), the crystals just forming will contain more and more copper. Likewise the remaining molten alloy will also contain a greater percentage of copper. Thus as the temperature falls, the material freezing out of solution at any particular moment corresponds to alloy of aluminum and copper that freezes at that particular temperature. This "differential freezing" was referred to in paragraph 19.

49 Thus, it is clear that at any point between curve "A" and curve "B", there exists a mixture of solid particles and molten alloy. The solid particles consist of aluminum with a certain amount of copper dissolved in them. When one metal remains dissolved in another in this manner, the combination is called a "solid solution".

DIFFUSION

50 At point 4, all the alloy has solidified.

By extending a horizontal line from point 4 to curve "A", it is noted that the very last crystals to solidify contain approximately 26% copper while the very first crystals to solidify (at point 2) contained practically pure aluminum. So at point 4, grains are present with centres consisting of almost pure aluminum crystals while the outer surfaces are formed of crystals having 26% copper. It must however be remembered that the entire copper content or average throughout the entire grain is only 3% since that was the percentage of copper in the alloy before it was melted.

51 At any position below point 4, the material is a solid. However, this does not mean that more changes do not occur. Any metal can exist in at least three different forms - vapour, liquid or solid. In addition, many common alloys appear in more than one solid form. These different forms are known as "phases".

52 The aluminum-copper alloy being studied has four phases - a completely liquid phase in the chart above curve "A", a second phase consisting of solid particles in molten material in the area between curves "A" and "B", a third phase in the area below curve "B" and to the left of curve "C" where the material is a solid, and a fourth phase in the area below curve "B" and to the right of curve "C" where the material is also solid but in a different form as will be explained.

53 Suppose the temperature of the material is held at 1018° F. - point 5. At this comparatively high temperature, the phenomena we called solid diffusion (explained under "homogenizing" paragraph 35) proceeds at a comparatively rapid rate. This means that the fairly large amounts of copper near the grain boundaries diffuse rapidly inward throughout all portions of the grain so that it is not long before every crystal in the grain contains the same amount of copper - 3% in the case being studied. Point 5 can be said to be typical of any point between point 4 and point 6 in that anywhere in this range, the copper will diffuse throughout the entire structure if the temperature is held for a sufficient period of time. Of course, the diffusion progresses more rapidly at the higher temperature, which means that a shorter period of time would be required for complete diffusion at those temperatures - again emphasizing the importance of time in the heat-treating cycle.

PRECIPITATION

54 Curve "C" is the line indicating the beginning of the formation of a compound containing copper and aluminum called copper aluminide ($Cu.Al_2$). This compound starts to separate or precipitate out of the material at any temperature below point 6 - 493.3° C. (920° F.) for the 3% alloy being discussed. The precipitation of a solid from another solid was mentioned previously in paragraphs 33 and 34.

55 At point 7 454° C. (859° F.) more copper has separated out as copper aluminide. At this temperature 99% of the material is in the form of copper-aluminum alloy containing 2 1/2% copper. The other 1% of the material containing the remaining 1/2% copper has precipitated out of the copper-aluminum alloy and is present between the crystals and grains. At point 8, still more copper has precipitated out in the form of copper aluminide.

56 To develop maximum strength in the aluminum alloys, it is necessary to control carefully the size and distribution of the material precipitated out as it is the material which affords the added strength due to the keying action previously explained.

CONTROLS AND QUENCHING

57 The first step in carrying out heat treating is to bring the aluminum alloy up to the specified temperature so that the precipitated constituents will dissolve. The material must be held at the specified temperature for a sufficient length of time for this dissolving action to occur throughout all portions of the piece being treated. This maintaining "at temperature" for the specified time is called "soaking" and constitutes the second step in the heat-treating cycle.

58 The third step is to cool the work rapidly which is called "Quenching". The purpose of quenching is to prevent certain constituents from precipitating out, which would occur in slow cooling. Slow cooling here would tend to produce a precipitate consisting of large particles, which are not desired.

59 Quenching from any particular temperature range tends to retain in the metal the

structure that was present just before quenching. Thus quenching not only prevents the precipitation of certain constituents that are not desired to precipitate at that time, but it also helps control the constituents that are desired to be out of solution.

60 The purpose of the entire heat-treating cycle is to develop the right kind of precipitate in the right place in the metal structure. The precipitate required should be of the "gritty" rather than the "ball bearing" type in order to provide the maximum resistance to slippage of the crystals. Also the precipitate must be uniformly distributed in extremely minute particles between crystals where it can exert the maximum keying action, rather than outside the grains or along the grain boundaries.

AGING

61 The fast cooling to near room temperature upon quenching produces a "supersaturated" condition where the material has already dissolved in it more of the constituents than it normally can carry in solution at this temperature. Such a condition is unstable. The result is that certain constituents begin to separate out or precipitate from the main mass of the aluminum alloy.

62 This precipitation occurs at room temperature with many of the aluminum alloys and this action is known as "natural aging". Certain other alloys must be heated slightly to bring this precipitation to completion within a reasonable length of time. This heating is called "artificial aging". In either case, this controlled reprecipitation is aimed at providing the correct size, character and distribution of the precipitated particles in the aluminum to produce maximum strength and other desired mechanical properties.

63 It should be pointed out that aluminum alloys hardened in this manner can be made soft and easily workable again by an annealing treatment, However, annealing alone will not produce maximum workability in the aluminum alloys that have been heat treated, for additional cold working and subsequent re-annealing is required in these instances.

64 Recommended annealing cycles are designed to produce a precipitate in the form of large particles outside the grains along the grain boundaries and not inside between the crystals. In this manner, minimum keying effect results and the material is "soft" because the crystals easily slip along their slip planes. This redistribution of the precipitate is in addition to the recrystallization effect mentioned previously in paragraphs 7 and 8.

65 It will be evident from the explanation presented in the foregoing that it is necessary to follow closely the recommended heat-treating cycles in order to produce maximum mechanical properties in the aluminum alloy. Even slight variations from the recommendations may cause considerable difficulty.

SECTION 3

TABLE OF CONTENTS

ANNEALING

1 Many fabricating procedures for the wrought aluminum alloys incorporate an annealing treatment. The anneal may be required to remove the effects of plastic deformation (work hardening) or to soften solution heat-treated and aged material. The practices used for each of these types of material are different but their purposes are identical to obtain material of optimum workability.

REQUIREMENTS

2 To obtain annealed material with optimum workability, the following requirements should be met:-

(a) Complete recrystallization.

(b) Equally located grains of optimum size.

(c) Random adjustment of slip planes.

(d) Low degrees of solid solution.

(e) Uniform distribution of insoluble and precipitated particles.

(f) Optimum size of soluble and precipitated particles.

3 The above requirements are the basis upon which annealing practices are set up. However, they are the ideal requirements that are seldom completely fulfilled in actual practice. But any change from the annealing practices shown should always take these points under consideration.

MECHANICS OF ANNEALING

4 Partial relief of the internal stresses set up during the cold work and loss of ductibility resulting from cold work takes place during the initial stages of the annealing process. As the annealing progresses, the temperature becomes sufficiently high to permit fragments of the original grains to recrystallize or form new unstrained grains. This will only take place, though, if sufficient cold work is present in the material.

EFFECT OF SOLUBLE CONSTITUENTS

5 Basically, the mechanics of annealing all

cold-worked alloys are the same, but the addition of the elements used to produce the heat-treatable class of alloys makes it necessary to modify the practices used with these alloys. The heat-treatable alloys contain elements that possess considerable solubility at high temperature and restricted solubility at lower temperatures. The annealing practices, therefore, must be such that the effects of cold work are removed without obtaining a solution heat-treating effect.

EFFECT OF PREVIOUS HEAT TREATMENT

6 The annealing of solution heat-treated and aged material requires additional modification of practices because the finely dispersed precipitate must be coalesced by using a higher temperature. However, at this temperature solution of the precipitate is also occurring. Therefore, after coalescence, a slow coal is required to allow the constituents that went into solution to reprecipitate.

NON-HEAT-TREATABLE ALLOYS

7 The non-heat-treatable alloys, such as high purity aluminum, 2S, 52S and 56S are annealed to remove the effects of strain hardening produced by cold work. For the recommended annealing cycle, refer to Part 9.

HEAT-TREATABLE ALLOYS

8 The heat-treatable alloys are annealed to remove the effects of strain hardening produced by plastic deformation or to remove the effects of solution heat treatment

9 The annealing of solution heat-treated material should be avoided whenever possible if subsequent forming and drawing operations are to be performed. If such operations are not severe, it is generally advantageous to re-solution heat treat and carry out such drawing of forming operations in the freshly quenched condition.

HEATING RATE

10 A moderately fast heating rate, while not essential, is desirable. If slow heating rates are employed, diffusion of copper and other soluble constituents may be excessive in the clad products. There may also be a slight tendency to produce a coarse grain size.

TEMPERATURE

11 The use of temperatures in the excess of those recommended in Part 9 should be avoided. This group of alloys contain substantial amounts of soluble constituents and these constituents must be out of solution, uniformly distributed and of optimum size as previously mentioned.

12 When annealing to remove the effects of cold work, the temperature should be high enough to ensure complete recrystallization and yet low enough to prevent any appreciable solution of the soluble constituents. In addition, the precipitated constituents should be uniformly distributed and of optimum size.

13 When annealing to remove the effects of heat treatment, the temperature must be high enough to coalesce the precipitated constituents. Since some solution of the constituents occur at this temperature, the slow cooling rate to 260° C. (500° F.) is required to promote the reprecipitation and coalescence of the constituents that remain in solution after the coalescence period.

14 Any attempt to shorten the annealing cycle for alloys such as 24S by employing temperatures in excess of those recommended in Part 9 should be avoided because more and more of the soluble constituents go into solution as the temperature is increased. If the material is subsequently cooled rapidly, the soluble constituents either remain in solution or are later thrown out of solution by a process known as aging. In either case, the material does not possess fully annealed mechanical properties.

TIME AT TEMPERATURE

15 The time at temperature will vary depending upon the temperature, the type of anneal, the material and similar factors. Excessive time at temperature promotes grain growth, diffusion and discoloration.

COOLING RATE

16 The cooling rate is important only when the annealing practices employed cause part of the soluble constituents to go into solution. When this occurs, the rate of cooling to 260° C. (500° F.) must be controlled as recommended in Part 9.

SECTION 4

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SOLUTION HEAT TREATMENT

1 The hardening and strengthening of the heat-treatable group of aluminum alloys by thermal treatment is performed by a series of operations involving the controlled heating and cooling of the material in the solid state. The purpose of the operations is to control the size and distribution of the precipitates formed by soluble elements added to produce the alloys.

SOLUBLE ELEMENTS

2 Many elements are soluble in aluminum, the more important ones being silicon, iron, copper, magnesium, manganese, nickel, zinc and chromium. Some of these are soluble only in the molten state, others have appreciable solubility at room temperature, while still others are very soluble at elevated temperatures but have restricted solubility at lower temperatures. If these alloys did not possess this decreasing solid solubility, they would, by definition and response to heat treatment, be classified as non-heat-treatable alloys.

SOLID SOLUTION

3 The solution of one metal in another in the solid state, referred to as "solid solution" was explained in Section 2, paragraphs 24 to 29 using salt dissolved in water as the analogy. In the aluminum alloys, the alloying elements act similar to the salt, the aluminum like the water and the precipitate like the crystals of salt thrown out of solution as it cools.

4 The size of the precipitated salt crystals can be increased by controlling the temperature of the solution. In a somewhat similar manner,

the size of the precipitate in the heat-treatable alloys is increased to an optimum size during the annealing operation so that the metal can be more easily worked. After the forming of the material has been completed, it is hardened and strengthened by thermal treatments which cause the coarse particles of soluble constituents to go back into solution and be reprecipitated in a finely dispersed state.

SOLUTION OF SOLUBLE CONSTITUENTS

5 The thermal treatment used to put the soluble constituents into solution and to prevent or retard their immediate reprecipitation is known as "solution heat treatment". It consists of two steps - putting the soluble elements into solution by raising the temperature and then rapid quenching. The strength of a heat-treatable alloy is not obtained by solution heat treatment alone but by combination with a subsequent precipitation or aging treatment. It is, therefore, only one step in obtaining full strength or hardness.

DIFFERENCE BETWEEN ANNEALING AND SOLUTION HEAT TREATMENT

6 The solution heat treatment of an alloy is different from annealing in several ways. The processes of recovery (partial relief of internal stresses and partial recovery of the ductility), recrystallization and grain growth are similar in both treatments. However, when annealing, the temperature is such that the precipitate of soluble constituents is coalesced or allowed to grow into coarse particles so that they will have less effect in restricting deformation. When solution heat treating, the soluble constituents are actually dissolved in the aluminum.

BASIS FOR SELECTING TEMPERATURE

7 The amounts of the soluble elements added to some of the alloys are such that the temperature necessary for solution heat treatment must be near the melting point of the lower melting constituents present. With these alloys, overheating by only a few degrees will cause some of the lower melt elements to fuse. Once this occurs, the metal must be remelted and reprocessed.

8 After the solution of the soluble constituents is substantially completed, the material must be rapidly quenched to prevent their immediate reprecipitation. If excessive reprecipitation occurs during the solution heat-treatment operation, the size and distribution of the particles are such that little strengthening is accomplished. In addition, the precipitate is formed along the grain boundaries and certain slip planes causing a serious decrease in the resistance to corrosion of many of the alloys.

MECHANICS OF ANNEALING

9 Operations in hardening by heat treatment of an aluminum alloy consists of four distinctive steps namely:-

(a) Heating to a predetermined temperature ture.

(b) Soaking at temperature for a specified length of time.

(c) Rapidly quenching to a relatively low temperature.

(d) Aging or precipitation hardening either spontaneously at room temperature or as a result of a low temperature thermal treatment.

10 The first three steps are known as "solution heat treatment", although it has become common practice to use the shorter term "heat treatment". Room temperature hardening is known as natural aging while the low temperature hardening operation is called "artificial aging", or a "precipitation thermal treatment".

PRODUCTION OF "W" TEMPER

11 The alloys that require a precipitation thermal treatment (artificial aging) to develop their full strength also age a limited amount at room temperature, the rate and extent of strengthening depending upon the alloy. Some alloys reach their maximum "natural" or room temperature aging strength in a few days, at which time they are referred to as being in the "-T4" or "-T3" temper. Others continue to age appreciably over a long period of time so the "W" designation, because of natural aging, is specific only when the period of aging is indicated, e.g. 24S-W (1/2 hr.).

12 Thus, there is considerable difference in the mechanical and physical properties of "freshly quenched" ("-W") material and material that is in the "-T3" or "-T4" temper.

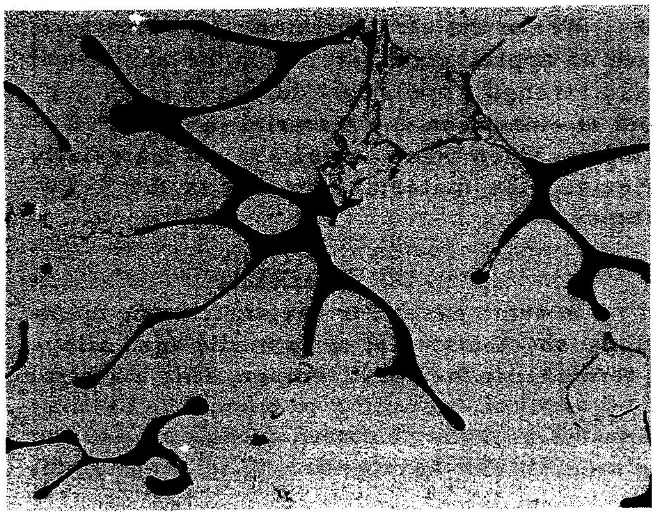

Figure 8-6 As Cast Quick Chilled 24S Alloy

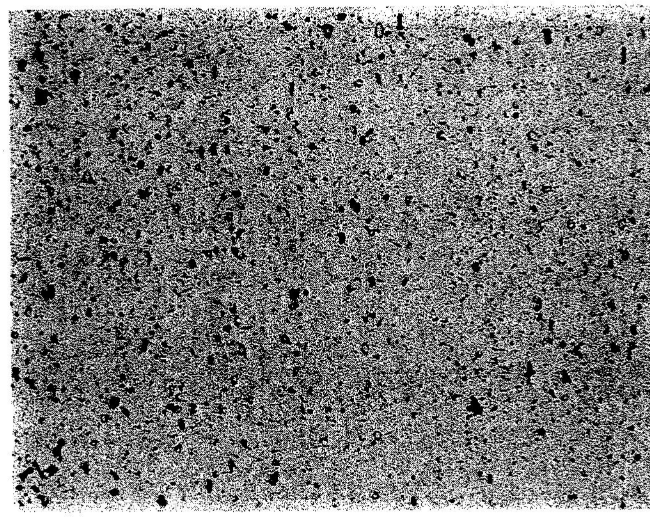

Figure 8-7 Properly Annealed 24S Alloy

The fact that material in the "-T3" or "-T4" temper is already in a partially aged condition should always be kept in mind.

PRACTICES

13 The temperatures used for solution heat treating depend upon the alloy, refer to Table 48. As a rule, they must be controlled within a very narrow range (±10°F), to obtain the best results.

14 If an insufficient temperature is used, the maximum strengths will not be obtained. When excessive temperatures are used, there is a danger of melting the lower melting constituents in some alloys. Even if melting does not occur, the use of higher than recommended temperatures promotes discoloration and increases quenching strains.

QUENCHING

15 After the soluble constituents are in solid solution, the material is quenched to prevent or retard immediate reprecipitation. Three distinct quenching methods may be employed depending upon the commodity, the alloy and the properties desired.

COLD WATER QUENCHING

16 Parts and articles produced from sheet, extrusion, tubing, small forgings and similar type material are generally quenched in a cold water bath. The temperature of the water, before quenching, should not be in excess of 30°C (86°F) with volume of water being sufficient to keep the temperature rise under 7.8°C (14°F). The use of such a drastic quench ensures maximum resistance to corrosion, particularly with such alloys as 17S and 24S, even though a less drastic quench may produce the required mechanical properties.

