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Non-Metallic Antenna-Support Materials

Second Annual Interim Report

Nixon Halsey, Donald E. Marlowe and Leonard Mordfin

Engineering Mechanics Section
Mechanics Division
Institute for Basic Standards
National Bureau of Standards
Washington, D. C. 20234

June 1974

Interim Report for Period October 16, 1972 - October 15, 1973

Prepared for
Air Force Materials Laboratory
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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by

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ABSTRACT

Thirteen samples of a pultruded, glass fiber-reinforced-polyester rod material were manufactured using a different combination of the manufacturing process parameters for each. These samples were tested to evaluate the effects of nine different process parameters on the properties and characteristics of the rods. Elevated-temperature stress-rupture tests under saturated humidity were used as an accelerated measure of long-term weatherability. The test results were somewhat inconsistent, but it appears that certain process parameters, such as collimation and ultrasonic agitation of the rovings during pultrusion, were beneficial to both tensile strength and weatherability. Other parameters, such as pretensioning of the rovings, were beneficial to weatherability but detrimental to tensile strength. Additives to the resin system were generally detrimental.

A high speed tension test method was developed and it was found that the strength of the rod is substantially greater under high loading rates.

An approximate relationship was observed between transverse tensile strength and electrical breakdown voltage. However, neither of these characteristics, nor surface hardness, correlated with axial tensile strength or weatherability.

Key Words: Composite materials; fiber-reinforced-plastic rod; glass-reinforced-polyester rod; guys, antenna; processing parameters, pultrusion; pultrusion; reinforced plastic rod; stress rupture of FRP rod; test methods, FRP rod; weatherability, FRP rod.

1. INTRODUCTION

Glass-reinforced-plastic rod and rope materials constitute one of the more interesting and valuable -- although lesser known -- products of composite materials technology. These products are generally fabricated from unidirectional glass fiber roving and a thermosetting plastic matrix by a process called pultrusion. They are strong, lightweight, nonconducting, corrosion resisting and comparatively inexpensive. This combination of properties has led to the use of these products in a variety of applications where steel wire rope had previously been employed almost exclusively. In terms of total volume, the largest application has been in communications towers and arrays, wherein the use of non-metallic rod and rope as guys and catenaries has permitted the elimination of the large, expensive, ceramic insulators which are required when steel wire rope is used.

As frequently happens when promising new products are developed, the rod and rope were introduced into service before they were adequately characterized and without the benefit of carefully compiled design data. The result has been the occurrence of failures in several field installations. Fortunately, most applications have performed satisfactorily. Some of the reported failures have involved arc tracking and flashover damage, and burning, in intense electromagnetic fields. However, most of the reported failures have been mechanical in nature and have occurred after a period of service, ranging from months to years, during which the materials have been under tension in a moist environment. With this as a point of departure, the National Bureau of Standards embarked upon a program to develop a new non-metallic fiber-reinforced-plastic rod or rope material which would exhibit superior mechanical properties and greater resistance to moisture in the form of a hot, humid environment. This program calls for the development to be accomplished through the selection of potential improvements in the manufacturing process, the reinforcing fibers and the matrix resin; the procurement of experimental materials, which are manufactured in accordance with these potential improvements; and the subsequent evaluation of these materials. The evaluations are based primarily upon two types of mechanical tests: tensile tests at normal and high rates of loading, and stress-rupture tests at 160 ^{o} and 200 ^{o}F under saturated humidity conditions. The results of the stress-rupture tests, when performed on a variety of materials, are considered to be indicative of the relative weatherabilities of the materials.

This program, which was initiated October 16, 1971, is being carried out in the Engineering Mechanics Section of NBS under the sponsorship and with the financial assistance of the Air Force Materials Laboratory. During the first year of activity on this program [1]

- six 30000-lbf-capacity creep testing machines were designed for the stress-rupture tests. These machines, which have since been assembled, will accommodate test specimens up to nine feet long and are equipped with environmental chambers for use to 200 ^{o}F under saturated humidity conditions.

- a study of industrial manufacturing capabilities led to the selection of pultruded, glass-reinforced-polyester rod as the basic form of material which will be upgraded in this program.

- two new end fittings for glass-reinforced-plastic rod were developed in order that the tensile strengths of these materials may be accurately determined. These new fittings have been found to perform better, in this application, than commercial end fittings.

- deficiencies in the physical characteristics of existing glass-reinforced-polyester rod materials were identified, and modifications to the manufacturing processes were proposed to overcome these deficiencies. A subcontract was let for the manufacture of experimental glass-reinforced-polyester rods using the modified processes.

The second year of activity on this program was devoted primarily to the manufacture and testing of these experimental materials, and to the interpretation of the test results. This interim report describes the progress made during the second year.

The U.S.A. is a signatory to the General Conference of Weights and Measures which gave official status to the metric SI system of units in 1960. However, for simplicity, only U.S. customary units have been used in this report. Conversion factors for these units are given in Appendix A.

2. OPTIMIZATION OF THE MANUFACTURING PROCESS, PART I

The basic features of the manufacturing process for pultruded rod have been reviewed [1]. The process is quite complex, involving many variable parameters. In this effort toward optimizing the process, a subcontract was let for the manufacture of thirteen different samples of 1/2-in diameter rod using E-glass roving and an isophthalic polyester resin matrix. (The characteristics of these two constituent materials have been given [1].) Runs 1 through 11 were designed to examine the effects of nine different process parameters using two values, or settings, of each parameter. On the basis of the subcontractor's experience plus the results obtained from a preliminary sample, which had been manufactured and tested previously [1], constant values were assigned to three additional process parameters for the purposes of this study. (Runs 12 and 13 will be discussed later.)

2.1 Process Parameters

2.1.1 Roving Preheat. Earlier studies have shown that the wetting of the fibers by the resin might be improved by preheating the rovings to drive off surface moisture before they enter the dip trough. This was done, in this program, by passing the rovings through an oven prior to entry into the dip trough. The oven is 54 in long and is capable of continuous operation between 250 and 300 °F.

2.1.2 Roving Twist. Glass roving is commercially available either twisted or untwisted. The use of untwisted roving would conceivably facilitate wetting and might also be conducive to achieving straight, parallel fibers in the finished product. On the other hand, since twisted rovings have less fuzz and catenary, these might, in fact, result in better collimated fibers. Both twisted and untwisted rovings were used.

2.1.3 Roving End Count. Glass roving is also available in a wide range of end counts (number of strands per roving). The pultrusion of a larger number of rovings with a smaller end count could, perhaps, provide a more uniform distribution of fibers throughout the cross section. At the same time, the difficulties in achieving good collimation probably increase with the number of rovings used. End counts of 30 and 60 were examined.

2.1.4 Roving Tension. It had been observed during the study of the pultrusion process [1] that the fibers in pultruded rod are frequently not straight but, rather, follow tortuous paths. This does not allow the development of a uniform distribution of load among the fibers in a tensile application. In the present work, therefore, several samples were manufactured with the fibers pretensioned to straighten them. This was accomplished by passing the rovings over an S-bend, as shown in Figure 1. Initially, the vertical separation of the two rods which form the S-bend was 6 in and the horizontal separation was 4 in. Later, to increase the tension, the vertical separation was reduced to 3 in and the horizontal separation increased to 5 in. In addition, each roving was passed through an eyebolt, as shown in the figure. The individual eyebolts were rotated, as necessary, to approximately equalize the tension in the various rovings.

2.1.5 Roving Collimation. In addition to being straight it is also important that the rovings be alined parallel to the axis of the rod. This was promoted by constraining the rovings to follow essentially parallel paths through the dip trough. The rovings were passed through a series of three polyethylene guide plates which were mounted in the dip trough, Figure 2. Each plate contained holes -- one hole for each roving -- arranged in a pattern of concentric circles. All of the holes were below the resin level in the trough, and the middle guide plate was set somewhat higher than the other two to introduce some tension into the rovings. After passing through the third guide plate the rovings followed an essentially horizontal path to the die, leaving the dip trough through a 5/8-in orifice beneath the surface of the resin.

