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# Candidate Materials for Saturn

# Paraglider Recovery System

Contract NAS-8 2420

GER 10372 August 1961

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This report was prepared by the Goodyear Aircraft Corporation under Contract NAS 8-2420, Research and Development of Materials for Saturn Paraglider Recovery System, for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the direction of the Structures and Mechanics Division, Engineering Materials Branch of the George C. Marshall Space Flight Center with Mr. Clyde M. Holmes acting as project engineer. of Marshall SFC

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# ABSTRACT

The purpose of this survey was to ascertain the state-of-the-art of inflatable and flexible types of materials for use in paraglider recovery systems. The various materials considered are steel, superalloys, refractory metals, ceramics, glasses, and graphite. Materials suitable for inflatable or flexible structure applications must necessarily be in the form of woven cloths, films, or foils to provide the flexibility required for easy and compact packaging. Little of the past research and development effort on high temperature materials has been directed toward filaments or foils. Most of this effort has been directed toward the development of bulk materials exposed to high temperatures for extended periods of time. As a result, evaluation of the various materials must be based upon data generated for the materials in bulk form.

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## Introduction

The purpose of this survey was to ascertain the state-of-the-art of inflatable and flexible types of materials for use in paraglider recovery systems.

Materials suitable for inflatable or flexible structure applications must necessarily be in the form of woven cloths, films, or foils to provide the flexibility needed for easy and compact packaging. In the case of metal filaments, diameters on the order of 1.5 mils are desirable while foils approximately 1 mil thick will have about the same flexibility.

Little of the intense research and development effort on high temperature metal alloys has been concerned with filaments or foils, because of the limited demand for such products until recently.

These past efforts have been primarily directed toward the development of bulk materials applicable to high temperature power plants or propulsion systems. Nevertheless, the results of these programs have produced a host of super-alloys capable of operating at temperatures up to 1900 °F. To a lesser extent, efforts have been devoted to the development of the refractory metals and their alloys, which at the present time, provide the only promising candidates for applications above 1900 °F.

The fact that the super-alloys and refractory metal alloys were developed for high density components exposed to elevated temperatures for extended periods, does not preclude their use in paraglider applications. Providing the individual alloys possess the desired mechanical and physical properties, the only prerequisite for their use in inflatable structures is that they are capable of being wrought into the desired forms; namely, filaments and foils.

Also available for potential high temperature use are ceramic cloths, fibreglass, fused quartz, etc., and graphite cloth. These materials have not been fully evaluated and further development work is necessary. A more detailed discussion of these materials is presented later in this report.

Since the substrate materials discussed above were to be in the form of woven cloth to provide the desired flexibility, they must be coated with a material to provide minimum gas permeability throughout the vehicle temperature operating range. In the case of the refractory metals, two coatings or a dual purpose coating is required to prevent the oxidation of the substrate as well as prevent gas diffusion.

Steel

Iron alloyed with such metals as Chromium, Nickle, Molybdenum, Cobalt, and Aluminum is extremely oxidation resistant. Dense, adherent oxide layers are formed which retard the rate of oxidation. Even at temperatures of 2000°F stainless steel wire does not oxidize to an appreciable degree. Regardless of this desirable quality, the use of high strength or stainless steel is limited to temperatures below 1400°F. The limiting factor is the reduced tensile strength of the materials above this temperature. Recent development in the preparation of stainless steels have resulted in materials with impressive tensile strengths. Strengths in excess of 100,000 psi have been obtained at 1000°F. However, the strength falls off very rapidly at temperatures in excess of $1000^{\circ}$F. Because of the basic composition of steel, and the nature of its strengthening mechanism, there is little hope of retaining strength above $1400^{\circ}$F by alloying. However, there are certain advantages in the use of stainless steel wire at temperatures where the strength is adequate. Fine wires (.5 mil) are available commercially and the material possesses excellent oxidation properties.

Superalloys

These alloys can be separated into two general catagories, Nickle base and Cobalt base alloys. As was stated before, the majority of these alloys were developed for high temperature power plant applications. The first superalloys developed were casting alloys and were almost invariably investment cast. Today, however, some are available as wrought alloys and can be obtained in the form of sheet, bar stock, or wire.

The superalloys are applicable at temperatures above which the low strength of steels is a limiting factor. They exhibit good strength and oxidation resistance properties at temperatures ranging to $1900^{\circ}$F. Because of their excellent non-oxidation characteristics, oxidation coatings are not necessary.

Very limited information is available on the mechanical properties of the superalloys in fine filament or woven cloth form. Figures I to III on pages 4,5, and 6 present curves of strength to density ratio versus temperature. These curves are based on values for sheet stock and serve only as a guide to the relative efficiencies of the various superalloys. Table I on page 8 summarizes some of the more important physical properties of the superalloys.

