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# A BASIC COMPUTER PROGRAM TO CALCULATE MOISTURE CONTENT IN RESINS AND FIBRE REINFORCED RESIN COMPOSITES

by

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# A BASIC COMPUTER PROGRAM TO CALCULATE MOISTURE CONTENT IN RESINS AND FIBRE REINFORCED RESIN COMPOSITES

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## SUMMARY

A basic language computer program is presented which calculates the moisture absorption of epoxy resin and fibre composite sheets from the sheet thickness, the diffusivity and the relative humidity of the environment. One-dimensional Fickian diffusion is assumed in the calculations. The program gives the water absorbed by the material in a given exposure time, together with the times for the material to absorb 95% and 99% of the maximum water uptake. In addition, the distribution of water through the laminate thickness is calculated and displayed graphically. The programme can be used for any resin or fibre composite in which the primary moisture diffusion mechanism is bulk diffusion through the resin. Examples for typical fibre reinforced epoxy composite laminates are given and the implications are discussed. Diffusion data for three materials at room temperature and two materials at 50°C are listed for use in the program.

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## 1 INTRODUCTION

Fibre reinforced plastics, because of their high strength and stiffness combined with their low density and the low cost of the finished components, are being used increasingly in airframe structures. In a service environment, fibre composite structures will be exposed to ultra-violet radiation, lightning strikes, acoustic fatigue, corrosive fluids and atmospheric moisture and consideration must be given to their effect on mechanical properties. In this Memorandum only absorbed moisture is considered.

The current generation of epoxy resins used in high performance fibre composites absorb water from the atmosphere. The immediate effect of this is a swelling of the resin which counteracts to some extent the shrinkage during the curing process and it can result in significantly reduced residual thermal strains in laminates[1]. Water absorption by the epoxy resins also leads to a reduction in the glass transition temperature and to a softening of the resin with a loss of resin stiffness and strength, particularly at elevated temperatures[2]. In the longer term the resin may be permanently damaged and a further degradation in properties may result[3]. These degraded resin properties manifest themselves in the fibre composite as a loss of performance in the resin dominated properties such as reductions in strength and stiffness under shear loading, compressive loading and loading perpendicular to the fibres[2,4,5]. In some composites, such as those reinforced with polymer fibres or glass fibres, the fibre properties may also be degraded by moisture absorption.

The quantity of water absorbed by a laminate is thus of considerable importance, in particular to the designer when setting design limits for structures operating in moist environments. In this Memorandum a basic computer program is presented for the calculation of the quantity of water absorbed by a fibre composite or resin sheet for a given exposure time in an environment of known relative humidity. It is assumed that the rate controlling mechanism is one-dimensional Fickian diffusion through the resin, and that diffusion of moisture in the fibres or along the fibre-resin interface is negligible. The equilibrium quantity of water absorbed in the environment is calculated as well as that in the specified time. In addition the time taken for the laminate to absorb 95% and 99% of the maximum water uptake in the environment is calculated. The program also permits a profile of the distribution of water through the laminate thickness to be plotted for the given conditions. The only input requirements are the laminate thickness, exposure time, relative humidity of the environment, the saturation water content (in a 100% RH environment) the diffusivity of water in the material and the initial moisture content. Diffusivities of three materials at two temperatures are given in section 5, together with the saturation water contents of the materials. The program was written specifically to run on a CBM PET computer with a usable RAM (random access memory) of at least 8K bytes. However, the program could easily be modified to run with any basic language compiler.

## 2 MOISTURE ABSORPTION THEORY

In a glass, carbon or boron fibre reinforced epoxy resin, moisture is absorbed by the resin; the fibres do not absorb moisture. Most of the evidence in the literature[2,6] suggests that moisture is absorbed by a bulk diffusion mechanism in the resin and that for sheet laminates the rate of absorption $\partial c/\partial t$ can be described by Fick's second law of diffusion in one dimension (*ie* through the thickness):

$$\frac{\partial c}{\partial t} = D_x \frac{\partial^2 c}{\partial x^2} \tag{1}$$

where $c$ is the moisture concentration at time $t$ and $x$ is the distance from the laminate surface. $D_x$ is the diffusion coefficient (diffusivity) in the $x$ direction; this is a thermally activated parameter of the Arrhenius type and varies with temperature such that diffusion occurs more rapidly at higher temperatures. The fit between Fickian diffusion theory and experiment is generally good but not perfect and there is evidence that in some circumstances there can be large discrepancies[7,8]. These may be due to anomalous diffusion processes such as more rapid diffusion along the fibre-resin interfaces (or fibres in the case of polymer fibre reinforced resins) which is not included in bulk diffusion theory. In addition, the diffusivity may also be a function of laminate thickness, fibre orientation, internal stress or moisture concentration, in which case equation (1) would be inapplicable and the problem would be significantly more complex. At present, however, Fickian diffusion theory provides a simple technique for describing the approximate moisture absorption characteristics of resins and fibre composite laminates and this is the basis of the calculations in this work.

