FATIGUE ENDURANCE PROGRAM FOR CLASSIFICATION OF BUILT-UP ROOFING

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The paper provides a computer listing for the classification of bituminous membranes with respect to fatigue endurance according to the Centre Scientifique et Technique du Batiment F.I.T. proposals.

The program is based on mathematical models and data presented at previous conferences. The general theoretical treatment is not repeated here in detail. The program is to be regarded as an interim proposal on the best information available, but subject to validation and improvement. It does appear to provide plausible classifications consistent with experience.

KEYWORDS

Amstrad 8256/8512 PCWs, computer program, fatigue, F.I.T. classification, indentation, Mallard Basic (CP/M), temperature.

INTRODUCTION

This paper presents a simplified computer program for the fatigue endurance of fully- or partially-bonded built-up membrane systems. The program accommodates single or two layer systems composed of oxidized or modified asphalt roofings applied with hot bonding asphalt or installed by torching techniques.

The program listing is given (in full) in the Appendix. The program language is Mallard Basic (CP/M), which is the standard language for the Amstrad 8256/8512 PCWs. It is possible to transcribe the listing into MS-DOS for use on IBM compatible computers. The program should be regarded as a first version and no more than a basis for further development. Improvements are clearly possible, both in respect of programming technique and in quality and range of product data stored.

This particular exercise was prompted by a recently published project in France by the Centre Scientifique et Technique du Batiment concerned with the F.I.T. performance classification of bitumen membrane systems.[1] The F.I.T. acronym stands for a system performance grading in respect of Fatigue (F) endurance, Indentation (I) resistance and Temperature (T) resistance. It is assumed that the reader is familiar with the project details. A paper by A. Chaize, elsewhere in the *Proceedings* introduces F.I.T. The present program is concerned solely with the Fatigue element of the classification proposal. It is derived from earlier versions of a program developed by the author for the Ruberoid Company (now part of Tarmac Roofing Systems Ltd.) for the ranking of specification options according to relative fatigue endurance.

The French F.I.T. project, which is of interest in its own right, could well assume some importance if a rational approach towards performance standards is to be achieved. But the French proposal presently involves system classification by elaborate and costly testing. If it were possible to predict by calculation, even approximately, the more important Fatigue (F) classification, then this would represent a major cost saving advantage. This paper introduces a fatigue endurance program for just this purpose.

The paper touches upon its features and operation of the listed program with model calculations where appropriate. Attention is drawn to the several assumptions the verification of which would usefully form the basis of future research. There is also a need to confirm the accuracy of some of the functional relationships and data presently stored in the program.

The mathematical aspects of the membrane system model are not discussed. The subject has been dealt with at several international conferences over the past decades. The reader is referred to the relevant papers for information on formulas and assumptions.[2,3] Suffice it to say that there is general international agreement on the form of the equations which underpin membrane models.

The system model is restricted to the case where both the bitumen matrix and reinforcement are taken to be Hookeon (elastic) bodies, even though this is not strictly correct. Viscoelastic effects are discarded, as is age hardening of the bitumen. Allowance for these effects can be made, but introduces complexity which is beyond the scope of this paper and hardly warranted for broad classification purposes.

PRODUCT CODING

The computer program requires roofing products to be identified by a generic five character alpha-numeric product description, (e.g., BP180) as defined below:

First letter: Type of bitumen coding

B	105/35	Oxidized bitumen
E	100/45	SBS-modified bitumen
P	145/30	APP-modified bitumen

The second column above gives the assumed 'equivalent' grade of bitumen from which the stiffness, or shear modulus, is derived as a function of temperature and loading time. In this connection, the stiffness corresponds with that given by the van der Poel Nomograph. Changing the grades of bitumen in lines, 2570, 2580 and 2590 will automatically give the corresponding stiffness values in the computer program.

Second letter: Type of reinforcement

V	Glass fibre tissue
W	Woven glass fabric
P	Polyester mat

This could be expanded to include materials not specifically mentioned above. Last three numbers give the mass (gsm) of the reinforcement. Thus, BP180 refers to a product reinforced with 180 gsm polyester mat (PET) and coated with

105/35 oxidized bitumen, and so on generally. There is a case for the use of six coding characters to include reference to nominal product thickness, which is presently absent. There are products which differ only in respect of thickness, but which are otherwise similar. These cannot be identified separately using the five character product code. But this possible change presents no special programming difficulty.