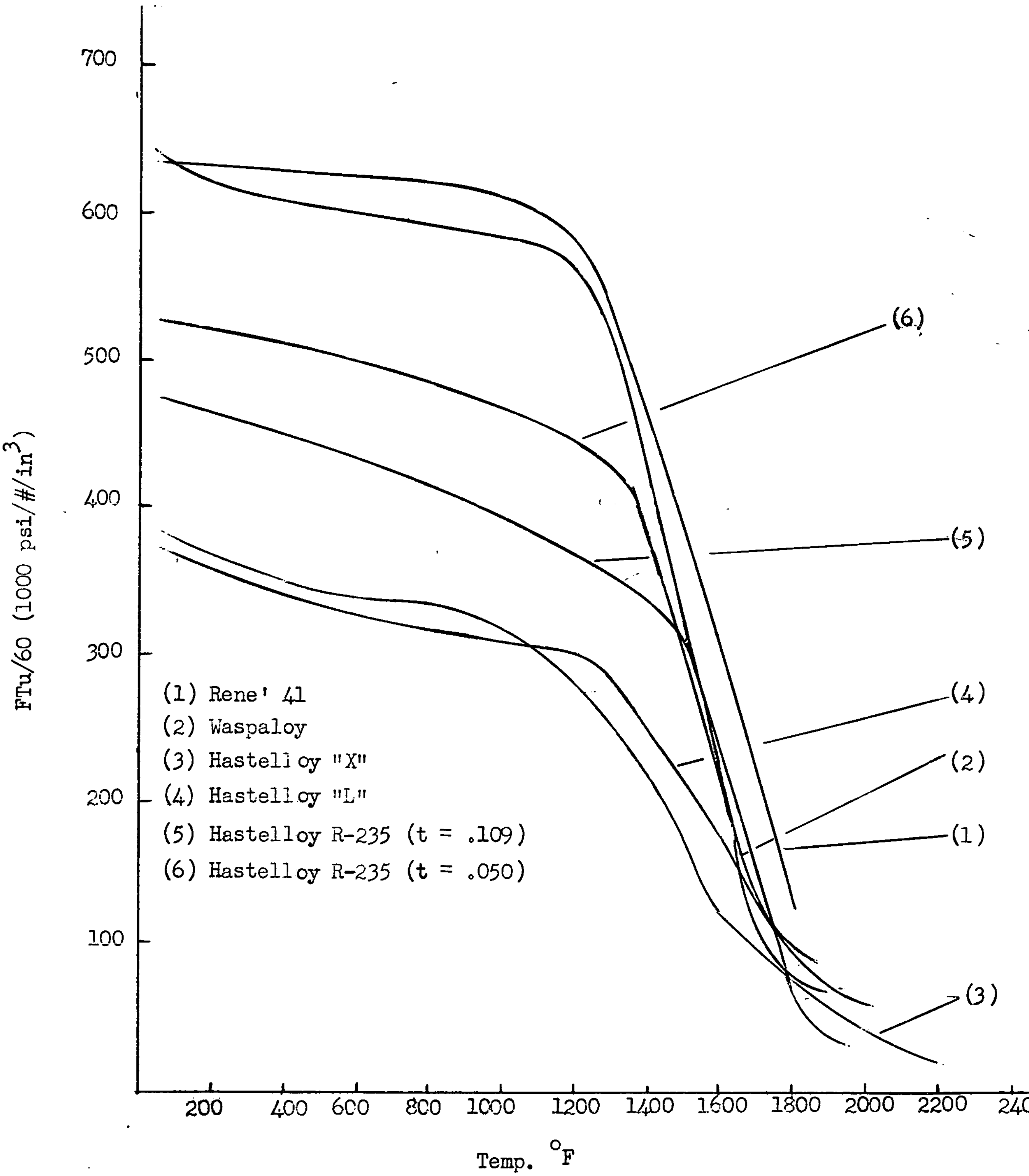


Figure I - Strength to Density Ratio vs Temperature - Nickel Base Superalloy

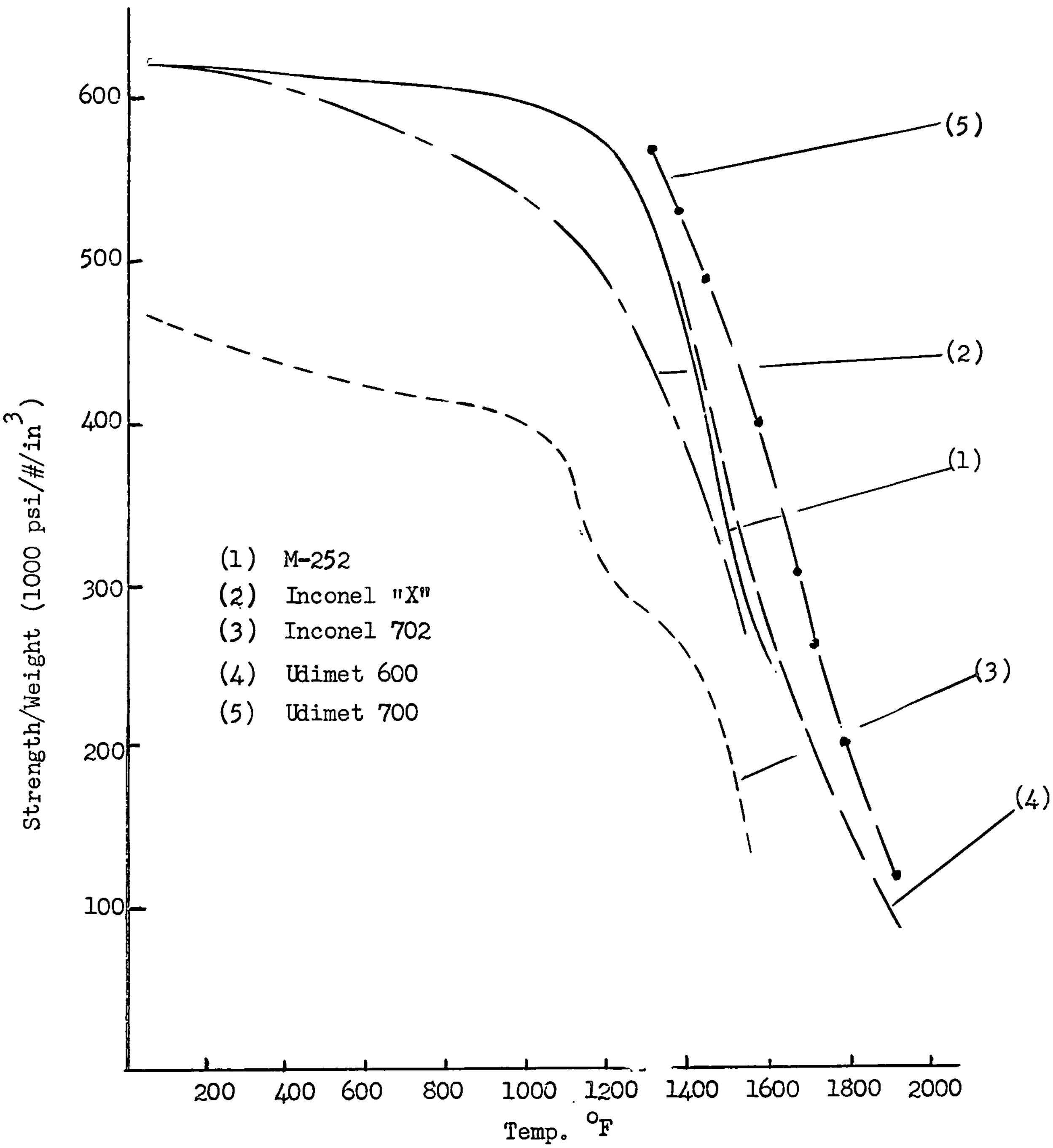


Figure II - Strength to Density Ratio vs Temperature - Nickel Base Superalloy

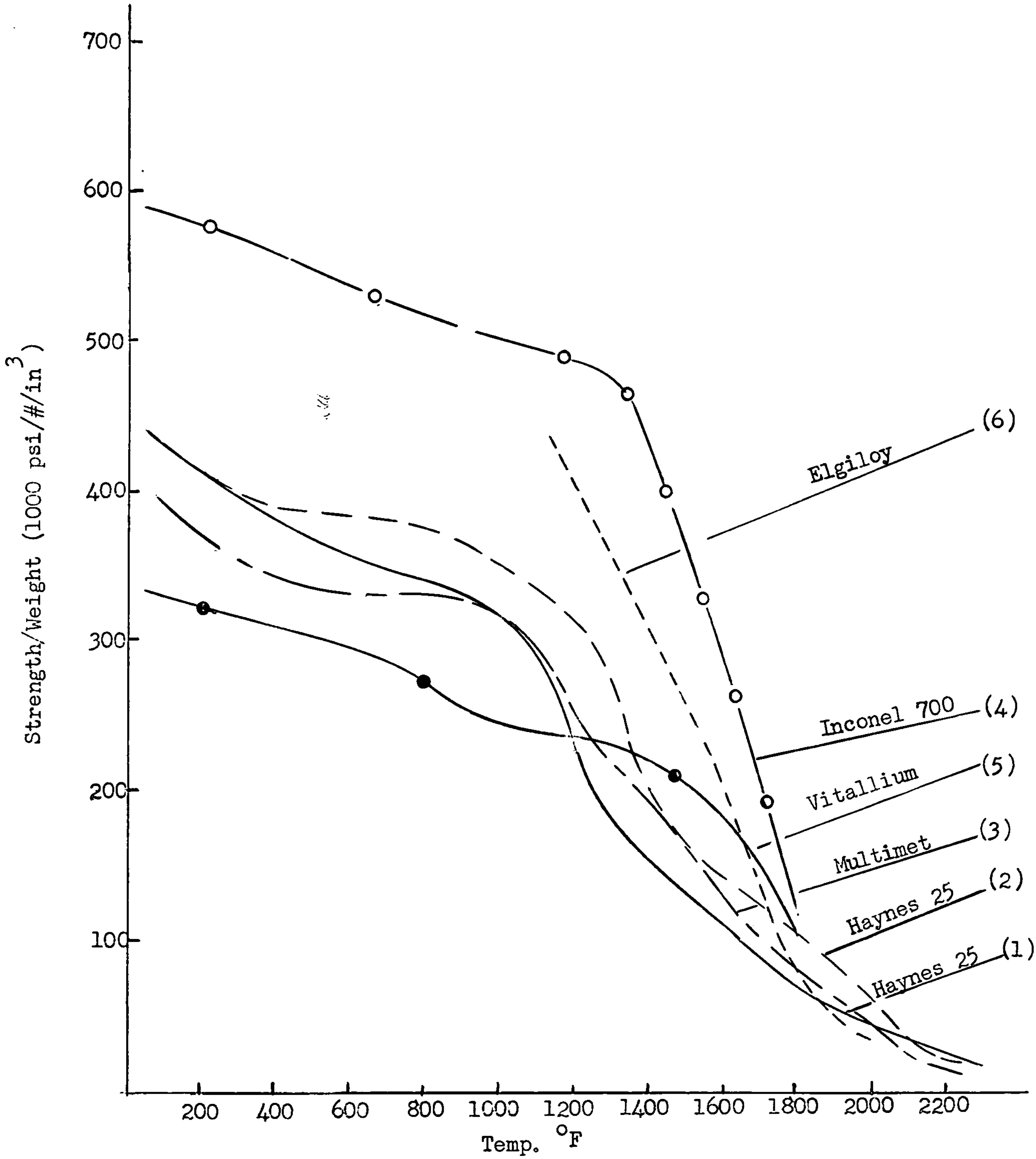


Figure III - Strength to Density Ratio vs Temperature — Cobalt Base Superalloy

GAC was instrumental in interesting wire manufacturers to develop processes for production of very fine Rene' 41 wires. Weavers of metal cloths also were persuaded to weave this very fine wire into cloths with very high warp and fill filament counts. These efforts have resulted in cloths considered satisfactory for decelerator applications such as the AVCO drag brake.

Figure IV compares the properties of Rene' 41 sheet with the ultimate strength of wire in a partially annealed state as tested by GAC. A cloth of this wire, with a count of 200 by 200 wires per inch, exhibited the strength versus temperature curves shown in Figure IV. The fill strength ($F_{tu}$ = 206,000 psi) was considerably higher than the warp strength ($F_{tu}$ = 127,000 psi) at room temperature. As a fill specimen is tested uniaxially, the wires are subjected to practically pure tension, while a warp wire, when a warp specimen is tested, is subject to tension and bending.

This is borne out by observing the difference in Young's Modulous, where $E_{Fill} = 16 \times 10^6$ psi and $E_{Warp} = 6.5 \times 10^6$ psi. Table II summarizes the material properties for various weaves. The more nearly equal strengths in warp and fill directions, for twill and basket weaves, is attributed to the fact that the crimp is more evenly divided between the warp and fill threads.

A.D. Little, Incorporated of Cambridge, Mass. is currently investigating the properties of fine filaments and fabrics of superalloys and refractory metals for parachute applications. Their work with superalloys involves Rene' 41, Elgiloy, and Inconel 702. To date, their efforts have been confined to determining the oxidation properties, the room-temperature-tensile and ductility properties of samples exposed to 1500°F, 1800°F, and 2000°F and short term tensile properties