The solution of equation (1) has been given by Shen and Springer[6] as:

$$\frac{c - c_0}{c_m - c_0} = 1 - \frac{4}{\pi} \sum_{j=0}^{\infty} \frac{1}{2j + 1} \frac{\sin(2j + 1)\pi x}{h} \exp\left[ - \frac{(2j + 1)^2 \pi^2 D_x t}{h^2} \right] \tag{2}$$

where $c_0$ is the initial concentration at zero time and $c_m$ is the maximum concentration in the given environment (both per unit volume). Equation (2) thus gives the moisture concentration through the laminate thickness $h$ at any time $t$ and position $x$. This equation has been used in this work to calculate moisture profiles across laminate thicknesses. The summation was performed for up to $j = 100$, but the series usually converges for $j < 10$.

The total moisture content per unit volume in a laminate is determined by integrating equation (2) over the laminate thickness

$$m = \frac{1}{h} \int_0^h c \, dx \quad . \tag{3}$$

Shen and Springer have given an approximate solution to equation (3) which fits the appropriate boundary conditions[6]:

$$G = \frac{m - m_0}{m_m - m_0} = 1 - \exp\left[-7.3\left(\frac{D_x t}{h^2}\right)^{0.75}\right] \qquad (4)$$

where $m$ is the total moisture content per unit volume in the laminate at time $t$, $m_m$ is the maximum moisture content per unit volume in the given environment and $m_0$ the moisture content per unit volume at zero time. In practical applications it is the percentage moisture content $M$ that is of interest, as given by

$$M = \left(\frac{W - W_d}{W_d}\right)100 \qquad (5)$$

where $W$ is the mass of moist material and $W_d$ that of the dry material. Since $W = W_d + m$, it is apparent that:

$$G = \frac{m - m_0}{m_m - m_0} = \frac{M - M_i}{M_m - M_i} \qquad (6)$$

where $M_i$ is the initial and $M_m$ the maximum percentage moisture content. Current evidence on typical epoxy based laminates supports the idea that, although $D_x$ is a strong function of temperature, $M_m$ is independent of temperature (at least within the normal range of working temperatures). Equations (4) and (6) have been used in this work to calculate the total moisture content $M$ in the specified environment for a known time $t$ and laminate thickness $h$. For large $t$, the quantity $G$ in equation (4) tends to unity, only reaching this at infinite time. To make an estimate of the time for $M$ to approach $M_m$ it is thus necessary to set $G$ to less than unity. In this work the time for $M$ to reach 95% and 99% of $M_m$ was calculated by the appropriate substitution in equation (4).

The maximum moisture content in an environment with $\phi$% relative humidity is given by the empirical relationship[6]:

$$M_m = a(\phi/100)^b \qquad (7)$$

where $a$ and $b$ are experimentally determined constants for each material ($a$ is the saturation moisture content in % of the material in a 100% RH environment). For many materials, $b$ in equation (7) can be set approximately to unity and only the value of the parameter $a$ varies with material type[9,10]. This approximation usually provides an adequate description of moisture content as a function of relative humidity, although deviations frequently occur in very wet environments[11]. Thus in this work $b$ was set to unity and values of the parameter $a$ were obtained from various sources[9,11].

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## 3 INPUT DATA REQUIREMENTS

Before the program may be executed, the following parameters must be known:

(a) The laminate thickness in mm.

(b) The relative humidity of the environment in % .

(c) The exposure time in days.

(d) The initial moisture content in % .

(e) The name of the resin for reference purposes.

(f) The diffusivity of the material at the required temperature in $mm^2 s^{-1}$ .

(g) The saturation water content of the material in % (in a 100% RH environment).

## 4 THE COMPUTER PROGRAM

A complete listing of the program is given in Table 1. This should be entered into the computer's memory, then the command RUN followed by RETURN will cause the program to be executed.

