E.R.D.E. 7/R/66

MINISTRY OF TECHNOLOGY

EXPLOSIVES RESEARCH AND DEVELOPMENT ESTABLISHMENT

REPORT No. 7/R/66

The Influence of Environment on Static Fatigue of Polymers

D. Gordon

WALTHAM ABBEY
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The Influence of Environment on Static Fatigue of Polymers

by

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References: WAC/173/07
WAM/14/011

1. SUMMARY

The effects of several gaseous environments on the static fatigue of nylon 6.6 and atactic polystyrene filaments ~~have been~~ studied. Considerable care was taken to reduce the influence of light, temperature fluctuation, vibration and contamination, all of which may affect the life of materials under stress.

No statistically-significant difference in stress lives could be attributed to the environments studied, namely, humid air, dry air, dry nitrogen and vacuum for both materials at 30°C and humid air, dry air and dry nitrogen at 50°C for nylon.

2. INTRODUCTION

2.1 Static Fatigue

It has long been known that structural materials will fail when loaded for long periods at somewhat below their short-term ultimate tensile stresses. The phenomenon, which has been called endurance, creep failure, delayed stress rupture and static fatigue, was first studied by Wohler in the 1870s, using steel wire. This, and the related subject of creep, have been widely studied in metals since that time. In the field of high polymers, Midgley and Pierce (1) investigated the related effect of rate-of-loading on the time to break in cotton yarn in the 1920s, while Leaderman (2) made an extensive study of creep in fibres in the 1940s. Coleman and Knox (3) studied the creep failure of nylon 6.6 fibres and interpreted their results in terms of a rate process. Bueche (4), working with polystyrene and polymethylmethacrylate in bulk form, established a logarithmic relationship between time-to-rupture and applied stress. He interpreted his results in terms of the energy needed to rupture a chemical bond in the polymer chain. This energy is, to a considerable extent, supplied by thermal fluctuations within the material: the effect of external stress should be to increase the energy within a chain bond, making it more susceptible to random thermal rupture than the unstressed linkage. Later (5), Bueche extended his theory to include the effects of flaws and chain relaxation, suggesting that the latter was the major time-dependent process influencing strength. Zhurkov and his co-workers at the Physico-technical Institute in Leningrad have developed Bueche's original theory, using data obtained with aluminium, silver chloride, polymethylmethacrylate, polyvinylchloride, polytetrafluoroethylene, polythene, isotactic polypropylene, nylon-6, and viscose rayon over a wide range of

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temperatures, stresses and rupture times (6 - 8). They find that the following expression relates time-to-break (τ) to stress (σ) and absolute temperature (T):

$$\tau = \tau_o e^{(Vo-\gamma\sigma)/RT}$$

where R is the gas constant and τ_o, Vo and γ are constants of the material. Vo is identified with the activation energy of rupture of a load-bearing chemical bond, γ is a measure of the amount of microstructure present and τ_o is a time of the same order of magnitude as that during which the average thermal fluctuation occurs. γ has been shown to be highly dependent on orientation and degree of crystallinity and is also sensitive to the presence of plasticisers. The field covered by this introduction has been comprehensively reviewed by Dukes (9).

2.2 Influence of Environment

Little attention has been given to this subject by workers with organic fibres, except that steps have generally been taken to ensure a constant chemical environment (e.g. relative humidity). More attention has been given to environment in the case of polymers in bulk, particularly to the cracking induced in stressed polythene by certain surface active agents. Glass has been intensively studied by Charles (10) and metals have been the subject of many investigations [e.g. (11) and (12)]. Zhurkov et al. (6) stressed aluminium, silver chloride and polymethylmethacrylate foils in air and in vacuo at 25°C, finding no difference in behaviour except in the case of the polymer which gave shorter lives in vacuo than in air. This effect was shown, however, to be caused by the vapour of the oil used in the vacuum pump. Other instances of attack by normally innocuous substances on stressed polymers have recently been reported (13,14). Ultra-violet light has been shown (15) to accelerate the breakdown of nylon 6 fibres under stress.

2.3 Significance of Static Fatigue

Man-made fibres, because of their excellent mechanical properties, are widely used in exacting conditions. In many uses, the fibres remain under substantially constant stress for long periods, e.g. in pneumatic tyres, flexible storage and transport tanks, hoses and conveyor belts. Fatigue phenomena make it necessary to over-design these structures to allow a sufficient margin of strength throughout service life. Considerable savings could be made, and reliability increased if, through a better understanding of the process involved, fatigue could be eliminated or reduced in extent.

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3. SCOPE OF THE INVESTIGATION

3.1 Materials

From the broad spectrum of polymers now used in the production of man-made fibres two were chosen: one, nylon 6.6, was selected to represent the class of highly-ordered materials while the other, atactic polystyrene, was chosen because of its low degree of order, i.e. absence of crystallinity. The present programme represents part of a projected wider study of environmental effects on static fatigue: the physical form of the polymers was restricted to filaments intermediate in cross-sectional area between textile fibres and small mouldings, both of which were to be studied separately. Nylon 6.6 filament was obtained from a commercial source: polystyrene filament of similar diameter was obtained to order from a contractor.

3.2 Chemical Environments

Since static fatigue in man-made fibres is commonly observed in moist air at room temperature, it was decided to examine the influence of those constituents of this environment which might be expected to react chemically or physically with the chosen materials. These constituents were: oxygen, nitrogen, moisture and acidic trace gases such as carbon dioxide and oxides of sulphur.

3.3 Physical Environments

The principal environment to be controlled was temperature. The bulk of observations were made at 30°C, near to normal ambient temperatures but sufficiently high to permit the operation of a thermostat bath without resort to a cooling circuit. Some observations were also made at 50°C to accelerate chemical reactions which might compete with the mechanical rupture process. Close control of temperature was maintained during testing: Findley (16) and Kruger (17) stress the importance of this precaution. In view of the possible influence of light (15), tests were carried out in darkness and steps were taken to avoid mechanical vibrations which Regel and Leksovskii (18) have shown can reduce life considerably in viscose, nylon 6 and polyacrylonitrile fibres as well as in zinc, aluminium and polymethylmethacrylate foils.

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4. EXPERIMENTAL

4.1 General

The conditions chosen for the investigation imposed certain experimental difficulties. The use of time-to-rupture as a criterion of failure meant that a large scatter of results was likely. Charles (10) acknowledges the magnitude of this problem: he found it necessary, in his work with glass fibres, to use 40 - 60 tests for each condition. Even this number of tests enabled him to place the most probable breaking time within no better than a half-cycle on a logarithmic-time basis. A first study of the nylon filament in the controlled atmosphere of a testing laboratory indicated that more than 100 tests might be necessary to obtain a reasonably-accurate mean life. It therefore seemed desirable to make provision for carrying out many tests at once. To enable the necessary thermostat to be fully used, it would be necessary to provide a separate enclosure for each test. Had a single enclosure been used for a number of tests, it would have been necessary to wait for the last tests to finish before opening the enclosure to use the 'dead' positions.

