FIBROUS MATERIALS

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ORGANIC AND INORGANIC FIBROUS MATERIALS

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The past role of fibrous materials in the protection of man and his accouterments from environments encountered in an oxygen rich atmosphere are well known. This was accomplished by employing commercially available fibers to fulfill overall Air Force requirements which effectively limited research to overcoming such unique requirements as abrasion, chemical deterioration, shock loading and flash thermal, to name a few. The role of fibrous materials in the space age, of necessity precludes such an approach.

In the early stages of the space age which began with the firing of instrument packages to the extreme outer edge of our atmosphere, the first deficiency of commercial fibers became apparent. (figure 1) (Melted Ribbon Chute). The poor resistance of nylon to elevated temperatures resulted in the melting of the materials at 482°F. Concurrently, high shock loads, imposed by deployment of decelerators at super and hypersonic speeds, have been extremely detrimental to fibrous materials. (figure 2) (Shredded Ribbon Chute). This damage resulting from deployment at Mach 3 at 60,000 ft. altitude, was caused by high stresses imposed on the horizontal members. These stresses are a combination of tension and high frequency flutter or vibration.

As the Air Force continues probing into the extremes of space, fibrous materials used must be capable of functioning under the hyper environments that future aerospace systems will encounter. The flexible fibrous materials will be utilized as deceleration devices for aerospace vehicles (including re-entry), instrument and capsule recovery. The need for light weight but large volumes for aerospace systems has pointed up acceleration of research in the area of materials for expandable structures. The advantage of inflatable structures include facility of compaction and subsequent ease of expansion upon achievement of operational altitude.

Flexible fibrous materials will also be required where high strength is needed as a substrate for elastomeric coatings to be utilized in tires, fuel containers, diaphrams and ducting which must withstand unusual environmental conditions of temperature and pressure while under load and continuous flexing. Further uses of these fibrous materials include thermal insulation and, because of inherently high strength to weight ratios, rigid structures by means of fiber reinforcements for plastic and other composite materials. Figure 3 covers a broader spectrum of planned uses.

The utilization of unique systems composed of fibrous materials in aerospace environment will necessitate ability to withstand structural loading, cryogenic temperatures, micrometeoritic bombardment, aerodynamic re-entry heating, vacuum and solar radiation, abrasion, and repeated or cyclic flexing. In analyzing the referenced environments as related to presently available fibers, it can be shown that present fibers will fail to withstand one, or more of these environments. For example:

1. Nylon has the strength, flexibility, abrasion resistance, and energy absorbing capability desired, but is unusable above 300°F.

2. Fiberglass has the strength, and ability to resist temperatures up to about 800°F, but has extremely poor abrasion resistance, cannot be flexed, and due to low elongation has poor energy absorbing characteristics.

Analysis of known and anticipated requirements for fibrous materials can best be summed up generally in figure 4 and specifically in figure 5. Other requirements must be considered which include the ability of coated fibrous structures to rigidize upon loss of plasticizer, time to rigidize at specific levels of low density, and resistance to cryogenic temperatures during and after rigidization, and fabricability.

Strength and temperature resistance are the most important requirements for fibrous materials. However, a review of the overall requirements reveals that flexibility is a critical factor. Especially so, when it becomes apparent that fibers with high strength at elevated temperatures have a high modulus and quite a bit of stiffness. Figure 6 shows the Modulus, (E) for various materials as well as the fiber diameter necessary to achieve the equivalent flexibility of nylon. An indication of good flexibility is evidenced in fibers which have good knot strength. For fibers to have good knot strength, they must have a clearly defined yield region (on the stress-strain curve), in order to permit redistribution of the stresses to the lowest possible levels; they should also have a high ultimate tensile strength, since glasses, ceramics, and refractory metals are poor in flexibility; progress toward their usage will undoubtedly be slow. This becomes more evident when we review the present fibrous materials applied research program.

Basically, this research program is divided into three broad areas:

1. Fiber Drawing and Modification

2. Fibrous Structural Materials, and

3. Coatings for Fibers and Fibrous Materials.

These areas are of sufficient depth to prevent the overlooking of any approach which might lead us to the desired goal. Considering this, all basic types of materials-organic, ceramic and metallic are included in the fiber research program.

Research programs in the area of new fiber achievement is concentrated in forming of fibers from new polymers, impregnating organic polymers with metallic oxides and drawing of metal fibers.

The practice of spinning inorganic fibers from a melt suffers from serious disadvantages when extremely high melting inorganic materials are used. The materials must be handled at extremely high temperatures and are often corrosive. Spinning equipment is not available for handling such melts and the development of such equipment will be extremely difficult. As a result of research efforts, a technique has been found to bypass the problem of equipment to handle batches of molten materials. The method consists of spinning an organic fiber at room temperature, which contains a large percentage of inorganic components (Oxides). The composite fiber is then sintered to remove the organic portion of the fiber and form the inorganic fiber. The organic polymer employed must meet the following criteria: 1. Must form strong flexible fibers. 2. Must char without melting, at a temperature high enough that an inorganic liquid phase will form. 3. It must burn out completely, leaving no carbonaceous residue.

The inorganic constituents employed must meet the following criteria: 1. A small amount of inorganic liquid must form at temperatures low enough to be present before charring of the organic material is complete; 2. At all stages after the start of charring there must be an inorganic liquid phase of high viscosity and surface tension; 3. The liquid phase must be controlled in order to maintain a fibrous form; 4, The particle size must be controlled according to the desired size of the finished fibers.

Composite fibers have been produced that contain 80 percent by weight of inorganic material in poly-acrylonitrile. These composite fibers were then heat treated to raise the decomposition temperature of the poly-acrylonitrile. After heat treating, the composite fibers are charred at 400°C and the residual carbon removed at 1000°C to produce a completely inorganic fiber. Inorganic fibers several feet in length and 100 microns in diameter have been produced in this way.

Problems still to be solved are the use of more refractory inorganic materials, diameter, crystallinity, and achieving flexibility in the fibers formed; the latter is related to diameter. Most of the operations of the spinning method are carried out at room temperature in a fairly straight forward manner; only a minor portion of the operation is high temperature.

Organic fibrous materials in use at present have very definite limitations on their capabilities to resist high temperatures, ultraviolet light and other environmental extremes. Additives have been widely used with only marginal improvements.

In the search for high temperature organic fibers, difficulties are encountered in forming fibers from the high melting material. Fibers are generally formed by one of three methods: melt, coagulation, or solvent spinning. With melt spinning the polymer often decomposes rather than melt at the molecular weights required for fiber formation. In solvent and solution spinning the polymer, finding a suitable solvent or system of solvents is the difficulty.