Between lines 180 and 260 of the program the operator is requested to enter the name, diffusivity and maximum moisture uptake of the resin based material. At line 190 the relative humidity of the environment should be entered on request. In addition the exposure time, laminate thickness and initial moisture content should be entered as directed. Equation (4) is used to calculate the moisture content $M$ in the specified conditions; this appears as lines 280-290 in the program. Lines 300-330 are concerned with printing the results of the initial calculations on the vdu screen. Lines 340-350 and 410-420 make use of equation (4) to calculate the time taken for the material to reach 95% and 99% respectively of the maximum moisture content $M_m$ . This information is printed out through lines 370, 400, 450 and 470. At line 490 the operator is asked whether a moisture profile across the laminate thickness is required. The GET command in line 500 responds to a positive reply by initiating the graph plotting subroutine from line 570 onwards. Any other response leads to termination of the programme at line 550, but a re-run with the same material and environmental conditions can be triggered by a positive response to the GET statement of line 530. Output on either the computer vdu or an external printer can be selected by the appropriate command at lines 580-590.

In lines 670-770 the distribution of moisture across the laminate thickness is calculated using equation (2). Thirty values are calculated at equal spacings across the thickness. The rest of the programme is a graph plotting routine which displays the water content of the laminate versus the distance across the laminate thickness. Automatic scaling and labelling of the axes is incorporated in the routine. When the plot is complete a RETURN command at line 2110 returns control to line 510 and at line 520 the operator can request a re-run with the same material and environmental conditions by typing Y . Any other response leads to the termination of the program.

## 5 TYPICAL RESULTS

Diffusivities and values of the parameter $a$ for three epoxy resin based materials at room temperature and two at 50°C are listed in Table 2 (fibre volume fractions are approximately 0.6 for all five cases). This information may be loaded into the program as directed (see section 4 for details).

The following data for an XA-S/914 laminate exposed at room temperature was entered as described in section 4. Use was made of the data in Table 2.

### 5.1 Example 1

(a) Laminate thickness = 2 mm.

(b) The relative humidity of the environment = 65%.

(c) Exposure time = 30 days.

(d) Initial moisture content = 0%.

(e) Resin name = 914.

The output for this material is summarised below:

```
MAXIMUM MOISTURE CONTENT = 1.125%
MOISTURE CONTENT = 0.6653% AT 30 DAYS
TIME TO REACH 95% OF MAXIMUM WEIGHT INCREASE IS 150.19 DAYS
TIME TO REACH 99% OF MAXIMUM WEIGHT INCREASE IS 266.47 DAYS
```

The moisture profile across the laminate thickness is given in Fig 1.

### 5.2 Example 2

(a) Laminate thickness = 10 mm.

(b) The relative humidity of the environment = 65%.

(c) Exposure time = 100 days.

(d) Initial moisture content = 0%.

(e) Resin name = 914.

The output for this material is summarised below:

```
MAXIMUM MOISTURE CONTENT = 1.125%
MOISTURE CONTENT = 0.2016% AT 100 DAYS
TIME TO REACH 95% OF MAXIMUM WEIGHT INCREASE IS 10 YEARS AND 104.9 DAYS
TIME TO REACH 99% OF MAXIMUM WEIGHT INCREASE IS 18 YEARS AND 91.75 DAYS
```

The moisture profile across the laminate thickness is given in Fig 2.

## 6 DISCUSSION

The computer program presented in section 4 permits the moisture absorption behaviour of thin sheets of resins or fibre reinforced resins to be calculated. Example data is included in section 5 which permits the behaviour of three materials at room temperature and two materials at $50^{\circ}$C to be calculated, although the moisture absorption behaviour may be calculated for any sheet material if the diffusivity at the required temperature and the saturation moisture content are known.

In a service environment, both the relative humidity and temperature of the environment will be changing daily and seasonally, so that both the diffusivity and the maximum moisture content will vary. The relative humidity may vary from dry to wet, 0 to 100% RH, although in a typical North European environment this range would probably be smaller. The operating temperature of a typical military aircraft may vary from $-50$ to $+120^{\circ}$C. Thus the maximum moisture content of a resin-based structural component will vary considerably and the diffusivity of the material also, from less than $10^{-8}$ to greater than $10^{-7}/\mathrm{mm}^2\ \mathrm{s}^{-1}$. However, an average quasi-steady state moisture content is reached after long exposure times, typically about 10 years for panels more than a few mm thick, with only minor fluctuations superimposed[13]. The moisture distribution in the surface layers, however, is more changeable because they can respond more rapidly. Although the computer program is only applicable for constant relative humidity environments, this behaviour is demonstrated in the example in section 5.2 for a typical North European environment of 65% relative humidity. In this example a 10mm thick CFRP laminate was shown to take over 10 years to absorb 95% of the maximum moisture content, but after 100 days continuous exposure only the surface layers had absorbed significant quantities of moisture, the interior of the laminate still being dry.