TABLE I
SUMMARY OF PHYSICAL PROPERTIES OF SUPERALLOYS

| Material | Melting Point (°F) | Density #/in$^3$ | Maximum Useful Temp. (°F) | Ult. Tensile Strength (psi) (RT) | Yield Strength (RT) | Elongation e % (RT) | Modulus of Elasticity E (RT) | Creep Rupture (100 Hour) Ult Str. | Temp deg. F |
|---|---|---|---|---|---|---|---|---|---|
| Rene' 41 | 2400 | 0.296 | 1800 | 195,000 | 160,000 | 31 | 31.8$(10)^6$ | 9,500 | 1800 |
| Waspaloy | 2450 | 0.296 | 1700 | 180,000 | 115,000 | 28 | 30.6$(10)^6$ | 25,000 | 1600 |
| Udimet 600 | 2400 | 0.286 | 1900 | 235,000 | 200,000 | 10 | 31.0$(10)^6$ | 14,000 | 1800 |
| Udimet 700 | 2400 | 0.286 | 1900 | 202,000 | 140,000 | 17 | 31.0$(10)^6$ | 16,000 | 1800 |
| Hastelloy "X" | 2350 | 0.297 | 2200 | 113,000 | 54,000 | 41 | 28.6$(10)^6$ | 3,400 | 1800 |
| Hastelloy "C" | 2380 | 0.323 | 1800 | 145,000* | | 40** | 29.8$(10)^6$ | 11,000 | 1650 |
| Hastelloy "R235" | 2400 | 0.296 | 1750 | 147,000 | 79,000 | 43 | | 26,000 | 1600 |
| M-252 | 2470 | 0.298 | 1600 | 175,000 | 98,000 | 25 | 29.8$(10)^6$ | 23,000 | 1600 |
| Inconel X | 2540 | 0.298 | 1800 | 155,000** | 100,000** | 20 | 31.0$(10)^6$ | 2,000 | 1800 |
| Inconel 702 | | 0.302 | 2400 | 140,000 | 82,000 | 38 | 31.4$(10)^6$ | 5,000 | 1700 |
| Astroloy | | 0.287 | 1900 | 194,000 | 142,000 | 15 | | 18,000 | 1800*** |
| Elgiloy | | | | 225,000 | | | | | |
| Haynes 25 | 2425 | 0.330 | 1600 | 146,000 | 67,000 | 64 | 34.2$(10)^6$ | 7,000 | 1800 |
| Haynes Multimet | 2350 | 0.296 | | 116,000 | 57,000 | 43 | 28.8$(10)^6$ | 5,600 | 1800 |
| Inconel 700 | 2450 | 0.295 | 1800 | 170,000 | 105,000 | 26 | 32.0$(10)^6$ | 6,000 | 1800 |
| Vitallium | 2465 | 0.300 | | 125,000 | 90,000 | Neg. | 34.0$(10)^6$ | 9,000 | 1800 |

* Maximum
** Minimum
*** (50 Hr.)

at elevated temperatures. Their preliminary findings show that the oxidation rate of Rene' 41 is consistently greater than the other two alloys. However, the loss of metal due to oxidation of any of the three alloys was rather small and does not appear to be a serious problem. The three alloys demonstrate a marked decrease in room temperature strength and ductility after being exposed to elevated temperatures for various periods of time. For the tests conducted in air, there is not a large degree of variation in the strength and ductility for the three alloys. Strengths at elevated temperatures indicate Elgiloy to be superior to Rene' 41 at temperatures up to 1500°F, with Rene' becoming superior between 1500°F and 2000°F. Observations by A.D. Little suggest the behavior of the Elgiloy and Rene' 41 in the 1800° -2000°F environment to be one of plastic flow rather than reversible elastic strain. They are contemplating some short-term creep tests to substantiate this observation. It may well be that short-term creep tests would be a better criteria for judging metals in the 1800 - 2000°F range.

An inquiry to the Electric Wire Company, Incorporated, of Northhampton, Massachusettes, regarding their new super alloy disclosed that the material has been drawn to 1 mil wire. The material's physical and mechanical properties are now being determined; no details in this area are available at the present time. However, preliminary results indicate excellent strength properties to 1900°F. The alloy has a composition similar to Vitallium.

Another relatively new super alloy is Astroly, developed by the Flight Propulsion Division Laboratories of General Electric. Not much data is presently available on this material, however, it is purported to posses mechanical properties which are superior to those of Rene' 41 at elevated temperatures.

