TABLE 4

*Quaternary Ammonium Salts of 4-N-dimethylamino-pyridine and their periodate and perchlorate derivates:*

| Compound | m.p.°C |
|---|---|
| II a | 246 (100%) |
| IIb | 240 ( 64%) |
| IIc | 270 ( 58%) |
| IId | 275 (100%) |
| IIe | 71 ( 85%) |
| IIf | 120 ( 60%) |
| IIg | 219 ( 65%) |
| IIh | 86 ( 55%) |
| IIi | 211 (100%) |
| IIj | 188 ( 56%) |
| IIIa | 212 ( 40%) |
| IIIb | 125 ( 54%) |

The yield percentage of each compound is shown in brackets.

required alkyl halide or alkyl dihalide (0.01 mole) in acetone (50 ml). The reaction mixture was heated under reflux for 3–5 hr, then allowed to stand until precipitation took places. The precipitated solid was collected, washed with benzene, recrystallised from ethanol and the m.p. shown in table 4.

*Periodate and Perchlorate derivatives (IIb) and (IIc):*

The methiodide derivative (IIa) about 1 g. was dissolved in cold water (20 ml) and an excess of cold saturated solution of potassium perchlorate or periodate was added and shaked for 15 min. The product formed was filtered off, recrystallised from ethanol and m.p. determined (table 4).

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# MACROSCOPIC DESCRIPTION OF THE STRENGTH OF COMPOSITE LAMINATES

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ABSTRACT

The strength of laminated composites can be calculated by measuring the strength and elastic properties of the unidirectional lamina and by applying a failure criterion. The results obtained distinguish between the first ply failure and the ultimate failure of the laminate. Using the first ply failure as the design criterion, a simple method for laminate optimisation is suggested and used for a specific problem. The present approach which takes into account the anisotropic composite properties and their tensor transformations and simplifies them by using graphical methods, will lead to simple methods of optimal design with composite laminates.

## INTRODUCTION

IN the laminated composites, the basic building block is the unidirectional lamina or the ply which contains continuous aligned fibres in a matrix. The structural elements are then made by stacking up the plies and each ply can be selected to have any given orientation. Such a material offers a remarkable opportunity to tailor the material to meet a given loading condition. The number of plies and the orientation for each ply can be so chosen as to get a structure with minimum weight. However, the designers often surrender this opportunity and tend to use the laminates in a quasi-isotropic configuration so that the formulas, so familiar in conventional material technology can be used. This approach to design is too conservative and penalises the composite materials. To counteract this tendency, simple methods of calculations must be made available so that designing with composites can become conceptually simple. The aim of the present work is to discuss a simple method for the optimal design of laminates for biaxial loading conditions.

## Micro vs Macro Description Of Strength

The failure of composite laminates can be studied at two levels. At the microscopic level, several features have to be studies[1] such as (i) the occurrence of cracks at the fibre end; (ii) crack propagation along the fibre; (iii) cracking in the matrix; (iv) morphology of cracks; (v) delamination.

Most of the studies are post-mortem as it is difficult to follow the various events involved in fracture.

At the macroscopic level, the application of fracture mechanics is frustrating because, unlike in metals, fracture does not occur by the propagation of a single dominent flow. Again, composites differ from metals in another respect. High strength metals tend to have low fracture toughness but this is not the case with composites.

These considerations lead us to the third possibility, that of describing the strength of composites by using a macroscopic failure criterion. By using an appropriate criterion, the strength of laminates can be calculated and comparisons can be made between the laminates so as to evolve the optimum.

## Failure Criterion

A failure criterion enables the prediction of strength under different conditions of loading using data obtained in simple tests, for example a tensile test. For materials that are isotropic on the macroscale, a single parameter such as the yield or ultimate strength may suffice.