## 7 CONCLUSIONS

A basic computer program was presented and discussed that allows the moisture content to be calculated in a thin sheet of resin based material exposed to an environment of known temperature and relative humidity, for a specified time. The program also permits the calculation of the time taken for the material to absorb 95% and 99% of the maximum moisture content in the specified environment. The distribution of moisture through the sheet thickness may also be plotted. The programme can be used for any resin or fibre composite in which one-dimensional Fickian diffusion adequately describes the moisture absorption mechanism through the sheet thickness. Examples for typical fibre composites are given. Fibre composite laminates more than a few mm thick were shown to take many years to reach saturation and in the short term only the surface layers responded rapidly to the exposure environment.

Table 1

## THE COMPUTER PROGRAM

```
100 DIM MOI(100),DIS(100),X(100),Y(100),Z(100),Q(100)
110 I=0
120 PRINT"█"
130 PRINT"-----------------
140 PRINT"█LAM.WATER UPTAKE"
150 PRINT"-----------------█
160 PRINT"█THIS PROG DETERMINES WATER UPTAKE FOR    ANY LAMS.FROM DIFFUSION DATA
"
170 PRINT"IT IT ASSUMED THAT FICKIAN DIFFUSION IS APPLICABLE
180 INPUT"█DIFFUSIVITY IN MM↑2*S-1";DX
190 INPUT"█RH OF ENVIRONMENT IN %";RH
200 INPUT"█MAXM.% WATER UPTAKE ";MX
210 MM=MX*RH/100
220 INPUT"█NAME OF RESIN";S$
230 I=I!1
240 INPUT"█EXPOSURE TIME IN DAYS";T
250 INPUT"█THICKNESS OF LAMINATE IN MM";S
260 INPUT"█INITIAL MOISTURE CONTENT IN %";IM
270 T=T*24*3600
280 G=1-EXP(-7.3*(DX*T/S↑2)↑.75)
290 M=(INT(10000*G*(MM-IM)-IM)/10000)+IM
300 PRINT"█":PRINT"█LAM.WATER UPTAKE------RESULTS█"
310 PRINT"██";S;"█MM THICK ",S$;" LAM.IN ";RH;"██RH"
320 PRINT"█MAXM.MOISTURE CONTENT=";MM;"%"
330 PRINT"█MOISTURE CONTENT=";M;"% AT";(T/24/3600);"DAYS "
340 Q=1-(.95*MM-IM)/(MM-IM)
350 FT=INT(100*((-LOG(Q)/7.3)↑(4/3))*S↑2/DX/3600/24)/100
360 IF FT>365 THEN 390
370 PRINT"█TIME TO REACH 95% OF MAX.WT.INCREASE IS";PT;"DAYS█"
380 GOTO410
390 T1=INT(PT/365):T2=PT-T1*365
400 PRINT"█TIME TO REACH 95% OF MAX.WT.INCREASE IS";T1;"YEARS AND";T2;"DAYS█"
410 Q=1-(.99*MM-IM)/(MM-IM)
420 PT=INT(100*((-LOG(Q)/7.3)↑(4/3))*S↑2/DX/3600/24)/100
430 IF PT<366 THEN 470
440 T1=INT(PT/365):T2=PT-T1*365
450 PRINT"TIME TO REACH 99% OF MAXM.WT.INCREASE IS";T1;"YEARS AND";T2;"DAYS"
```