Research is being conducted to form polymers which contain residual unsaturation; thus the molecular weight can be increased by affecting crosslinking after the formation of the fiber.

Continual screening of industry's research is carried on. An example of this effort is the studies of HT-1. Since it has been brought to our attention considerable effort has been expended toward defining the fiber's characteristics. It's resistance to gamma radiation has been found to be far superior to nylon (figure 7). Under certain conditions gamma radiation and heat caused cross-linking resulting in increased strength. (figure 8). HT-1 has excellent strength retention, if properly treated, at temperatures up to 600°F. (figure 9). Its non-melt, non-fuse characteristics, coupled with toughness superior to nylon cannot be overlooked for decelerators, and related fibrous structures.

As RT-1 is being proven, another polymer capable of being drawn has been discovered. From the polybenzimidazole family, this fiber is spun from a solution of dimethyl sulfoxide and has been evaluated with promising results for high temperature applications. The fiber had a tenacity of 3.93 grams/denier approximately 6.8 percent elongation and modulus of elasticity of 2.2×10^6 psi based on a 8 denier fiber. The fiber retained structural integrity after exposure to 977°F. Further studies of techniques to increase the molecular weight, achieve greater orientation, crystallinity, and subsequently higher strength, are being conducted.

Polymeric materials are susceptible to damage by various types of radiant energy. Ultraviolet light is an example of radiant energy which causes extensive damage to polymers used in fibrous materials. Since a considerable portion of the most energetic ultraviolet light is screened from the earth by the atmosphere, much more severe damage can be expected in a space environment. Research has shown that properties of fibers such as elongation, tensile strength, Young's modulus, and the molecular weight of the polymer are decreased after relatively short exposure to ultraviolet radiation. As was predicted damage was more severe at the shorter wave lengths. At 375 Mu there was no damage since the energy at this wave length corresponds to the energy of the carbon-to-carbon bond.

In the deterioration there are two competing reactions: chain scission and cross-linking. The environment seems to have considerable influence as to which reaction dominates. In an inert atmosphere such as nitrogen, chain scission is the dominant reaction. The effects of orientation of molecular chains in the fiber on deterioration are being investigated. The effect of the presence of oxygen in the ambient atmosphere is also being studied. Polymers that have been investigated to date are nylon, poly-acrylonitrile, polyethylene-tereplithalate, polyethylene, and polytetrafluoroethylene. Evidence shows that the dominance of chain scission in nitrogen is due to pressure effects rather than to the atmosphere. The nitrogen present tends to retain hydrogen which has been split off from the polymer and thus promote chain scission over crosslinking.

The utilization of metal fibers in various high temperature flexible structures poses problems seldom encountered or experienced with organic type fibers. For high temperature use, oxidation, abrasion, and flexibility must be considered, since these can seriously affect the operating capability of fine metallic fibers. Therefore, the metal whether it be pure or an alloy is of concern. A number of factors have had to be considered in choosing a metal for study. These factors are: 1. Oxidation resistance at temperatures of plus 1500°F; 2. Strength at high temperature; 3. Ductility or elongation; 4. Drawability.

From the beginning it was apparent that most pure metals could not be utilized due to inherent low strength, however, certain of the refractory metals have excellent strength properties, are easily drawn to diameters of 0.4 mil and still retain some ductility. The refractory metals have high melting points and good high temperature strengths. A problem to overcome making use of them is the resolution of their extremely low oxidation resistance. The refractory metals of most interest are Molybdenum and Tungsten. Although the tensile strength of Molybdenum is not as good at high temperatures as Tungsten, its lower density 10.28 g/cc to 19.3 g/cc makes it a more interesting material. Figure 10 shows the tensile properties of Molybdenum and how drawing it results in increasing tensile strength as diameter is decreased. To overcome the problem of oxidation, our research is being aimed at protective coatings. Many methods of applying coatings exist, and electrodeposition is the most promising.

Some of these studies have been concerned with gold plated moly and tungsten utilizing in addition platings of palladium, rhodium, chromium and nickel. Oxidation tests are conducted by hanging a loose coil of fiber in the center of a furnace at 2000°F. Preliminary results show that gold is unsatisfactory, due to the rapid diffusion of the molten gold into the refractory metal. Using a 2-mil Moly as a base, a 0.1-mil coating of nickel was applied, followed by 0.05-mils of chromium. The chromium plating was diffused into the nickel coating. After exposure to 2000°F for 60 seconds, the fiber had a tensile strength of 158,000 psi. In addition, thin electrodeposits of nickel and chromium, electronless nickel and combinations of these have been added to 1-mil Moly. In all cases, the

electro-plated fibers were heated in argon for 5 minutes at 2000°F, to diffuse the nickel and chromium so as to form a more oxidation resistance coating and to improve the adherence of the coating to the Moly. Tests have shown that the electroless nickel affords much better protection in combination with chromium. Although the melting point of electronless nickel is only 1635°F, it alone will provide some protection to Moly fibers at 2000°F up to 3 minutes in air. It is probable that the thin coating alloys very quickly with the moly at 2000°F and prevents catastrophic oxidation. These coatings will be applied to basic refractory fibers as fine as 0.4-mil dia., to achieve a final diameter of 0.5 mil or less. It must be noted that even though anticipated usage of these metals would be in a low density atmosphere, the oxidation studies are conducted at ground level densities. Considering the velocity of satellites in orbital flight, and during re-entry, even in hard vacuum environment, oxygen concentrations will build up, necessitating the simulation of such critical conditions.

Another class of metals the high temperature alloys or "Super Alloys" are worthy of consideration in the quest for high temperature fibers. There is sufficient data on fully heat treated sheet material rolled from some of these alloys (figure 11) to indicate that they have sufficient tensile strength at elevated temperatures to attempt drawing them into fine fibers. With respect to the oxidation characteristics, it is known for example that certain iron alloys form a dense adherent oxide layer when exposed to air which creates extreme oxidation resistance. However, the tensile strength of most iron alloys falls below 20,000 psi as the temperature reaches 1500°F and efforts to increase the tensile strength have not been too successful.

The nickel alloys on the other hand exhibit good oxidation resistance while retaining a good percentage of strength after exposure to 1500°F. The present research program on metal fibers include two nickel alloys—Rene 41 and Inconel 702. The excellent original tensile strength of the nickel alloys as represented by Rene 41 (figure 12) combined with good oxidation resistance, explains our reasoning in conducting research toward the fine fibers of this alloy.