But anisotropic materials require a more general criterion. A quadratic criterion[2] is used in the present paper.

$$F_{ij}\,\sigma_i\,\sigma_j + F_i\,\sigma_i = 1 \qquad (1)$$

where $\sigma$'s are applied stresses and $F$'s are coefficients. This criterion is applicable to anisotropic materials such as composites, bone, wood, paper etc. The coefficients obey the transformation laws for the fourth rank tensor and (1) is often referred to as the tensor polynomia criterion[3]. Applications of this criterion are known in the literature[4-6] and hence the discussion is here cut to the bone. For a tensile test (1) specialises to

$$F_{xx}\,X^2 + F_x\,X = 1 \qquad (2)$$

where $X$ is the tensile strength and for a compression test,

$$F_{xx}\,X'^2 - F_x(X')^2 = 1 \qquad (3)$$

The two unknown $F_{xx}$ and $F_x$ are determined from the two simultaneous equations (2) and (3). The other coefficients in (1) are determined similarly in transverse tension and compression and shear tests.

The interaction term $F_{xy}$ is difficult to determine unambiguously[7,8]. In this paper it is assumed to have a value such that

$$F_{xy}/\{F_{xx}\,F_{yy}^{1/2}\} = -1/2 \qquad (4)$$

The plane-stress approximation of the (1) is given by

$$F_{xx}\,\sigma_x^2 + 2F_{xy}\,\sigma_x\,\sigma_y + F_{yy}\,\sigma_y^2 + F_{ss}\,\sigma_s^2 + F_x\,\sigma_x + F_y\,\sigma_y = 1$$

By using the (anisotropic) stress-strain relation, (1) can be expressed in strain ($\epsilon$) coordinates:

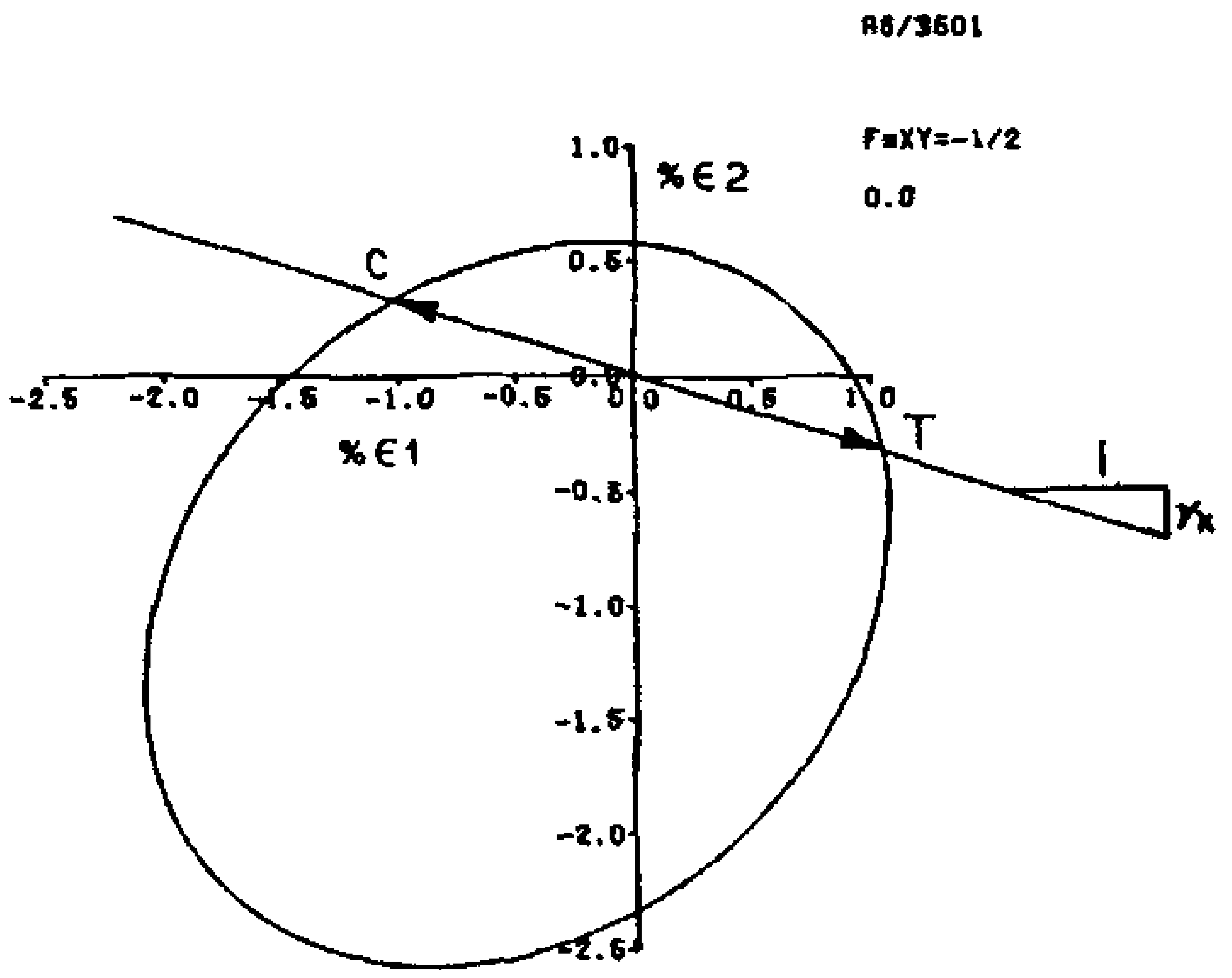
$$G_{ij}\,\epsilon_i\,\epsilon_j + G_i\,\epsilon_i = 1 \qquad (6)$$