Zhurkov (6) and Catsiff (19) have felt that it was necessary to maintain constant stress throughout the test period. They therefore applied their stresses by wires passing over cams profiled to transmit a diminishing load to the specimen as the latter elongates. When working with atmospheres differing considerably from ambient, it is necessary to transmit the load to the enclosure by a wire or rod passing through a gland. Zhurkov admits that the provision of a frictionless gland is a difficult problem. Coleman and Knox (3) and Findley (16), believing the problem to be almost insuperable, adopted the dead-weight test, calculating stress from initial conditions and neglecting the variations introduced by the slightly different elongations in specimens at rupture. For these reasons, the dead-weight method was adopted in the present investigation. A more elaborate technique would have made test equipment with many stations prohibitively bulky, expensive and difficult to maintain at constant temperature.

The stipulation that experiments should be done in darkness presented problems in recording the time and place of failures. Photographic means could not be used while electrical methods might have proved difficult to operate in a humid enclosure. This problem was simply solved by using the upward thrust of the individual enclosure at the moment of rupture to operate an external recorder. The method of recording is described below.

The requirement of freedom from vibration proved easy to fulfil: the thermostat was mounted on foam rubber and was stirred externally by a centrifugal pump.

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4.2 Materials

4.2.1 Properties

Nylon 6.6 filament, free from additives, was obtained from Imperial Chemical Industries Ltd. (Plastics Division). Its relevant properties are given in Table 1, together with those of polystyrene filament made to order by Yarsley Research Laboratories Ltd. Quality control was by determination of breaking load on 5-cm lengths, adjusted by dividing the load by the root of the specific weight (i.e. the weight in mg. of 25 cm). This adjustment, equivalent to calculating the rupture stress for each speciment, reduced the variability of the results by allowing for the effect of varying cross-section. While this step was hardly necessary for nylon, it was essential for polystyrene if scatter in the long term test results were to be kept down to manageable proportions. Figure 1 shows the variation of breaking load with root of specific weight: excellent correlation exists over the range covered by the pecked line. Specimens for long term testing were therefore drawn only from this range of diameters. The applied stress was calculated for each test to be the appropriate fraction of the short-term (9-second) value determined from Figure 1 and the specific weight.

TABLE 1

Properties of Materials

Property		Nylon	Polystyrene	
			Overall	9 - 13 mg.
Specific weight (of 25 cm), mg.	mean	6.5	10.8	11.4
	std. dev.	0.12	3.7	0.8
	range	6.3 - 6.8	4.4 - 17.8	10.0 - 12.7
Breaking load, g. (at 20 ± 2°C, 65 ± 2% r.h. on 5 cm length, breaking in 9 ± 1 sec*)	mean	740	355	365
	std. dev.	14	48	16
	range	710 - 760	285 - 440	345 - 390
Specific breaking load [(Breaking load)/(Specific weight)$^{\frac{1}{2}}$] measured individually	mean	290	108	110
	std. dev.	5	7	2
	range	280 - 290	103 - 109	108 - 113
Elongation at break, per cent	range	25 - 30	7 - 90	19 - 27
Tensile strength, kp/mm^2**	mean	29.9	8.61	8.39
Draw ratio (from supplier)	nominal	3.5	3.0	
Polymer		polyamide 6.6	Carinex HRM (Shell) High Molecular Weight	

*breaking time applies to nylon and 9 - 13 mg. polystyrene only

**assuming densities of: nylon 1.14 g/cm^3
polystyrene 1.05 g/cm^3
(kp = kilopond = kilogramme-force).

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4.2.2 Precautions in Handling

In storing and handling the filaments, precautions were taken to prevent their being contaminated with substances which experience suggested might adversely affect their endurance under load. Previous work (20) with cotton suggested that atmospheric dust carried acidic contaminants effective in degrading cotton. Mounting was therefore carried out in an air-conditioned laboratory in which the air was filtered. Immediately after mounting, specimens were enclosed. Only forceps were used in mounting filaments since it had emerged from a comparison of E.R.D.E. and Yarsley Research Laboratories tests on polystyrene that body fat or perspiration weakened the material; handling was therefore avoided.

In early tests with nylon filaments in enclosed tubes, silicone rubber stoppers were used in the mouths of the glass bottles containing lead shot to make the load (it was felt desirable at that stage to isolate the lead shot from the rest of the enclosure). Stress life was considerably reduced in presence of the stoppers, presumably by residual peroxide curing agent with a considerable vapour pressure. A similar reduction of life was observed when phosphorus pentoxide was included as desiccant. Although slower in action than the pentoxide, the calcium oxide used throughout this investigation is almost as efficient at equilibrium. No evidence of chemical action by the alkaline earth oxide was found throughout the work.

4.3 Apparatus

To allow a considerable number of tests to be carried out simultaneously or in succession, it was decided to provide detachable mounts for filaments, a separate tube for each experiment and a multi-station thermostat bath. Loads were designed to be continuously variable in weight over a wide range. Each item is described in detail below.

4.3.1 Enclosure Tubes

The enclosure tube (Figure 2) was made of resistance glass with a thickened bottom to withstand the impact of falling loads. Evacuation and back filling was accomplished through the tube sealed into the stopper and closed by the glass vacuum cock. Joints were sealed with silicone vacuum grease. When vacua were used, joints were carefully cleaned before greasing. Tubes were carefully cleaned inside before use.

4.3.2 Load

The hooked bottle (Figure 2) was filled to the nearest 0.1 g. with clean lead shot to give the desired weight.

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4.3.3 Specimen Mounts

Specimens were attached to resistance glass hooks (Figure 3) mounted on a jig so that a reproducible gauge length of 50 ± 2 mm was obtained. The filaments were stiff and did not knot easily; the ends were therefore secured by belaying around the narrow ends of the hooks. As with filaments, the hooks, after thorough cleaning, were touched with forceps only to avoid contamination.

4.3.4 Thermostat Bath

An aluminium bath (Figures 4 and 5) was designed to hold 30 tubes in darkness within 0.1 degC of the mean operating value. A three-element immersion heater, H, provided two levels of permanent heating and a third controllable by a contact thermometer, T, working through a thermal relay in the control panel, P. A reservoir, R, containing distilled water, automatically maintained the water-level, L, while the overflow, X, prevented it from rising too high. The bath was closed by a lid locating on studs, S, and resting on an asbestos-rubber gasket which helped seal in moisture and exclude light. The automatic reservoir fed through a rubber tube and stopper assembly (not shown) which prevented light from entering by way of the reservoir and permitted the self-feeding action to be temporarily suspended while tubes were being changed. As a further protection for the bottoms of the tubes against impact, the bottom of the bath was lined with foamed polyvinyl chloride. Circulation was effected by a 200 gal/hr centrifugal electric pump drawing water from O and injecting it at I. Temperatures at specimen level were within 0.05 degC of mean at 30°C and within 0.1 at 50°C. The bath was mounted on a foamed rubber sheet on a wooden-framed pedestal. When in use, no vibration could be detected anywhere on the bath.