PRODUCT DATABASE

The product database included in the program is given in the lines 9000-9120 with typical product details as below:

Column 1	Product code
Column 2	Nominal product thickness, mm
Column 3	Elastic modulus of reinforcement, N/mm
Column 4	Maximum permitted elongation of reinforcement
Column 5	Coating type; i.e., B, E, P
Column 6	Bonding layer thickness allowance, mm

The program is such that the database may be extended or amended, and will operate accordingly without further action other than bringing the optional screen display (lines 2060-2180) up to date for the convenience of the user.

PROGRAM OUTLINE

The first screen display following the RUN instruction requires the rate of joint movement to be entered and then asks the user whether he wishes to display the contents of the database before proceeding. The rate of movement corresponds to speed of separation between the two elements of the substrate. The F.I.T. classification specifies a rate of 16 mm/min, but other rates may be accommodated if required.

The program proper moves on to request the membrane specification to be entered in abbreviated code (one or two layers); e.g., BV060/BP180, EV060/EP250, PP180, etc. The last entry always relates to the top layer; the stacking order is therefore important. BV060/BP180 is NOT the same as BP180/BV060.

There is then a choice between F for a fully bonded system, or V for a partially bonded system (vented) in which the first layer is a perforated glass base sheet of the type specified in British Standard 747 Type 3G placed beneath the primary membrane composed of one or two chosen layers.

The screen then clears and the system operating temperature is entered where prompted, followed by the substrate joint opening (g) in mm. The joint is assumed to open from 0 to g mm and back again, all at the constant rate of movement entered at the start of the program.

The reinforcement is taken to be located in the middle of the product except for torching sheets where some nominal allowance is made for the fact that the reinforcement is usually nearer the top of the product. The program automatically calculates the distance of each layer of reinforcement from the substrate beneath (h1 and h2, respectively).

The program proceeds to determine the number of cycles to failure based on the lesser of (1) the fatigue endurance of the reinforcement, and (2) that of the coating bitumen in the top most sheeting. Failure is deemed to have occurred when the endurance of the critical element at the top of the membrane is exhausted, regardless of whether embedded reinforcement has ruptured or not. In practical terms, failure is said to have occurred when a fissure is visible in the upper surface of the membrane. It is then safe to presume that waterproofing integrity has been compromised.

A display will appear if the underlayer reinforcement fails prematurely before the endurance of the system as a whole has been reached, as is usually the case with polyester reinforced systems.

The program is looped so that one may change the joint movement figure to obtain a corresponding endurance for the given system and temperature. It is also possible to return to the original specification prompt to change the membrane and imposed system conditions.

An optional print-out routine is provided to make hard copies of results, if required. The print-out records system information, its F.I.T. classification and the system endurance under the stated conditions, including the bitumen stiffness, shear modulus and strain at break. The distances above the substrate (h1 and h2) and moduli (E1 and E2) of the reinforcing mats are also recorded. Classification is obtained by a trial process.

TYPICAL RESULTS

The program was used to grade the two layer specifications according to the F.I.T. classification proposals for fatigue endurance. An F classification means that the unaged membrane passes 500 cycles on a movement simulator operating at constant speed of 16 mm/min. at the specified temperature and substrate joint opening given in Table 1.

Typical membrane system classes with the aid of the program are given in Table 2. The computer print-out for some of the classifications in Table 2 is given at the end of the paper.

It is possible to rank specifications in order of ascending movement capability for a given number of cycles to failure. If 500 cycles is arbitrarily taken as the fixed number of cycles, then the calculated joint opening (mm) for the specifications listed in Table 2 at constant temperatures of −10°C and 0°C are given in Table 3.

Compare the effect of inverting BW200 + EP250 to EP250 + BW200, as given in the last line above. This is to emphasize the importance of product combination on system performance.

One can express relative movement capability by choosing one specification as a datum and then expressing others by comparison with the datum. The advantage is that the ratio does not change very much with changes in cycle time for a given temperature, and is a fair measure of how much better one system is with respect to another. The ratio will change for different temperatures, but not excessively.

Taking the datum specification as BV060 + PP180 and assigning an arbitrary value of 10 for the movement capability at the chosen reference temperature, Table 4 gives the relative performance capabilities of the other specifications.