Similarly, cobalt can be alloyed so that the oxidation resistance is of the same magnitude as the better nickel alloys. Studies are concentrated on fibers produced from Eligiloy. To a certain degree Elgiloy and Rene 41 are quite similar. Similarity exists in specific gravity (8.25 to 8.3), Elongation (17.5 percent to 17 percent) and Tensile Strength (225,000 psi to 286,000 at 0.5 mil). Their compositions are shown in figure 13. Fibers of 5,2,1, and 0.5-mil diameter have been drawn for utilization in our research studies. Primary studies are being conducted to determine the oxidation resistance, tensile strength and elongation after exposure to 1500, 1800 and 2000°F, for 1.5 and 10 minutes. These studies to date on Elgiloy and Rene 41 have revealed that: 1. Oxidation rate decreases with decreasing diameter in the range of 5 to 0.5-mil fibers. 2. Percent area reduction due to oxidation increased with decreasing diameter, and 3. Oxidation decreased the total cross sectional area by less than 4 percent (figure 14).

A comparison of the tensile strength (figure 15) of these alloys after exposure to 1500, 1800, and 2000°F for 1, 5 and 10 minutes reveals, at 1500°F the Rene 41 is superior, but as the temperature increases the Elgiloy retains the larger percentage of tensile strength. Even more significant than the loss in strength has been the reduction in room temperature ductility after oxidation. Losses of as much as 90 percent have been noted for the specimens exposed at 2000°F for 10 minutes. The loss is much greater for the Rene 41 fiber (in diameters of less than 2 mils) than for the Elgiloy.

The fact that a metal is resistant to temperatures and has high original and at temperature tensile strength is not the only indication of its fiber forming ability. The metal must be capable of being drawn to the diameter most satisfactory for use in flexible fibrous materials. Normal practice today is to reduce the diameter of a metal gradually, starting with a bar and through intermittant drawing, annealing and coldworking, achieving an extremely fine fiber. In the case of refractory metals and super alloys the last drawing operation utilizes diamond dies to achieve roundness and consistency of product. This approach is extremely expensive and time consuming. New techniques are being considered, which could result in fine fibers at relatively low costs. These approaches include 1. Drawing from a melt. 2. Drawing over hot pins. 3. Drawing bundles of wires through a single die. 4. Etching by Electrolysis. Included in this phase of research, are studies on the techniques for gathering and bundling fine metal fibers, to achieve multifilament yarns capable of being woven. Present studies in stranding of 1/2-mil fibers of super alloys have resulted in strands of 50 filaments in such combinations as 7/7/1, 5/10/1, 10/5/1. Translation of fiber strength to yarn strength is of prime concern in continuous filament yarns with the goal 100 percent translation. In the case of these fibers the strength achieved in the first yarn was 1.47 lbs. and the second was 1.46 lbs. The 1/2-mil fiber had a strength of .0288 lbs. Roughly all of the fiber strength was therefore retained in the plied yarn.

A brief summary of the status of our fiber research is graphically presented in figure 16.

It might be pointed out that the obvious advantages of fibers for flexible, pure tensile loaded materials has received by far the greatest amount of attention. For more rigid applications, the substantial increase in load carrying efficiency realized through fiber formation has been exploited for the most part only as so called "reinforcements" with other types of materials. It is believed that much could be accomplished with new and refined means of fiber assembly into highly efficient flexible structural members.

Our research on fibrous structures is slanted toward the affecting of optimum low or zero porosity materials for decelerators and other devices that could advantageously be fabricated from fibers which are resistant to temperatures up to 2000°F. In the case of high temperature resistant fibers such as the super alloys, their density is of such a magnitude to preclude achieving a high strength to weight ratio solely with metals. Consideration must be given to techniques for achieving low controlled or zero porosity, such as: 1. Single Fiber Coatings;2. Yarn Coatings;3. Flexible Fibrous Structure Coatings; 4. Yarn Blending.

In reviewing these four areas, it became apparent that applying coatings to the individual fibers of a yarn bundle is of a challenging nature. The ability to diffuse coatings through fiber bundles can be difficult especially where consistency of coating thickness is desired. The only possible use of this type coating can be made when the coating is applied as the fibers are drawn and before gathering, as in the case of glass or ceramic fibers. A very good example of this latter approach is our work with fused silica yarn and fibers. Using as a base, a fused silica yarn, various finishes or coatings ranging from silicone oils through various oxides which can be deposited as thin films have been studied. Most successful to date has been magnesium acetate. Tensile tests have shown that fibers removed from treated yarns were equivalent to fibers from unfinished yarns exposed to 1000°F for 16 hours. Abrasion resistance has been improved by a factor of 2. These fibers were treated at the bushing prior to gathering into a bundle.

The step to yarn coating, could open many new fields with respect to achieving yarns which have strength, and when woven have greater flexibility and abrasion resistance. As far back as 1956, we studied the effect of coating glass yarns prior to weaving (3). This study revealed that teflon coated glass yarns could be woven to give a controlled porosity flexible structure, capable of withstanding flexing and abrasion on itself, yet capable of use at temperatures to 700°F. The use of chemical and mechanical treatments for enhancing flexibility and abrasion resistance is now being studied using glass yarns. Concerning chemical treatments those referenced for fibers as well as certain silicone finishes have been found to be most satisfactory. Tape samples having silicone (XET-4327) added, retained a greater percent of strength after being compressed under 250 psi, at 500°F, (this was a specific unfulfilled requirement). Another area of chemical treatment involved converting the flexible yarn to a rigid bundle when exposing it to the environment of outer space. By using treated yarns (prior to weaving) and then coating the woven structure, maximum rigidity and impermeability with a minimum of weight, was possible. Chemical systems being used include the urethanes and vinyls. By careful selection of the plasticizing compound, rigidization can be effected in a hard vacuum using the vapor pressure generated for inflating the structure. The use of this type fibrous material for antennas, and solar collectors in space could open an entirely new concept in exploration. Mechanical treatments for the yarns involve techniques such as texturizing. This type yarn has loose ends or loops protruding from its surface; these offer advantages in the rigidization, including high resistance to internal shear forces.

Use of texturized yarns in fibrous structures can increase adhesion of coatings and add structure flexibility prior to rigidization. In coating the woven structure, the ideal approach would be to fill only the interstices or openings between the yarns, however this has not yet been successfully accomplished. Processes such as knife coating, dip coating, and flame spraying are being investigated. The use of flake or frit added to the woven structure as flock or to a coating can effectively increase elevated temperature resistance.