HOT WATER QUENCHING

17 Large forgings and heavy sections can be quenched in hot or boiling water 66°-100°C. (150°-212°F). This type of quenching minimizes distortion and alleviates cracking, which may be produced by the unequal temperatures obtained during the quench. The use of such a quench is permitted with this class of material because the temperature of the quench water does not critically affect the resistance to corrosion of the alloys from which forgings are generally produced. In addition, the resistance to corrosion of heavy sections is not as critical a factor as for thin sections.

SPRAY QUENCHING

18 The use of high velocity water spray is applicable to parts formed from cladded sheet and for large sections of practically all alloys provided it meets the requirements of Part 9, Section 3. This type of quenching minimizes distortion and reduces quench cracking. However, spray quenching reduces the resistance to corrosion in the base 17S and 24S alloys.

TRANSFER TIME

19 The time interval between the removal of the material from the furnace and quenching is

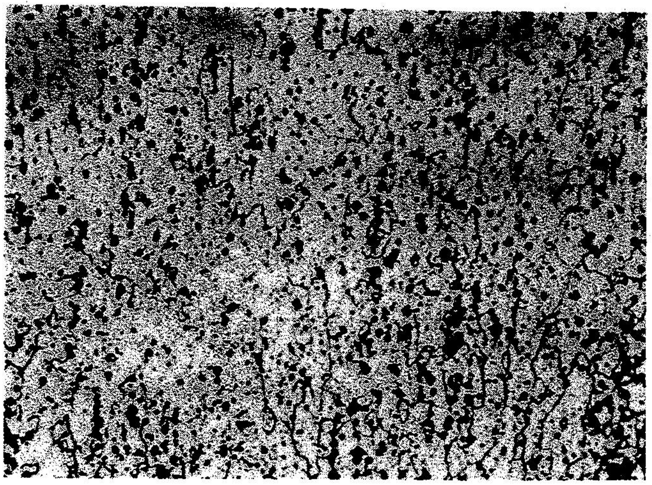

Figure 8-8 Improperly Annealed 24S Alloy

critical for some alloys and should be held to a minimum. When solution heat treating 17S and 24S sheet material, the elapsed time must not exceed ten seconds. The allowable time interval for heavy sections may be slightly greater.

20 Allowing the metal to cool slightly before quenching promotes reprecipitation from the solid solution. The precipitate forms out along the grain boundaries and certain slip planes causing poorer formability and, in the case of 17S and 24S, adversely affects their resistance to intergranular corrosion.

RE-SOLUTION HEAT TREATMENT

21 The bare heat-treatable alloys may be re-solution heat treated repeatedly without harmful effects providing high temperature oxidization does not occur. The number of re-solution heat treatments allowed for clad material is restricted, due to the increase in the degree of diffusion into the cladding with each re-heat treatment. Part 9 lists the number of re-heat treatments allowable for the various cladded alloys and anodized parts.

STRAIGHTENING AFTER SOLUTION HEAT TREATMENT

22 Warpage generally occurs during solution heat treatment operation producing kinks, buckles, waves or twists particularly in formed parts. These imperfections are generally removed by straightening and flattening operations, or, in the case of the formed parts, by restriking.

23 Where the straightening operations produce an appreciable increase in the tensile and yield strengths and slight decrease in the percent of elongation, the material is in the "T3" temper. When these valves are not materially affected, the material remains in the "-T4" temper.

"-T4" TEMPER

24 In some cases for certain forming operations sheet material of naturally aged alloys is furnished in the "-T4" temper. This material is superior in ductibility to normal "-T3" material because the flattening operations used in its manufacture have been held to a minimum.

DIFFICULTIES

25 The following difficulties may be encountered when solution heat treating the aluminum alloys:-

(a) Low tensile and yield strength are caused by:-

(1) Inadequate "soak" or insufficient temperature.

(2) Slow transfer from the furnace to the quench tank.

(3) Slow quench.

(4) High temperature oxidization.

(b) Excessive diffusion in the cladded material is caused by:-

(1) Prolonged heating during solution heat treatment or during a previous high temperature annealing operation.

(2) Excessive number or re-heat treatments. In the lighter thickness, some diffusion to the surface is unavoidable with practices necessary to develop the desired mechanical properties.

(c) Intergranular corrosion is usually found after long exposure to a saline-bearing atmosphere. It drastically lowers the tensile strength and the percent of elongation. It is caused by:-

(1) Slow transfer from the furnace to the quenching media.

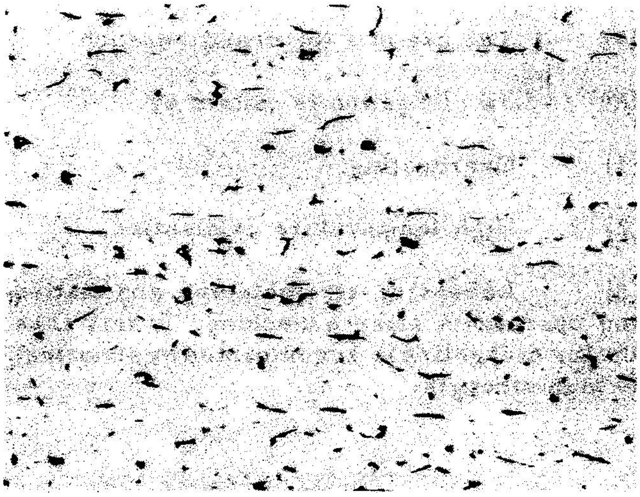

Figure 8-9 High Temperature Slow Cool Anneal 24S Alloy

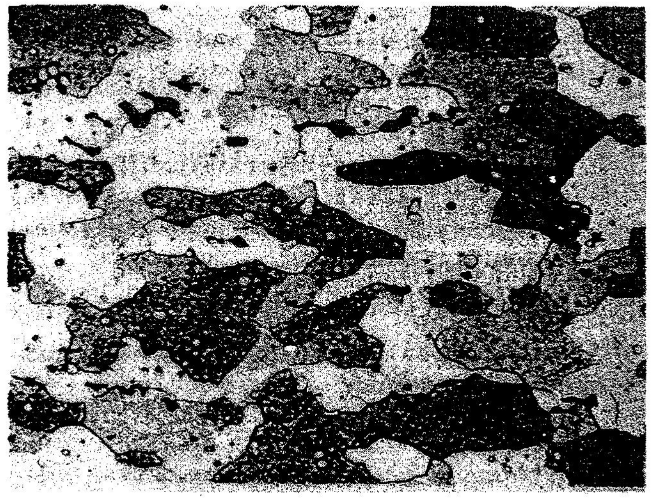

Figure 8-10 Insufficient Temperature Heat Treat R301 Alloy

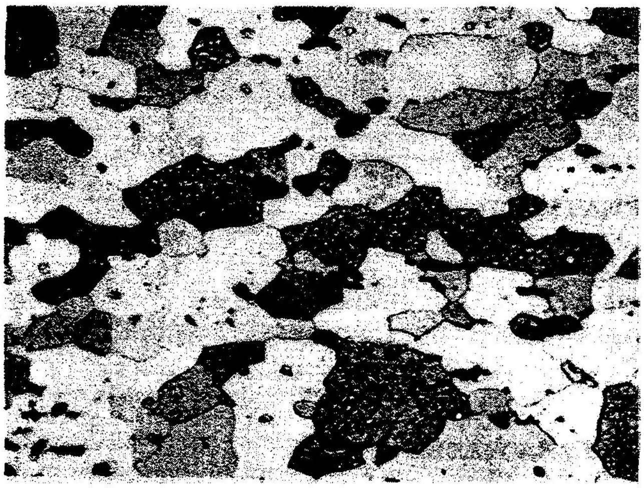

Figure 8-11 Properly Heat Treated R301 Alloy

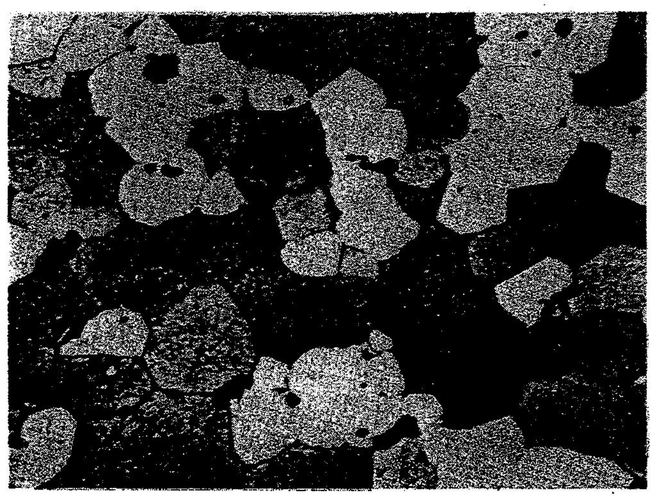

Figure 8-12 Incorrectly Heat Treated R301 Alloy

(2) Use of a mild quench.

(3) Uncontrolled or improper reheating to an elevated temperature after heat treatment.

(d) Overheating is also known as melting, eutectic melting, incipient melting, grain boundary melting or resetting. It results in loss of ductility and in severe cases produces blisters and reduces strengths. It also promotes cracking during quenching.

(e) High temperature oxidization, also known as high temperature deterioration, is generally confined to the bare products heat treated in air furnaces and is caused by:-

(1) Prolonged exposure at high temperature.

(2) Furnace atmosphere, being more prevalent in oil and gas fired furnaces.

(3) Presence of moisture and sulphur compounds.

(f) Quenching cracks generally occur during or after quenching heavy sections and pieces that have abrupt changes in cross section. They are caused usually by the use of a too drastic quench.

(g) Excessive distortion and warpage result from:-

(1) An excessive temperature differential between various areas of the material during the heating period caused by inadequate heat distribution in the furnace.

(2) Improper support of the material during the heating period.

(3) The use of a too drastic quench.

(h) Low elongation is caused by:-

(1) Overheating.

(2) High temperature oxidization.

(3) Excessive straightening and flattening operations after quenching. In this case, the low elongation is accompanied by abnormally high strength.

SECTION 5

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PRECIPITATION HEAT TREATMENT

1 As previously stated, the aluminum alloys are in a comparatively soft state immediately after quenching from a solution heat-treating temperature. To obtain their maximum strengths, they must be "aged" or "precipitation hardened".

2 During this hardening and strengthening operation, precipitation of the soluble constituents from the supersaturated solid solution takes place. As precipitation progresses, the strength of the material increases, often by a series of peaks, until a maximum is reached. Further aging (overaging) causes the strength to steadily decline until a somewhat stable condition is obtained.

3 Precipitation hardening produces a large increase in the strength and hardness of the material with corresponding decreases in the ductile properties. The process used to obtain the desired increase in strength is therefore known as aging or precipitation hardening.

4 The strengthening of the heat-treatable alloys by aging is not due merely to the presence of a precipitate. Instead, it is due to both the uniform distribution of a finely dispersed submicroscopic precipitate and the distortion and other effects of its formation upon the crystal structure.

5 The aging practices used depend upon many properties other than strength. As a rule, the artificially aged alloys are slightly "overaged" to increase their resistance to corrosion.

This is especially true with the artificially aged high copper-bearing alloys that are susceptible to intergranular corrosion when inadequately aged.

6 The heat-treatable aluminum alloys are subdivided into two classes - those that obtain their full strength at room temperature and those that require an artificial aging treatment.

7 The alloys that obtain their full strength four or five days at room temperature are known as "natural aging" alloys. Precipitation from the supersaturated solid solution starts soon after quenching with 90% of the maximum strength generally being obtained in twenty-four hours.

8 The alloys that require a precipitation thermal treatment to develop their full strength are referred to as "artificially aged" alloys. However, these alloys also age a limited amount at room temperature, the rate and extent of the strenghtening depending upon the alloys.

9 Many of the artificially aged alloys reach their maximum natural or room temperature aging strengths after a few days and can be stocked for fabrication in the "-T4" or "-T3" temper. Others continue to age appreciably over a long period ot time (e.g. some of the high zinc-bearing alloys), their mechanical property changes being sufficient to cause their formability to be constantly reduced. The ad vantage of the "W" temper formability can be utilized, however, in the same manner as with natural aging alloys and that is by fabricating shortly after solution heat treatment or by the use of refrigeration.

10 Refrigeration retards the rate of natural aging. At 0° C. (32° F.), the beginning of the aging process is delayed for several hours, while dry ice -10° to -38° C. (-50° to -100° F.) retards aging for an extended period of time.

11 The strengths of the natural aging alloys can be increased by subjecting the naturally aged material to a precipitation thermal treatment with a resultant decrease in the percent of elongation.

12 The presence of small amounts of cold work, subsequent to natural aging but prior to artificial aging, has a pronounced effect on the strength of 24S alloy. The increase in strength realized by this method is dependent upon the degree of cold work present.

13 Artificially aging the natural aging alloys increases the susceptibility of the material to intergranular corrosion. For this reason, the process is generally confined to cladded sheet, extrusions and similar products.

MECHANICS OF PRECIPITATION HEAT TREATMENT

14 The natural aging alloys 17S and 24S require only exposure at room temperature for several days to develop their full strengths. The other heat-treatable alloys require a controlled precipitation thermal treatment to develop their full strengths.

15 The degree of strengthening of a properly solution heat-treated alloy by precipitation or aging depends upon both time and the temperature. An increase in temperature decreases the time necessary to obtain maximum hardening. Thus, there may be several aging practices applicable to an alloy. Refer to Part 9, Section 3, paragraph 11.

16 The use of higher temperatures and shorter times generally produces lower elongation and higher yield strength whereas the lower temperature procedures develop higher elongation with slightly lower yield strength.

17 The elapsed time between quenching from solution heat-treating temperature and artificial aging has an effect on the properties obtained but is, at present only important with the high zinc bearing alloys such as 75S. This alloy requires an incubation period of at least twenty-four hours at room temperature prior to the precipitation thermal treatment to obtain the desired mechanical properties.

PRACTICES

18 The temperatures used for precipitation hardening depend upon the alloy and the properties desired. The time and temperature for each alloy and alloy form should be consistent with Table 52.

19 The rate of heating is not critical, but the material should be placed in the furnace in

Figure 8-13 Incorrectly Heat Treated R301 Alloy

such a manner that a large temperature differential between various parts of the load will not exist for an extended period of time. If this occurs, part of the material will receive an incorrect aging treatment.

20 On completion of the precipitation thermal treatment, material should preferably be air cooled to room temperature. Water quenching produces no harmful effects but furnace cooling has a tendency to produce over-aging.

DIFFICULTIES

21 The following difficulties may be encountered when artificially aging properly solution-heat treated material:-

(a) Low tensile and yield strengths are caused by:-

(1) Insufficient time or temperature during the precipitation thermal treatment, commonly referred to as "under-aging".

(2) Excessive time or temperature during the precipitation thermal treatment, commonly referred to as "over-aging".

(b) High yield strength and low elongation are often caused by the use of too high an aging temperature, or too long a soaking time.

(c) Low yield strength and high elongation are usually caused by the use of too low an aging temperature, or too short a soaking time.

(d) Intergranular corrosion is usually due to improper aging, particularly with the high copper-bearing alloys. Slightly overaging tends to reduce this fault.

PART 9

PROCESS FOR THE HEAT TREATMENT

SECTION 1

GENERAL

1 The following Sections of Part 9 of this Engineering Order presents the requirements for the heat treatment of aluminum alloy products for use in the construction, repair and overhaul of service aircraft. For more detailed information, refer to Specification MIL-H-6088.

2 The temperature required for the various thermal treatments vary from a minimum of 121 C. (250 F.) for precipitation thermal treatment to a maximum 543.3°C(1010°F.) for solution heat treatment. This wide range of temperatures, in conjunction with the close temperature control required and in some cases the fast heating rate, necessary to produce fine grained material, makes it desirable to consider the equipment for each of the thermal processes separately. However, it should be kept in mind that equipment for one type of thermal treatment may also be suitable for another type of treatment.

SECTION 2

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HEATING MEDIA

1 The heating media used are divided into two groups - liquid baths and gaseous atmospheres. Air-chamber furnaces or molten fused salt baths are acceptable for the heat treatment of aluminum alloys. Superheated steam, not in contact with the material, or oil baths, may also be used for the precipitation treatment.

