WADC TECHNICAL REPORT 54-68

DEVELOPMENT OF AN IMPROVED IN-FLIGHT REFUELING HOSE

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Materials Laboratory
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Wright Air Development Center
Air Research and Development Command
United States Air Force
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FOREWORD

This report was prepared by the United States Rubber Company, under USAF Contract No. AF 33(616)-386. This contract was initiated under Research and Development Order No. 426-266, "Development of an Improved Aircraft In-Flight Refueling Hose", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. C. E. Jaynes acting as project engineer.

ABSTRACT

A laboratory study was made to determine what type of plastic material would be suitable as a seamless tube for Aircraft In-flight Refueling Hose.

Of the various materials evaluated, FM-6901 type Nylon was chosen as the most suitable. A sample length of hose was manufactured using this material as an inner liner. The hose carcass used is identical to that now being furnished by the United States Rubber Company in 2-1/4" Mil-H-4495-A (ASG), Rubber, In-flight Refueling Hose which this company is qualified to manufacture. A nylon tube was extruded and incorporated into the carcass using special techniques developed for this purpose.

The resultant hose sample was subjected to the low temperature test required by the contract and failed to meet requirements. The nylon liner cracked during bending.

It is concluded from this work that even though Nylon FM-6901 in strip specimens is flexible at -65°F it is unsatisfactory at this temperature when used in a hose.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Directorate of Research

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OBJECT

The object of this contract was to develop an Aircraft In-Flight Refueling Hose with a seamless nylon or similar plastic inner tube, for improved low temperature performance. The detailed requirements for this hose are as follows:

Detailed Requirements

A. Construction. The hose shall consist of a seamless nylon type FM6901, or similar plastic inner tube, a jacket consisting of a carcass of cotton yarns interwoven with helixes of round wire or wires and filler of cotton yarn alternately spaced, and a cover of a synthetic rubber oil resistant material with a mildew inhibitor.

B. Cotton Jacket. The jacket shall be interwoven from a good grade of cotton. It shall be even and firm in texture throughout and as free from all injuries or unsightly defects as is consistent with best manufacturing practices. It shall cover the helical wire uniformly and tightly.

C. Wire Reinforcement. The helix or helixes shall be of round steel galvanized wire having a tensile strength of not less than 180,000 lbs./square inch (Rockwell C. Hardness 40) with an ultimate elongation not greater than 4 percent. There shall be 4 turns of wire per inch of hose; the cross section of the wire shall be .080 inch plus or minus .005 inch.

D. Size. The outside diameter of the hose shall be 2-3/4" plus or minus 1/16".

E. Length. The length of the hose shall be 10 feet.

F. Weight. The weight of the hose shall not exceed 1.5 pounds per foot.

G. Adhesion. The adhesion between the tube and carcass shall be such that the rate of separation of a 1" width specimen shall not exceed 2" per minute under a load of 6 pounds.

H. The physical properties of the tube shall be as follows:

1. Original tensile strength, p.s.i., 1250 min.
2. After aging in Mil-H-3136 Type III Fuel for 70 plus or minus 1 hour at 75 plus or minus 5°F.:

Tensile Strength, Change, %,	plus or minus 25 maximum
Elongation Change, %	plus or minus 25 maximum
Volume Change, %	plus or minus 35 maximum

I. Low Temperature Flexibility. A five foot length of hose bent into a "U" shape so that the ends of the "U" are approximately 22" apart and cooled at minus 65°F. for 70 plus or minus 2 hours shall not require a force greater than 50 pounds to straighten to an approximately 90 degree angle within one minute. The hose shall not break nor show signs of cracking during such opening or further straightening.

J. Bending. The hose must be able to be wound on a 16" drum at -70 plus or minus 5°F. without deformation of the cross section.

K. Crush Resistance. The outside diameter of the hose shall not be compressed more than 25% when subjected to a weight of 1000 pounds distributed evenly over a one foot longitudinal section.

L. Pull Resistance. The hose shall not break nor lose its couplings when subjected to pull of 4000 pounds directed along the longitudinal axis.

M. Proof pressure. The hose shall not leak at a proof pressure of 200 pounds per square inch.

N. Concentricity Test. A 2.15 inch diameter ball shall pass freely through the hose while subjected to a vacuum of 20" of mercury.

INTRODUCTION

The work done can be divided into two categories, the laboratory evaluation of the various plastic materials which were chosen as having possible suitability for this application and the final fabrication of a hose sample utilizing this material as a liner. Since this company has developed in the past a hose carcass which meets the fundamental requirements of specification Mil-H-4495 (ASG) no work was done on this element of the hose.

PART I

LABORATORY INVESTIGATION

The following materials were selected as possibilities and investigated.

Teflon	Polyethylene
Kel-F	Nylon

Literature research and discussions with suppliers indicated that of these materials only the nylon might be suitable. The reasons for the unsuitability of the other materials are outlined as follows:

Teflon - Although Teflon has exceptional resistance to all chemicals and solvents, a property which would make it desirable as a hose liner, the inability to fabricate with this material using conventional equipment eliminated all possibility of using it for this application. The high temperature (620°F. ≠) which would be required to bond this material to the carcass is greatly in excess of what the cotton carcass will stand without damage. This material is also quite rigid at room temperature and would be extremely stiff at -65°F. although it may not be brittle.

Kel-F - The objections to this plastic are the same as those for Teflon. Although the molding temperature is much lower, 450°F., this is still in excess of what can be tolerated in bonding to the carcass. In addition, Kel-F is more rigid than Teflon at room temperature and would be entirely too stiff at -65°F.