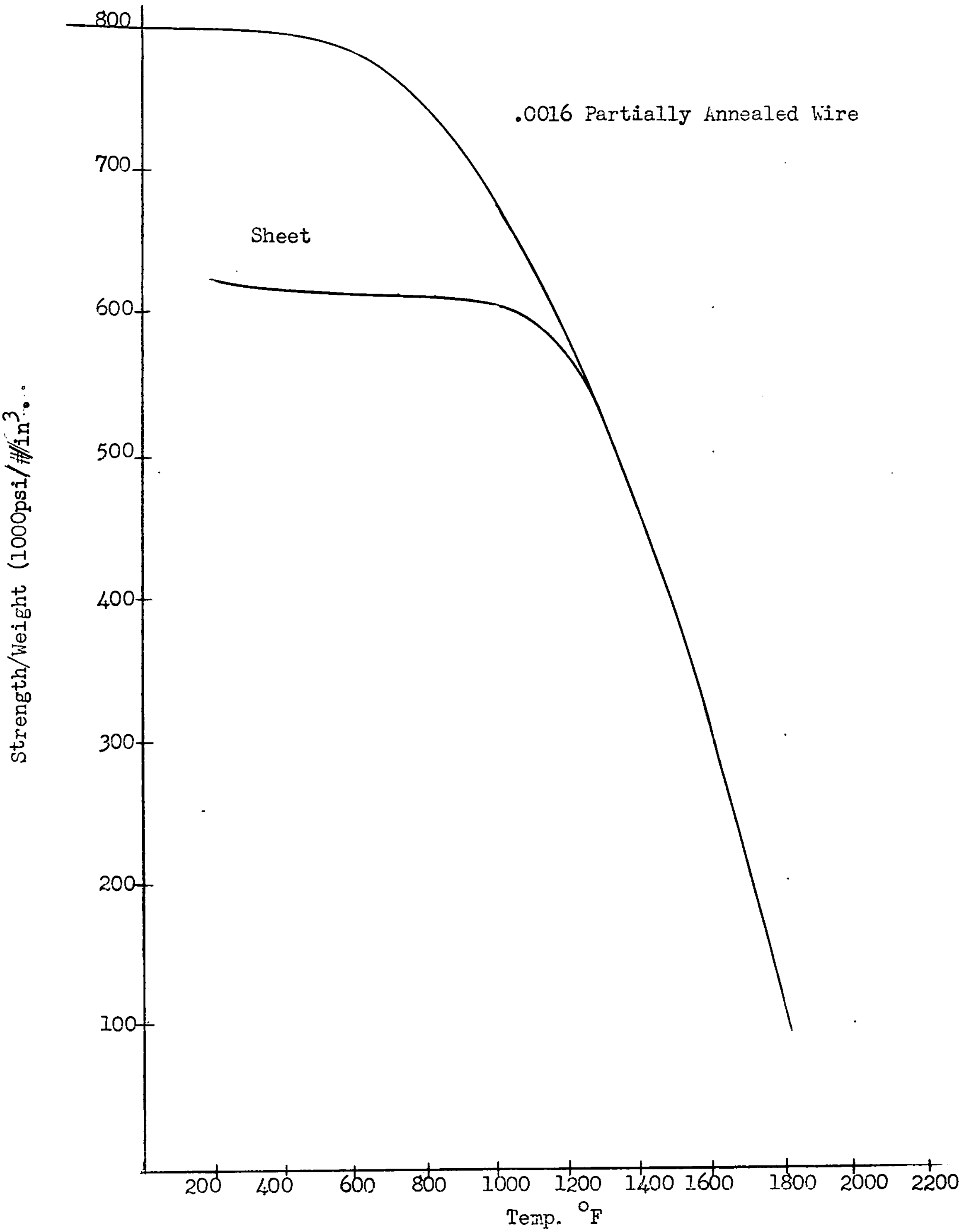


Figure IV - Strength of Rene' 41 Sheet and Wire

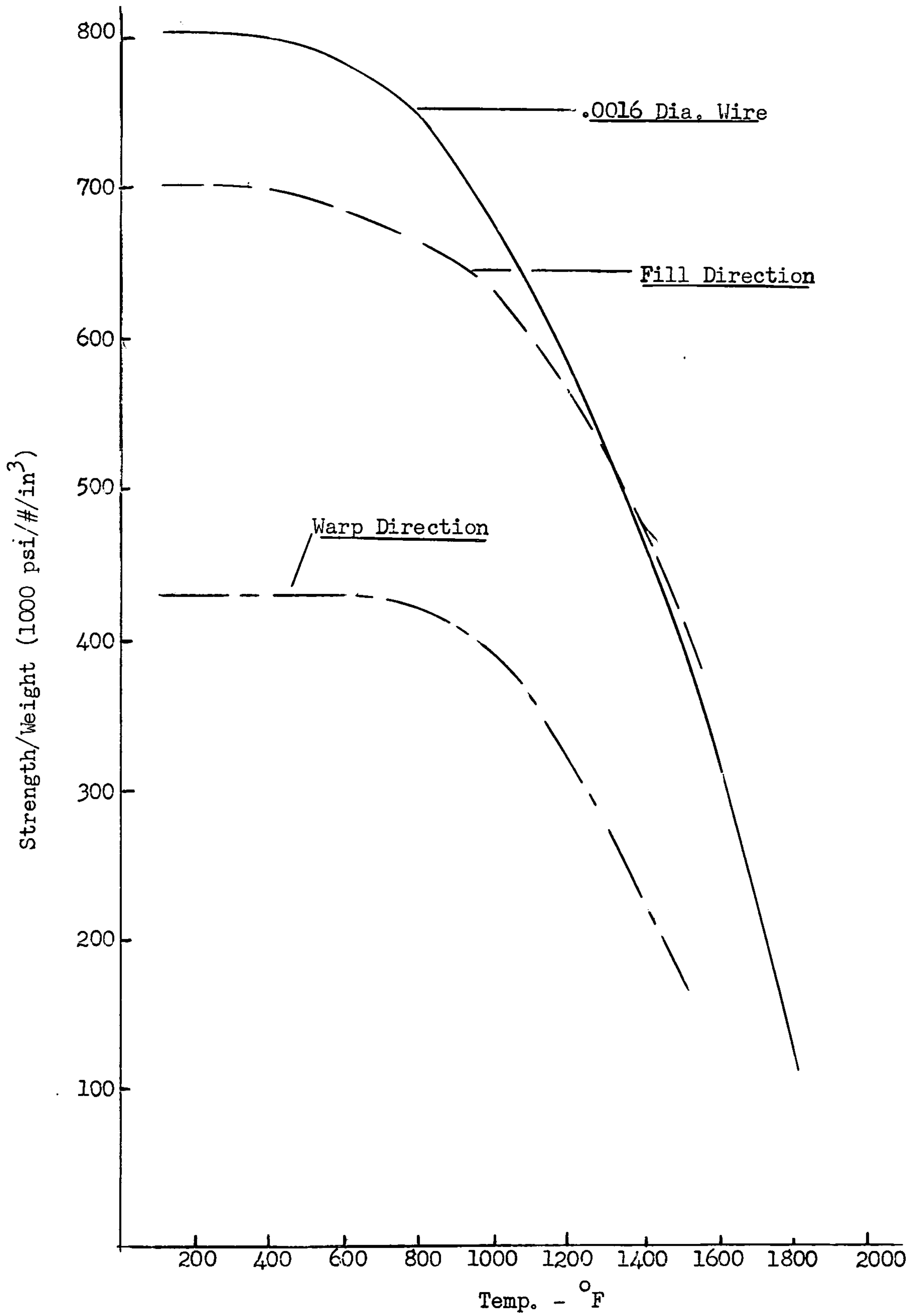


Figure V - Strength Properties of Rene' 41 Cloth

TABLE II

SUMMARY OF MATERIAL PROPERTIES - RENE' 41 CLOTH

| Material | $F_{tu}$ (psi) | Wire $F_{tu}$ (percent) | E (psi) |
|---|---|---|---|
| 0.0016 wire | 235,000 | | $28.5 \times 10^6$ |
| 200 by 200 plain weave | | | |
| Fill | 206,000 | 88 | 16 x 106 |
| Warp | 127,000 | 54 | $6.5 \times 10^6$ |
| 200 by 200 twill 2 by 2 | | | |
| Fill | 195,000 | 83 | $10.8 \times 10^6$ |
| Warp | 172,000 | 73 | $8.8 \times 10^6$ |
| 200 by 200 basket 2 by 2 | | | |
| Fill | 180,000 | 77 | |
| Warp | 173,000 | 74 | |

Refractory Metals

Table III lists the various refractory metals, their crystal structure, melting point, density, and atomic number. Of the metals listed, the technology of Tungsten, Tantalum, Molybdenum, and Columbium is the most advanced. Research on these four metals has been given a great deal of emphasis in recent years because of the desire to use these metals or their alloys for jet engine blading and rocket or nuclear applications. As was stated previously, at the present time, the refractory metals are the only materials which can be considered promising candidates for paraglider applications at temperatures above 1900$^{o}$F. They possess high melting points and exhibit good strength properties at elevated temperatures. However, they possess one serious draw-back, that is, they are extremely susceptible to oxidation at elevated temperatures. Considerable research has been done, and is being done at the present time to surmount this problem. Basically, two approaches have been used, (1) the development of oxidation resistant coatings and (2) the alloying of the base material to increase oxidation resistance. To date, neither approach has resulted in much success. This aspect of refractory metals will be discussed in more detail in the section on coatings. Table IV lists the oxides and their relative stability of the refractory metals. Figure VI presents curves of strength to density ratio versus temperature for the refractory metals while Table V summarizes their physical properties.