One of the most practical approaches to achieve low porosity structures is the utilization of yarns composed of more than one fiber. The use of a high strength, temperature resistant metal wrapped with a staple yarn composed of a flame proofed cellulosic, acrylic fiber, or wool would effectively create a yarn array having a good cover factor. The staple fibers would increase coating adhesion and their low density, generally less than 2, would result in lower weight structures. Actual blends composed of Elgiloy and wool are being prepared and will be woven into structures. Flexibility, determination of repeated stressing characteristics at high temperatures, in addition to tensile and energy absorption will be obtained on these blended fiber structures. The inclusion of new high temperature organic fibers such as HT-1, or PBI could effectively create an ablative type structure for use in leading edges, nose cones, and re-entry bodies.

In the area of inflated or expandable structures, consideration must be given to the woven structures used for protecting man in the low density or vacuum environment of space. Materials used in space suits must when pressurized, remain dimensionally stable, and yet be flexible enough to permit body movements. This presents a design problem because the materials which are rigid enough to provide dimensional stability are not flexibile, and materials which are extensible enough to flex do not remain dimensionally stable.

The two requirements cannot be compromised but must be resolved by special techniques by making "structures" that have both characteristics. If these "structures" are not air tight, as in the case of fabrics, they must be placed over some type of bladder which will retain the air. Bending flexibility has been solved by two different design

principles. The first one utilizes a cylinder constructed from a one-way stretch material that is restrained from stretching by longitudinal cords placed at the cylinder sides (figure 17). Since these cords are on the cylinder sides, they do not interfere with bending flexibility. The material used in this method can be either bellows, one-way stretch fabric, or even a fibrous material cylinder with large longitudinal wrinkles.

The second method consists of taking a loose material, (a net for example) and placing it in the shape of a joint in such a way that it will not change its dimensions when pressure is applied. (figure 18). This can be done by calculating or measuring the equilibrium geometry at the desired pressurization and then setting the structure initially at that geometry. If the structure starts out at its equilibrium geometry, it will not change shape when pressure is applied. However, since the fibrous material is loose it can still allow extensions to take place; and therefore the cylinder can bend. The difficulty of bending will depend upon the type of fabric.

In the design studies, mathematical and experimental work was done. Many fibrous structures have been designed, analyzed, and evaluated as pressurized cylinders. The aim is always to minimize bending moments, and the tendency to spring back to the original position. Present research consists of extending some of the useful results found for cylinders into the more complicated shapes that are required in a space suit. In addition, several new types of fibrous structures are under study for use in cylindrical joints.

The fabrication of expandable structures such as re-entry lifting surfaces and space-stations necessitates new coated fibrous structures impermeable to gas penetration, with sea level pressure on one side and vacuums as low as 10^{-9} mm Hg on the other side, ability to withstand re-entry temperatures to 1500°F for time cycles of 10 minutes. But basically these are requirements shown at the beginning of this presentation, as are other requirements for expandable structures. However problem areas exist which must be resolved to achieve optimum fibrous structures. These areas include: 1. Yarn and structure construction to attain optimum strength and flexibility; 2. High temperature coatings capable of gas impermeability and retaining flexibility up to 1500°F; 3. Techniques for joining high temperature fibrous structures without affecting flexibility, in both uncoated and coated conditions; 4. Ability to resist cryogenic temperatures.

It is difficult to conclude a presentation of this type because each month new advances are made in fibrous materials in our research programs. Each advance seems to indicate the next step to be taken to achieve optimum fibrous material. This has been clearly shown in the case of metal fibers. Two years ago 1/2-mil fibers of Rene 41 and Elgiloy were unknown. With their conception, forming of multi-filament yarns become a possibility. Now that yarns of this type are becoming a fact, construction of the optimum fibrous material for specific space systems will follow. New challenges arise which must be met, new techniques must be proven, and requirements must be fulfilled so that aerospace systems can successfully accomplish their anticipated and required missions.

REFERENCES

1. "Candidate Materials for High Temperature Fabrics", WADC TR 59-155, Sept. 1959.

2. Hamburger, Walter J., "A Technology for the Analysis Design and Use of Textile Structures as Engineering Materials", Edgar Marburg Lecture, 1955, A.S.T.M.

3. "Development of Heat Resistant Glass Textile for Parachute Applications", Contract AF 33(600)-29002, Coast Mfg. Co.

BIBLIOGRAPHY

1. WADD TN 60-299, "Thermal and Gamma Radiation Behavior of a New High Temperature Fiber", 1961, Capt. C.O. Little, Jr.

2. WADD TN 60-298, "Elevated Temperature Behavior of Fibers", 1961, Stanley Schulman.

3. WADD TR 60-897, "The Theoretical Behavior of a Knitted Fabric Subjected to Biaxial Stresses", 1961, 1/Lt. P. Popper, USAF.

