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STATE-OF-THE-ART LITERATURE SURVEY ON FABRICATION TECHNIQUES OF ADVANCED DUCTING COMPONENTS

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George C. Marshall Space Flight Center, Huntsville, Alabama

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ABSTRACT

13309

The purpose of this state-of-the-art literature survey is to determine and define the manufacturing techniques required and the process difficulties likely to be encountered in the fabrication of elbows, bellows, and ducting assemblies for use in advanced ducting systems ranging from 2 inches to 50 inches in diameter.

This report briefly covers the methods currently used in elbow, bellows, and ducting fabrication as well as some alternate methods available and new methods under development. Some information concerning the properties and fabricability of several aluminum, iron-base, nickel-base, and cobalt-base alloys suitable for use in cryogenic ducting systems is also presented.

The survey indicates that advancements in the state-of-the-art of fabricating large-diameter elbows, bellows, and ducting will be necessary for new, larger ducting system applications.

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MANUFACTURING ENGINEERING LABORATORY
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STATE-OF-THE-ART LITERATURE SURVEY ON FABRICATION TECHNIQUES OF ADVANCED DUCTING COMPONENTS

SUMMARY

A literature survey of fabricating techniques for advanced ducting assemblies was conducted to determine and define manufacturing techniques and to process difficulties for elbows, gimbals, bellows, and ducting assemblies in diameters ranging from 2 inches to 50 inches. The survey also included the acquisition of data pertaining to advanced ducting materials such as Hastelloy C, Inconel 718, Rene 41, N-155, 19-9 DL, L-605, AM 350, and some of the newer aluminum alloys. Forming, joining, surface treating, and compatibility of these advanced ducting materials are discussed when information is available.

This literature survey has revealed that future ducting system requirements demand state-of-the-art extensions in advanced materials research, especially at cryogenic temperatures where a paucity of data presently exists. Manufacturing processing data related to the newer materials, larger sizes, and new design philosophies, demanded by future aerospace concepts, is limited. Thus while negative results are reported in general, the information obtained is of value in that its scarcity emphasizes the importance of advanced ducting studies in progress today to solve these problems and to preclude their deferment to some time in the future when delivery schedules may be at stake.

SECTION I. INTRODUCTION

In the construction of the Saturn V S-IC stage, large-diameter elbows, gimbals, bellows, and ducting assemblies will be required to handle the necessary flows of lox and RP-1. To date, there has been no known commercial production of these items in the size range and of the quality which will be required for the S-IC stage.

At the present time, there is a great deal of interest in advanced materials from which these components might be fabricated as well as in the fabrication techniques and the processing difficulties which may be encountered in the manufacture of elbows, gimbals, bellows, and ducting assemblies ranging from 2 inches to 50 inches in diameter. This literature survey has therefore been performed and the information obtained is presented in an attempt to answer questions which now exist.

The bibliography, which is a part of this literature survey, contains all of the sources encountered which seemed to have some application to the subject of the survey. No claim is made that it is an exhaustive or critical compilation. The inclusion of any item in the bibliography is not to be construed as an endorsement of all of the information contained in that item.

This report was prepared by the Missile and Space Support Division, Hayes International Corporation, and by the Metals Processing Section, Methods Development Branch, Manufacturing Engineering Laboratory, MSFC.

SECTION II. DUCTING FABRICATION

A. GENERAL

Maximum performance of air and space vehicles requires minimum weight structures including ducting. Fabrication of minimum-weight, large-size structures constitutes one of the most critical problems requiring solution by the aerospace industry. Problems of producibility, reliability, and dimensional accuracy continue to become more acute as structures increase in size. The performance and reliability requirements for the present generation of large aerospace structures clearly indicate the desirability for new methods and techniques permitting fabrication with optimum structural efficiency, dimensional accuracy, reliability, and manufacturing economy.

B. RAW MATERIAL FORM

The most desirable form of material for use in the fabrication of ducting assemblies for advanced space vehicle applications is seamless piping or tubing. The presently available commercial piping and tubing production equipment, while capable of producing seamless tubing up to 160 inches in diameter, is not capable of producing the lengths required in the 25-inch to 50-inch diameter range desired in the Advanced Space Vehicle Ducting Program. In addition, presently available equipment does not consistently produce the necessary surface finishes or wall thickness tolerances. This lack of present-day industrial capability to produce seamless tubing in the full range of diameters, tolerances, and lengths desired means that large-diameter ducting systems must consequently be fabricated from a less desirable form of material. One of these less desirable forms of material is seamless tubing in its presently available lengths and diameters, several of which must be welded together to achieve the desired length and the walls of which must be machined or chem-milled to achieve the desired surface finish and thickness tolerance. A second less desirable form is sheet and plate which has been precision rolled on a Sendzimir mill to the exact thickness required but then must be formed and welded into tubing. Neither of these material choices is the ultimate desired.

C. TUBING PRODUCTION

Present-day tubing production methods, which most closely approach the ideal of a seamless tube having the correct wall thickness and of any desired length, are known by several different names, for example, roll extrusion, spin forging, and flo turning. All of these methods are basically similar in that the starting material for each method is a high-quality ring forging of approximately the desired final diameter. Through the application of extremely high mechanical pressures to these ring forgings, the metal in the thick original ring forging is displaced and caused to flow over a cylindrical mandrel of the desired diameter, resulting in a tubular product of the desired diameter and wall thickness. By these and similar production methods, seamless tubes from 3 1/2 inches to 160 inches in diameter and from a few inches to 20 feet in length can be routinely produced from a number of different alloys. The length of tubing that can be produced by these methods depends upon the amount of force a machine can exert and upon the amount of metal available in the ring forging used. Theoretically, a tube of any diameter or any length could be produced assuming that a large enough machine and a ring forging of unlimited size are available. One present-day company, the Parsons Corporation, Traverse City, Michigan, has publicized the fact that they have equipment capable of producing aluminum seamless tubing up to 25 inches in diameter and up to 100 feet in length.

The leading alternate method of producing tubing for large-diameter aerospace ducting is by forming of plates or sheet into cylinders and then longitudinally welding. Most of the large-diameter piping and tubing has always been made by this method in the United States, therefore there is a great deal of background experience and information available. For aerospace use, the principal objections to this method of producing tubing are the inaccuracies in shape and dimensions resulting from weld shrinkage or heat distortion, and the decrease in reliability of weld metal as compared to parent metal of the same thickness. Despite these objections, however, this method of tubing production is, and will undoubtedly continue to be, used when and where there is no seamless tubing available.

D. SIZING OF TUBING

There are two principal methods of sizing tubing after it is produced. The first method is to place the tubing in a female die and apply hydraulic pressure to the inside of the tubing and expand it against the walls of the outer die. The second method commonly used is a mechanical method in which a collapsed mechanical expanding head, supported by a long horizontal column, is inserted into the tubing and expanded, thus expanding the tubing to the predetermined inside diameter. The first of these methods results in piping or tubing with a constant outside diameter. The second method gives tubing or piping with a constant inside diameter which results in more efficient internal chemical cleaning after welding, more efficient flow of gases or liquids through the piping or tubing, and easier and improved welding by using internal lineup clamps.

SECTION III. FORMING OF ELBOWS

A. BENDING AND WELDING

Forming of elbows up to six inches in diameter by bending thin-wall tubing is a routine production operation in most aerospace companies. Techniques for bending seamless tubing up to 10 inches in diameter have been developed by some companies but are not too widely used. In sizes above approximately eight inches in diameter, hydraulic bulge forming methods are used in the production of most elbows. The hydraulic bulge forming method has not been developed well for sizes greater than 14 inches in diameter. One alternate method for making elbows and bends in tubing that are too large for presently available tube-bending equipment and methods is to hammer form two halves of an elbow and then join these two halves by making two longitudinal fusion welds.

B. RAM FORMING

A newer and improved method for making tubular elbows in the 10-inch to 22-inch diameter range is ram forming in which a tube blank, which may or may not be preheated, is hydraulically forced over a form mandrel which is preheated and maintained at a temperature within the range of 450° F. to 600° F. Ram forming has been under development by the Boeing Company and appears to have several advantages which other forming techniques do not have. Among these advantages are:

1. A part can be formed without intermediate anneals.

2. The process is more economical than hammer forming and welding.

3. Thinout of part walls is minimized and appears to be approximately 25 percent maximum.

C. MATERIAL REQUIREMENTS

The requirements for the materials to be used in forming elbows or bends in large-diameter, thin-wall tubing are stringent. Such things as tensile strength, yield strength, hardness, elongation, reduction in area, straightness, roundness, and diametrical tolerances are extremely important. All of these things must be accurately controlled and uniform from piece to piece if a repeatable operation is to result. Failure to properly control any of these parameters will only result in a fabrication operation in which the production of an acceptable part is purely by chance.

SECTION IV. FABRICATION OF BELLOWS

A. GENERAL

At the present time there are two principal fabrication methods used in the manufacture of flexible bellows. The first method, which appears to be the most suitable for space vehicle applications, is by forming the desired corrugations in the walls of seamless or welded tubing of the desired diameter. In this method, multi-plies of tubing are frequently employed to form bellows which have increased formability, increased fatigue life, and reduced springrate. The second method in common use is by welding together a series of metal diaphragms to achieve any desired bellows length. Each of these two fabrication methods has peculiar advantages in certain specific applications.

B. FORMED BELLOWS

In the forming method, there are basically three types of machines used to produce the convolutions in the tubing walls. These machines differ only in the means each uses to apply the force necessary to deform the tubing walls into the desired convolution depth and shape. The different means used to apply the necessary force are as follows:

1. Hydraulic. The ends of the tubing are sealed off; the tubing is pressurized internally with a liquid such as water or oil, and is allowed to expand into the cavities of an external die as the internal hydraulic pressure increases.

2. Mechanical. The desired convolutions are formed in tubing walls by means of a male die forcing the walls into the cavities of a female die or rubber pad while acting under the influence of a force created by either hydraulic or mechanical means.

3. Roll. The desired convolutions are formed in the tubing walls by means of roll forming dies, for example, Yoder dies.

The roll forming type of equipment has unlimited capability but depends on the skill of the operator to a greater extent than the other types of equipment do. Stainless steels are work hardened more by roll forming, thinout is usually greater, and repeatability is lacking when different operators vary in the degree of skills. Thus hydraulic and mechanical types of equipment are preferred for forming missile or flight hardware. In general, the mechanical bellows machines in the larger sizes produce one convolution at a time to a relatively simple design such as a "U" shape convolution. Although the height of the convolution can be varied with the mechanical machines, the hydraulic machines are more adaptable to producing varied shapes of convolutions; thinout is less and work-hardening tendencies are minimal.

C. CORRUGATION STYLES

There are two principal styles of corrugations used in transforming pieces of tubing into bellows. The first style is the helical corrugation which is in reality one continuous corrugation, just as screw threads are actually one continuous thread. This style of corrugation has the following advantages:

1. It is less likely to collect the stresses of flexing within a confined area.

2. The spiral construction tends to swirl the flow of liquids through the tubing, thus imposing a somewhat lower pressure drop than tubing with annular corrugations.

The principal disadvantage of this style of corrugation is that it tends to twist when subjected to extension and compression. This twisting, however, does result in tensile or compressive stresses being distributed over the entire length of the corrugation rather than in a limited section of corrugations.

The second style of corrugation is the annular corrugation, each of which is separate and complete within itself. Tubing, into which annular corrugations have been impressed, does not tend to twist when subjected to extension or compression. Therefore it is more suitable for limited extension and compression service than tubing having helical corrugations. The principal disadvantage of annular corrugated hose is that the highest stresses are developed at the peak or in the trough of each corrugation where metal thinout is the greatest during corrugation forming.

D. CORRUGATION SHAPES

The three principal corrugation shapes used in bellows fabrication today are as follows:

1. Standard "U". Although the standard "U" shaped corrugation is suitable for the majority of expansion joint applications, there are limitations to its use at high pressures and high temperatures. Even at medium pressures and medium temperatures, substantial supporting of the bellows by control rings is necessary to allow use of thin-wall bellows material. The use of thin-wall bellows material is desirable because it results in lower flexural stresses than with thicker wall material. These lower stresses are a large factor in the service life of an expansion joint. In addition, with the standard "U" corrugation shape, stresses due to pressure increase proportionately with increasing expansion joint diameters even though the thickness of material and shape of corrugations do not change.

2. Omega. The omega shaped corrugation places slightly more formed metal at the peak and in the trough of each corrugation, thereby furnishing more metal for involvement in each compression or extension of the bellows. This extra amount of metal involved in each deflection results in slightly lower stresses than with the standard "U" corrugation. The decrease in stresses is so slight however that substantial support of the bellows by control rings is still necessary at high or medium pressures.

3. Toroidal. The toroidal corrugation is circular in cross section and is placed like a curved tube wrapped around the circumference of the expansion joint. It has pressure-stress characteristics which are practically independent of the diameter of the expansion joint. The pressure stresses are directly proportional to the radius and wall thickness of the tubular cross section. This results in lower operating stresses than in the standard "U" or omega shaped corrugations for any given pressure. Since the pressure stresses are low, the use of thin walls for toroidal bellows corrugations is

practical even at large bellows diameters. The use of thin walls results in flexural stresses which are moderate because flexural stresses are less in thin-wall corrugations than in thick-wall corrugations. The toroidal corrugation shape is also suitable for high temperature applications where materials must operate with reduced mechanical properties.

E. WELDED BELLOWS

In the welding method of fabricating bellows or expansion joints, a series of annular diaphragms are cut from sheet or plate of the desired thickness. These diaphragms are then welded together at alternate outer and inner edges, continuing in this fashion until an assembly of the desired length has been obtained. A welded diaphragm expansion joint or bellows has the following advantages:

1. Light weight

2. Short face-to-face dimensions, compact

3. Wide range of sizes

4. Unlimited selection of metals from which to fabricate

5. Thickness tolerances of sheet or plate materials not critical

6. Long life - in excess of one million cycles

7. Ruggedness under extreme vibration and shock

8. Varied diaphragm contours can give welded bellows a wide range of characteristics.

SECTION V. MATERIALS

A. GENERAL

The selection of materials for use in large-diameter elbows, gimbals, bellows, and ducting used on board the Saturn S-IC is based upon the following factors:

1. Strength-to-density ratio (-423° F. to +800° F.)

2. Compatibility with the gas or liquid to be conveyed

3. Toughness (-423° F. to +800° F.)

4. Formability

5. Weldability

6. Availability

7. Cost.

Among the engineering materials which have been found to meet most or all of the criteria above, depending upon the specific application under consideration, are some aluminum alloys, the austenitic iron-base alloys, some titanium alloys, some nickel-base alloys, and some cobalt-base alloys. In general, it may be said that metals having a face-centered cubic (FCC) crystalline structure are the best in cryogenic service, while metals having a close-packed hexagonal (CPH) crystalline structure also have good properties at cryogenic temperatures. All of the kinds of alloys listed above have one or the other of these crystalline structures.

B. ALUMINUM ALLOYS

Several of the aluminum alloys have been used and have provided excellent service results at cryogenic temperatures. In general, the aluminum alloys which have performed best in cryogenic applications have been from the 2000, 5000, and 6000 series of alloys, especially the 2014-T6, 2219-T81 and -T87 alloys. Comparatively recently, new experimental aluminum alloys in the 7000 series have been indicated to have improved mechanical properties at cryogenic temperatures. Some of these new alloys are X7005, 7039, and X7106.