Polyethylene - Although the chemical and fabricating properties of polyethylene are satisfactory, low temperature flexibility is not. Samples of polyethylene were flex tested at -65°F. and found to be brittle.

Nylon - The du Pont Company recommended the following types of nylon as having the most desirable properties for this application:

FM-2081	FM-7001
FM-3001	FM-8001
FM-6503	FM-10001
FM-6901	

The published physical test data on these nylon compounds indicated that anyone of them would make a superior hose tube providing that it met the freeze flexibility requirements. Tests were run in accordance with paragraphs H and I of the detailed requirements to determine the effect of low temperature on these compounds. These tests (Paragraph I) were made on nylon samples 1" wide x 6" long by approximately .075" thick. The samples were soaked in the freeze box for 72 hours at -65°F. and then bent at a 90° angle. Those samples which did not fail after the first flex were flexed an additional 25 times to determine if cracking would occur after repeated bending. The physical properties of the nylon types evaluated, including the fuel resistance and low temperature flexibility, are shown in Table A, page 5.

AIRCRAFT IN-FLIGHT REFUELING HOSE

TABLE A

Type Nylon	Low Temp. Flexibility 72 Hours @ -65°F.	Original Tensile (PSI)	Elongation %	After Aging 72 Hrs. in Mil-M-3136 Type III Fuel: Tensile (PSI)	After Aging 72 Hrs. in Mil-M-3136 Type III Fuel: Elongation %	Increase in Weight and Volume after 72 Hrs. in Mil-H-3136 Type III Fuel: Weight %	Increase in Weight and Volume after 72 Hrs. in Mil-H-3136 Type III Fuel: Volume %
FM-2081	Brittle	7425	118	7400	113	.43	.58
FM-3001	Brittle	6470	6	7170	55	—	—
FM-6503	O.K.*	4640	225	5325	210	1.1	.87
FM-6901	O.K.	5575	250	5050	247	—	.83
FM-7001	Brittle	5675	143	7900	322	.49	.16
FM-8001	Brittle	6200	425	6075	460	1.8	1.3
FM-10001	Brittle	9325	37	9100	39	—	.35

* The FM-6503 sample necked down considerably after 25 flexes at -65°F. while this condition was hardly noticeable on the FM-6901. On this basis the FM-6901 was chosen as the more suitable compound.

Note: 1. Tests have been performed by ASTM Methods. Data shown are average values, and were determined on molded slabs which are subject to variation, depending upon molding conditions.

2. Fuel had no visual effect on samples.

CONCLUSIONS

All the nylon samples met the Fuel test requirements showing excellent resistance to Mil-H-3136 Type III Fuel. However, only two types of nylon FM-6503 and FM-6901, were flexible at -65°F. Of these two, the FM-6901, was the most flexible. On repeated flexing the FM-6503 tended to thin out at the flex point to approximately 1/2 its original gauge whereas this condition was barely noticeable on the FM-6901. The latter was selected for the final hose sample.

PART II

FABRICATION OF SAMPLE

Extrusion of Tube

The extrusion of nylon is more difficult than most plastics because of its sharp melting point. As the nylon leaves the extrusion die it is very fluid, making it difficult to handle the material without distortion. This is particularly true with large diameter thin wall tubes.

Several attempts to extrude a satisfactory tube of FM-6901 nylon were made. Of the techniques tried, the most successful is outlined below:

1. Temperatures:

Die	340°F.
Barrel (Front)	320°F.
Barrel (Rear)	280°F.

2. Air (Inflation of Tube)

   Air under a constant pressure 1.5 p.s.i. was introduced into the tubing through the die to prevent the tube from collapsing while it is still hot.

3. Cooling

   The cooling device consisted of a portable air conditioning unit attached to two tubes, one within the other, the inner tube being perforated with 1" diameter holes. The cold air was directed around the extrusion by the outer tube and contacted the surface of the extrusion through the perforated sleeve or baffle. The entire device covered the extrusion over a 10 ft. length. This method proved very satisfactory and it was possible to maintain quite accurate dimensions. Preliminary trials with a direct water spray and air streams were not satisfactory as they tended to ripple the surface of the tube.

Using this extrusion set up, FM-6901 nylon tube samples were produced in the gauges shown.

#1	.035 - .040"
#2	.055 - .065"
#3	.045 - .063"

The #3 tube was discarded because there was considerable variation in wall thickness. Both #1 and #2 tubes were used in hose samples.

Efforts were made to produce thinner wall tubes but these were not successful because the flow of the nylon could not be controlled well enough to obtain uniform wall gauge. A gauge of .035 - .040" was the thinnest wall that could be obtained using this particular set up.

It was concluded after these trial runs that the extrusion of a nylon tube having a wall gauge of .035" or heavier is entirely feasible, even in long lengths. Using a suitable take-away table it should be possible to extrude the nylon tube in 103 ft. lengths holding a tolerance of ± 1/16" I.D. and ± .005" on the wall thickness.

Hose Construction

In the fabrication of hose samples the standard U. S. Rubber Company Flight Refueling Hose carcass was used with exception to the tube liner. This construction is included in the Appendix on page 19.

This hose carcass is woven on a standard Chernak vertical loom having room for 144 warp yarn ends. In manufacturing conventional woven hose, the tube is pulled into the carcass after the latter is woven. It is necessary to semi-cure the tube in order to perform this operation without distorting same. A raw layer is jacketed over the tube prior to its insertion in the carcass so that a good bond will be effected between the two elements. In the case of nylon a similar operation was used except that no bonding layer was necessary for adhesion.

