THE APPLICATION OF STATISTICAL TECHNIQUES TO INSULATION AGING TEST

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RINGKASAN

Kertas kerja ini membentangkan cara-cara untuk mendapatkan maklumat hayat dan daya ketahanan sesuatu penebat. Maklumat dan dada-data yang diperolehi masih lagi dalam keraguan atau belum boleh dibuat ketetapan disebabkan oleh perselisihan perangkaan pada keputusan ujian, justeru itu keputusan daripada ujian-ujian dinilai dengan menggunakan kaedah-kaedah perangkaan. Kaedah-kaedah ini ialah grafik dan kebolehjadian maksima. Dibentangkan juga di sini perbandingan di antara kedua-dua kaedah tersebut. Bahan penebat padat yang digunakan untuk ujikaji ini adalah polychloroprene (P.V.C.) dan polypropylene.

ABSTRACT

In this paper, methods for obtaining the information on the life and endurance of the insulating materials are presented. The information obtained is compounded by uncertainties due to statistical variance of the test results, hence the results of the tests are therefore evaluated by statistical techniques. These methods are known as graphical and Maximum Likelihood methods. Comparisons between the two methods are presented here. The solid insulating materials subjected to test are polychloroprene (P.V.C.) and polypropylene.

1. Introduction

An accelerated aging test is an accepted method of estimating the long term, or service life, characteristics of solid electrical insulation. In this test, a component's life is shortened by the application of stresses much greater than would occur in normal service. Voltage is the most important factor in the high voltage insulation, in the case of failure by electric freeing mechanism.

Hence, accelerated aging tests on solid insulation are often performed at voltage much higher than normal operating voltage, resulting in breakdown or "end of life" in a short – time, say a few hours or days.

There are two common accelerated aging test procedures:

(a) The constant – stress test and (b) the progressive or stepped – stress test. In the constant – stress test, the applied voltage is held constant and the time to breakdown noted. The stepped – stress test consists of raising the voltage is steps until the specimen fails. The result of the latter method is the voltage required to puncture the specimens. The stepped – stress test appears to be most popular accelerated aging method since all the specimen can be forced to fail in a reasonably short– time even though the failure mechanisms may conceivably change during the test. The results from an accelerated life test can be used to estimated the service life of an insulation system directly. This can leave doubts due to the compounding of test uncertainties. More commonly, test are performed to compare two types of insulations which differ by manufacture and chemical composition etc. The insulation which passes the test, should than be expected to give long service. If service experience has been obtained with one of the insulations tested, qualitative service – life estimation of the other tested insulations is then possible.

1.1 Theory

Application of the probalistic theory.

The electric breakdown time and the electric field necessary to result in breakdown of solid insulation, is best represented by a Weibull probability distribution function.

The cumulative Weibull distribution function [1] can be given by:

$$F(t) = 1 - \exp\left[\frac{t-\gamma}{\alpha}\right]^{\beta} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where α, is the scale parameter.
β, the shape parameter.
γ, the location parameter variable, and
t, the random variable, usually time to breakdown or the electric field required to puncture the dielectric where the electric increases linearly with time.

In the paper by Simoni [2], it is stated that the distribution function of the failure probability has the form

$$\phi(t, G) = 1 - \exp(-\alpha G^{b} t^{a}) \quad \ldots\ldots\ldots (2)$$

where a, b and α are constants (parameter of the distribution equation (2)). If G is constant we obtain the distribution function of the failure times, similar to equation (1). If 't' is constant we get that of the failure gradient, both are Weibull distributions from equation (1), F(t) indicates the proportion of specimens initially tested which will fail by time t (voltage is applied at t = O). The scale parameter (α) represents the time required for $(1-e^{-1})$ or 63.2 per cent of the tested units to fail. The shape parameter (β) is a measure of dispersion of the failure times from t = α. The parameter γ indicates the time from voltage application in which failure of any unit is not possible. Therefore equation (l) is written for $t > \alpha$ and

$$F(t) = O \text{ for } O < t \leqslant \gamma$$

The unit of α and β is time (or electric field when this is the random variable), while β is dimensionless. The location parameter (γ) is usually taken to be zero (a two – parameter distribution).

The most common techniques employed in engineering to estimate α and β is a graphical method using Weibull probability technique and Maximum Likelihood techniques. The details of the technique is explained in appendix I.

From equation (2) Simoni [2], mentioned that by plotting in the Weibull paper (log log $(1/(1-\phi))$, log x), we then obtained straight line in both cases the slope of the straight line of the failure lines is 'a', that of the failure gradient 'b'. As stated in (1) 'a' is a measure of aging and it is called "the aging coefficient".

2. Experimental Procedure

This test was conducted on solid insulating materials, namely P.V.C. and Polypropylene. The constant test was used to test polypropylene because this insulating material cannot be made to puncture in a short – time due to its long breakdown time. On the other hand P.V.C. can be made to breakdown by employing progressive or stepped – stress. In this test small and medium size samples were required to be punctured, whether subjected to prestressing or not. The electric strength cell was used for puncturing the samples and the breakdown voltage was registered by the voltmeter.

3. Discussions

3.1. Breakdown of nonprestressed small size sample of polychloroprene.

	$\bar{\beta}$	$\bar{\alpha}$(Kv/mm)	b
Graphical method	4.04	52.0	3.49
Maximum Likelihood	3.21	135.4	

The graphs are shown in Fig 1, 2 and 3. The values obtained by the Maximum Likelihood method is shown in appendix I.

3.2 Breakdown of polychloroprene, prestressed at 31.0Kv/mm for 22hrs.

	$\bar{\beta}$	$\bar{\alpha}$ (Kv/mm)/b	
Graphical method	4.42	57.0	3.33
Maximum Likelihood	4.412	58.52	

The graphs are shown in Fig. 4, 5 and 6.

3.3 Breakdown data on medium size sample of nonprestressed polychloroprene.

	$\bar{\beta}$	$\bar{\alpha}$ (Kv/mm)	b
Graphical method	4.213	50	4.267
Maximum Likelihood	4.39	40.82	

The graphs are drawn in Fig. 7 and 8.

3.4 Breakdown data on medium no. polychloroprene, prestressed at 34 Kv/mm. for 33 hours and 13 minutes.

	$\bar{\beta}$	$\bar{\alpha}$ (Kv/mm)	b
Graphical method	4.213	50	4.267
Maximum Likelihood	4.39	40.82	

The graphs are drawn in Fig. 9 and 10.

3.5 Breakdown data on small no. nonprestressed polypropylene based on constant stressing at 41.44 Kv/mm.

	$\bar{\beta}$	$\bar{\alpha}$ (mins)	b
Graphical method	0.3	212	0.288
Maximum Likelihood	0.4557	14.43	

The graphs are drawn in Fig. 11.