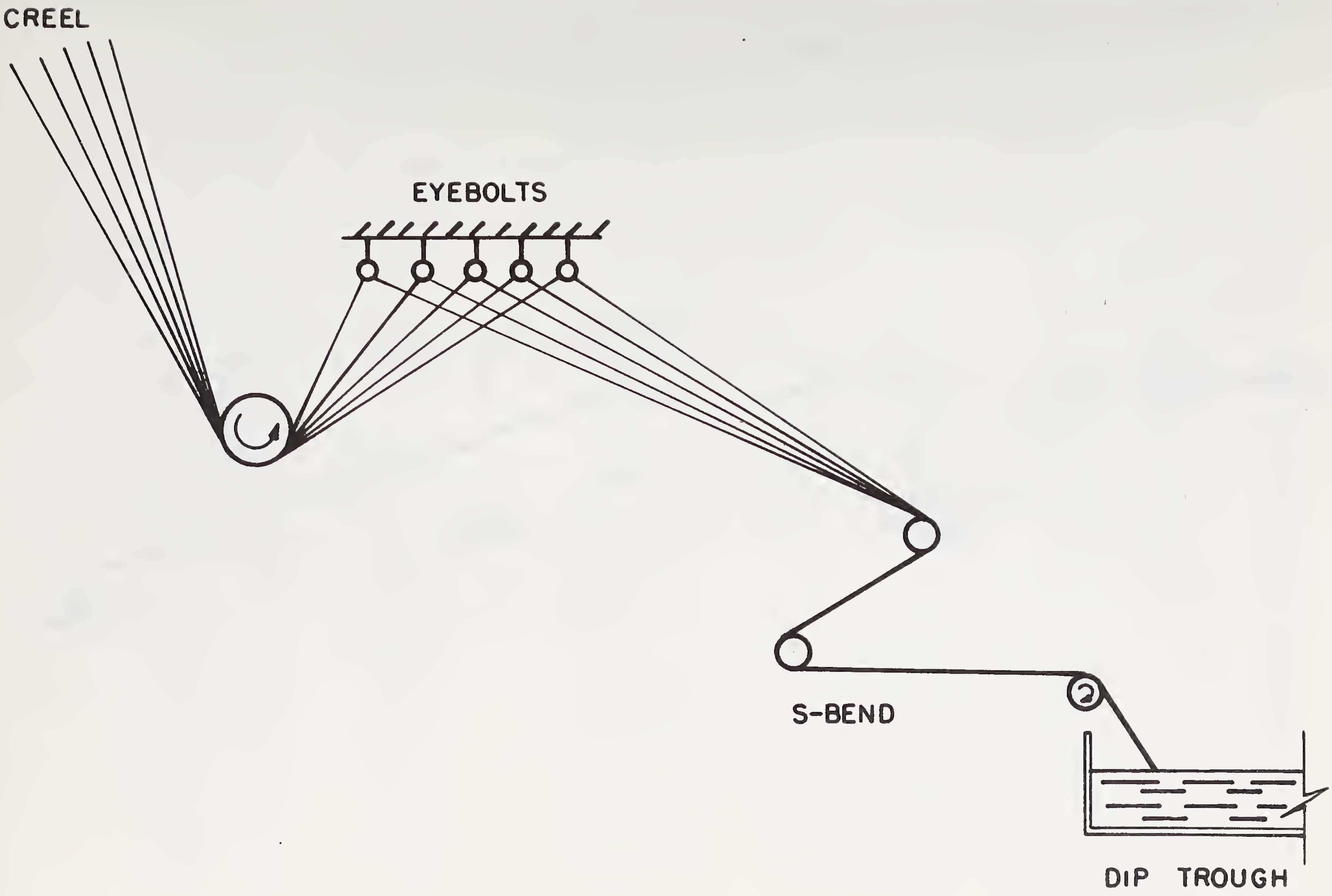

Figure 1 - Schematic representation of tensioning apparatus for pultrusion.

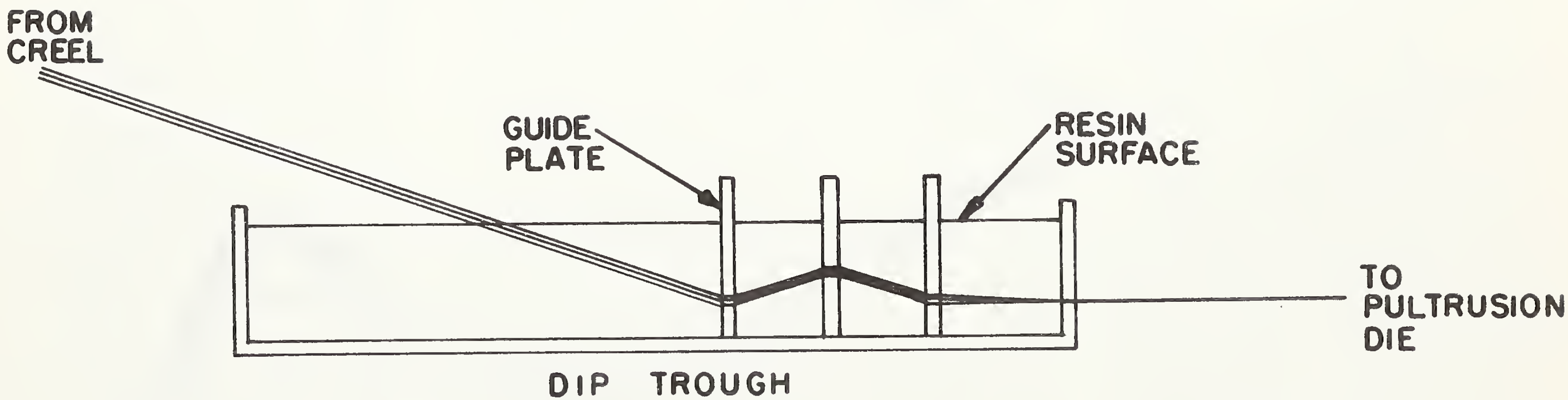

Figure 2 - Schematic representation of collimating apparatus for pultrusion.

This apparatus is believed to reduce the inadvertent intertwining of rovings, and to promote resin penetration by separating the mass of rovings in the trough.

2.1.6 Immersion Length. The wetting of the fibers with the resin could conceivably be improved by increasing the duration of the immersion in the dip trough. This can be accomplished either by reducing the pulling speed of the rovings or by increasing the immersion length in the dip trough. In this program pulling speed was maintained constant, as discussed below, and the effects of immersion time were examined by using either a "standard" dip trough, which provides an immersion length of approximately 23 in, or a long trough, for an immersion length of approximately 54 in.

2.1.7 Ultrasonic Agitation. Another approach to improving fiber wet-out involves the use of ultrasonic excitation to agitate the fibers and drive entrapped air from the rovings. In this program a 250-W ultrasonic exciter, which vibrates at 20000 Hz, was used in the manufacturing process for several samples. The end of the ultrasonic horn, which has a 3 1/2-in by 1/2-in rectangular cross section, was immersed in the dip trough and placed in contact with the rovings near the point of their emergence from the resin. The ultrasonic vibrations were damped out, and the instrument rendered inoperative, if the horn was immersed to a depth exceeding about 1/16 in.

2.1.8 Wetting Agent. Improved wet-out of the fibers was also sought through the use of a wetting additive in the resin system. Poly (ϵ-caprolactone) or, simply, polycaprolactone, was selected for this purpose on the basis of its demonstrated ability to facilitate the dispersion of glass particles in resins [2]. Polycaprolactone is a thermoplastic polymer which is formed through the ring-opening reaction of ϵ-caprolactone. It has the structure

$$\left[CH_2CH_2CH_2CH_2CH_2\overset{\overset{\displaystyle O}{\|}}{C} - O \right]_n$$

where the subscript n depends on the molecular weight of the product. It is commercially available in flake form and, according to the manufacturer, is readily compatible with styrene-unsaturated polyesters. In concentrations of 5 to 10 percent it also imparts improved surface properties to glass-reinforced plastics.

2.1.9 Resin System Formulation. On the basis of prior experience it was known that the resin system should have a dynamic viscosity in the range of 11.5 to 13.0 poises for satisfactory pultrusion. This was accomplished by adding monostyrene to the isophthalic polyester resin. The proportion of monostyrene had to be increased when the polycaprolactone wetting agent was used since the latter tends to raise the viscosity of the system. The resin system formulation, both with and without the wetting agent, is given in Table 1.

Table 1. - Resin System Formulation, Runs 1 - 11

	Without wetting agent wt pct	With wetting agent wt pct
Monostyrene	4.91	7.09
Peroxide catalyst	0.73	0.70
Die lubricant	0.92	0.86
Ultraviolet inhibitor	0.13	0.12
Wetting agent	-	4.96
Isophthalic polyester resin	Bal.	Bal.

2.1.10 and 2.1.11 Curing Conditions. With a given resin system, attainment of a satisfactory cure is dependent upon two parameters: the pulling speed and the die temperature. From the results on a preliminary sample [1] a pulling speed of 12 in/min and a thermostat setting of 350 ^{o}F on the curing die were selected. These two processing parameters were maintained for all of the pultrusion runs.

2.1.12 Post Curing. It has been found [1] that pultruded rods, in the as-received condition, are not fully cured. At normal pultruding speeds each increment of rod is exposed to the curing die for a very short time and it is not possible to effect a complete cure in this interval. Although cure undoubtedly proceeds to completion under ambient conditions over a period of months, the addition of a post cure to the manufacturing process would provide the benefits of a complete cure from the outset. These benefits may include enhanced weather resistance as well as increased strength. This parameter was examined by adding a post cure (16h at 275 ^{o}F) to the manufacturing process for one sample.