Table 1 (continued)

```
460 GOTO480
470 PRINT"TIME TO REACH 99% OF MAX.WT.INCREASE IS":PT;"DAYS"
480 T=T/24/3600
490 PRINT"QQLIKE TO SEE THE MOISTURE PROFILE ACROSS THE LAMINATE WIDTH AT";T;"D
AYS?"
500 GET IT$:IF IT$="" THEN 500
510 IF IT$="Y" THEN GOSUB 560
520 PRINT"QQRE-RUN WITH SAME MATERIAL & ENVIRONMENT?"
530 GET T$:IF T$="" THEN 530
540 IF T$="Y" THEN 230
550 END
560 PRINT"J"
570 REM GRAPH PLOTTING SUBROUTINE
580 PRINT"FOR OUTPUT ON PRINTER TYPE P, FOR SCREENANY OTHER KEY"
590 GET PR$:IF PR$="" THEN 590
600 IF PR$<>"P" THEN 630
610 PRINT"START PRINTER AT NEW PAGE TYPE ANY KEY  TO CONTINUE"
620 GET W$:IFW$="" THEN 620
630 A=0:B=0:T=T*24*3600
640 PRINT"JQQQQQ                 NOW WAIT!"
650 IF PR$<>"P" THEN 670
660 OPEN4,4:CMD4

670 IN=DX*T/(S↑2)
680 FOR K=1 TO 31
690 DIS(K)=S*(K-1)/30
700 A=0:B=0
710 FORJ=0 TO 100
720 A=EXP(-((2*J+1)↑2)*(π↑2)*IN)*SIN((2*J+1)*π*DIS(K)/S)*1/(2*J+1)
730 B=B+A
740 IF A=0 THEN 760
750 NEXTJ
760 MOI(K)=((MM-IM)*(1-(4/π)*B))+IM
770 NEXT K
780 CC=0:DD=0:MY=20:MX=33:XI=0:XA=0
790 IF PR$<>"P" THEN 810
800 MY=53:MX=60
810 OP$="S":TL$="MOISTURE PROFILE"
```

Table 1 (continued)

```
820 FORI=1TO MX
830 X(I)=0.0:Q(I)=0.0:Y(I)=10↑20
840 IF MOI(I)=0 AND DIS(I)=0 THEN 930
850 Y=MOI(I):X=DIS(I)
860 IF I<>1 THEN 880
870 CC=Y:DD=Y:XA=X:XI=X
880 IF Y>CC THEN CC=Y
890 IF Y<DD THEN DD=Y
900 IF X>XA THEN XA=X
910 IF X<XI THEN XI=X
920 X(I)=X:Q(I)=Y
930 NEXTI
940 IF DD>(0.9*CC) THEN DD=0.9*CC
950 REM MX IS NO.SPACES ON X AXIS:MY IS NO.ON Y AXIS
960 FOR T=1 TO MX:Y(T)=10↑20:NEXT T
970 FORI=1TO MX
980 IF X(I)=0.0 AND Q(I)=0.0 THENGO TO 1070
990 P=((X(I)-XI)*(MX-1))/(XA-XI)
1000 IF(P-INT(P))>0.5 THEN P=P+1
1010 P=ABS(INT(P+1))
1020 Y(P)=((Q(I)-DD)*(MY-1))/(CC-DD)
1030 IF(Y(P)-INT(Y(P)))>.5THENZ(P)=1
1040 Y(P)=INT(Y(P))
1050 GO TO 1070
1060 PRINTY(P);"  ";P;"  ";Z(P):STOP
1070 NEXTI
1080 PRINT"▮"
1090 FORI=1TO MY
1100 YT=0
1110 IFI=1THENPRINT"▮MOISTURE-%",TL$
1120 IF PR$="P" THEN 1140
1130 PRINT"▮";
1140 IF((I-1)/4-INT((I-1)/4))<>0THEN PRINT"        |";:GO TO 1390
1150 REM
1160 YT=((CC-DD)*((MY+1)-I))/(MY-1)+DD
1170 IF ABS(YT)>=100 THENPRINT"       |";:GO TO 1390
1180 SG=0.0
1190 IF YT<0.0 THEN SG=1.0
1200 YT=ABS(YT)
```

Table 1 (continued)

```
1210 IF(YT*100.-INT(YT*100))>0.5 THEN YT=YT+0.01
1220 IF YT<10. THEN 1280
1230 IF(YT-INT(YT))>0.5 THEN YT=YT+1.0
1240 IF(YT*10.-INT(YT*10))>0.5 THEN YT=YT+0.1
1250 YT=(INT(YT*10.))/10.
1260 YT=INT(YT)
1270 GO TO 1290
1280 YT=(INT(YT*100.))/100.
1290 SE=1
1300 IF YT>=10. THEN SE=2
1310 IF (YT-INT(YT))>10↑-5 THEN 1330
1320 IF YT<10. AND YT>=1. THEN SE=3
1330 IF (((YT+1E-9)*10.)-INT((YT+1E-9)*10))>10↑-5 THEN1350
1340 IF YT<1. AND YT>=0.1 THEN SE=2:GOTO1360
1350 IF YT>1 THEN SE=0
1360 IF YT=0 THEN SE=3
1370 IF SG=1 THEN YT=-YT
1380 PRINTYT;SPC(SE);"7";
1390 J=MY-I
1400 M=+1
1410 FORK=1TOMX
1420 IFY(K)=JANDZ(K)=1 THENPRINTSPC(K-M);"*";
1430 IFY(K)=JANDZ(K)=0 THENPRINTSPC(K-M);"•";
1440 IFY(K)=I THEN M=M+1
1450 NEXTK
1460 PRINT
1470 NEXTI
1480 PRINT"        ";
1490 IF PR$="F" THEN PRINT" ";
1500 FORI=1TO (MX-1)
1510 IFI=1THEN1530
1520 IF((I-1)/8-INT((I-1)/8))=0THENGOTO1550
1530 PRINT"‾";
1540 GOTO1560
1550 PRINT"Γ";
1560 NEXTI
1570 REM JJ IS X-AXIS SCALING FACTOR
1580 IF ABS(XI)>=ABS(XA) THEN QQ=ABS(XI):GO TO 1600
1590 QQ=ABS(XA)
```