TABLE III

CHARACTERISTICS OF REFRACTORY METALS

| Material | Melting Temperature (F) | Density at room temperature (lb per cu. in.) | Crystal Structure* | Atomic Number |
|---|---|---|---|---|
| Vanadium | 3450 | 0.220 | BCC | 23 |
| Columbium | 4380 | 0.310 | BCC | 41 |
| Tantalum | 5425 | 0.600 | BCC | 73 |
| Chromium | 3450 | 0.260 | BCC | 24 |
| Molybdenum | 4730 | 0.269 | BCC | 42 |
| Tungsten | 6170 | 0.697 | BCC | 74 |
| Rhenium | 5760 | 0.759 | HHCP | 75 |
| Osmium | 5432 | 0.810 | HHCP | 76 |

*BCC = body-centered cubic: HHCP = hexagonal close packed

TABLE IV

STABILITY OF OXIDES OF METAL AT HIGH TEMPERATURES

| Material | Oxide | Stability of Oxide |
|---|---|---|
| Osmium | $Os\ O_4$ | Melts at 107 deg F; boils at 268 deg F |
| Rhenium | $Re_2\ O_7$ | Melts at 565 deg F; boils at 685 deg F |
| Vanadium | $V_2\ O_5$ | Melts at 1270 deg F |
| Molybdenum | $Mo\ O_3$ | Volatile above 1465 deg F |
| Tungsten | $W\ O_3$ | Volatile above 1830 deg F |
| Columbium | $Cb_2\ O_5$ | Nonvolatile below 2500 deg F |
| Tantalum | $Ta_2\ O_5$ | Nonvolatile below 2520 deg F |
| Chromium | $Cr_2\ O_3$ | Melts at 4424 deg F; metal volatile above 1830 deg F |

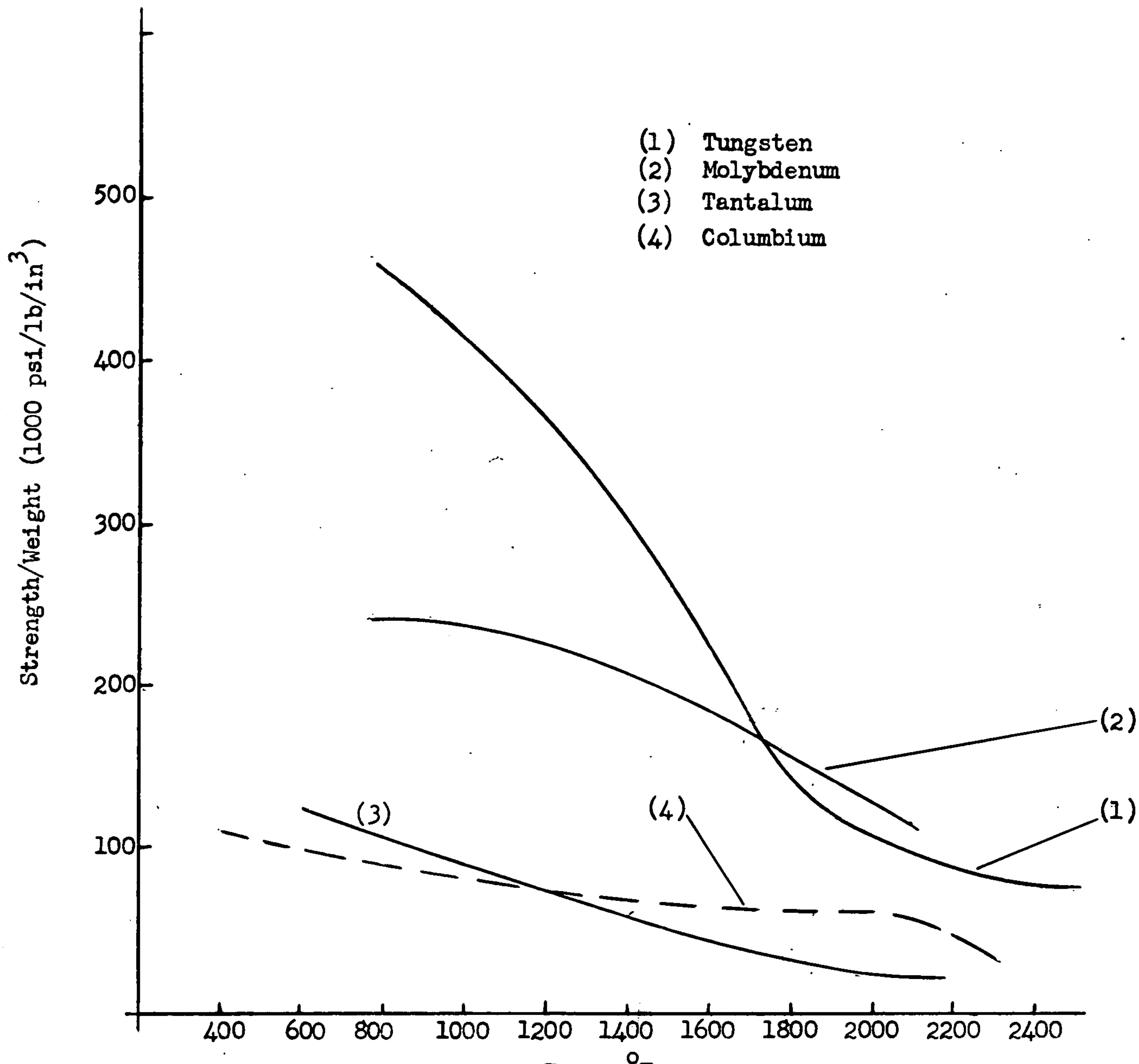


Figure VI - Strength to Density Ratio vs Temperature Refactory Metals

REFRACTORY METALS

| | Melting Point | Density | Max. Useful Temp. | Ult. Tensile Strength (RT) | Modulus of Elasticity (RT) | Creep Rupture (100 Hour) Ult.Str. | Creep Rupture (100 Hour) Temp. |
|---|---|---|---|---|---|---|---|
| | (deg F) | ($\#/in^3$) | (deg F) | (psi) | (psi) | (psi) | (deg F) |
| Tantalum | 5425 | 0.600 | | 150,000 | $27.0(10)^6$ | | |
| Tungsten | 6170 | 0.697 | | 580,000 | $51.4(10)^6$ | | |
| Molybdenum | 4760 | 0.369 | 3000 | 132,000 | $47.0(10)^6$ | 34,000 | 2000 (10 Hr) |
| Columbium | 4380 | 0.310 | | 140,000 | | | |

TABLE V

SUMMARY OF PHYSICAL PROPERTIES OF REFRACTORY METALS

## Non-Metals

Several non-metallic cloths are in existence which are capable of withstanding elevated temperatures. Among the most promising materials are fiberglass, leached fiberglass, quartz, and graphite or carbon. Cloth fabricated from each of the above materials has certain limitations or drawbacks. However, it is felt that these limitations are not unsurmountable.

