THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE FATIGUE PROPERTIES OF A UNIDIRECTIONAL GLASS FIBRE REINFORCED PLASTIC MATERIAL SUITABLE FOR LEAF SPRINGS

by

L.F. Reynolds, M.Sc.Tech., M.I.M.

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SUMMARY AND CONCLUSIONS

The fatigue properties of unidirectional Scotchply SP1002 glass fibre reinforced plastic (G.F.R.P.) have been determined in bending from zero initial stress.

Fatigue testing was carried out on an Avery 5303 machine using measurements of the reduction in the flexural modulus of the sample, during the course of the test, as a criterion of failure. Such a criterion of failure was considered to be more appropriate than the norman fracture criteria used for metals, since large changes in the elastic properties of the composite could take place relatively early in the life of the specimens, well before actual fracture occurred.

The work has shown that the fatigue strength of the G.F.R.P. at 10^6 cycles is equal to that of a typical free peened spring steel, but is less than that of either strain peened spring steel or Type A carbon fibre reinforced plastic. (C.F.R.P.)

The specific flexural fatigue properties of the G.F.R.P., however, are superior to those of the strain peened spring steel, but are generally lower than those of the C.F.R.P.

On the basis of the present work, therefore, the unidirectional SP1002 G.F.R.P. could provide a satisfactory alternative to spring steel for leaf spring applications, provided that the design makes allowance for the lower modulus of the composite.

In view of the considerable price differential which exists between G.F.R.P. and C.F.R.P. it is more likely that composite leaf springs will take the form of "hybrid" components, which will use both materials together in the same design.

Such a design, in its optimum form, will exploit the relative cheapness of the G.F.R.P. and the high stiffness characteristics of the C.F.R.P. to their fullest advantage.

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1. INTRODUCTION

The potential of fibre reinforced plastics in the spring industry has been the subject of a SRAMA report(1), whilst the fatigue properties in bending one side of zero of a carbon fibre reinforced plastic material has also been recently reported(2).

Very little information is available concerning flexural fatigue properties of unidirectional glass fibre reinforced plastics in bending one side of zero, however, and the present programme of work was therefore undertaken to generate appropriate fatigue data which would be suitable for the design of leaf springs.

A major setback to the use of existing fatigue data lies in the fact that the chosen criteria of failure very often involves fracture of the material. This is a serious drawback, in that composites have been shown to exhibit progressive damage, during the course of fatigue, which may easily result in effective failure of the structural component well before actual fracture is imminent(3). For this reason, many of the published data are of only limited value for design purposes, and cannot generally be used with any reasonable degree of confidence.

A more useful approach to the assessment of composite materials in fatigue, therefore, involves sequential measurement of a meaningful material property, such as the elastic modulus, during the course of the test. Failure can then be defined in terms of a maximum test stress resulting in a stipulated reduction in modulus within a specific number of fatigue cycles(4).

This approach was in fact adopted in previous work carried out on a unidirectional carbon fibre reinforced plastic composite at SRAMA,(2) and has been retained in the present work on unidirectional glass fibre reinforced plastic.

2. EXPERIMENTAL PROCEDURE

2.1 Material

Samples of a unidirectionally aligned G.F.R.P., Scotchply SP1002, were obtained from 3M (UK) Limited.

The composites, which nominally consisted of 64% w/w of 'E' glass in an epoxy resin matrix, had a nominal cross section of 15 mm x 3 mm (13 ply) and were obtained as specimens varying from 80 to 200 mm in length.

2.2 Static Mechanical Properties

2.2.1 Tensile testing

Tensile specimens were prepared from 200 mm lengths of the composite, to the design shown in Fig. 1A.

The tensile tests were carried out on a Hounsfield tensometer capable of testing up to loads of 20 kN, the tensile strength being calculated from the load at failure.

2.2.2 Flexural strength testing

Flexural strength tests in both 3 point and 4 point bending were carried out on a Hounsfield tensometer with suitable jig attachments.

Specimens of plain rectangular cross section were used for the 3 point test, whilst shaped samples of the design shown in Fig. 1B were used for the 4 point test.

In each case, the supports through which the loads were applied were radiused to reduce the possibility of damage at the surface of the composite.

The maximum stress at fracture was then calculated from the relationships:

3 point bending

$$\sigma_f = \frac{3}{2} \frac{WL}{BD^2} \qquad \text{..........(1)}$$

and 4 point bending

$$\sigma_f = \frac{6Wa}{BD^2} \qquad \text{..........(2)}$$

where

σ_f = Maximum stress at fracture, N/mm^2

W = Applied load, N

L = Distance between outer supports, mm

a = Distance between inner and outer supports, mm (4 point test only)

B = Specimen width at centre, mm

D = Specimen thickness, mm

2.2.3 Determination of flexural modulus

A Coats "Comaco" cantilever type spring load testing machine was modified for this test, by incorporating three radiused triangular supports. The strip specimens, of nominal dimensions 80 x 15 x 3 mm, were supported horizontally on two of the supports which were mounted on a steel block, the complete arrangement being attached to the bottom plate of the load tester. The third radiused edge was attached to the top plate of the tester, and thus varying loads were applied to the centre of the specimen across a known gauge length (63.5 mm), the mid-span deflection being noted on a "Baty" dial gauge.

The deflections at known loads were recorded, and the flexural modulus was then calculated from the relationship:-

$$E = \frac{W L^3}{48 I y} \qquad \text{..........(3)}$$

where

E = Flexural modulus, N/mm^2

W = Applied load, N

L = Distance across horizontal supports, mm

I = 2nd moment of inertia, $= \frac{BD^3}{12} mm^4$

y = Central deflection of specimen at load W, mm

Measurements were made of the deflection, y, at loads up to 390 N, and a mean value of E was calculated from the results.

2.3 Fatigue Testing

Composite specimens of the design shown in Fig. 1.C were fatigue tested in bending one side of zero using an Avery 7303 machine which was capable of applying a maximum bending moment of 2.83×10^4 N/mm.

The maximum stress in pure bending was calculated from the relationship:-

$$\sigma_{max} = \frac{6\ M}{BD^2} \qquad \text{..........(4)}$$

where

σ_{max} = Maximum stress, N/mm^2

M = Maximum bending moment, N.mm

B = Specimen width, mm

D = Specimen thickness, mm

The bending moment was measured using a spring dynamometer which was connected to two dial gauges by a measuring arm. The dynamometer spring was calibrated using a system of standard weights and free-running pulleys, the calibration being carried out in the direction of bending to be used in the fatigue tests. In all cases, fatigue testing was carried out from zero initial bending stress to the selected maximum stress.

Damage to the gripped compression faces of the test specimens was avoided by using suitably radiused composite shims, which were interposed between the steel grips and the gripped compression faces of the sample.

The edges of all the specimens tested were carefully smoothed off using fine, dry 800 grade emery paper, prior to dimensional measurement and fatigue testing.

After the specimen had been set up for fatigue testing at the relevant maximum test stress, measurements were made of the vertical throw of the eccentric applying the bending moment, and of the deflection at the end of the dynamometer arm by means of appropriately placed dial gauges.

From these measurements, and by the consideration of the machine/sample geometry, it was possible to calculate the radius of curvature, R, of the arc through which the specimen was bent by the applied moment. By further calculation involving the known specimen gauge length, the central deflection of the specimen could then be estimated, measured with respect to the centre of the chord of the circle, radius R, which intersected the ends of the specimen over the fixed gauge length.

The initial flexural modulus of the composite could then be estimated from the relationship:

$$E = \frac{M L^2}{8 y I} \qquad \ldots\ldots\ldots\ldots(5)$$

where

M = Applied moment, N.mm
L = Gauge length = 25.4 mm
y = Central deflection of specimen, mm
I = 2nd moment of inertia = $\frac{BD^3}{12}$ mm^4

Since the 7303 machine used an eccentric of constant throw to apply a particular maximum bending moment, the deflection of the dynamometer by the specimen decreased as the stiffness (modulus) decreased during the course of the tests. The change in the central deflection of the specimen could be derived as previously stated, together with the change in the applied moment, M, via the calibration curve which had previously been determined experimentally.