The conventional steam cure was found unsatisfactory and it was necessary to experiment with several other methods in order to make a sample length of hose. The results obtained using the steam cure and various other methods are outlined below:

1. Steam Cure

   This operation consists of injecting steam into the carcass containing the nylon tube. Both ends of the hose were attached to special cone shaped clamps to seal them. The clamp on one end of the hose was attached to a steam line while the clamp on the other end was provided with a valve to bleed off the condensate. Trials using this method did not give satisfactory results. The thin nylon tube (.035" to .040" wall gauge) tended to soften too rapidly causing blow outs or too much flow into the carcass. Varying the rate at which the steam pressure was applied did not rectify this condition. The heavier tube (.055" to .065" wall gauge) did not flow uniformly tending to blow thin in some spots and remain heavy in others. Further work with this method of bonding the tube was discontinued.

2. Dry Heat

An attempt was made to bond the tube by merely placing the hose in a hot air oven. This was entirely unsatisfactory as the tube immediately collapsed and fused together.

3. Heater Cylinder

After the failure of the first two methods, it was realized that a special curing device would be necessary. Such a device was designed and built. A drawing of the heater cylinder, Figure 1, and special end plugs, Figure 2, are included at the end of this report. This curing device consists of two steel tubes, one inside the other, both ends of which are capped. Steam is circulated in the annular space between the two tubes creating a hot air chamber around the inner steel tube. The hose sample was placed in the heated tube after both ends were coupled with special steel end plugs. Air was supplied through one of the end plugs to prevent tube collapse and obtain flow into the carcass. Figure 3, page 14, shows the heater cylinder arrangement and Figure 4 on page 15 shows one of the end plugs attached to the hose.

The pressure necessary to effect a bond without excessive flow or distortion was determined to be approximately 4 p.s.i. A steam pressure of 115 p.s.i. was required in the pipe jacket to sufficiently soften the nylon so that flow would take place (347°F.). A total cycle of 20 minutes was required for the entire curing operation. Ten minutes of heat followed by ten minutes of cooling at room temperature prior to removal of the end plugs was sufficient to process the nylon.

Using this equipment, satisfactory samples of hose using the two gauges of nylon tube were fabricated. These samples were identified as:

XH-F.R. #1 (.035" - .040" gauge tube)

XH-F.R. #2 (.055" - .065" gauge tube)

Lengths of each construction were forwarded to WPAFB for testing. Additional lengths were retained for our own evaluation.

TEST RESULTS

Preliminary examination of the two samples revealed that the sample with the heavier nylon tube (XH-FR #2) was much stiffer than the thin tube sample (XH-FR #1). Tests run at room temperature indicated that the XH-FR #1 sample could be bent around a 24" diameter sleeve with a force similar to the conventional Buna-N tube hose whereas the XH-FR #2 was limited to 35"-40" diameter bend with much greater bending force necessary.

The low temperature flexibility test in accordance with paragraph I of the detailed requirements was conducted on XH-FR #1 sample. A five foot length of hose was bent into a "U" shape so that the ends of the "U" were approximately 22" apart and cooled at -65°F. for 70 ± 2 hours. At the end of the cold soak period an attempt to straighten the hose to a 90° angle was made. Fifty-five to eighty-three pounds force was necessary to straighten the sample. As the hose was straightened (See Figure 5 page 16) a crack occurred in the tube. The point of fracture can be seen in Figure 5 just above the tester's hand. Figures 6 and 7 on pages 17 and 18 show how the cracking occurred in the nylon tube.

In addition to conducting the low temperature flexibility test on the hose sample, 1" wide tube strips taken from both XH-FR #1 and XH-FR #2 were freeze flexed in accordance with ASTM D-736-43-T. Neither of these samples failed, confirming the original tests conducted on FM-6901 slab stock.

A sample of the X.H.-FR-#2 hose was tested for low temperature flexibility to determine if the thicker nylon tube would have a greater resistance to cracking. The same cracks developed in this sample as the X.H.-FR-#1 hose sample. The force necessary to bend this sample was 95-100 pounds.

Since both samples failed at -65°F., flexibility tests were conducted at various temperatures to determine what the limiting cold temperature is for this hose. Results indicated that the nylon tube starts failing at approximately -10°F. The bending force at this temperature is in the order of 25 pounds.

Tests run by the Materials Laboratory at WPAFB verified the above results. Both hose samples cracked at -65°F. On the basis of these failures no attempt was made to produce the 110 ft. flight test length and further testing of the samples was discontinued.

CONCLUSIONS

Although FM-6901 nylon appeared satisfactory for -65°F. service when tested as a strip sample, it was found to be too brittle at -65°F. when incorporated in the hose as a liner. The limiting temperature for FM-6901 nylon in a woven hose carcass was found to be approximately -10°F.