Table 1 (continued)

```
1600 IF QQ<100 THEN1630
1610 QQ=QQ/100:JJ=2:IFQQ<100THEN1630
1620 QQ=QQ/100:JJ=4
1630 IF QQ>0.1THEN 1660
1640 QQ=QQ*100:JJ=-2:IFQQ>0.1THEN1660
1650 QQ=QQ*100:JJ=-4
1660 PRINT
1670 IF PR$<>"P" THEN 1700
1680 PRINTSPC(5);
1690 GOTO 1710
1700 PRINTSPC(5);
1710 REM
1720 FORI=1TO (MX-1)
1730 IF I=1 THEN 1750
1740 IF((I-1)/8-INT((I-1)/8))<>0 THEN 2040
1750 SG=0
1760 EX=0.0
1770 XT=((XA-XI)*(I-1))/((MX-1)*(10↑JJ))+XI/10↑JJ
1780 IF XT<0THEN SG=1
1790 IF (XT*1000-INT(XT*1000))>0.5 THEN EX=0.001
1800 XT=(INT(ABS(XT)*1000)/1000)+EX
1810 AX=ABS(XT)
1820 IF AX>=10 THEN XT=INT(ABS(XT)*10)/10
1830 IF AX<10 AND AX>=1 THEN XT=(INT(ABS(XT)*100)/100)
1840 IF SG=1 THEN XT=-XT
1850 SE=3
1860 AX=ABS(XT)
1870 IF AX<10 THEN 1910
1880 SE=5
1890 IF ABS(AX-INT(AX))>10↑-4 THEN SE=3
1900 GO TO 1990
1910 IF AX<1 THEN1960
1920 SE=6
1930 IF ABS(AX-INT(AX))>10↑-4 THEN SE=4
1940 IF ABS(AX*10-INT(AX*10))>10↑-4 THEN SE=3
1950 GO TO1990
1960 SE=5
1970 IF ABS(AX*10-INT(AX*10))>10↑-4 THEN SE=4
```

Table 1 (concluded)

```
1980 IF ABS(AX*100-INT(AX*100))>10↑-4 THEN SE=2
1990 IF AX=1 OR AX=0 THEN SE=6
2000 IF AX=100 THEN SE=5
2010 SE=SE-1
2020 IF(MX-I)<8 THEN PRINTXT;" ";:GO TO 2040
2030 PRINTXT;SPC(SE);
2040 IF I=(MX-1) THEN PRINT"I";IJ;
2050 NEXT I
2060 PRINTSPC(MX-10);CHR$(18);"DISTANCE-MM"
2070 IF PR$<>"P" THEN 2100
2080 PRINT#4:CLOSE4
2090 GOTO2110
2100 GET AW$:IF AW$="" THEN 2100
2110 RETURN
```

## Table 2

## RESIN DIFFUSIVITY AND MOISTURE CONTENT DATA

| Temperature degrees C | Fibre type and manufacturer | Resin type and manufacturer | Diffusivity mm$^2$ s$^{-1}$ | a percent | Source |
|---|---|---|---|---|---|
| 23 | XA-S<br>Courtaulds | BSL-914C<br>Ciba-Geigy | $9.4 \times 10^{-8}$ | 1.731 | Ref 9 |
| 23 | XA-S<br>Courtaulds | Code 69<br>Fothergill and Harvey | $5.04 \times 10^{-8}$ | 1.354 | Ref 9 |
| 23 | A-S<br>Courtaulds | 3501-5<br>Hercules | $1.06 \times 10^{-7}$ | 1.416* | Ref 11 |
| 50 | HT-S<br>Courtaulds | 3501-5<br>Hercules | $1.2 \times 10^{-7}$ | 1.416* | Ref 12 |
| 50 | XA-S<br>Courtaulds | BSL 914C<br>Ciba-Geigy | $1.26 \times 10^{-7}$ | 1.731 | Ref 12 |