BITUMEN DATA

The rheological properties of bitumen are based on the well-known van der Poel Nomograph. A paper was presented at the International Symposium on Roofs and Roofing in 1981,[4] which proposed a generalized mathematical model which adequately encapsulates the Nomograph data.

No allowance is made for aging in the program. One could allow for this by raising the softening point and reducing the penetration by suitable amounts. Previous work carried out by the Ruberoid International Technical Committee has suggested that the terminal hardness of fully aged bitumen is obtained roughly by increasing the softening point by 30 percent and reducing the penetration by 50 percent. It takes from 10 to 15 years to achieve the terminal hardness.

The fracture and fatigue properties of bitumen are based on Heukelom's work published in Shell Bitumen Reprint No. 19 on rheology and fracture of bitumens and asphalt mixes. Where necessary, data in graph form have been converted into mathematical expressions by fitting a curve through experimental points and then determining parametric constants for the curve by the method of least squares. The expression for strain in line 3100 has been determined in this way and accurately represents the experimental data published by Heukelom.

The treatment of APP- and SBS-modified bitumens in the program is speculative at present. APP is regarded as equivalent to an 145/30 oxidized bitumen. Similarly, the SBS-modified bitumen is taken as a 100/45 bitumen, but the strain at break is doubled by comparison with an unmodified 100/45. Otherwise modified bitumens are regarded as quasi-oxidized bitumens for the purposes of stiffness and fracture. These assumptions clearly need to be verified. There is yet little published information on the rheological behavior and fracture mechanisms of these polymer modified bitumens, but the assumptions made for the purposes of the program appear plausible.

REINFORCEMENT (BASES)

The fatigue endurance of glass fibre tissue (typically line 6600) is based on earlier experimental work by Key and Kramer, and presented in 1977.[5] Nothing is known about the fatigue characteristics of polyester mats, except that it is of a much higher order than that for glass mats. The assumption is that polyester generally follows the characteristics of glass fibre tissue with the important difference that the elongation at break corresponding to one cycle is some 20 times or so greater.

Symbolically, the fatigue function for a material may be expressed as:

$$\epsilon_f(n) = \epsilon(1).U(n)$$

where $\epsilon(1)$ = strain to rupture in first loading cycle

$U(n)$ = fatigue usage function which decreases with increasing number of loading cycles (n), with $U(1) = 1$.

For glass fibre tissue, the empirical function U is given by

$$U(n) = \{1\text{-}0.25.\ln[\cosh(\log n)]\} \text{ for } n \geq 1$$

The U function is assumed to hold for polyester mats, but $\epsilon(1)$ is then some 20 percent as opposed to about 1 percent for glass fibre mats.

FUTURE WORK

The program sets a scene. It provides a basis for future work whose aim must be to verify and improve the model. The end objective is worthwhile and is precisely what many people are looking for with regard to a performance-oriented approach to membrane roofing.

The most pressing technical need is to understand the rheological behavior and fracture/fatigue mechanisms of APP- and SBS-modified bitumen blends. One is not necessarily looking for deep scientific understanding, although this is no way spurned, but rather to identify approximate working relationships and data for a practical and realistic membrane system computer program for design and rational classification.

ACKNOWLEDGMENTS

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REFERENCES

[1] CSTB Brochure No. 302, "Classement F.I.T. des étanchéités de toitures," September 1989.

[2] Proceedings, DOE-ORNL, Workshop on Mathematical Modeling of Roofs, Atlanta, Ga., November 1981.

[3] Proceedings, DOE-ORNL, Mathematical Modeling of Roof Systems, Oak Ridge, Tenn., September 1988.

[4] Bonafont, R.L., ISSR, "An improved rheological model for bitumen with particular reference to thermal shock," Brighton, England, 1981.

[5] Proceedings, 2nd International Symposium on Roofing Technology, NBS/NRCA, September 1977.

COMPUTER LISTING: ANNEX

The computer program listing and typical print-out is given in the Appendix.

Class	mm	°C
F_1	1	+20
F_2	1	0
F_3	2	0
F_4	2	−10
F_5	2	−20

Table 1 Typical membrane system classes.

BP180 + BP180	F_2
BV060 + PP180	F_2
BW200 + EP250	F_4
EV060 + EP180	F_4
EP180 + EP180	F_5

Table 2 Classification using program.