1. Aluminum Alloy X7005

a. General. X7005 alloy is a heat-treatable aluminum-zinc-magnesium alloy of the following composition:

Constituent	Content, Percent
Zn	4.2 - 5.0
Mg	1.0 - 1.8
Mn	0.20 - 0.70
Ti	0.01 - 0.06
Cr	0.06 - 0.20
Zr	0.06 - 0.20
Fe	0.35 max
Si	0.35 max
Cu	0.10 max
Others, each	0.05 max
Others, total	0.15 max
Aluminum	Remainder

This alloy fills a demand for a high-strength alloy with a high-melting range, that can be easily brazed, soldered or welded and maintain its high mechanical properties after brazing or welding without the requirement for solution heat treatment.

Due to its low quench sensitivity, this alloy requires only a moderate rate of cooling from brazing or soldering temperatures. This eliminates the severe distortion that generally results from uneven cooling in alloys that require solution heat treatment and rapid quenching prior to artificial aging.

Alloy X7005 will naturally age to a high level of mechanical properties as shown in Figures 1 and 2. Strengths comparable to those of 6061-T6 can be developed by artificial aging.

In general, alloy X7005 has good-corrosion and stress-corrosion resistance, high mechanical properties at room and cryogenic temperatures, and excellent fracture toughness as shown in Figure 3.

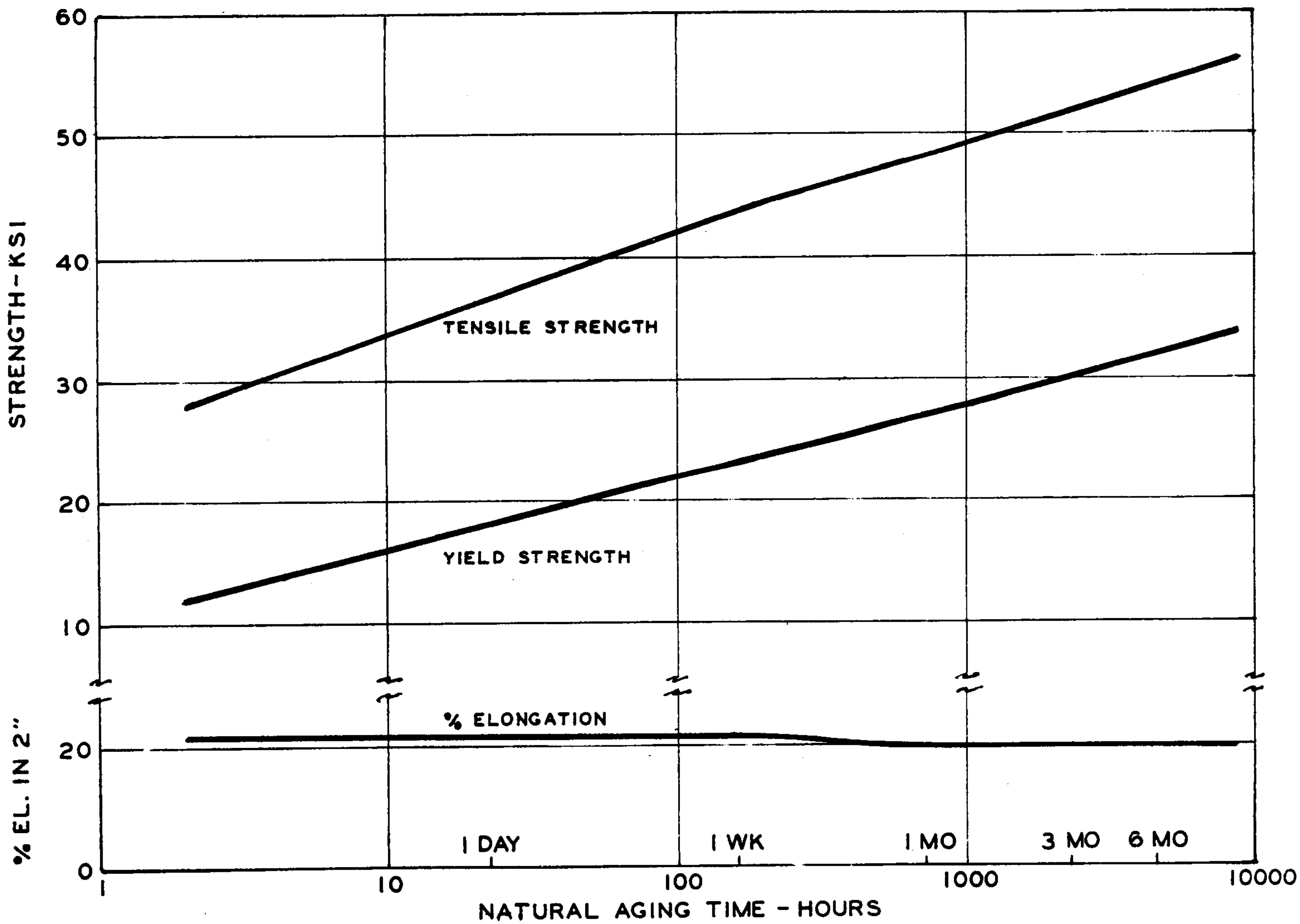


FIGURE 1. NATURAL AGING OF ALLOY X7005 SHEET AND PLATE

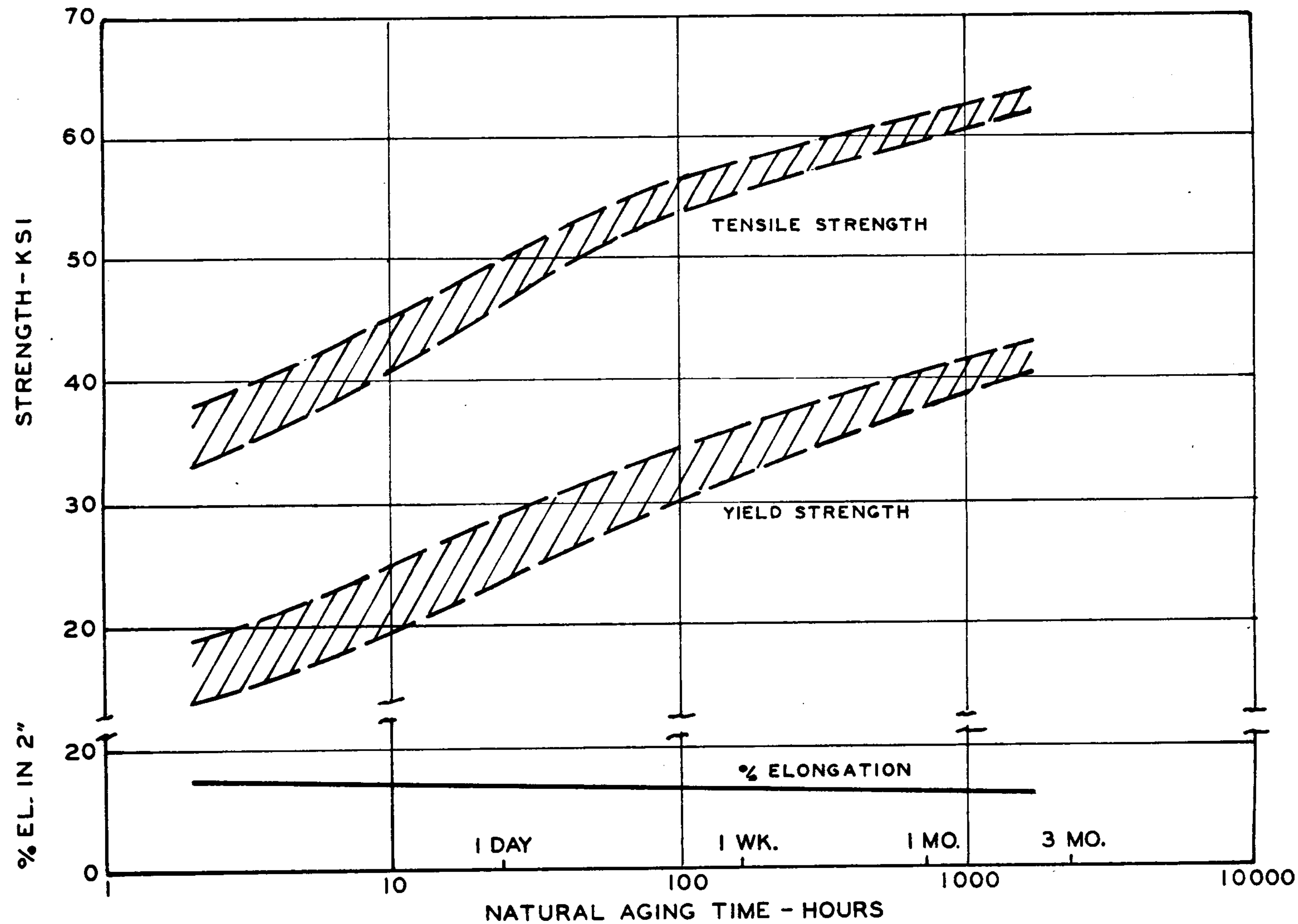


FIGURE 2. NATURAL AGING OF ALLOY X7005 EXTRUSIONS

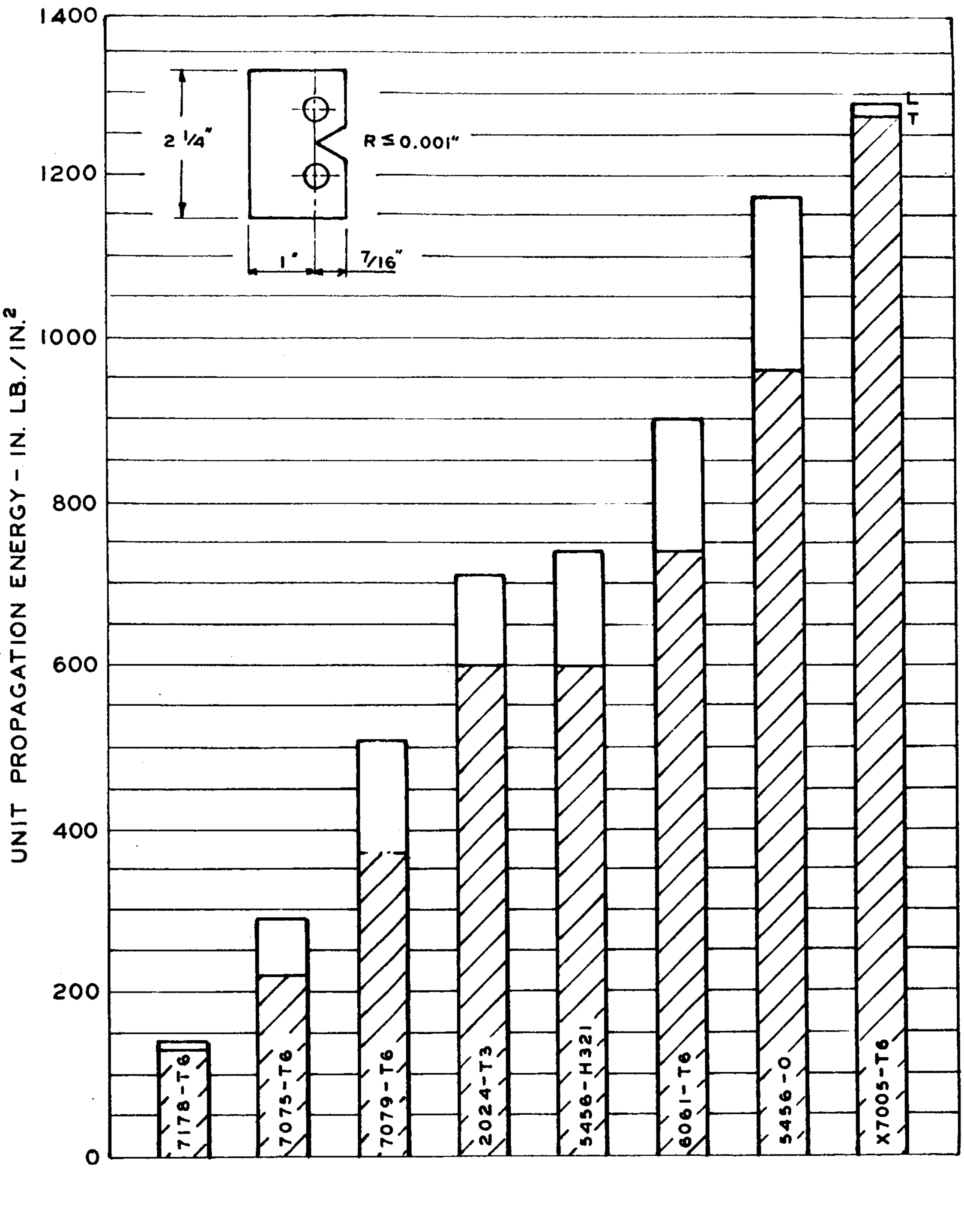


FIGURE 3. UNIT PROPAGATION ENERGIES OF SOME ALUMINUM ALLOYS, 0.063-INCH SHEET

b. Heat treatment

(1) Annealing. A soak of several hours at temperatures within the range of 650° F. to 750° F. should be used for annealing X7005.

(2) Stabilization. Cooling at a rate of 50° F. per hour to about 400° F. after annealing should be used with X7005 to precipitate zinc and magnesium from solid solution and prevent hardening at room temperature.

An alternate practice of heating for 4 to 6 hours at 450° F., after annealing and air or furnace cooling, may also be used to stabilize the alloy.

(3) Aging. Optimum strengths and resistance to stress-corrosion cracking are obtained by a thermal treatment resulting in the -T53 or -T63 temper. This thermal treatment is covered by an Alcoa patent application and a license for its use must be obtained from an Alcoa sales office.

(4) Solution treating. Alloy X7005 may be solution heat treated over a wide temperature range varying from 750° F. to 1120° F. Because of its low quench sensitivity, it may be air cooled from any of these solution treating temperatures and then either naturally or artificially aged to the desired temper.

c. Workability. Ninety-degree cold-bend tests indicate that X7005-T63 forms similarly to 6061-T6. The recommended bend radii for various thicknesses of X7005-0 and X7005-T63 tempers are shown in Table 1.

Table 1

APPROXIMATE RADII FOR NINETY-DEGREE COLD BEND FOR X7005 SHEET AND PLATE

Thickness, in.	X7005-0	X7005-T63
0.064	1/2 – 1 1/2 t	1 – 2 t
0.125	1 – 1 1/2 t	1 1/2 – 2 1/2 t
0.187	1 – 2 t	2 – 3 t
0.250	1 – 2 t	2 1/2 – 3 1/2 t
0.375	2 – 3 t	3 – 4 t
0.500	2 – 3 t	3 – 4 t

Radii expressed in terms of thickness "t"

d. Weldability. X7005 has excellent weldability using gas-tungsten arc (TIG) and gas-metal arc (MIG) welding processes and X5180 filler wire. It can be welded to dissimilar aluminum alloys of the 5000 and 6000 series using X5180, 5356, and 5556 as the recommended filler metals.

Welding procedures, joint preparation, machine settings, and other welding variables are the same when welding X7005 as for other aluminum alloys. Procedures resemble most closely the shop practices for the 5000 series alloys. Precleaning procedures are the same as for other heat-treatable aluminum alloys.

After welding, this alloy will naturally age in several weeks (12 to 24) to produce a stronger weld joint than any of the non-heat-treatable aluminum alloys. Welded joints of X7005 with X5180 filler can be artificially aged to develop weld strengths comparable to those obtained with many post-weld solution-heat-treated aluminum alloys.

The presence of zinc as a constituent in X7005 and X5180 filler metal results in the presence of zinc in the welding fumes from this alloy. Adequate ventilation must therefore be provided for field or shop welding.