From these two measurements of 'y' and 'M', the new modulus of the sample could be estimated at intervals throughout the test by the simple expedient of stopping the machine and measuring the deflection of the spring dynamometer, via the two dial gauges attached to the moment arm, as the eccentric applying the load was rotated by hand to apply the maximum bending moment to the specimen. This was particularly convenient in that it was not necessary to remove the specimen from the machine for the estimation of 'E', a procedure which could have led to considerable difficulties in respect of specimen re-alignment and re-stressing to the required level. The results were readily converted into modulus values by means of a Burroughs C-7400 card programmable calculator.

3. EXPERIMENTAL RESULTS

The results of the tensile tests carried out on the composite are shown in Table I. The flexural strength results are shown in Tables II and III, whilst the flexural modulus results are presented in Table IV. The initial flexural moduli of the fatigue specimens, calculated from the geometry of the stressing technique employed by the Avery 7303 fatigue machine, are shown in Table V.

The reduction in flexural modulus, exhibited by the composite during fatigue testing at varying levels of maximum stress, are shown in Figs. 2-8, whilst the S/N data derived from these curves, and corresponding to varying levels of reduction in modulus, are shown plotted in Fig. 9. The S/N data were all described by a log/linear straight line relationship, the regressions of which were all significant at over the 95% level of the 't' distribution.

4. DISCUSSION

4.1 Static Properties

The composite had a mean tensile strength of 840 N/mm^2, which is rather lower than the published value of 1100 N/mm^2 quoted for this material$^{(5)}$. The flexural strength in 3 point bending was very similar to the tensile strength, with a mean value of 760 N/mm^2.

The apparent similarity of magnitude between these two parameters was also observed in previous work on a carbon fibre reinforced plastic material, which was carried out at SRAMA$^{(2)}$. This latter report also drew attention to the possibility that determinations of the flexural strength in 3 point bending were not likely to give representative estimates of the true strength of fibre reinforced plastics, due to the considerable risk of surface damage resulting from the very high local stresses generated at the central compressive region of the material where the load is applied. This parameter should therefore be treated with extreme caution.

The flexural strength in 4 point bending, however, was assessed at 1420 N/mm^2. This latter value would possibly be a more realistic estimate of the strength in bending, in the context of leaf springs, since these would generally operate under this type of loading condition.

The flexural modulus of the material was estimated at 2.48 x 10^4 N/mm^2. This value is in reasonable agreement with the mean value of 3.04 x 10^4 N/mm^2 for the initial flexural modulus in 4 point bending, estimated for the fatigue specimens by consideration of the machine/specimen geometry, in view of the approximations made for the purposes of these determinations.

These values are rather low, however, when compared to the published value of 3.65 x 10^4 N/mm^2,$^{(5)}$ and the theoretical value of 4.31 x 10^4 N/mm^2. This latter value can be estimated from the general relationship:-

$$E_c = Eg.\ Vg. + E_r(1-Vg) \qquad \text{..........(6)}$$

where

E_c = Estimated modulus of composite

Eg = Modulus of 'E' glass = c. 7 x 10^4 N/mm^2

E_r = Modulus of thermosetting resin matrix
= c. 3 x 10^3 N/mm^2 (7)

Vg = Volume fraction of glass fibre in composite
= c. 0.60

It is interesting to note that both the tensile and the flexural modulus results obtained in the present work were consistently low, in that they were each approximately 70% of the values quoted in the literature concerning this material.(5) The reason for this difference is not clear.

4.2 Dynamic Properties

The results of the fatigue tests carried out on the composite are given in Fig. 9, which presents the fatigue strength in terms of a specified reduction in modulus at a given maximum flexural stress for a selected number of fatigue cycles in bending one side of zero from zero initial stress

From these data, the fatigue strengths can therefore be derived, as shown below in Table A.

TABLE A

Reduction in modulus, ΔE%	Fatigue strength, N/mm^2, for cycles to failure*		
	10^4	10^5	10^6
2	560	420	(275)
4	660	540	425
6	740	625	510
8	815	690	570

*Figures in parentheses are extrapolated values.

As stated previously, it is difficult to reliably obtain a meaningful comparison between these results and the published data(5), since the latter have generally been obtained using fracture as a criterion of failure, rather than the number of cycles to produce a stipulated reduction in elastic properties.

The data derived from the present work carried out on SP1002 in bending one side of zero, from zero initial stress, is shown plotted in Fig. 10, however, together with the available published fatigue data for this material(5). These latter data were obtained in reverse plane bending using fracture as a criterion of failure, and are therefore not directly comparable to the results of the present work, which considers reduction of modulus as the failure criterion.

The fatigue strength in bending one side of zero from zero initial stress can be estimated from the reversed plane bending fatigue strength, however, by means of the relationship(6)

$$\sigma_f = \frac{2y}{(\frac{y}{Rm} + 1)} \qquad \text{..........(7)}$$

where

σ_f = Fatigue strength in bending one side of zero from zero initial stress, at N cycles.

y = Fatigue strength in reversed plane bending, at N cycles

Rm = Tensile strength of material

= c. 1100 N/mm^2 for published data (Ref. 5)

The values of σ_f thus calculated are also shown plotted in Fig. 10.

The comparison serves to indicate that the results obtained at SRAMA are in broad agreement with the published data on this material, however, and hence the results of the present work (Table A) can be taken as representative of the fatigue properties of unidirectional SP1002 glass fibre reinforced plastic under the present experimental conditions.

4.3 Comparison of G.F.R.P. SP1002 with other spring materials

4.3.1 Static properties

A useful comparison can be made between the static properties of G.F.R.P., C.F.R.P. and a typical spring steel material by reference to work previously carried out at SRAMA(2,8,9), as shown below in Table B.

TABLE B

Material	Material Condition	Rm N/mm^2	Rpo.1 N/mm^2	E N/mm^2	Flexural elastic strength in 4 point bending, N/mm^2
CS80(8)	Hardened and tempered strip 2.5 mm	1620	1385	2.08×10^5	-
CS80(9)	Pre-hardened and tempered strip, 0.25 mm	1660	1100	2.08×10^5	1560
Type A(2)	Unidirectional pultruded strip, 2 mm	1225	-	1.12×10^5	3000
SP1002	13 ply unidirectional strip, 3 mm	840	-	2.48×10^4	1420

The elastic properties of the glass fibre composite are thus consistently lower than those of both the carbon fibre composite and the spring steel. The specific gravities (S.G.) of steel, C.F.R.P. and G.F.R.P. are 7.7, 1.7 and 1.8 respectively, however. The effect of the S.G. in terms of the relative strength/weight ratios is shown below in Table C, together with the specific stored energy coefficient, $\sigma^2 f/6E\rho$.

This latter parameter represents the strain energy per unit weight stored in a beam element of specific gravity, ρ, and elastic modulus, E, when subjected to a bending moment which produces a maximum flexural stress, σ_f, in the material.

TABLE C

Material	(Rp 0.1)/ρ N/mm^2	σ_f/ρ N/mm^2	E/ρ N/mm^2	$\sigma^2_f/6E\rho$ N/mm^2
CS80[8]	180	-	2.7×10^4	-
CS80[9]	140	200	2.7×10^4	0.25
Type A[2] C.F.R.P.	720*	1765	6.6×10^4	7.88
SP1002 G.F.R.P.	470*	790	1.38×10^4	7.53

*Tensile strength, approximately equal to elastic limit for fibre reinforced plastics.

It can be seen that the glass fibre composite is superior to the spring steel in every property but the specific stiffness, whilst being the equal of the carbon fibre composite in terms of the specific stored energy coefficient. Considerable savings in weight should therefore be possible in a spring designed to operate in bending and manufactured from the glass fibre composite, as opposed to steel. For the case of a double cantilever single leaf spring of rectangular cross section, for example, the spring rate, S, is given by the relationship:-

$$S = \frac{B\ D^3\ E}{2L^3} \qquad \text{..........(8)}$$

where

B = width of leaf
D = thickness of leaf
L = total length of leaf
E = Young's modulus of material

Since steel has a Young's modulus which is approximately 8 times that of the glass fibre composite, it can readily be appreciated that, all other things being equal, a glass fibre spring will have twice the thickness of a steel spring of equivalent rate, i.e. the volume of material will be doubled if the composite material is used. The specific gravity of the composite is only a quarter that of steel, however, so that the composite spring will weigh only half as much as the equivalent steel spring of equal rate. Hence the use of the glass fibre reinforced composite in place of steel should result in a significant weight advantage, if the component is designed to exploit the specific strength advantages of the composite.