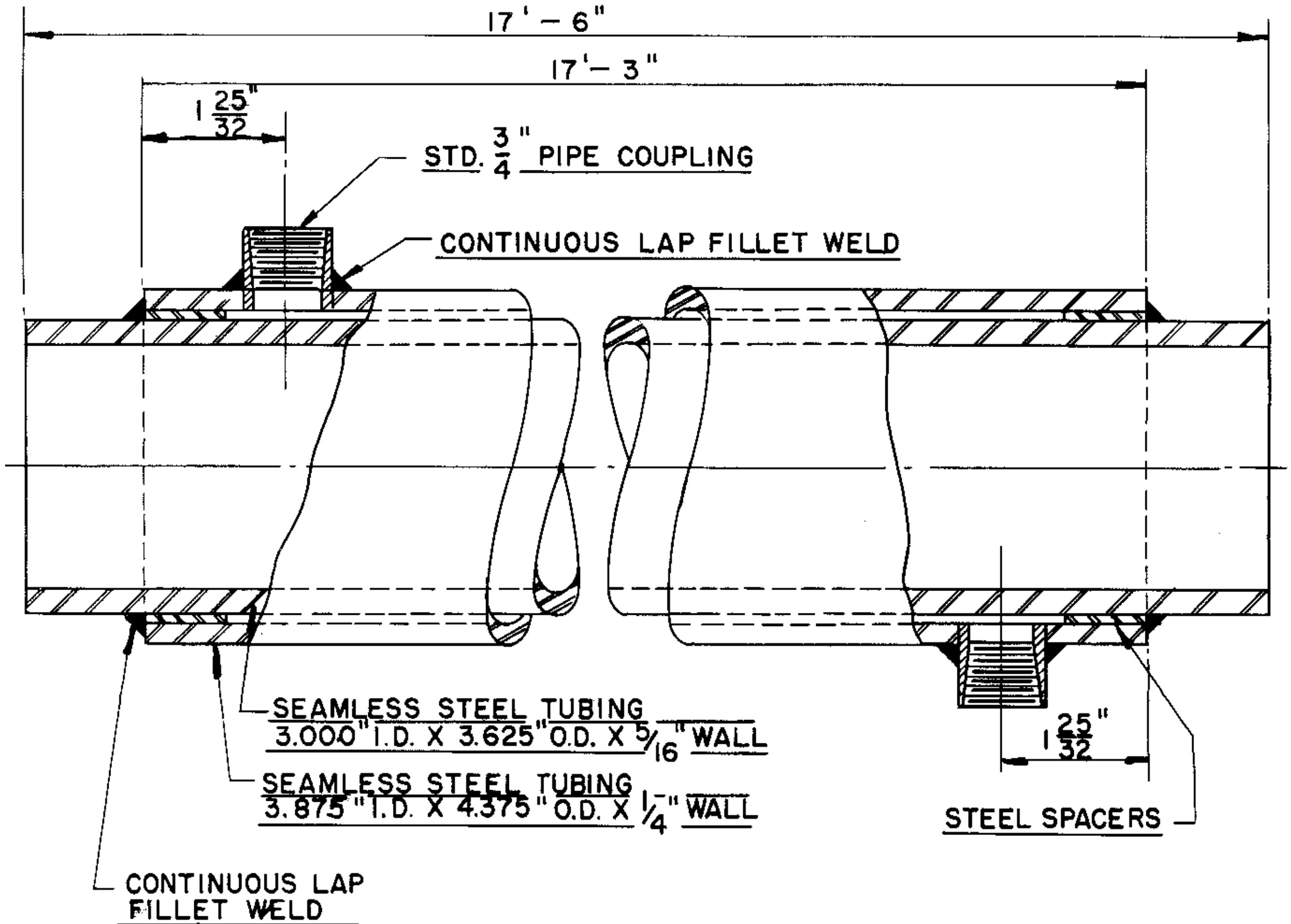
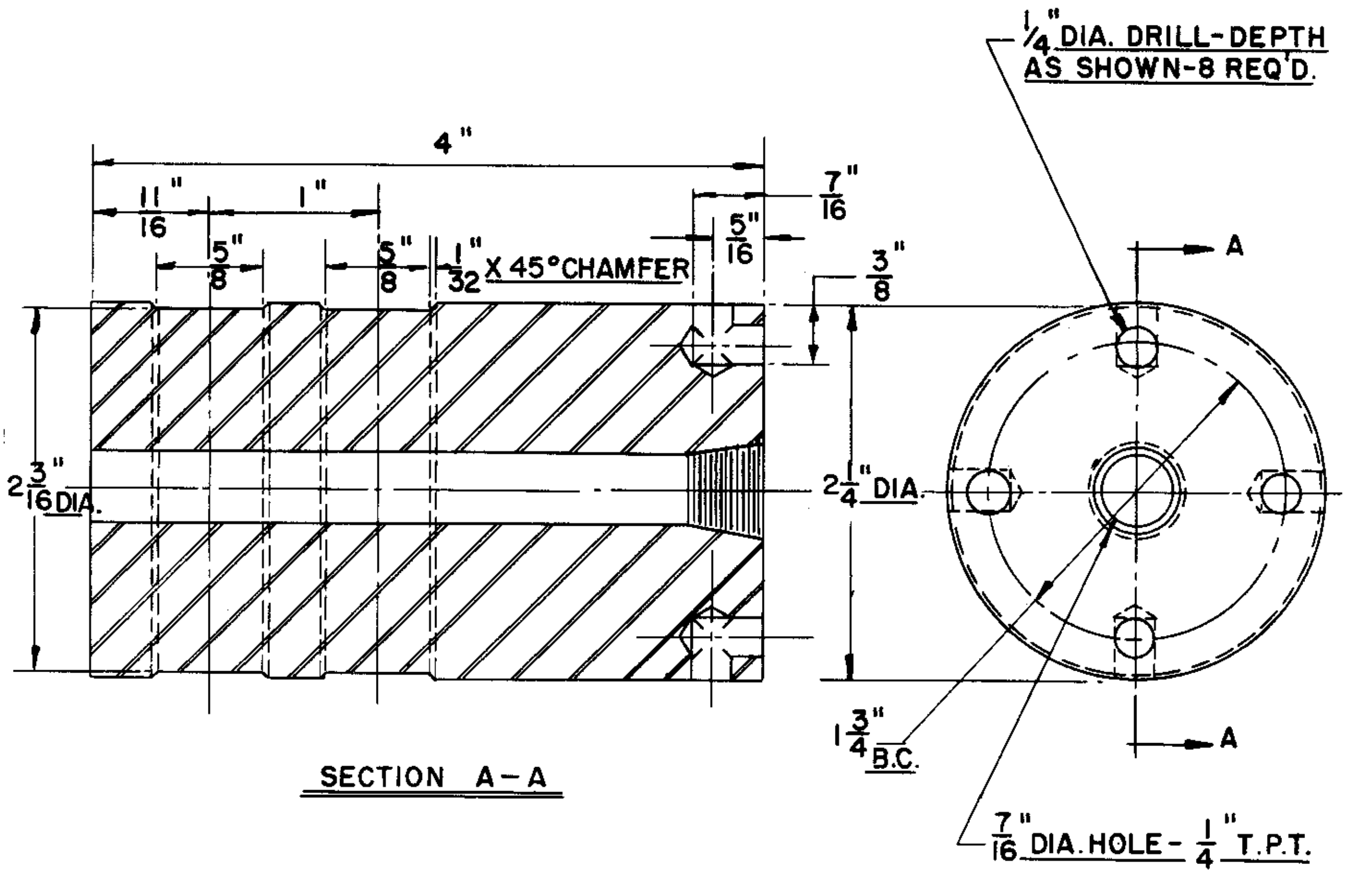