and the coefficients of (6) and (1) are related by the moduli, $Q_{ij}$. The physical significnce of the (1) and (6) can be stated simply, using four points determined experimentally an ellipse is drawn through them and is used to represent the failure surface.

Table I

*Input parameters of the unidirectional ply for Laminate Strength Calculations*

| No. | ELASTIC PROPERTIES | No. | STRENGTH PROPERTIES |
|---|---|---|---|
| 1. | Longitudinal young's Modulus, $E_x$ | 1. | Longitudinal Tensile Stength, $X$ |
| 2. | Transverse Young's Modulus, $E_y$ | 2. | Longitudinal Compressive Stength, $X'$ |
| 3. | Shear Modulus, $E_s$ | 3. | Transverse Tensile Strength, $Y$ |
| 4. | Longitudinal Poisson's ratio, $\nu_x$ | 4. | Transverse Compressive Strength, $Y'$ |
| | | 5. | Shear Strength, $S$ |
| | | 6. | Assumed Value of the Interaction Parameter, $F_{xy}$ |




**Figures 1.** Failure Surface of Unidirectional (0 ply) Graphite/Epoxy AS/3501 in Strain Space. The loading path in longitudinal tension is given by a line passing through the origin with slope equal to major Poisson ratio.

## Lamina Failure and Laminate Failure

For any material, a plot of the (6) can be obtained by using the input parameters listed in table 1. In the present approach, the unidirectional ply properties form the starting point and these are measured experimentally. The micromechanics approach of measuring the fibre and matrix properties and calculating the composite properties is not used here. A graphite-epoxy material, AS 3501 is used as an example and the properties of the unidirectional, 0° ply are listed in table 2. Using these data, the coefficients of the (6) can be calculated and the equation plotted as shown in figure 1. If the imposed strain ($\epsilon_1, \epsilon_2$) is represented by a point within the ellipse, the material will not fail. If the point lies on the ellipse, the material will fail. In a tensile test, a strain in the direction of the test, $\epsilon_1$ and the Poisson strain $\epsilon_2$ are produced. The test can therefore be represented by a straight line with a slope of $\nu$, the Poisson ratio as shown in figure 1.

TABLE 2
*Properties of Unidirectional (0°) Graphite Epoxy*

Fibre: Graphite AS
Resin: Epoxy 3501
Volume Fraction of the Fibre 0.66

$E_x$ = 138 GPa
$E_y$ = 8.96 GPa
$\nu_{xy}$ = 0.3
$E_s$ = 7.1 GPa
$X$ = 1447 MPa
$X'$ = 1447 MPa
$Y$ = 51.7 MPa
$Y'$ = 206 MPa
$S$ = 93 MPa

A laminate in which the fibres are unidirectional but the direction is at an angle $\theta$ to the loading axis is known as the off-axis unidirectional composite. The failure surface of this composite can be mapped using the (6) but with the new value of coefficients now calculated using the tensor transformation equations[9] for $G_{ij}$.

In engineering practice laminates are formed by stacking up plies, each displaced at an angle $\theta$ from 0° ply. For such a laminate the failure surface can be obtained by superposing the failure surfaces of individual plies. This is shown for a $(0/90/\pm45)_S$ laminate in figure 2. What makes the superposition possible is the fact that the strain remains the same through the entire thickness of the laminate.