4.3.2 Dynamic properties

Table D below compares the fatigue properties in bending, one side of zero from zero initial stress, of free peened and strain peened CS80 strip and of Type A carbon fibre reinforced plastic, with the results of the present work on SP1002 glass fibre reinforced plastic.

Table D

Material	Condition	Flexural fatigue strength at 10^6 cycles, σ_L, N/mm^2
CS80 (8)	Hardened and tempered, 2.5 mm shot peened	600
CS80 (8)	Hardened and tempered, 2.5 mm strain peened	1340
Type A (2) C.F.R.P.	Unidirectional pultruded strip, 2 mm	1200[a] 1475[c]
SP1002 G.F.R.P.	13 ply unidirectional strip, 3 mm	425[a] 570[b]

[a] σ_L for 4% reduction in flexural modulus

[b] σ_L for 8% reduction in flexural modulus

[c] σ_L for 13% reduction in ~~flexural~~ modulus

It can be seen that the fatigue strength at 10^6 cycles of the glass fibre composite for an 8% reduction in modulus is approximately equal to that of the free peened spring steel, but is lower than that of either the strain peened steel or the carbon fibre composite material.

When the appropriate specific gravities of the materials are considered, the differences in the specific fatigue performance of the various materials is more readily apparent, as shown below in Table E.

TABLE E

Material	Condition	Specific fatigue strength, $\sigma L/\rho$ N/mm^2	Specified stored energy coefficient $\sigma L^2/6E\rho$ N/mm^2
CS80 (8)	H & T, 2.5 mm shot peened	78	0.037
CS80 (8)	H & T, 2.5 mm strain peened	174	0.187
Type A (2) C.F.R.P.	Pultruded 2 mm	706^a 868^c	1.261^a 1.904^c
SP1002 G.F.R.P.	13 ply strip 3 mm	236^a 317^b	0.674^a 1.213^b

[a] σ_L for 4% reduction in flexural modulus

[b] σ_L for 8% reduction in flexural modulus

[c] σ_L for 13% reduction in flexural modulus

This compilation serves to indicate the advantages of the composite materials, with respect to both the specific fatigue strength and the specific stored energy coefficient.

The Potential for G.F.R.P. Leaf Springs

A simple cost/benefit analysis can be made, if the operating costs of a typical commercial vehicle are used as a basis for the calculations. In such a case, a reduction in the unladen weight of the vehicle would lead to an increase in the potential pay load carried by the vehicle.

Consider the following values:-

Weight of unladen vehicle = 8 tonnes
Pay load carried by vehicle = 16 tonnes
Total weight of laden vehicle = 24 tonnes
Weight of 2 rear steel springs at 127 kg each = 254 kg
Weight of 2 front steel springs, at 118 kg each = 236 kg
Total weight of steel springs = 490 kg

The individual steel leaves of a multi-leaf spring would normally be free peened prior to the construction of the complete spring unit.

It has been shown that, under dynamic conditions, the specific stored energy coefficient has a value of 0.037 N/mm^2 for free peened spring steel, and 1.213 N/mm^2 for the G.F.R.P. composite investigated. Hence, if G.F.R.P. was used in this application, about 15 kg of material would be required, which would result in a weight saving of 475 kg, or 0.475 tonne.

Since G.F.R.P. and spring steel costs about £10/kg and £0.26/kg respectively, a simple price comparison shows that the material cost for the steel spring unit would be £128, whilst the G.F.R.P. spring unit would cost about £150.

In the operating life of the vehicle, 300,000 km, the pay load could therefore be increased by 142,000 tonne km. Recent estimates suggest that the operating cost of the vehicle would be approximately 1.69p/tonne km., hence the increased pay load would yield £2400 (without the profit factor) over the 4-5 year operational life of the vehicle.

This conclusion is very similar to that drawn from the previous work on a carbon-fibre reinforced plastic material(2), although, for this type of application the material cost for the C.F.R.P. unit would be about 3 times that for the G.F.R.P. unit.

The G.F.R.P. units would therefore be expected to provide operating cost benefits similar to those of the C.F.R.P. springs, for a capital outlay about one third that of the latter units. This apparent advantage of G.F.R.P. over C.F.R.P. has to be balanced against the reported fact that the strength properties of the glass fibre materials are more likely to suffer adversely from the effects of moisture and salt, both of which will, of course, be encountered in a leaf spring at some time during its life(10).

Glass fibre composite springs are already used in light aircraft landing gear(11) whilst carbon fibre composite leaf springs have been tested as a direct replacement for the steel spring units of a heavy goods vehicle with considerable success(12), weighing only 20-25% as much as the steel units which they replaced. In view of the cost differential between glass fibre and carbon fibre, however, future work in this field is likely to be directed towards the development of hybrid constructions, using these two materials together to optimise the cost and spring properties of the units .

In its simplest form, such a construction could consist of a layer of the stiffer C.F.R.P. sandwiched between approximately equal thicknesses of G.F.R.P. Such a design would stand well above the conventional spring steel in respect of specific strength and specific stored energy coefficients, whilst being about 15% lighter than the equivalent all G.F.R.P. spring but considerably cheaper than the all C.F.R.P. spring design(11).

In this context, it should be mentioned that the epoxy matrix of Scotchply SP1002 is compatible with the epoxy/epoxide resin systems used for the manufacture of carbon fibre reinforced composites(13).

In conclusion, therefore, the glass fibre composite tested in the present work would be suitable for the manufacture of leaf springs, as replacements for spring steel, provided that the spring design is adjusted to allow for the lower modulus of the composite, although the use of hybrid G.F.R.P./C.F.R.P.

probably holds more promise for future development in this field, as C.F.R.P. has such high stiffness characteristics.

5. CONCLUSIONS

1. The uniaxial elastic properties and the flexural elastic properties in pure bending of the glass fibre plastic are both inferior to those of either a typical spring steel or a carbon fibre reinforced plastic composite, both of which were previously investigated at SRAMA.

2. When the specific gravities of the materials are considered, the glass fibre reinforced plastic possesses specific elastic properties which are intermediate between those of spring steel and carbon fibre reinforced plastic.

   The strain energy storage capabilities of the G.F.R.P. and the C.F.R.P. materials are approximately equal, and are better than those of the spring steel.

3. The work has resulted in the generation of fatigue data for SP1002 G.F.R.P., which is presented in terms of a failure criterion based on a reduction of the flexural modulus. It is considered that such a criterion of failure will be more appropriate for design purposes, bearing in mind the progressive reduction in properties associated with these materials during the course of fatigue.

4. The fatigue strength at 10^6 cycles of the G.F.R.P., in bending one side of zero, is equal to that of spring steel in the free peened condition, but is less than that of either the strain peened spring steel or a typical C.F.R.P. composite.

5. The specific flexural fatigue properties of the G.F.R.P., which allow for the low S.G. of the composite, are superior to those of the strain peened spring steel, but are generally lower than those for the C.F.R.P. material.

6. On the basis of the data derived from the present work, the Scotchply SP1002 unidirectional G.F.R.P. composite is

suitable for the manufacture of leaf springs.

However, it is more likely that future leaf springs manufactured from these materials will consist of G.F.R.P. and C.F.R.P. together in a hybrid composite. An optimum design of this hybrid will fully utilise the adequate strength and relative cheapness of G.F.R.P. together with the high strength and stiffness of the C.F.R.P. material.

6. RECOMMENDATIONS

The results of the work are sufficiently encouraging to warrant the testing of full size single leaf springs of a hybrid design, manufactured from glass fibre reinforced plastic and carbon fibre reinforced plastic together in suitable layups. It should be appreciated, however, that the failure modes in such a construction may be markedly different to those observed on the small specimens of G.F.R.P. which have so far been tested individually at SRAMA.

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TABLE I TENSILE STRENGTH OF SCOTCHPLY SP1002 UNIDIRECTIONAL G.F.R.P.