The values of the distribution parameter for the small no. of P.V.C. samples are shown in sections 3.1 and 3.2 for the cases of nonprestressing and prestressing. The values obtained for $\bar{\beta}$, $\bar{\alpha}$ and b showed that there is remarkable difference in terms of the solid electrical insulation characteristic between nonprestressed and prestressed solid insulating materials. The difference in values of $\bar{\beta}$ and $\bar{\alpha}$ obtained by Graphical Method and Maximum Likelihood is quite large.

This is so because, the line drawn for the Graphical Method is based on judgement of the eye. The value of $\bar{\beta}$ obtained from this method is then used to calculate $\bar{\beta}$ in the Maximum Likelihood Method but data from section 3.2 is very satisfactory.

The distribution parameters for medium no. P.V.C. samples for the cases of nonprestressing and prestressing are shown in section 3.3 and 3.4.

The data of $\bar{\beta}$ and $\bar{\alpha}$ in the Section 3.3 by the two methods are quite different whereas in section 3.4 the values of $\bar{\beta}$ and $\bar{\alpha}$ are quite near to each other. From the Fig. 7 the best fitted line for the points of the graph according to the judgement of the eye leads to a very large value of $\bar{\beta}$ whereas the line drawn in Fig. 9 is not the best fitted one but provides the values of $\bar{\beta}$ and $\bar{\alpha}$ from the two methods within reasonable limits of accuracy.

In section 3.5, the distribution parameters polypropylene was shown. In this case, the values of $\bar{\alpha}$ for the two methods are very far from each other. From the graph in Fig. 11 is scrutinised, it is quite possible that 63.2 per cent of the whole samples break down before 14 minutes moreover from Fig. 11, many possibilities of lines can be drawn from the given points on the graph. For each possible line drawn, a different value of $\bar{\alpha}$ is obtained. It is possible to obtain the value of $\bar{\beta}$ = 0.4557 and $\bar{\alpha}$ = 14.43 minutes, as shown in Fig. 11 which is obtained by Maximum Likelihood Method.

4. Conclusions

The statistical analysis of insulation breakdown for P.V.C. and Polypropylene in this work can be summarised as follows:

(a) The Maximum Likelihood method is quite a powerful technique to calculate $\bar{\alpha}$ and $\bar{\beta}$. This requires only a modest computer time and storage applicable to any number of sample breakdowns or censoring.

(b) Even though the graphical parameter gives a statistical estimates of $\bar{\beta}$ and $\bar{\alpha}$, but they can be used to obtain the initial values for the Maximum Likelihood computation and to see if the experimental data is reasonably represented by the Weibull Distribution.

(c) The Weibull distribution is a general distribution which can fit a wide variety of data, however with an advantage of being flexible, caution should be taken when dealing with experimental data with apparently large deviations in order to avoid misa-judgements of various factors influencing dielectric systems.

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6. References

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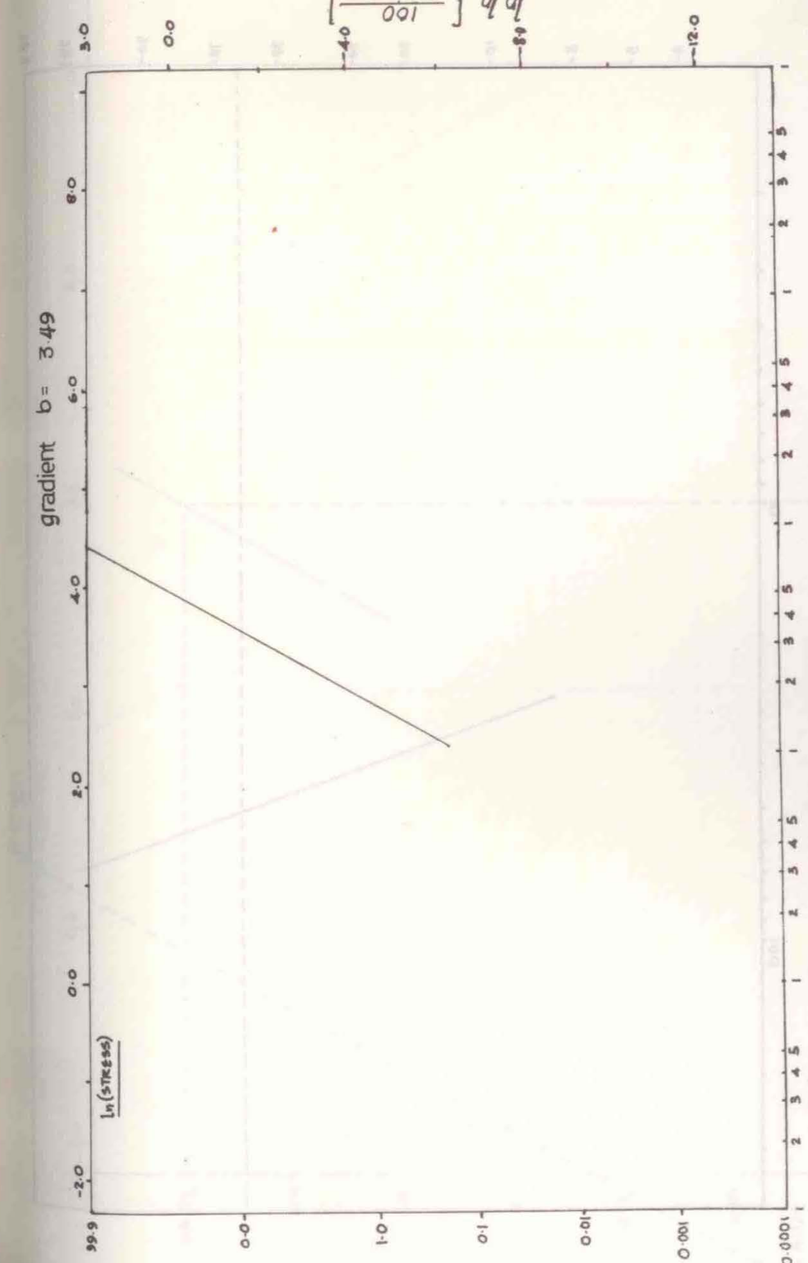


FIG 1 : GRAPH OF ln ln $\left[\frac{100}{100-F(ti)}\right]$ AGAINST ln (STRESS)