4.3.5 Timing Device

To make it possible to use the bath continuously and to avoid the need to open the lid frequently to look for failed specimens, a simple time recorder (Figures 5(b) and 5(c)) was devised depending on the upward thrust of the enclosure tube in the bath at the moment of rupture. The device consisted of a shallow aluminium tray mounted, as in Figure 5(b), at an angle of 7° to the main axis of the lid of the thermostat bath and perforated above each test position to permit free upward movement of the push rods (see inset in Figure 4). The tray carried a roll of paper (indicated in Figure 5(c) by a dotted line) which was pulled at 0.7 cm/hr from its holder, under the steel roller, E, by the spiked roller, D, driven by a clock, C. Another steel roller above D held the paper taut against the surface of the tray. The inclination of the tray gave a separate recording track for each push rod, as indicated for a few by the arrows in Figure 5(b). The upward movement of the push rod at rupture

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punctured the paper in the appropriate track. From the position of the puncture and that of a mark made above the rod concerned at the time of first loading, the length of a filament's life could be determined. For lives longer than 24 hours, the necessary additions were made. Time of rupture could be read to the nearest 15 minutes. Shorter times could be observed aurally and the position checked visually. The device proved very reliable.

4.4 Environments

4.4.1 Assembling and Preconditioning Enclosure Tubes

As mentioned in Section 4.2.2, assembly was done in an air conditioned test room at 20 ± 1°C and 65 ± 2 per cent relative humidity. Specimens, attached to hooks as in Section 4.3.3, were placed in the enclosures by connecting one hook to a load resting with its curved neck projecting from the mouth of a horizontal tube. The other hook was attached to the curved inlet-tube of the stopper, and the enclosure carefully inclined to slide the load inwards. The stopper was allowed to follow so that no tension was applied to the specimen. When the stopper was in place the cock was closed. Tests to be done in humid air were then conditioned horizontally in a thermostat at the appropriate temperature, the cock being momentarily opened after some time to reduce the internal pressure to atmospheric. Where other environments were to be used, the tube was evacuated, back-filled, evacuated again and finally back-filled with the desired gas. In the case of the vacuum environment, of course, no back-filling was necessary. Details of the methods used to obtain other environments follow in the next sections.

4.4.2 Dry Air

15 g. of pure calcium oxide was charged into a clean, dry tube by means of a thistle funnel attached to a long glass rod. The tube was inverted over the funnel containing the desiccant, both were turned over and the funnel carefully withdrawn, leaving the oxide in the bottom of the tube.

4.4.3 Dry Nitrogen

Calcium oxide was added as above, the tube was evacuated to 0.01 mmHg on a vacuum line for 30 minutes and back-filled with high purity nitrogen. This operation was repeated before laying the tube in the preconditioning bath.

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4.4.4 Vacuum

A tube containing a specimen and load only was evacuated to 0.01 mmHg for 4 hours, stored for 24 hours at preconditioning temperature then evacuated again to 0.01 mmHg for 30 minutes. This procedure was continued for a week. Those tubes which showed a tendency to leak to pressures higher than 0.02 mmHg were dismantled, cleaned and reassembled with fresh specimens. Pressure was measured at the end of each static fatigue test in vacuo. Where pressure exceeded 0.05 mmHg, the test was disregarded. Tests under vacuum were restricted to short times (not longer than one week) and to 30°C because of difficulty in meeting vacuum requirements beyond these conditions.

5. RESULTS

5.1 Distribution of Stress Lives

Because of the large degree of scatter associated with long-term loading tests, it was necessary to obtain reliable statistical data on the distribution of lives under stress. Preliminary experiments with the nylon filament indicated that stresses greater than 26 kp/mm² were liable to cause instantaneous failure on loading. A series of 30 tests was therefore run at this level in humid air at 30°C: the results are given in Table 2.

TABLE 2

Lives (hours) of Nylon Filaments at 26.0 kp/mm² in Humid Air at 30°C

1.4	2.2	2.8	3.2	4.2	5.6
1.5	2.4	2.8	3.4	4.4	5.6
1.9	2.6	2.9	3.4	4.5	6.9
2.0	2.7	2.9	3.5	4.8	7.4
2.2	2.7	3.1	3.6	5.1	8.5
Median 3.2			Arithmetic Mean 3.7		

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These results are plotted as a histogram in Figure 6(a). The distribution is decidedly skew with considerable divergence between median and mean values. A logarithmic transformation was applied with result shown in Figure 6(b). The distribution is more nearly normal and median and mean at 0.50 and 0.52 (log values) are almost coincident. A further 90 tests were carried out under the same conditions and statistical parameters were calculated for the first 60 results and for the total population (Table 3). Histograms are shown in Figures 6(c) and 6(d).

TABLE 3

Statistical Parameters of Distribution of Logarithms of Stress lives of Nylon Filaments at 26 kp/mm² in Humid Air at 30°C

Set	Number of tests (n)	Mean	Standard Deviation (σ)	Standard error of estimate ($\sigma/\sqrt{n}$)	95 per cent Confidence Interval [$2(\sigma/\sqrt{n})$]
1	60	0.531	0.203	0.026	0.052
2	120	0.527	0.197	0.018	0.036

Calculations were made from this data of the number of tests needed to establish differences between such populations with various degrees of certainty. The confidence interval was fixed at twice the standard error of estimate, corresponding to 95 per cent certainty of detecting a difference within these limits on either side of the mean. "Student's" t distribution was used, with two values of "t" (5 per cent corresponding to "probably significant" and 1 per cent corresponding to "significant") to find the number of samples needed to establish these levels of significance. The formula used was

$$t = \frac{|\bar{X} - \bar{x}|\sqrt{n}}{\sigma}$$

where $|\bar{X} - \bar{x}|$ is the difference (without regard to sign) between the population mean and the sample mean, i.e. the confidence interval. The results of the calculations are given in Table 4 (p. 11).

/TABLE 4 .....