Sample No.	Tensile strength N/mm^2
1	840
2	850
3	830
Mean value	840
Standard error of the mean	6

TABLE II FLEXURAL STRENGTH OF SCOTCHPLY SP1002 UNIDIRECTIONAL G.F.R.P. IN 3 POINT BENDING

Sample No.	Flexural Strength N/mm^2
1	740
2	760
3	770
Mean value	760
Standard error of the mean	9

TABLE III FLEXURAL STRENGTH OF SCOTCHPLY SP1002 UNIDIRECTIONAL G.F.R.P. IN 4 POINT BENDING

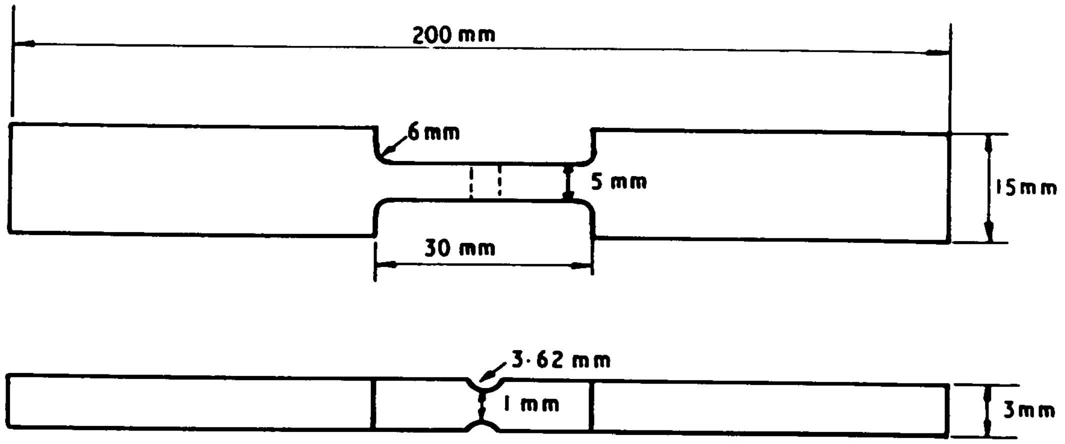
Sample No.	Flexural Strength N/mm^2
1	1310
2	1545
3	1410
Mean Value	1420
Standard error of the mean	68

TABLE IV FLEXURAL MODULUS OF SCOTCHPLY SP1002 UNIDIRECTIONAL G.F.R.P., DETERMINED IN 3 POINT BENDING

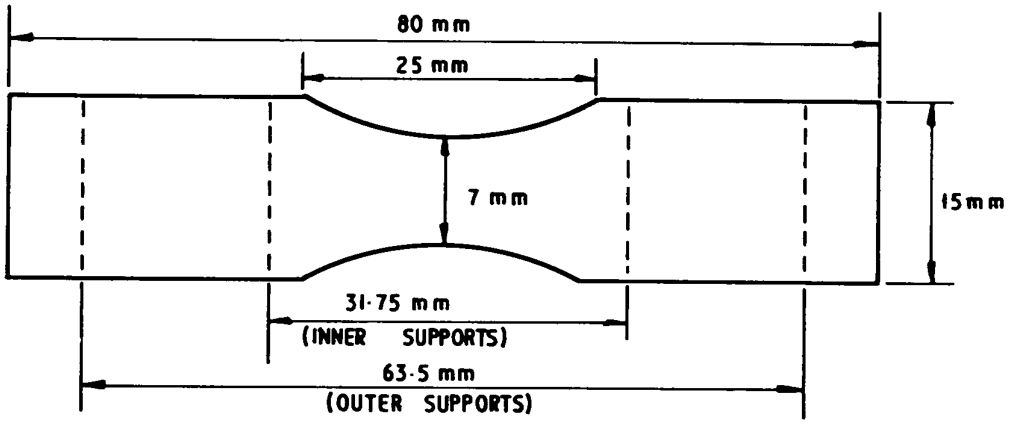
Sample No.	Flexural Stress, N/mm^2	Flexural Modulus, E, N/mm^2
1	150	2.50×10^4
"	240	2.53×10^4
2	141	2.42×10^4
"	225	2.47×10^4
3	152	2.46×10^4
"	244	2.53×10^4
Mean Value		2.48×10^4
Standard error of the mean		1.8×10^2

TABLE V CALCULATED VALUES OF INITIAL FLEXURAL MODULUS IN 4 POINT BENDING FOR SCOTCHPLY SP1002 UNIDIRECTIONAL G.F.R.P.

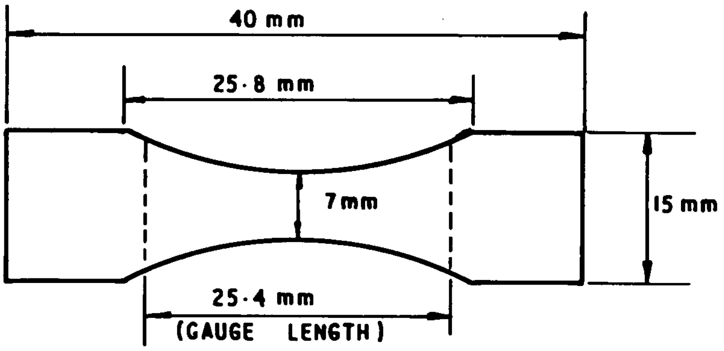
Sample Identification No.	Initial flexural stress, N/mm^2	Initial flexural modulus, E, N/mm^2
F8	410	2.78×10^4
F7	500	2.89×10^4
F9	560	3.02×10^4
F6	600	3.04×10^4
F1	660	2.72×10^4
F3	710	3.38×10^4
F2	745	3.48×10^4
Mean Value		3.04×10^4
Standard error of the mean		1.1×10^3



A. TENSILE SPECIMENS.



B. FOUR - POINT FLEXURAL STRENGTH SPECIMENS.



C. FATIGUE SPECIMENS.

FIG. 1 TEST SPECIMENS OF UNIDIRECTIONAL SP1002 GLASS FIBRE REINFORCED PLASTIC. (NOT TO SCALE)