AIR-CHAMBER FURNACES

2 Air-chamber furnaces are ideal for precipitation thermal treatment, for annealing and are rapidly adaptable for solution-heat-treating

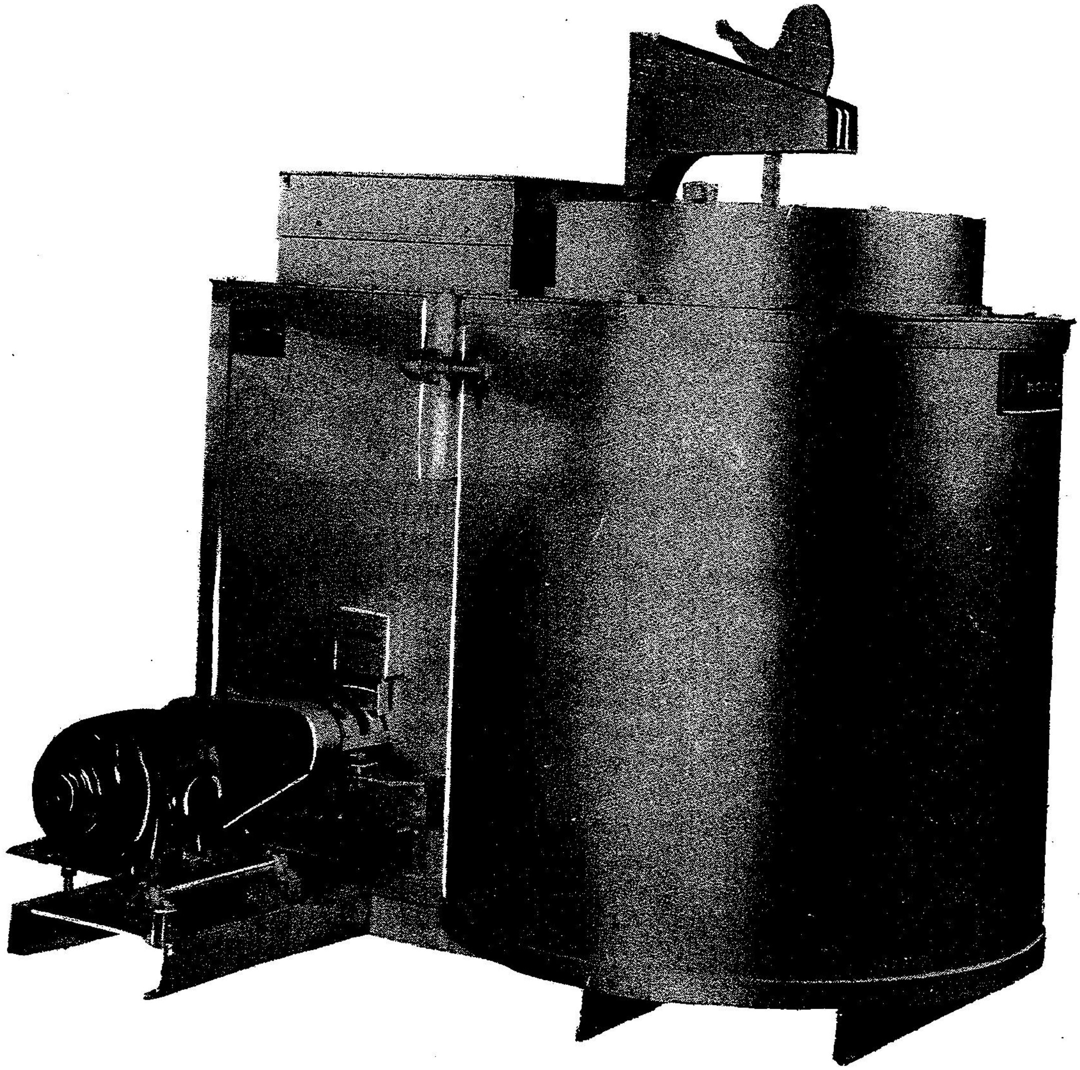

Figure 9-1 Electric Air Circulating Furnace

procedures. Air furnaces are also generally used if several alloys are to be heat treated with the same equipment since the temperature can be raised or lowered quickly.

3 When heat treating certain of the aluminum alloys, it is necessary to control the atmosphere in order to avoid high-temperature oxidation. Air-chamber furnaces, in which the products of combustion come in contact with the charge, may be used for heat treatment of only those products which have been demonstrated by test to be substantially free from high-temperature oxidation after heat treatment in the furnace.

4 The most desirable air furnaces for solution heat treating and annealing are the recirculating air types where the products of combustion are excluded from the furnace atmosphere or the electric heated air circulating furnace where no products of combustion exist.

5 Electrical heating elements and radiation tubes in air furnaces used for heating sheet, strips and other material of thin sections shall be so shielded that no direct radiation can strike any part of the furnace charge. This shielding is not required in furnaces used for heat treating heavy sectional material only, provided it has been demonstrated that the design of the furnace is such as to prevent localized overheating of the furnace charge.

SALT BATH FURNACES

6 The salt used in salt baths shall be of a type and grade which will not react corrosively

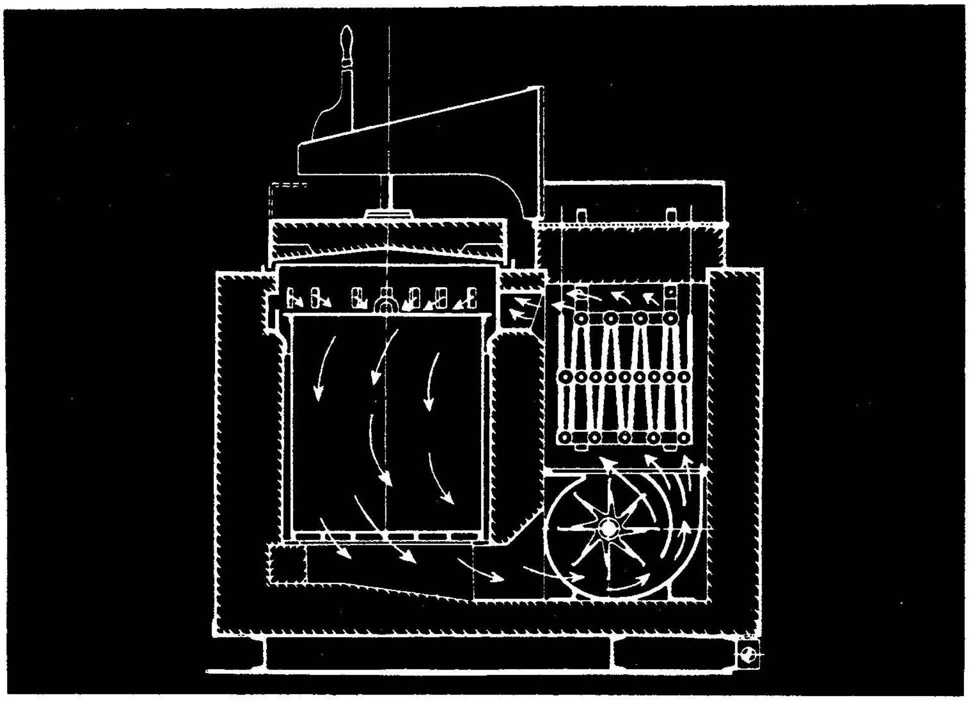

Figure 9-2 Sectional View Electric Air Circulating Furnace

with the alloys being heat treated, and such mixture shall not be explosive. Nitrate baths shall not be used in the heat treatment of 56S and 220 type alloys. Superficial surface discoloration of the other aluminum alloys by the salt bath shall not be cause for rejection.

7 There are many salt mixtures in commercial use, ranging from commercial fertilizer to a mixture of equal parts of sodium and potassium nitrates. A common mixture consists of 90% sodium nitrate and 10% potassium nitrite, the nitrite lowering the melting point of the mixture several degrees. There is no danger of high-temperature oxidation when heat-treating in molten salt. After prolonged use, there is some decomposition of the sodium nitrate to form compounds which, when dissolved in the quenching water, attack the aluminum alloys. The addition to the salt bath of approximately 1/2 ounce of sodium or potassium dichromate per 100 pounds of nitrate tends to inhibit this attack.

TEMPERATURE UNIFORMITY

8 The design and construction of the furnace shall be such that the temperature at any point in the working zone, for any normal charge shall be controllable within 5° C. (10° F.) o[f] the desired heat-treating temperature afte[r] the charge has reached operating temperature At no time shall the temperature in any part o[f] the working zone exceed the maximum permissible temperature for the alloy being hea[t] treated.

TEMPERATURE CONTROL EQUIPMENT

9 A sufficient number of suitable automati[c] temperature-control devices, properly arranged, shall be provided on all heat-treatin[g] equipment to assure adequate control of temperatures in all working zones. Good temperature control is a necessity in order to maintai[n] the work load within the ranges specified fo[r] the various treatments. It may be pointed ou[t] that a substantial portion of the difficultie[s] encountered in heat-treating aluminum alloy[s] is due to improper temperature control.

QUENCHING CONTROL

10 Cold water tanks shall be so located tha[t] the load can be transferred from the furnac[e] into the water with a minimum of elapsed time The maximum lapse of time for the coppe[r]

bearing alloys should not exceed ten seconds Means shall be provided for circulation of the quenching media and for cooling or chilling as necessary.

11 All water baths employed in quenching parts which have been heated in salt-bath furnaces shall be provided with an inflow of fresh water to prevent a concentration of dissolved salts in the tanks. Rinse tanks or sprays shall be employed for removing all salt residues from the surfaces of materials which have been immersed in molten salt baths.

SECTION 3

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PROCEDURE AND OPERATIONS

1 Heat-treating operations shall be performed on the whole of a part or piece of material, never on a portion only, and shall be applied in a manner that will produce the utmost uniformity.

2 Individual pieces of material or parts shall be racked or supported in such a manner as to permit free access of the heating or quenching media in order to facilitate bringing the entire load to a uniform temperature in a minimum time interval. It is very important when treating clad sheet in air-chamber furnaces that the charge be so spaced as to permit the entire load to come quickly to the specified temperature range. Charges of clad alloys involving various thicknesses of material shall be avoided as much as possible.

SOLUTION HEAT TREATMENT

3 Aluminum alloy products shall be solution treated within the temperature ranges specified in Table 48.

4 The charge shall be held within the specified solution temperature range after the coldest part of the load has reached the minimum of the range for a sufficient period of time to ensure that the specified properties will be developed. Suggested holding periods are given in Tables 49, 50 and 51.

5 When a charge includes parts of various thicknesses, whether in an assembly, in separate pieces, or as overlapping members, the soaking period shall be determined by the thickness of the maximum section. The time interval between opening the heat-treating furnace or starting to remove the charge from the salt bath and complete immersion of the charge in the quenching media, shall be the minimum practical.

6 Wrought-alloy products in 14S, 17S, A17S, 24S, 75S and R301 alloys (except forgings) should be quenched by total immersion in water at a temperature not higher than 37. 8°C (100°F) at the completion of the quenching operation.

7 The use of high-velocity, high-volume jets of cold water in which parts are thoroughly and effectively flushed is satisfactory for quenching wrought alloys provided the parts so quenched will pass the corrosion test described in Specification MIL-H-6088.

8 When the use of a cold-water quench will result in too great distortion of a finished part, the use of oil, hot water, water spray, or forced-air draft on clad material is satisfactory, provided that the parts will not be subject to sever conditions of corrosion in service and provided that the section thickness is such that the required mechanical properties can be developed after the milder quench.

9 Rivets, washers, spacers and small parts are to be quenched by dumping into cold water or by immersion into cold water a wire mesh basket or tray that contains the parts.

10 Castings, except those of the 220 alloy, and forgings shall be quenched by total immersion in water at 66°-100°C. (150° -212° F.). When quenching 75S alloy forgings, the temperature of the water shall be not less than 60°C. (140°F.).

PRECIPITATION HEAT TREATMENT

11 After solution heat treatment and quenching, materials should be given an appropriate heat treatment to develop the specified characteristics and properties. Time-temperature cycles are presented in Table 52 for use as an approximate guide.

12 The following aging treatment may be used in lieu fo the 24-hour treatment on 75S and clad 75S sheet only.

(a) Interrupted treatment: Heat at 93°-100° C. (200° -212° F.) for four hours, cool to room temperature and then heat at 154° - 160°C. (312° -320° F.) for eight hours.

(b) Interrupted treatment: Heat at 110°-121°C. (230° -250° F.) for three to four hours, air cool to below 38°C. (100° F.) and then heat at 156° - 168° C. (315° -335°F.) for three to four hours.

(c) Progressive treatment: Heat at 93°-100°C. (200°-212°F.) for four hours, increase temperature to 154° -160° C. (310°-320°F.) and heat for eight hours. (Do not cool between steps).

(d) Progressive treatment: Heat at 90°-95°C. (195°-205°F.) for four hours; increase temperature to 118° -124° C. (245°-255°F.) and heat for four hours; increase temperature to 146° - 151° C. (295°-305°F.) and heat for four hours. (Do not cool between steps).

REHEAT TREATMENT

13 The heat treatment of material which has been previously heat-treated shall be considered as a reheat treatment. Accordingly, the first heat treatment of material purchased in the heat-treated condition shall be considered as a reheat treatment. Annealing shall not be considered a heat treatment for the purpose of this paragraph.

14 Clad alloys may be reheat treated (solution treated) not more than once for thickness under 0. 125" and twice for over 0. 125" thickness. Rivets, washers, spacers and other small parts which have been anodically oxide coated shall not be reheat treated in direct contact with molten salts more than five times.

ANNEALING TREATMENTS

15 The provisions of paragraphs 16 to 18 inclusive are not mandatory, provided the annealed material meets all the requirements of the applicable material specification.

16 For the work-hardened wrought alloys other than 3S, annealing should be accomplished by heating to 343°C. (650°F.) or above, holding at temperature until uniform temperature has been established throughout the furnace load, and cooling in air or in the furnace. The maximum permissible annealing temperature is not critical, but should not exceed 399°C. (750°F.) to prevent surface oxidation and grain growth. 3S alloy should be heated to 399°C ± 9°C. (750° ± 15°F.) using a relatively rapid heating rate and the minimum soaking period necessary to attain temperature uniformity,

17 Annealing of heat-treated alloys other than 75S alloy should be accomplished by heating to 413° C. (775° F.) ± 14° C. (25° F.) and holding at this temperature for not less than one hour. The material should be cooled at a rate not greater than 28°C. (50° F.) per hour until the temperature is below 260° C.(500° F.). The rate of cooling from 260° C. (500° F.) is not restricted. Full annealing of 75S material should be accomplished by heating to 413° C.-454° C. (775° F.-850° F.) (the higher temperature being required for material having the smaller amount of cold work) soaking for two hours at this temperature, cooling in air, re-heating to 232° C. (450° F.) ± 5° C. (10° F.) holding at this temperature for two hours, and cooling to room temperature.

18 Castings should be annealed by heating within the temperature range 343°-399° C. (650°-750° F.) soaking at this temperature for two hours, and cooling to room temperature. The purposes of such annealing are the relief of stresses and the attainment of dimensional stability.

19 When materials in the heat-treated condition are given an anneal as described in paragraph 16 (for work-hardened materials) the effects of the heat treatment are removed in considerable measure, but not completely. This partial anneal may be employed when moderate, but not severe, forming operations are to be performed.

SOLUTION HEAT TREATING TEMPERATURES

ALLOY	TEMPERATURE (DEGREES F.)
WROUGHT (EXCLUDING FORGINGS)ALLOYS	
14S and 17S	925 - 950
A17S	890 - 950
(1)24S and Clad 24S	910 - 930
53S	960 - 980
61S	960 - 1010
63S	960 - 980
75S(extruded bars, shapes and tubing)	860 - 880
75S and Clad 75S (rolled or drawn products)	860 - 930
R301 and Clad 14S sheet	925 - 950
FORGING ALLOYS	
14S	925 - 950
17S	925 - 950
18S	940 - 970
25S	950 - 970
32S	940 - 970
A51S	950 - 980
53S	950 - 980
61S	960 - 1010
75S	860 - 890

Table 48 (Cont'd on page 83)

SOLUTION HEAT TREATING TEMPERATURES (Cont'd)

ALLOY	TEMPERATURE (DEGREES F.)
SAND CAST ALLOYS	
108	920 - 950
122	930 - 960
142	950 - 980
195	940 - 970
S195 (105)	940 - 970
220	800 - 820
319	920 - 950
355	960 - 990
356	980 - 1010
40E Solution heat treatment not required	
PERMANENT MOULD CAST ALLOYS	
122	930 - 960
A132	940 - 970
142	950 - 980
B195	935 - 965
319	920 - 950
355	960 - 990
356	980 - 1010

(1) Temperature lower than 488 C. (910 F.) may be employed in the solution heat treatment of 24S alloy provided the material is tested and the properties conform to the requirements of the applicable specification.

Table 48

SUGGESTED SOAKING TIME FOR SOLUTION TREATMENT WROUGHT ALLOYS (EXCLUDING FORGINGS)

ALLOY	TIME FOR GIVEN THICKNESS(MINUTES - INCHES (1)			
	Under 0.032	0.032 0.125	0.125 0.250	Over 0.250
Clad 14S and R301 (2)	7	15	25	45
14S	-	-	30	60
A17S	20	20	30	60
17S	20	20	30	60
24S	30	30	40	60
Clad 24S (2)	20	30	40	60
53S	20	30	40	60
61S	20	30	40	60
63S	20	30	40	60
75S	25	30	40	60
Clad 75S	20	30	40	60

(1) Measured from the time at which the load reaches the minimum heat-treating temperature.

(2) For clad material, the time at temperature shall be a minimum compatible with resultant specified physical properties in order to prevent excessive diffusion.

Table 49

SUGGESTED SOAKING TIME FOR SOLUTION TREATMENT OF FORGED ALLOYS

ALLOY	TIME FOR GIVEN THICKNESS (HOURS)	
	UP TO 2 INCHES	OVER 2 INCHES
14S	0.5 - 6	2 - 12
17S	0.5 - 6	2 - 12
18S	0.5 - 6	2 - 12
25S	3.0 - 6	4 - 12
32S	0.5 - 6	2 - 12
A51S	0.5 - 6	2 - 12
53S	0.5 - 6	2 - 12
75S	0.5 - 6	2 - 12

Table 50

SUGGESTED SOAKING TIME FOR SOLUTION TREATMENT CAST ALLOYS

ALLOY	TIME (HOURS)
SAND CAST ALLOYS	
108	6 - 24
122	6 - 24
142	2 - 16
195	6 - 24
S195 (105)	6 - 24
220	12 - 24
319	6 - 12
355	6 - 24
356	6 - 24
PERMANENT MOULD CAST ALLOY	
122	4 - 12
A132	4 - 12
142	2 - 12
B195	4 - 12
319	4 - 12
355	4 - 12
356	4 - 12

Table 51

SUGGESTED PRECIPITATION HEAT-TREATING CONDITIONS

ALLOY	Aging Time (Hours)	Aging Temperature (Degrees F.)
WROUGHT ALLOYS (EXCLUDING FORGINGS)		
A17S-T4, 17S-T4, 24S-T4, Clad 24S-T4	96	Room Temperature
14S-T6	8	340 - 360
	5	350 - 370
53S-T6, 61S-T6, 63S-T6	12 - 20	310 - 330
53S-T6, 61S T6	6 - 10	340 - 360
R301-T and Clad 14S-T6	18	310 - 330
75S-T6, Clad 75S-T6	24	240 - 260
FORGING ALLOYS		
14S-T6	5 - 14	330 - 360
14S-T4, 17S-T4	96	Room Temperature
18S-T6	4 - 12	330 - 350
25S-T6	6 - 14	330 - 350
32S-T6	4 - 12	330 - 350
A51S-T6	4 - 12	330 - 350
53S-T6	6 - 10	340 - 360
75S-T6	12 - 20	310 - 330
	24	240 - 260
SAND CAST ALLOYS		
142-T61	1 - 3	400 - 450
195-T6	1 - 6	300 - 320
S195-T6	1 - 4	300 - 320
220	96	Room Temperature
319-T6	1 - 6	300 - 330
355-T6	1 - 6	300 - 320
356-T6	1 - 6	300 - 320
356-T51	6 - 12	430 - 450
40E	9 - 11	345 - 365
40E	21 days	Room Temperature
PERMANENT MOULD CAST ALLOYS		
142-T61	1 - 3	400 - 450
B195-T6	1 - 8	300 - 320
319-T6	1 - 6	300 - 330
355-T6	1 - 6	300 - 320
356-T6	1 - 6	300 - 320
A132-T65	14 - 18	300 - 350

Table 52

PART 10

FORMING

SECTION 1

GENERAL

1 Conventional methods are all that are required to complete most of the shaping and forming of aluminum alloys. It is mandatory, however, that precautions be taken when handling the sheet alloys to avoid marking the surfaces. Most sheet aluminum alloys are supplied in a bright finish and scratching or marking the surfaces not only mars the appearance but in the clad materials reduces or destroys the resistance to corrosion provided by the aluminum coating.