Membrane	at −10°C mm	at 0°C mm
BV060 + PP180	0.88	1.10
BP180 + BP180	1.36	1.90
EV060 + EP180	2.09	2.88
BW200 + EP250	2.70	3.70
EP180 + EP180	3.75	5.15
EP250 + BW200	0.61	0.93

Table 3 Joint movement for 500 cycles.

Membrane	at −10°C mm	at 0°C mm
BV060 + PP180	10	10
BP180 + BP180	15	17
EV060 + EP180	24	26
BW200 + EP250	31	34
EP180 + EP180	43	47

Table 4 Joint movement for 500 cycles.

PROGRAM NOTES

For convenience, the program is divided into blocks as listed below:

lines 100—set up functions and strings
lines 180—input rate of movement mm/min.
lines 500—input specification and F/V bonding
lines 2000—optional database screen display
lines 2510—reading data and calculating h1 and h2
lines 3000—bitumen modulus and strain subroutine
lines 3300—coding specification for system combinations
lines 4000—effective strain lengths computed
lines 6000—system combinations selection
lines 6500—GLASS/GLASS subroutine
lines 7000—PET/PET subroutine
lines 7500—PET/GLASS subroutine
lines 8000—GLASS/PET subroutine
lines 8500—single layer glass subroutine
lines 8910—product DATABASE
lines 9600—optional print-out subroutine
lines 10000—"F" classification subroutine
Note: Program lines are not numbered consecutively.

TYPICAL COMPUTER PRINT-OUT

** SYSTEM SPECIFICATION :BP180 + BP180 :No 1
F-CLASS for Specification is :F2

SYSTEM DATA:-
:Fully bonded
Joint movement, mm 1.00
Temperature, deg C : 0.00
Cycles to rupture : 4913

Cycle time, seconds = 8
Shear modulus Gi, N/mm2 = 2.74
Stiffness, Si, kgf/cm2 = 80.61
Coating strain : 0.395

Bitumen SP/pen : 105 / 35
Dimensions: h1 = 2.2 ; E1 = 200; h2 = 5.4 ; E2 = 200
****

** SYSTEM SPECIFICATION : BV060 + PP180 :No 2
F-CLASS for Specification is :F2

SYSTEM DATA:-
:Fully bonded
Joint movement, mm 1.00
Temperature, deg C : 0.00
Cycles to rupture : 718

Cycle time, seconds = 8
Shear modulus Gi, N/mm2 = 2.71
Stiffness, Si, kgf/cm2 = 79.67
Coating strain : 0.397

Bitumen SP/pen : 145 / 30
Dimensions: h1 = 2 ; E1 = 300 ; h2 = 5.3 ; E2 = 200

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** SYSTEM SPECIFICATION : BW200 + EP250 : No 3
F-CLASS for Specification is : F4

SYSTEM DATA:-
:Fully bonded
Joint movement, mm 2.00
Temperature, deg C : −10.00
Cycles to rupture : 1448

Cycle time, seconds = 15
Shear modulus Gi, N/mm2 = 2.84
Stiffness, Si, kgf/cm2 = 83.61
Coating strain : 0.778

Bitumen SP/pen : 100 / 45
Dimensions: h1 = 2.2 ; E1 = 1000 ; h2 = 6.1 ; E2 = 270
****