(* estimated from known moisture content in a 65% RH environment)

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Mat 375

Fig 1

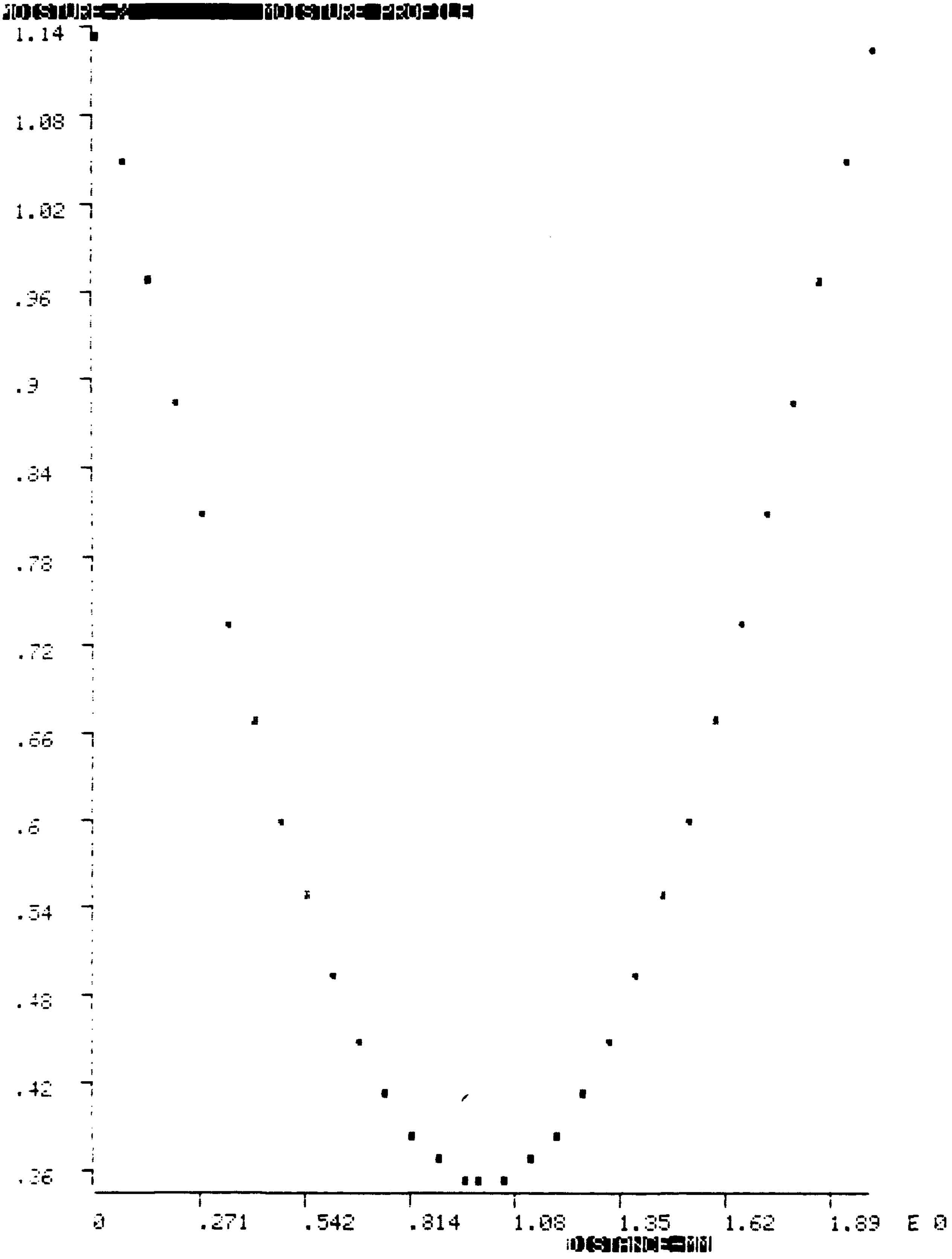

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Fig 1 A typical output for a 2mm thick XAS/914 laminate exposed for 30 days at 65% RH 23°C