FIG. 1 HEATER CYLINDER
INFLIGHT REFUELING HOSE
DEV. CONTRACT NO. AF 33(616)386



NOTE:
MAT'L - STEEL

FIG. 2 END PLUGS
IN-FLIGHT REFUELING HOSE
DEV-CONTRACT NO. 33(616)386

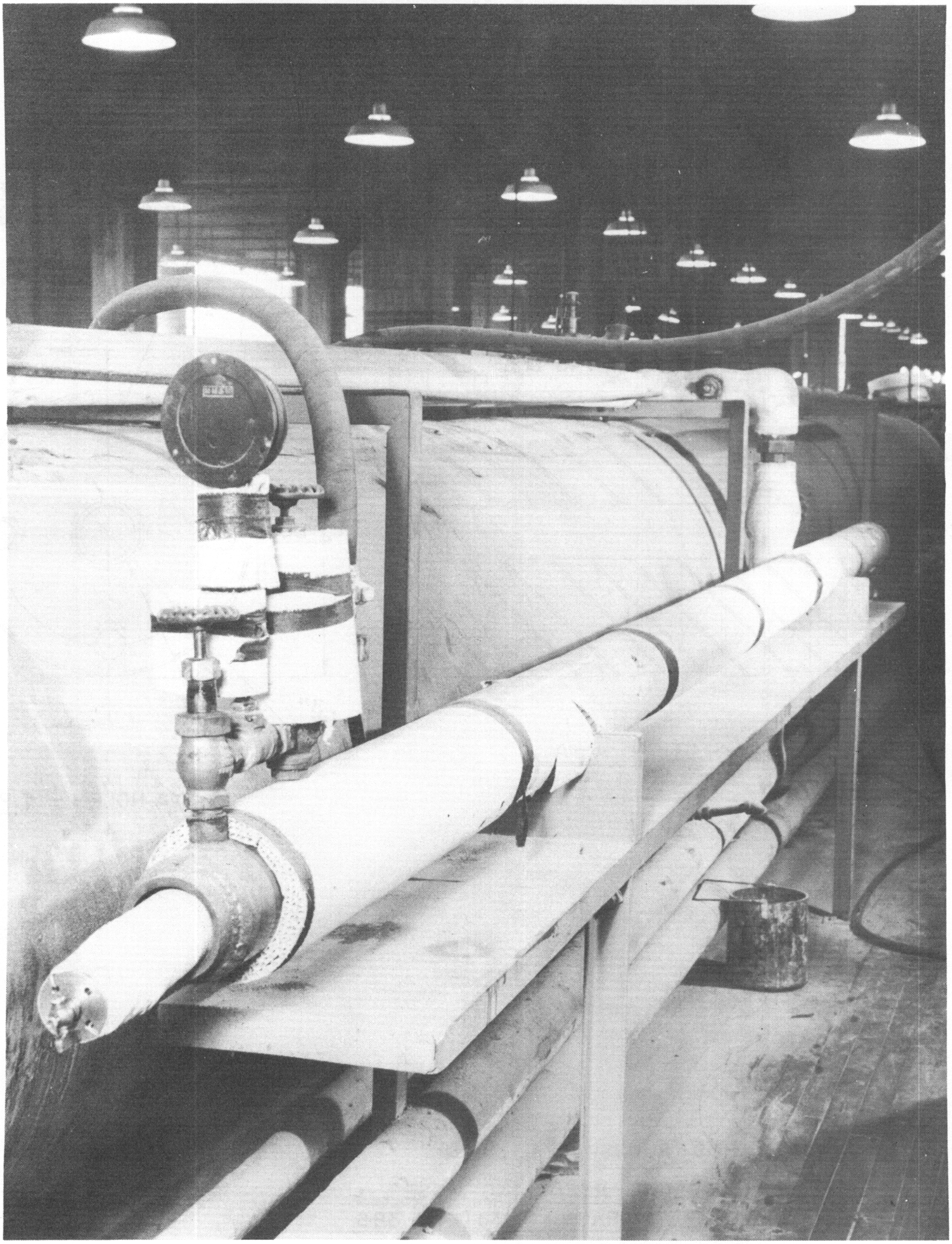


Figure 3 - Heater Cylinder

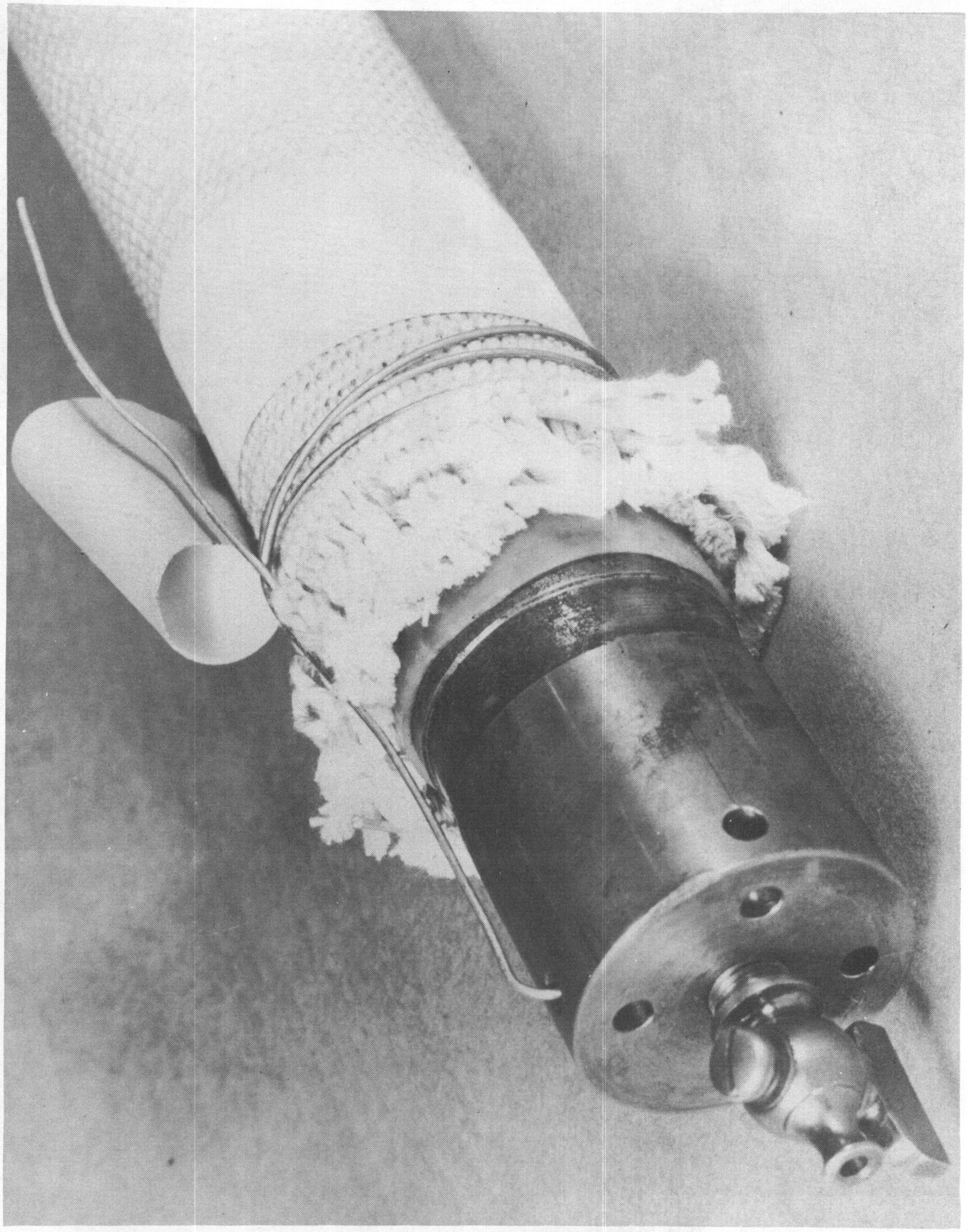


Figure 4 - Hose End Plug

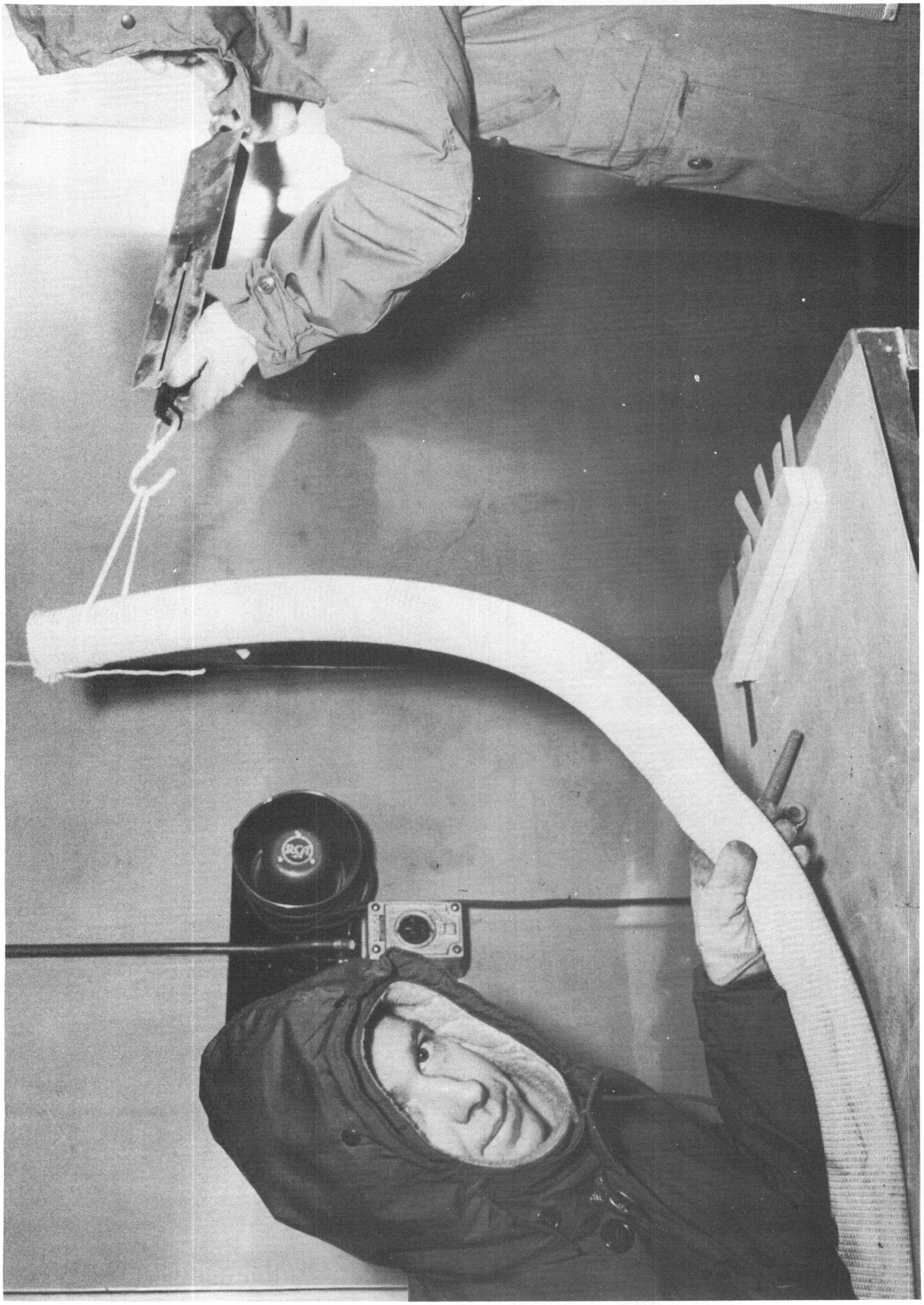