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10 REM ********* IRSS 1991A: MONTREAL *********
20 REM  ** FATIGUE ENDURANCE PROGRAMME  **
3 REM ** INCLUDES (F)ATIGUE CLASSIFICATION **
40 REM  ***** Filename:"ISRR91A.bas"-JAN 1991  *****
50 REM  * Mallard Basic Programme : Version No 1.6  *
60 REM  ************** R L Bonafont **************
70 REM *** Output N(g) : Optional printed output :***
80 REM   TARMAC ROOFING SYSTEMS - RUBEROID
90 REM ****************************************
95 :
100 e$=CHR$(27):
cs$=e$+"E"+e$+"H": von$=e$+"p": vof$=e$+"q"
110 PRINT cs$: bel$=CHR$(7) : DEF
  FNnr(x)=10^LOG(x+SQR(x*x-1))
120 wk$="WRONG KEY!!-try again":cl$=e$+"p CLASS
  "+e$+"q"
122 ucl$=e$+"p LOWER CLASS than "+e$+"q"
130 lon$=e$+"r": loff$=e$+"u"': N%=0: PRINT loff$
140 cyc$="Cycles to rupture :": jnt$="Joint movement
  :"
150 frt$="First layer ruptures in first cycle!!"
160 syst$="System ruptures in first cycle!!"
170 DIM RFG$(15,6) 172 PRINT "FATIGUE ENDUR-
  ANCE PROGRAMME: see ISRR 91 paper;':PRINT
180 INPUT "Rate of joint movement, mm/min
  :",rt:PRINT
200 PRINT "Do you wish to display contents of product
  database? (Y/N):PRINT
205 PRINT bel$
210 K$=UPPER$(INKEY$) : IF K$="" THEN 210
220 IF K$◄►"Y" AND K$◄►"N" THEN PRINT wk$:
  GOTO 210
230 IF K$="Y" THEN GOTO 2040 ELSE GOTO 510
240 :
500 REM *********** MEMBRANE SPEC ***********
505 :
510 PRINT von$+" Press RETURN to end programme
  "+vof$
520 INPUT "PRIMARY MEMBRANE Abbv code (eg
  BP125+BP350):",spec$
525 PD$=UPPER$(spec$)
530 IF PD$="THEN END
535 PRINT
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540 PRINT "Is membrane fully bonded or partially bonded
  over venting layer?"
545 PRINT "PRESS F of V according to case to con-
  tinue":PRINT
550 K$ = UPPER$(INKEY$): IF K$ = " " THEN 550
560 IF K$◄►"F" AND K$◄►"V" THEN PRINT wk$ + "
  PRESS F or V only!": GOTO 550
570 IF K$ = "F" THEN ho = 0: bond$ = ":Fully bonded"
580 IF K$ = "V" THEN ho = 2.7: bond$ = ":partially bonded"
590 PRINT "You have selected"K$:PRINT cs$
700 GOTO 2500
2000 REM *********** PRODUCT DATA BASE ***********
2010 REM
2040 PRINT" Prod"," D"," E"," S1","Ctg":PRINT
2060 PRINT"BV060","1.6"," 300","0.010","B :Oxidized
  bitumen"
2070 PRINT"BW200","2.0","1000","0.015","B"
2075 PRINT"BP125","1.8"," 150","0.200","B"
2080 PRINT"BP180","2.0"," 200","0.200","B"
2090 PRINT"BP250","3.3","270","0.2.00', "B"
2100 PRINT"BP350","3.4"," 260","0.200","B":PRINT
2110 PRINT"EV060","1.6"," 300","0.010","E :SBS modified
  bitumen"
2120 PRINT"EP180","2.0"," 200","0.200","E"
2130 PRINT"EP250","3.3"," 270","0.200","E"
2140 PRINT"EP350","3.4"," 260","0.200","E":PRINT
2150 PRINT"PV100","3.0"," 400","0.015","P :APP modified