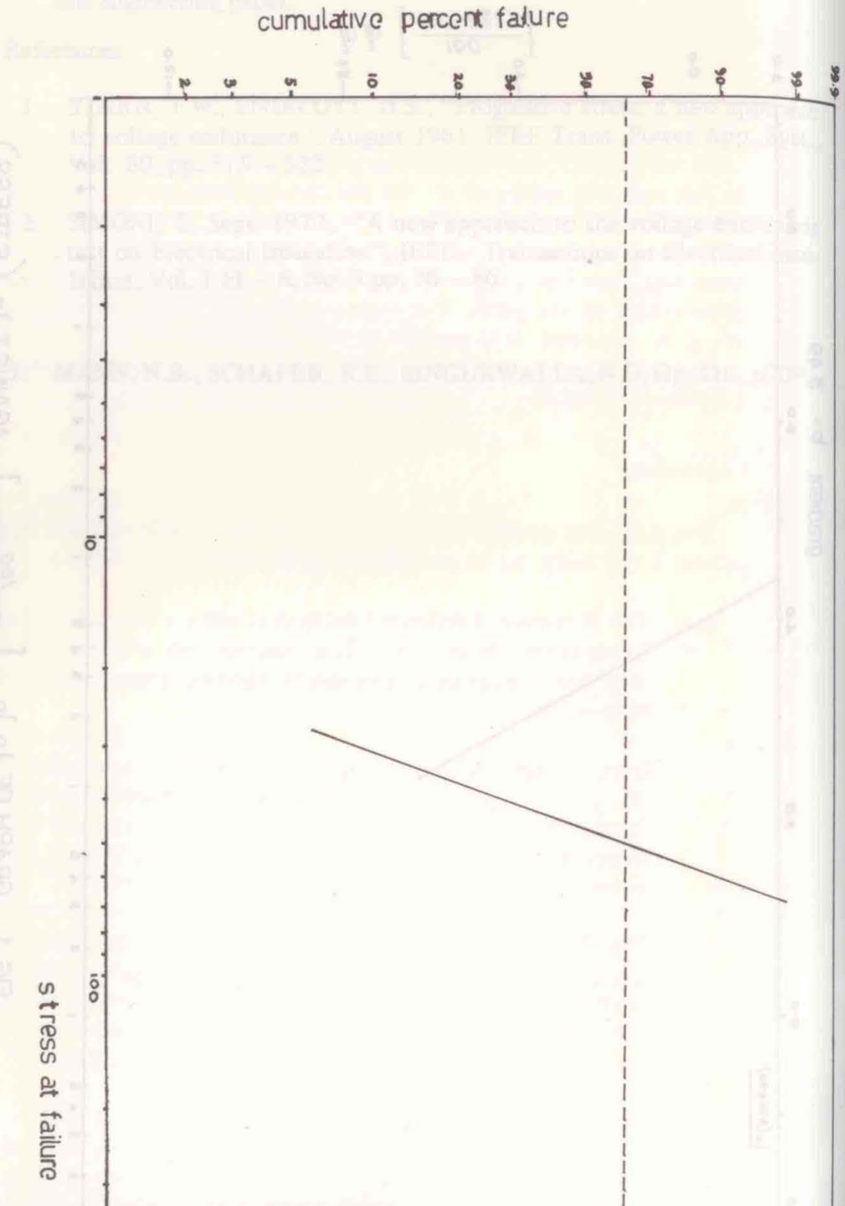
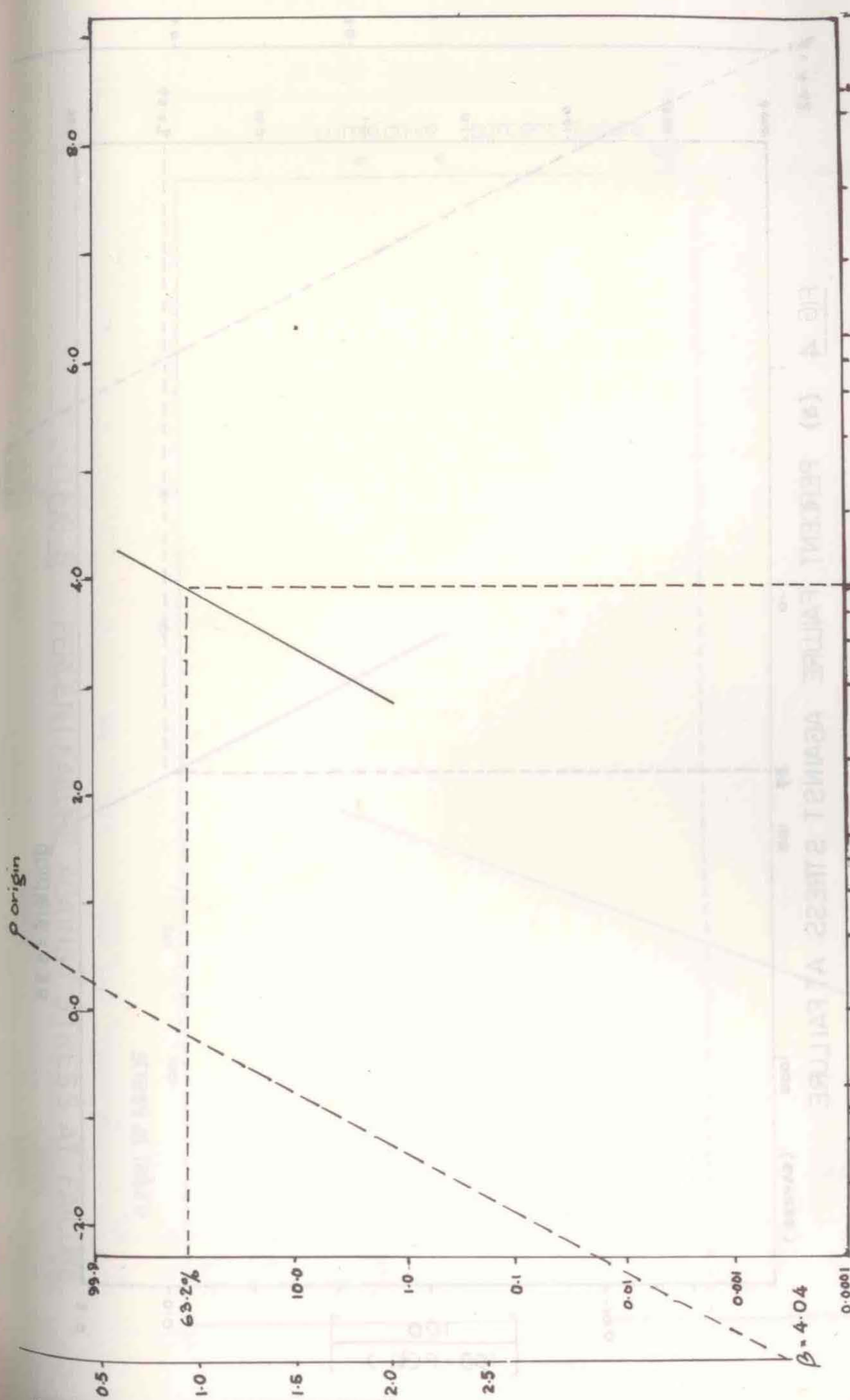