Figure 5 - Low Temperature Flex Test

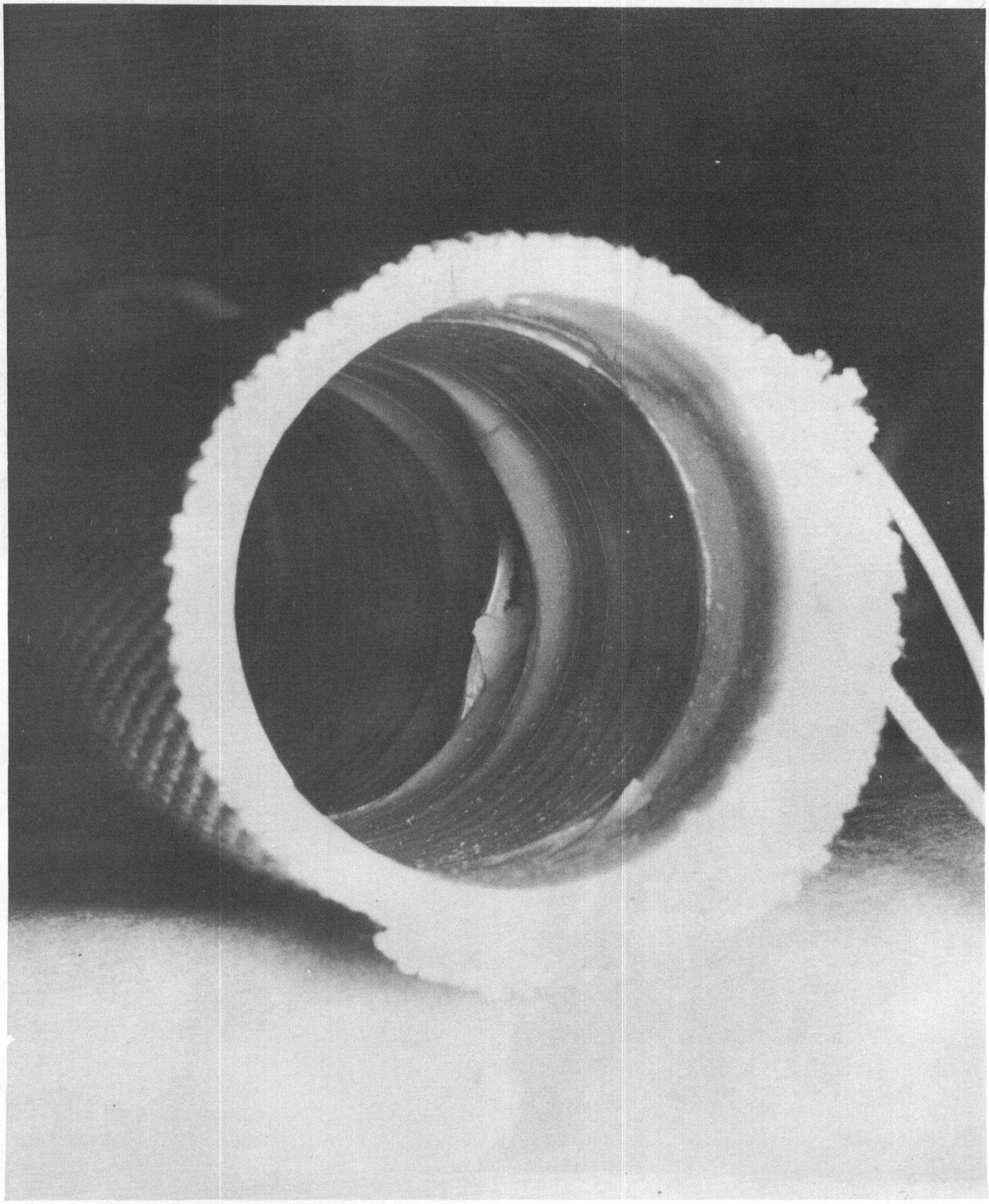


Figure 6 - Nylon Tube - Freeze
Flex Failure

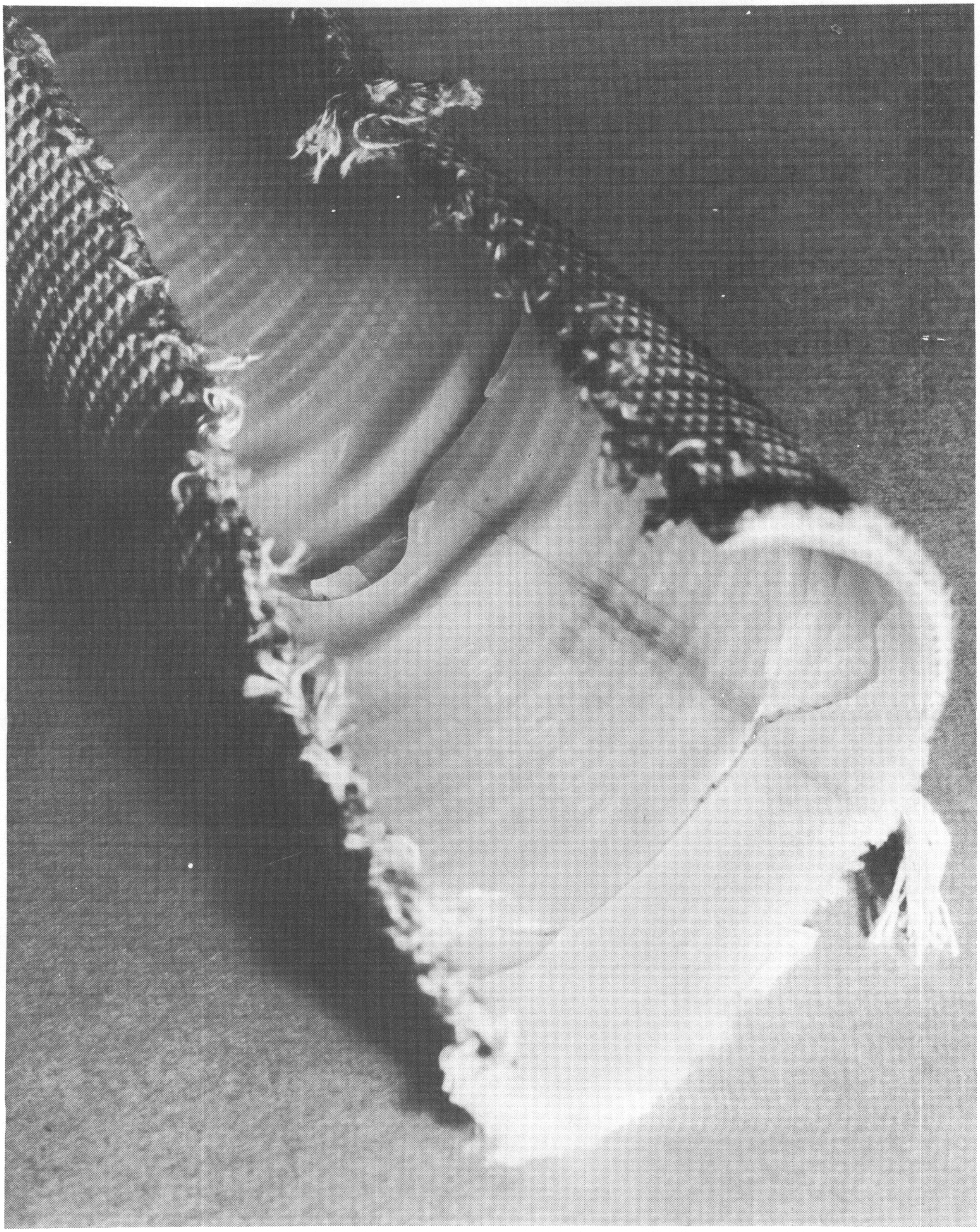


Figure 7 - Sectional View of
Cracked Nylon Tube

APPENDIX

Yarns, Wire

A. YARNS

Specification No.	820RB	P-2568-F
Construction	8/20	8/26 ply (fill)
Kind of Cotton	Ustex Hydentex	Carded American
Tensile Strength	88 lbs.	73 lbs.
Yards per Pound	336	251
Gauge	.050"	.067"
2nd Twist	1.2	1.7

B. WIRE

Specification No.	4
Code No.	H-1-T
Type of Wire	Hard #1 Temper
Finish	Galvanized
Shape	Round
Size	#14 (.080" gauge)
Tensile	180,000 lbs. minimum
Elongation in 10"	4% maximum
Dimension Tolerance	± 2%

C. CARCASS

2-1/4" I.D. x 2-3/4" O.D. ± 1/16" x 100'

Tube: Nylon FM-6901

Weaving Specification:

Warp

Pin	Warp Ends	Yarn Specification
2-29/64"	144	8/20 Ustex Hydentex Cotton

Fill

Yarn Specification	Wire	Gauge	Picks/4"
8/26 Cotton	#14 Galvanized	.080"	32

Weights

Warp Yarn 100 ft.	18.7#
Fill Wire/100 ft.	67.8
Fill Yarn/100 ft.	4.6
Total weight of carcass of .911#/ft.	91.1#