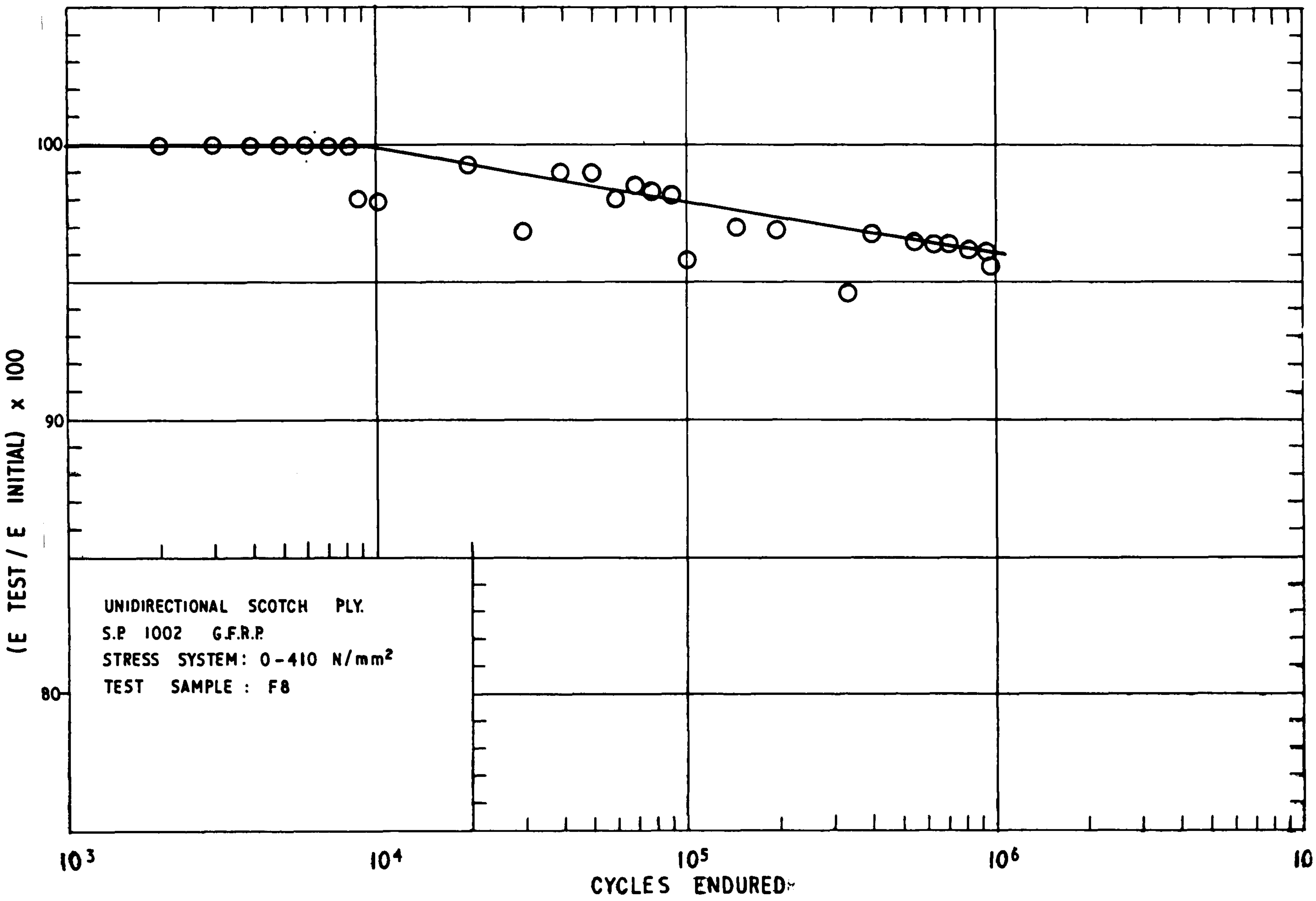


FIG. 2 PROGRESSIVE CHANGE IN MODULUS OF G.F.R.P. DURING FATIGUE TEST.

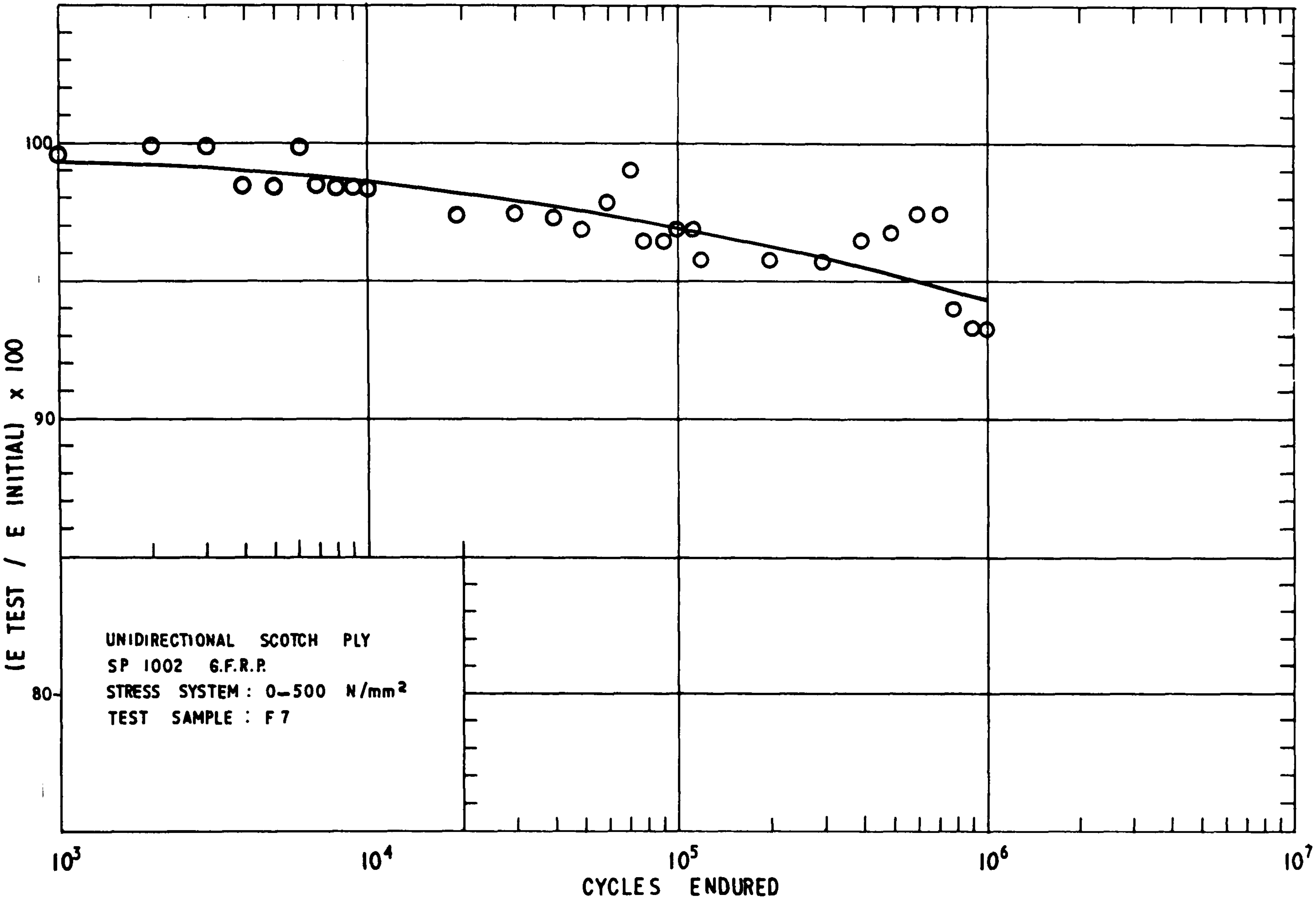


FIG. 3 PROGRESSIVE CHANGE IN MODULUS OF G.F.R.P. DURING FATIGUE TEST.

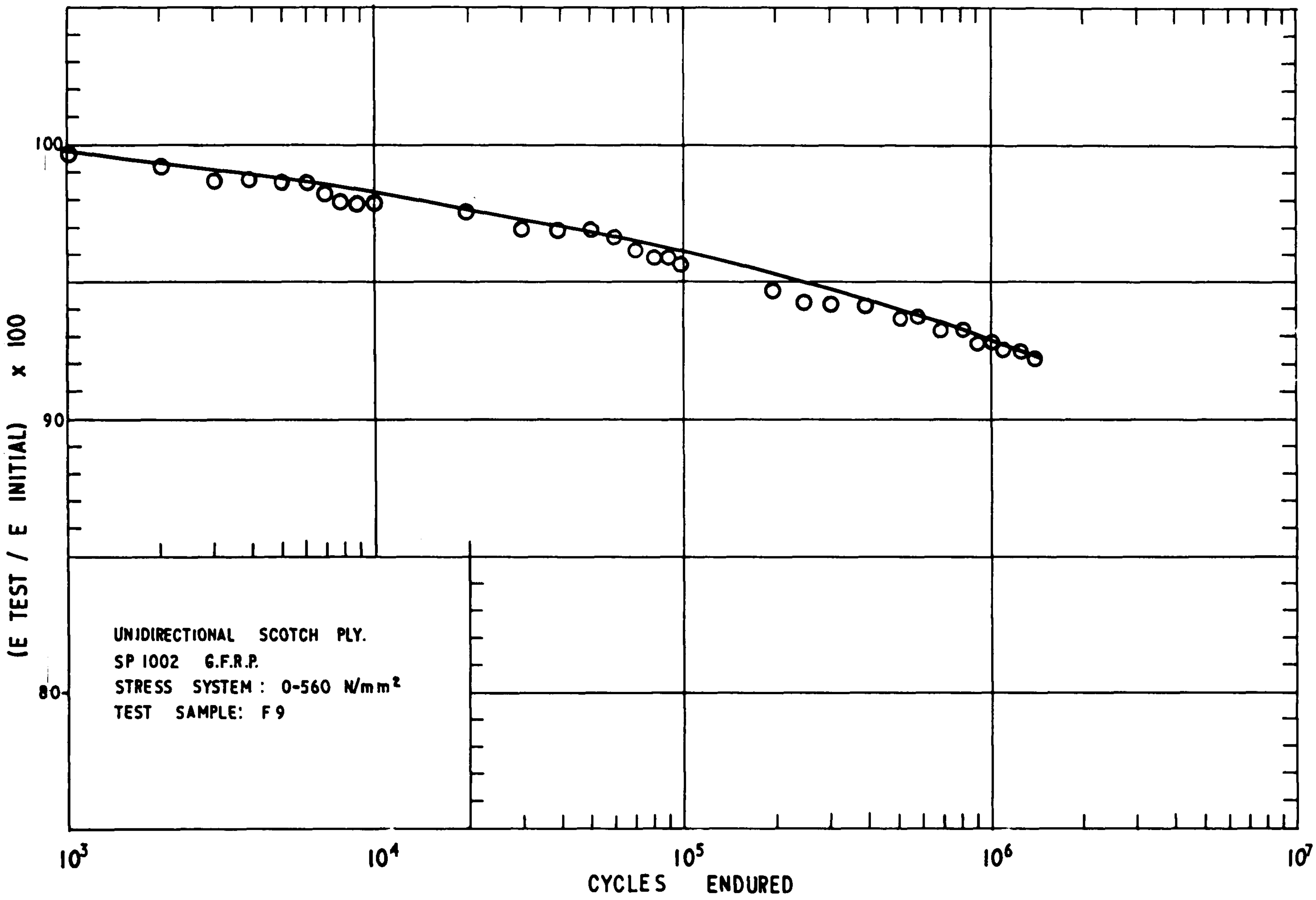


FIG. 4 PROGRESSIVE CHANGE IN MODULUS OF G.F.R.P. DURING FATIGUE TEST.