## Fiberglass

Fiberglass is readily available commercially. The technology of producing fiberglass cloth is quite advanced. The yarn is available in both the staple and monofilament form, and the cloth is available in any number of different types of construction. Several types of fiberglass are produced commercially, however, Type "E" appears to hold the most promise for the application at hand. This material has found extensive use in the field of electrical insulation.

Under closely controlled conditions strengths up to 475,000 psi at room temperature have been recorded, for monofilament yarns. Of course, commercially available material exhibits strength properties considerably below this. Above $1300^\circ$F fiberglass exhibits no strength. Therefore, applications for fiberglass are limited to temperatures below $1300^\circ$F.

A serious drawback to ceramic fibres is their abrasive nature. This abrasive quality produces surface defects which in turn cause large variations in the strength of individual fibres. This problem has been allieviated to a considerable degree by coating the fibres immediately upon drawing. Several different coatings have been used, the most successful being Teflon.

Leached Fiberglass

This product is marketed under the tradenames of Refrasil by the H.I. Thompson Fiberglass Co., Los Angeles, and Sil-Temp by Haveg Industrites, Inc., Wilmington, Delaware. The manufacturing process consists of leaching conventional fiberglass cloth with acids so as to extract all of the oxides except silica. The cloth is then heated to temperatures to approximately $1500^\circ$F for the purpose of flexibility and strength. The leached fibres do not possess the tenacity exhibited by conventional glass yarns. They do, however, have the same abrasive property as fiberglass and are sometimes coated with Teflon to minimize this effect.

The leached material has a sofetening point of about $3000^\circ$F and has extremely good resistance to thermal shock. At the present time the material is capable of withstanding $2000^{\circ}$F for prolonged periods. Considerable efforts are being expended to increase the capabilities of the material both strength and temperature wise.

Quartz Fibres

Another method of producing fused silica fibres is the drawing of quartz. This method results in a product in excess of 99% pure silica. Several companies are presently active in this area. General Electric is, at present, marketing a quartz fibre on a commercial basis. G.E. reports a room temperature strength of 130,000 psi with a 3% elongation at ultimate. They also report 15,000 psi at $1800^{\circ}$F. We have been able to substantiate the 100,000 psi figure in our own laboratory, however, at $1700^{\circ}$F we recorded strengths of 115,000 psi. As yet we have been unable to explain the discrepancy. One possibility is a difference in specimen soak time at temperature. More tests with this material are planned for the near future.

Quartz fibres exhibit the same abrasive qualities exhibited by fiberglass.. Therefore special coatings will be necessary to prevent breakdown of the material.

Graphite Cloth

At the present time several firms are active in the production of graphite cloth. Pittsburg Consolidated Coke produces carbon filaments by a patented process involving the dissociation of hydro carbon gases. However, most firms produce the cloth by the controlled decomposition of rayon cloth at elevated temperatures. During the latter process the rayon undergoes a weight loss and shrinkage.

We have partially evaluated Pluton which we believe is fabricated by the decomposition of rayon. Pluton is a product of 3M. We have found that Pluton tends to shrink at elevated temperatures, making it unsuitable for the applications under consideration. We have just received a similar product produced by the National Carbon Co. As yet no evaluation tests have been made. Indications, from the accompanying literature, are that the material undergoes no shrinkage when subjected to temperature. The reason for this variance from Pluton is that the National Carbon Product was carried to a higher degree of refinement in the fabrication process.

Graphite cloth is reportedly capable of withstanding temperatures to $6000^{\circ}$F. It is susceptible to oxidation and erosion in high temperature air, and therefore must be coated for protection. Nevertheless, its high strength to density ratio makes it an attractive candidate for paraglider applications.

## Coatings

We are concerned with two types of coatings; a permeability coating for inflation gas retention and porosity minimization, and oxidation coatings which are to be used primarily withrefractory metals. Each type is discussed individually in the following text.

### Permeability Coatings

Several permeability coatings are now available and research in this area is continuing. However, to date, GAC's CS 105 elastomer seems to hold the most promise of meeting high temperature permeability requirements. CS 105 is composed of a silicone rubber base with a glass frit in suspension.

Silicone rubber was selected as the basic ingredient because of its ability to withstand temperatures to $800^{\circ}$F. Near this temperature, the organic materials in the elastomer begin to decompose and eventually only silica remains. The problem then was to find a means of extending the effectiveness of the elastomer above this temperature of $800^{\circ}$F. It was reasoned that if a material with a fusing temperature corresponding to the decomposing of the silicone rubber was compounded with the silicone rubber, this material in the fused state would support the silica residue and be effective as a gas barrier. After trying over 200 formulations a glass frit was selected as the most promising.

Although the performance of this elastomer has not been evaluated fully, it does not appear to be completely satisfactory. This is due to the mode of thermal decomposition of the elastomer and the fusing of the glass frit. The rate of decomposition is a time-temperature phenomenon that progresses very slowly at $800^{\circ}$F and increases as the temperature rises. The glass frit, however, does not fuse until a temperature of 1100 to $1200^{\circ}$F has been reached. Hence there is a range of temperatures (800 to $1000^{\circ}$F) where the rubber is decomposing and the glass frit has not fused and therefore the bond between the solids in the coating is reduced. This causes a relatively brittle ash which is susceptible to flaking off the metal cloth. This behavior limits the ability of the coating to act as a complete gas barrier. A solution to this problem is now being pursued by GAC.

Another coating which has come to our attention, but has not been evaluated, is a product of Microseal Products, Incorporated of Torrance, California. Microseal is a specialist in the dry lubricant field for aerospace applications. Cloth samples of various materials have been submitted to Microseal for coating. These samples will be subjected to evaluation tests to determine their permeability properties and resistance to aerodynamic shear.

Oxidation Coatings

The primary drawback, to the use of refractory metals for elevated temperature applications, is their extreme susceptibility to rapid oxidation at these temperatures. There are three principal possibilities to reduce the oxidation tendencies of the refractories.