TABLE 4

Numbers of Tests Needed to Establish Given Levels of Significance of Differences Between Sets of Results

Set used (Table 3)	1		2	
Values of "Student's" t	1.98	2.56	1.96	2.51
Significance level, per cent	5	1	5	1
Number of tests needed	58	96	118	200

The larger number of tests obtained from the data of Set 2 reflect the narrower confidence interval (Table 3) obtained with that data. The smallest number of tests entered (58) is associated with a 95 per cent chance that the value of "t" (1.98) will not be exceeded in successive sets of experiments. The confidence interval (0.052) for this set of data is some 10 per cent of the mean value (0.531): there is a further 95 per cent chance that the sample mean will fall within this interval on either side of the population mean. Thus with 58 samples there is an overall chance of 90 per cent (95 x 95/100) that a probably significant difference between sets of results could be detected. This was accepted as a sufficiently good criterion in the present investigation.

Similar analyses were made for the other reference condition for nylon (humid air at 50°C) and for polystyrene in humid air at 30°C. 60 samples sufficed for nylon throughout but polystyrene needed 97 (say 100) to assure the same level of certainty in the results. Throughout the investigation, results were plotted in histogram form (after log transformation to ensure that distributions were approximately normal and that the above statistical techniques were applicable). Examples are given Figures 7(a) and 7(b).

Tests were carried out at various stress levels as well as in various environments. The results are given in Tables 5 - 8 as the logarithm of the lives in hours, for convenience in statistical manipulation. In each entry, the arithmetic mean of the logarithms of stress lives is followed by the standard deviation.

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5.2 Stress Lives of Nylon Filament at 30°C

Stress lives were determined in dry air at three stress levels and in dry nitrogen at two levels. The length of experiments *in vacuo* was restricted, as stated earlier, because of the difficulty of obtaining a good vacuum for long periods of time. The logarithms of stress lives in hours were used throughout in calculation, as previously mentioned. Results obtained at 30°C are given in Table 5. Insufficient time was available to carry out a long-term test in nitrogen as well as air.

TABLE 5

Logarithmic Stress Lives of Nylon Filament at 30°C

Environment	Initial Stress, kp/mm²		
	26.0	24.0	22.0
Humid air	0.53 ± 0.20	1.63 ± 0.61	2.35 ± 0.87
Dry air	0.49 ± 0.19	1.78 ± 0.64	2.51 ± 0.78
Dry nitrogen	0.57 ± 0.27	1.49 ± 0.57	-
Vacuum	0.55 ± 0.16	1.54 ± 0.63	-

5.3 Stress Lives of Nylon Filament at 50°C

Tests were made in humid air, dry air and dry nitrogen but not *in vacuo* because of the difficulty in holding vacua at this temperature. Stress levels were changed slightly to allow for the effect of the increased temperature.

TABLE 6

Logarithmic Stress Lives of Nylon Filament at 50°C

Environment	Initial Stress, kp/mm²		
	25.0	23.0	21.0
Humid air	0.46 ± 0.17	1.24 ± 0.48	1.98 ± 0.70
Dry air	0.51 ± 0.19	1.29 ± 0.46	1.86 ± 0.63
Dry nitrogen	0.49 ± 0.17	1.36 ± 0.53	1.80 ± 0.68

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5.4 Stress Lives of Polystyrene Filament at 30°C

Considerably lower stresses were used with this material because of its lower load-bearing ability than nylon. Tests were restricted to 30°C because it was found that only very small loads could be sustained at 50°C. The weight of the standard load-bottles (about 100 g.) was of the order needed to produce failure within minutes at 50°C. The present technique was therefore unsuitable for studying this material at that temperature. The results obtained at 30°C are given in Table 7 (100 tests for each condition and load).

TABLE 7

Logarithmic Stress Lives of Polystyrene Filaments at 30°C

Environment	Initial Stress, kp/mm²		
	7.50	7.20	7.10
Humid air	0.64 ± 0.30	1.71 ± 0.67	2.58 ± 1.04
Dry air	0.59 ± 0.32	1.67 ± 0.63	2.70 ± 0.98
Dry nitrogen	0.69 ± 0.39	1.59 ± 0.61	2.44 ± 0.89
Vacuum	0.57 ± 0.90	1.79 ± 0.72	2.39 ± 0.93

5.5 Significance of Results

"Student's" t was calculated for each modified environment at each stress level, using the results obtained in humid air as the standard for reference. Values of "t" for nylon and polystyrene are given in Tables 8 and 9 respectively.

/TABLE 8 .....

TABLE 8

Values of "Student's" t for Stress Life Distributions of Nylon Filaments

Environment	Temp., °C	Initial Stress Level, kp/mm²					
		26	25	24	23	22	21
Dry air	30	1.6		1.8		1.5	
Dry nitrogen	30	1.3		1.8			
Vacuum	30	0.9		1.1			
Dry air	50		2.1		0.8		1.4
Dry nitrogen	50		1.4		1.8		2.0

TABLE 9

Values of "Student's" t for Stress Life Distributions of Polystyrene Filaments at 30°C

Environment	Initial Stress, kp/mm²		
	7.5	7.2	7.1
Dry air	1.6	0.6	1.2
Dry nitrogen	1.5	1.9	1.5
Vacuum	2.0	1.2	1.9

The value of "t" at the 5 per cent (probably significant) level for both 60 and 100 degrees of freedom is, to the first place of decimals, 2.0. This value is exceeded only once in the 22 values of "t" given above. This single excursion into the "probably significant" region is consistent with a random occurrence within the "t" distribution and need not, therefore, be taken to indicate a genuinely significant difference in this case. If "Student's" t is calculated for other inter-environmental comparisons this value of 2.0 is exceeded several times, e.g. for nylon in dry air and dry nitrogen at 26 kp/mm² and 30°C the value is 2.9. Such large results do not, however, occur systematically. There is therefore no reason to believe them significant above the level stipulated in Section 5.1.

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From the generally low level of the values of "t" in Tables 8 and 9, it must be concluded that none of the environmental changes used in the study produces a significant change in life for the polymers studied, under equal stress conditions. It might be expected that the life of nylon in humid air would be less than in dry conditions, since it is common experience that absorption of moisture by hygroscopic materials reduces their tensile strength (as determined by short-term loading methods). No such difference is apparent in the results. This apparent discrepancy between short and long-term behaviour has been observed for nylon by Coleman and Knox (3) who found that, although the initial elongation under dead-weight load was higher for wet than for dry nylon fibres, no change in mean life could be detected at equal stress levels.

6. CONCLUSIONS

From the statistical conditions chosen for the investigation, it can be concluded, from the values of "Student's" t found by comparison with results obtained in humid air, that the constituents of air (nitrogen, oxygen, moisture and acidic trace gases) likely to produce chemical action on nylon and polystyrene, are without effect at 30°C in both cases and at 50°C also for nylon. The statistical conditions would have permitted detection of a 10 per cent change in stress life with change in atmosphere in 9 cases out of 10.

The use of filtered air as the primary environment excluded from the study the effects of air-borne dust acting as a carrier of potentially corrosive oxides of sulphur. With the reservation of this case, it can be concluded that contact with air is not the cause of the phenomenon of static fatigue observed in polymers.