2.2 Design of Experiment

Nine of the variable process parameters were examined in two values, or settings, of each. For example, the effects of roving end count were investigated by manufacturing some rod samples with 30-end roving and others with 60-end roving. For most of the parameters, however, the two values, or settings, consisted of a "yes" or "on" condition and a "no" or "off" condition. Thus, the effects of ultrasonic agitation were investigated by manufacturing some rod samples with agitation (the "yes" setting) and others without agitation (the "no" setting). The nine parameters and their settings were:

Roving preheat (yes, no)
Roving twist (yes, no)
Roving end count (60, 30)
Roving tension (yes, no)
Roving collimation (yes, no)
Immersion length (long, standard)
Ultrasonic agitation (yes, no)
Wetting agent (yes, no)
Post curing (yes, no)

Three other process parameters (resin viscosity, pulling speed, die temperature) were kept constant.

Eleven samples of rod were manufactured. Table 2 gives the selected settings of the nine variable process parameters for each of Runs 1 through 11. This scheme permits the effects of each of three parameters (preheat, collimation, post curing) to be examined by comparing the properties of two samples, which had been manufactured such that all of the process parameters were the same for both except the parameter being studied. Thus, for example, the process parameters for Runs 1 and 2 were nominally identical except that the roving was preheated in Run 2 while in Run 1 it was not.

The remaining six variable parameters (twist, end count, tension, immersion length, ultrasonics, wetting agent) were investigated more extensively using eight rod samples. The parameter settings for these eight manufacturing runs were designed, by Dr. G. M. Jouris of the Mathematics Department at the Westinghouse Research Laboratories, such that each of the six variable parameters occurs four times at its high or "yes" setting and four times at its low or "no" setting. The other three variable parameters (preheat, collimation, post curing) were kept constant throughout these eight manufacturing runs. This method permits samples from all eight runs to be used in making a decision about each of the six variable parameters being studied. A large difference between the average value of a given rod property at the high setting, and the average value of that property at the low setting, indicates that the variable parameter is important to that property. Conversely, a negligible difference suggests that the property is essentially independent of the variable parameter.

Table 2. - Selected Settings of the Variable Process Parameters for Manufacturing Runs 1 through 11

Run No.	Roving preheat	Roving twist	Roving end count	Roving tension	Wetting agent	Immersion length	Ultrasonic agitation	Colli-mation	Post cure
1	No	Yes	60	No	No	Std	No	No	No
2	Yes	Yes	60	No	No	Std	No	No	No
3	Yes	Yes	60	No	Yes	Long	Yes	No	No
4	Yes	Yes	30	Yes	Yes	Std	No	No	No
5	Yes	Yes	30	Yes	No	Long	Yes	No	No
6	Yes	No	60	Yes	No	Long	No	No	No
7	Yes	No	60	Yes	Yes	Std	Yes	No	No
8	Yes	No	30	No	Yes	Long	No	No	No
9	Yes	No	30	No	No	Std	Yes	No	No
10	Yes	Yes	60	No	No	Std	No	Yes	No
11	Yes	Yes	60	No	No	Std	No	No	Yes

Examination of Table 2 shows which samples must be compared in order to evaluate the effects of each variable process parameter. This information is summarized in Table 3.

2.3 Manufacture of Experimental Materials

Eleven samples of 1/2-in diameter glass-reinforced-polyester rod were manufactured in accordance with the process parameter settings given in Table 2. Some of the operating conditions for these manufacturing runs are given in Table 4 and discussed below.

2.3.1 Number of Rovings. The number of rovings used in the manufacture of each sample was not arbitrary but was determined by the amount of glass needed to produce good quality rod under the preselected processing conditions. The use of tension, for example, made it necessary to increase the number of rovings to properly fill out the die. The glass contents in the finished samples were measured by the manufacturer and are reported in Table 4. Note that for a given glass content twice as many 30-end rovings are required as 60-end rovings.

2.3.2 Ultrasonic Loading. The ultrasonic generator was operated at the minimum power level required to maintain loading of the ultrasonic horn without stalling. When tension was used on the glass roving, increased power was required to keep the horn operating.

2.3.3 Resin Temperature. Use of ultrasonic agitation caused the temperature of the resin in the dip trough to rise, resulting in partial polymerization of the resin. This problem was serious when the standard immersion length was used rather than the long immersion length since, in the latter case, the energy could be dissipated to a greater volume of resin. In Run 9, for example, which employed the standard immersion length, the increased resin temperature made it necessary to remove 2- to 3-oz chunks of gelled resin, from the vicinity of the horn, at 15- to 20-min intervals. Small resin additions were, therefore, frequently required in order to maintain the proper resin level, and this helped to control the temperature rise.

The higher power levels required for ultrasonic agitation, when roving tension was used, increased the heating problem. In Run 7, when ultrasonic agitation was used in conjunction with roving tension and a standard immersion length, the problem became most severe and the dip trough had to be cooled externally. This was only partially successful, and it was necessary to discontinue this run after only about 60 ft of rod had been pultruded.

A certain amount of resin heating was found to be desirable when the wetting agent was used since it tended to separate from the resin solution at temperatures below about 77 ^{o}F. Consequently, infrared lamps mounted beneath the dip trough were employed when ultrasonic agitation was not being used.

Table 3. - Evaluation of the Variable Process Parameters

To evaluate the effect of:	Compare the average rod properties from these runs (high or "yes" setting)	with these runs (low or "no" setting)
Preheat	2	1
Collimation	10	2
Post Cure	11	2
Twist	2, 3, 4, 5	6, 7, 8, 9
End Count	2, 3, 6, 7	4, 5, 8, 9
Tension	4, 5, 6, 7	2, 3, 8, 9
Immersion Length	3, 5, 6, 8	2, 4, 7, 9
Ultrasonics	3, 5, 7, 9	2, 4, 6, 8
Wetting Agent	3, 4, 7, 8	2, 5, 6, 9

Table 4. - Operating Conditions for Manufacture of Runs 1 through 11

Run No.	No. of rovings	Glass content wt pct	Ambient relative humidity percent	Ultrasonic loading W	S-bend spacing[a] in	Resin temperature °F
1	22	70.8	30-31	-	-	(b)
2	22	70.7	30-31	-	-	(b)
3	22	71.9	36-38	200-225	-	82-100
4	46	73.8	16-18	-	(4,6)	81-86
5	49	76.2	20-23	238-250	(4,6)	84-93
6	23	73.4	22-25	-	(5,3)	74-79
7	23	73.8	18-21	250	(5,3)	108-118
8	44	71.9	24	-	-	77-81
9	44	70.6	22-25	150-175	-	68-106
10	23	73.7	25	-	-	(b)
11	22	70.7	27-28	-	-	(b)

[a] (x,y) means x inches horizontal spacing, y inches vertical spacing.

[b] Not measured, approximately ambient.

2.4 Tests and Results

Some of the more important product characteristics and mechanical properties of the rods, from Runs 1 through 11, were evaluated by means of the following tests:

- Hardness tests.
- Diametral compression tests (to measure approximate transverse tensile strength).
- Electrical breakdown tests (to obtain a relative indication of the degree of fiber wetting).
- Tensile tests.
- High-speed tensile tests.
- Stress-rupture tests at 160 °F and saturated humidity.
- Stress-rupture tests at 200 °F and saturated humidity.

The test methods that were used for all of these tests, except the high-speed tensile tests, were described earlier [1].

2.4.1 Product Characteristics. The average results of the tests to determine the surface hardness, the transverse tensile strength and the breakdown voltage, for each of Runs 1 through 11, are given in Table 5.

2.4.2 Tensile Breaking Load. Forty-one tensile tests were performed on rod specimens from Runs 1 through 11. These were carried out at room temperature using a crosshead speed of 0.75 in/min.

The test results are given in Appendix B and the average breaking loads are summarized in Table 6.

2.4.3 High-Speed Tensile Tests. These tests were carried out at room temperature in a 50000-lbf-capacity, closed loop, electrohydraulic testing machine [3]. Special adapters were designed and fabricated to enable H3M end fittings [1,4] to be used in this machine. A calibrated load cell in series with the test specimen was used to measure load, and the load-time trace for each test was recorded with a calibrated storage oscilloscope. See Figure 3. The crosshead speed in these tests was measured using an LVDT extensometer and was found to be approximately 300 in/min.

In the first three high-speed tensile tests that were performed the failures appeared to initiate in an end fitting. Because of the visco-elastic nature of the C2W3 potting compound (which is normally used with H3M end fittings) it was surmised that the high loading rates were causing the potting compound to behave like a stiff material. Consequently, a new potting compound, C1W2, was formulated, which is more flexible than C2W3. Nevertheless, failure in most of the high-speed tensile tests appeared to initiate in an end fitting.