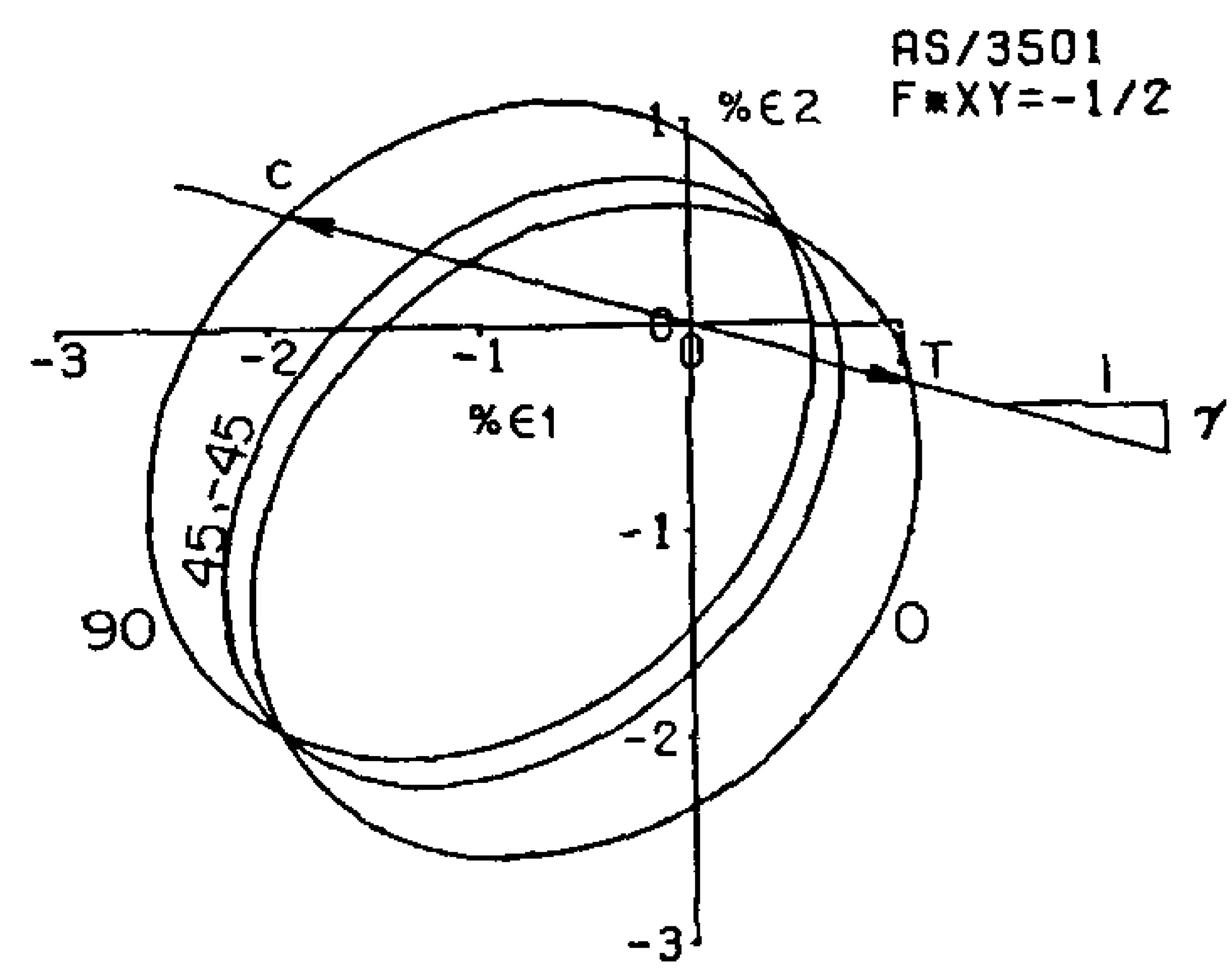



**Figure 2.** Failure Surface of $(0/90/\pm45)_S$ laminate.

In the present paper only the laminates which are symmetric with respect to the midplane are considered; that is why the subscript $S$ is used. Although the unsymmetric laminates have unique properties, a discussion of this topic is beyond the scope of this paper. In figure 2, there is a failure surface corresponding to each ply. The failure surfaces for the +45 and −45 plies overlap in the absence of shear ($\epsilon_6 = 0$). There is an inner envelope corresponding to the first ply failure and an outer one corresponding to the final failure. There are theories which apply the failure criterion such as equation 1 to the laminate as a whole. They obtain only one failure surface and cannot distinguish between the first and final ply failures. Furthermore, for each laminate the properties shown in table 1 have to be determined and used in equation 1. The present approach needs only the properties of the 0 ply. To