X7005 can be successfully resistance welded by using machine schedules similar to those established for 7075 or X7106 alloys.

e. Soldering. X7005 may be easily furnace soldered with Zn-Al or pure Zn solders and a reactive zinc chloride flux. This alloy may be air cooled from the soldering temperature; then either naturally or artificially aged to the desired temper. Soldering time and temperature should be held to a minimum to reduce the possible damaging effects of zinc penetration into aluminum. X7005 is more compatible with zinc solders, due to its higher zinc content, than 1100, 3003, or 6061 alloys.

Lead-silver solders penetrate into aluminum to a lesser extent than zinc solders, therefore they are particularly attractive for soldering thin X7005 to copper or brass.

f. Finishing. Alumilite finishes, including Alumilite hard coatings, can be applied to X7005 without difficulty. Chromic acid anodized coatings and chemical conversion films may also be applied.

2. Aluminum Alloy 7039

a. General. 7039 is an aluminum alloy produced by the Kaiser Aluminum and Chemical Corporation, which has the following nominal composition (percent):

Si	Fe	Cu	Mn	Mg	Zn
0.30 max	0.40 max	0.10 max	0.10-0.40	2.3-3.3	3.5-4.5

Cr	Ti	Others, each	Others, total
0.15-0.25	0.10 max	0.05 max	0.15 max

Al
Remainder

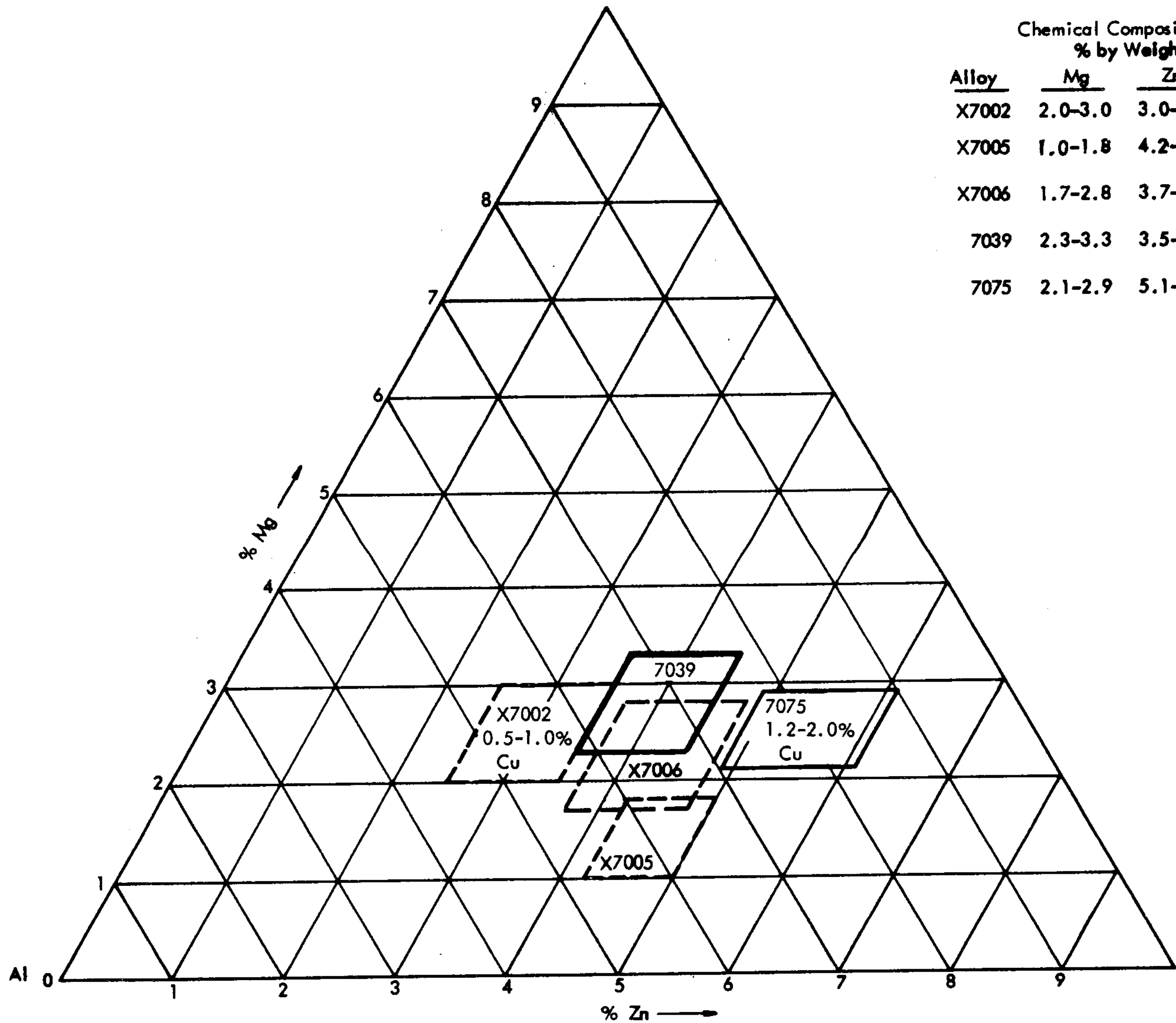
In relation to other aluminum alloys of similar composition, the composition of 7039 is as shown in Figure 4.

The alloy is heat treatable, has high strength, ductility, and toughness plus good weldability and stress corrosion resistance. Its mechanical properties at -320° F. equal or exceed those of other weldable high-strength alloys (Fig. 5). When the NASA edge-notched specimen is used to evaluate properties in a transverse direction at -423° F., the notched strength-yield strength ratio of 7039-T6 sheet is 0.92. Its transverse yield strength at -423° F. is 65,500 psi, providing a yield strength - density ratio of about 650,000 at -423° F.

b. Fatigue properties. Figure 6 shows the fatigue strength of 7039 -T6 plate after 10^8 cycles is superior to that of 2014-T6, 5083-H113, and is almost 12,000 psi higher than that of 2219-T81.

c. Weldability. 7039 aluminum alloy is very resistant to cracking after welding, even in heavier plate after multiple-pass or repair welding. Table 2 gives a comparison of the cracking tendencies of 7039, 7079, and 2219 aluminum alloys after multiple-pass welding using a cruciform shape to heavily restrain the weld metal.

d. Formability. In the annealed condition, 7039 alloy may be formed to smaller bend radii than several other alloys of the same strength classification. This advantage grows larger as thickness of the alloys increases from 0.125 inch to 1.38 inches. Tables 3 and 4 show that guided bend tests also indicate that 7039-T6 is more formable than 2014-T6 or 2219-T87. These tables also show that 7039-T6 is as formable as the lower strength alloy 5083-H113 except in thickness of 0.25 inch or less.



Chemical Composition
% by Weight

Alloy	Mg	Zn	Cu
X7002	2.0-3.0	3.0-4.0	0.5-1.0
X7005	1.0-1.8	4.2-5.0	0.10 Max.
X7006	1.7-2.8	3.7-4.8	0.10 Max.
7039	2.3-3.3	3.5-4.5	0.10 Max.
7075	2.1-2.9	5.1-6.1	1.2-2.0

FIGURE 4. CHEMICAL COMPOSITION FIELDS OF 7039 AND OTHER ALLOYS, Mg-Zn RICH CORNER OF Al-Mg-Zn TERNARY DIAGRAM

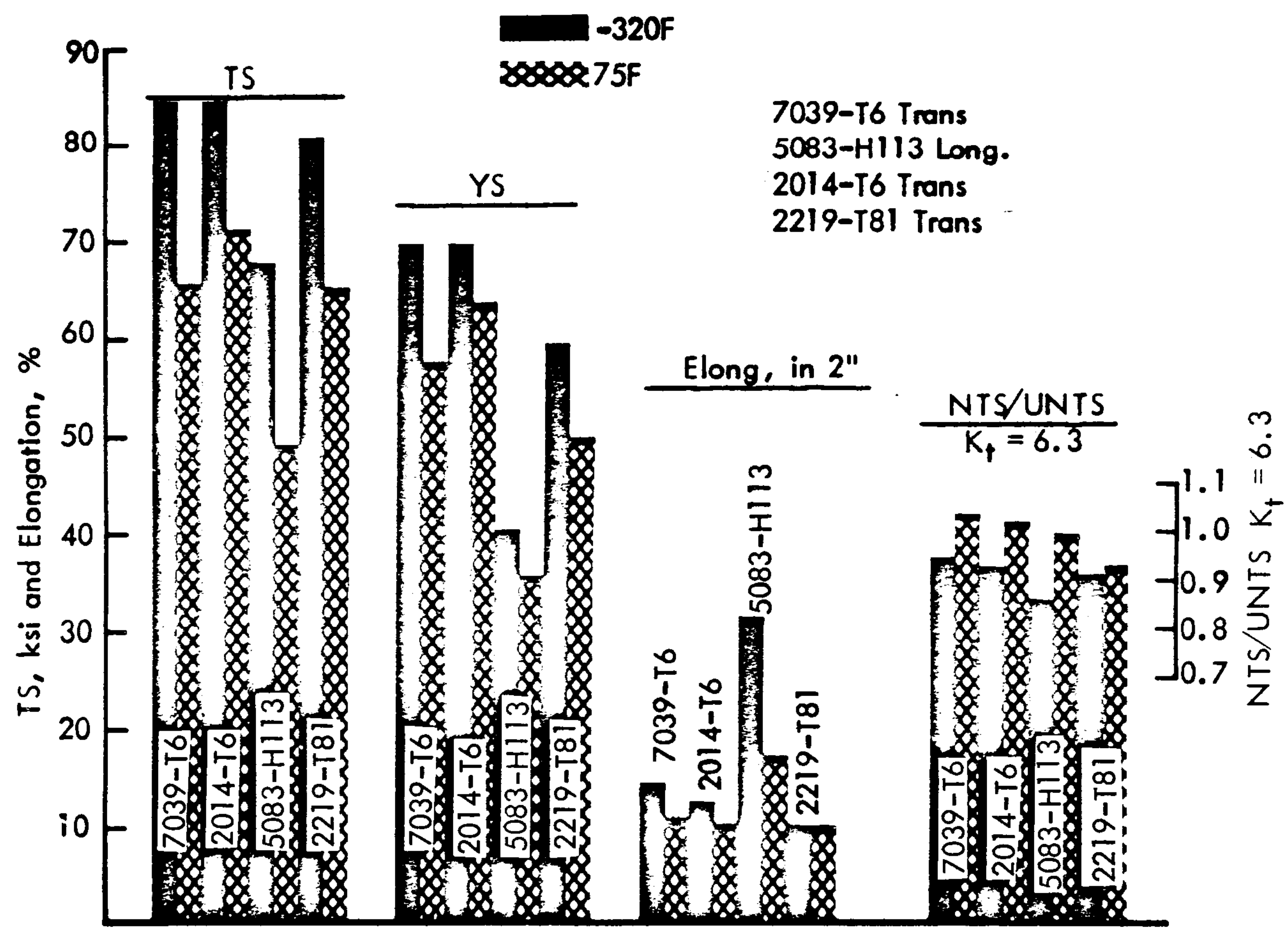


FIGURE 5. COMPARISON OF TENSILE PROPERTIES OF SHEET AT 75° F. and -320° F. (7039-T6 compared with 2014-T6, 5083-H113 and 2219-T81)

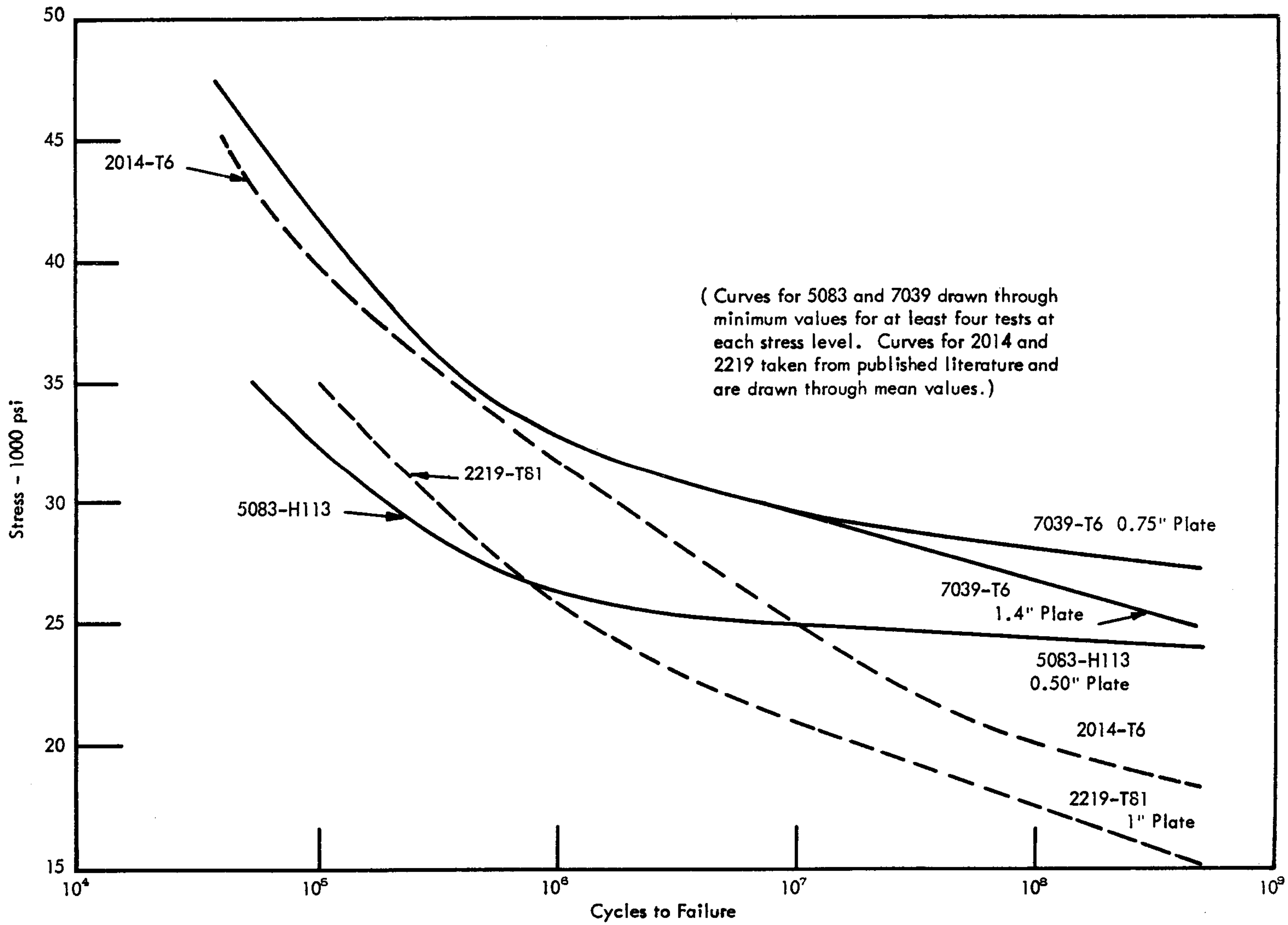


FIGURE 6. ROTATING BEAM FATIGUE, LONGITUDINAL DIRECTION

Table 2

CRUCIFORM CRACKING RESULTS

Cruciform Material		Filler					Total Cracking, Inches	
	Thickness,		Composition, %					
Alloy	Inches	Alloy	Mg	Cu	Zn	Mn	Root Passes	Later Passes
7039	0.75	5183	4.9		0		0	0
7039	1.50	5183	4.9		0		0	0
		5356	5.0		0		0	0
		X5039	4.0		2.6		0	1
7079	0.75	5183	4.9		0		0	3
2219	1.38	2319	0	6.3	0	0.3	0	4-12

Table 3

GUIDED BEND TESTS IN ANNEALED MATERIAL
Ratio of Bend Radius to Thickness

Gauge, Inches	Test Direction	7039-O	2014-O	2024-O	2219-O	5083-O
0.064	Long. Trans.		0		0.5-1.5	0-0.5
0.125	Long. Trans.	0 0	0	0	0.5-1.5	0-1
0.250	Long. Trans.		0-1	0-1	1-2	0.5-1.5
0.375	Long. Trans.	0.5 0.65	1.5-3	1.5-3	1-2	1.5-2
0.500	Long. Trans.	0.65 0.65	3-5	3-5	2-3	1.5-2.5
0.750	Long. Trans.	0.65 0.65			2-3	
1.00	Long. Trans.				3-4	
1.38	Long. Trans.	1.0 1.0				

Table 4

GUIDED BEND TESTS FOR HARDENED TEMPERS
Ratio of Bend Radius to Thickness

Gauge, Inches	Test Direction	7039-T6	2014-T6	2219-T87	5083-H113
0.064	Long. Trans.	1.2 1.2	3-5	3-5	0.5-1
0.125	Long. Trans.	1.2 1.8	4-6	4-6	0.5-1
0.250	Long. Trans.	1.2-2.0 1.8-2.5	6-10	6-9	1-2
0.375	Long. Trans.	1.2-2.0 1.8-2.5	7-10	7-10	1.5-2
0.500	Long. Trans.	1.2-2.0 1.8-2.5	8-11	8-11	2-3
0.750	Long. Trans.	1.2-2.0 1.8-2.5			
1.00	Long. Trans.	1.2-2.0 1.8-2.5			
1.25	Long. Trans.	2.1 2.6			
1.38	Long. Trans.	2.1 2.6			
1.50	Long. Trans.	2.1 2.6			

e. Heat treatment

(1) Solution treatment. Heat to 850° F., soak for one hour per inch of thickness, then water quench.