7. ACKNOWLEDGEMENTS

The author wishes to thank Dr. H. Warburton Hall, formerly Superintendent Materials 1, for suggesting the work and for continued interest in it. It is also desired to thank Dr. W.M. Garvie for assistance in obtaining the nylon filament and for helpful discussions.

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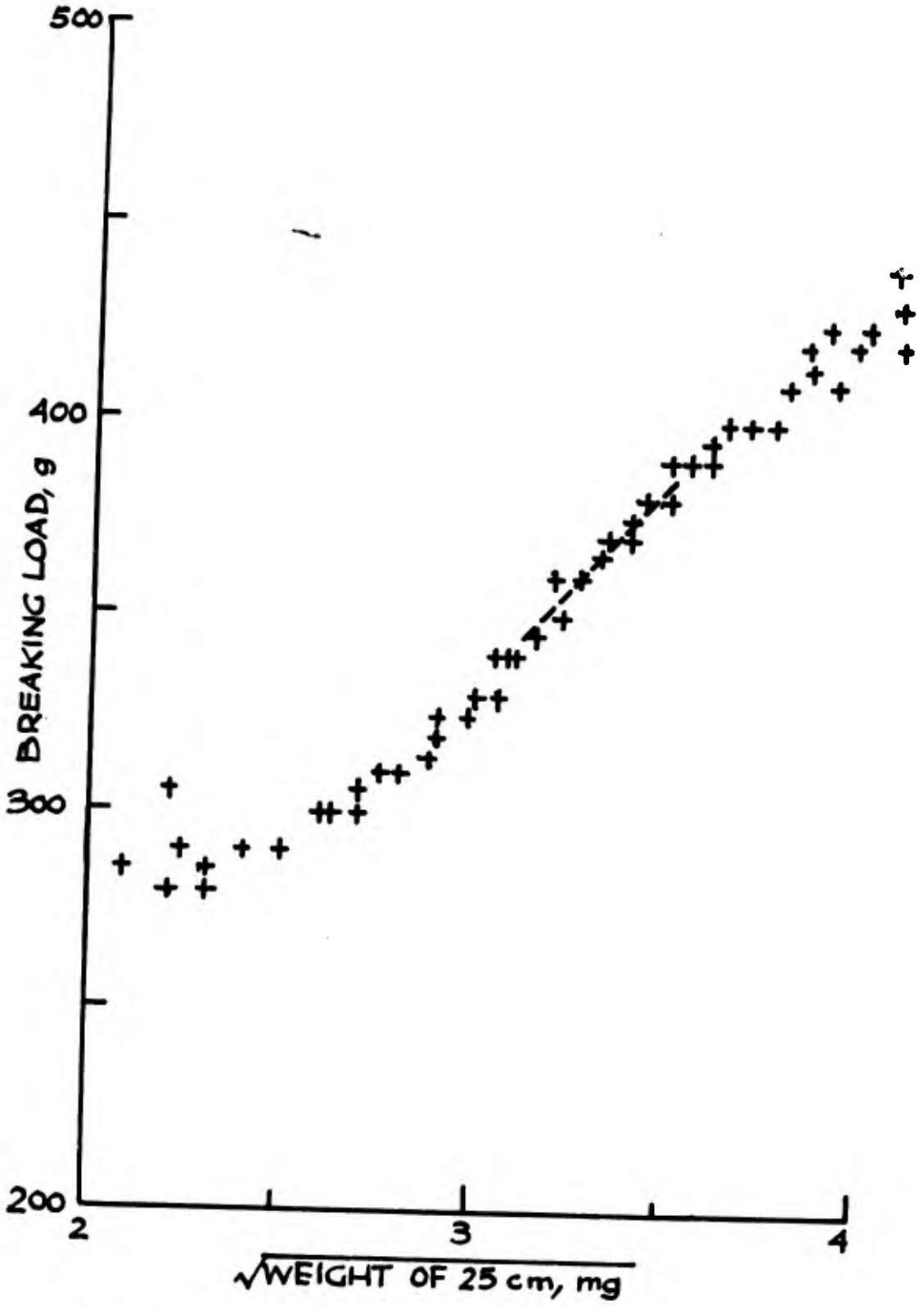


FIGURE 1. VARIATION OF BREAKING LOAD WITH WEIGHT PER UNIT LENGTH (POLYSTYRENE FILT)