Fig 2

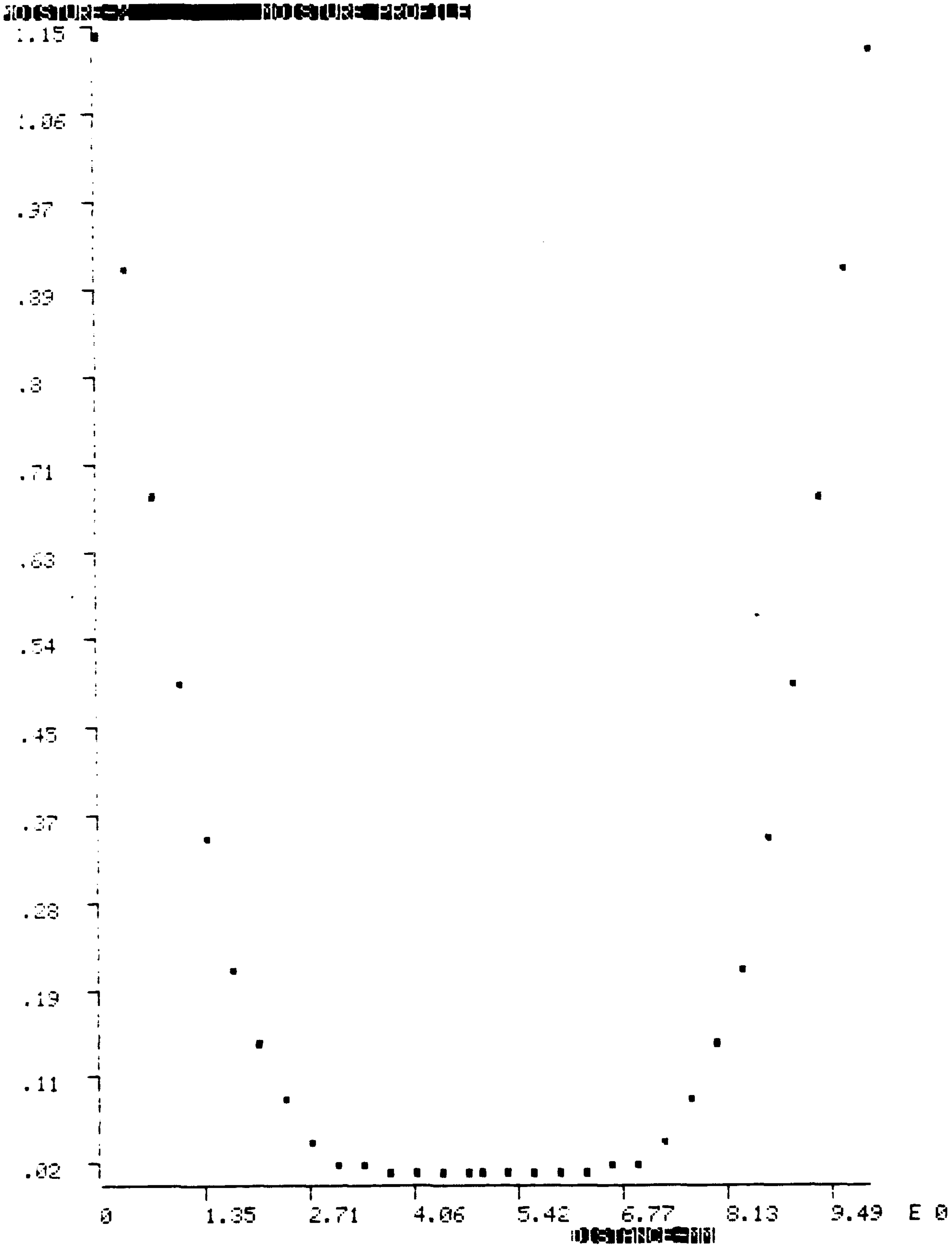

Fig 2 A typical output for a 10mm thick XAS/914 laminate exposed for 100 days at 65% RH 23$^{\circ}$C

# REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNLIMITED

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17. Abstract

A basic language computer program is presented which calculates the moisture absorption of epoxy resin and fibre composite sheets from the sheet thickness, the diffusivity and the relative humidity of the environment. One-dimensional Fickian diffusion is assumed in the calculations. The program gives the water absorbed by the material in a given exposure time, together with the times for the material to absorb 95% and 99% of the maximum water uptake. In addition, the distribution of water through the laminate thickness is calculated and displayed graphically. The program can be used for any resin or fibre composite in which the primary moisture diffusion mechanism is bulk diffusion through the resin. Examples for typical fibre reinforced epoxy composite laminates are given and the implications are discussed. Diffusion data for three materials at room temperature and two materials at 50°C are listed for use in the program.

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