(2) Natural (room temperature) aging. 7039 is a naturally aging alloy. After solution treatment it will age at room temperature showing a moderate rate of increase in strength with increasing time as shown in Table 5.

3. Aluminum Alloy X7106

a. General. X7106 alloy is a heat-treatable aluminum-zinc-magnesium alloy of the following composition:

Constituent	Content, Percent
Zn	3.7 - 4.8
Mg	1.7 - 2.8
Mn	0.10 - 0.40
Zr	0.08 - 0.25
Cr	0.06 - 0.20
Ti	0.01 - 0.06
Fe + Si	0.35 max
Cu	0.10 max
Others, each	0.05 max
Others, total	0.15 max
Aluminum	Remainder

X7106 fills a demand for a high-strength alloy with excellent weldability and high mechanical properties without the requirement for solution heat treatment after welding. Due to its low quench sensitivity, this alloy requires only a moderate rate of cooling from solution heat treatment or welding

Table 5

NATURAL AGING CHARACTERISTICS OF ALLOY 7039

Tensile Properties of 7039
With Various Natural Aging Periods
After Solution Heat Treatment

Natural Aging Time	Tensile Strength (psi)	Yield Strength (psi)	Elongation (% in 2")
10 minutes	39,900	18,600	27.5
4 hours	43,700	21,600	26.0
1 day	49,500	26,700	22.5
7 days	54,000	30,300	21.0
15 days	56,100	31,400	20.0
30 days	57,400	33,200	20.5
90 days	60,500	35,500	20.0

temperatures. This slower cooling eliminates the severe distortion that generally results from uneven cooling in alloys that require solution heat treatment and rapid quenching prior to artificial aging.

Alloy X7106 will naturally age quite rapidly to a high level of mechanical properties after cooling as shown in Figure 7. Higher strengths can be obtained by artificial aging.

b. Weldability. X7106 has excellent weldability using inert-gas tungsten arc (TIG) and inert-gas metal arc (MIG) welding processes and X5180 filler wire. It can be welded to dissimilar aluminum alloys of the 5000 and 6000 series using 5356 and 5556 as the recommended filler metals.

Welding procedure, joint preparation, machine settings, and other welding variables are the same when welding X7106 as for other aluminum alloys. Procedures resemble most closely the shop practices used for the 5000 series alloys. Precleaning practices are the same for X7106 as for other heat-treatable aluminum alloys.

After welding, X7106 will naturally age in several weeks (Fig. 7) to produce a stronger weld joint than any of the non-heat-treatable aluminum alloys. Welded joints of X7106 with X5180 filler can be artificially aged to develop weld strengths that are equal to or greater than those obtained with many post-weld solution-heat-treated aluminum alloys.

Using biaxial loading conditions, welds in X7106-T6 sheet with X5180 filler developed an average ultimate strength of 55, 000 psi after one month natural aging. This average strength and the elongation for X7106 are superior to those of as-welded 2219-T87 or 7178-T6.

The presence of zinc as a constituent in X7106 and X5180 filler metal results in the presence of zinc in the welding fumes from this alloy. Adequate ventilation must therefore be provided during all fusion welding operations.

X7106 can be successfully resistance welded by using machine schedules similar to those established for 7075 alloy.

Figures 8, 9, and 10 show that X7106 has good strength at cryogenic temperatures and has a higher level of notch toughness and tear resistance at these temperatures than any of the aluminum alloys presently used in this application.

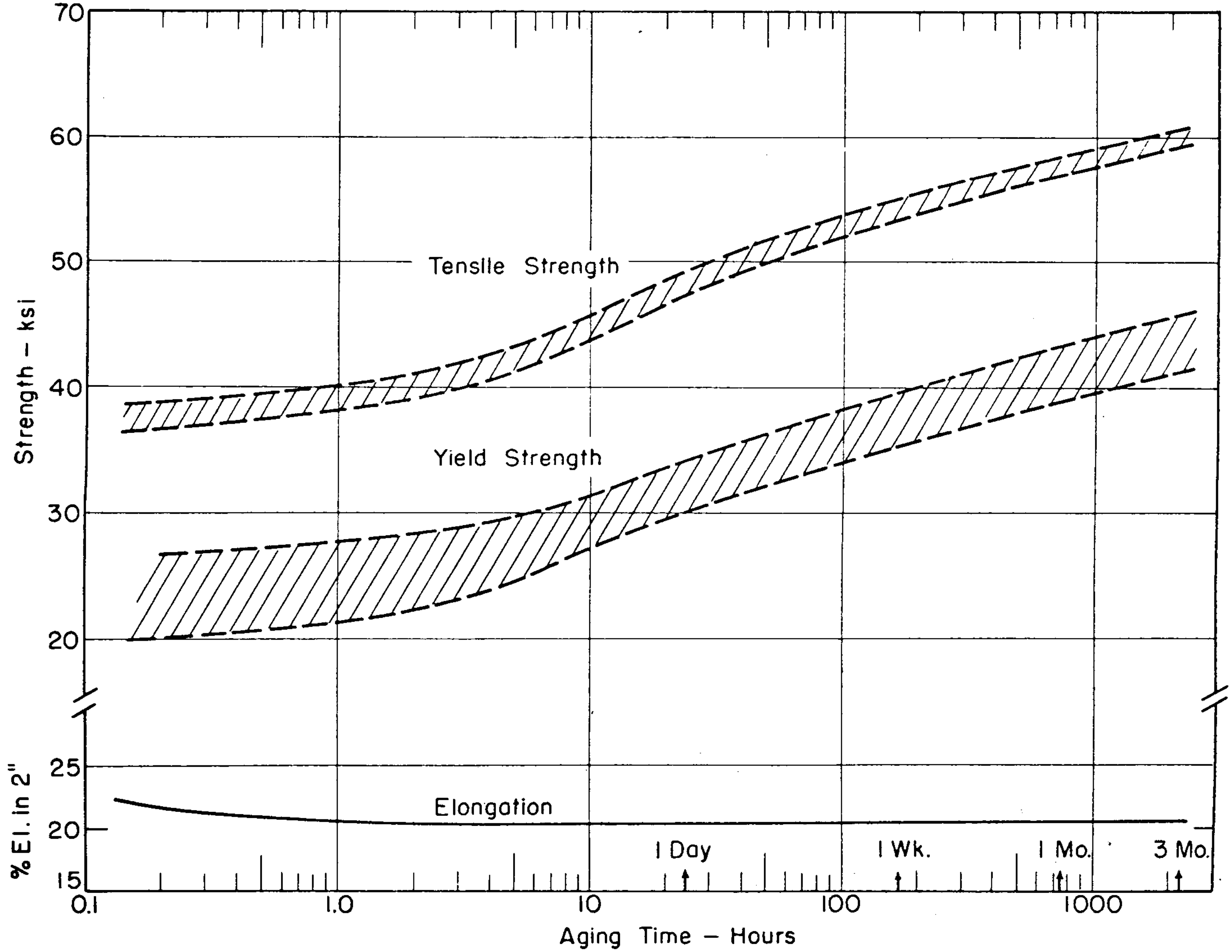


FIGURE 7. NATURAL AGING OF ALLOY X7106

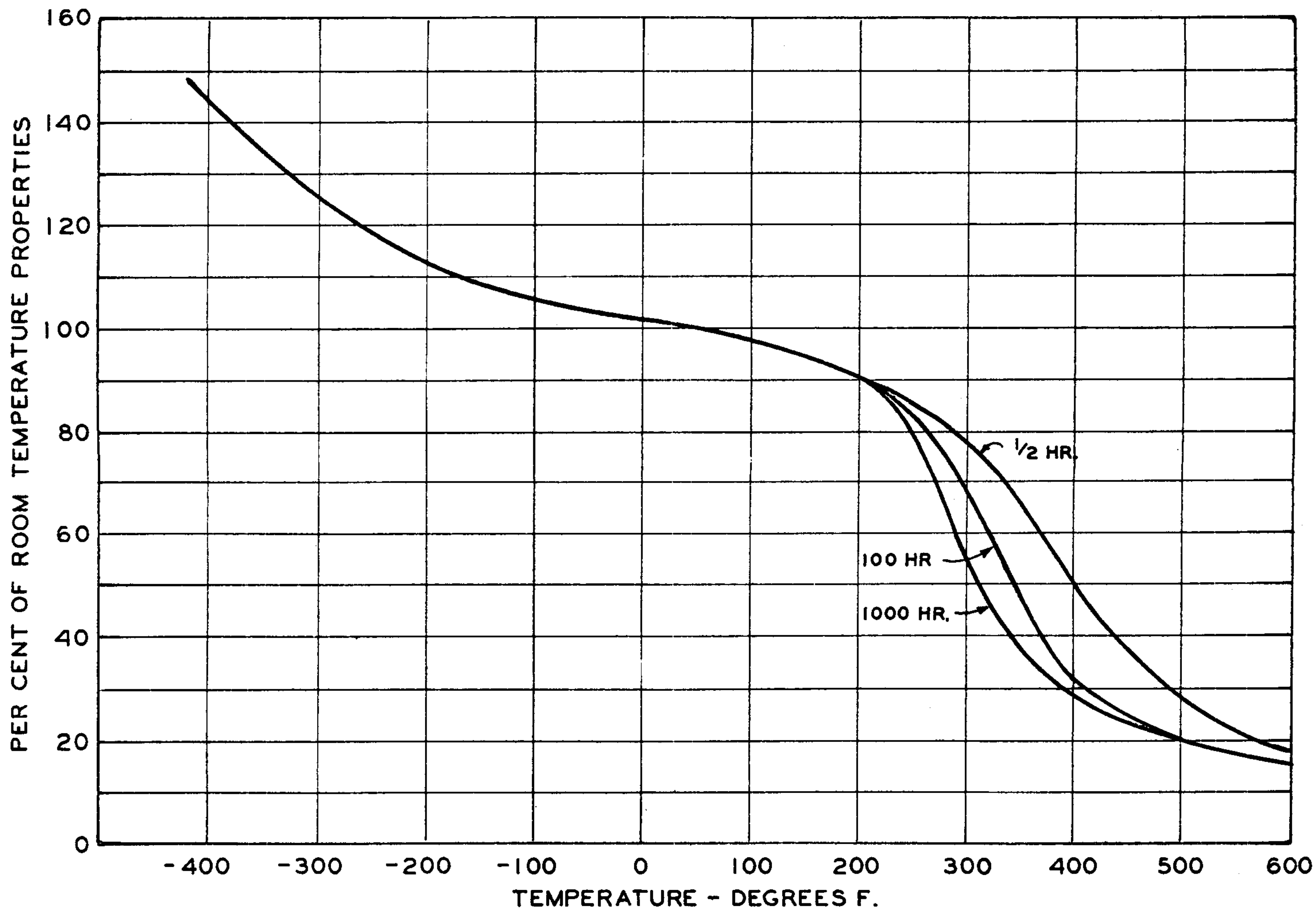


FIGURE 8. CHANGE OF TENSILE STRENGTH WITH TEMPERATURE, ALLOY X7106-T6, -T63

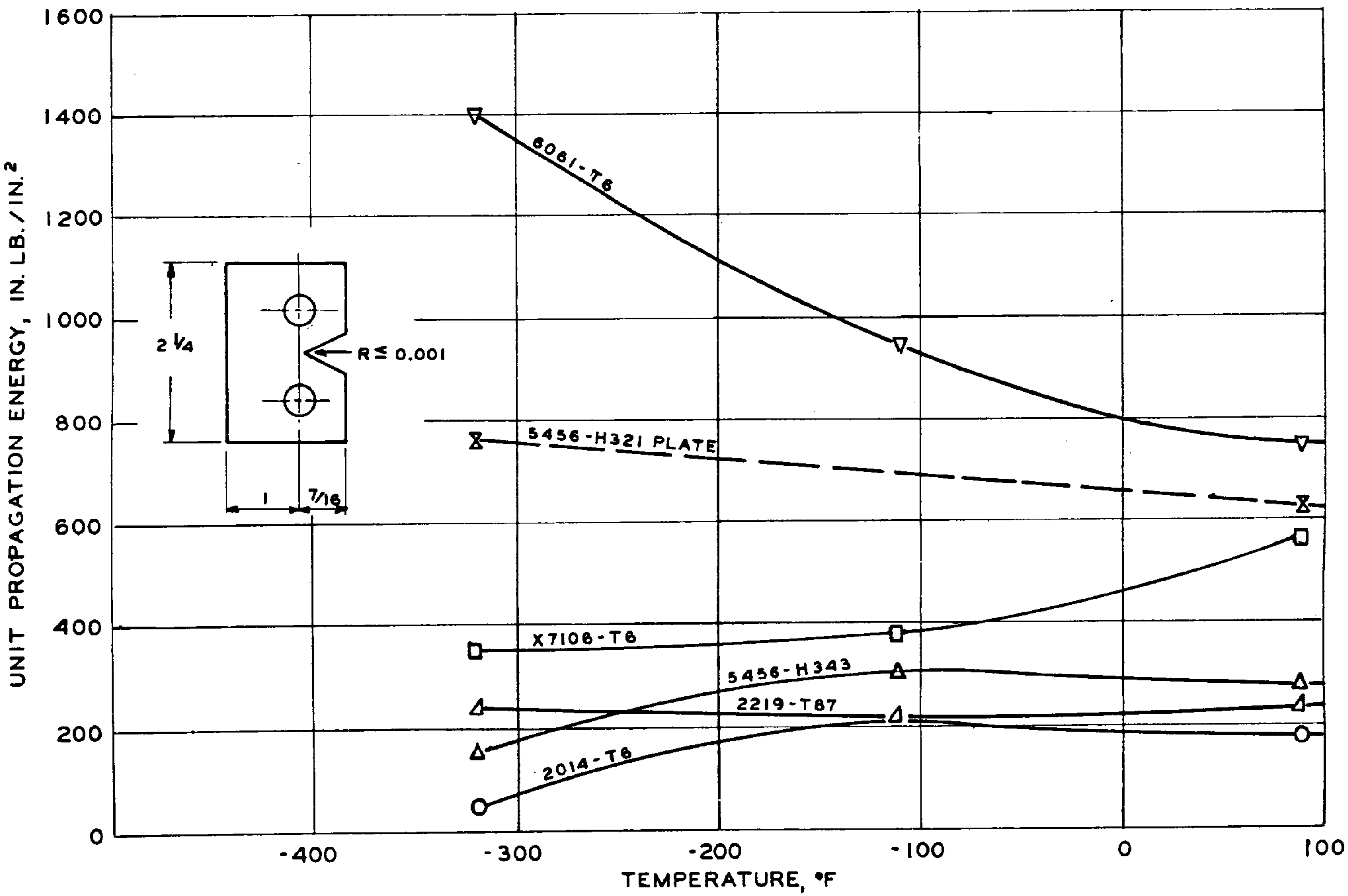


FIGURE 9. UNIT PROPAGATION ENERGIES OF ALUMINUM ALLOYS AT ROOM AND LOW TEMPERATURES, 0.063-INCH SHEET (TRANSVERSE)