FIG. 2 : PERCENT FAILURE AGAINST AT FAILURE



stress at failure

FIG.3 PERCENT FAILURE AGAINST STRESS AT FAILURE

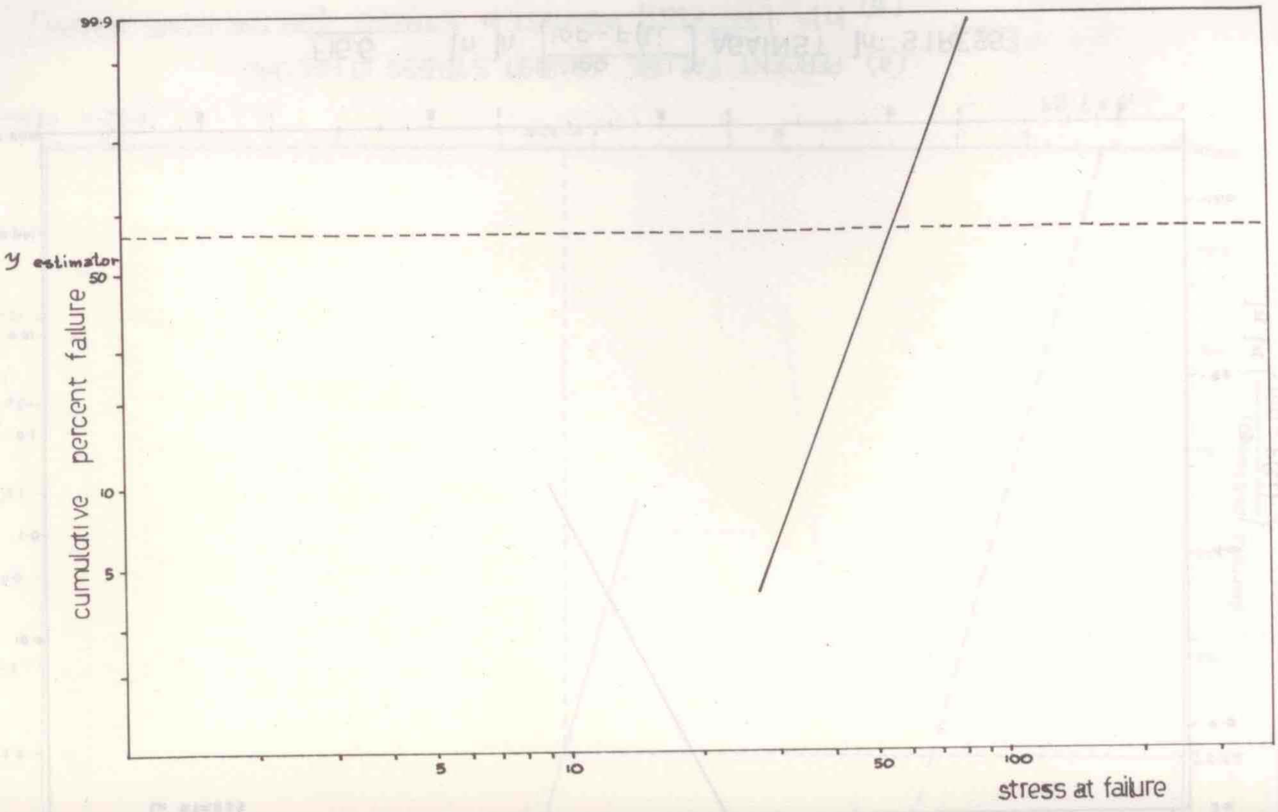


FIG. 5 PERCENT FAILURE AGAINST STRESS AT FAILURE

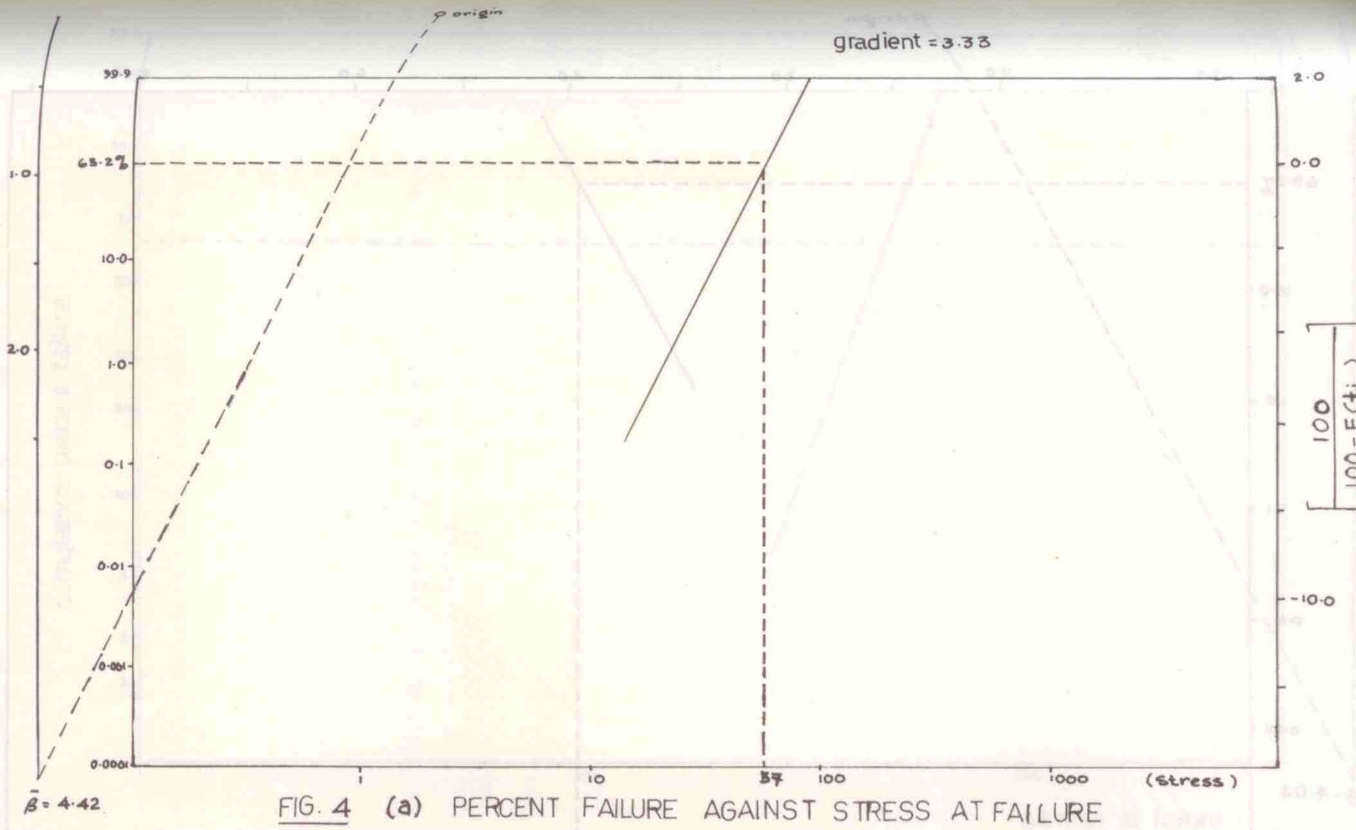


FIG. 4 (a) PERCENT FAILURE AGAINST STRESS AT FAILURE

(b) $\ln \ln \left[\frac{100}{100 - F(t_i)}\right]$ AGAINST $\ln$ STRESS ON THE SAME LINE