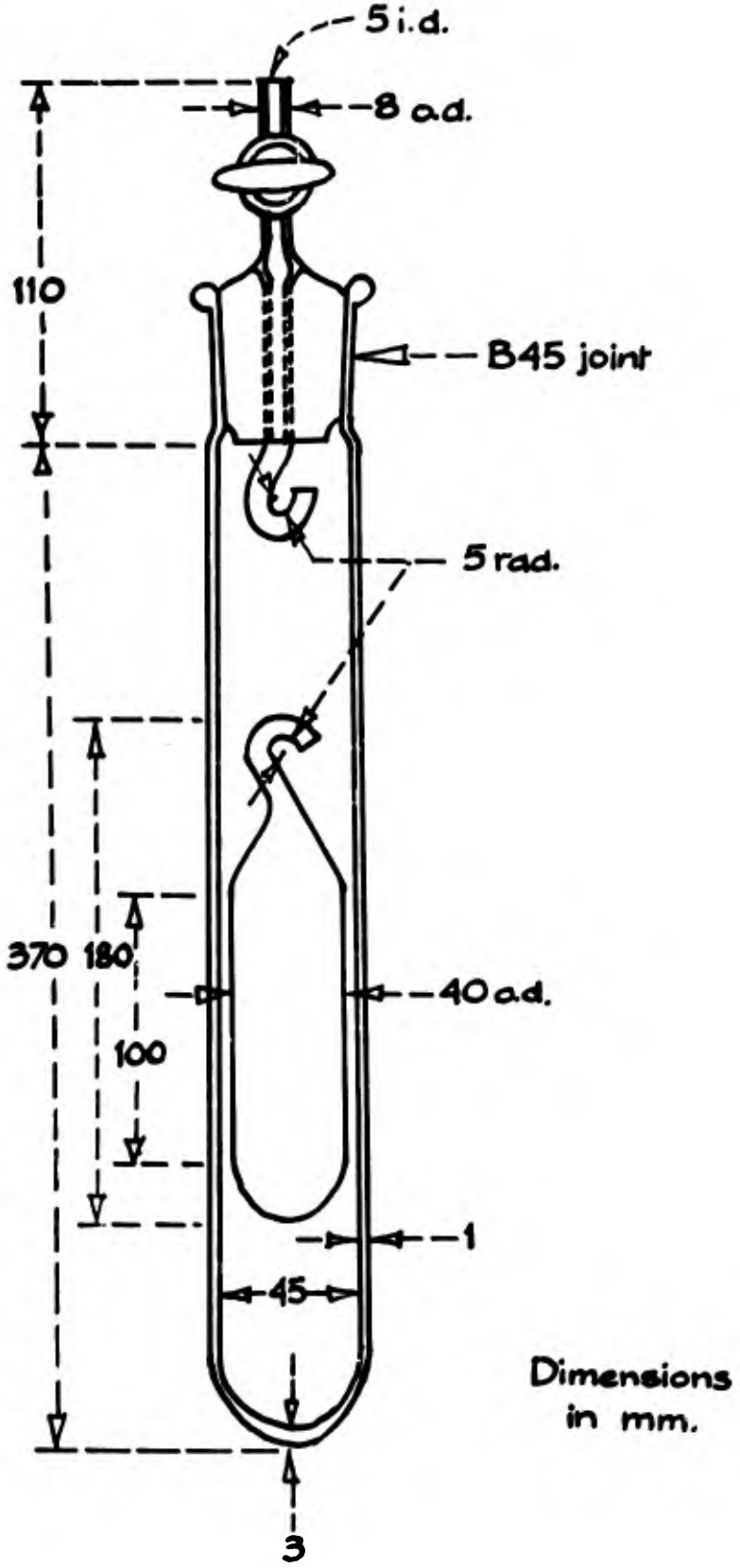


FIGURE 2. TEST ENCLOSURE & LOAD

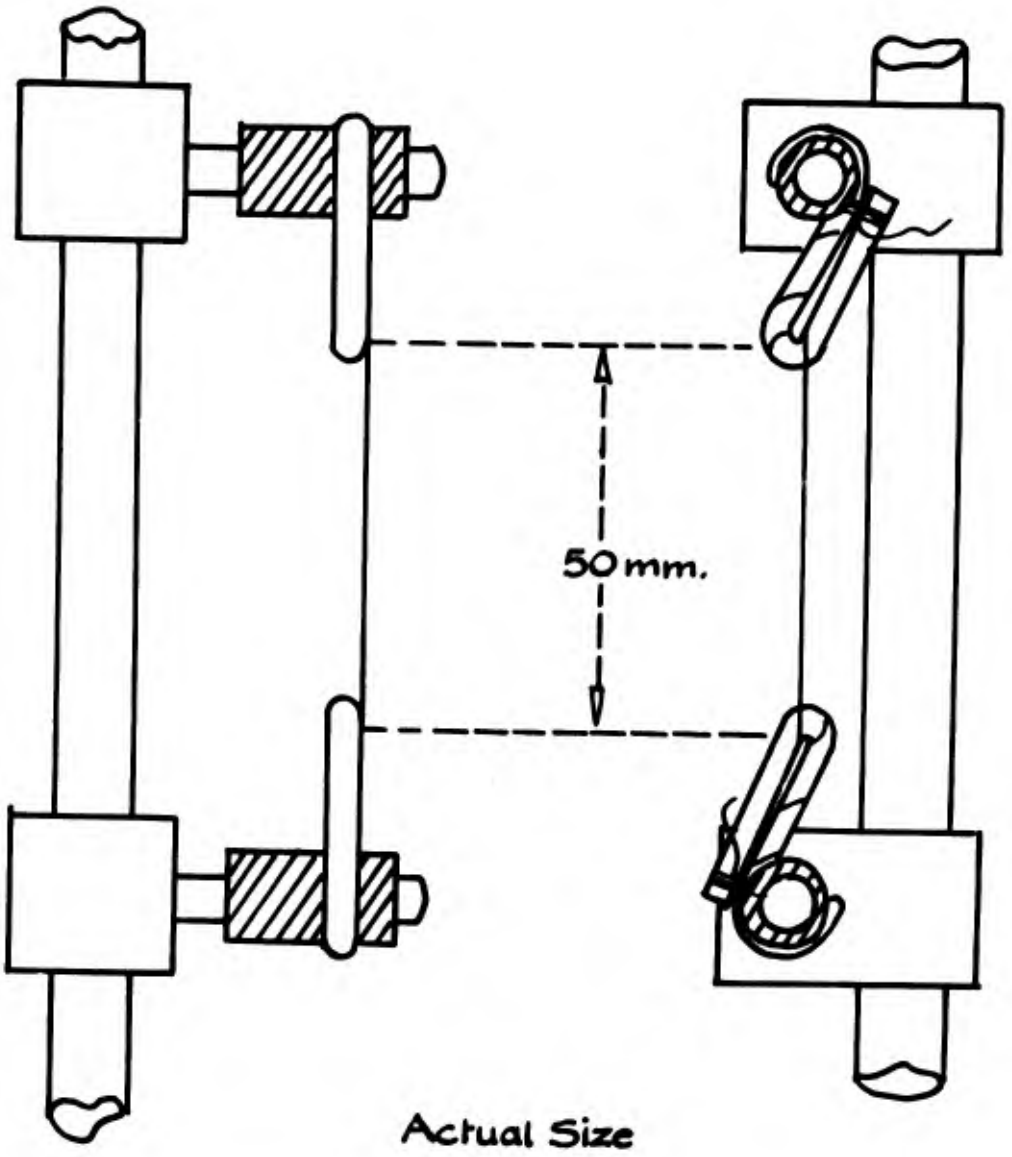


FIGURE 3. MOUNTING FOR FILAMENT

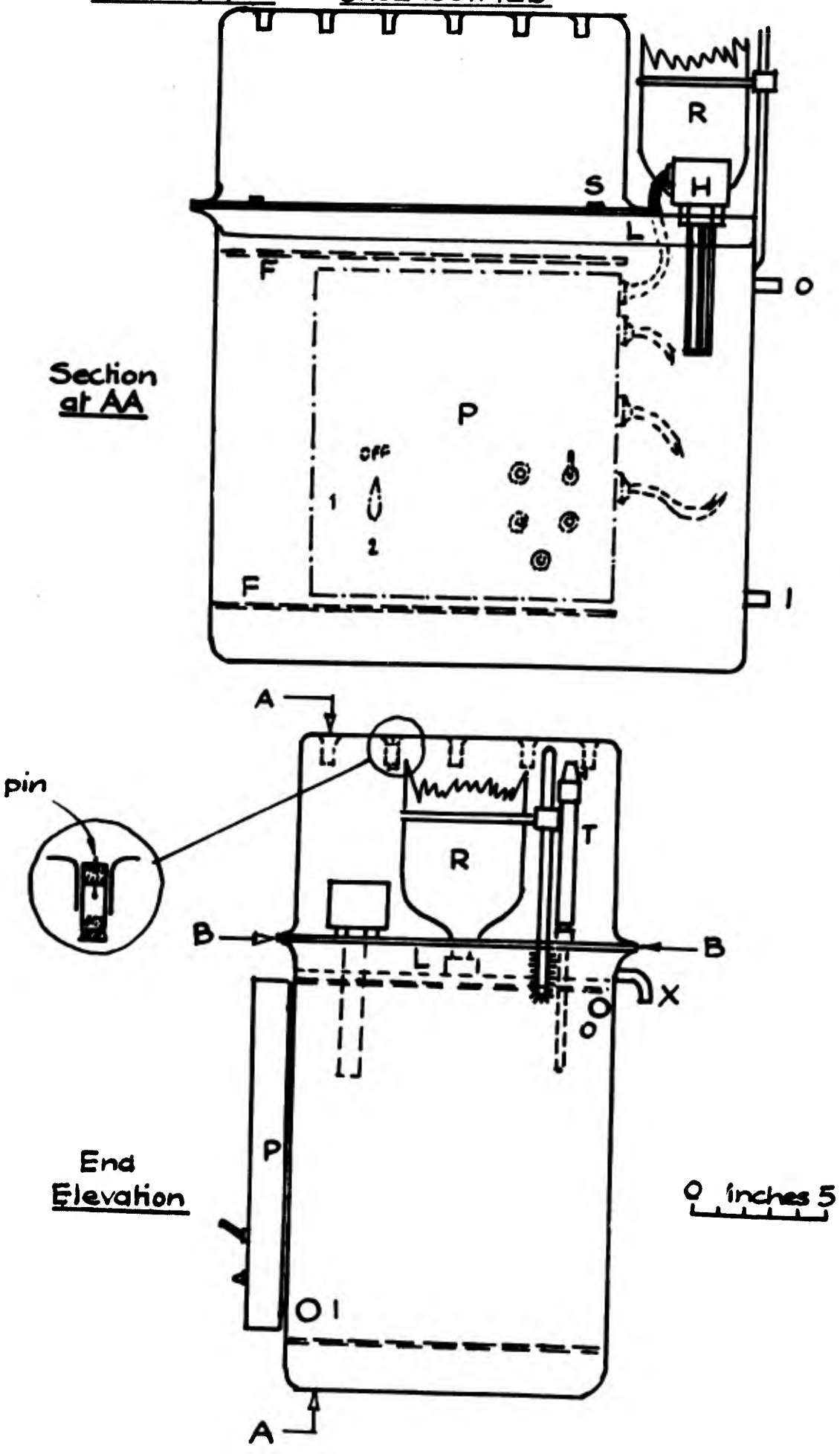