In all, nineteen high-speed tensile tests were carried out on rod specimens from Runs 1 through 11. The results of these tests are given in Table 7. The free lengths of all specimens were 27 or 28 in and, except as noted, all failures appeared to have initiated in an end fitting.

Table 5. - Average Product Characteristics, Runs 1 - 11

Run No.	Rockwell hardness (Scale E)	Transverse tensile strength	Breakdown voltage
		lbf/in^2	kV
1	53	1300	22
2	51	1300	22
3	24	2200	43
4	34	1400	23
5	53	1600	29
6	56	1700	25
7	44	1900	35
8	42	2000	45
9	47	1200	19
10	47	1200	20
11	62	1800	22

Table 6. - Average Breaking Loads, Runs 1-11

Run No.	Average breaking load
	lbf
1	29000
2	29100
3	27100
4	22500
5	23000
6	24700
7	26200
8	25900
9	28000
10	30400
11	29600

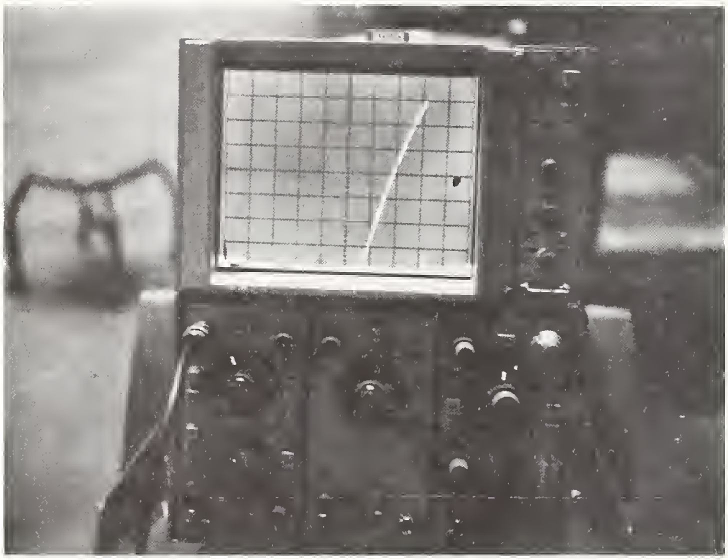

Figure 3 - Storage oscilloscope used in high-speed tensile tests, showing a typical trace of load (ordinate) vs time (abscissa).

Table 7. - Results of High-Speed Tensile Tests, Runs 1-11

Run No.	Specimen No.	Potting compound	Average diameter in	Average density lb/in^3	Average weight lb/ft	Maximum load lbf	Notes
1	R1Pc8C	C2W3	0.5021	0.0687	0.163	-	a
1	R1Pc7B	C1W2	.5013	.0691	.164	36000	b
2	R2Pc7C	C2W3	.5008	.0691	.163	34700	
2	R2Pc5D	C1W2	.5023	.0688	.164	33200	
3	R3Pc1C	C1W2	.4954	.0696	.161	33500	
3	R3Pc5A	C1W2	.4960	.0695	.161	37000	
4	R4Pc6A	C1W2	.4964	.0702	.164	29000	
4	R4Pc6B	C1W2	.4964	.0702	.164	28500	
5	R5APc2B	C1W2	.4977	.0697	.163	32500	
6	R6Pc6A	C1W2	.4951	.0714	.165	38100	b
6	R6Pc6C	C1W2	.4951	.0714	.165	17000	c
6	R6Pc9A	C1W2	.4966	.0710	.165	35000	
8	R8Pc11A	C1W2	.4947	.0699	.161	34000	
9	R9Pc5A	C1W2	.4959	.0697	.161	36000	
10	R10Pc4C	C2W3	.4967	.0706	.164	-	a
10	R10Pc3C	C1W2	.4956	.0709	.164	-	a
10	R10Pc6A	C1W2	.4960	.0708	.164	15000	c
10	R10Pc6B	C1W2	.4960	.0708	.164	34000	
11	R11Pc2A	C1W2	.5002	.0691	.163	32500	

Notes:

a. Maximum load not measured.

b. Failure appeared to have initiated in the free length.

c. Specimen pulled out of an end fitting.

2.4.4 Stress-Rupture Tests. Eighty-three stress-rupture tests were carried out on rod specimens from Runs 1 through 11 under saturated humidity conditions. Thirty-eight of these tests were performed at 160 °F and forty-five at 200 °F. The original intent of the tests was to study the rupture strength of each sample of material, at each temperature, over the time range from 1 to 1000 h. It was soon realized, however, due to scatter in the test results and to the occasional occurrence of long-term failures which initiated in the end fittings, that far more tests would be required to characterize the rupture strengths than had been planned. Some trade-offs were effected by conducting fewer tests on samples which exhibited low rupture strengths so that additional tests could be conducted on the other samples. In particular, no tests were carried out at loads less than 10000 lbf because 1/2-in rods with rupture loads below this are clearly not competitive with commercially available products.

The results of the stress-rupture tests are given in Appendix C. These results show several interesting features. If the data are plotted on semi-log coordinates (see, for example, Fig. 4) the slope of the curve of load vs log time-to-rupture becomes increasingly negative with increasing time. This is contrary to the behavior of most structural materials. Also, there was no clear distinction between the stress-rupture properties at 160 °F and those at 200 °F. Certain samples of material appeared to be stronger at 200 °F than at 160 °F while in some cases (see, for example, Fig. 5) the rupture curves appear to intersect.

These anomalies make it difficult to rank the eleven samples in terms of their stress-rupture strengths. Nevertheless, such a ranking would be very helpful in assessing the effects of the various processing parameters. Accordingly, the 100-h rupture load was arbitrarily selected as the characteristic which would be used for comparing the anticipated weatherabilities of the samples. Values of the 100-h rupture loads were derived by interpolating -- and, in some cases, extrapolating -- the test data. In so doing, considerable judgement had to be exercised regarding the shapes of the rupture curves between data points. The derived values are given in Table 8 and must be regarded as estimates at best; the table is provided solely to enable the most general comparisons to be made between the rupture strengths of different samples.

2.5 Analysis of Results

The effects of the nine variable process parameters, on the properties of the rods, were calculated by applying the evaluation procedures (Table 3) to the average tensile breaking load values (Table 6) and to the average estimated rupture load values (Table 8). The results of these evaluations are given in Table 9.

It may be seen that four of the process parameters appear to be beneficial to both the tensile strength and the rupture strength, namely, collimation and ultrasonic agitation of the rovings, increased end count, and post cure of the rod. Two of the process parameters are detrimental to the strength properties, namely, increased immersion length and the

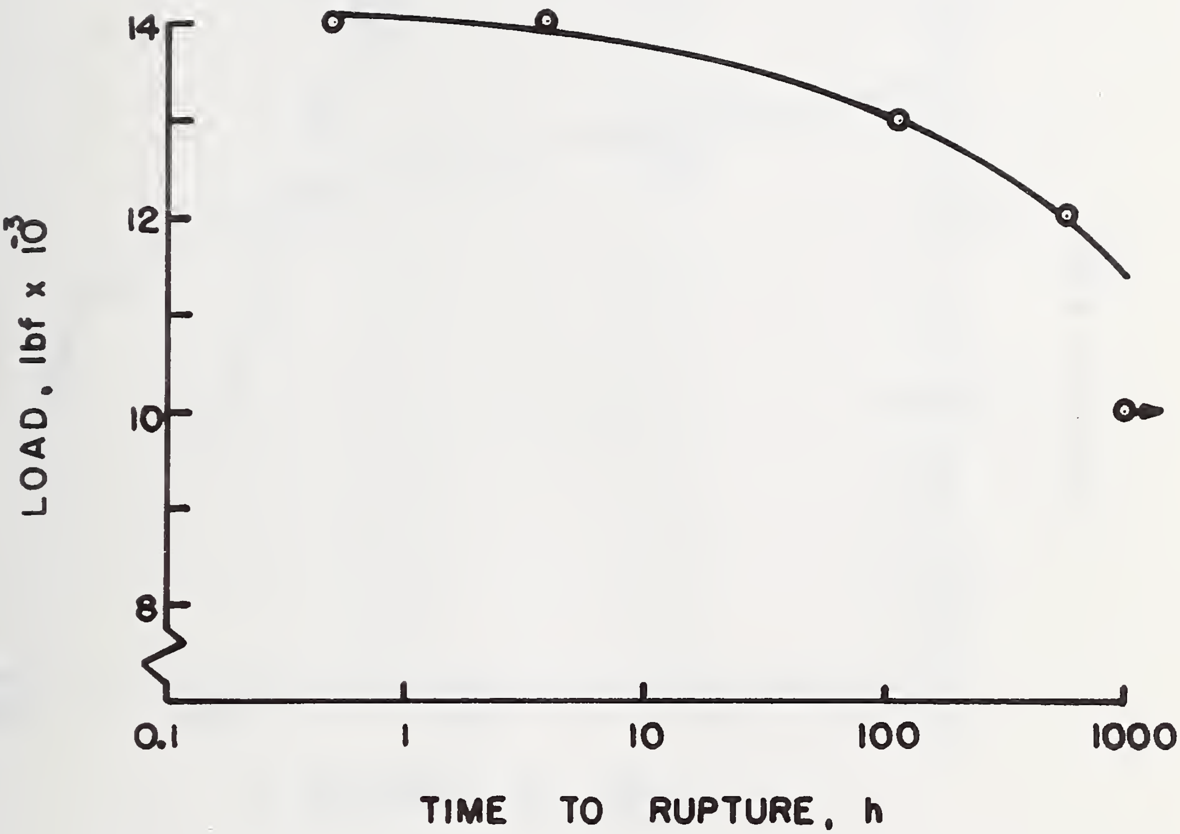

Figure 4 - Stress-rupture properties of rod from Run 1 at 200 °F under saturated humidity.