  bitumen"
2160 PRINT"PP180","4.0"," 200","0.200","P"
2170 PRINT"PP250","4.0"," 270","0.200","P"
2180 PRINT"PP350","4.0"," 260","0.200","P"
2250 PRINT: GOTO 510
2490 REM
2500 FOR R% = 1 TO 14: FOR C% = 1 TO 6
2510 READ RFG$(R%,C%)
2520 NEXT:NEXT:RESTORE
2530 FOR R% = 1 TO 14
2540 IF RFG$(R%,1)◄►LEFT$(PD$,5) THEN NEXT
2550 IF RFG$(R%,1) = LEFT$(PD$,5) THEN 2555
2555 LFT$ = LEFT$(PD$,5)
2560 D1 = VAL(RFG$(R%,2)):E1 = VAL
  (RFG$(R%,3)):S1 = VAL(RFG$(R%,4)):M$ = RFG$(R%,5)
2565 hb = VAL(RFG$(R%,6))
2570 IF M$ = "B" THEN SPt = 105: pen = 35: Kctg = 1: GOTO
  2600
2580 IF M$ = "E" THEN SPt = 100 : pen = 45: Kctg = 2: GOTO
  2600
2590 IF M$ = "P" THEN SPt = 145 : pen = 30: Kctg = 1: GOTO
  2600
2600 RESTORE
2605 IF LEN(PD$)►5 THEN GOTO 2610 ELSE 2900
2610 FOR R% = 1 TO 14
2620 IF RFG$(R%,1)◄►RIGHT$(PD$,5) THEN NEXT
2630 IF RFG$(R%,1) = RIGHT$(PD$,5) THEN 2635
2635 RHT$ = RIGHT$(PD$,5)
2640 D2 = VAL(RFG$(R%,2)):E2 = VAL
  (RFG$(R%,3)):S2 = VAL(RFG$(R%,4)):M$ = RFG(R%,5)
2645 hb2 = VAL(RFG$(R%,6))
2650 IF M$ = "B" THEN SPt = 105 : pen = 35: Kctg = 1: GOTO
  2680
2660 IF M$ = "E" THEN SPt = 100 : pen = 45: Kctg = 2: GOTO
  2680
2670 IF M$ = "P" THEN SPt = 145 : pen = 30: Kctg = 1: GOTO
  2680
2680 RESTORE
2690 h1 = 0.5*D1 + hb + ho:h2 = h1 + 0.5*(D1 + D2) + hb2 + ho
2700 nt$ = " ": GOTO 3000
2900 h1 = 0: h2 = 0.5*D1 + ho + hb: nt$ = " : single layer"
2905 E2 = E1: E1 = 0: S2 = S1: S1 = 0
2910 GOTO 3000
2990 :
3000 REM ***** BITUMEN MODULUS SUBROUTINE *****
3010 :
3020 PRINT"Primary membrane specification :"PD$:PRINT
3030 PRINT"Systems is "bond$:PRINT
3050 INPUT"Mean service temperature, deg C :",TP:PRINT
3055 PRINT"SPt ="SPt,"pen ="pen,"Kctg ="Kctg:PRINT
3060 INPUT"Substrate joint movement, mm = ",jnt
3070 ct = 120*jnt/rt
3075 IF jnt = 0 THEN GOTO 510 ELSE 3080
3080 Ai = 17*(2.903-LOG10(pen))/(SPt-25)
3085 REM SHEAR MODULUS OF BITUMEN N/mm2
3090 Gi = 0.00256*0.4^Ai*EXP(0.258*Ai*(SPt-TP))/ct^Ai
3100 Si = 29.4*Gi: Strain = 2.51*Kctg/(Si^0.434 + Si^(-0.434))^0.96
3110 PRINT
3290 :
3300 REM ******* IDENTIFICATION OF SYSTEM *******
3310 :
3330 IF MID$(LFT$,2,1) = "P" THEN code1$ = "P" ELSE
  code1$ = "G"
3335 IF LEN(PD$)►5 THEN GOTO 3340 ELSE GOTO 3350
3340 IF MID$(RHT$,2,1) = "P" THEN code2$ = "P" ELSE
  code2$ = "G"
3345 GOTO 3380
3350 RHT$ = nt$: code2$ = " "
3380 PRINT"SYSTEM selected : "LFT$" + "RHT$
3410 PRINT
3990 :
4000 REM ******** EFFECTIVE STRAIN LENGTH ********
4010 :
5000 CV = 33.5*SQR(1 + 0.0106*h2*E2/Gi)
5010 M = h1/(h2-h1): R = E1/E2: L = 2*SQR(h2*E2/Gi)
5020 W = SQR(M*R/(1 + M))
5030 Z = SQR(1 + M*(1 + R) + 2*SQR(M*R ))
5040 AF = L*W*Z/(1 + SQR(M*R))
5050 BF = L*Z/SQR(1 + M)