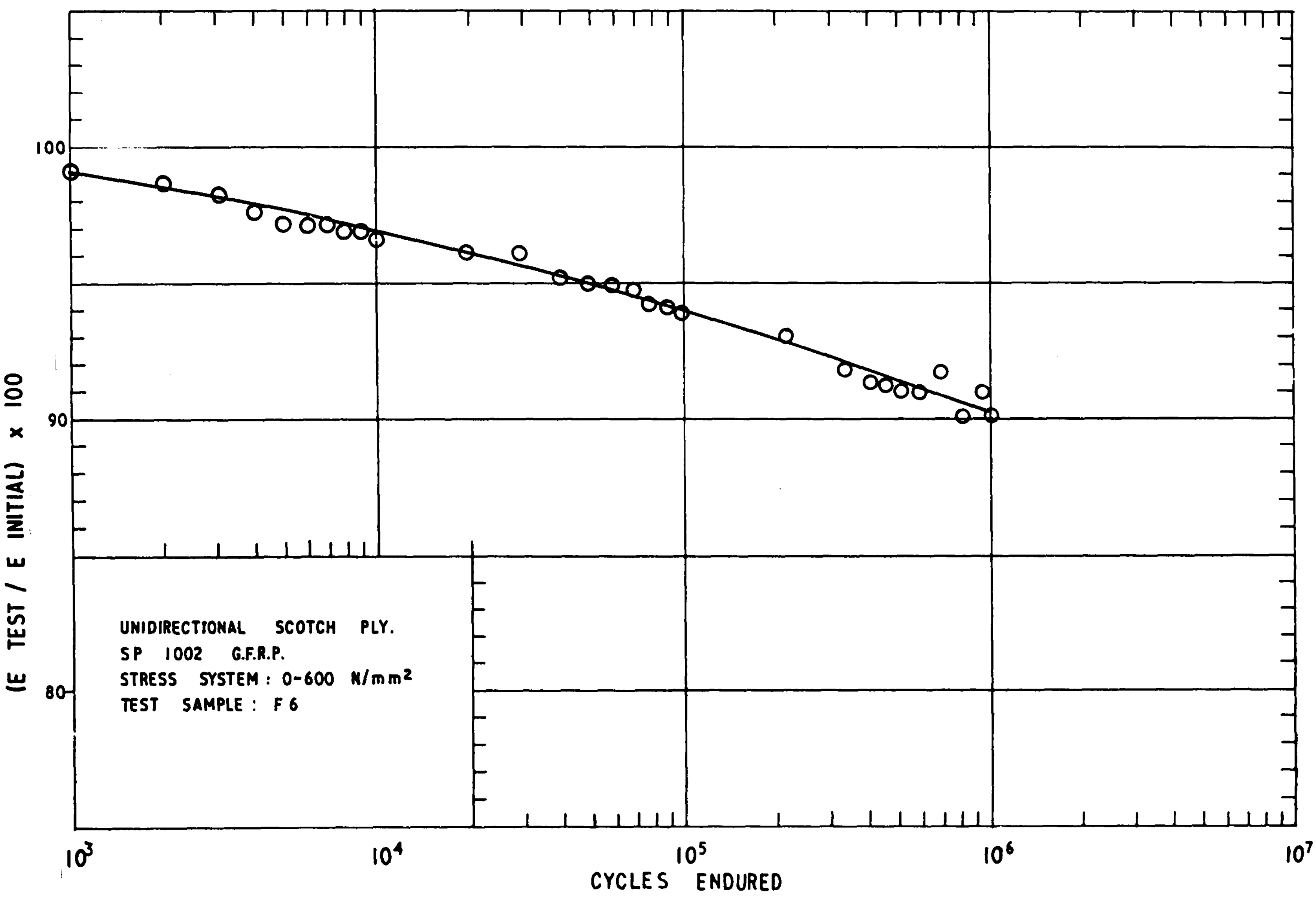


FIG. 5 PROGRESSIVE CHANGE IN MODULUS OF G.F.R.P. DURING FATIGUE TESTS.

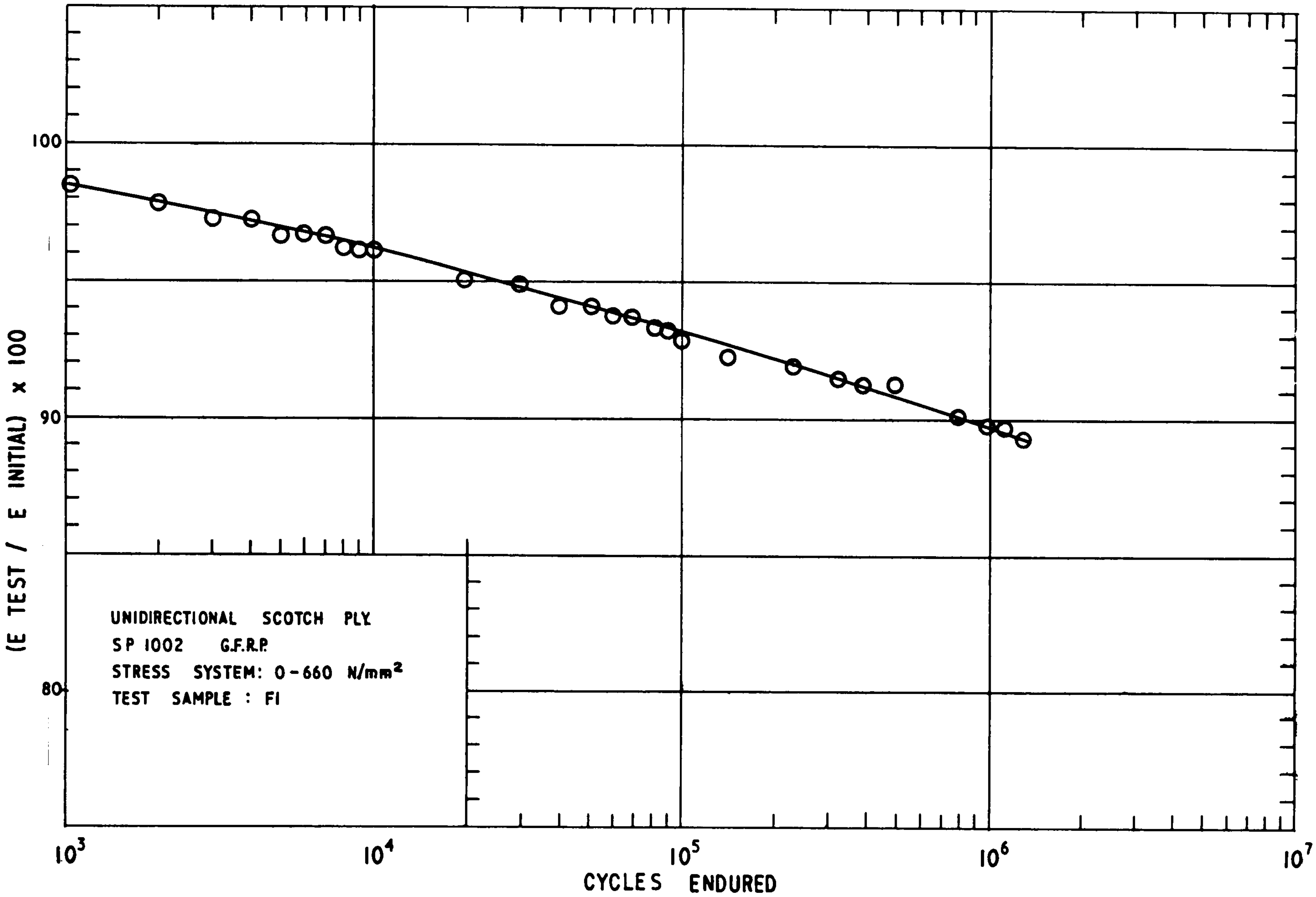


FIG. 6 PROGRESSIVE CHANGE IN MODULUS OF G.F.R.P. DURING FATIGUE TESTS.