2 Hold-down pads or bars on shears and brakes should be faced with rubber or other shock-absorbing material to avoid marking the sheet surface. Shear beds and benches used for handling aluminum sheets in and out of the shear are invariably rough, causing scratches and other undesirable scuffing of the sheet. Such surfaces should be covered by shellacking heavy cotton flannel to these faces.

3 In order to successfully form aluminum alloys, it is necessary to understand the mechanical properties of the alloy. As the degree of temper increases, the plastic and elastic ranges decrease, making forming more difficult to accomplish and control. Material must be stressed beyond its yield strength in order to permanently form it to a desired shape or contour, otherwise it will tend to return to its original shape. Thus material insufficiently stressed will spring back in proportion to the amount of stress applied. Although very little spring-back will be encountered in the use of "O" (annealed) plate and sheet, it will occur when forming tempered material. The exact amount of spring-back is difficult to compute. Therefore, tools should be provided with adjustments for overbending unless preliminary experiments are undertaken to determine the materials spring-back characteristics.

SECTION 2

SHEARING AND SLITTING

1 Regular conventional methods are all that are required to shear and slit aluminum alloys. While closer clearances are required between the guillotine shear blades for annealed material than for tempered and heat-treated material, slitter knives having a clearance of 0.0015" will suffice for all alloys and tempers. No rake is required for slitter knives.

2 Shearing energy can be determined by Formula 1. Ultimate strength in pure shear can be found for the various alloys in Tables 9 to 14 inclusive and illustrations showing the application of the formula are shown in Figure 10-3.

SHEARING ENERGY

$\frac{LtVS}{2000}$ = Shearing energy, inch tons.

L = Length of cutting edge, inches.

t = Thickness of material, inches.

V = Working stroke, inches (penetration to effect shearing)

S = Ultimate shear strength of material in psi.

Formula 1

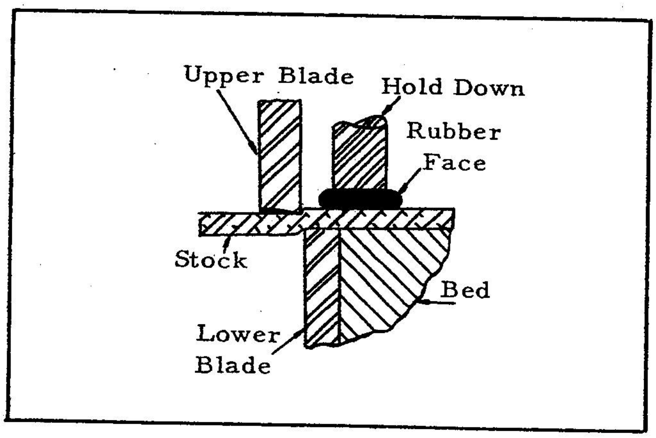

Figure 10-1 Shear Setup Diagrammed

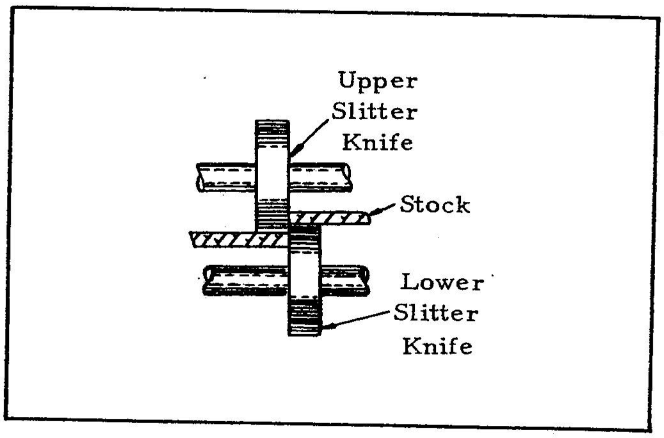

Figure 10-2 Slitter Setup Diagrammed

SECTION 3

BENDING

1 Many methods may be employed to bend sheet aluminum alloys. However, each temper of an aluminum sheet alloy establishes a specific workability characteristic that must be considered in planning operations for bending it. In addition, bending characteristics vary with a difference in thickness. It becomes especially important therefore, that consideration be given these factors and that recommended standards be used for determining bend radii in forming. These standards are shown in Table 53. The factor is expressed in terms of thickness of the sheet, e.g. 3 S3/4H sheet 0.182" thick, has a bend radius factor of 3 which means the sheet can be cold bent 90 over a radius of approximately 3 x 0.182" or 0.546". Alclad sheet can be bent over slightly smaller radii than the corresponding tempers of the bare alloy.

2 As is noticeable in Table 53, certain alloys and alloy tempers can be cold formed at 90° on a zero or sharp bend. Others must be formed on certain stipulated radii. It is essential that the metalworker know what allowances to make for both sharp bend and radii forming in order to properly calculate the dimensions of the material required in the flat. This is especially important where several bends are required in the production of a part. Formula 2 is recommended for radius bending the aluminum alloys. The inside bend radius may be computed from Table 53 which shows the radius for a 90° bend. Formula 3 is recommended for zero 90° bending.

RADIUS BENDING

$$L = \frac{2 \times 3.1416 \times a}{360} \times (r + .40t)$$

L = Length to allow in inches.
a = Total number of degrees bending takes place.
r = Inside bend radius in inches.
t = Material thickness in inches.

Formula 2

SHARP 90° BEND

Material Thickness	Allowance
.023	None
.025 - .032	1/32"
.036 - .051	1/16"
.057 - .064	3/32"
.072 - .091	1/8
.102 - .128	3/16
.144 - .162	1/4
.182 - .204	9/32
.229 - .289	3/8

FORMULA - Add all outside dimensions and subtract the number of bends x the allowance figure above. For 45° bends subtract 1/2 the allowance figure for each bend.

Formula 3

Part 10
Section 3

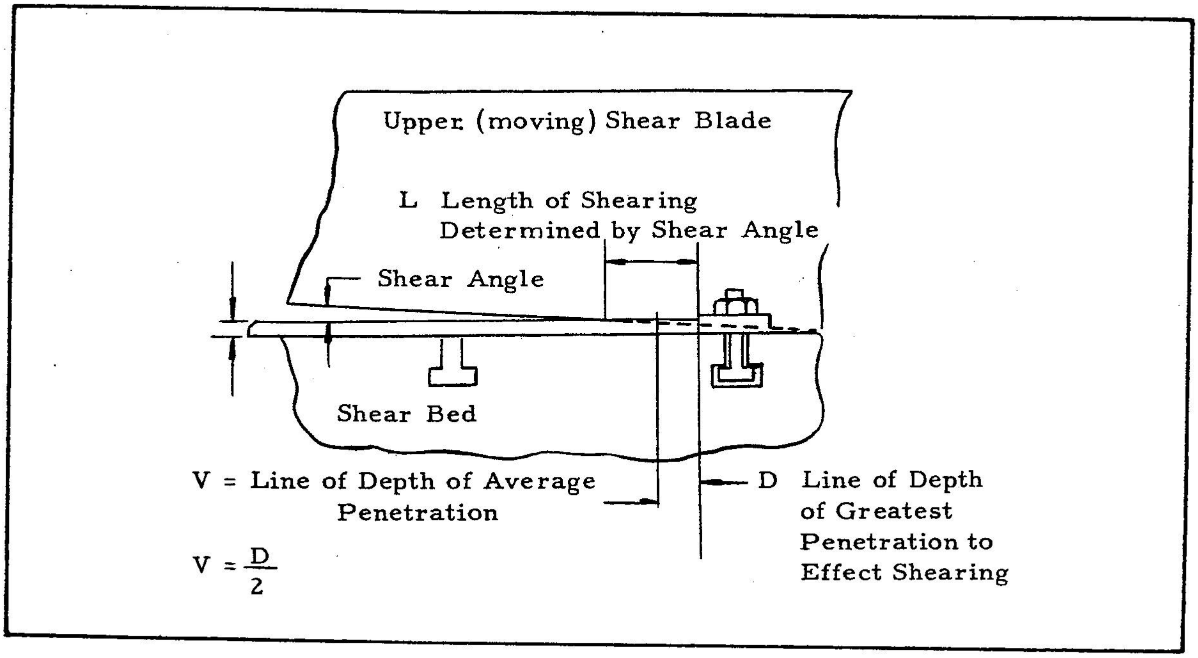

Figure 10-3 Guillotine Shearing

BEND RADIUS FACTOR FOR 90° COLD BEND - SHEET

ALLOY AND TEMPER	THICKNESS IN INCHES					
	0.258 - 0.183	0.182-0.129	0.128 - 0.065	0.064-0.033	0.032-0.016	0.015 ---
2S-O	0	0	0	0	0	0
2S-1/4H, H12	1	0	0	0	0	0
2S-1/2H, H14	1	1	0	0	0	0
2S-3/4H, H16	3	2	1.5	1	0	0
2S-H, H18	4	3	2	1.5	1	0
3S-O	0	0	0	0	0	0
3S-1/4H, H12	1	1	0	0	0	0
3S-1/2H, H14	1 1/2	1	1	0	0	0
3S-3/4H, H16	4	3	2	1.5	1	1
3S-H, H18	6	5	4	3	2	1
24S-O	1	1	0	0	0	0
24S-T	7	6	6	5	4	3
24S-T3	5-7	4-6	4-6	3-5	2-4	1.5-3
24S-T36	6-10	5-7	4-6	3-5	3-5	2-4
57S-O	0	0	0	0	0	0
57S-1/4H, H32	5-1.5	0.1	0-1	0	0	0
57S-1/2H, H34	3	2	1.5	1	0	0
57S-3/4H, H16	4	3	2	1.5	1	1
57S-H, H18	6	5	4	3	2	1

Table 53 (Cont'd on page 91)

BEND RADIUS FACTOR FOR 90° COLD BEND - SHEET (Cont'd)

ALLOY AND TEMPER	THICKNESS IN INCHES					
	0.258 - 0.183	0.182-0.129	0.128 - 0.065	0.064-0.033	0.032-0.016	0.015 ---
65S-O	0	0	0	0	0	0
65S-W	4	3	2	1.5	1	1
65S-T	4	4	3	2	1.5	1
65S-T4	2-4	1.5-3	1-2	.5-1.5	0-1	0-1
65S-T6	2-4	2-4	1.5-3	1-2	.5-1.5	0-1
75S-O	1.5-3	1-2	.5-1.5	0-1	0	0
75S-T	6	5	4	3	3	2
75S-T6	10	7	6	5	5	4

Table 53

SECTION 4

BLANKING AND PIERCING

1 Blanking aluminum sheet is the same as blanking other metals with the exception of punch and die clearances. Since there are a considerable number of alloys produced in various tempers, and since in actual practice it has been noted that clearances can be evaluated very closely in relation to the shear strength of the material, a simple method of determining punch and die clearances is to determine the shearing strength of the material from Tables 9 to 14 and establish the proper clearance from data in Table 54.

BLANKING TOOL CLEARANCES

Shear Strength PSI	Die Size
Up to 10,000	Punch Size + .12t
10,000 to 12,000	Punch Size + .13t
12,000 to 15,000	Punch Size + .14t
15,000 to 18,000	Punch Size + .15t
18,000 to 24,000	Punch Size + .16t
24,000 to 30,000	Punch Size + .17t
Above to 30,000	Punch Size + .18t
t = Sheet Thickness	

Table 54

2 Blanking punches should be made from annealed tool steel and dies of hardened tool steel. Surfaces of both should be ground. Press loads may be reduced, if desirable, by angle-grinding the face of the punch or die. If the blank is to be flat, the angle-grinding must be done on the die. If the material being blanked is to be kept flat, the angle grinding should be done on the punch. Blanking tools should preferably be mounted on guide pin die sets.

3 The shearing edges of blanking tools and the sheet material should be kept well lubricated at all times. Material having a low shearing strength requires the use of a heavier lubricant than one of higher strength.

4 Shearing energy for blanking can be determined by use of Formula 1. Blanking pressures can be calculated from Formula 4 which is based upon the employment of flat punches and dies. When shear is provided on faces of punches or dies by angle-grinding as stated above, blanking pressures can be computed by use of the Formula 5.

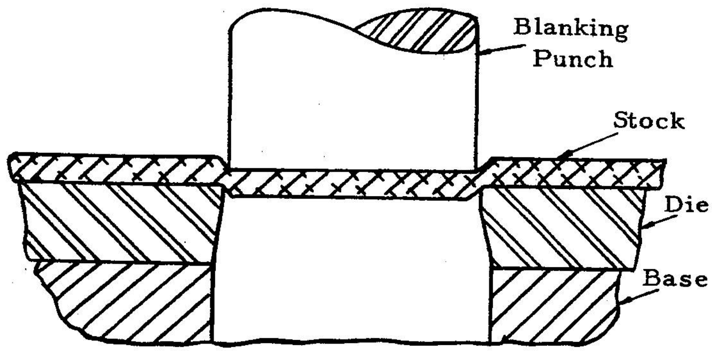

Figure 10-4 Punch Action in Blanking and Piercing

BLANKING PRESSURES - NO SHEAR

$\frac{Lts}{2000}$ = Maximum blanking pressure, tons.
L = Length of cutting edge, inches.
t = Thickness of material, inches.
s = Ultimate shear strength of material, psi

Formula 4

BLANKING PRESSURES - SHEAR PROVIDED

$\frac{\frac{Lts}{2000} \times t}{t + Sh}$ = Maximum blanking pressure, tons.
L = Length of cutting edge, inches.
t = Thickness of material, inches.
s = Ultimate shear strength of material, psi
Sh = Amount of shear, inches.

Formula 5

5 What has already been outlined in regard to blanking procedure also applies to the piercing of aluminum alloys. With the exception of punch and die clearances, clearances for piercing or perforating should be kept to an absolute minimum, a suggested size for dies being the punch size plus 5% of the metal thickness.

6 Sufficient die relief, at least 0.75°, should be provided for a quick "get away" of the punchings. Attempts to pierce holes of a size or diameter less than the metal thickness will usually cause excessive punch breakage. Smooth sheared edges of small pierced holes, similar to a reamed hole, can be obtained by pre-piercing slightly under-size followed by "shaving" to required size, using angle-ground punches.

7 Stripping is a function of blanking and piercing inasmuch as the metal being blanked tends to grip the punch after the actual shearing and as the punch returns from the die. The required stripping pressure necessary to strip metal from a punch is generally considered to be approximately 1/8 of the maximum blanking pressure.

SECTION 5

SPINNING

1 Spinning of aluminum is the most specialized of all the forming operations and requires highly trained personnel. Many aluminum parts are produced by spinning due to its ease of spinning and the reduced cost of spinning in comparison to other methods of forming.

2 Proper flow of the aluminum is as important in spinning as in drawing. Wrinkles and buckles must be avoided. If they appear during spinning, it is a good indication that the metal is being worked too fast, meaning that too great a reduction is being attempted in one operation.

3 When break-down spinning is necessary, it is essential to retain a flange on the shell to provide sufficient stiffness and rigidity as well as control of metal flow in subsequent operations.