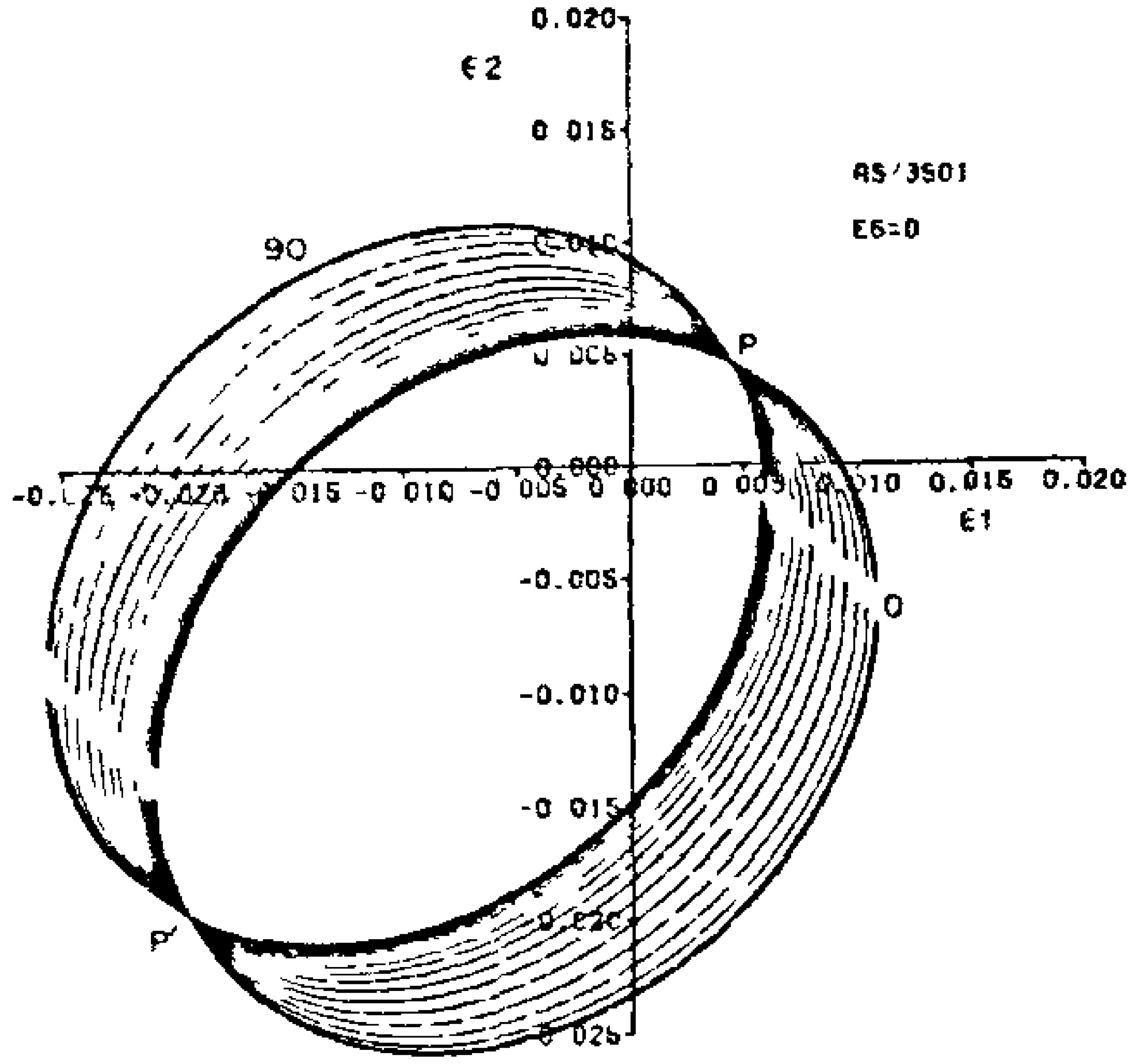



**Figure 3.** The Failure Surface of AS/3501 Composites. The innermost envelope represents the minimum first ply failure strength in normal strain space for this material. All failure surfaces meet at two points A and A'.