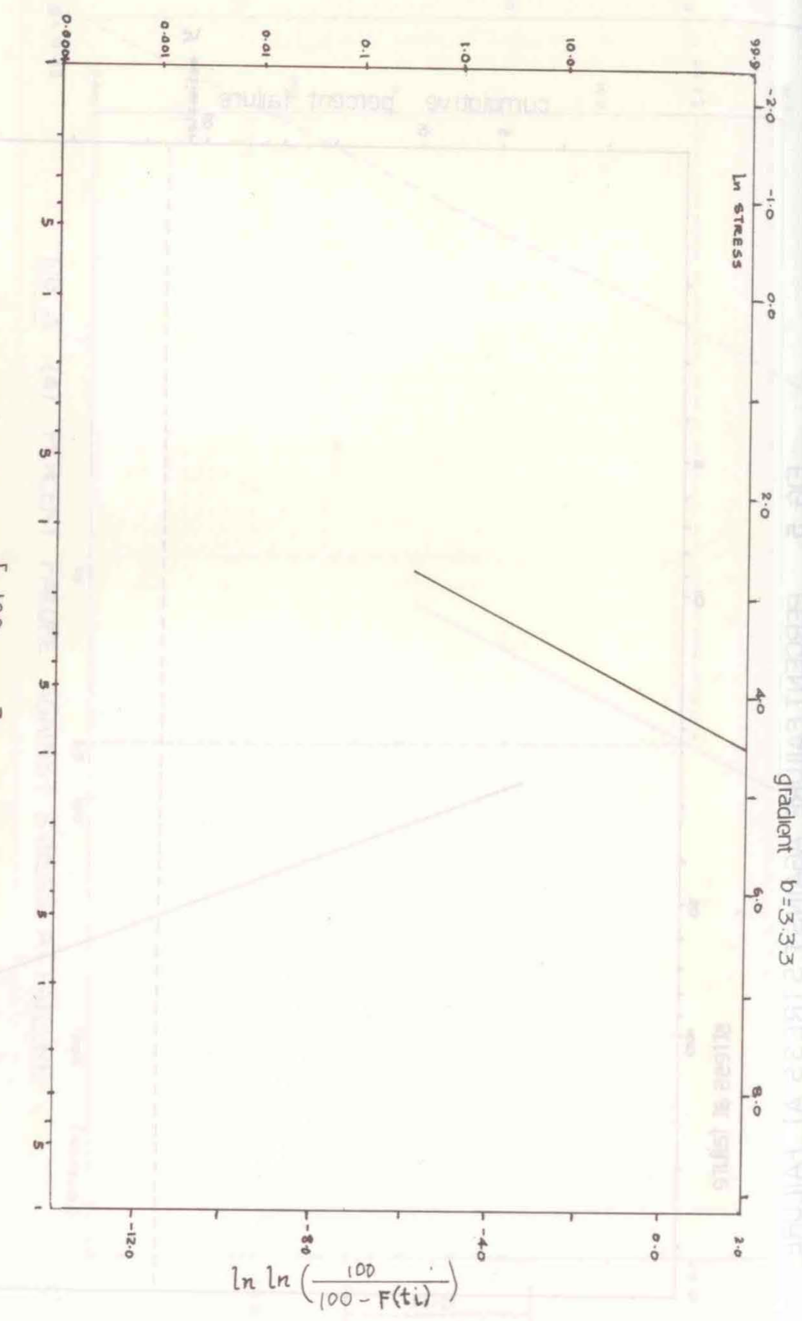


FIG.6 ln ln $\left[\frac{100}{100 - F(ti)}\right]$ AGAINST ln STRESS

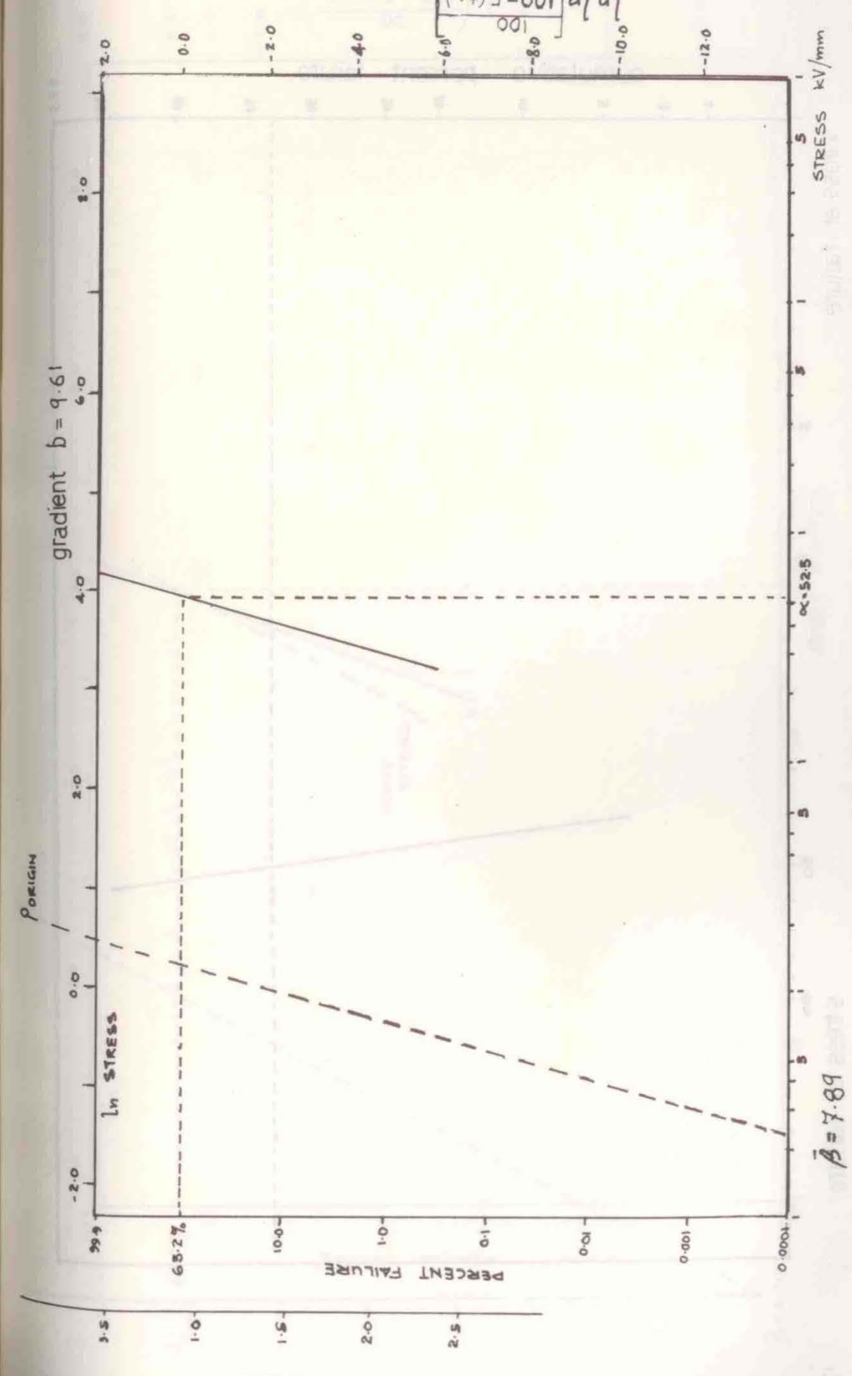


FIG.7 (a) PERCENT FAILURE AGAINST STRESS AT FAILURE
(b) ln ln $\left[\frac{100}{100 - F(ti)}\right]$ AGAINST ln STRESS [ON THE SAME GRAPH]