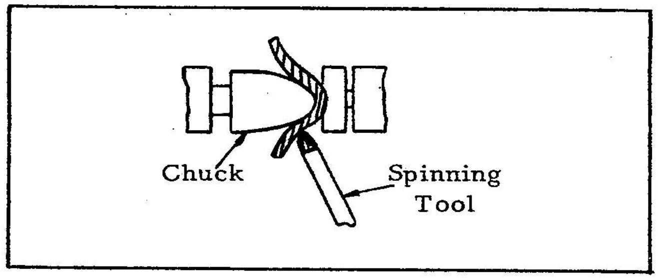

Figure 10-5 Making a Spun Part

4 Spinning and trimming should always be done slightly below the axial centre line of the lathe.

5 Aluminum is readily spun on hardwood chucks, usually of maple. They are ordinarily of segmented and laminated construction, all joints staggered and firmly glued. Wood chucks

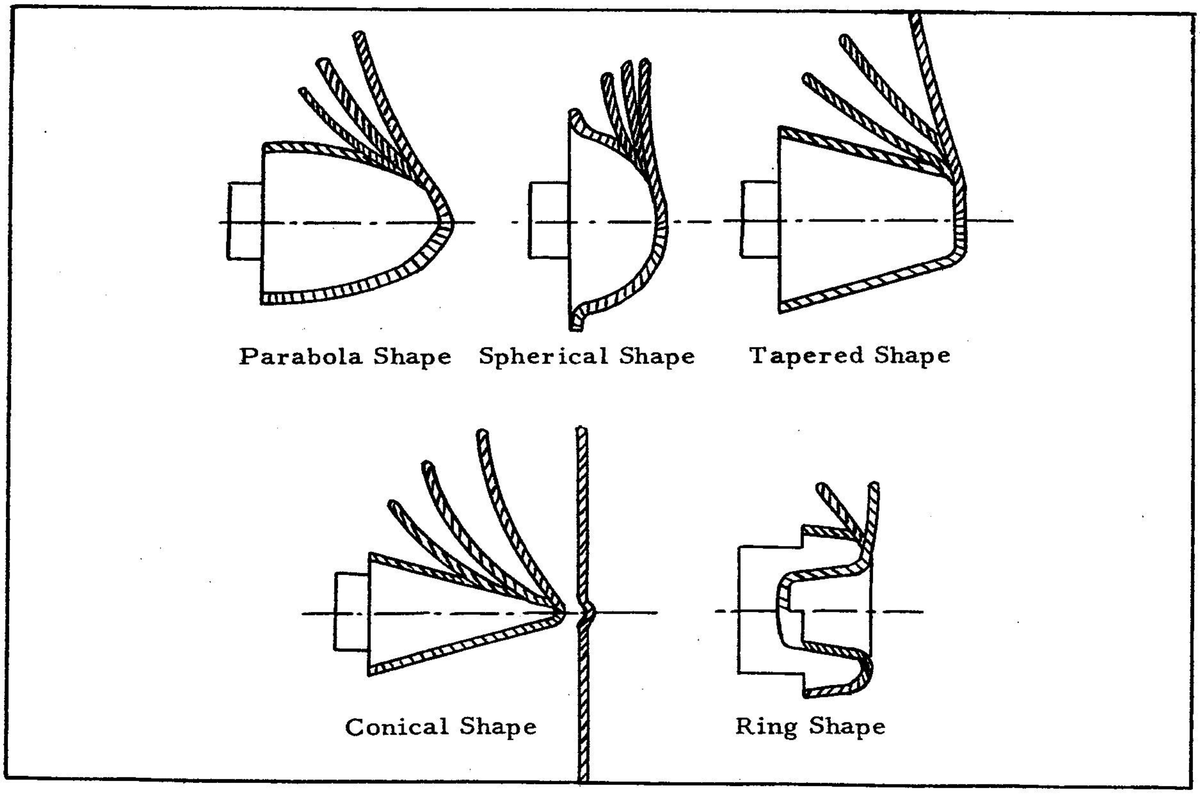

Figure 10-6 Typical Spun Shapes

cannot be turned sufficiently smooth to entirely eliminate all evidence of chuck construction on the inside of the spinning. However, generous shellacking of the chuck surface minimizes marking of the spinning and also protects the chuck surface. Metal chucks should have highly finished surfaces. Cast iron or steel draw punches are quite often used as spinning chucks when adapted to the lathe spindle.

6 Hand spinning tools are rather simple but must be rigid and of high quality. Break-down operations are generally done with a plain hickory stick with a well rounded end. Finish spinning employs a highly polished forged steel tool with a wood handle to reduce its overall weight. Mechanical spinning tools are usually attached to holders actuated from the lathe slides or from an arrangement attached to the chuck itself. Most mechanical spinning tools are the roller type.

7 Aluminum spinnings are generally started from blanks of annealed material. Alloys 2 S-O and 3 S-O are commonly used because of their low rate of work hardening, making it possible to produce relatively difficult spinning without the necessity of intermediate annealing.

8 Alloys containing magnesium and other hardening elements such as silicon, work harden at a faster rate. They should be spun on metal chucks due to the substantially greater pressure required. They also require more break-down operations than the more ductile alloys and intermediate annealing becomes more of a necessity. Heat-treatable alloys can be spun roughly in the annealed condition, heat treated and quenched, and immediately finish spun before excessive natural aging takes place.

9 Lubrication during spinning is essential. Ordinary naphtha laundry soap is usually preferred. Other suitable lubricants are tallow, pump grease, beeswax and lard oil-white lead mixtures.

10 The proper speed to employ for spinning aluminum is governed by the experience and skill of the spinner. Peripheral speeds of approximately 3000 feet per minute are recommended.

11 Blank size for spun parts are determined by the same procedure used for drawn shells; that is, the blank size should equal in area, the area of the final part. This assures ample metal and when there is considerable thinning of the metal in spinning, the actual developed blank will be somewhat smaller than the computed size.

12 It is difficult to produce spinnings without some thinning of the metal thickness in certain areas. Therefore, thickness of the starting blank should be increased when the permissible reduction is not sufficient for spinning. Experienced operators will have learned how to control the flow of the metal and consequently require less allowance for spinning than those of lesser experience and skill.

13 Various shapes and information on usual spinning methods are shown in Figure 10-6.

SECTION 6

FORMING CHARACTERISTS OF TUBING

1 Forming aluminum alloy tubing and pipe can be accomplished by conventional methods used for other alloys. It is necessary, of course, to become thoroughly informed regarding the mechanical properties of the tubing and pipe alloys for successful bending.

2 The stretch property (elongation) of aluminum tubing is the major factor for consideration in forming. The tensile properties are also very important. An aluminum alloy having good stretch properties and reasonably high tensile strength is desirable for forming. An alloy with high stretch properties and low tensile strength, while the easiest to bend, will require careful tooling to avoid fracturing, flattening and collapse of the inner wall. Such collapse will occur if the ability of the alloy to absorb compressive stresses is exceeded.

3 The stretch and shrink properties of aluminum alloys, like other alloys, are proportionately less for thin cross-sections than for heavier ones. This means that the minimum possible bending radius will increase in proportion to a decrease in wall thickness. Thin-wall tubing is especially susceptible to fracturing or buckling unless extreme care is used to confine the shape properly in the forming tools. Naturally, the tools must be of the best design, and the actual bending must be done with generous and effective lubrication and at a steady and reasonably moderate speed.

4 It is not recommended to bend aluminum tubing hot. However, if this is necessary, the temperature of the alloy should not exceed 190°C. (375°F.).

MACHINE FORMING

5 Tube bending on machine formers, Figure 10-8, where the tube is clamped at one end and is pulled around a hub could better be described as tube drawing. What actually takes place is similar to drawing parts from sheet. Where the tensile stresses are exceptionally high, a certain degree of stretching takes place, and where metal is flowing from a larger area into a smaller area, compressive stresses are encountered. This is illustrated in Figures 10-7 and 10-9. Diagram 10-9 shows how the wall thickness of the tube thins out on the outside of bend and thickens on inside of the bend.

6 It has been observed that these stresses are not constant throughout the forming cycle, but vary in proportion to the length of the forming or bending arc. They reach their maximum intensity within a 90° bending arc. Forming over a longer arc than 90° does not create greater stresses.

7 The cause of the variation in stresses is the direct result of compressive forces and increased friction developing in intensity as the forming progresses. These forces are zero at start of forming. Before these forces have sufficient effect to create tensile stress in the tubing beyond its elastic limit, actual drawing

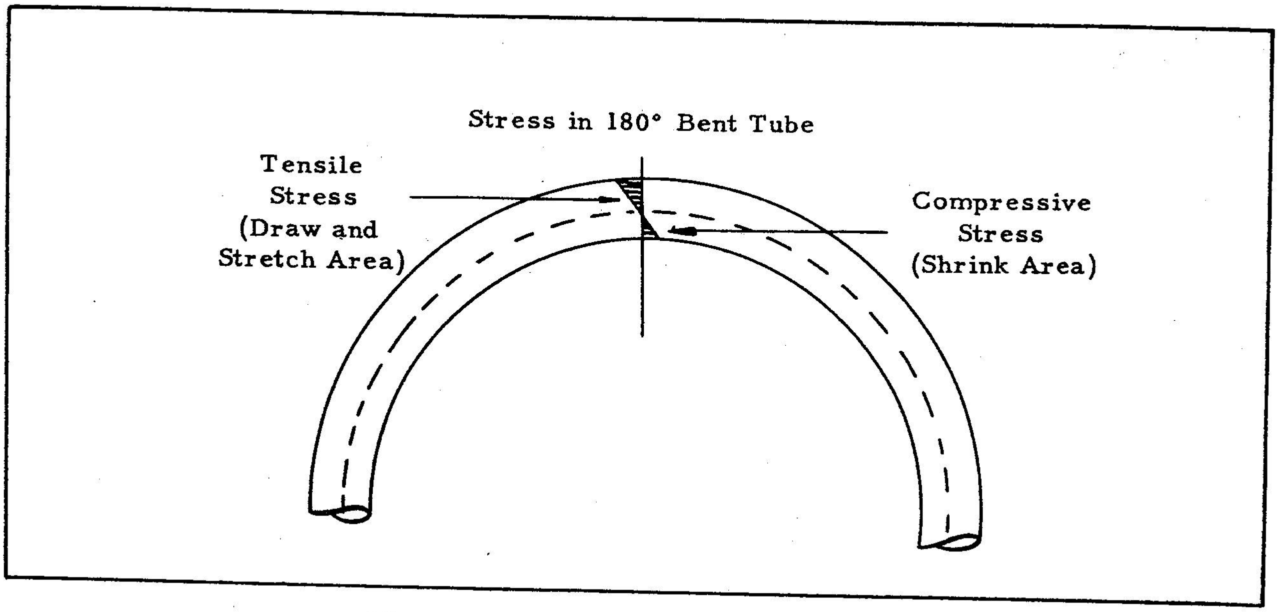

Figure 10-7 Stress in 180° Bent Tube

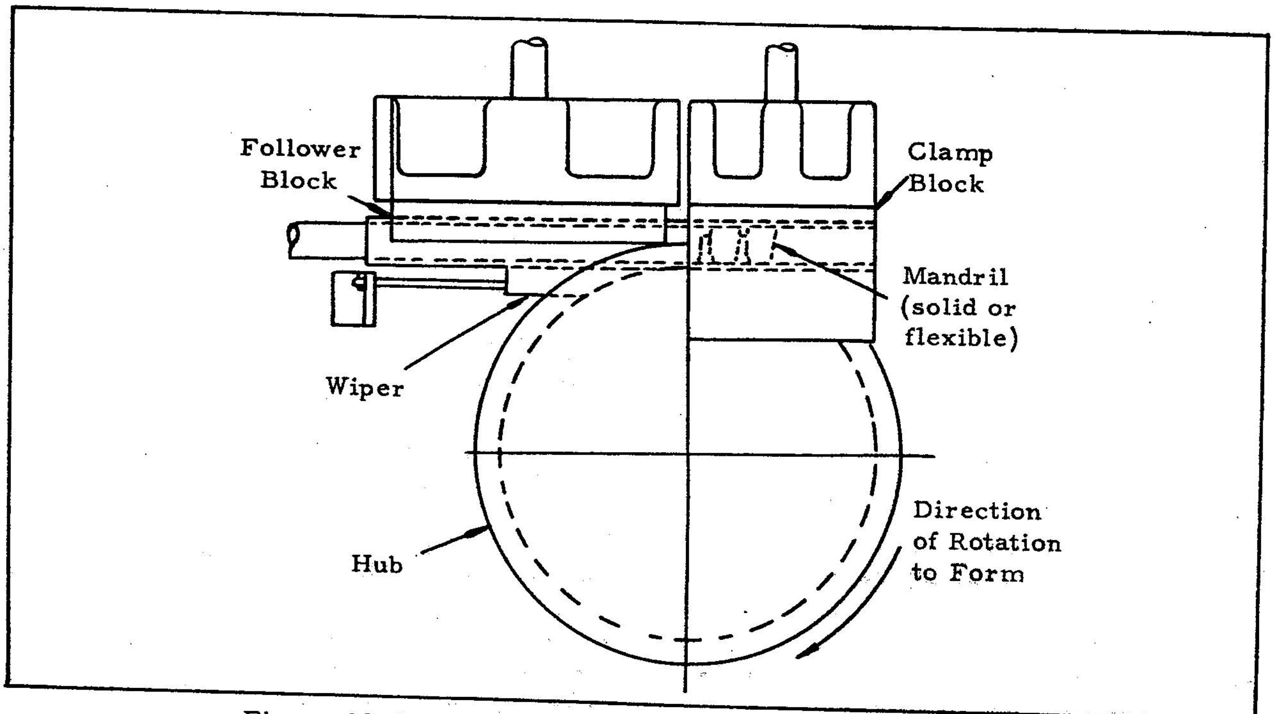

Figure 10-8 Functional Parts of Tube Bending Machine

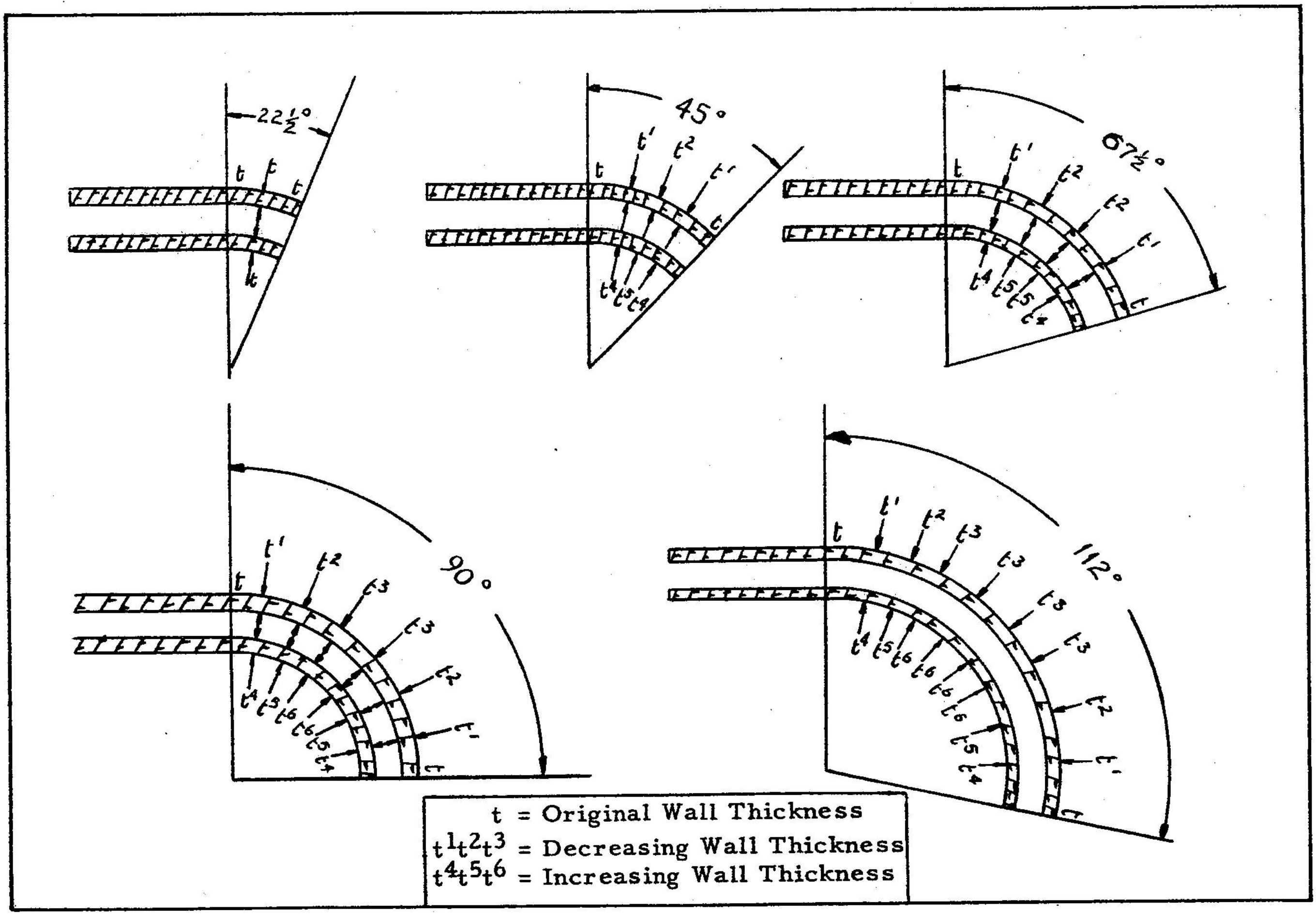

Figure 10-9 Diagrammatical Cross Section of Bent Tubes

of the tubing around an arc of the forming hub is taking place.

8 It is estimated that the first 22 1/2° arc of a bent tube is primarily a drawn tube. As forming progresses past the first 22 1/2° arc, the already drawn portion becomes stressed beyond its elastic limit and starts to stretch. At the same time, additional tubing is drawing into the stretch zone.

9 As pointed out above, the maximum forming stresses are reached within a 90° arc. Since it is considered practical to establish stretch values for aluminum tubing on the basis of a gauge length equal to four times the tubing diameter, such gauge length can be used as the outside radius of a tube formed through a 90° arc.

10 The outside surface is the point of greatest tensile stress and resultant elongation. Using this as a starting point as illustrated in Figure 10-9, and by estimating the average stretch values and base wall thicknesses from available data, a workable formula can be developed. With complete and proper tooling, it should be possible to form aluminum alloy tubing using the minimum inside bend radii calculated from Formula 6, using data in Table 55.

MINIMUM TUBE INSIDE BENDING RADIUS

Minimum Inside Forming Radius =

$$\left(\frac{4D - 4D2S}{1.5708} - D\right) \times \frac{W}{T} + (1.5708D \times C)$$

Where:
D = Outside diameter of tubing, in inches.
S = Stretch value (see Table 55).
W = Base wall thickness = D divided by 15

T = Wall thickness of tubing, in inches.
C = A difficulty constant = 0. 15 (see note)

NOTE

The more ductile alloys have better shrink properties, but cause higher frictional loads and are more liable to flattening than the harder alloys, therefore, one advantage is considered to off set the other, making it possible to establish a standard constant.