One approach is the use of coatings of high melting, intrinsically oxidation, resistant metals or alloys. Another way is to alloy the refractory with other metals resulting in an inherently oxidation resistant alloy. A third possibility is the formation of oxidation resistant intermetallic compounds with the refractory substrate itself on its surface.

A great deal of research along the approaches cited above, as well as others not mentioned, has been pursued and is continuing with varying degrees of success. Within limitations, several systems have been developed that successfully protect the refractories. Some of the problems encountered are (1) high diffusibility between the coating and substrate causing embrittlement of the substrate, (2) extreme volatility of the substrate oxides, (3) lack of healing properties in coating should defects occur, (4) and the formation of low melting eutectics between the substrate and coating. Attempts to improve oxidation resistance of the refractories by alloying has been relatively unsuccessful. This approach has been more successful in increasing the strength of the refractories.

Several processes are currently being used to apply metallic coatings. These include electroplating, vapor plating, hot dipping, electroless plating, clodding, and spraying. The properties of a coating depend not only on the coating material but also to a great extent on the method used to apply the coating. As an example, electro deposited coatings will differ in behavior from those of the same material deposited by vapor plating or hot dipping. The reason being, that in the latter two processes, the base metal is heated.

Some of the more common plating metals and processes used are listed in Table VI.

The Sylcor Division of Sylvania Electric Products, Incorporated, is presently engaged in the development of an oxidation coating which shows considerable promise. The substrate materials they are working with are pure Tantalum and Ta - 10W alloy. The coatings consist of aluminum and aluminum alloys which are applied by either a dipping, spraying, or pack-calorizing process followed by a diffusion treatment. A Sn-50 AL spray-diffusion-spray-diffusion treatment appears to have the most promise.

A treatment of this type gave good protection to 3000$^{\circ}$F and withstood 10 cycles in 10 hours to 2950$^{\circ}$F. The samples used were 0.10 inches thick with an approximate coating thickness of .002 inches. Evaluation of this coating is continuing. Some experimentation has been done with a Beryllide coating without much success.

The coating of tungsten, tantalum and molybdenum with silicon has been accomplished with varying degrees of success. Molybdenum filaments have displayed a life of 1000 hours when heated in air to 3090$^{\circ}$F. The results with tungsten filaments has

TABLE VI

OXIDATION RESISTANT COATINGS FOR ELEVATED TEMPERATURES

| Coating | Method of Application | Temp. of Rapid Oxidation - °F |
|---|---|---|
| Aluminum mp 1220°F | Hot dipping, Metal spraying aluminum paint, plus heat diffuse, Electro plating Vapor plating | 935 to 2000 |
| Chromium mp 3350°F | Electro plating Vapor plating | 2000 to 3100 |
| Cobalt mp 2715°F | Electro plating Electro less plating Vapor plating Spraying | 1470 to 2000 |
| Gold mp 1945°F | Electro plating | |
| Nickel mp 2650°F | Electroplating Electro less plating Vapor Metal spraying | 2000 to 2500 |
| Platinum mp 3224°F | Electro plating Vapor plating | Above 3100 |
| Silicon mp 2580°F | Vapor plating | 2000 to 2550 |
| Chromium Nickel alloy | Electro plating plus diffusion Vapor plating | Up to 2100 |

not been quite so successful. New York University Research Division reports that tungsten filaments so treated exhibit brittleness and vulnerability to low temperature oxidation.

However, they express the opinion that these drawbacks can possibly be overcome.

The considerable research effort which has been expended in the development of protective coatings for the refractory metals and their alloys has been almost entirely directed toward the coating of gross metal parts such as turbine buckets and nozzles. Little effort has been directed toward the coating of individual filaments suitable for use in high temperature paraglider applications. Since the filaments being considered are approximately 1.5 mils in diameter a coating thickness of approximately .1 mil is desirable. With coatings so thin it is impossible to predict, on the basis of available information, whether or not processes and materials suitable for coating gross metal parts would be applicable to the coating of filaments.

Weaving

The possibility of ultimately using a particular metal for paraglider applications, regardless of its desirable physical and mechanical properties, depends upon its capability of being drawn into fine diameter filaments and woven. To date, only limited efforts have been expended in this area. As was previously stated, GAC was instrumental in interesting wire drawers and metal cloth weavers in the fabrication of Rene' 41 fine mesh cloth. Since that time GAC has devoted considerable research and development efforts in improving Rene' 41 cloth quality and processing.

At the present time some superalloys and refractory metals are available in filament form. These include Rene' 41, Elgiloy, Inconel 702, Chromel R, Stainless Steel*, Tantalum, Tungsten, and Molybdenum. To our knowledge Rene' 41 and Stainless Steel are the only materials that have been woven successfully to date. Of course, stainless steel cloth is readily available on a commercial basis.

In the course of our survey, we were able to locate only one weaving program other than that being conducted by GAC. Fabric Research Laboratories, Inc., of Dedham, Massachusettes is under subcontract to A.D. Little Company to develop equipment and weaving processes for Elgiloy yarns. Due to delays in acquiring .5 mil Elgiloy wire, FRL is experimenting with available Chromel R .5 mil wire. Chromel R has room temperature tensile properties similar to those of Elgiloy. FRL has attempted to prepare single yarns of seven .5 mil filaments (7/1) and plied yarns of 49 to 50 filaments (7/7 or 7/7/1). As of this writing the stranding operation has not met with much success due to the wildness of the yarn as a result of the twist. This wildness has prevented successful weaving of the cloth. One approach they have used to "kill" the yarn is run the yarn through an alcohol - soluble solution of nylon. This binds the yarn and minimizes the pig-tailing effects. After weaving, the binder will be dissolved out of the cloth.

GAC has just recently started a two phase weaving and stranding program of Rene'41 material. The purpose of the first phase of the program is to develop cloths for Ballute Drag Devices. To date monofilament cloth has been woven with an openness of 34%. A fair degree of success was attained. Thirty-four percent approximately represents the minimum openness factor present day weaving equipment

* High temperature steel

is capable of achieving. Under the same program seven 1.6 mil Rene' 41 filaments have been laid stranded into a yarn. This operation has been quite successful as the yarn displays no wildness. No attempts have been made to weave this yarn as yet.

The second phase of the program, has not commenced as yet. The purpose of this phase is to develop highly flexible and lightweight metal cloths using textile methods. GAC's textile ring strander and power loom will be in operation in time to carry on this program.

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