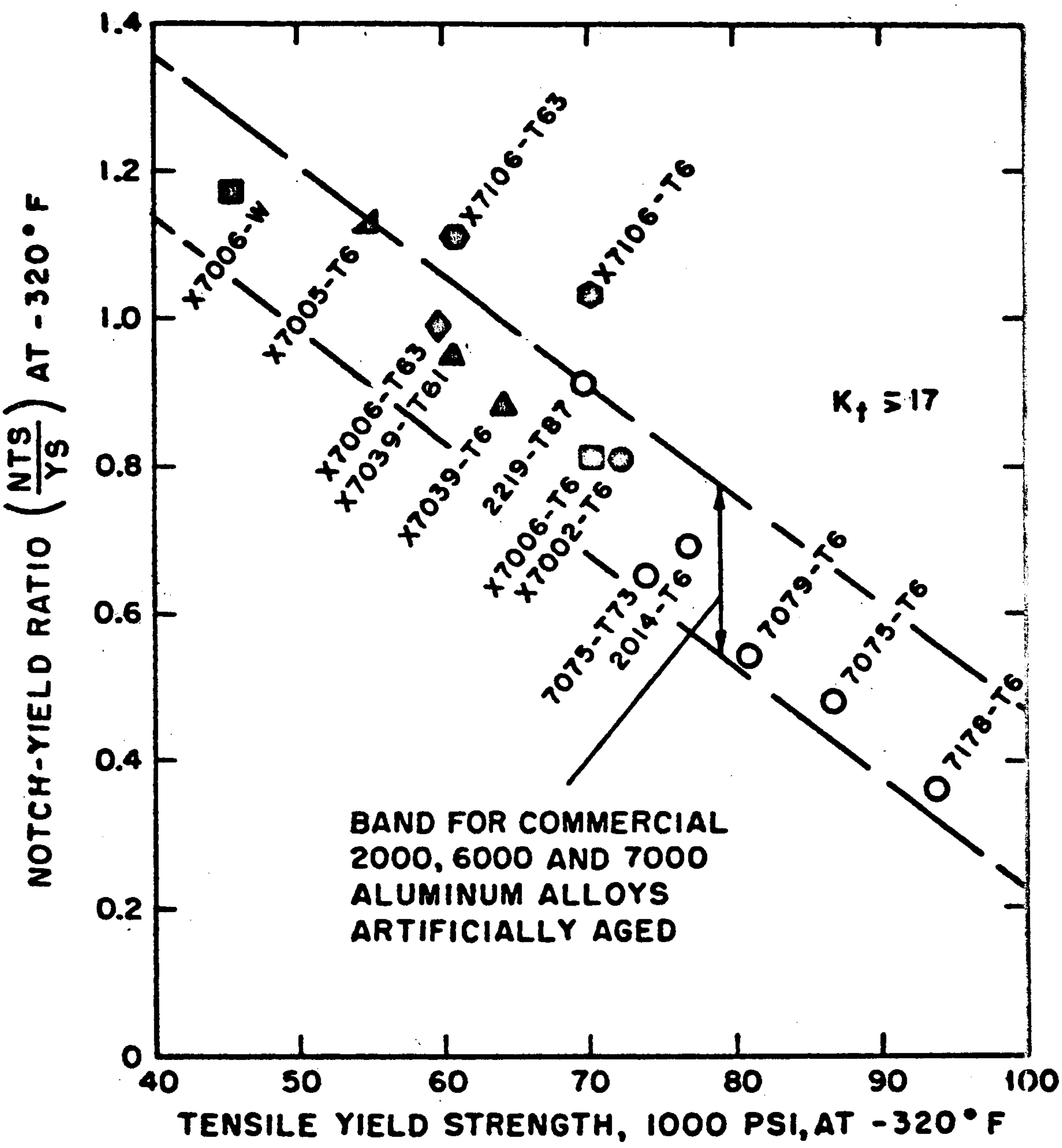


FIGURE 10. RELATIONSHIP BETWEEN NOTCH-YIELD RATIO AND TENSILE YIELD STRENGTH AT -320° F., 0.063-INCH THICK SHEET (TRANSVERSE)

c. Heat treatment

(1) Annealing. A soak of several hours at temperatures within the range of 650° F. to 750° F. should be used for annealing X7106.

(2) Stabilization. Cooling at a rate of 50° F. per hour to about 400° F. after annealing should be used with X7106 to precipitate zinc and magnesium from solid solution and to prevent hardening at room temperature.

An alternate practice of heating for 4 to 6 hours at 450° F., after annealing and air or furnace cooling, may also be used to stabilize the alloy.

(3) Aging. Optimum strengths and resistance to stress corrosion cracking are obtained by a thermal treatment resulting in the -T53 or -T63 temper. This thermal treatment is covered by an Alcoa patent application. A license for its use must be obtained from an Alcoa sales office.

(4) Solution treating. Alloy X7106 may be solution heat treated over a wide temperature range varying from 900° F. to 1050° F. Because of its low quench sensitivity, it may be air cooled from any of these solution treating temperatures and then either naturally or artificially aged to the desired temper.

d. Workability. Ninety-degree cold-bend tests indicate that X7106-T63 forms similarly to 6061-T6. Severe forming operations should be performed within four hours after solution heat treatment. Recommended bend radii for various thicknesses of X7106-0 and X7106-T63 tempers are shown in Table 6.

e. Soldering. X7106 may be easily soldered with Zn-Al or pure Zn solders and a reactive zinc chloride flux. Soldering time and temperature should be held to a minimum, 750° F. to 850° F., to reduce the possible damaging effects of zinc penetration into aluminum. X7106 is more compatible with zinc solders, due to its higher zinc content, than are 1100, 3003, or 6061 alloys.

Lead-silver solders penetrate into aluminum to a lesser extent than zinc solders. These solders are particularly attractive for soldering thin X7106 to copper or brass.

Table 6

APPROXIMATE RADII FOR NINETY-DEGREE COLD BEND, SHEET AND PLATE

X7106

Radii expressed in Terms of Thickness "t"

Thickness, in.	X7106-0	X7106-T63
0.064	1 – 1 1/2t	2 – 3t
0.125	1 – 1 1/2t	2 – 3t
0.250	1 – 1 1/2t	3 – 4t
0.375	3 – 4t	4 – 5t
0.500	3 – 4t	4 – 5t

f. Finishing. Alumilite finishes, including Alumilite hard coatings, can be applied to X7106 without difficulty. A good color match of anodized welded joints results if the filler alloy is X5180. Chromic acid anodized coatings and chemical conversion films may also be applied.

C. AUSTENITIC IRON-BASE ALLOYS

The austenitic stainless steels (300 series) demonstrate their maximum cold-rolled strengths and toughness at cryogenic temperatures. They have consequently been widely used for extremely low-temperature applications. Other austenitic iron-base alloys which are not so well known, but which have properties justifying their consideration for use at cryogenic temperatures are 19-9DL, A-286, AM350, and Multimet (N-155).

1. <u>19-9 DL</u>

a. General. Uniloy 19-9 DL is a chromium-nickel super alloy, capable of withstanding high static and dynamic stresses. It has a predominantly austenitic matrix and is characteristically fine grained, with relative freedom from notch sensitivity and other forms of brittle failure. It does not age harden appreciably and is stable over its full range of service temperatures as shown in Table 7.

b. Heat treatment

(1) General. 19-9 DL contains a relatively high amount of carbon. Consequently, the alloy must not be exposed to corrosive media.

(2) Solution treating. Heat to 1800° F. Maintain at temperature for 15 to 30 minutes, then water or oil quench.

(3) Aging. For optimum long-time creep and rupture resistance, age at 1200° F. to 1400° F. following solution treatment.

(4) Annealing. Heat to 1800° F. ± 25° F. Maintain at temperature for 1/2 to 1 hour, then water or oil quench.

(5) Stress relieving

(a) When resistance to intergranular corrosion is not a major factor, 19-9 DL may be stress relieved by heating to 1200° F., holding for 30 to 60 minutes, then air cooling.

Table 7

19-9 DL, SHORT TIME TENSILE PROPERTIES - BAR STOCK

Temp. °F	UTS, psi	YS psi (0.2%)	Elongation % in 2"
80	118000	69000	55
300	101000	59000	57
500	99500	53000	52
700	94000	48000	56
900	92000	44000	55
1000	89000	42000	52
1200	75000	37000	34
1400	43000	35500	60
1500	33000	30000	72

(b) If resistance to intergranular corrosion is a major factor, 19-9 DL must be stress relieved by heating to 1800° F. followed by quenching in oil or water.

(c) If severe cold forming is done on 19-9 DL, it should be stress relieved at a minimum temperature of 1200° F. as soon as possible thereafter to avoid strain cracking of parts.

c. Machinability

(1) General. Use the same machining techniques for 19-9 DL as for 18-8 stainless steels. Use super high-speed steel or carbide tools. Use sulphurized or sulphurized and chlorinated cutting fluids. 19-9 DL machines with a tough, stringy chip therefore chip curlers and breakers are helpful. Cold drawing improves machinability.

(2) Turning. Single-point tools of HSS should be ground to 5 to 10 degrees back rake 5 to 10 degrees top rake, 5 to 8 degrees side clearance, 7 to 10 degrees front clearance, 8 to 15 degrees cutting-edge angle, and 10 to 15 degrees lead angle. Cutting edges should be maintained sharp, smooth, and free from rough spots. Cutting speeds should be from 40 to 85 sfpm with a feed of 0.003 to 0.008 inch per revolution.

(3) Drilling. Drills should be ground to a 140-degree included angle at the drill tip and a 9 to 15-degree lip clearance. Drill speed should be from 15 to 40 sfpm with a feed rate of 0.003 to 0.007 inch per revolution.

d. Workability. 19-9 DL is readily forged from 2150° F. down, preferably in neutral or slightly oxidizing atmospheres. Forging may proceed to as low as 1200° F., because 19-9 DL is not hot short in its working range.

e. Weldability. 19-9 DL is readily weldable by any of the inert-gas-shielded or metallic-arc processes. Use 19-9 WX bare welding rod or 19-9 W-Mo coated rod.

f. Pickling. The preferred method for descaling, deoxidizing, or cleaning 19-9 DL is by means of a sodium hydride or other molten salt bath. When strong acid pickling baths must be used, the material should be annealed at 1800° F. and water or oil quenched prior to pickling.

2. A-286

a. General. A-286 is an age-hardenable austenitic iron-nickel-chromium alloy originally designed for service up to 1300° F. where high strength and corrosion resistance are required, and for service at higher temperatures in lower-stress applications. Since the original development of A-286, it has been found that its low temperature properties, shown in Table 8, make it suitable also for use in cryogenic applications.

The presently recommended chemical constituent ranges for A-286 are given in Table 9. The presence of a minimum of 0.001 percent boron has been shown to be necessary to prevent formation of a weak, soft (Rockwell B97), lamellar-type precipitate of Ni_3Ti after age hardening. When this lamellar-type precipitate is present, stress-rupture values are very low, and creep rate increases many fold. When boron is present in percentages over 0.001, a "herringbone" type of precipitate forms in strained areas after aging at a temperature in the range of 1100° F. to 1500° F. This "herringbone" precipitate has a hardness of Rockwell C 30, which is comparable to the hardness of the base metal in the aged condition, and is thought to be a form of metallic carbide of the approximate M_6C composition. A maximum limitation of 0.010 percent boron is necessary because it has been found that boron contents only slightly higher than this cause the formation of a low-melting-point eutectic in the grain boundaries. This condition is analogous to hot shortness in steels and results in cracking during welding or hot roll forging.

b. Heat treatment

(1) Solution treatment. For normal formability and highest stress-rupture strength, heat to 1800° F., soak for one hour at temperature, then cool rapidly to room temperature. (Thick sections should be oil quenched, while thin sections such as sheets may be air cooled.)

(2) Solution treatment. For maximum yield strength, tensile strength, and hardness values, heat to 1650° F., soak for one hour at temperature, then cool rapidly to room temperature. It is thought that the higher strength following the 1650° F. solution treatment is due to incomplete recrystallization at this temperature.

(3) Solution treatment. For maximum formability and improved weldability, heat to within the range of 1828° F. to 2000° F., soak for one hour at temperature, then cool rapidly to room temperature. Some grain coarsening can occur at the upper end of this temperature range but

Table 8

TYPICAL TENSILE PROPERTIES OF A-286 AT CRYOGENIC, ROOM, AND ELEVATED TEMPERATURES

Test Temperature, °F	Yield Strength, 0.2% Offset PSI	Ultimate Tensile Strength, PSI	Elongation, % in 2"	Ratio, Notched (K_t=6.3) To Unnotched Tensile Strength
-423	139,000	233,000	18	0.87
-320	122,000	203,000	23	0.88
78	96,900	150,000	15	0.98
1000	86,000	130,000		
1300	80,000	90,000		

Table 9

CHEMICAL COMPOSITION OF A-286

Constituent	Content, %
Carbon	.08 max.
Manganese	1.00 - 2.00
Silicon	0.40 - 1.00
Phosphorus	0.040 max.
Sulphur	0.030 max.
Chromium	13.50 - 16.00
Nickel	24.00 - 27.00
Molybdenum	1.00 - 1.50
Titanium	1.90 - 2.30
Boron	0.0010 - 0.010
Vanadium	0.10 - 0.50
Aluminum	0.35 max.

tensile and stress-rupture properties are satisfactory after aging. The improved formability and weldability resulting from these higher solution-treating temperatures results from a more complete solution of Ni_3Ti and M_6C (metallic carbides) than occurs at 1650° F. or 1800° F.

(4) Aging. Reheat to within the range of 1300° F., soak for 16 hours at temperature, then air cool to room temperature. During aging, metal shrinkage amounts to approximately 0.001 inch per inch. This metal shrinkage begins to occur at approximately 1100° F., even though the other effects of aging cannot be observed. Shrinkage is believed to occur as a result of nucleation which takes place prior to the precipitation of Ni_3Ti and M_6C. If aged material is subsequently solution treated, A-286 will expand approximately 0.001 inch per inch.