obtain the minimum strength properties of the graphite-epoxy material considered, all orientations from 0° to 90° are considered in steps of 5° in figure 3. The inner envelope corresponds to the minimum strength of this material, no matter what orientations are employed[10 11]. Simultaneous ply failure occurs at two points whose co-ordinates are $\epsilon_1 = \epsilon_2$.

Beyond the first ply failure, the stress-strain curve is non-linear and the load has to be redistributed among the surviving plies[12 17]. The ultimate failure can then be calculated. In design, a clear distinction must be made between these two modes and the required factor of safety is much less if the first ply failure is used as is done in the present paper. In stress co-ordinates, the laminate failure can be written as

$$H^{\theta}_{ij} N^*_i N^*_j + H^{\theta}_i N^*_i = 1$$

where $N^*$ are the stress resultants (or the average stresses) and $H_{ij}$ are obtained from $G_{ij}$ and the laminate compliances. The superscript $\theta$ denotes that a failure surface is obtained for each ply of angle $\theta$ in the laminate. Equation (7) and its graphical representation have been discussed elsewhere[18].

## Applications To Design

*The optimum laminate for a given loading condition*: The ideas discussed above can be used for laminate optimisation[19]. Consider a biaxial loading condition in which the longitudinal tensile stress is twice the transverse tensile stress, <2,1,0>. It is intended to design the optimum laminate and to predict how much of stress it can withstand. In the solution, only the 0 and 90 plies need be considered since there is no shear stress. From figure 3, the condition for simultaneous ply failure is

$$\epsilon_1 = \epsilon_2 \tag{8}$$

By applying the stress-strain relation, (8) can be written in stress co-ordinates as

$$\frac{N^*_1 + N^*_2}{N^*_1 - N^*_2} = \frac{(Q_{xx} + Q_{yy} + 2Q_{xy})}{(Q_{xx} - Q_{yy})}\frac{1}{(V_0 - V_{90})}$$

where $Q_{ij}$ are the elements of the modulus matrix and can be calculated from the elastic properties given in the table 1 and $V_0$ and $V_{90}$ are the volume fractions of the 0 and 90 plies.

For $N^*_1 = N^*_2$

$$V_0 - V_{90} = 0.38 \tag{10}$$

and

$$V_0 + V_{90} = 1 \tag{11}$$

Hence

$$V_0 = 0.69 \tag{12}$$

and

$$V_{90} = 0.31 \tag{13}$$

A laminate with 11 plies at 0° and 5 plies at 90° is the optimum. The stress, it will withstand is

$$N^*_1 = (Q_{xx} + Q_{yy} + 2Q_{xy}) \times 2/3 \times 4.69 \times 10^{-3} \tag{14}$$

= 462 MPa OR

<462, 231, 0> MPa

Table 3

*Ply Failure Stress (MPa) for (2,1,0) loading of AS/3501 Cross-ply laminates*

| Laminate | 0 Ply | 90 Ply |
|---|---|---|
| [90] | - | 26 |
| [0/$90_{49}$] | 53.5 | 33.5 |
| [0/$90_8$] | 105 | 67.6 |
| [0/$90_4$] | 151.3 | 100.2 |
| [0/$90_2$] | 209 | 147.4 |
| [0/90] | 251 | 199 |
| [$0_2$/90] | 239.7 | 230 |
| [$0_{11}$/$90_5$] | 231.3 | 231.3 |
| [$0_4$/90] | 186.5 | 217 |
| [$0_8$/90] | 132.7 | 176 |
| [$0_{49}$/90] | 68 | 101 |
| [0] | 53 | - |

If any other laminate is chosen either the 0 or the 90 ply will fail at lower stresses as shown in table 3. The data for other candidate laminates are plotted in figure 4 and it is seen that the maximum value for first ply strength is at the point of intersection of the ply failure stresses. This point corresponds to $\epsilon_1 = \epsilon_2$ in strain space. There are other laminates with higher value for the ultimate strength but if the first ply failure is used as a design criterion the optimum is the laminate $(0_{11}/90_5)_s$. If a biaxial stress greater than <462, 231, 0> MPa must be withstood, then the choice will have to be another material subject to the constraints of thickness, cost, weight etc.