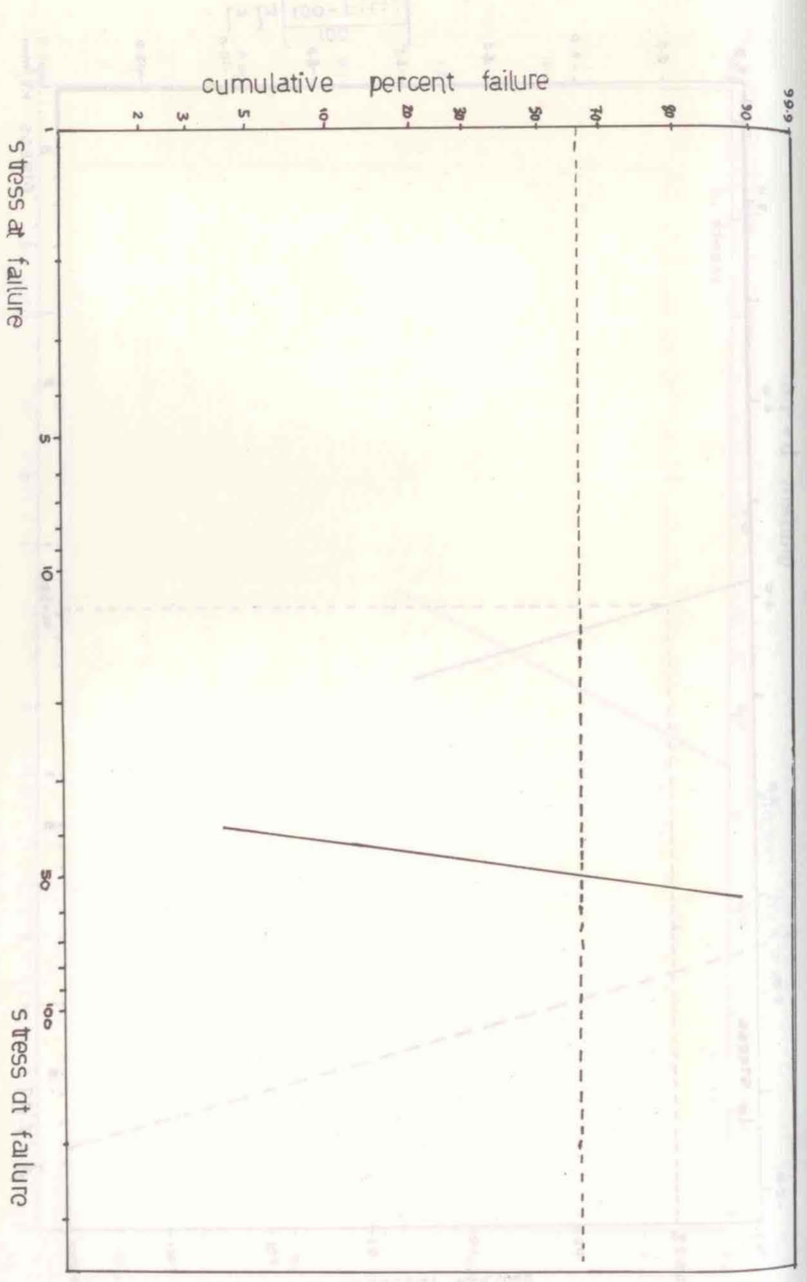


FIG.8 PERCENT FAILURE AGAINST STRESS AT FAILURE

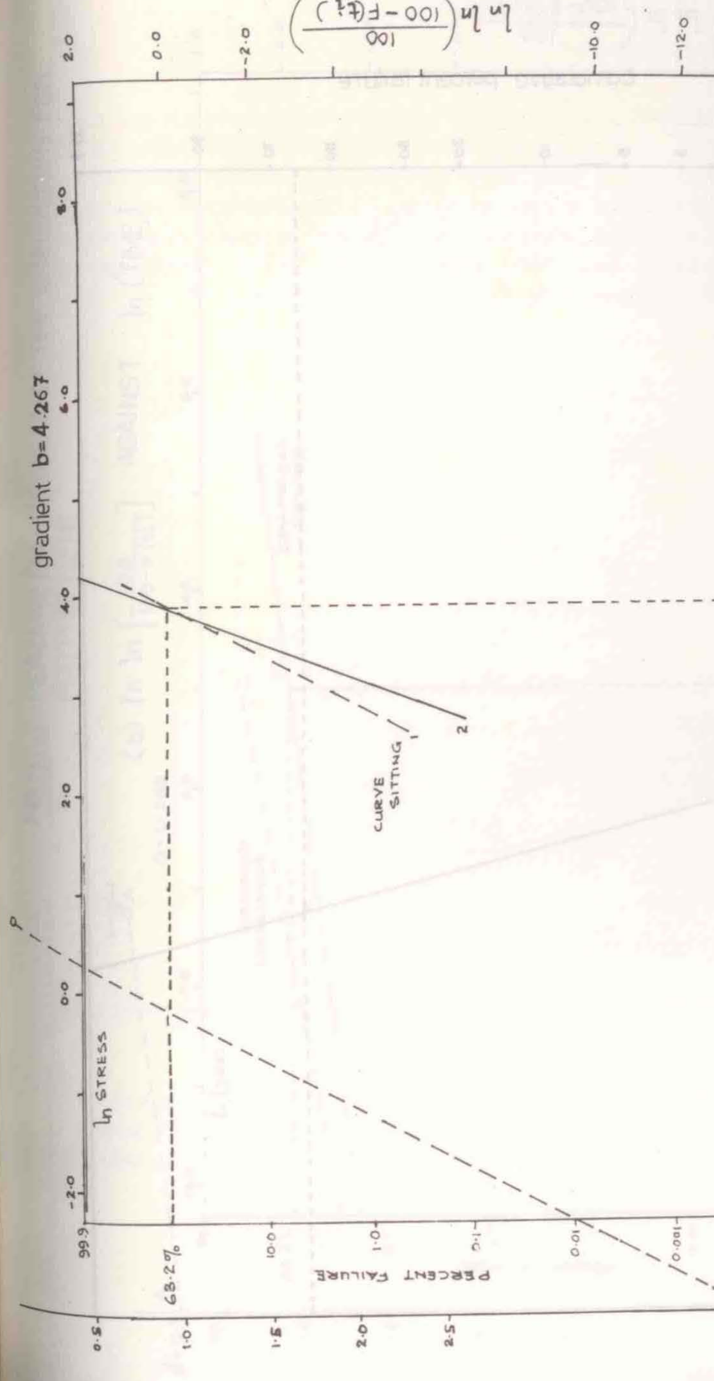


FIG.9 (a) PERCENT FAILURE AGAINST STRESS AT FAILURE

(b) $\ln \ln\left[\frac{100}{100-F(t_i)}\right]$ AGAINST ln (STRESS) ON THE SAME LINE