Formula 6

STRETCH VALUES FOR BENDING ALUMINUM TUBING

Alloy and Temper	Stretch Value = S
2So, 3So, 52So	.20
63So	.18
61So	.16
61S-T4, 63S-T4	.14
14So, 14S-T4, 24So, 63S-T42	.12
2S-H12, 3S-H12, 52S-H32, 24S-T3, 24S-T4, 63S-T5, 75SO	.10
61S-T6, 63S-T6	.08
2S-H14, 3S-H14, 52S-H34, 14S-T6, 75S-T6	.07
2S-H16, 3S-H16, 52S-H36	.05
2S-H18, 3S-H18, 52S-H38	.03

Table 55

11 Allowances must be made for spring-back encountered when bending tubing. The minimum inside bending radius as calculated from the above formula determines the radius of the forming hub and not necessarily the radius of the final formed tube. "Draw" type and "stretch" type tube forming require less allowance for spring-back than other common methods of tube bending.

12 Where exceptionally thin-wall round tubing is being formed or for forming square or rectangular tubing on a small radii, it is necessary to add a wiper and a flexible mandrel to provide extra support for the tube adjacent to the point of forming. These will "wipe out" or "disperse" the flow of metal toward the compression area on the inside of the forming radii to prevent or minimize wrinkling and buckling of the inner wall.

13 The minimum radius forming Formula 6 is applicable only when such complete forming equipment is used. The minimum possible radius using normal bending equipment will be approximately two and one-half times the radius developed by the formula. It must also be remembered that generous lubrication of the tubing, both inside and outside, is very essential in order to minimize frictional stresses and deformation.

PART 11

MACHINING

SECTION 1

TABLE OF CONTENTS

GENERAL MACHINING CHARACTERISTICS

1 Most of the wrought aluminum alloys possess excellent machining characteristics. In order, however, to take full advantage of the free-machining qualities of aluminum alloys, the user should be thoroughly familiar with the tool designs and machining practices recommended. The particular properties of the aluminum alloys require special machining techniques compatible with the high speeds and feeds at which they may be machined.

2 Due to their complex structure, wrought aluminum alloys possess considerably better machining properties than pure aluminum. The properties of the aluminum alloys which are important in machining are:

(a) High thermal conductivity. The heat generated by turning is rapidly conducted away from the point of the tool.

(b) Low resistance to penetration, relatively low impact strength and low modulus of elasticity and shear facilitate cutting and reduce energy required in machining.

(c) Relatively high coefficient of friction on steel requires polished tool surfaces and good lubrication.

(d) Lightness reduces inertia forces when machining large stock at high speeds.

3 These properties have a profound effect on the machining of aluminum alloys. Also these properties vary considerably in the different alloys, making it impossible to generalize the recommendation for machining practices.

4 Some aluminum alloys tend to form a build-up on the cutting lip of the tool, consisting of welded particles which have been partially melted under the heat generated in cutting. This is more pronounced in the softer alloys. It may be minimized by use of proper coolants and cutting compounds and by using tool surfaces free from grinding marks.

NON-HEAT-TREATABLE ALLOYS

4 This group of alloys include commercially pure aluminum and those alloys having no alloying elements present which would render them hardenable by solution heat treatment and precipitation. These alloys give continuous turnings which must be directed away from the stock by generous side and top tool rake angles to avoid scratching the finished surface by the work hardened chips.

5 These alloys offer little resistance to

cutting and tool pressure in machining is low. Care is required in order to obtain good finish, since they are inclined to gumminess. Their machinability is improved by cold working, the alloys in their full hard temper being much easier to machine to a good finish than when in the annealed state.

2S and 3S

6 These alloys are the most gummy of the group. Turnings are long and continuous, those of 3S being tough and difficult to curl, sometimes leading to difficulties in chip disposal which may be partially alleviated by reducing the chip cross-section and by decreasing the cut and feed Good results are obtainable through the use of tools having large top and side rake angles, properly finished tools surfaces and keen edges.

52S

7 This alloy will not machine to as good a finish as 3S, but may be drilled more easily. Turnings are long and continuous.

56S

8 This alloy does not present as great a problem in chip disposal as 2S and 3S, having chips more broken up than the other alloys in this group.

HEAT-TREATABLE ALLOYS

9 Most of the alloys in this group contain fairly high percentages of copper, which is in solid solution after heat treatment. These alloys can be machined to a good finish with or without lubrication. However, a good coolant-lubrication is recommended for most operations.

14S-T6 and 17S-T4

10 These alloys will machine to excellent finishes and are widely used for screw machine work. The chips are inclined to be long and curled, sometimes requiring reduction in feed and depth of cut.

24S-T3

11 This alloy has generally good machining characteristics, machining to smooth finishes with properly dressed tools. The chips are long and curled.

61S-T6

12 The alloys of the magnesium silicide type are somewhat more difficult to machine than others in the heat-treatable group, offering greater resistance to tool penetration. However, by the use of properly prepared tools and good lubrication, fine finishes are obtainable with moderately heavy cuts and feeds.

HIGH-SILICON ALLOYS

13 Alloys containing more than 10% silicon are generally considered to be the most difficult aluminum alloys to machine. The high silicon content together with the occasional presence of hard, free-silicon particles cause rapid tool wear, which can be reduced through the use of cemented carbide tipped tools.

14 None of the alloys containing over 5% silicon will finish to the bright machined surfaces obtained on the other aluminum alloys, but will have slightly gray surfaces. Chips tend to be torn rather than sheared from the work, and precautions are usually necessary to reduce the tendency for burrs to build upon the tool tip. A cutting compound of the lubrication type will minimize this tendency.

NOMINAL COMPOSITION AND RELATIVE MACHINABILITY ALUMINUM ALLOYS

PER CENT ALLOYING ELEMENTS - ALUMINUM AND IMPURITIES CONSTITUTE REMAINDER							
Type	Alloy	Copper	Silicon	Magnesium	Manganese	Zinc	Others.
			NON-HEAT-TREATED CASTINGS				
1	C113	7.0	3.5				
11	112	7.0				1.7	
	113	7.0	2.0			1.7	
	138	10.0	4.0	0.3			
	A214			3.8		1.8	
	212	8.0	1.2				
	F214		0.5	3.8			
	B214		1.8	3.8			
111	A108	4.5	5.5				
	108	4.0	3.0				
	319	3.5	6.3				
	43		5.0				
			HEAT-TREATED CASTING ALLOYS				
1	750	1.0					1.0 Ni., 6.5Sn.
	220			10.0			
	122	10.0		0.2			
11	142	4.0		1.5			2.0 Ni.
	195	4.5	0.8				
	B195	4.5	2.5				
111	355	1.3	5.0	0.5			
	319	3.5	6.3				
	356		7.0	0.3			
	D132	3.5	9.0	0.8			0.8 Ni.
	A132	0.8	12.0	1.2			2.5 Ni.
			NON-HEAT-TREATED WROUGHT ALLOYS				
11	56S			5.2	0.1		0.1 Cr.
111	52S			2.5			0.25 Cr.
	4S			1.0	1.2		
	3S				1.2		
	2S						

Table 56 (Cont'd on page 102)

NOMINAL COMPOSITION AND RELATIVE MACHINABILITY ALUMINUM ALLOYS (Cont'd)

Type	Alloy	Copper	Silicon	Magnesium	Manganese	Zinc	Others
			HEAT-TREATED WROUGHT ALLOYS				
1	11S	5.5					0.5 PB. 0.5 Bi.
11	17S	4.0		0.5	0.5		
	24S	4.5		1.5	0.6		
	14S	4.4	0.8	0.4	0.8		
	75S	1.6		2.5	0.2	5.6	0.3 Cr.
	25S	4.5	0.8		0.8		
	18S	4.0		0.6			2.0 Ni.
111	61S	0.25	0.6	1.0			0.25 Cr.
	53S		0.7	1.3			0.25 Cr.
	63S		0.4	0.7			
	A51S		1.0	0.6			0.25 Cr.
	32S	0.9	12.2	1.1			0.9 Ni.

Type 111 indicates Good Machinability.
Type 11 indicates Better Machinability
Type 1 indicates Best Machinability

Table 56

SECTION 2

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FILING

1 The filing of aluminum, whether by hand or with rotary burrs should be thought as a machining operation, requiring tools whose design should be based on the general principles governing other aluminum cutting tool designs.

2 Since the operation is essentially one of cutting with a gang tool, each file tooth may be considered as an individual shaper finishing tool having an exceptionally long, keen cutting edge, a large side rake angle, ample top rake and a large bottom clearance.

3 Because the cuttings are somewhat bulky, it is necessary that ample chip space be provided by spacing the teeth somewhat coarsely and by using deeply cut grooves with a generous side rake to render the grooves self-cleaning and to prevent clogging, see Figure 11-1.

HAND FILES

4 Hand files of the single cut type, having milled teeth with the above mentioned characteristics, are recommended for aluminum alloys. A general purpose file for heavy work is the curved tooth type having about ten deeply cut teeth per inch. It is capable of removing considerable quantities of stock while leaving a smoothly finished surface. An alternate type of the above design but having notched teeth for chip breakage will permit even more rapid removal of stock at the expense of surface finish.

5 For finish filing, a long-angle lath file with a side rake angle of approximately 45° to 55° and tooth spacing of from 14 to 20 teeth per inch is recommended. The large side rake angle of this type of file gives it a self-cleaning characteristic which permits the use of the finer tooth spacing without clogging. The same effect may be obtained on lesser rake angle files by using a side-sweep motion in filing .

ROTARY FILES

6 Rotary files or burrs are essentially miniature milling cutters and should have coarse, sharp spiralled teeth with smooth, deeply cut flutes. The notched tooth type has better cutting action and produces fine chips which do not clog the tool.

7 Like milling cutters, rotary files are operated at high speeds - up to 10,000 rpm in the case of the smaller types. A maximum peripheral speed of 2000 fpm is recommended for larger diameter files.

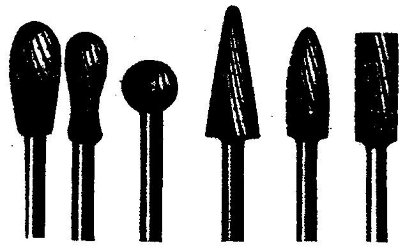
CLEANING

8 Badly loaded files may be cleaned by wire brushing or by immersion in a hot 20% caustic soda solution for a few minutes followed by a hot water rinsing. Drying may be accomplished

FILING OF ALUMINUM ALLOYS

TYPE OF FILING	RECOMMENDED FILE DESIGN: Tooth Pitch	Tooth Design	Tooth Angles	Size of Rotary File	Maximum File Speed
Rotary	Coarse	Spiral, Notched. Deep, polished flutes.	Approx. . . . . . . 10°-15° Spiral Angle; Top Rake . . . . 5°; Back Clear. . . . . 40°; Cutting Angle . . . . 45°	Smaller Diameters	Up to 10,000 r.p.m.
				Larger Diameters	Approximately 2000 peripheral feet/min.
Hand-Roughing	10 per inch	Straight Milled. Plain or Notched.	Side Rake . . . . 15°; Top Rake . . . . 5°; Back Clear. . . . . 40°; Cutting Angle . . . . 45°		
		Curved, Plain or Notched.	Side Rake – Varies with curvature of teeth.		
Hand-Finishing	14 to 20 per inch	Straight; Lightly Double-Cut	Side Rake . . . . 25°; Top Rake . . . . 5°; Back Clear. . . . . 40°; Cutting Angle . . . . 45°		
		Straight Long-angle	Side Rake . . 45° to 55°; Top Rake . . . . 5°; Back Clear. . . . . 40°; Cutting Angle . . . . 45°		

TYPICAL FILES FOR ALUMINUM



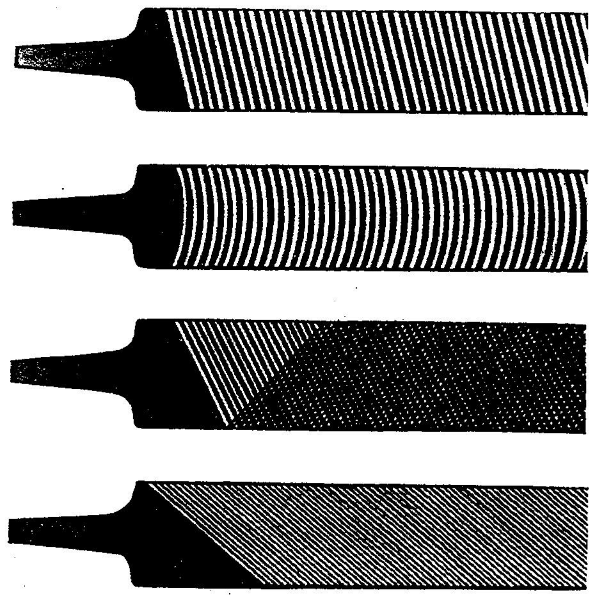


Figure 11-1 Filing of Aluminum Alloys

by compressed air or by blotting in sawdust. Files should be thoroughly dried before storing.

LUBRICANTS AND CUTTING COMPOUNDS

9 Lubrication is rarely necessary in coarse filing but may prove beneficial in some finished work. Light machine oil, turpentine, chalk or talc may be used to reduce clogging tendencies thereby keeping the cutting edges free. This will minimize surface scratches that may result from the adherence of work-hardened chips to the file teeth.

SECTION 3

DRILLING

1 Good results can generally be obtained on aluminum alloys through the use of standard high speed drills that are used for drilling steel. Some difficulty may be experienced when drilling holes deeper than six drill diameters due to the tendency of the drill to overfeed itself.

2 The included point angle 116° to 118°, commonly supplied on standard twist drills should be increased up to about 130° to 140° for drilling most aluminum alloys in order to facilitate chip removal and minimize burring. Drills for drilling high-silicon alloys should have an included angle of approximately 90° for ease of penetration. For drilling thin sheet, the point angle should be very obtuse to permit the drill to cut to its full diameter before the point breaks through the under surface. With this type of drill, a spur point may be necessary to assist in centering.

3 The standard lip clearance of 12° to 13° should be increased to approximately 17° for heavy feeds and for use on the softer alloys. Insufficient lip clearance will lead to excessive drill breakage.

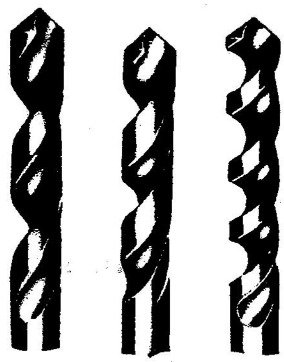
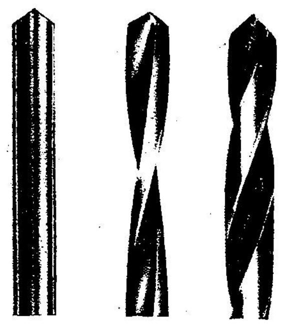
4 As with all other aluminum machining, it is important that the drill cutting lips be keen and smooth and that all surfaces over which the chips must pass be polished to minimize friction and chip build-up.

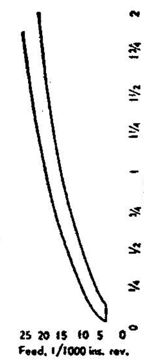
SPEEDS AND FEEDS

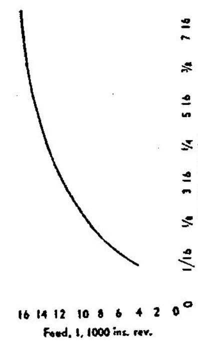
5 Since, with most available drilling equipment, the peripheral speed of smaller diameter drills is relatively low, these may be operated at the maximum efficient rotational speed of the machine. As a general rule, plain carbon steel drills may be operated at about 400 to 500 peripheral fpm, high-speed steel drills at about 600 fpm and carbide-tipped drills as high as 2000 fpm.

6 Because of the ease of penetration of most of the aluminum alloys, feeds up to triple those used for steel may be employed. Feed will vary according to drill diameter, the larger drills permitting heavier feeds, see Figure 11-2.

DRILLING OF ALUMINUM ALLOYS

OPERATION	RECOMMENDED TOOL ANGLES: Point Angle-θ: Thin Stock	General Work	High Silicon	Spiral Angle: Thin Stock	Medium Depths*	Deep Holes**	Lip Clearance: Soft Alloys	Strong Alloys	Silicon Alloys	TYPICAL TOOL DESIGNS	RECOMMENDED PRACTICES: Speed ft./min.	Feed inches/revolution
DRILLING On Drill Press	118° to 150° (Thinned Point) Diam. + 1.8 Stock Thick. = Tan θ/2	118° to 140°	Down to 90°	24°	28°	Up to 48°	17°	15°	12°		With Jig—Up to 650 Without Jig—Up to 1300	.004" to .030" Feed = $\frac{\sqrt{\text{Drill Diam., ins.}}}{60} \pm .002$
DRILLING On Lath or Screw Machine		118° to 140°			0° to 28°			15° to 20°			Stock Surface Speed—Up to 1300	.004" to .016"





*—Up to 6 drill diameters deep.
** Over 6 drill diameters deep.

Figure 11-2 Drilling of Aluminum Alloys

SECTION 4

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REAMING

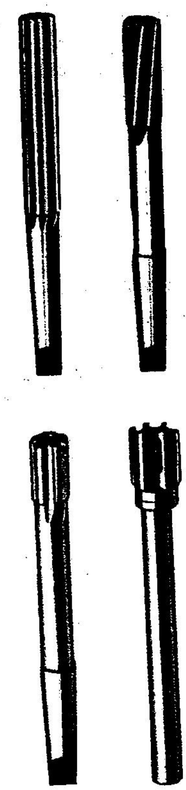
1 Most of the different types of reamers may be used when reaming aluminum alloys. However, the most desirable reamers are the spiral fluted type - either solid, expansion or adjustable. These have less tendency to produce chatter than do the straight fluted types. In most instances, it will be found advantageous to use a reamer having a negative spiral (i.e.