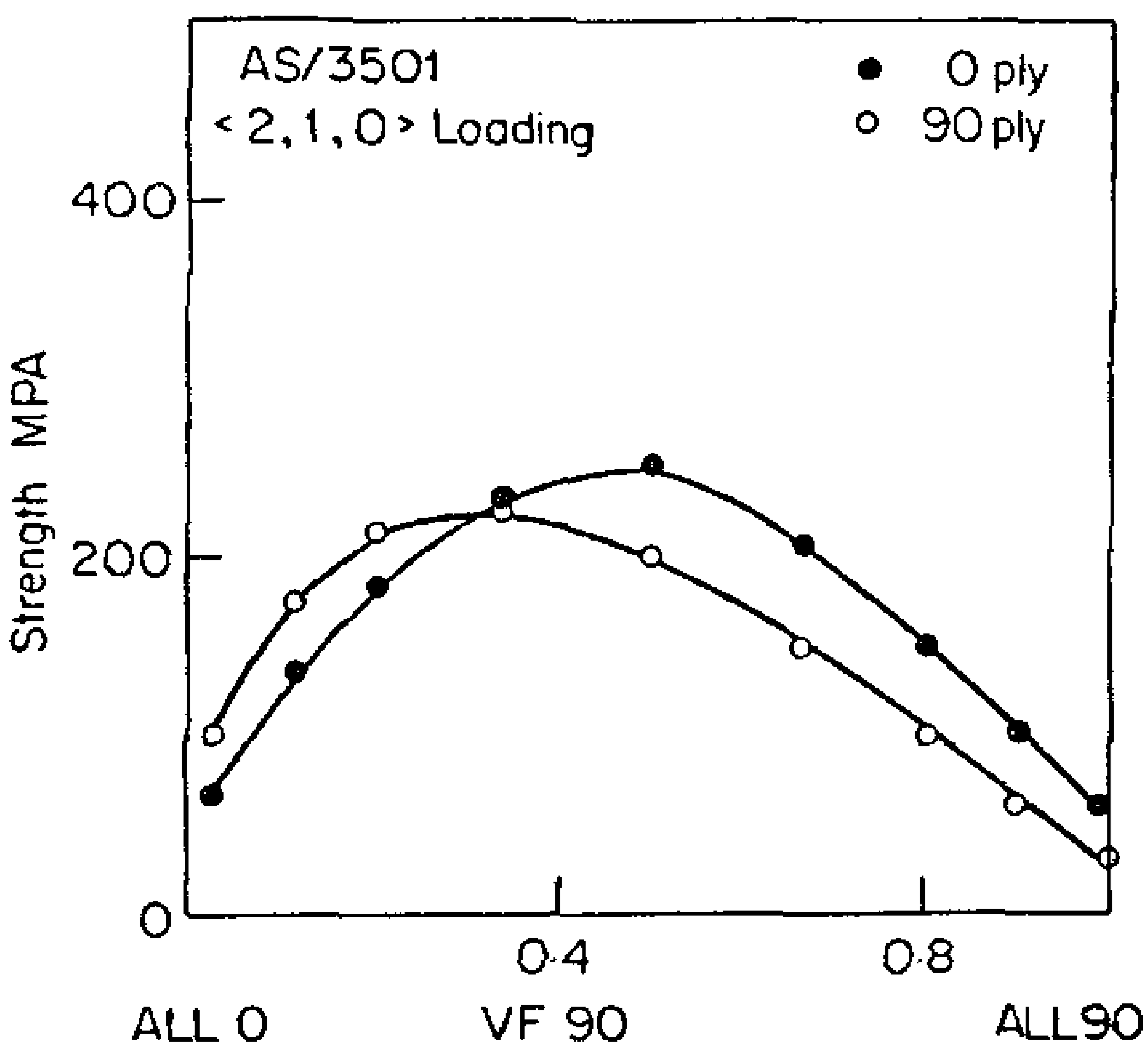



**Figure 4.** Ply failure stresses for cross-ply laminates of graphite-epoxy for <2, 1, 0> loading. In the optimum laminate the strain induced is hydrostatic and the plies fail simultaneously.