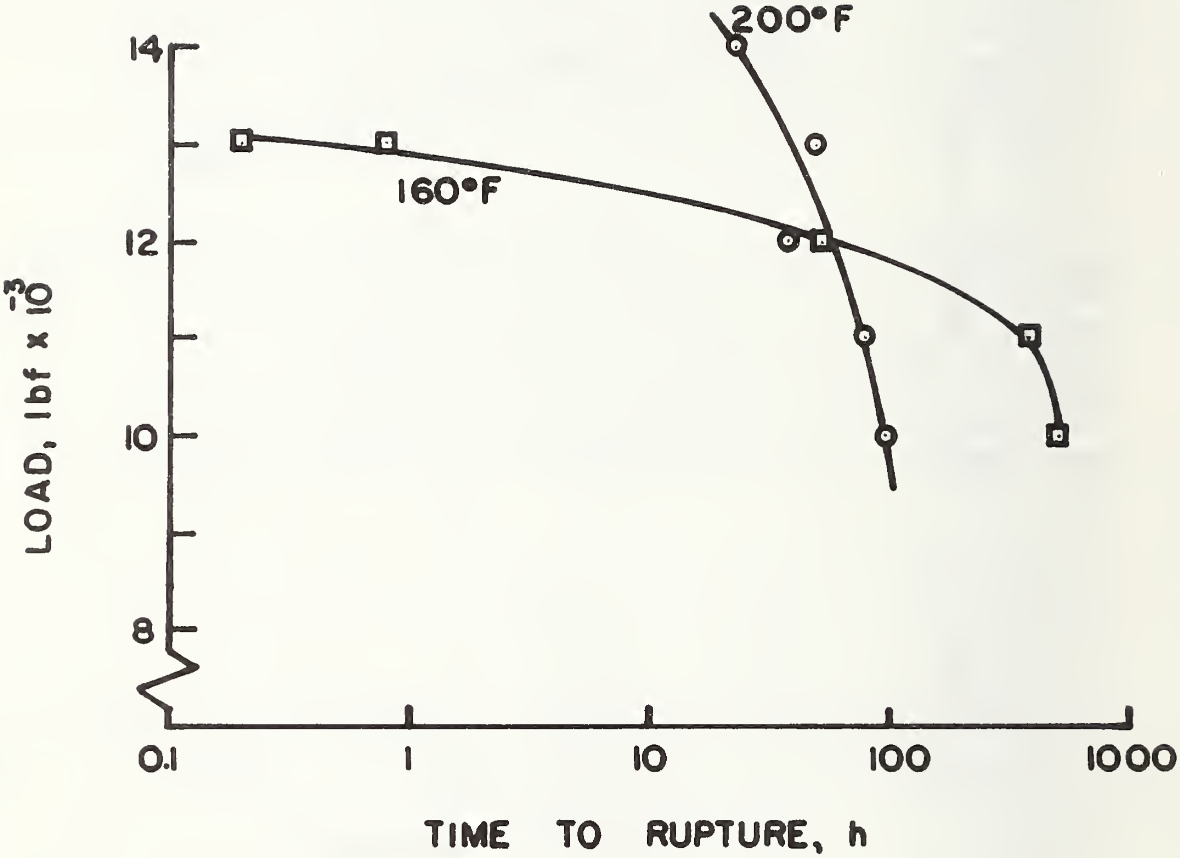

Figure 5 - Stress-rupture properties of rod from Run 2 under saturated humidity.

Table 8. - Estimated Stress-Rupture Loads, Runs 1-11

Run No.	Tensile load to produce rupture in 100h at 160 °F lbf	200 °F lbf	average lbf
1	10500	13000	11250
2	11700	10000	10850
3	9900	9500	9700
4	9000	9300	9150
5	12300	11500	11900
6	11900	11500	11700
7	11500	9800	10650
8	4000	3000	3500
9	10700	9000	9850
10	11600	11600	11600
11	12000	13000	12500

Table 9. - Effects of the Variable Process Parameters on Rod Properties, Runs 1-11

Parameter	Incremental effect on tensile breaking load, lbf	Incremental effect on 100-h rupture load, lbf
Preheat	+ 100	- 400
Collimation	+1300	+ 800
Post cure	+ 500	+1600
Twist	- 800	+1500
End count	+1900	+2100
Tension	-3400	+2400
Immersion length	-1300	- 900
Ultrasonics	+ 500	+1700
Wetting agent	- 800	-2800

wetting agent additive. The detrimental effect of increased immersion length is particularly puzzling; an explanation is not immediately apparent. The effect of preheating the rovings was found to be relatively insignificant. The use of twisted rovings, and the application of added tension in the rovings during pultrusion, were both found to be beneficial to the rupture strength but detrimental to the tensile strength.

Data presented in Appendix C also indicate that the stress-rupture strength under saturated humidity conditions is significantly greater at room temperature than at 160 or 200 ^{o}F. This tends to support the use of the elevated-temperature rupture tests as accelerated measures of long-term weatherability.

No meaningful correlation was found between the tensile breaking load values and the 100-h rupture load values. Similarly, there is no apparent correlation between either of these two quantities and any of the product characteristics given in Table 5. On the other hand, there does appear to be some correlation between transverse tensile strength and breakdown voltage, as shown in Figure 6. The degree of correlation is too poor, however, to be of much practical value.

Comparison of the tensile breaking loads (Table 6) with the results of the high-speed tensile tests (Table 7) shows that the maximum loads are significantly greater at high loading rates than at normal testing speeds. This suggests that special provisions need not be made for high loading rates in the design of glass-reinforced-plastic antenna-support systems and, also, that breaking strength data for glass-reinforced-plastic rod products are not entirely meaningful unless accompanied by information regarding the speed of loading.

3. OPTIMIZATION OF THE MANUFACTURING PROCESS, PART II

3.1 Experimental Materials

The processing conditions for Run 12 were selected with the intention of optimizing the long-term weatherability of the rod. Using the stress-rupture strength under conditions of elevated temperature and saturated humidity as the laboratory index of long-term weatherability, Table 9 indicates, in principle, what the processing conditions should be. In practice, this optimum combination of the variable processing parameters could not be employed with the available manufacturing facilities. Specifically, the special equipment required to introduce collimation is not readily compatible with the special equipment required to introduce added tension in the rovings. Also, the collimating equipment constrains the rovings to a path which is too far below the resin surface in the dip trough to permit the ultrasonic horn to be used. In addition, as described earlier, attempts to use ultrasonic agitation in combination with added tension in the rovings introduces overheating problems, particularly when the standard-length dip trough is used. Accordingly, the following values of the nine variable processing parameters were selected