FIGURE 4. LIGHTPROOF THERMOSTAT

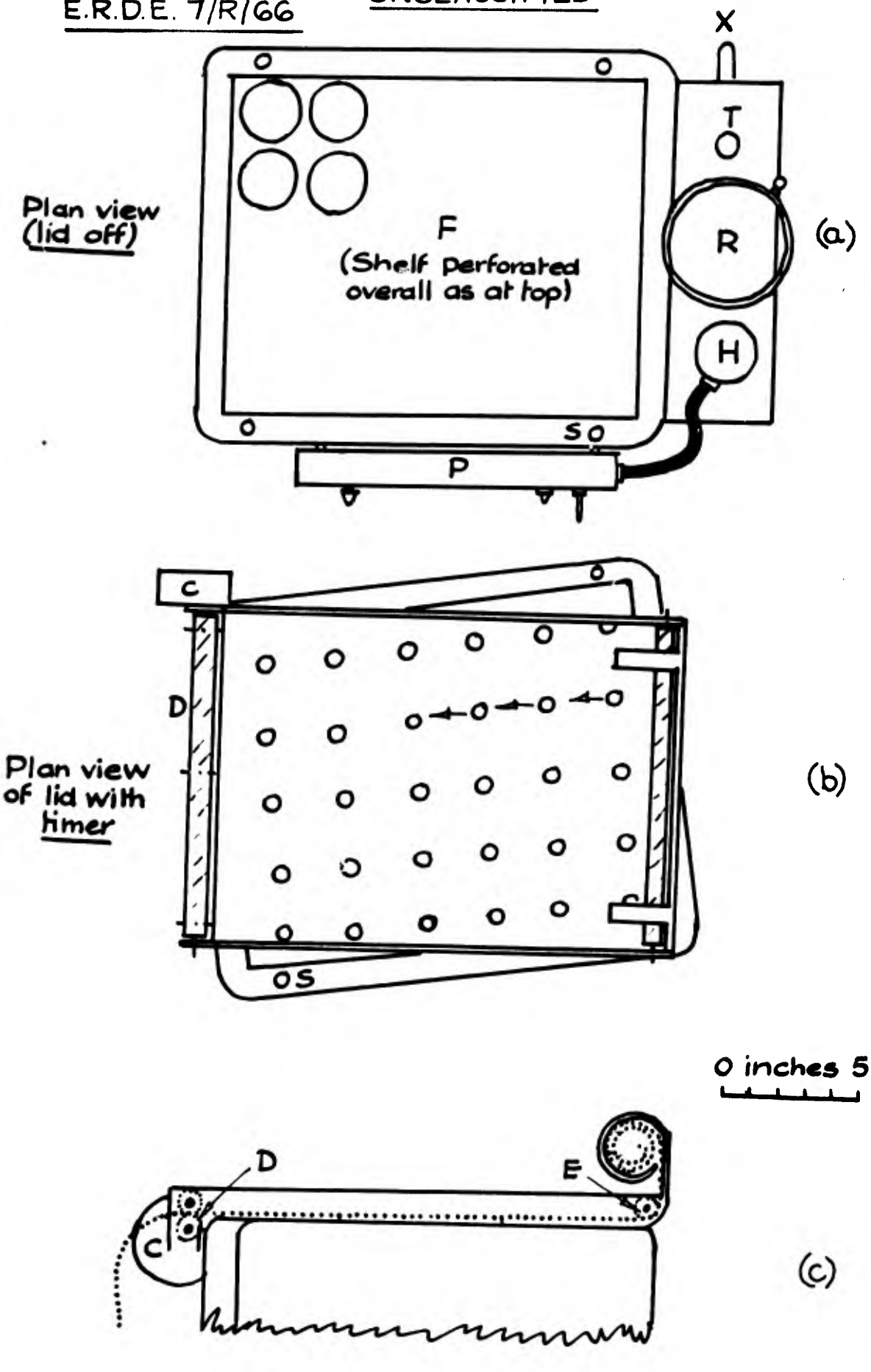


FIGURE 5. THERMOSTAT & TIMER

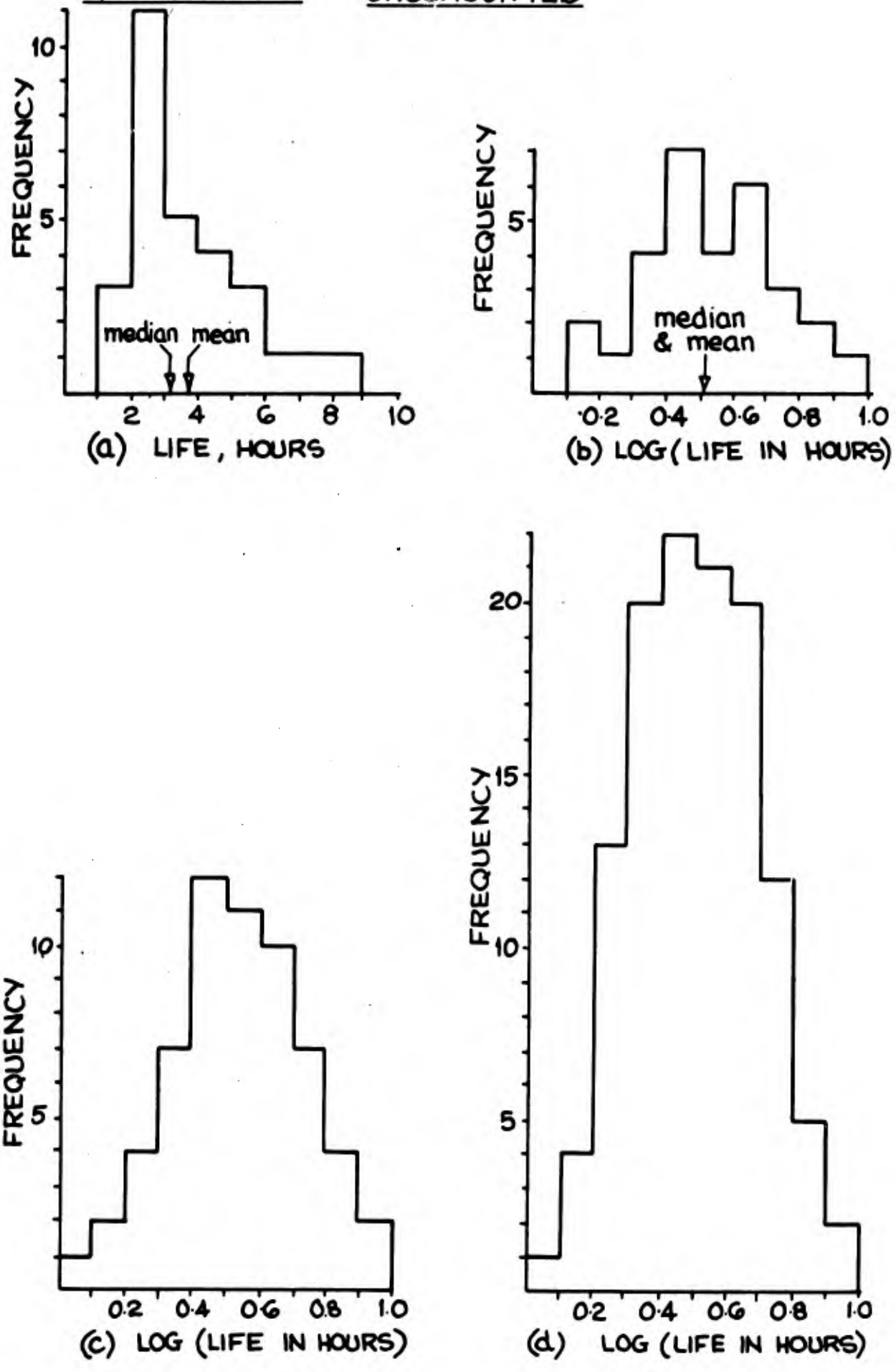
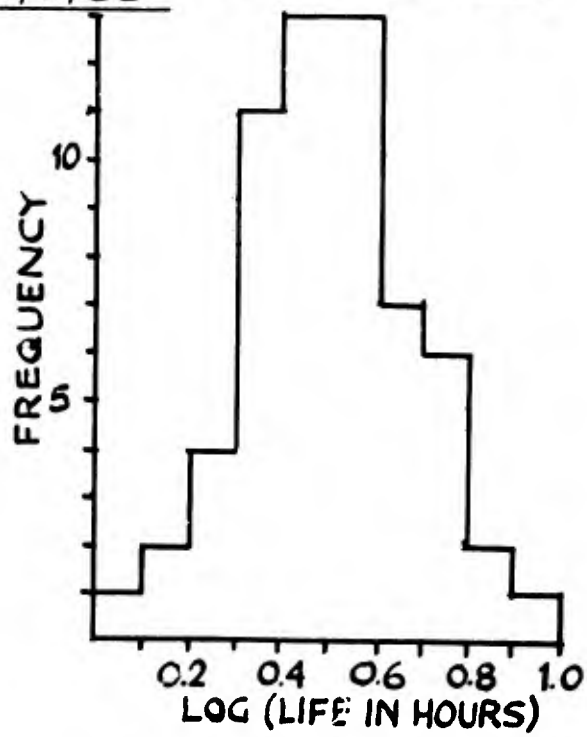