Heat treating A-286 without using any form of restraint is helpful in eliminating stress cracking of the material. In-process solution treatments at 1800° F. are desirable to permit heat treating of final assemblies without expensive and complicated fixtures.

c. Workability. A-286 of the composition range specified in Table 9 may be rolled and forged at temperatures as high as 2300° F. Finishing temperature may be as low as 1700° F. If the boron content is too high, a temperature of 2050° F. cannot be exceeded for rolling, forging, or roll forging without the material breaking up. A-286 is slightly more resistant to deformation than the austenitic stainless steels during hot working; consequently it may require more frequent reheating.

d. Machinability. A-286 is "gummy" in the solution treated condition; therefore machining is usually done after aging. Machinability of solution-treated material can be improved by partially aging for one hour at 1300° F. to 1325° F. or by overaging for several hours at 1500° F.

Single-point tool angles for high-speed steel turning tools should be 5 to 10 degrees back rake, 5 to 8 degrees side clearance, 7 to 10 degrees front clearance, 8 to 15 degrees cutting-edge angle, and 10 to 15 degrees lead angle. Cutting edges must be kept sharp, smooth, and free from rough spots.

Sulphurized and sulphur-chloride base cutting fluids are recommended for use with A-286.

e. Weldability. A-286, of the composition range specified in Table 9, is readily welded by any of the inert-gas-shielded processes. The most weldable condition for A-286 is after solution treatment in the 1825° F. to 2000° F. range. It is slightly less weldable after solution treating at 1800° F., and even less weldable after solution treating at 1650° F.

The tendency of A-286 to crack during welding, due to excessive boron content, can be evaluated by making a circular weld on one side of a specimen followed by welding a cross inside the circular weld. An examination of the opposite side of the specimen will reveal many tiny cracks if the material is hot short. When attempts are made to repair weld cracks resulting from excess boron content and consequent hot shortness in A-286, the cracks tend to spread and move rapidly ahead of the heat from the welding torch.

Welding A-286 without restraining is helpful in eliminating stress cracking of the material.

Inert-gas protection on both top and bottom during fusion welding helps to eliminate false Zyglo inspection indications which result from the uneven oxide film that forms on A-286 in unprotected weld areas.

f. Descaling and pickling. For satisfactory removal of heavy scale, a scale-conditioning treatment in a molten-salt bath may be required prior to acid pickling. The scale-conditioning treatment removes most of the scale more rapidly than acid pickling, but leaves a small amount which must be removed by pickling. Protective, antioxidant coatings such as Turco 4367 are commonly used on A-286 to minimize scale formation and to make scale removal easier.

Both reducing and oxidizing molten-salt baths are used for descaling and scale-conditioning treatment of A-286. These baths are of special value in descaling parts having close dimensional tolerances which will not permit the dissolution of basis metal that occurs in normal pickling. Reducing salt baths (sodium hydride) operate at temperatures in the range of 700° F. to 750° F. while the oxidizing salt baths operate at 950° F. to 1000° F.

The compositions of acid pickling baths used in scale and oxide removal, either after scale conditioning or without scale conditioning, are shown in Table 10.

The passivation step which follows most scale and oxide removal operations serves the following two important functions:

Table 10

DESCALING AND PICKLING OF A-286

OBJECTIVE	METHOD	COMPOSITION	TIME, MIN.	TEMP., °F	SPECIAL OPERATING CONDITIONS	REMARKS
Scale Removal	1. Molten Caustic Descaling a. Molten - caustic dip	Molten caustic		900	Thorough cleaning before heat treatment aids in scale removal afterwards.	Oxidizes the scale.
	b. Acid dip c. Chemical pickle	H_2SO_4-20 wt.% HNO_3-35 to 40wt.% HF -3 to 4 wt.%	5 20	75 ± 5 75		Neutralizes the caustic. Removes the scale without intergranular attack of the metal.
	2. Pickling	HNO_3-30 ± 5 wt.% HF - 2 ± 1 wt.%	30 max.	130 ± 5	Antioxidant(i.e. Turco 4367 or equal) should be applied to chemically clean parts before heat treatment to facilitate scale removal.	No intergranular corrosion up to 30 minutes immersion time; removes 99 to 100% scale in 5 minutes if pretreated with antioxidant; requires 25-30 minutes if not treated with antioxidant; preferred over most other chemical and electrolytic descaling compositions.
Oxide Removal and Passivation	Pickling	HNO_3(70wt.%) - 50 to 70 vol.%	15 to 30	130		Stainless steels are often pickled to produce a passive film on the surface and to remove other contaminating particles.
Oxide Removal and Passivation	Pickling	HNO_3(70wt.%) - 10 to 20 vol.%	15 to 20	130 to 140		Stainless steels are often pickled to produce a passive film on the surface and to remove other contaminating particles.

(1) To clean the metal surfaces of any free iron, steel, or rust particles that it may have picked up during prior processing.

(2) To end pickling operations with a step or process which inhibits later staining or rusting.

Passivation should therefore be the final step in the processing of A-286 parts.

3. AM 350

a. General. AM 350 is a heat-treatable type of chromium-nickel-molybdenum stainless steel which bridges the gap between the 300 and 400 series of stainlesses. In the annealed condition, this alloy is essentially austenitic with good ductility. It can be hardened by either a precipitation-hardening treatment or by subzero cooling. The subzero cooling method is preferred because of superior hardness, strength, ductility, impact strength, and corrosion resistance. This alloy combines the desirable forming properties of the austenitic grades of stainless with the high hardness and strength properties of the hardenable grades as shown in Table 11.

b. Heat treatment. AM 350 can be hardened at temperatures low enough to prevent excessive scaling and distortion. Times and temperatures used with this alloy are as follows:

(1) Anneal. Heat to 1750° F., hold at temperature for one-half hour, cool in air.

(2) Subzero treatment. Anneal, then cool to -100° F. for two hours.

(3) Subzero cooled and tempered. Anneal, cool to -100° F., then temper for two hours at 750° F.

(4) Precipitation hardening. Anneal, then age for one hour at 1350° F.

(5) Double aged. Anneal, age for one hour at 1350° F., then age for one hour at 850° F.

c. Workability. AM 350 has good forming properties. It has a high rate of work hardening with a subsequent high rate of increase in hardness and strength.

Table 11

TYPICAL TENSILE PROPERTIES OF AM 350
AT CRYOGENIC, ROOM, AND ELEVATED TEMPERATURES

Test Temperature, °F	Yield Strength, PSI	Ultimate Tensile Strength, PSI	Elongation, % in 2"	Ratio, Notched (K_t=6.3) To Unnotched Tensile Strength
(Cold rolled and tempered)				
-423	320,000	340,000	0	0.34
-320	320,000	346,000	9.5	0.46
-100	280,000	300,000	17	0.89
78	270,000	290,000	5.4	0.85
(Subzero cooled and tempered)				
R.T.	146,900	191,900	13.5	
800	116,500	179,100	13.5	
900	100,125	158,950	8.0	
1000	83,250	104,250	9.0	
1100	46,830	67,970	16.0	
1200	29,230	45,240	42.0	

d. Machinability. AM 350 can be machined in a manner similar to the austenitic (300) series stainless steels. The alloy has a high rate of work hardening; therefore sharp tools are required to prevent excessive surface hardening. In general, machining should be done using heavy feeds, slow speeds, and chip curlers. With high-speed steel cutters, use speeds of 70 to 90 sfpm for automatic screw machines, 60 to 80 sfpm for turret lathes, 40 to 60 sfpm for milling, 30 to 50 sfpm for drilling, 10 to 25 sfpm for tapping and threading, and 8 to 12 sfpm for broaching. In all cases use a sulphur-chlorinated cutting fluid.

Cutting speeds may be greatly increased by using carbide-tipped tools.

Single-point turning tools of high-speed steel should be ground with a 5 to 10 degree back rake, 5 to 8 degree side clearance, 7 to 10 degree front clearance, 8 to 15 degree cutting-edge angle, and 10 to 15 degree lead angle.

e. Weldability. AM 350 is weldable by all the techniques commonly used with the austenitic (300 series) stainless steels.

f. Descaling and pickling. In removing scale formed during homogenization or full annealing, the use of a 10 percent HNO_3 to 2 percent HF aqueous solution at 110° F. to 140° F. is effective. Exposure to the acid solution should be limited to three minutes. Removal of loosened scale may be assisted by the use of high-pressure water or steam. A uniform appearance of a surface is evidence of a well-cleaned part. The compositions of acid solutions used in descaling and pickling of AM 350 are shown in Table 12.

Austenite-conditioning treatments produce a scale that is best removed by mechanical means. Acids should be avoided because they are a possible source of intergranular attack. Wet grit blasting processes have been widely used to remove these scales and have been found to be highly satisfactory.

The precipitation hardening heat treatment produces a discoloration or heat tint on AM 350. It is desirable to use a mechanical means to remove this discoloration or oxide from AM 350. HNO_3-HF solutions have been used on this steel, but extreme care is required to prevent intergranular attack. To a lesser extent, electropolishing has also been used to remove the final heat tint resulting from precipitation hardening.

g. Corrosion resistance. The corrosion resistance of AM 350 after hardening by subzero cooling and tempering is comparable to Type 316 stainless steel and is superior to Type 304. Maximum resistance to strong

Table 12

DESCALING AND PICKLING OF AM 350

OBJECTIVE	METHOD	COMPOSITION	TIME, MINUTES	TEMP., ^{o}F	SPECIAL OPERATING CONDITIONS	REMARKS
Oxide Removal and Passivation	Pickling	HNO_3 (70 wt.%) 50 to 70 vol.%	15 - 30	130		Stainless steels are often pickled to produce a passive film on the surface and to remove other contaminating particles.
	Pickling	HNO_3 (70 wt.%) 10 to 20 vol.%	15 - 20	130 - 140		Stainless steels are often pickled to produce a passive film on the surface and to remove other contaminating particles.
Scale Removal After High or Low Anneal	Pickling	HNO_3 - 15 wt.% HF - 3 wt.%	3	110 - 140	All grease or other surface contamination should be removed before annealing.	Use minimum pickling time for scale removal; uniform scale can be removed in less than 3 minutes; scale from intermediate anneal must be removed before drawing or forming operations.
Oxide Removal After Tempering	Pickling	HNO_3 - 15 wt.% HF - 3 wt.%	Less than 1	130 or less	Blast cleaning can be substituted for chemical cleaning. If blast cleaned, remove residual scale by a brief acid pickle.	Tempering scale is very light. Weaker bath compositions could be used.

oxidizers, for example, 65 percent HNO_3, is obtained when the alloy is in the subzero-cooled condition without tempering. Because of the carbide precipitation which occurs during double aging, the corrosion resistance in all media is not as good in the double-aged condition as it is when subzero cooled only, or subzero cooled and tempered. Its resistance to pitting-type attack in 20 percent sodium-chloride salt-spray test is excellent.

4. Multimet (N-155)

a. General. Multimet (N-155) is a Co-Ni-Cr-Fe austenitic alloy. It tends to work harden but does not respond significantly to age hardening.

b. Heat treatment

(1) Solution treatment. For sheet, heat to 2150° F., AC; for heavy stock, heat to 2200° F., water quench. Properties are shown in Table 13.

(2) Aging. For wrought stock, hold at 1350° F. for 24 hours, AC. (Brinell 187-229.) For solution-annealed material, hold at 1500° F. for four hours, AC. (Brinell 193-241.)

(3) Stress relief. Hold at 1200° F. for two hours, AC.

c. Machinability

(1) General. With this material, use cast non-ferrous cutting tools at slower speeds and with lighter feeds than with the 300 series stainless steels. Tool cutting edges must be kept sharp, smooth, and free from rough spots.

(2) Turning. Single-point tools should be ground to 5 to 10 degrees back rake, 5 to 8 degrees side rake, 5 to 8 degrees side clearance, 7 to 10 degrees front clearance, 8 to 15 degrees cutting-edge angle, and 10 to 15 degrees lead angle.

(3) Cutting fluids. Sulphur or sulphur-chloride cutting fluids are recommended for cooling and tool lubrication.

Table 13

MULTIMET (N-155) TENSILE PROPERTIES - 0.063-INCH SHEET
(Mill Annealed at 2150° F., Air Cooled)

Temperature, °F	UTS, psi	YS, psi (0.2%)	Elongation, % in 2"
RT	118000	58000	49
400	101000	44000	48
600	98200	40000	50
800	98000	42000	54
1000	94000	40000	54
1200	74000	38000	28
1400	58000	36000	12
1600	39000	30000	15

d. Workability. Multimet can be drawn, spun, rolled, flanged, and dished cold. Annealing between forming stages may be required to overcome loss of ductility from work hardening.

Hot working is done at 1900° F. to 2200° F.

Forming is preferably done cold.

e. Weldability. Multimet can be welded by electric-arc, oxy-acetylene, inert-gas-shielded, submerged-arc, and solid-phase pressure-welding methods. In fact, it can be welded by all methods applicable to the stainless steels.

In fusion welding methods, travel rapidly without weaving to avoid a wide heat-affected zone. Use the minimum current required for the thickness of metal being welded.

Filler metal should be of the same composition as the base metal. Multimet (N-155) shows some hot-short characteristics when welded in a restrained condition.

f. Brazing and soldering. Multimet may be brazed or silver soldered by all methods used with stainless steels.

D. NICKEL- AND COBALT-BASE ALLOYS

Nickel- and cobalt-base alloys are most commonly thought of as high-temperature alloys for service in the temperature range of 1000° F. to 1800° F. Most of these alloys, however, have a face-centered cubic crystalline structure which results in their also possessing excellent mechanical properties at cryogenic temperatures. This fortunate combination of excellent high- and low-temperature properties qualifies these alloys, above all others, for applications in which they may be exposed to one temperature extreme during a portion of a flight profile, then to the opposite temperature extreme, during a later portion of the flight.

Alloys which fall into the category described above are Hastelloy C, Inconel 718, Rene 41, and L-605 (HS-25).

1. Hastelloy C

a. General. Hastelloy C is a nickel-base superalloy containing Cr, Mo, W, and Fe. It is both a corrosion- and heat-resistant material. It is work hardenable, but cannot be appreciably strengthened by heat treatment. Typical mechanical properties of Hastelloy C are shown in Table 14.

b. Heat treatment

(1) Annealing. Heat at 2235° F. ± 20° F. for one to two hours, then air cool.

(2) Solution treating. Cooling after solution treating from 1800° F. to 2100° F. should be within 10 minutes maximum.

(3) Aging. Heat to 1575° F. to 1600° F. and hold at temperature for 8 to 10 hours, then air cool.

(4) Cleaning. Material must be thoroughly cleaned of all grease and graphite to avoid carburization and loss of corrosion resistance.

(5) Atmosphere. Use neutral or slightly reducing sulphur-free atmosphere.

c. Machinability

(1) General. Hastelloy C is readily machined at comparatively low cutting speeds using HSS tools. Stellite and/or cemented carbide tools are recommended.

(2) Turning, facing, or boring. Use sintered carbide cutting tools ground to 10 to 15 degrees side rake angle and 6 to 7 degrees side clearance.

(3) Recommended cutting conditions

Type of Cut	Speed, sfpm	Feed, in./rev.	Depth of cut, in.
Rough turn, face or bore	30-40	0.020"-0.030"	1/16
Finish turn, face or bore	35-50	0.012 -0.018	1/32

Turning, facing, or boring at speeds shown above are usually done dry. If faster speeds are used, use a sulphur-base oil.

Table 14

HASTELLOY C, SHORT-TIME TENSILE PROPERTIES - SHEET
(0.065-Inch Thick, Annealed at 2225° F.)