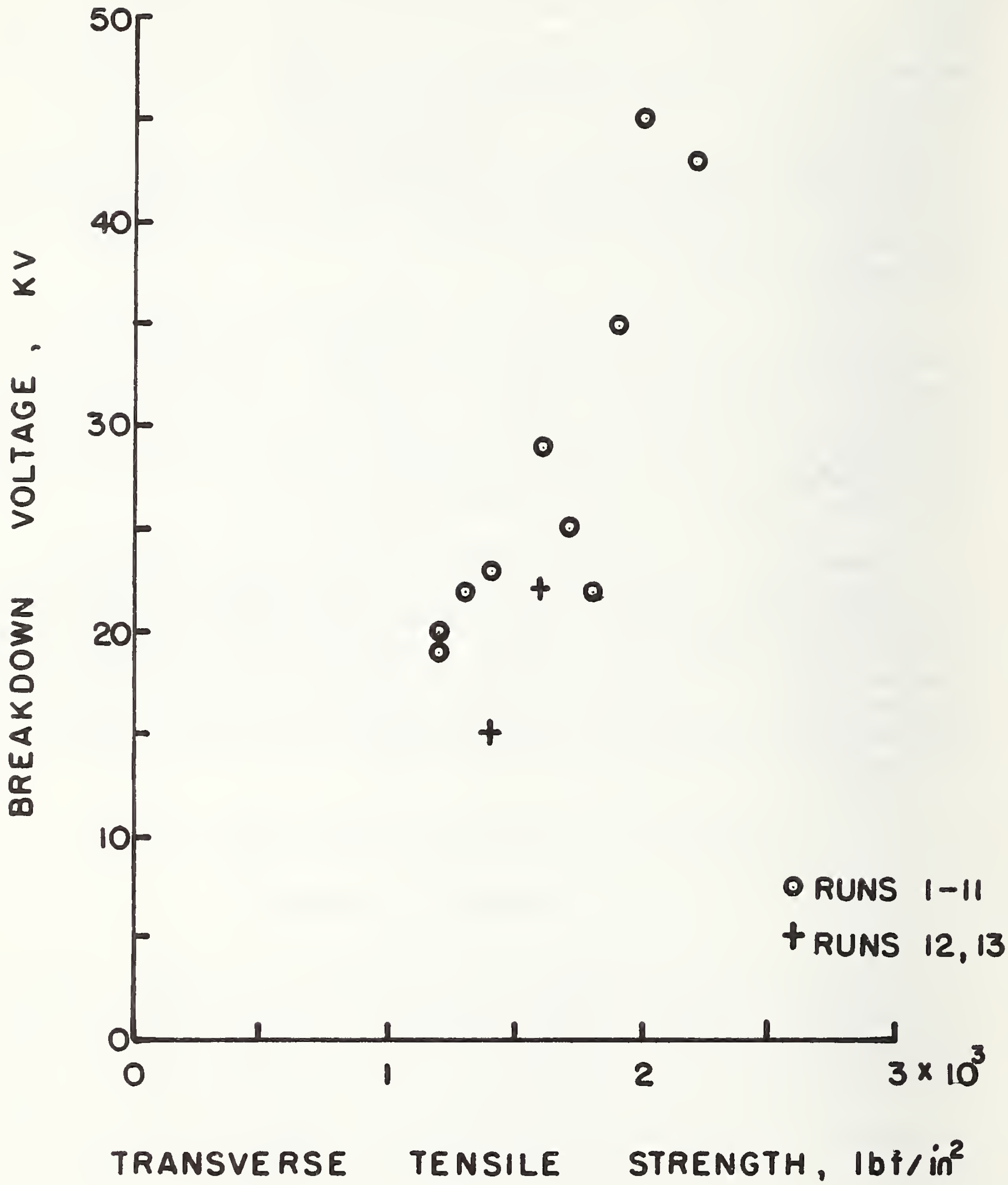

Figure 6 - Electrical breakdown voltage vs transverse tensile strength.

for Run 12. These represent a compromise between the ideal combination, as indicated by the results given in Table 9, and the limitations of the available manufacturing facilities.

Roving preheat: no	Immersion length: std
Roving twist: yes	Ultrasonic agitation: no
Roving end count: 60	Collimation: no
Roving tension: yes	Post cure: yes
Wetting agent: no	

The three constant processing parameters (resin viscosity, pulling speed and die temperature) were unchanged from those used in Runs 1 through 11, and the resin system formulation was the same as that used for those earlier samples which did not employ the wetting agent.

The singular lack of success which was achieved with the wetting agent in Runs 1 through 11 led to a decision to use Run 13 to evaluate the benefits of adding a coupling agent, rather than a wetting agent, to the resin system. The coupling agent selected for this purpose is a commercially available, cationic methacrylate functional silane having typical properties as shown in Table 10. The settings of the other process parameters for Run 13 were the same as those listed above for Run 12. The resin system formulations for the two runs are given in Table 11 and the operating conditions are given in Table 12.

3.2 Test Results and Analysis

The samples from Runs 12 and 13 were subjected to the same types of tests as had been used for Runs 1 through 11. The results of these tests are given in Tables 13, 14, 15, and 16, and the relationship between transverse tensile strength and electrical breakdown voltage is shown in Figure 6.

Unfortunately, the rods were somewhat bowed as received from the manufacturer, presumably because they had been inadequately supported during the post-curing operation. This caused longitudinal splitting, or delamination, to develop in the tensile tests (Table 14) prior to total failure. It is felt that this splitting promoted the initiation of premature failures in the end fittings. Nevertheless, the maximum loads attained with the Run 12 specimens are not far removed from the calculated breaking load for this run, which is 26100 lbf.* Comparison of the breaking loads for Run 13 with those for Run 12 shows that the coupling agent additive in Run 13 was ineffective, at best, insofar as the tensile breaking load is concerned.

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* This calculation is straightforward. Starting, for example, with the breaking load for Run 1 (Table 6), the breaking load for Run 12 is found by algebraically adding to this value the breaking load increments for tension and post cure (Table 9).

Table 10. - Typical Properties of Silane Coupling Agent[a]

Percent solids:	50.
Solvents:	Mostly diacetone alcohol.
Color:	Amber brown.
Refractive index at 77 °F:	1.457.
Specific gravity at 77 °F:	1.06.
Viscosity at 77 °F:	0.74 poises.
Flash point, open cup:	130 °F.
Suitable diluents:	Alcohols, water.

[a] According to the manufacturer.

Table 11. - Resin System Formulation, Runs 12 and 13

	Run 12 wt pct	Run 13 wt pct
Monostyrene	4.91	4.89
Peroxide catalyst	0.73	0.74
Die lubricant	0.92	0.93
Ultraviolet inhibitor	0.13	0.13
Coupling agent	-	0.30
Isophthalic polyester resin	Bal.	Bal.

Table 12.- Operating Conditions for Manufacture of Runs 12 and 13

Run No.	No. of rovings	Glass content wt pct	Ambient relative humidity percent	S-bend spacing[a] in	Resin temperature
12	24	75.4	37-39	(5,3)	(b)
13	24	75.6	39-40	(5,3)	(b)

(a)See Table 4.

(b)Ambient

Table 13.- Average Product Characteristics, Runs 12 and 13

Run No.	Rockwell hardness (Scale E)	Transverse tensile strength lbf/in^2	Breakdown voltage kV
12	67	1600	22
13	60	1400	15

Table 14.- Results of Tensile Tests, Runs 12 and 13

Run No.	Specimen No.	Average diameter	Average density	Average weight	Maximum load	Notes
		in	lb/in^3	lb/ft	lbf	
12	R12Pc16	0.4983	0.0720	0.168	23750	a
12	R12Pc17	.4967	.0721	.168	25750	b
12	R12Pc18	.4990	.0715	.168	24250	a
12	R12Pc2A	.4970	.0723	.168	26750	a, c
12	R12Pc2B	.4970	.0723	.168	24700	a, c
13	R13Pc16	.4990	.0715	.168	23950	a
13	R13Pc17	.4981	.0718	.168	25000	a
13	R13Pc18	.4972	.0721	.168	24400	a
13	R13Pc2B	.4970	.0721	.168	25250	a, c
13	R13Pc2C	.4970	.0721	.168	23750	a, c

Notes:

a. Failed in end fitting following delamination.

b. Failed in free length following delamination.

c. Free length, 23 to 26 in.

Table 15. - Results of High-Speed Tensile Tests, Runs 12 and 13

Run No.	Specimen No.	Potting compound	Average diameter	Average density	Average weight	Maximum load
			in	lb/in^3	lb/ft	lbf
12	R12Pc9A	C1W2	0.4968	0.0721	0.168	32600
12	R12Pc15A	C1W2	.4984	.0718	.168	34500
13	R13Pc6A	C1W2	.4966	.0728	.169	33000

Table 16.- Results of Stress-Rupture Tests, Runs 12 and 13

Run No.	Specimen No.	Average diameter	Average density	Average weight	Temperature	Load	Time to rupture	Notes
		in	lb/in^3	lb/ft	°F	lbf	h	
12	R12Pc11	0.4966	0.0727	0.169	200	13000	2.4	a
12	R12Pc4	.4985	.0723	.169	200	12000	190.1	
12	R12Pc13	.4970	.0729	.170	200	11000	568.	
12	R12Pc14	.4984	.0720	.168	160	13000	4.3	a
12	R12Pc12	.4977	.0719	.168	160	12000	165.7	
12	R12Pc1	.4969	.0715	.166	160	11000	233.4	b
12	R12Pc5	.4953	.0722	.167	160	11000	320.	
13	R13Pc9	.4968	.0724	.168	200	12000	24.9	
13	R13Pc5	.4968	.0721	.168	200	11000	96.0	
13	R13Pc1	.4991	.0714	.168	200	10000	400.	
13	R13Pc3A	.4966	.0725	.168	160	12000	0.8	
13	R13Pc15	.4969	.0721	.168	160	11000	220.8	
13	R13Pc12	.4964	.0725	.168	160	10000	804.	