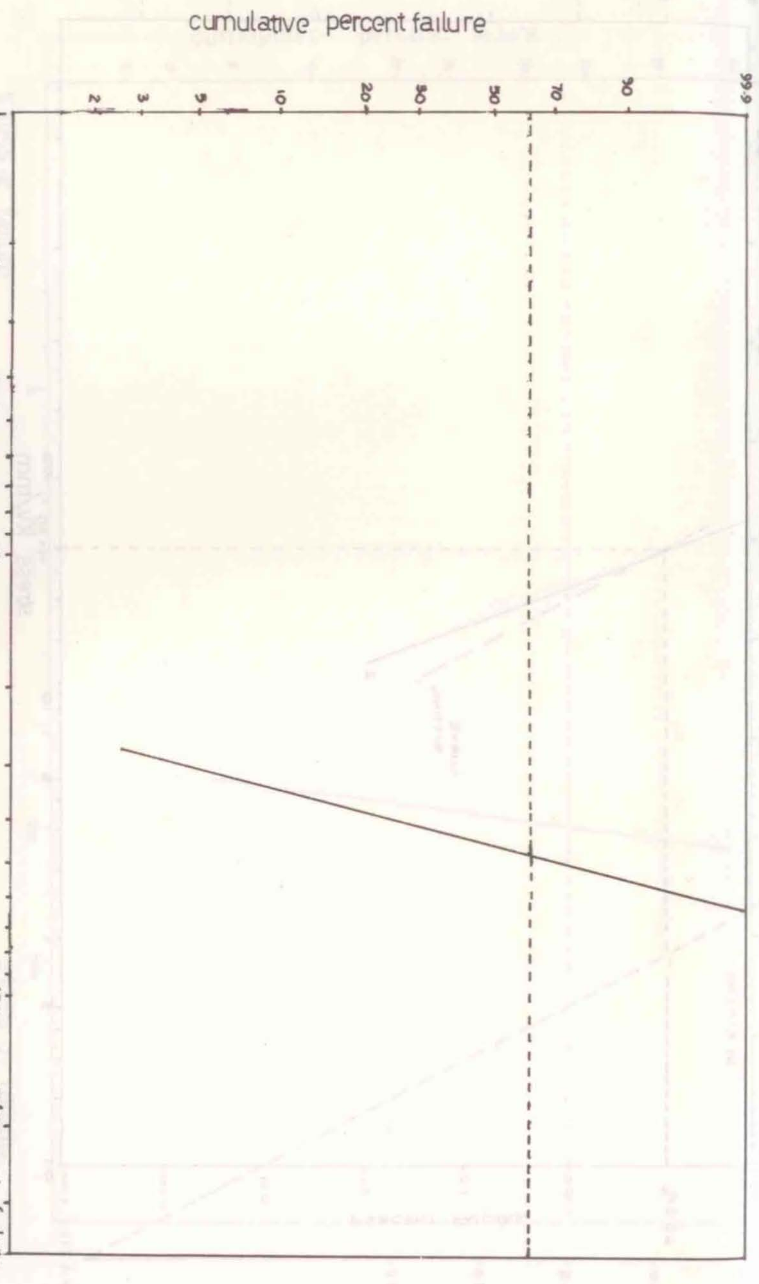


FIG. 10 (a) PERCENT FAILURE AGAINST STRESS AT BREAKDOWN

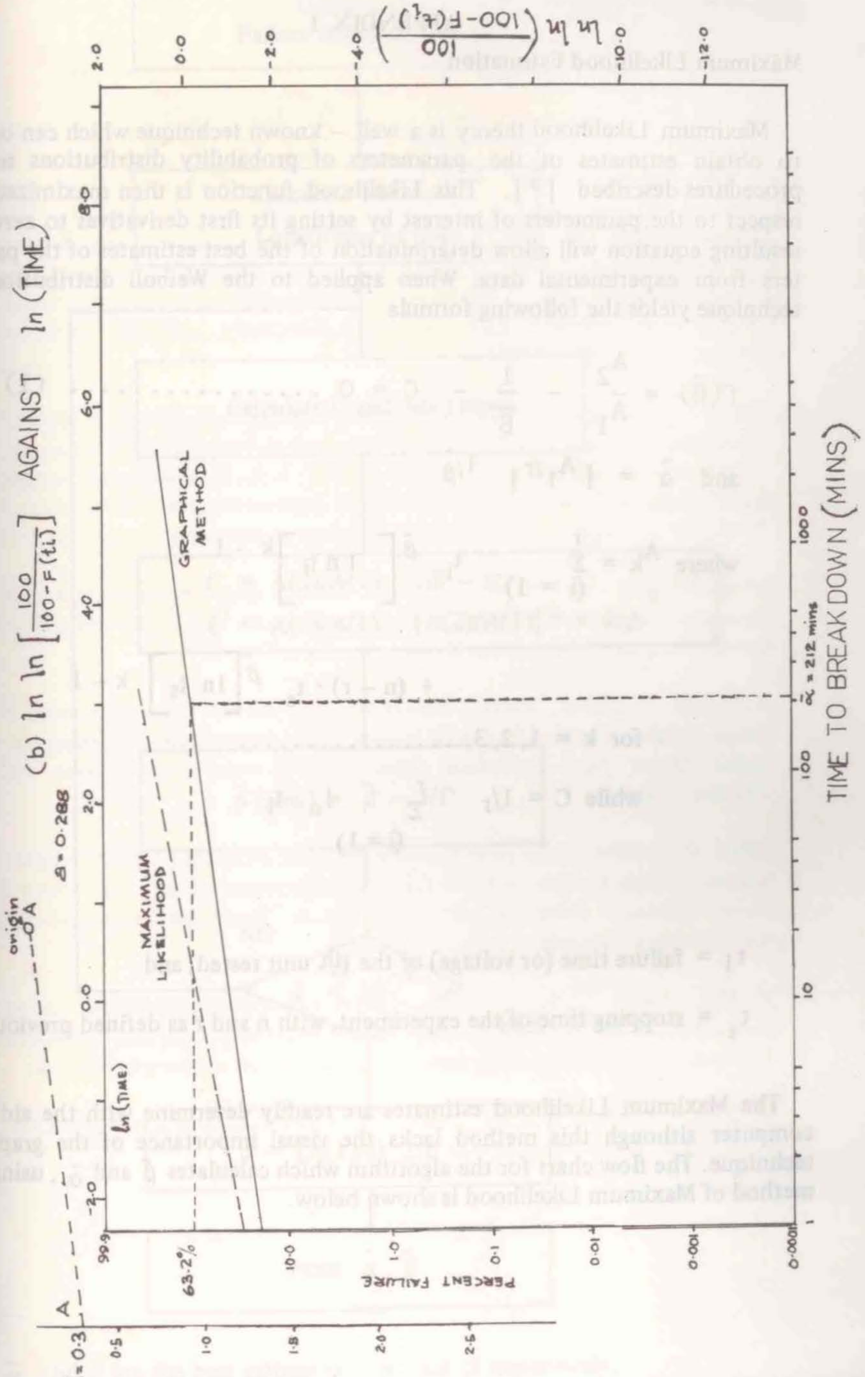


FIG.11 (a) PERCENT FAILURE AGAINST TIME TO BREAKDOWN FOR POLYPROPYLENE

(b) $\ln \ln \left[\frac{100}{100-F(t_i)}\right]$ AGAINST $\ln(\text{TIME})$

APPENDIX I

Maximum Likelihood Estimation

Maximum Likelihood theory is a well – known technique which can be used to obtain estimates of the parameters of probability distributions to the procedures described [3]. This Likelihood function is then maximized with respect to the parameters of interest by setting its first derivatives to zero. The resulting equation will allow determination of the best estimates of the parameters from experimental data. When applied to the Weibull distribution this technique yields the following formula

$$f(\bar{\beta}) = \frac{A_2}{A_1} - \frac{1}{\bar{\beta}} - C = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