5060 CF = BF*(1 + M + SQR(M*R))/Z/Z
5070 AV = SQR(CV*CV + W*W*(CV*CV-1122)): BV = AV
5990 :
6000 REM ********* SYSTEM COMBINATIONS *********
6010 :
6030 IF jnt = 0 THEN GOTO 510
6050 IF code1$ + code2$ = "G" + "G" THEN GOTO 6500
6060 IF code1$ + code2$ = "P" + "P" THEN GOTO 7000
6070 IF code1$ + code2$ = "P" + "G" THEN GOTO 7500
6080 IF code1$ + code2$ = "G" + "P" THEN GOTO 8000
6090 IF code1$ = "G" AND code2$ = " " THEN GOTO 8500
6100 IF code1$ = "P" AND code2$ = " " THEN GOTO 7000
6490 :
6500 REM ******** GLASS/GLASS SUBROUTINE ********
6510 :
6515 PRINT von$ + " GLASS/GLASS SUBROUTINE
  " + vof$:PRINT
6520 IF ho = 2.7 THEN 6530 ELSE GOTO 6540
6530 A = AV:B = BV:C = CV: GOTO 6550
6540 A = AF:B = BF:C = CF: GOTO 6550
6550 Y = 4-4*jnt/A/S1
6560 Y3 = 4-4*jnt/C/S2
6570 IF Y3◄0 THEN PRINT syst$ : GOTO 3060
6580 IF Y◄0 THEN PRINT frt$:H = 0: GOT0 6600
6590 U = EXP(Y): H = FNnr(U)
6600 Y2 = 4-4*jnt/B/S2 :U = EXP(Y2): I = FNnr(U)
6610 U = EXP(Y3): J = FNnr(U)
6620 NS + (J + H*(1-J/I))
6630 PRINT lon$ + cyc$ROUND(NS),jnt$jnt:PRINT loff$
6650 GOSUB 10000
6660 PRINT: GOSUB 9620
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6900 GOTO 3600
6990 :
7000 REM *********** PET/PET SUBROUTINE ***********
7010 :
7015 PRINT von$+" PEP/PET SUBROUTINE "+vof$:PRINT
7020 K=strain*SQR(Si)*0.0385
7030 IF ho=2.7 THEN GOTO 7040 ELSE GOTO 7060
7040 A=AV:B=BV:C=CV : GOTO 7070
7060 A=AF;B=BF:C=CF
7070 NS=(K*B/jnt)^4
7075 PRINT:PRINT"Coating strain
  ="ROUND(strain,2):PRINT
7080 PRINT lon$+cyc$ROUND(NS),jnt$jnt: PRINT loff$
7085 GOSUB 10000
7090 PRINT: GOSUB 9620
7100 PRINT: GOTO 3060
7490 :
7500 REM ********** PET/GLASS SUBROUTINE **********
7510 :
7515 PRINT von$+" PET/GLASS SUBROUTINE
  "+vof$:PRINT
7520 PRINT"S2  ="S2:PRINT
7530 IF ho=2.7 THEN GOTO 7540 ELSE GOTO 7560
7540 A=AV:B=BV:C=CV: GOTO 7570
7560 A=AF:B=BF:C=CF
7570 IF jnt/B/S2►1 THEN PRINT syst$: GOTO 3060
7580 Y=4-4*jnt/B/S2: U=EXP(Y):NS=FNnr(U)
7590 PRINT lon$+cyc$ ROUND(NS),jnt$jnt: PRINT loff$
7592 GOSUB 10000
7595 PRINT: GOSUB 9620
7980 PRINT: GOTO 3060
7990 :
8000 REM ********** GLASS/PET SUBROUTINE **********
8010 :
8015 PRINT von$+" GLASS/PET SUBROUTINE
'+vof$:PRINT
8025 K=strain*SQR(Si)*0.0385
8030 IF ho=2.7 THEN GOTO 8040 ELSE GOTO 8050
8040 A=AV:B=BV:C=CV: GOTO 8060
8050 A=AF:B=BF:C=CF
8060 IF jnt/A/S1►1 THEN PRINT frt$: H=0:I=1: GOTO
  8090
8070 Y=4-4*jnt/A/S1
8080 U=EXP(Y):H=FNnr(U)
8090 I=(K*B/jnt)^4: J=(K*C/jnt)^4
8100 NS=J+H*(1-I/J)
8110 PRINT:PRINT lon$+cyc$ROUND(NS),jnt$jnt:PRINT
  loff$
8200 GOSUB 10000
8400 PRINT: GOSUB 9620
8490 PRINT: GOTO 3060
8495 :
8500 REM *********** SINGLE LAYER GLASS ***********
8510 :
8515 PRINT von$+" SINGLE LAYER GLASS SUBROUTINE