Notes:

a. Delaminated prior to failure.

b. Failure initiated at end fitting.

In the high-speed tensile tests (Table 15) the failures also appeared to have initiated in the end fittings. However, just as with Runs 1 through 11, the breaking loads in the high-speed tests are significantly greater than those achieved in the conventional tensile tests.

Some delamination due to bowing was also experienced in the stress-rupture tests (Table 16) but the conclusion is nevertheless clear that the coupling agent additive in Run 13 was detrimental to the stress-rupture strength.

The average 100-h rupture load for Run 12, interpolated and estimated from the data in Table 16, is approximately 12300 lbf. This is considerably less than the calculated value (from Tables 8 and 9) of 15300 lbf. It is, however, approximately equal to the 100-h rupture load for Run 11 (12500 lbf) which was the highest of all. It may be that this is about the limit of the improvement that can be attained in the rupture load through modification of the manufacturing process parameters.

4. PLANS

The third and final year of effort on this program will be devoted primarily to improvements in non-metallic antenna-support rods that can be achieved through variation of the constituent materials. Experimental rods with different resin and fiber materials will be manufactured and tested.

* * *

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APPENDIX A. CONVERSION FACTORS

Factors for converting U. S. customary units to the International System of Units (SI) may be found in ASTM Standard Metric Practice Guide (ASTM Designation E380-70). Copies are available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103. Conversion factors for units used in this paper are given in Table A.1.

APPENDIX B. TENSILE TEST RESULTS, RUNS 1-11

The results of forty-one tensile tests on rod specimens from Runs 1 through 11 are given in Table B.1. Except as otherwise noted, each specimen was fitted with H3M end fittings using cruciform wedges and C2W3 potting compound [1,4], and had a free length between 52 and 62 in. Also given in Table B.1 is the average breaking load for each run. In general, this was calculated by averaging the maximum loads that were attained with specimens that failed in their free lengths. However, this procedure could not be applied to the results from Runs 3 and 7 because, in these cases, failures in the free lengths were not obtained. Run 3 was one of the runs which utilized the wetting agent, which is a very effective low-profile additive, and this, together with a long immersion time and ultrasonic agitation, produced a rod with an extremely slick outer surface which could not be adequately gripped. Four tensile tests resulted in four pullouts. The average breaking load of Run 3 is, therefore, only estimated on the basis of the highest maximum load attained.

Two tensile tests on rod specimens from Run 7 resulted in failures which apparently initiated in an end fitting. The shortage of material from Run 7 precluded additional testing and the average tensile strength of this run is also estimated on the basis of the limited data obtained.

In calculating the average tensile strength for Run 10, the results of two tests, which had culminated in pullouts, were included in the average since the maximum loads in these two tests exceeded that obtained with one specimen which had failed in its free length.

APPENDIX C. STRESS-RUPTURE TEST RESULTS, RUNS 1 - 11

The results of eighty-three rupture tests on rod specimens from Runs 1 through 11 are given in Tables C.1 and C.2. Each specimen was fitted with Type R/P commercial end fittings [5] using cruciform wedges and C2W3 potting compound [1]. Except as otherwise noted, each specimen failed in its free length within the temperature-humidity chamber.

In addition, one specimen from Run 10 was tested at room temperature and saturated humidity under a load of 12000 lbf. This test was discontinued after 2255 h without any indication of impending failure. The data for this specimen are as follows:

Specimen No. R10Pc7A	Density, 0.0708 lb/in^3
Diameter, 0.4960 in.	Weight, 0.164 lb/ft.

Table A.1.- Conversion Factors

Quantity	U. S. customary unit	SI unit	Conversion factor
Force	pound-force (lbf)	newton (N)	1 lbf = 4.448 N
Length	inch (in) foot (ft)	centimeter (cm) meter (m)	1 in = 2.54 cm 1 ft = 0.3048 m
Mass (weight)	ounce (oz) pound (lb) pound (lb)	gram (g) gram (g) kilogram (kg)	1 oz = 28.35 g 1 lb = 453.6 g 1 lb = 0.4536 kg
Temperature	degree Fahrenheit (°F)	degree Celsius (°C)	°C = (5/9) (°F - 32)
Density	lb/in^3	g/cm^3	$1\ lb/in^3 = 27.68\ g/cm^3$
Speed	in/min	m/s	$1\ in/min = 4.233 x 10^{-4}\ m/s$
Stress	lbf/in^2	N/m^2	$1\ lbf/in^2 = 6895\ N/m^2$
Viscosity, dynamic	poise (P)	$N \cdot s/m^2$	$1\ P = 0.1\ N \cdot s/m^2$
Weight per unit length	lb/ft	kg/m	1 lb/ft = 1.488 kg/m

Table B.1. - Results of Tensile Tests, Runs 1 - 11

Run No.	Specimen No.	Average diameter	Average density	Average weight	Maximum load	Notes
		in	lb/in^3	lb/ft	lbf	
1	R1Pc8B	0.5021	0.0687	0.163	29450	a
1	R1Pc3B	.5016	.0688	.163	29000	a
1	R1Pc6B	.5023	.0686	.163	28600	a
1	R1Pc8A	.5021	.0687	.163	25300	a,b
1	Average				29000	
2	R2Pc5B	.5023	.0688	.164	28700	a
2	R2Pc7B	.5008	.0691	.163	20550	c
2	R2Pc1A	.5017	.0689	.163	26550	d
2	R2Pc1B	.5017	.0689	.163	29450	a
2	R2Pc4B	.5065	.0676	.163	7150	c,e
2	Average				29100	
3	R3Pc1A	.4954	.0696	.161	24650	c
3	R3Pc2A	.4959	.0694	.161	11850	c
3	R3Pc2A	.4959	.0694	.161	25250	c,f
3	R3Pc4A	.4960	.0694	.161	27050	c
3	Average				27100	g
4	R4Pc3B	.4956	.0709	.164	22950	a
4	R4Pc4A	.4957	.0708	.164	21000	a
4	R4Pc8A	.4954	.0710	.164	20000	d
4	R4Pc8B	.4954	.0710	.164	10300	c
4	R4Pc8C	.4954	.0710	.164	23550	a
4	Average				22500	
5	R5APc4A	.4950	.0732	.169	23150	a
5	R5APc1B	.4960	.0729	.169	22800	a
5	R5APc1A	.4960	.0729	.169	18500	d
5	Average				23000	
6	R6Pc2B	.4960	.0714	.166	20700	a
6	R6Pc2A	.4960	.0714	.166	25450	a
6	R6Pc2C	.4960	.0714	.166	28000	a
6	Average				24700	
7	R7Pc1A	.4946	.0712	.164	25750	d
7	R7Pc1B	.4946	.0712	.164	26150	d
7	Average				26200	g
8	R8Pc1A	.4957	.0697	.161	25400	a
8	R8Pc2A	.4953	.0698	.161	26750	a
8	R8Pc3A	.4957	.0697	.161	25700	a
8	Average				25900	

Continued

Table B.1. - (continued)

Run No.	Specimen No.	Average diameter	Average density	Average weight	Maximum load	Notes
		in	lb/in^3	lb/ft	lbf	
9	R9Pc1A	0.4949	0.699	0.161	27800	a
9	R9Pc2A	.4958	.0695	.161	28150	a
9	R9Pc3A	.4951	.0697	.161	26650	d
9	Average				28000	
10	R10Pc1A	.4961	.0708	.164	30700	h
10	R10Pc2A	.4965	.0707	.164	23750	c
10	R10Pc3A	.4956	.0709	.164	31400	a
10	R10Pc4A	.4968	.0706	.164	28400	a,i
10	R10Pc8A	.4966	.0707	.164	31250	h,i
10	R10Pc7A	.4960	.0708	.164	26100	a,b
10	Average				30400	
11	R11Pc5	.5001	.0696	.164	28000	c
11	R11Pc1A	.5008	.0699	.165	28150	a
11	R11Pc7B	.5008	.0699	.165	30950	a
11	Average				29600	

Notes:

a. Failed in the free length.

b. Exposed to stress-rupture conditions prior to tensile test. (See Appendix C.) Free length, 62 or 63 in. Result not included in the average.

c. Pulled out of end fitting. Result not included in the average.

d. Failure appeared to have initiated in an end fitting. Result not included in the average.

e. End fittings potted with C1W2 compound. Free length, 47 in.

f. Same specimen as above, retested with Mod 4 end fittings.

g. Estimated.

h. Pulled out of end fitting. Result included in the average.

i. Free length, 48 to 51 in.