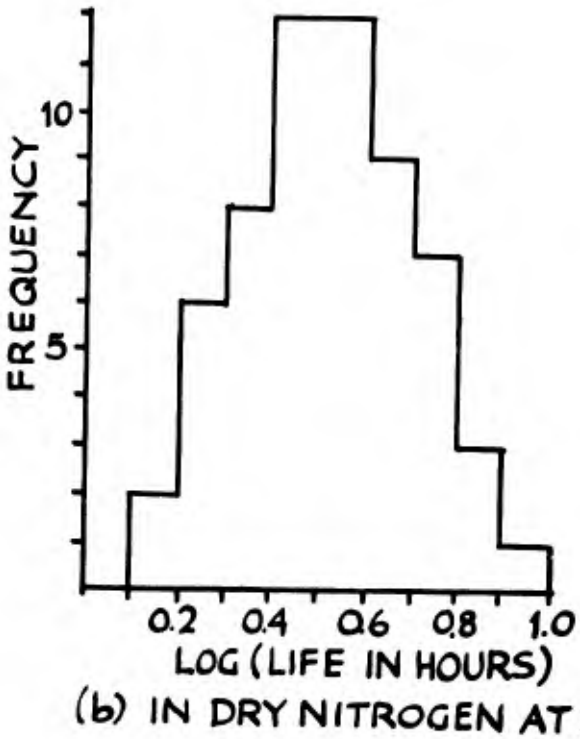


FIGURE 6. STRESS LIFE DISTRIBUTION FOR NYLON IN HUMID AIR AT 30°C.



(a) IN DRY AIR AT 30°C



(b) IN DRY NITROGEN AT 30°C

FIGURE 7. STRESS LIFE DISTRIBUTIONS FOR NYLON MONOFILS