REAMING OF ALUMINUM ALLOYS

RECOMMENDED TOOL ANGLES AND CONTOURS

Flute Type	Tooth Spacing: Straight Flute	Tooth Spacing: Spiral Flute	Tooth Style: Roughing	Tooth Style: Finishing	Top Rake	Clearance Angles: Primary	Clearance Angles: Secondary	Cutting Angle	Land Width
Straight flute to 10° spiral flute	Teeth unevenly spaced to avoid chatter and marking.	Evenly spaced teeth	Solid or nicked teeth	Solid teeth	5° to 8°	4° to 7°	15° to 20°	85° to 91°	.020 in. to .060 in. Land width = Reamer Diameter / 25, (approximately)

TYPICAL TOOL DESIGNS



RECOMMENDED PRACTICES

Speed ft./min.: Roughing	Speed ft./min.: Finishing	Feed in./rev.: Roughing	Feed in./rev.: Finishing	Allowance: Hand Reaming	Allowance: Machine Reaming
Soft Alloys: Up to 200; Hard Alloys: 60 to 100	Straight Reamers: Up to 400; Taper Reamers: Up to 300	.013 to .035	.003 to .010	Drill Diameter = 0.99 x Reamer Diameter, (approximately)	Drill Diameter = 0.98 x Reamer Diameter, (approximately)

Figure 11-3 Reaming of Aluminum Alloys

spiralled in the opposite direction to the rotation) in order to prevent the reamer from feeding itself into the hole. All holes which are to be finished by reaming should be drilled sufficiently undersize to permit the reamer to have a positive cutting rather than scraping or burnishing action, see Figure 11-3 for recommended tooling, speeds and feeds.

2 As mentioned above, the reaming allowance on drilled holes should be sufficient to permit the reamer to take a positive cut to avoid compression of the metal through burnishing and resultant poor finish and undersize holes. An allowance of 0.005 to 0.010" is usually sufficient, the lesser allowance applying to the smaller diameter holes.

3 The reamer should operate at peripheral speeds ranging from 60 to 200 fpm, depending on the hardness of the alloy being cut, the harder alloys requiring the slower speeds. Feeds ranging from 0.013 to 0.035" per revolution are satisfactory for rough reaming. For finish reaming, the feeds should be reduced to approximately 0.003 to 0.010" per revolution.

COOLANTS AND LUBRICANTS

4 For high speed reaming, a coolant lubricant is necessary to reduce the work temperature, to minimize distortion and to prevent undersize reaming. For this purpose, pure lard oil, lard oil and paraffin oil mixtures or petroleum mixtures are recommended for use with plain carbon or high speed steel reamers. For carbide-typed reamers, soap solutions or soluble oil emulsions may be used.

SECTION 5

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TAPPING AND THREADING

1 Straight-fluted taps are satisfactory for many aluminum alloys, expecially those of Types 1 and 2 shown in Table 56. Spiral-fluted taps, Figure 11-4, may be used for any of the alloys and are more satisfactory than the straight-fluted taps when tapping the softer alloys. Spiral-fluted taps for cutting right-hand threads should have a right-hand spiral of about the same spiral angle as that used on an ordinary twist drill.

2 Some taps have a short spiral ground on the front end like the straight-fluted tap in Figure 11-4. They are known as "Gun" taps and cut aluminum freely. Most of the cutting occurs at the end of the tap and cuttings curl ahead of the tool. It is only suitable where there is room for the cuttings to be forced ahead of the tool, as in through holes or blind holes that are deep enough for the chips to collect at the bottom.

3 The tapping allowance on drilled holes should be slightly less on aluminum than on iron or steel. This will help to compensate for the elastic deformation of the alloy during tapping and thereby avoid a tight-running thread. Refer to Figure 11-4 for recommended tooling speeds and allowances.

DIES

4 Dies for cutting male threads on aluminum alloys should have ample clearance for cuttings. As with taps, the leading edge should be undercut more than is usual for other metals, to provide top rake, and the backs of the lands slightly undercut to prevent clogging of the tool when backing off the thread.

5 For lathe work, a chasing tool with a top rake of about 30° is recommended. Threads may be chased on aluminum alloys with a single point tool having a large top rake angle and no side rake provided the tool is set perpendicular to the axis of the work. Where side rake is provided, the tool should be set so that it cuts only on the leading edge.

THREAD CHASERS

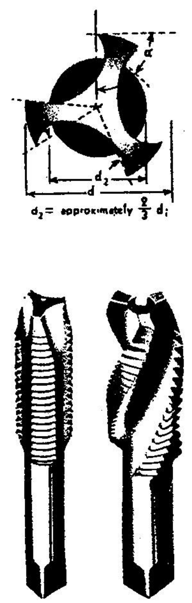
6 For most of the aluminum alloys, chasing tools for use in self-opening die heads should be ground with about 20° to 30° hook and should be set sufficiently above the axis of the work to give an effective top rake of 30° to 40°. A spiral angle ground into the lead end of the tool will help prevent chip build-up within the die head. A side rake of 8° to 10° will assist cutting. A lead chamber of 25° to 35°, extended back about one and one half to two threads, will guide the tool in starting and will produce smoother more accurate threads.

TAPPING OF ALUMINUM ALLOYS

RECOMMENDED TOOL ANGLES AND CONTOURS

Hole Type	
Blind	Spiral Fluted & Bottoming Taps
Semi-Blind*	Spiral Pointed (Gun) Taps
Through	Spiral Pointed (Gun) Taps
Thread Type	
General	Rounded or Truncated (Flattened) Thread Contour
Soft Alloys	Staggered or Interrupted Thread
"Gun" Tap	Grind a lead spiral, extending 1 full thread beyond chamfer.
Spiral Angle	
Spiral Flute	28° to 40°
Cutting Angle α	40° to 45°
Top Rake β	45° to 50°
Back Rake δ	Up to 8°
Included Angle θ	
2 Flutes	36° to 72°
3 Flutes	24° to 48°

TYPICAL TOOL DESIGNS



RECOMMENDED PRACTICES

Cutting Speed, ft./min.: 40 to 130

Tapping Allowance

Required Drill Diameter =

$$(1.005 \times \text{Tap Diameter}) - \frac{k}{\text{Threads per inch}}$$

where (k) is a thread constant for various standard thread forms and percentages of full thread depth, as given in the table.

THREAD CONSTANT (k) FOR VARIOUS STANDARD THREAD FORMS

THREAD FORM	PERCENT OF FULL THREAD DESIRED			
	75%	80%	85%	90%
American Standard (Coarse Series) k =	.9743	1.0392	1.1042	1.1691
Whitworth Standard k =	.9605	1.0245	1.0886	1.1526
British Ass'n Std. k =	.9000	.9600	1.0200	1.0800
Amer. Std. 60° Stub, k =	.6525	.6960	.7395	.7830
Amer. Std. Square k =	.7500	.8000	.8500	.9000
Amer. Std. 10° Modified Square k =	.7500	.8000	.8500	.9000

*Semi Blind Holes: Blind holes having enough depth to permit chips to collect in bottom.

Figure 11-4 Tapping of Aluminum Alloys

COOLANTS, LUBRICANTS AND CUTTING COMPOUNDS

7 For high speed tapping or threading, a moderate viscosity lubricant (such as lard oil or mineral oil, with or without paraffin additions) may be used satisfactorily. The lubricant should be supplied voluminously under some pressure to assure thorough lubrication to all portions of the tool and to assist chip removal.

8 For hand tapping, a more viscous lubricant (such as heavy grease or oil, or white lead) is recommended.

SECTION 6

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SAWING

1 The high speeds recommended for sawing aluminum alloys require sturdy machines, capable of operating efficiently at these speeds. Excessive vibration will cause imperfect, uneven cuts and decreased saw life. Certain circular saws have top rakes incorporated in their tooth designs that give them a tendency to feed themselves into the work. These saws require power feeds to prevent "over-feeding". It is essential that the work be rigidly clamped to the machine.

BAND SAWS

2 Band saws of spring temper steel having a tooth spacing of four to eleven teeth per inch and with ample radiused gullets are recommended for aluminum alloys. The finer tooth spacing is best suited to the sawing of thin stock where the cuttings clear themselves easily. Where heavy sections are to be sawed, the restricted chip space requires the use of coarser tooth spacing of about four teeth per inch to avoid clogging and binding.

3 An alternate set type of blade is preferable, the softer alloys requiring appreciably more set than do the harder, heat-treated alloys. Usually an alternate side rake of approximately 15° and a top rake or "hook" of 10 to 20° proves satisfactory. This amount of hook, however, requires power feeding and thoroughly clamped work. For hand feeds, the top rake must be reduced considerably to avoid over feeding, refer to Figure 11-5.

4 The blades should be well supported by side rollers and back supports both immediately below the saw table and about two or three inches above the work. The top blade supports should be placed slightly in advance of those below the table and the blade should be allowed to vibrate freely to prevent excessive breakage. Ordinarily, a noisy band saw cuts more efficiently than one which cuts quietly. The latter will usually be found to produce smooth burnished surfaces accompanied by excessive heat and consequent decreased blade life.

HACK SAWS

5 Hack saws of the wavy set type having about five to fifteen teeth per inch have sufficient chip space to avoid clogging and binding. For teeth sets and spacing for power and hand saw blades, refer to Figure 11-5.

CUTS, FEEDS AND SPEEDS

6 For both circular and band saws, high speeds and moderate to fine feeds are recommended. Peripheral speeds ranging from 2,000 to 7,000 fpm on high speed circular saws and 10,000 to 15,000 fpm on carbide tipped saws are generally satisfactory. The higher speeds, however, depend upon the machine's ability to withstand speed, The higher speeds, however,

SAWING OF ALUMINUM ALLOYS

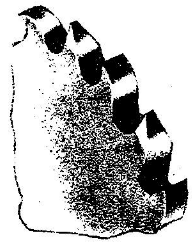
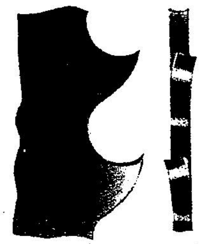
Type of Saw	Tool Mat'l	Feed Control	Recommended Tool Angles and Contours: Cutting Angle	Top Rake	Clearance Angles: Prim.	Second.	Side	Side Rake	Teeth Spacing	Set	Typical Tool Design	Practices: Speed ft./min.	Feed in./min.
CIRCULAR SAWS	High Speed Steel	Hand	69° to 79°	5° to 12°	6° to 9°	25° to 35°	1° to 2°	0° to 15°	Coarse—Generally 2 or 3 teeth should be engaged in cut at all times.	Alternate set or Chip-breaker teeth.		2,000 to 7,000	Hard Alloys — 4 to 17 Soft Alloys —17 to 24
		Power	61° to 74°	10° to 20°									
	Carbide Tipped	Hand	76° to 83°	1° to 5°	6° to 9°	25° to 35°	1° to 2°	0° to 10°				10,000 to 15,000	
		Power	71° to 79°	5° to 10°									
BAND SAWS	Spring Temper Steel or Hard Tooth, Flexible Back	Hand	72° to 80°	5° to 10°	5° to 8°	30° to 40°		About 5° to 15° resulting from alternate set.	Heavy Work—4 to 5 per in. General—Up to 7 per in. Thin Stock—Up to 11 per in.	Alternate set		Heavy Work—Up to 2500 General—4000 to 5500 Thin Stock—Up to 7500	2 to 24
		Power	62° to 75°	10° to 20°									
HACK SAWS	Hard Tooth, Flexible Back	Hand or Power	55° to 75°	10° to 25°	5° to 10°	30° to 40°			Hand —10 to 15 per in. Power— 5 to 10 per in.	Wavy set or Alternate set			

Figure 11-5 Sawing of Aluminum Alloys

depend upon the machine's ability to withstand speed and the maximum speed recommended by the manufacturer should not be exceeded.

7 The rate of feed ranges from two inches to two feet per minute depending on the alloy being sawed, the type of blade, and the thickness of the material.

COOLANTS, LUBRICANTS AND CUTTING COMPOUNDS

8 For circular saws, it is recommended to supply copious amounts of soluble oil emulsion of about 1:20 constituency for all higher speed cuts, the lower speeds requiring no lubricant. The coolant should flood the blade and work under slight pressure. It should be screened before recycling. The addition of small amounts of kerosene or lard oil to the emulsion may prove beneficial or soapy water may be used as an alternate to the soluble oil.

9 For band saw blades, lubrication is essential for all but the lightest gauges. A wide selection of lubricants exist, ranging from tallow or grease stick to kerosene-thin mineral-based lubricating oil or soluble oil emulsions. It the stick type lubricant is used, it should be applied very frequently. In many cases, it will be found more convenient to use the fluid type lubricant, supplied generously to the blade.

SECTION 7

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TURNING

1 The lathe set-up for machining aluminum alloys is essentially the same as for ordinary steels, except that the machine should be capable of operating efficiently at much higher speeds than are usually employed for the heavier metals.

2 The tool should contact the stock on or above the horizontal centre line, depending on the stock diameter, the smaller diameters requiring higher tool settings for best results. Tool settings as high as 45° above the horizontal diameter, while requiring frequent resetting for successive cuts, will minimize the effect of lost motion in the lathe cross-slide and will prevent the tool from feeding itself into the work. Refer to Figure 11-6 for recommended tooling, feeds and speeds.

3 A wide variety of high carbon and high-speed steel turning tool designs have been developed for turning aluminum alloys. However, the various types have a number of points in common, most of them being "hook" type, round-nosed tools with relatively large rake angles.

4 In most cases, the harder the alloy being machined, the greater should be the cutting angle and the smaller the rake angle of the tool. Clearance and side rake angles are fairly constant within a relatively narrow range. The cutting edge should be well cleared and must be keen and extremely smooth to prevent welding of the metal particles to the cutting edge caused by the pressure and heat of cutting. Better work surface quality and longer tool life will amply repay the time spent in tool preparation.

5 The free-machining alloys produce relatively fine, discontinuous chips and so may be turned with tools having less top and side rake than normally used for the other strong alloys. When material of a soft gummy nature is being machined, the rake angles may be increased toward the top of their recommended ranges.

6 For irregular cuts on any of the alloys, a sturdy solid shank tool ground to the largest efficient cutting angle is recommended. This type is more able to withstand the pressure and impact of heavy intermittent cuts.

7 The long continuous turnings produced by some of the alloys may be curled and broken up to some extent by decreasing the rake angles, although too much effort in this direction will lead to build-up on the tool and consequently will produce poorer machined surfaces.

PARTING TOOLS

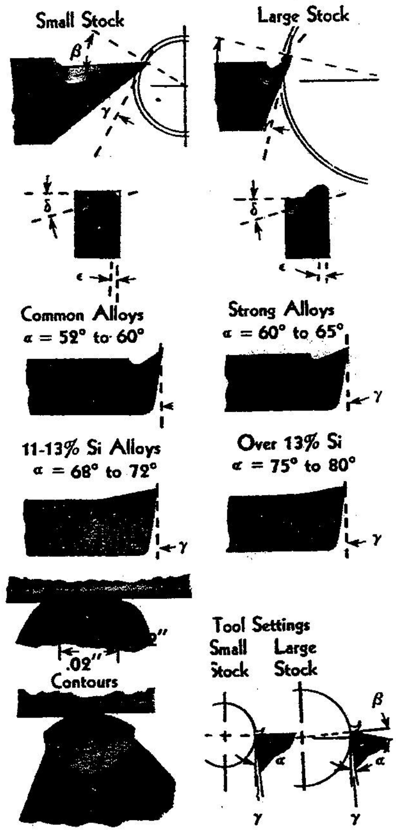
8 Parting tools for aluminum alloys should have considerable less top rake than turning tools. Top rake angles in the range of 12° to 20°

TURNING OF ALUMINUM ALLOYS

RECOMMENDED TOOL ANGLES

TOOL MATERIAL	Cutting Angle α	Top Rake β	Front Clear. γ	Side Rake δ	Side Clear. ε
Plain High Carbon or High Speed Steel Tools	30° to 50°	53° to 30°	7° to 10°	10° to 20°	7° to 10°
Cemented Carbide Tipped Tools	52° to 80°	32° to 0°	6° to 10°	5° to 10°	6° to 10°
Diamond Tipped Tools	74° to 90°	10° to 0°	6° to 0°		

TYPICAL TOOL DESIGNS



RECOMMENDED MACHINING PRACTICES

OPER.	Alloy Type	Cut Inches	Cutting Speed ft., min.	Feed in./rev.
ROUGH.	Soft	Up to .250"	700 to 1600	Up to .050"
	Hard	Up to .200"	Up to 650	.007 to .020"
	High Silicon	Up to .120"	Up to 400	.007 to .020"
FINISH.	Soft	Up to .040"	1500 to 3500	.004 to .015"
	Hard	Up to .020"	600 to 2000	.002 to .010"
	High Silicon	Up to .020"	Up to 600	.002 to .004"
ROUGH.	Soft	Up to .250"	4000 to 7000	Up to .012"
	Hard	Up to .200"	500 to 1300	Up to .010"
	High Silicon	Up to .120"	500 to 1000	Up to .008"
FINISH.	Soft	Up to .020"	6000 to 8000	Up to .006"
	Hard	Up to .020"	700 to 2500	Up to .010"
	High Silicon	Up to .020"	500 to 1500	Up to .004"
ROUGH.	Soft	Diamond tipped tools		
	Hard	are not recommended		
	High Silicon	for Roughing.		
FINISH.	Soft	Up to .010"	Maximum without vibration.	.002 to .005"
	Hard	Up to .006"		.002 to .004"
	High Silicon	Up to .006"		.001 to .003"

Figure 11-6 Turning of Aluminum Alloys

with front clearances of 3° to 4° are recommended. As with turning tools, smoothness of tool surfaces and keenness of cutting edge are essential. In shaping these tools, the front face should be ground slightly concave. The corner adjacent to the work should be ground to lead the opposite corner slightly, so that the final increment of parting will occur at the work face, leaving it clean.

CUTS, SPEEDS AND FEEDS

9 Best results in turning aluminum alloys are obtained from high surface speeds and moderate to light feeds. If stock surface speeds are too low, poor surfaces will usually result. Excessive feed will decrease tool life considerably. Parting cuts should be made at low rate of feed to obtain clean finish.