4. WADD TR 60-510, "Deterioration of Textile Materials by Ultra-Violet Light", Oct. 1960.

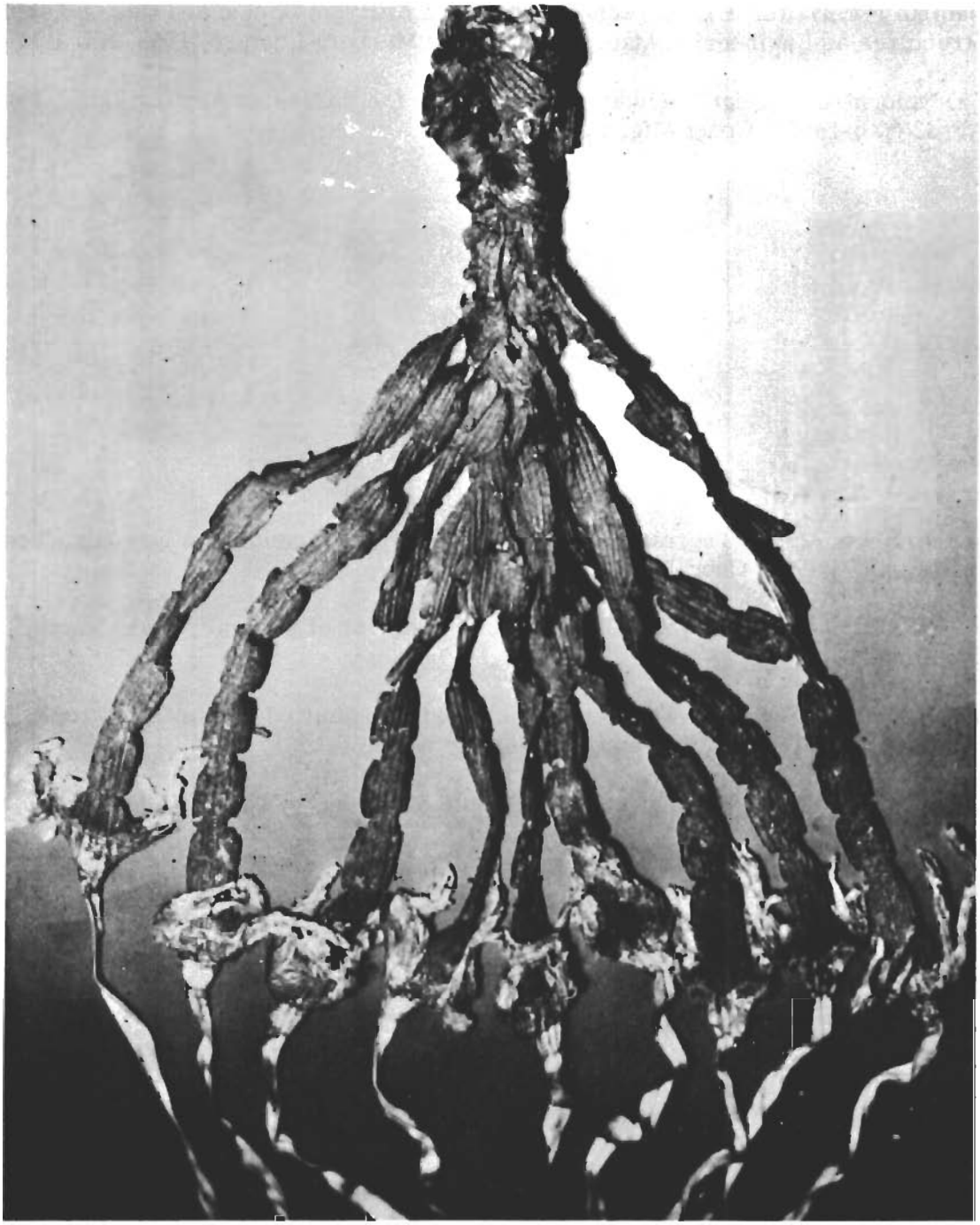

Figure 1.

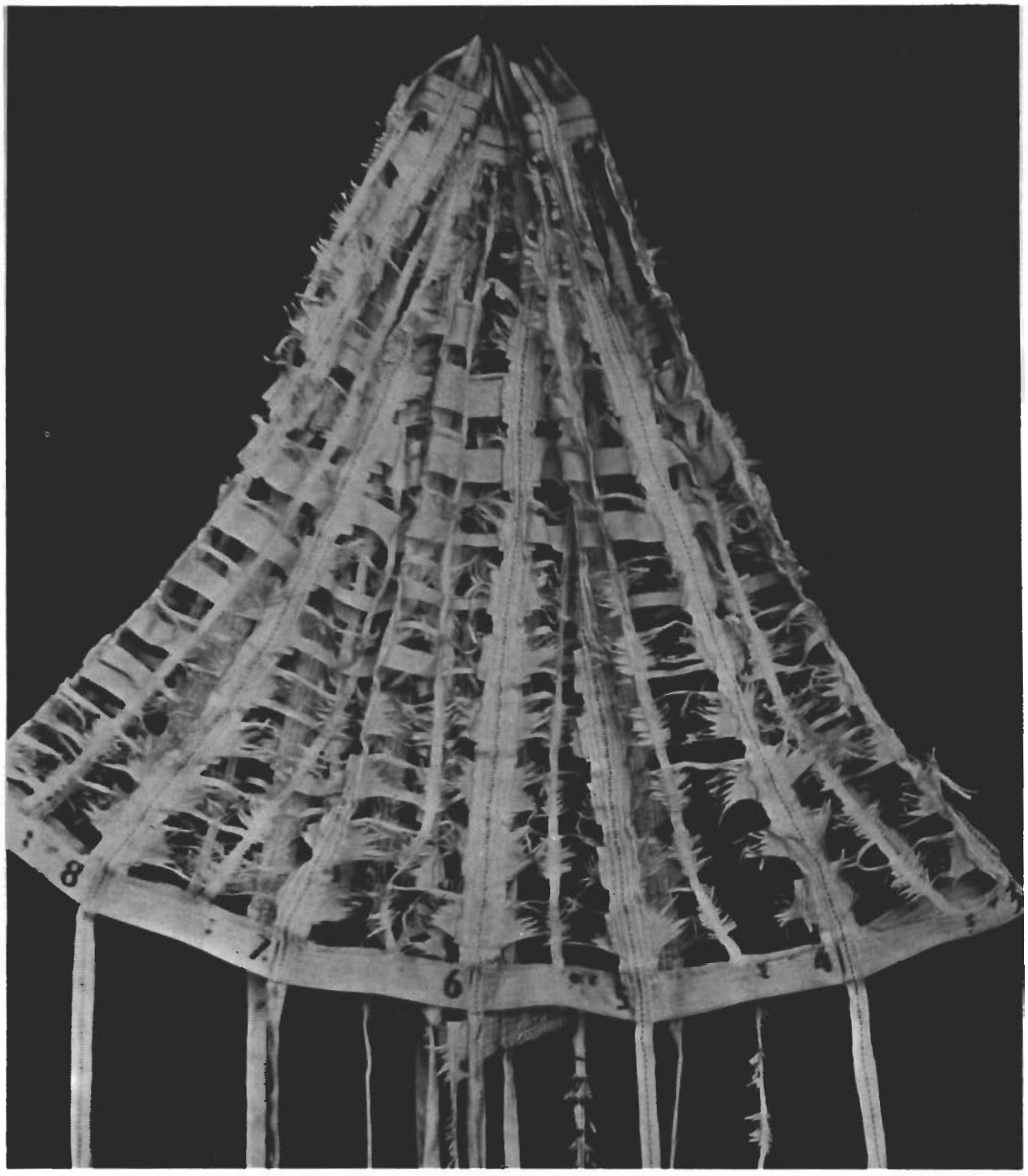

Figure 2.

USES FOR FIBROUS MATERIALS

DECELERATORS

- Aero Space Vehicles
  - Instrumentation Recovery
  - Terminus Approach Control
  - Reentry Of Space Vehicles
  - Capsular Delivery

INSULATION MATERIALS

- Electro Magnetic Radiation Ranges
  - Mechanical-Shock, Vibration
  - Accoustical
  - Thermal

RIGID STRUCTURES

- Composites
- Laminates
- Satellites

FIBER OPTICS

- Instrument Review
- Area Scanning
- Remote Photography

INFLATABLE STRUCTURES

- Energy Collectors, Reflectors And Communication } For Space Systems
- Dissipators
- Station Protection
- Satellites
- Re-entry Vehicles
- Targets

PRESSURIZED CONTAINMENT

- Fluid Storage
- Pressure Suits
- Tires

PROTECTIVE COVERING

- Hyper Environment
- Thermal Radiation
- Weathering

Figure 3.