and $\bar{\alpha} = [A_1/r]^{1/\bar{\beta}}$

where $A_k = \sum_{(i=1)}^{r} t_i^{\bar{\beta}} \left[\ln t_i \right]^{k-1}$

$$+ (n - r) \cdot t_s^{\bar{\beta}} \left[\ln t_s \right]^{k-1}$$

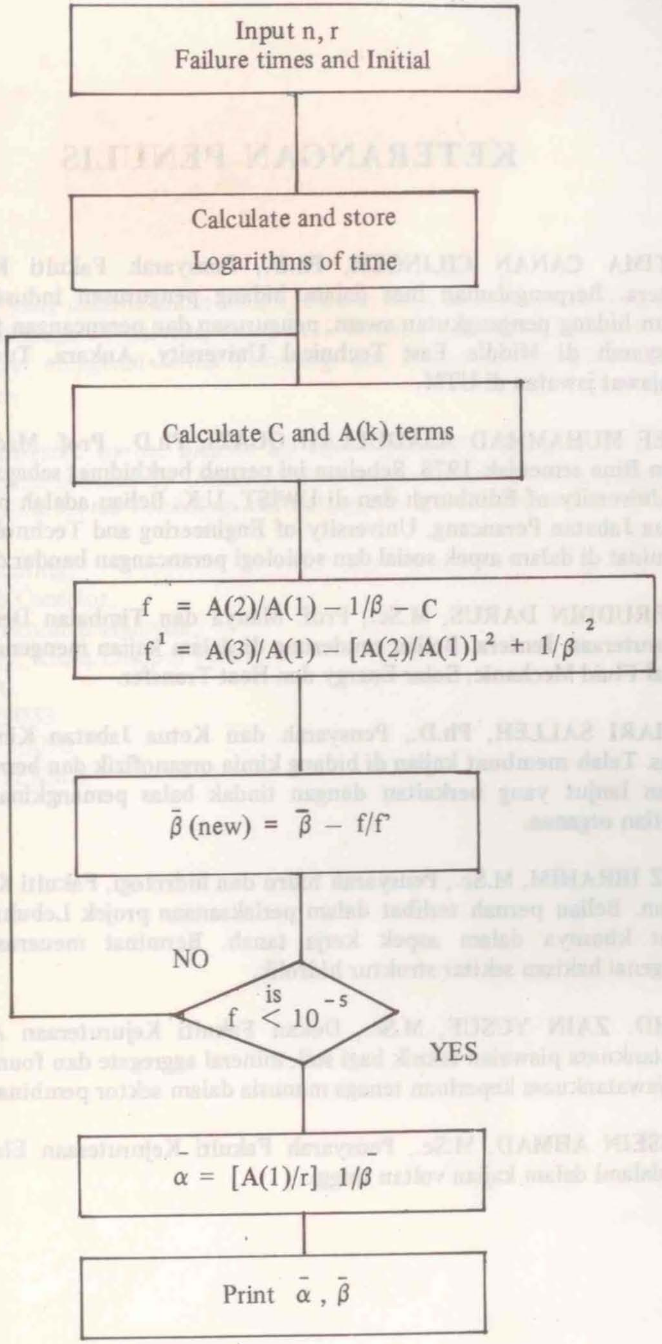
for $k = 1, 2, 3, \ldots\ldots\ldots\ldots\ldots$

while $C = 1/r \sum_{(i=1)}^{r} \ln t_i$

t_i = failure time (or voltage) or the ith unit tested, and

t_s = stopping time of the experiment, with n and r as defined previously.

The Maximum Likelihood estimates are readily determine with the aid of a computer although this method lacks the visual importance of the graphical technique. The flow chart for the algorithm which calculates $\bar{\beta}$ and $\bar{\alpha}$, using the method of Maximum Likelihood is shown below.



Note:–

$\bar{\alpha}$ and $\bar{\beta}$ are the best estimates of α and β respectively.

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