Test Temp., °F	Tensile Strength, psi	Yield Strength, psi (0.2%)	Elongation, % in 2"	Red. of Area, %
Room	129500	64000	37.5	31.5
200	126000	---	36	35
400	119000	---	33	31
600	113000	---	29	27
800	105000	---	25	25
1000	106000	48000	--	--
1200	95000	46000	22.0	22.5
1400	64000	---	32	40
1500	50700	---	36.0	45.5
1700	27200	---	40.5	45.5
1900	14200	---	35.5	39.5

(4) Drilling. For drilling, a short drill is preferred. Drill point should be ground to a 140-degree total included point angle with just enough clearance to clear the work. Too much clearance may cause the tool to chatter.

Sulphur-base oil should be used for drilling.

(5) Grinding. Grinding is recommended for finishing to close tolerances.

d. Workability. Hastelloy C can be forged using hot-working procedures of hammering, pressing and/or rolling. Preheat temperatures normally used are in the range of 2200° F. to 2250° F.

e. Weldability

(1) The material can be readily fusion welded by metallic arc or by any of the inert-gas-shielded methods.

(2) The material can be spot or seam welded following careful, thorough cleaning of faying surfaces.

(3) In metallic-arc welding, use a flux-coated rod of the same metal composition and DCRP. Use the minimum current necessary to melt the rod without entrapping flux in the weld deposit. The stringer-bead method of welding should be used. Avoid weaving the bead.

(4) It is desirable to solution treat the parts after welding for maximum corrosion resistance.

(5) Do the following things when fusion welding.

(a) Keep weld restraint at a minimum.

(b) Keep heat-affected zone narrow and parent metal as cold as possible.

(c) Maintain alignment.

(d) Preheat castings to 1200° F. to 1400° F.

(e) Use 310 stainless or Hastelloy W filler wire when welding to a dissimilar metal.

f. Descaling and pickling. For satisfactory removal of heavy scale, a scale-conditioning treatment in a molten-salt bath may be required prior to acid pickling. The scale-conditioning treatment removes most of the scale more rapidly than acid pickling, but leaves a small amount which must be removed by pickling. Protective, antioxidant coatings, such as Turco 4367, may be used on Hastelloy C to minimize scale formation and to make scale removal easier.

Both reducing and oxidizing molten-salt baths are used for descaling and scale-conditioning treatments of Hastelloy C. These baths are of special value in descaling parts having close dimensional tolerances which will not permit the dissolution of basis metal that occurs in normal acid pickling. Reducing salt baths (sodium hydride) operate at temperatures in the range of 700° F. to 750° F. while the oxidizing salt baths operate at 950° F. to 1000° F.

The compositions of acid baths used in scale and oxide removal, either after scale conditioning or without scale conditioning, are shown in Table 15.

The passivation step which follows most scale and oxide removal operations serves the following two important functions.

(1) To clean the metal surfaces of any free iron, steel, or rust particles that it may have picked up during prior processing.

(2) To complete the pickling operation with a step or process which inhibits later staining or rusting.

For these reasons, passivation should be the final step in the processing of Hastelloy C parts.

2. <u>Inconel 718</u>

a. <u>Heat treatment</u>

(1) Annealing. Heat at 1750° F. to 1800° F. for one to two hours, then air cool.

(2) Solution treatment. Heat to 1575° F. to 1600° F. for one-half hour.

Table 15

DESCALING AND PICKLING OF HASTELLOY C

OBJECTIVE	METHOD	COMPOSITION	TIME, MINUTES	TEMP., °F	SPECIAL OPERATING CONDITIONS	REMARKS
Scale and Oxide Removal	Molten Caustic (a) Molten Caustic Dip	Virgo Descaling Bath	1 to 2	970	Heavy material may require longer time.	Adaptable to high production rates.
	followed by (b) Acid Dip	HNO_3 (70wt.%)-15 vol.% HF (48wt.%)- 8 vol.%	20	125 to 150	For severe conditions, redip in acid and check at 15-minute intervals.	
Oxide Removal	Pickling	Dilute aqua regia	5 to 15	140 to 160		Gives moderately good results; molten caustic or hydride dip followed by acid dip is preferred for this corrosion resistant alloy.

(3) Aging. Cold rolled sheet should be heated to 1275° F. and maintained at temperature for 16 hours. Air cool. Hot rolled or annealed products should be heated to 1325° F. and maintained at temperature for 16 hours. Air cool. Material contracts about 0.05 percent during aging. Typical mechanical properties of aged sheet material at cryogenic, room, and elevated temperatures are shown in Table 16.

b. Machinability

(1) General. Inconel 718 is readily machinable, but the alloy is tough and requires low cutting speeds and ample cutting fluid.

(2) Turning, facing, or boring. High-speed steel cutting tools should be ground to 6 to 10 degrees back rake, 5 to 8 degrees side clearance, 8 to 10 degrees front clearance, 8 to 14 degrees cutting-edge angle, and 10 to 15 degrees lead angle. Recommended cutting speeds are 25 to 40 sfpm with a feed of 0.003 to 0.008 inch per revolution for turning. Use a sulphur-base cutting fluid.

(3) Drilling. With HSS tools, recommended cutting speeds are 25 to 40 sfpm with a feed of 0.003 to 0.007 inch per revolution. Carbide drills should be ground to smaller angles than HSS tools and should operate at higher cutting speeds. Use a sulphur-base cutting fluid.

(4) Tapping. With HSS tools, recommended cutting speeds are 10 to 20 sfpm with a feed of 0.001 to 0.003 inch per revolution.

(5) Milling. With HSS tools, recommended cutting speeds are 25 to 40 sfpm with a feed of 0.002 to 0.007 inch per tooth.

(6) Reaming. With HSS tools, recommended cutting speeds are 20 to 60 sfpm with a feed rate of 0.001 to 0.003 inch per revolution. Carbide tools should be ground to smaller angles than HSS tools and should operate at higher cutting speeds. Use a sulphur-base cutting fluid.

c. Workability. Heating for working should be done in a reducing atmosphere using a low-sulphur fuel. Maximum recommended heating temperature for hot working is 2050° F. Hot working may be continued down to 1700° F. Below 1700° F., the alloy becomes very stiff, therefore only light reductions should be attempted.

Table 16

TYPICAL MECHANICAL PROPERTIES OF INCONEL 718
AT CRYOGENIC, ROOM, AND ELEVATED TEMPERATURES

Test Temp., °F	Yield Strength, KSI	Ult. Tens. Strength, KSI	Elongation, % in 2"	Notched Ult. Tens. Strength, KSI	Notched/ Unnotched Ratio
Cold rolled and aged sheet specimens 0.015 to 0.050-inch thick K_t=6.3 for notched specimens					
-423	228	281	22.0	286	1.02
-320	214	254	21.0	262	1.03
75	183	204	13.2	226	1.11
Mill annealed sheet, aged 1325°F for 16 hours					
R.T.	145	185	22		
200	138	180	22		
400	132	173	22		
600	128	170	22		
800	126	168	22		
1000	124	160	22		
1200	128	164	22		
1400	104	120	26		
1500	85	90	32		

d. Weldability. The material can be readily welded by any of the inert-gas-shielded fusion processes. Inconel 718 filler wire may be used for many applications. For severely restrained joints, other filler alloys such as Rene 41 are preferred. It can be repair welded in the age-hardened condition.

e. Pickling. Hot-work oxide should be removed by pretreating in any of the proprietary salt baths such as Virgo, hydride, Kolene, followed by pickling in HNO_3-HF.

3. Rene 41

a. Heat treatment

(1) General. Mechanical properties vary with solution and aging treatments. High-solution temperatures result in better room temperature ductility and higher rupture strength at elevated temperatures. Lower solution temperatures give high tensile strength. Typical mechanical properties at cryogenic, room, and elevated temperatures are shown in Table 17.

(2) Solution treating. For better room temperature ductility, heat for one-half hour at 2150° F., then air cool. For higher room temperature tensile strength, heat for one-half hour at 1950° F., then air cool.

(3) Aging. For better room temperature ductility, heat for four hours at 1650° F., then air cool. For higher room temperature tensile strength, heat for 16 hours at 1400° F., then air cool.

(4) Stress relieving. Age for one additional hour at the original aging temperature, or resolution treat and reage at the original temperatures.

b. Machinability

(1) General. In the annealed and solution-treated conditions, Rene 41 is gummy. It should therefore be machined in the aged condition. Straight tungsten carbide cutting tools such as Carboloy Grade 883 should be used.

(2) Turning, facing, or boring. Tungsten carbide cutting tools ground to 0 to 8 degrees top rake, 10 degrees side rake, 7 degrees

Table 17

TYPICAL MECHANICAL PROPERTIES OF RENE 41 AT ROOM, ELEVATED, AND CRYOGENIC TEMPERATURES

SHORT TIME TENSILE PROPERTIES - SHEET (0.062" THICK) (Heated 12 min. at 1950°F, AC, Aged 16 hrs. at 1400°F, AC)				
Test Temp., °F	UTS, psi	YS, psi (0.2%)	Ratio, Notched (K_t=6.3) to Unnotched Tensile Strength	Elongation, % in 2"
70	185000	148000	-	9
1000	174000	136000	-	8
1200	164000	130000	-	8
1400	140000	121000	-	5
1500	118000	110000	-	4
1600	88000	84000	-	5
1700	54000	50000	-	8
(Heated 12 min. at 2150°F, AC, Aged 4 Hrs. at 1650°F, AC)				
70	140000	97000	-	12
1000	128000	90000	-	10
1200	120000	86000	-	10
1400	105000	78000	-	6
1500	92000	72000	-	4
1600	74000	62000	-	6
1700	47000	45000	-	11
TENSILE AND NOTCHED TENSILE PROPERTIES AT LOW TEMPERATURES (Double Aged at 1950 and 1400°F.)				
70	181000	138000	0.91	18
-100	192000	148000	0.90	13
-320	202000	161000	0.94	9
-423	212000	179000	0.99	6

side clearance, 6 degrees end clearance, 45 degrees cutting edge, and a 1/16-inch nose radius should be used. For rough machining use speeds of 30 to 40 sfpm with a depth of cut of 1/16 inch to 1/8 inch and a feed of 0.011 ipr; for finish machining use speeds of 50 to 60 sfpm with a depth of cut of 1/32 inch and a feed of 0.005 ipr.

c. Workability. Forging must be done at temperatures between 2150° F. and 1850° F.

d. Weldability. Rene 41 should be in the fully-solutioned condition before welding. After welding, the material should be solution treated for homogenization and stress relief, then aged for maximum strength.

(1) Rene 41 can be fusion welded by any of the inert-gas-shielded processes with or without the use of filler metal.

(2) Use inert gas mixture of two helium to one argon. Start and finish of weld should be on tabs of same thickness.

(3) Rene 41 may also be resistance welded with conventional equipment.

(4) Welds have at least 90 percent of base metal strength.

(5) Follow torch with water spray to reduce hardness and produce maximum ductility.

e. Fabricability. The ease with which Rene 41 may be fabricated makes it one of the most versatile high-temperature materials available.

4. <u>L-605 or Haynes Alloy No. 25 (HS-25)</u>

a. General. Haynes alloy No. 25, also known as L-605 and HS-25, is a wrought, cobalt-base alloy containing chromium, nickel, and tungsten. Its nominal chemical composition is as follows:

Ni, %	Cr, %	W, %	Fe, %	C, %	Si, %	Mn, %	Co, %
9.0-11.0	19.0-21.0	14.0-16.0	3.0 max.	.05-.15	1.0 max.	1.0-2.0	Bal.

This alloy was developed originally to provide good oxidation and corrosion resistance as well as high-strength properties at temperatures up to 1900° F. Its crystalline structure is austenitic under all conditions. It also has excellent mechanical properties at cryogenic temperatures as shown in Table 18.

b. Heat treatment

(1) Solution anneal. For maximum formability, L-605 (HS-25) sheet is solution annealed at 2250° F. ± 25° F. for one hour per inch of thickness followed by rapid air cooling or water quenching. Bar stock and plate (1/4 inch and heavier) are solution heat treated at 2260 ± 25° F. and then water quenched.

(2) Aging treatment. Age-hardening tendencies are noted after exposure to temperatures in the 1600° F. to 1900° F. range, accompanied by some loss in ductility.

c. Workability. L-605 (HS-25) has excellent ductility at room temperature. Sheets can be readily formed by bending, stamping, drawing, and spinning. The power requirement for these forming operations is relatively high because of the strength of the alloy. The alloy work hardens very rapidly, consequently it may be necessary to solution heat treat the alloy after each stage of cold work. Preheating the material to approximately 450° F. has been found to be helpful in some severe forming operations.

d. Machinability. L-605 (HS-25) is machinable with high-speed steel tools using low speeds and small depth of cut. It is easily machined with carbide-tipped tools.

Tool angles for single-point HSS cutters are 4 to 5 degrees front and side relief, 0 to 8 degrees back rake, 8 degrees side rake, 15 to 30 degrees side cutting-edge angle, 10 to 15 degrees end cutting-edge angle, and 1/32 to 1/16 inch nose radius.

Tool angles for single-point tungsten carbide tools using moderate speeds and light cuts are 5 to 8 degrees side rake angle, 5 to 7 degrees back rake angle, 5 to 7 degrees end relief angle, 15 to 30 degrees side cutting-edge angle, and a nose radius of 1/32 inch or less.

Table 18

TYPICAL TENSILE PROPERTIES OF L-605 (HS-25) AT CRYOGENIC, ROOM, AND ELEVATED TEMPERATURES (20 Percent Cold Rolled)

Test Temperature, °F	Yield Strength, 0.2% Offset PSI	Ultimate Tensile Strength PSI	Elongation, % in 2"	Ratio, Notched (K_t=6.3) To Unnotched Tensile Strength
-423	208,000	268,000	20	0.98
-320	181,000	238,000	19	0.91
-100	146,000	189,000	16	1.00
78	126,000	164,000	16	1.03
		(Water quenched from 2250°F.)		
1000	80,000	130,000		
1600	35,000	46,000		

For drilling, HSS or tungsten carbide-tipped drills ground to an included angle of 135 to 140 degrees, a clearance angle of 10 degrees, and a web thinned to about 1/3 of the web thickness of the standard drill are recommended. Keep as much pressure as possible on the drill at all times (preferably by machine feeding) and make certain the drill is kept sharp to avoid work hardening and tool chatter.

Cutting fluids are required for all machining operations. "Vantrol" No. 523 (Van Straaten Chemical Co., 630 W. Washington Blvd., Chicago, Ill.) mixed in a ratio of 15 parts water to 1 part "Vantrol" oil is recommended for machining operations because of its good cooling properties.

Best finishes can be obtained on L-605 (HS-25) parts by increasing cutting speed and decreasing the feed. Sharp tools and a rigid tool setup are necessary.

Machined parts can be made from L-605 (HS-25) after it has been cold reduced up to 40 percent. Machined surfaces of such cold reduced material are smoother than those of solution heat-treated material.

e. Weldability. L-605 (HS-25) can be fusion welded by metallic arc, inert-gas-shielded tungsten arc, and inert-gas-shielded metal arc methods. Submerged-arc welding is not recommended. Welding surfaces and immediately adjacent areas should be thoroughly cleaned down to bright metal and wiped dry before welding.

V-joint preparation is used for butt welds in plate thicknesses up to 1/4 inch and U-joint preparation for greater thicknesses.

Use of a machine tool in beveling edges is the best way to obtain correct edge fitup although hand grinding can also yield satisfactory results. Thermal cutting and beveling of plates can be done, but with the exception of of Heliarc cutting. These are not recommended procedures.