PROPERTIES of INTEREST

- Compatibility With Associated Materials And Treatments
- Surface Characteristics
- Configuration Control
- Flexibility Or Rigidity
- Stability To Radiation
- Fatigue Resistance
- Energy Absorption
- Chemical Stability
- Heat Resistance
- Permeability
- High Strength
- Bulk

Figure 4.

TARGET REQUIREMENTS

Temperature	75%	2,000°F For Max. Of 10 Min. 1,500°F For 10-20 Min.
Vacuum And Solar Radiation	80% Strength Retention	Continous Or Intermittent Exposure Totaling 4×10^7 Langleys At Orbital Altitude
Flexibility	No Failure	Crease Flexing And Compressive Creasing In Cycles For 24 Hours
Compaction	90% Strength Retention	Packing Pressure Up To 150-250 lbs/sq. in.
Vapor Permeability	Impermeabile	Inflated With Air Or Helium In An Atmosphere Of Complete Vacuum At 1,200°F
Chemical Resistance	Inert Or Non-Corrosive	Ozone (11 P/M 100 M FT) Ionized Gases
Meteorites	No Penetration	Micro Meteorite Bombardment

Figure 5.

FILAMENT DIAMETERS REQUIRED to GIVE EQUIVALENT FLEXIBILITY AS NYLON

MATERIAL	MODULUS (p.s.i. x 10^{-6})	DIA. REQUIRED for SAME FLEXIBILITY 19μ NYLON (Microns)
NYLON	0.4	19.0
CARBON	0.7	16.8
FIBERGLASS	8.0	9.1
FUSED SILICA	10.0	8.6
COLUMBIUM	22.7	7.1
IRON, NICKEL	30.0	6.6
TUNGSTEN, MOLY.	50.0	5.8

Figure 6.

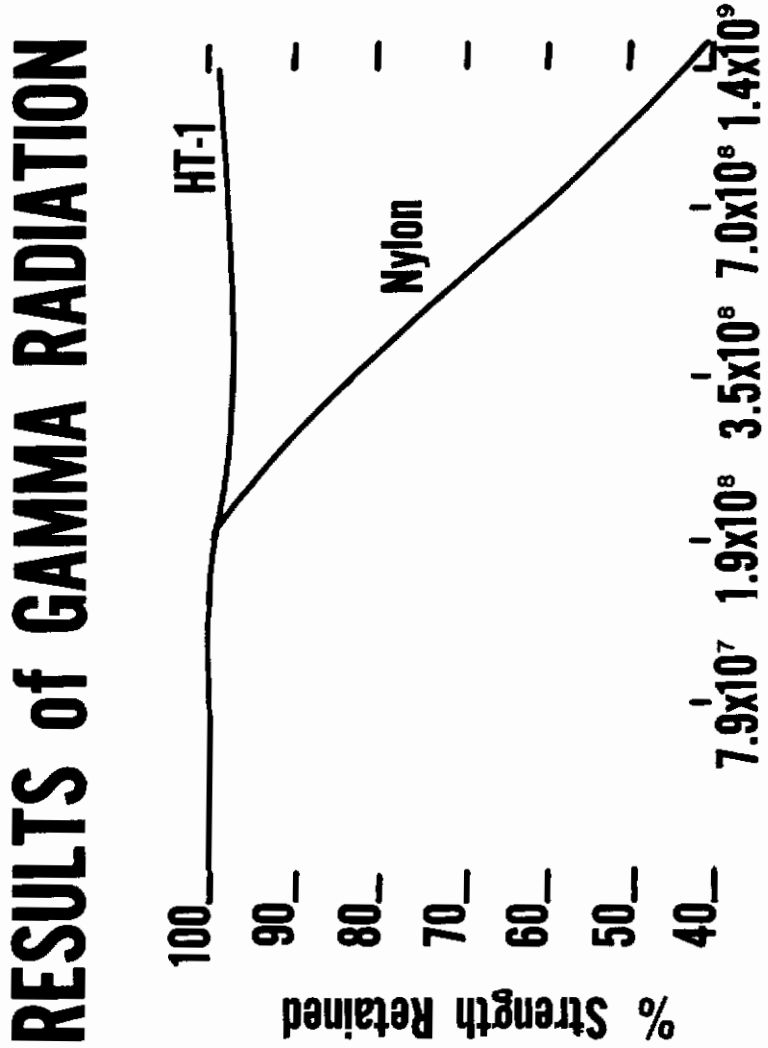

Figure 7.

TEMPERATURE RESISTANCE of HT-1 ENHANCED BY RESEARCH

	Conditions	% Of Original Strength Retained
400°F	Strength Determined While At Temperature	70.7
400°F	Sample Properly Crosslinked Using Heat & Gamma Radiation- Then Strength Determined At Temperature	98.1
400°F	Sample Properly Crosslinked. Oven Aged @ 400°F For 9 hrs. 36 min. Then Strength Determined At Temperature	96.6

Figure 8.

BREAKING STRENGTH DATA of HT-1

Conditions

Oven Aged At Indicated Temperatures For 8 Hrs.	1. Subjected Simultaneously To Gamma Radiation Plus 400°F. (Tot.Dosage-1.4×10^{9} Ergs/gm-Carbon-Hr)	2.Oven Aged At Indicated Temp. For 8 Hours.
	% Of Original Strength Retained	
400°F	96.3	96.3
500°F	85.1	89.5
600°F	58.6	78.2

Figure 9.

Tensile Strength Of Pure Molybdenum

Dia. of Wire – Mils	Tensile Strength – PSI
48 – AS DRAWN	$14.0 - 20.0 \times 10^4$
10 – AS DRAWN	$20.0 - 30.0 \times 10^4$
48 – ANNEALED	$10.0 - 17.0 \times 10^4$
10 – ANNEALED	$9.0 - 21.0 \times 10^4$
5 – ANNEALED	$20.0 - 26.0 \times 10^4$
2.8 – ANNEALED	$23.0 - 27.0 \times 10^4$
1.2 – ANNEALED	$27.0 - 32.0 \times 10^4$

Figure 10.

STRENGTH VALUES of ALLOYS at ELEVATED TEMPERATURES

ALLOY	SHORT TIME TENSILE STRENGTH (10^3 p.s.i) 1,000°F	1,500°F	2,000°F
STAINLESS STEEL			
310	67	42 (1400)	11
321	61	28 (1400)	5
COBALT BASE			
L-605	100	45	—
N-155	90	58 (1400)	—
NICKEL BASE			
HASTALLOY X	94	63 (1400)	21
RENE'41	180	110	40

Figure 11.