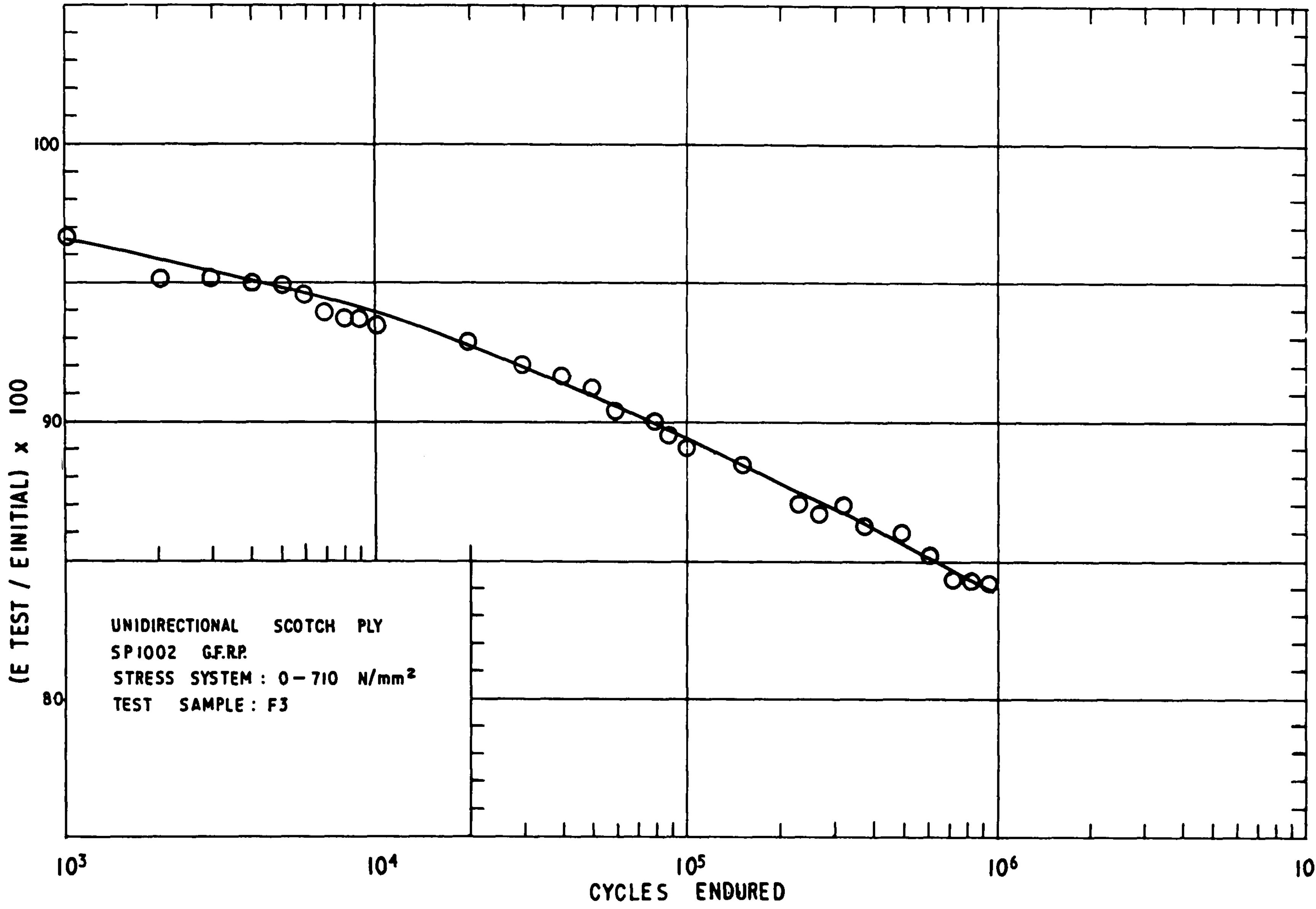


FIG. 7 PROGRESSIVE CHANGE IN MODULUS OF G.F.R.P. DURING FATIGUE TEST.

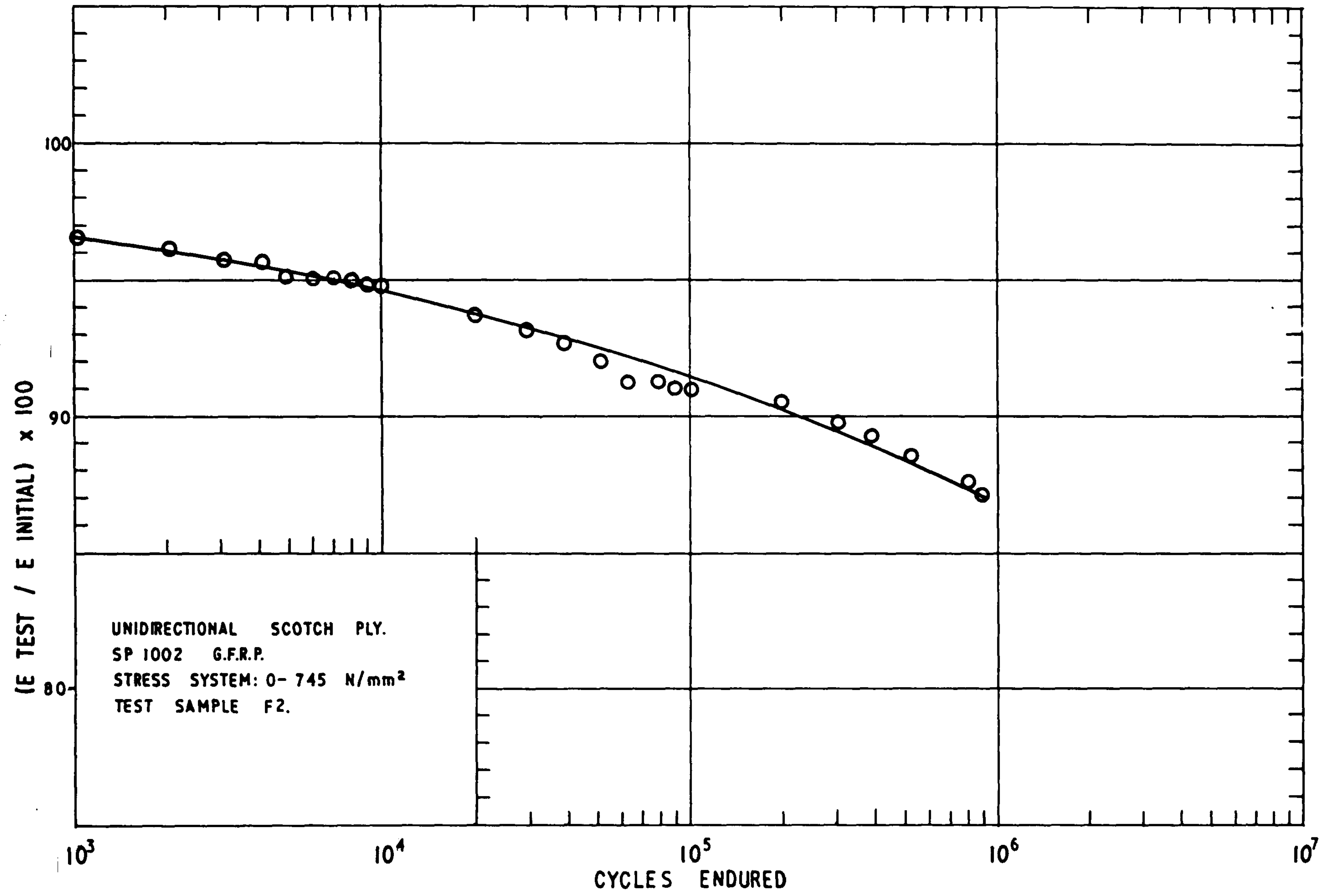


FIG. 8 PROGRESSIVE CHANGE IN MODULUS OF G.F.R.P. DURING FATIGUE TEST.