COOLANTS, LUBRICANTS AND CUTTING COMPOUNDS

10 Although many turning operations could be performed dry, a good cutting fluid is recommended for maximum tool life and surface quality

11 The soluble oil emulsions combine the functions of cooling and lubricating and are excellent for all but the heavier types of lathe cuts. When heavy cuts are to be made at relatively slow speeds, lard or mineral oil, which are the high viscosity lubricants, are recommended. For lighter cuts, kerosene-thinned lard oil has also been found satisfactory. For efficient lubrication, chip control and cooling action, it is recommended that the cutting fluid be supplied freely to the junction of the tool tip and the work.

SECTION 8

MILLING

1 For conventional milling of aluminum alloys, the cutters should generally have fewer teeth and be ground with greater top and side rake than tools normally used for milling steal. Coarse tooth, spiral type cutters with smoothly finished tooth faces and cutting edges perform very well for most applications.

2 High-carbon steel or high-speed steel are recommended for the majority of the aluminum alloys.

3 To minimize chatter, cutters should be inclined to the work and should be bevelled on the leading corner from as little as 3° to as much as 45°, depending on the type of cut. Fine finishing cuts require the least bevel. The teeth should be ground with sufficient clearance or relief to permit face-cutting action and to eliminate back drag and generation of excessive heat.

4 The optimum number of cutter teeth is largely determined by the type and depth of cut. Light finish cuts permit a greater number of teeth than heavy roughing cuts, where the power demand and chip volume per tooth engagement are much greater.

CUTS, SPEEDS AND FEEDS

5 Milling operations on aluminum alloys should be performed at high cutter speeds. Below certain peripheral speeds, the cutters show a tendency toward gumming and loading, but usually clear as speed is increased. Cutter speeds in many cases are limited only by the equipment available. In general, plain carbon steel tools are operated at speeds up to 600 fpm and high-speed steel cutters considerably faster. Refer to Figure 11-7 for recommended tool angles and speeds.

COOLANTS, LUBRICANTS AND CUTTING COMPOUNDS

6 Cutting compounds for milling aluminum alloys should combine the properties of cooling and lubrication, and should be supplied generously to the cutter and the work under pressure, preferably as a fine spray. For most applications; soluble oil emulsions of about one part in fifteen are recommended for high speeds. Paraffin-turpentine mixtures, with or without machine oil additions may be used, however such mixtures render working conditions much less pleasant than do the soluble oils.

MILLING OF ALUMINUM ALLOYS

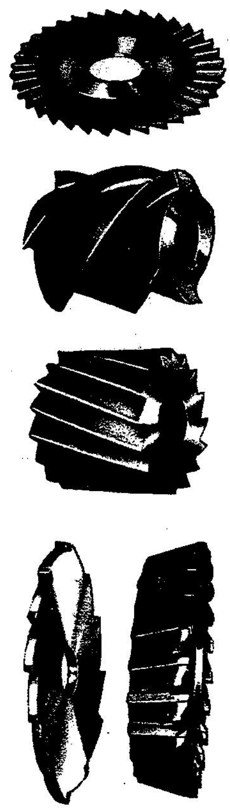
Tool Mat'l	Cutting Angle	Top Rake	Clearance: Primary	Clearance: Secondary	Spiral or Helix	Tooth Spacing	Typical Tool Designs	Oper.	Alloy Type	Cut. Inches	Cutter Speed ft./min.	Feed: ft. per minute	Feed: in. per tooth
High Speed Steel Cutters	48° to 67°	20° to 35°	3° to 7°	7° to 12°	10° to 50°	Coarse spacing for ample chip room.		Roughing	Soft	Up to .250	700 to 2000	Up to 10	.005 to .025
								Roughing	Hard	Up to .200	500 to 1500		
								Finishing	Soft	Up to .020	Up to 5000		
								Finishing	Hard	Up to .020	Up to 4000		
Cemented Carbide Tipped Cutters	68° to 97°	−10° to 15°	3° to 7°	7° to 12°	−10° to 20°	Approximately 1 tooth per inch of diameter, or fewer.		Roughing	Soft	Up to .300	3,000 to 15,000	Up to 20	.004 to .020
								Roughing	Hard	Up to .250			
								Finishing	Soft	Up to .020			
								Finishing	Hard	Up to .020			

Figure 11-7 Milling of Aluminum Alloys

SECTION 9

SHAPING AND PLANING

1 Due to equipment limitations, shaping and planing are relatively slow operations. However, this slowness may be partially compensated for by clamping the work very securely in the machine and removing the bulk of surplus stock with a heavy roughing cut, using a sturdy tool properly ground to operate on heavy feeds at relatively high speeds. The desired finish may then be imparted with a finishing tool using much finer cuts. Refer to Figure 11-8 for recommended tooling speeds and feeds.

2 The tools recommended for shaping and planing are of the modified "hook" type, similar to lathe tools in principle, but requiring much more side rake, For roughing cuts, a sturdy round-nosed tool, ground to the majority of its cutting on its side, is recommended. The finishing tool does not need to be so sturdy, since it is confined to light cuts. It should be ground to a flat base and should have extreme top and side takes to impart a decided slicing action to the cut. The cutting edge should be keen and all tool surfaces smooth, to minimize friction and adhesion of chips.

3 High-carbon or high-speed steel tools will perform satisfactorily on shaping and planing operations, the latter type being more durable and practical for extended runs.

CUTS, SPEEDS AND FEEDS

4 Since the speed of milling is relatively low, it is often desirable to remove as much surplus stock as possible during the roughing by means of heavy cuts and feeds. The impact and thrust of such heavy cuts makes it imperative that the workpiece be supported securely and clamped very rigidly to the machine to prevent kick-up or slippage. When proper support and clamping is provided, the maximum efficient speed of the shaper may usually be employed in roughing as well as finishing.

5 For finishing, the cut should be light, usually not exceeding 0.018. The feed may be quite high, since the long cutting edge of the finishing tool will smooth a relatively wide area at each stroke.

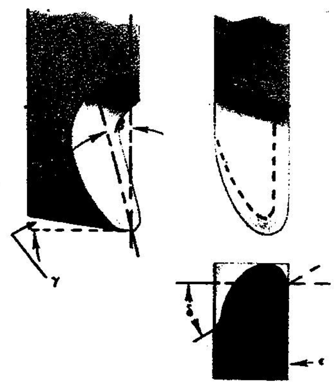
COOLANTS, LUBRICANTS AND CUTTING COMPOUNDS

6 While lubrication is not usually essential to roughing cuts on shaping or planing, the surface resulting from the finer finishing cuts may be somewhat improved through the use of cutting compounds, kerosene, a 50-50 lard-oil mixture, soluble oil emulsions or any of the commercial cutting compounds may be used to advantage.

SHAPING AND PLANING OF ALUMINUM ALLOYS

TYPES OF CUT	RECOMMENDED TOOL ANGLES: Cutting Angle α	Top Rake β	Bottom Clear. γ	Side Rake δ	Side Clear. ε	OPER.	RECOMMENDED MACHINING PRACTICES: Cut inches	Cutting Speed ft., min.	Feed inches
ROUGHING	64° to 71°	19° to 10°	7° to 9°	30° to 40°	7° to 9°	SHAPING	1/4" maximum	Maximum speed of ram	.008" to .031"
						PLANING	3/8" maximum	Maximum speed of table	.020" to .100"
FINISHING	30° to 37°	52° to 43°	8° to 10°	50° to 60°	0° 0°	SHAPING	.005" to .012"	Maximum speed of ram	.094" to .156"
						PLANING	.005" to .018"	Maximum speed of table	.050" to .375"

TYPICAL TOOL DESIGNS



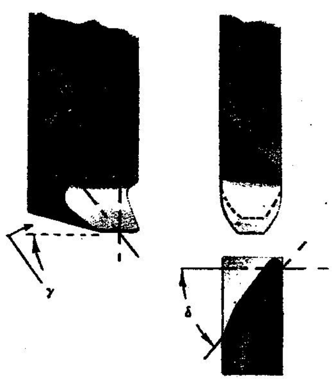


Figure 11-8 Shaping and Planing of Aluminum Alloys

SECTION 10

TABLE OF CONTENTS

GRINDING AND FINISHING

1 The grinding characteristics of the various aluminum alloys differ appreciably. Alloys of the harder temper are comparatively easy to rough and finish grind satisfactorily. On the other hand, the softer nonheat-treatable alloys, particularly in their soft temper, have a pronounced tendency to clog the wheels and do not finish to as bright and smooth surface as the harder metals.

2 Proper care and sufficient lubrication will improve these characteristics. The type of wheel, the work and wheel speeds, and the type of grinding compound are controlling factors in surface quality.

GRINDING MATERIALS

3 In general, a free cutting wheel of silicon carbide abrasive in a flexible base (carborundum, crystalon, etc.) is recommended in preference to an aluminum oxide abrasive.

4 For rough grinding, a silicon carbide wheel of medium hardness and of about 24 to 30 grit in a synthetic resin bond is satisfactory. For finish work, a softer silicon carbide wheel of finer grit (30 to 40) in a vitrified bond is commonly employed. For more specific information on the correct grades of grinding wheel for specific types of work on aluminum, it is recommended that a wheel manufacturer be consulted.

5 A mechanical wheel dresser is recommended, although a single pointed diamond may be employed. Dressing should be done carefully at relatively low speeds.

SPEEDS

6 Rough grinding of aluminum alloys using synthetic resin bond wheels of peripheral speeds up to 9000 fpm are used. With the softer wheels ordinarily employed in finish grinding, peripheral speeds of 6000 to 7000 fpm are recommended. These peripheral speeds should be maintained by increasing the rate of revolution as the wheel diameter is decreased by wear and re-dressing.

CAUTION

In no case should the wheel manufacturer's maximum speed rating be exceeded.

7 A normal table traverse speed should be used in rough grinding. The table speed should be decreased appreciably for finish grinds.

MECHANICAL FINISHING ALUMINUM ALLOYS

	ROUGHING			Greasing or oiling	Buffing	Colouring	Finish (1) Grinding
	Solid Wheel	Cloth Belt	Sewed Muslin				
Abrasive	Sic	Al_2O_3	Al_2O_3	Turkish Emery	Tripoli	Fine Lime or Silica	Sic
Carrier	Solid Wheel	Cloth Belt	Sewed Muslin Buffs	Sewed Muslin Buffs	Packed Muslin Buffs	Open Muslin or flannel	Solid Wheel
Grit	24 - 30	46 - 300	46 - 80	120 - 240			30 - 40
Bond	Synthetic Resin	Glue	Glue	Glue			Vitrified
Hardness	Medium		Medium	Medium	Soft	Very Soft	Soft
Peripheral Speed fpm	6000 - 9000	3000	6000	6000	7000 - 8000	7000 - 10000	6000 - 7000
Lubricant	Stick Grease	Grease or Kerosene	Grease	Grease	Grease		Soluble Oil 35 to 40

(1) Mechanical finish applied to castings - to be preceded by machining.

Table 57

The harder alloys should be finish ground carefully with ample coolant to prevent the generation of excessive heat.

LUBRICANTS AND COOLANTS

8 To prevent clogging of the wheels during rough grinding, generous applications of stick grease are recommended. For finish grinding, however, copious quantities of low viscosity, coolant type grinding compound are essential. To obtain the best surface finish, it is essential that all grindings be strained from the grinding compound before it is recycled to the work. A low viscosity lubricant facilitates the removal of these particles and provides better cooling characteristics. Refer to Table 57.

FINISHES

9 Polishing procedures may be divided into four distinctive operations: roughing, oiling, buffing and colouring. Roughing is a coarse polishing operation used to prepare uneven or deeply scratched surfaces and is applicable mainly to sand castings. Portable disc sanders may be used for roughing as well as those methods shown in Table 57 where the abrasive surface is applied by treating the wheel with a layer of glue in which the abrasive is embodied.

10 Oiling or greasing is an extension of the roughing treatment. Softer wheels set up with finer abrasives are used, and the work is invariably lubricated with tallow, stearic acid, beeswax or various mixtures of these greases, refer to Table 57.

BUFFING

11 This is really the first stage in the polishing of aluminum that brings out the high lustre of the metal. Buffing differs from the earlier polishing operations in that the abrasive, mixed with a grease binder and moulded into a cake, is applied to the wheel from time to time instead of being glued to the cutting surface.

13 The degree of lustre obtained by buffing depends upon the softness of the buff, the fineness of the abrasive and the pressure of the work against the buff. Buffing defects such as pits, surface roughness and buffing clouds may be overcome by softening of the buff, changes in the lubricant and abrasive, lowering the wheel speed as well as lightening the pressure of the work on the wheel. The skill of the operator in finding the correct combination of the above factors is generally the result of experience, experimentation and instruction. Table 57 may be used as a guide.

COLOURING

13 This is the final step in the polishing of aluminum and its function is merely to increase the lustre and impart to the surface the highest possible gloss. The colour does not materially change.

14 Buffed articles should be cleaned in commercial solvents and dried before colouring. This will remove the lubricant and any abrasive adhering to the article.

15 The wheels used are of open muslin or flannel construction. The abrasive is generally Vienna lime or soft silica in a grease binder, although in the case of a very soft wheel, the lubricant is frequently omitted. Peripheral speeds from 7000 to 1000 fpm are common, and when no lubricant is used the speed may be as high as that which the machine will stand. Very light pressure is employed.

PART 12

WELDING ALUMINUM AND ALUMINUM ALLOYS

SECTION 1

GENERAL

1 An understanding of the materials concerned is a first essential in obtaining successful results when welding aluminum. Many alloys of aluminum have been developed to provide the most suitable material for machining, forming, corrosion resistance or other requirements. Likewise, the alloys suitable for welding applications are those which do not have constituents that make welding difficult.

2 Because the melting temperature of aluminum alloys is below the visible light range, no change of colour occurs on heating to welding temperatures. However the surface takes on a slightly discernable cobweb-like appearance just before melting occurs. In brazing, a silvery sheen appears through the flux which has become very fluid and transparent when the metal is at brazing temperature.

3 The resistance of aluminum and its alloys to chemical attack is due to the oxide film which forms on all exposed surfaces. This film does not melt at welding temperatures; its formation is accelerated by heat and certain alloying constituents such as magnesium, and must be removed by chemical means such as flux or a deoxidizing agent to ensure a sound weld. Mechanical means, such as filing or wire brushing do not completely remove the oxide film. In most welding processes a flux is employed to remove the oxide film and to prevent its reformation on the weldment during welding and cooling. The flux combines chemically with the oxide film and forms a fusible slag-like product which rises to the surface of the weldment. Fluxes should be removed as soon as possible after welding has been completed.

4 The heat required to melt a unit volume of aluminum alloy is less than one-third of that required to melt the same volume of mild carbon steel. However, the thermal conductivity of aluminum is four to five times that of mild steel. This fact dictates the necessity of applying the heat to the joint as fast as possible to avoid:

(a) Wasting heat.

(b) Extending the annealed zone in the parent metal.

(c) Weakening the metal in the vicinity of the joint to the extent that it may not be possible to obtain a satisfactory weldment.

5 This last condition is called "hot-shortness" and does not give rise to any difficulty in the welding of the non-heat treatable alloys. In the heat-treatable alloys, however, it may result in unsound structure usually revealed by cracks in the welded area. corrective measures are to be found in jigging, technique of welding, edge preparation, pre-heating, cooling, welding speed and proper selection of filler material.

6 The high thermal expansion of aluminum alloys necessitates a proper sequence of welding steps and careful jigging and spacing to prevent cracks, buckling and distortion. For more detailed information refer to EO 105-1-3.

SECTION 2

WELDING CHARACTERISTICS

1 The non-heat-treatable alloys 2S, 3S and 57S have similar welding characteristics. The alloys 2S and 3S are the most weldable of all the aluminum alloys. 57S has fusion welding characteristics similar to 2S and 3S, provided the material has been etch cleaned and a slightly more active flux is used.

2 The heat-treatable alloys, generally speaking, are not quite as weldable as the non-heat-treatable alloys. If welded prior to heat treatment, they develop high strengths but if welded after heat treatment their strength will be lowered, depending in extent on the method and technique employed.

3 The aluminum-magnesium-silicon alloys 50S and 65S weld satisfactorily, their rating being equivalent to 2S when welded by arc processes and to 57S when welded by oxy-gas processes. 65S has a greater tendency towards weakness at or near the welding temperature (hot-shortness) than any of the above mentioned alloys.

4 The copper-bearing alloys 17S and 24S are not recommended for fusion welding since this lowers their strength, produces a brittle area around the weld and impairs resistance to corrosion. However, resistance welding methods may be employed.

5 The aluminum magnesium-zinc alloy 75S is not recommended for fusion welding but may be joined by spot or seam welding.

6 In brief, 2S, 3S, 50S, 57S and 65S may be welded by gas, resistance or arc welding. 24S and 75S are recommended for resistance welding processes only. 2S and 3S alloys are welded with 2S welding rod or wire and the 50S, 57S, 65S alloys and castings are welded with 33S rod or wire. Strips cut off the sheet material being welded may be used as filler material.

SECTION 3

BRAZING

1 Brazing of aluminum alloys is a simple method of joining and is often advantageous for joining thin material to heavier material, tubing and more particularly, complicated assemblies having inaccessible parts. Brazed assemblies present a good appearance with smooth fillets. The strength of a brazed joint is comparable with that of a welded joint, while at the same time the tendency towards distortion is greatly reduced.

2 Brazing may be carried out by torch, furnace or flux dip methods. The torch method is similar to the oxy-gas welding process. Furnace brazing is a production method and is employed in complex assemblies that cannot be joined successfully by other methods. The flux-dip method is a development of the furnace brazing process. In all processes the base metal is not melted and the filler material melts at a slightly lower temperatur than the base metal.

3 The 2S and 3S alloys have excellent braz eability using 33S, 34S or C35S filler material 57S is more difficult to braze requiring extr care in preparation and use the same fille material as 2S and 3S. The brazeability of 50 alloy is good using 34S or C35S filler materia while 65S brazes very well when C35S fille material is used.

CAUTION

Aluminum brazing shall not be used on aircraft applications without Air Material Command Headquarters' specific approval of materials, process and application.