Effect of Wire Diameter On Tensile Strength & Elongation

Dia. of Wire – Mils	Tensile Strength – PSI	Elongation – %
10	18×10^4	33
8	20×10^4	27
5	21.4×10^4	24
4	21.6×10^4	24
3	22.8×10^4	19
1.5	25.6×10^4	16
0.5	28.6×10^4	17

Figure 12.

NOMINAL COMPOSITION of ALLOY WIRES

	WEIGHT %	
	RENE'41	ELGILOY
Nickel	55.31 (Bal.)	15.0
Cobalt	11.0	40.0
Chromium	19.0	20.0
Molybdenum	10.0	7.0
Iron	--	15.81 (Bal.)
Titanium	3.1	--
Manganese	--	2.0
Aluminum	1.5	--
Beryllium	--	0.04
Carbon	0.09	0.15
Specific Gravity, gm./cu. cm.	8.25	8.3

Figure 13.

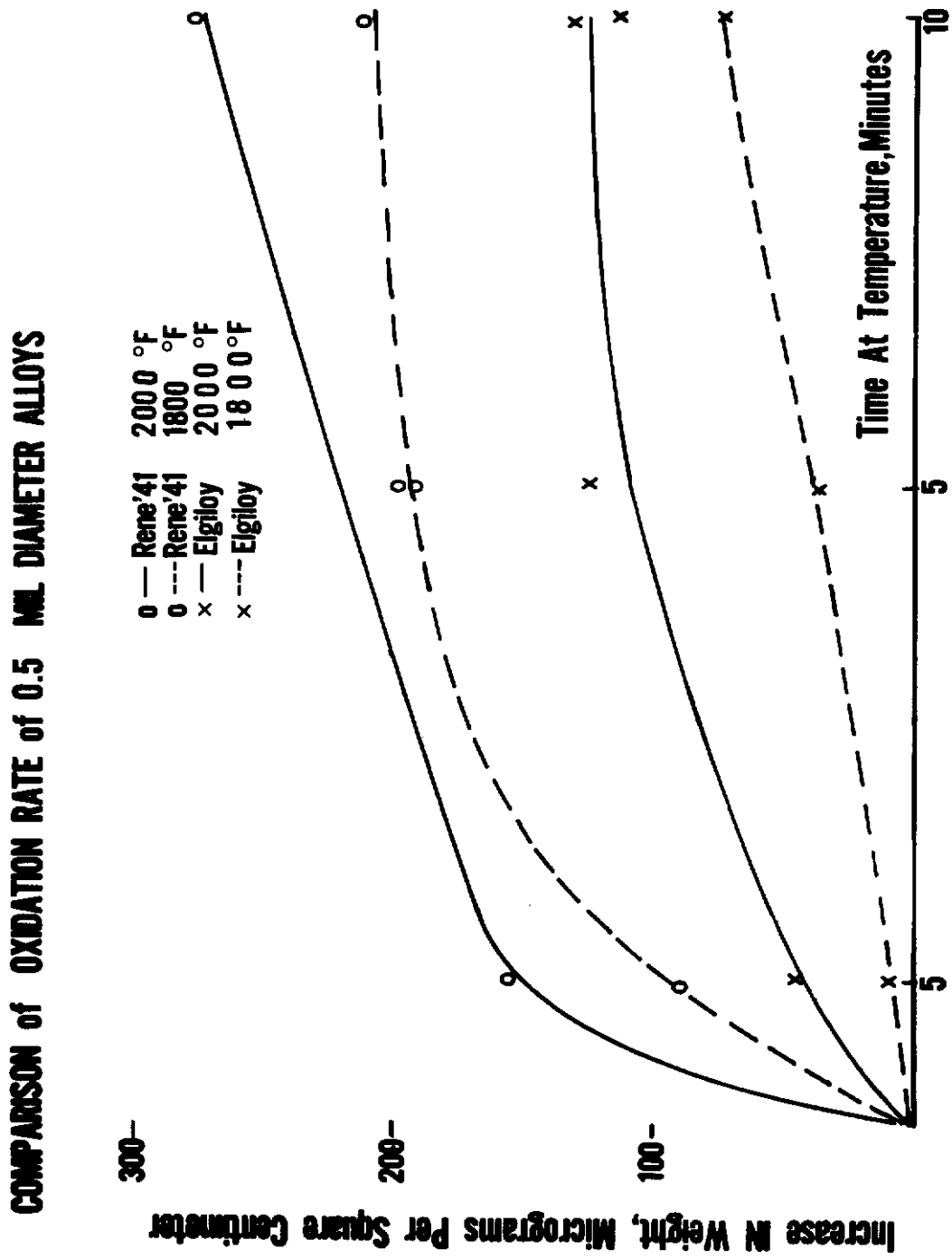

Figure 14.

COMPARISON of STRENGTH of TWO ALLOYS AFTER HEATING IN STAGNANT AIR 1 MIL FIBERS

TEMP. TO WHICH FIBERS WERE EXPOSED °F	HEATING TIME MINUTES 1		5		10	
	Elgiloy	Rene'41	Elgiloy	Rene'41	Elgiloy	Rene'41
	ULTIMATE TENSILE STRENGTH p.s.i × 10					
NOT HEATED	200	169	200	169	200	169
1500	194	203	179	207	169	200
1800	155	146	118	114	85	66
2000	113	130	87	Too Brittle	77	Too Brittle
	ELONGATION %					
NOT HEATED	28	23	28	23	28	23
1500	21	13	13	13	7	8
1800	6	6	3	1	< 2	1
2000	6	3	5	0	3	0

Figure 15.