Table C.1. - Results of Stress-Rupture Tests at 200 °F, Runs 1 - 11

Run No.	Specimen No.	Average diameter	Average density	Average weight	Load	Time to rupture	Notes
		in	lb/in^3	lb/ft	lbf	h	
1	R1Pc6C	0.5023	0.0686	0.163	14000	0.5	
1	R1Pc4A	.5010	.0692	.164	14000	3.9	
1	R1Pc10A	-	-	-	13000	114.3	a
1	R1Pc3A	.5016	.0688	.163	12000	550.	
1	R1Pc8A	.5021	.0687	.163	10000	-	b
2	R2Pc5C	.5023	.0688	.164	14000	22.2	
2	R2Pc10A	.5007	.0688	.163	13000	47.6	
2	R2Pc4A	.5065	.0676	.163	12000	37.3	
2	R2Pc10B	.5007	.0688	.163	11000	76.9	
2	R2Pc6B	.5013	.0705	.167	10000	92.8	
3	R3Pc1B	.4954	.0696	.161	11000	2.6	
3	R3Pc4B	.4960	.0694	.161	10000	16.5	c
3	R3Pc2B	.4959	.0694	.161	10000	29.6	
4	R4Pc7A	.4953	.0709	.164	11000	0.3	
4	R4Pc7B	.4953	.0709	.164	10000	8.3	
5	R5APc8	.4982	.0725	.170	12000	27.9	
5	R5APc6A	.4970	.0726	.169	11000	21.0	c
5	R5APc6A	.4970	.0726	.169	11000	424.	d
5	R5APc6B	.4970	.0726	.169	11000	172.6	
5	R5APc3A	.4973	.0725	.169	10000	180.4	
6	R6Pc8B	.4962	.0711	.165	13000	4.8	
6	R6Pc9	.4966	.0710	.165	12000	57.4	e
6	R6Pc5A	.4961	.0712	.165	11000	114.4	f, g
6	R6Pc1A	.4957	.0712	.165	10000	169.6	
7	R7Pc1	.4945	.0714	.164	12000	0.8	
7	R7Pc3A	.4950	.0711	.164	11000	73.0	f
7	R7Pc2A	.4950	.0711	.164	10000	66.0	
8	R8Pc3B	.4957	.0697	.161	11000	0.08	
8	R8Pc1B	.4957	.0697	.161	10000	0.2	
9	R9Pc1B	.4949	.0699	.161	13000	0.05	
9	R9Pc2B	.4958	.0695	.161	12000	2.2	
9	R9Pc9B	.4958	.0696	.161	11000	26.5	

Continued

Table C.1. - Results of Stress-Rupture Tests at 200 °F, Runs 1 - 11 (Continued)

Run No.	Specimen No.	Average diameter	Average density	Average weight	Load	Time to rupture	Notes
		in	lb/in^3	lb/ft	lbf	h	
9	R9Pc3B	0.4951	0.0697	0.161	10000	13.3	
9	R9Pc10A	-	-	-	10000	20.0	a
10	R10Pc3B	.4956	.0709	.164	13000	2.0	
10	R10Pc2B	.4965	.0707	.164	12000	28.4	
10	R10Pc4B	.4968	.0706	.164	11000	450.	h
11	R11Pc13A	.5010	.0692	.164	14000	0.3	
11	R11Pc4A	.4998	.0694	.163	13000	168.	
11	R11Pc11A	.5017	.0688	.163	12000	25.6	e
11	R11Pc19A	.5009	.0690	.163	11000	0.00	c
11	R11Pc20A	.5012	.0690	.163	11000	214.5	
11	R11Pc9A	.5015	.0687	.163	11000	293.3	e
11	R11Pc15	.5023	.0687	.163	10000	67.7	
11	R11Pc3	.5004	.0692	.163	10000	123.4	i

Notes:

a. Diameter, weight and density not measured.

b. Test discontinued after 1000h without failure.

c. Specimen pulled out of end fitting.

d. Same as specimen above. Ends repotted. Sustained 402.8h additional before failure.

e. Failure initiated at or in end fitting.

f. Test interrupted by 3-day power outage during which load was maintained but temperature and humidity decreased to ambient. This interval not included in time to rupture.

g. $\pm$7.5h; timer failed to function properly.

h. $\pm$25h; timer failed to function properly.

i. $\pm$12.2h; timer failed to function properly.

Table C.2. - Results of Stress-Rupture Tests at 160 °F, Runs 1-11

Run No.	Specimen No.	Average diameter	Average density	Average weight	Load	Time to rupture	Notes
		in	lb/in^3	lb/ft	lbf	h	
1	R1Pc1A	0.5001	0.0694	0.164	13000	0.6	
1	R1Pc2B	.5002	.0694	.164	12000	5.1	
1	R1Pc2A	.5002	.0694	.164	11000	148.1	
1	R1Pc1B	.5001	.0694	.164	10000	83.4	
1	R1Pc4B	.5010	.0692	.164	10000	229.2	
1	R1Pc7A	.5013	.0691	.164	10000	270.7	a
2	R2Pc8	.5010	.0691	.163	13000	0.2	
2	R2Pc2	.5001	.0692	.163	13000	0.8	
2	R2Pc6A	.5013	.0705	.167	12000	49.4	
2	R2Pc3A	.5008	.0701	.166	11000	362.	
2	R2Pc3B	.5008	.0701	.166	10000	480.	
3	R3Pc9A	.4954	.0697	.161	10000	0.7	
3	R3Pc3A	-	-	-	10000	4.6	b
4	R4Pc9	.4959	.0709	.164	10000	2.3	
5	R5APc5	.4977	.0724	.169	13000	3.3	
5	R5APc8B	.4982	.0725	.170	12000	167.	c
5	R5APc2A	.4977	.0697	.163	11000	780.	d
5	R5APc3B	.4973	.0725	.169	10000	444.	
6	R6Pc8A	.4962	.0711	.165	13000	6.2	
6	R6Pc6B	.4951	.0714	.165	12000	80.8	
6	R6Pc5B	.4961	.0712	.165	11000	540.	
6	R6Pc1B	.4957	.0712	.165	10000	599.	
7	R7Pc4	.4954	.0710	.164	12000	2.0	e
7	R7Pc3B	.4950	.0711	.164	11000	114.4	f
7	R7Pc2B	.4950	.0711	.164	10000	418.	
8	R8Pc2B	.4953	.0698	.161	10000	0.5	
9	R9Pc8B	.4851	.0698	.161	11000	0.07	
9	R9Pc8A	.4951	.0698	.161	11000	0.5	
9	R9Pc10B	-	-	-	10000	847.	b

Continued

Table C.2. - Results of Stress-Rupture Tests at 160 °F, Runs 1-11 (Continued)

Run No.	Specimen No.	Average diameter	Average density	Average weight	Load	Time to rupture	Notes
		in	lb/in^3	lb/ft	lbf	h	
10	R10Pc8	0.4966	0.0707	0.164	12000	2.0	
10	R10Pc6A	.4960	.0708	.164	12000	46.7	g
10	R10Pc5A	.4967	.0706	.164	11000	241.5	
10	R10Pc5B	.4967	.0706	.164	10000	411.	
11	R11Pc8A	.5008	.0691	.163	13000	22.9	
11	R11Pc17	.5009	.0690	.163	12000	94.7	
11	R11Pc18	.5008	.0696	.165	11000	145.5	
11	R11Pc12	.5007	.0693	.164	10000	509.	f
11	R11Pc6	.5019	.0688	.163	10000	600.	f

Notes:

a. ±9.5h; timer failed to function properly.

b. Diameter, weight and density not measured.

c. ±7.5h; timer failed to function properly.

d. Test interrupted by 3-day power outage during which load was maintained but temperature and humidity decreased to ambient. This interval not included in time to rupture.

e. Failure initiated at surface blemish on specimen.

f. Failure initiated at or in end fitting.

g. Specimen pulled out of end fitting.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Thirteen samples of a pultruded, glass fiber-reinforced-polyester rod material were manufactured using a different combination of the manufacturing process parameters for each. These samples were tested to evaluate the effects of nine different process parameters on the properties and characteristics of the rods. Elevated-temperature stress-rupture tests under saturated humidity were used as an accelerated measure of long-term weatherability. The test results were somewhat inconsistent, but it appears that certain process parameters, such as collimation and ultrasonic agitation of the rovings during pultrusion, were beneficial to both tensile strength and weatherability. Other parameters, such as pretensioning of the rovings, were beneficial to weatherability but detrimental to tensile strength. Additives to the resin system were generally detrimental.

A high speed tension test method was developed and it was found that the strength of the rod is substantially greater under high loading rates.

An approximate relationship was observed between transverse tensile strength and electrical breakdown voltage. However, neither of these characteristics, nor surface hardness, correlated with axial tensile strength or weatherability.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Composite materials; fiber-reinforced-plastic rod; glass-reinforced-polyester rod; guys, antenna; processing parameters, pultrusion; pultrusion; reinforced plastic rod; stress rupture of FRP rod; test methods, FRP rod; weatherability, FRP rod.

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