*Design of bolted joints*:

Composites are joined to each other or to metals by bolted joints. The failure criterion discussed in the present paper can be used to predict the strength of bolted joints[20]. The stress analysis can be done using the finite element method. The hole is filled with a rigid cone simulating a bolt and to represent the forces acting at the bolted joint, displacement boundary conditions are applied to the rigid core. The predicted stress data are substituted in (1) and the individual ply failures determined as discussed above. The stress distribution for the laminate can be determined by the application of the rule of mixtures if the stress distribution for the individual plies are known. The predicted strength data are in reasonably good agreement with the experimental results, although a number of complicating factors, *e.g.* stacking sequence, delamination etc have not been considered. These would necessitate a three dimensional stress analysis.

## Concluding Remarks

The recent progress made by combining the laminated plate theory with computer graphics enables a simple evaluation of first ply failure stresses. Consequently designing with composites is now better under-stood. It is no longer necessary to lay up composites in quasi-isotropic configurations in order to simplify the design procedure.

Although a number of unique properties of composites are well appreciated[21], a lack of confidence on the part of designers has acted as a deterrent in the widespread use of composites. It is hoped that this situation will improve and the composite laminates will be used in novel and cost-effective configurations.

## Acknowledgements

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# A REVIEW OF THE TAXONOMIC POSITION OF *MINIOPTERUS* BASED ON EMBRYOLOGICAL CHARACTERS

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ABSTRACT

On the basis of morphological characters the genus *Miniopterus* has been included in the family Vespertilionidae among Microchiroptera. However, a study of the embryology of *Miniopterus schreibersii fuliginosus* reveals that this bat differs from all vespertilionids in several important embrological characters, such as, the nature of implantation of the blastocyst, the method of development of the amnion and the morphogenesis and the final structure of the chorio-allantoi placenta. These developmental characters suggest that the morphological resemblances between *Miniopterus* and the vespertilionied bats are due to convergent evolution rather than to phyletic relationship, and that *Miniopterus* deserves a familial status. The creation of a new family, Miniopteridae, has been proposed to receive this genus.

## INTRODUCTION

THE relative conservatism of developmental characters in mammals, and therefore, the importance of these characters in determining the phylogenetic relationships of mammalian orders and families were demonstrated by Mossman[1-3]. He showed by numerous illustrations that the morphological characters, (such as, those of the skin, dentition, foot, alimentary canal etc) being under the direct influence of the environment, are precisely the characters which are pliable and are, therefore, adaptive. On the other hand the developmental characters of mammals are not directly under the influence of environment since the development takes place inside the maternal uterus in all mammals (except monotremes). Torpin[4] supported this thesis and mentioned that "classification of animal evolution be founded upon embryological progression rather than upon morphological similarities, which are ecologically determined". Several authors[5-13] have utilised foetal membrane characters for determining phylogenetic relationships of different mamallian groups. The present paper embodies the description of some major features in the development of *Miniopterus schreibersii fuliginosus*. These embryological characters justify the separation of the genus *Miniopterus* from the family Vespertilionidae, in which it has been included so far, and the creation of a new family, Miniopteridae, to include this genus.

## MATERIAL AND METHODS

352 specimens of *Miniopterus schreibersii fuliginosus* carrying different stages of pregnancy were examined for the present study. The female genitalia were dissected out after killing the specimens with chloroform and fixed in various ways such as in neutral formalin, Bouin's, Carnoy's, Rossman's and Zenker's fixative. The fixed tissues were dehydrated by passing through graded ethanol, cleared in xylol, embedded in paraffin and sectioned serially at a thickness of 3-8 $\mu$. For routine histological study the sections were stained with Ehrlich's haematoxylin and counter stained with eosin. A few selected sections from each series were stained by the periodic acid-Schiff (PAS) procedure[31], some by Heidenhain's Azan technique and some by Mallory triple procedure.