For good penetration, material 12 gage and heavier should be beveled and welded from both sides whenever possible. When this is not possible, joint spacing should be increased and a copper backing bar used. Currents slightly higher than normal are then used to obtain complete penetration. Proper jigging and clamping of weld joints should be used to hold buckling and warping to a minimum.

DCRP welding produces the best mechanical properties with metallic-arc welding. Rapid travel using the stringer bead technique is preferred to minimize heat. Position welding is difficult due to the fluidity of the molten alloy, therefore welding should be done in the flat position when possible.

With all types of welding, minimum heat input should be used followed by a rapid cooling of the weld deposit to avoid weld cracking.

L-605 (HS-25) may also be resistance welded to meet the strength requirements of Specification MIL-W-6858A.

L-605 (HS-25) is commonly brazed using brazing alloys of silver, copper, manganese, and nickel basis metals. Most brazing of parts is done in purified, dry (dew point, -60° F.) hydrogen. Other means have also been devised (vacuum brazing, plating, and brazing-alloy preplacement) to obtain brazed joints with this type of alloy.

f. Descaling and pickling. After heat treatment, the oxide film found on L-605 (HS-25) is more adherent than that found on stainless steels. This oxide film is relatively inert to cold acid pickling solutions. Two different molten caustic baths, "Virgo" (Hooker Electrochemical Company) and sodium hydride (E. I. DuPont De Nemours and Company), have been found to be most efficient in removing this scale when followed by warm acid pickling as shown in Table 19.

SECTION VI. CONCLUSIONS

This literature survey has revealed that future ducting system requirements demand state-of-the-art extensions in advanced materials research, especially at cryogenic temperatures where a paucity of data presently exists. Manufacturing processing data related to the newer materials, larger sizes, and new design philosophies, demanded by future aerospace concepts, is limited. Thus while negative results are reported in general, the information obtained is of value in that its scarcity emphasizes the importance of advanced ducting studies in progress today to solve these problems and to preclude their deferment to some time in the future when delivery schedules may be at stake.

Table 19

DESCALING AND PICKLING OF L-605 (HS-25)

OBJECTIVE	METHOD	COMPOSITION	TIME, MINUTES	TEMP., °F	SPECIAL OPERATING CONDITIONS	REMARKS
Scale or Oxide Removal	"Virgo" Molten caustic plus acid dips	A. Molten caustic	4-8	970		A. Oxidizes the scale
		B. Water rinse	1-2	Room		B. Rinse off caustic & loose scale
		C. H_2SO_4 rinse 15-17 wt.% H_2SO_4 .5- 1 wt.% HCl				
		D. HNO_3 bath 7.8 wt. % HNO_3 3.4 wt. % HF	25	125 - 160		D. Final pickle and passivation
		E. Water rinse	3	Room		E. Remove final traces of acid
Scale or Oxide Removal	Sodium Hydride	A. Sodium Hydride 2-2.5 wt.% NaH	15	750 - 800		A. Reduces scale
		B. Water rinse	1-2	Room		
		C. Permanganate bath 4-6 wt. % $KMnO_4$ 1-2 wt. % NaOH	15	135 - 155		C. Removes most reduced scale
		D. Water rinse	2-3	Room		
		E. HNO bath 8-12 wt.% HNO_3 2-3 wt. % HF	15	125 - 160		E. Final oxide removal and passivation
		F. Water rinse	3	Room		F. Remove final traces of acid
Light Oxide Removal and Passivation	Pickling	HNO_3 (70 wt.%) 10-20 vol.%	15 - 20	130 - 140		This pickling operation is to remove contaminating particles from the surface and to produce a passive surface film.

BIBLIOGRAPHY

1. "Diaphragm Bellows," Western Metalworking, V. 19, November 1961, p. 54.

2. Kihlgren, T. E., "New Nickel Alloys for High Temperature Service," Mechanical Engineering, V. 83, November 1961, pp. 50-51.

3. Olofson, C. T., and Boulger, F. W., "Machining of Superalloys and Refractory Metals, Defense Metals Information Center, Batelle Memorial Institute, DMIC Memorandum 134, October 27, 1961, 40 pages.

4. Marron, A. J., and Everhard, J. L., "Nickel and High-Nickel Alloys," Industrial and Engineering Chemistry, V. 53, November 1961, pp. 913-916.

5. Servi, I. S., and Boesch, W. J., "Two Superalloys for Jet Engines," Metal Progress, V. 80, December 1961, pp. 73-78.

6. Mahlin, B. M., and Coles, D. R., "How to Make Reliable Seam and Spot Welds in Rene 41," Metal Progress, V. 80, December 1961, pp. 67-72.

7. Stanton, W. A., "Super-Alloys for High Temperature Springs," Space/Aeronautics, V. 36, November 1961, pp. 73-82.

8. Watson, J. F., and Christian, J. L., "Low-Temperature Properties of K-Monel, Inconel-X, Rene 41, Haynes 25, and Hastelloy B Sheet Alloys," American Society of Mechanical Engineers, Transaction (Journal of Basic Engineering), Paper No. 61-WA-12, 1961, 13 pages.

9. Crawford, J. H., "Developments in Electrolytic Machining of High Temperature Materials," Machine Design, V. 34, No. 18, August 2, 1962, pp. 126-130.

10. "Steels at Cryogenic Temperatures," Metal Progress, V. 82, No. 3, September 1962, pp. 186-188.

11. Hamilton, Howard, and Meredith, Russell, "How to Work 17-4 PH Stainless," American Machinist/Metalworking Manufacturing, V. 106, No. 17, August 20, 1962, pp. 94-95.

12. "Flexible Ducting," Light Metals, V. 25, No. 290, July 1962, pp. 197-198.

13. Allen, J. S., "Air Pipework for a Supersonic Speed Wind Tunnel," Welding and Metal Fabrication, V. 30, February 1962, pp. 46-53.

14. Roberts, K. P., and Ware, P. H., "Corrugated Metallic Sheath for Communication and Data Transmission Cables," Wire and Wire Products, V. 37, March 1962, pp. 334-337, 401-403.

15. Barker, J. F., "A Superalloy for Medium Temperatures," Metal Progress, V. 81, May 1962, pp. 72-76.

16. "A Flexible Pipeline of Cast Iron," Lead, V. 26, No. 1, 1962, pp. 4-5.

17. Birong, Frank, and Purcell, Webb, "Pipeline Flexes Its Muscles," Welding Journal, V. 41, No. 8, August 1962, pp. 743-744.

18. Matt, Richard J., "High Temperature Metal Bellows Seals for Aircraft and Missile Accessories," ASME Paper No. 62-WA-25, 1963, 7 pages.

19. Toles, George E., "Water-Formed Big Expansion Joint for AECL Reactor, Design Engineering, V. 9, No. 8, August 1963, p. 41.

20. Gartner, D., and Kromrey, H., (German) "New Process for Production of Single Wall Metal Bellows by Chromizing and Their Testing," Technik, V. 17, February 1962, pp. 72-73.

21. Schane, Harry P., and Herring, James, "Advanced Technology in Drawing Difficult to Form Metals," Paper from "Metal Forming Seminar, Atlanta, Georgia, November 1962." Paper No. SP 63-24, ASTME, 10700 Puritan Avenue, Detroit 38, Michigan, 1963, pp. 1-11.

22. Wile, G. J., "Superalloys for Aerospace Application," Journal of Metals, V. 15, No. 9, September 1963, pp. 645-647.

23. Ross, Earl W., and McHenry, H. Thomas, "High Temperature Metals," Chemical Engineering, V. 70, No. 24, November 25, 1963, pp. 97-103.

24. "New Steels for Low Temperatures," Cryomet 9 and 10, Metal Treatment and Drop Forging, V. 30, No. 217, October 1963, pp. 418-419.

BIBLIOGRAPHY (Continued)

25. Colton, R. M., "Getting Better Tool Life When Machining Titanium," Tool and Manufacturing Engineer, V. 51, No. 4, October 1963, pp. 75-78.

26. "Water 'Die' Forms Giant Bellows," Machine and Tool Blue Book, V. 50, No. 10, October 1963, pp. 136-137.

27. Galloway, D. F., and Morgan, R. A. P., "Research for Productivity," Iron and Steel, V. 36, No. 11, October 1963, pp. 511-516.

28. Travell, Ronald E., "Hot Machining of Superhard Alloys," Canada's Machine Production, V. 24, No. 10, October 1963, pp. 22-23.

29. Ewell, J. R., "Rene 41 Can Be Welded," American Machinist/Metalworking Manufacturing, V. 107, No. 21, October 14, 1963, pp. 112-113.

30. Schwenk, W., and Trabold, A. F., "Weldability of Rene 41," Welding Journal, V. 24, No. 10, October 1963, pp. 460s-465s.

31. Hurlich, A., "Low Temperature Metals," Chemical Engineering, V. 70, No. 24, November 25, 1963, pp. 104-112.

32. Titus, G. W., and Brunhouse, J. S., "Long Term Air Corrosion of Several Nickel-Based Alloys," Corrosion, V. 19, No. 10, October 1963, pp. 339t-344t.

33. Gleekman, L. W., "Corrosion Resistant Metals," Chemical Engineering, V. 70, No. 23, November 11, 1963, pp. 217-224.

34. "Hydramold--The Hydrostatic Forming of Tubing," Tooling and Production, V. 29, No. 8, November 1963, pp. 55-57.

35. "Stainless Tubes 100 Feet Long!," American Machinist/Metalworking Manufacturing, V. 107, No. 25, December 9, 1963, pp. 88-89.

36. "Dry Ice Speeds Milling Cuts," Iron Age, V. 192, No. 21, November 28, 1963, p. 84.

37. Dickter, Irving A., "Hot Machining - An Economic Production Process," Metalworking Production, V. 107, No. 46, November 13, 1963, pp. 54-56.

38. "New High Temperature Superalloy is Weldable," Material's in Design Engineering, V. 58, No. 7, December 1963, p. 88

39. McHenry, H. Thomas, Barker, James F., and Stuligross, Ralph J., "Rene 62: A Strong Superalloy for Welded Structures," Metal Progress, V. 84, No. 6, December 1963, pp. 86-90.

40. Wood, W. W., "High Velocity Plus Heat Brings Increased Formability," Product Engineering, V. 34, No. 20, September 30, 1963, pp. 58-69.

41. Padian, W. D., and Robelotto, R. P., "Resistance Welding of Inconel 718 Nickel Base Alloy," Welding Journal, V. 43, No. 2, February 1964, p. 49s-56s.

42. Klima, S. K., Nachtigall, A. J., and Hoffman, C. A., "Preliminary Investigation of the Effect of Hydrogen on Stress Rupture and Fatigue Properties of an Iron, a Nickel, and a Cobalt Base Alloy," NASA Technical Note D-1458, December 1962.

43. Stacy, John T., "Heat Treatment of Rene 41," Metal Progress, V. 85, No. 3, pp. 92-95.

44. "Hastelloy Alloy-C," Engineering Alloys Digest, Inc., Upper Montclair, New Jersey, February 1956.

45. "Hastelloy-C," Aerospace Structural Materials Handbook, Volume II, Non-Ferrous Alloys, Code 4110, March 1963.

46. "Inconel 718," Aerospace Structural Materials Handbook, Volume II, Non-Ferrous Alloys, Code 4103, March 1963.

47. "Rene 41," Aerospace Structural Materials Handbook, Volume II, Non-Ferrous Alloys, Code 4205, March 1963.

48. "Multimet (N-155)," Engineering Alloys Digest, Inc., Upper Montclair, New Jersey, May 1955.

49. "19-9 DL," Engineering Alloys Digest, Inc., Upper Montclair, New Jersey, October 1954.

50. AD 276 300, Summary of Test Results, Pre-Qualification Test Program for Hose, UDMH/Hydrazine, 100-1000 psig, Flexible Metal, Wire Reinforced.

51. AD 276 303, Pre-Production Test Report of Joint Assembly, Missile Topping, Flexible, Launch Platform, Liquid Nitrogen, 160 psig.

52. Kendall, E. G., "Metals and Alloys for Cryogenic Applications - A Review," Report No. TDR-269(4240-10)-6, Aerospace Corporation, El Segundo, California, 20 January 1964.

53. Hickey, Jr., Charles F., "Mechanical Properties of Titanium and Aluminum Alloys at Cryogenic Temperatures," Technical Report WAL TR 340.2/1, Watertown Arsenal, Watertown 72, Massachusetts, March 1962.

54. Brisbane, A. W., "The Investigation of the Effects of Loading Rate and Stress Concentration Factors on the Notch Properties of Three Sheet Alloys at Subzero Temperatures," Technical Documentary Report No. ASD-TDR-62-930, Wright-Patterson Air Force Base, Ohio, March 1963.

55. "Metallurgical Characteristics of A-286 Alloy," DMIC Memo 59, Defense Metals Information Center, Battelle Memorial Institute, Columbus 1, Ohio, July 26, 1960.

56. "Recent Developments in Superalloys," DMIC Memo 64, Defense Metals Information Center, Battelle Memorial Institute, Columbus 1, Ohio, September 8, 1960.

57. "Pickling and Descaling of High-Strength, High-Temperature Metals and Alloys," DMIC Memo 85, Defense Metals Information Center, Battelle Memorial Institute, Columbus 1, Ohio, February 8, 1961.

58. "Superalloy Forgings," DMIC Memo 86, Defense Metals Information Center, Battelle Memorial Institute, Columbus 1, Ohio, February 10, 1961.

59. Campbell, J. E., and Achbach, W. P., "Current Tests for Evaluating Fracture Toughness of Sheet Metals at High Strength Levels," DMIC Report 124, Battelle Memorial Institute, Columbus 1, Ohio, January 28, 1960.

BIBLIOGRAPHY (Continued)

60. Ludwigson, D. C., and Morral, F. R., "A Summary of Comparative Properties of Air-Melted and Vacuum-Melted Steels and Superalloys," DMIC Report 128, Battelle Memorial Institute, Columbus 1, Ohio, March 28, 1960.

61. Langston, M. E., and Lund, C. H., "Physical Properties of Some Nickel-Base Alloys," DMIC Report 129, Battelle Memorial Institute, Columbus 1, Ohio, May 20, 1960.

62. Favor, R. J., Roberts, D. A., and Achbach, W. P., "Design Information on Nickel-Base Alloys for Aircraft and Missiles," DMIC Report 132, Battelle Memorial Institute, Columbus 1, Ohio, July 20, 1960.

63. Campbell, J. E., "Review of Current Data on the Tensile Properties of Metals at Very Low Temperatures," DMIC Report 148, Battelle Memorial Institute, Columbus 1, Ohio, February 14, 1961.

64. Olofson, C. T., "A Review of Bending Methods for Stainless Steel Tubing," DMIC Report 150, Battelle Memorial Institute, Columbus 1, Ohio, March 2, 1961.

65. Nichols, R., "Static, Fatigue, and Road Tests of Center Section Conduit Expansion Joints," Technical Memo SL-M17, Structures Laboratory Department, Chrysler Corporation Missile Division, 29 August 1957.

66. Rice, Leonard P., Campbell, James E., and Simmons, Ward F., "The Evaluation of the Effects of Very Low Temperatures on the Properties of Aircraft and Missile Metals," WADD TR 60-254, Battelle Memorial Institute, Columbus, Ohio, June 1960.

67. "Reliability Test Report for the Redstone Missile Propulsion System LOX Expansion Joint," Rocketdyne Engineering, Canoga Park, California, 4 May 1959.

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STATE-OF-THE-ART LITERATURE SURVEY ON FABRICATION TECHNIQUES OF ADVANCED DUCTING COMPONENTS

By C. N. Irvine and J. H. Barnett

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This document has also been reviewed and approved for technical accuracy.

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