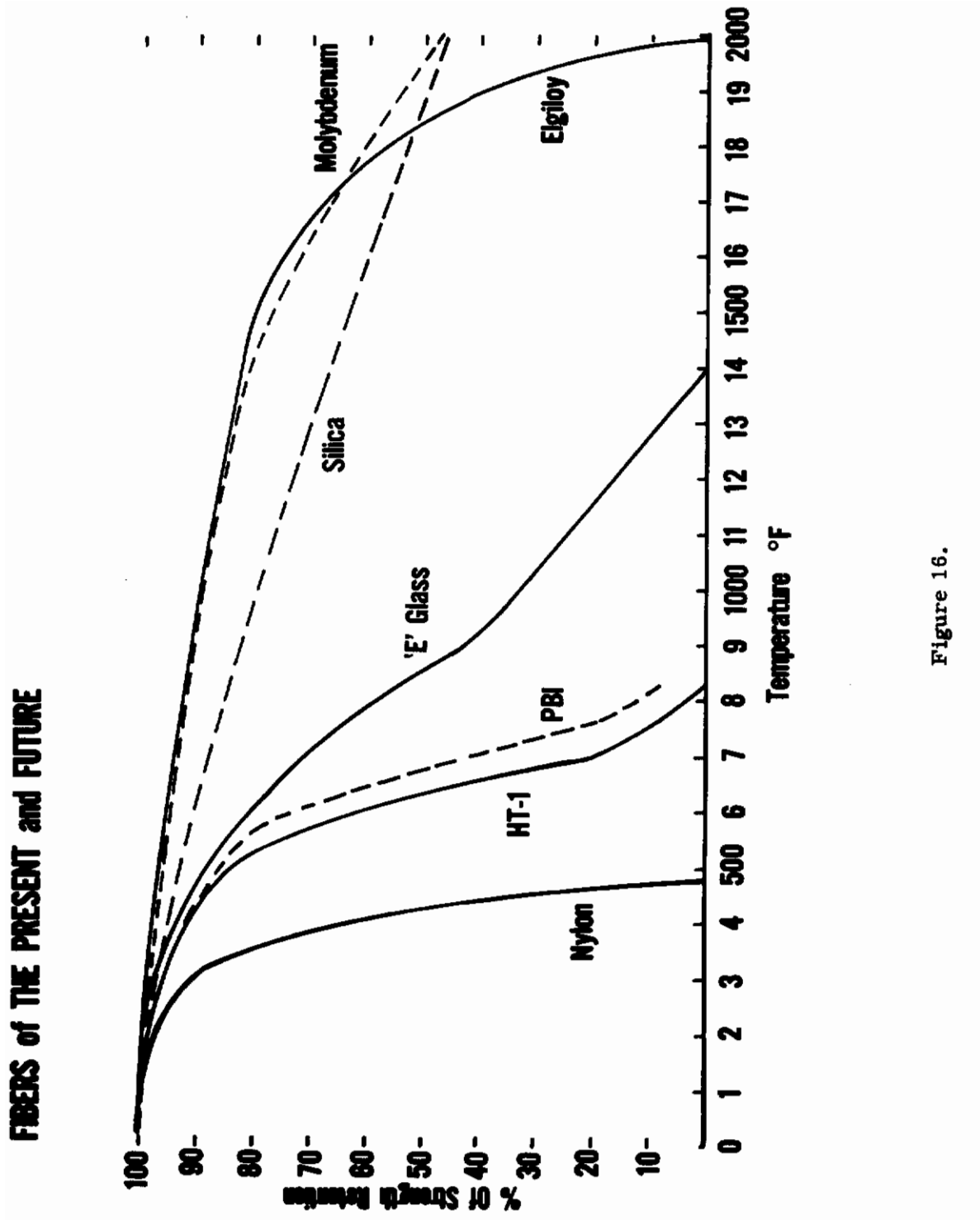

Figure 16.

ONE-WAY STRETCH MATERIAL WITH RESTRAINING CORD

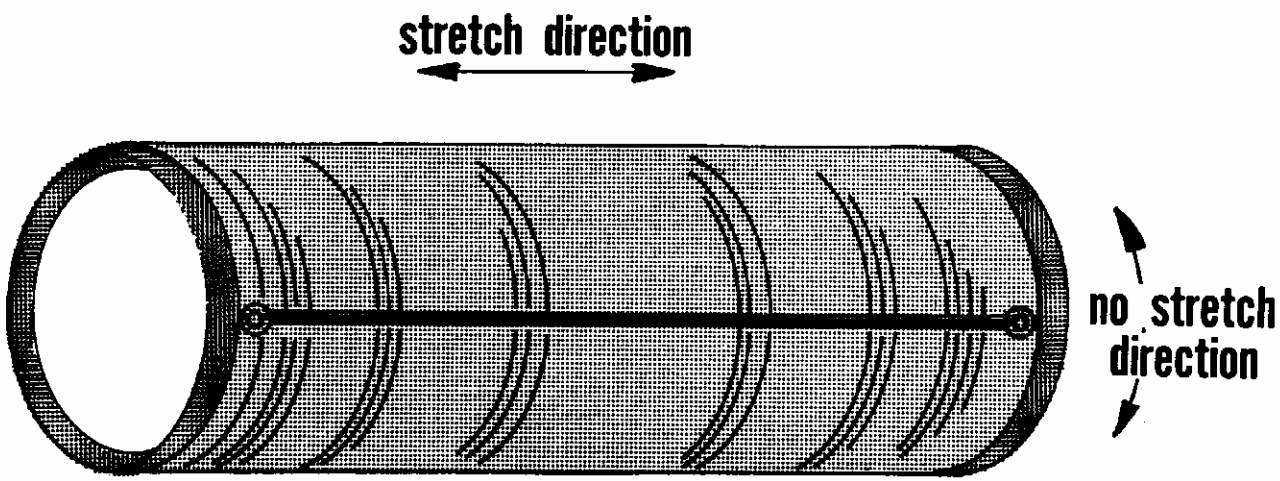

Figure 17.

NET TYPE STRUCTURE USED IN PRESSURIZED JOINT

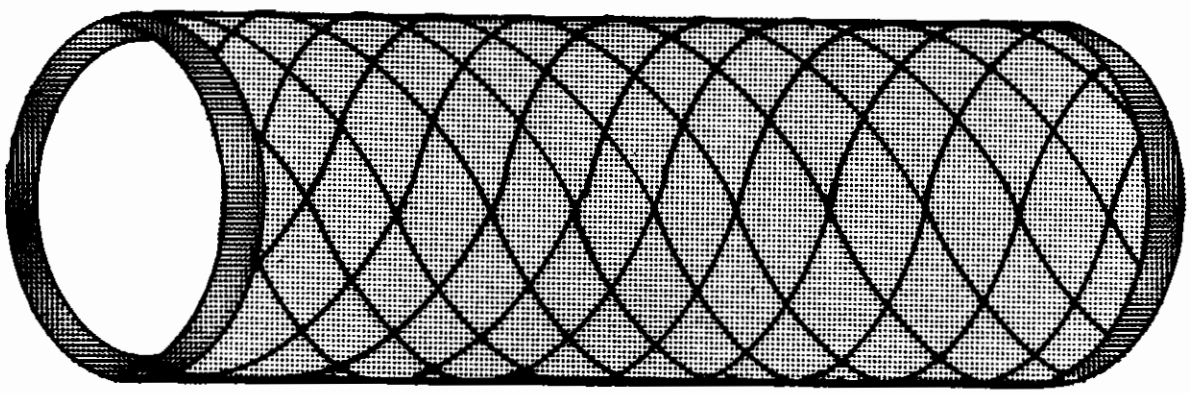

Figure 18.