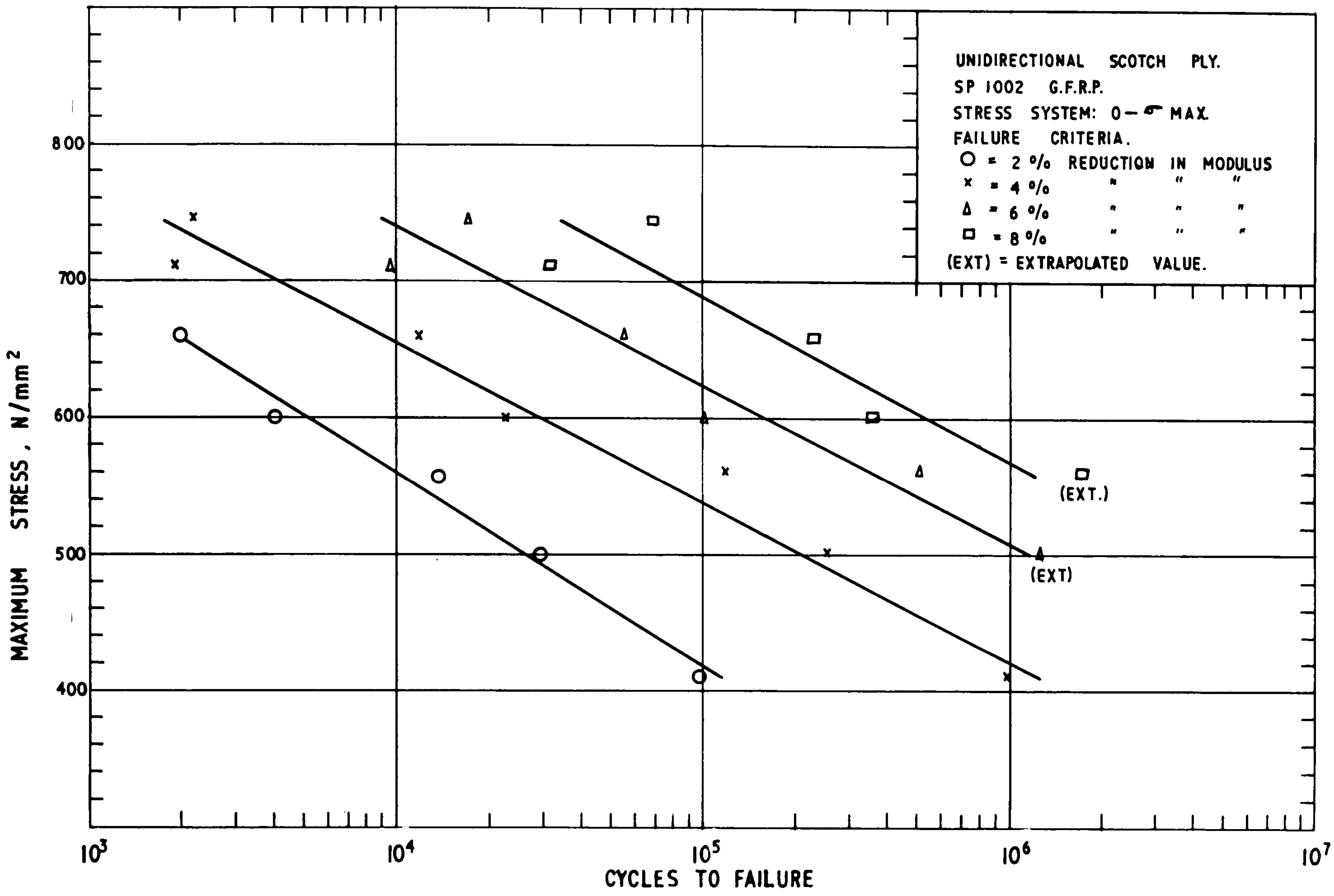


FIG. 9 S/N CURVES FOR UNIDIRECTIONAL SP 1002 G.F.R.P. IN BENDING ONE SIDE OF ZERO.

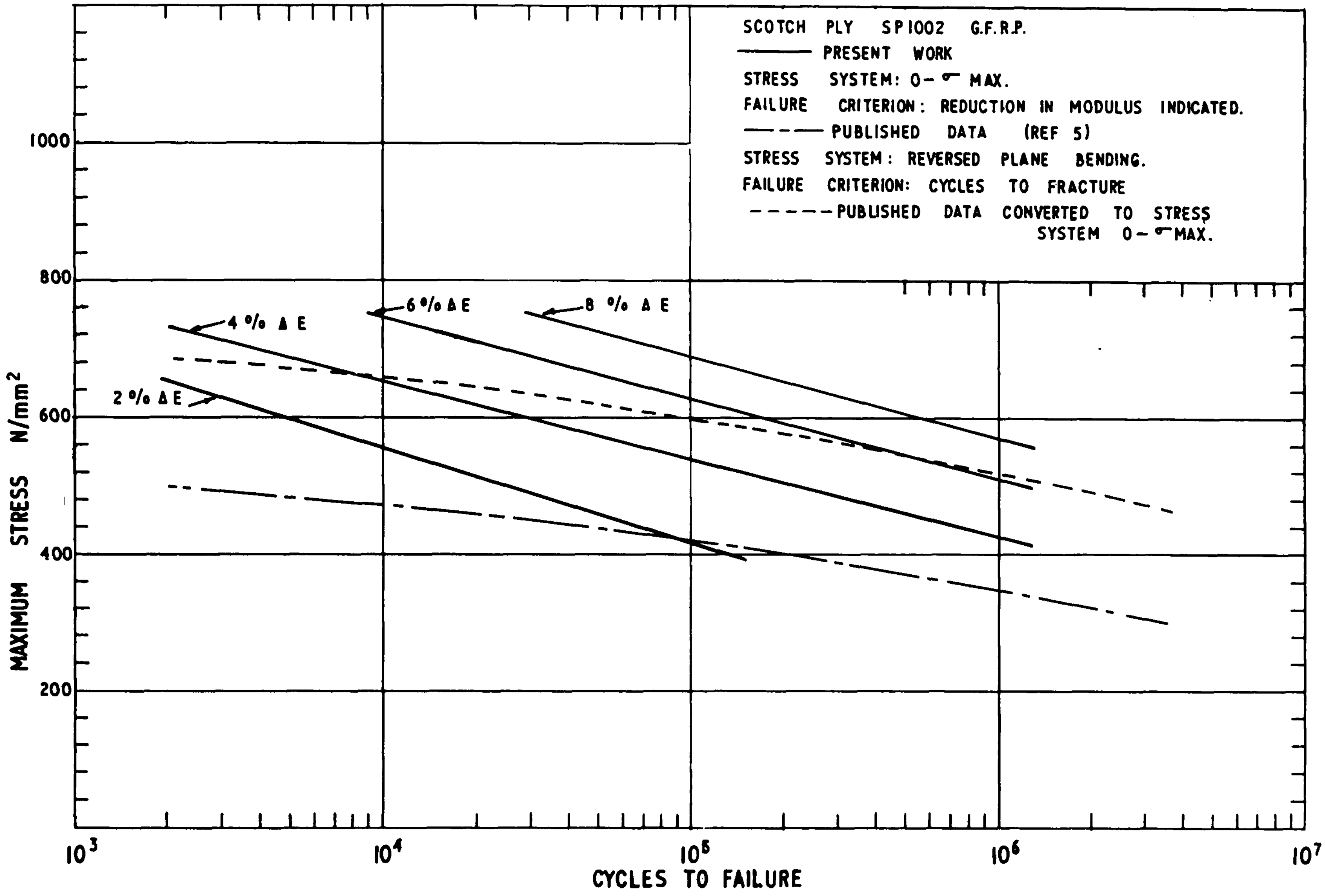


FIG. 10 S/N CURVES FOR UNIDIRECTIONAL SP 1002 G.F.R.P.