  "+vof$:PRINT
8520 IF ho=2.7 THEN C=CV ELSE C=CF
8530 PRINT"C  ="ROUND(C),"S2  = "S2
8550 Y3=4-4*jnt/C/S2
8560 IF Y3◄0 THEN PRINT syst$: GOTO 6020
8570 U=EXP(Y3): NS=FNnr(U)
8575 PRINT:PRINT "Coating strain :"ROUND(strain,2):PRINT
8580 PRINT lon$+cyc$ROUND(NS),jnt$jnt:PRINT loff$
8583 GOSUB 10000
8585 PRINT: GOSUB 9620
8590 GOTO 3060
8900 :
8910 REM *************** DATABASE ***************
8920 :
9000 DATA BV060,1.6, 300,0.010,B,1.2
9010 DATA BW200,2.0,1000,0.015,B,1.2
9015 DATA BP125,1.8, 150,0.200,B,1.2
9020 DATA BP180,2.0, 200,0.200,B,1.2
9030 DATA BP250,3.3, 270,0.200,B,1.2
9040 DATA BP350,3.4, 260,0.200,B,1.2
9050 DATA EV060,1.6, 300,0.010,E,1.2
9060 DATA EP180,2.0, 200,0.200,E,1.2
9070 DATA EP250,3.3, 270,0.200,E,1.2
9080 DATA EP350,3.4, 260,0.200,E,1.2
9090 DATA PV100,3.0, 400,0.015,P,0.5
9100 DATA PP180,4.0, 200,0.200,P,0.5
9110 DATA PP250,4.0, 270,0.200,P,0.5
9120 DATA PP350,4.0, 260,0.200,P,0.5
9590 :
9600 REM ********* PRINT OUT SUBROUTINE *********
9610 :
9620 PRINT"Do you wish to print result?: PRESS
  (Y/N)":PRINT
9630 K$=UPPER$(INKEY$): IF K$=" " THEN 9630 ELSE
  GOTO 9640
9640 IF K$◄►"N" AND K$◄►"Y" THEN PRINT wk$:
  GOTO 9630
9650 IF K$="N" THEN RETURN
9660 IF K$="Y" THEN GOTO 9670
9670 N%=N%+1:PRINT bel$
9700 PRINT von$+"Put paper in printer!!! then PRESS ANY
  KEY"+vof$
9710 k$=INKEY$: IF k$=" " THEN 9710 ELSE 9720
9720 LPRINT TAB (7)'** SYSTEM SPECIFICATION :
  "LFT$+"+"RHT$" :No"N%
9722 LPRINT TAB(7)"F-CLASS for Specification is
  "pcl$:LPRINT
9725 LPRINT TAB(7)"SYSTEM DATA:-"
9730 LPRINT TAB(10) bond$
9740 LPRINT TAB(10) "Joint movement, mm"
  TAB(40)USING"φφφ.φφ";jnt
9760 LPRINT TAB(10)"Temperature, deg C :"
  TAB(40)USING"φφφ.φφ";TP
9780 LPRINT TAB(10)"Cycles to rupture :" TAB
  (38)USING"φφφφφ";NS
9790 LPRINT
9800 LPRINT TAB(10)"Cycle time, seconds
  ="TAB(38)USING"φφφφφ";ct
9810 LPRINT TAB(10)"Shear modulus Gi, N/mm2
  ="TAB(40)USING"φφφ.φφ";Gi
9820 LPRINT TAB(10)"Stiffness, Si, kgf/cm2
  ="TAB(40)USING"φφφ.φφ";Si
9825 LPRINT TAB(10)"Coating strain :"
  TAB(40)USING"φφφ.φφφ";strain
9830 LPRINT
9840 LPRINT TAB(10)"Bitumen SP/pen :"TAB(40)SPt"/"pen
9860 LPRINT TAB(10)"Dimensions: h1  ="ROUND(h1,1);"; E1
  ="E1;"; h2  ="ROUND(h2,1)"; E2  ="E2
9890 LPRINT TAB(34)"***********":LPRINT
9900 RETURN
9990 :
10000 REM ********** (F).I.T. CLASSIFICATION **********
10010 :
10020 IF TP=20 AND jnt=1 THEN GOTO 10030 ELSE
  10050
10030 IF NS►=500 THEN PRINT cl$":F1" ELSE PRINT
  ucl$":F1"
10040 pcl$=":F1"
10050 IF TP=0 AND jnt=1 THEN GOTO 10060 ELSE 10080
10060 IF NS►=500 THEN PRINT cl$":F2" ELSE PRINT
  ucl$":F2"
10070 pcl$=":F2"
10080 IF TP=0 AND jnt=2 THEN GOTO 10090 ELSE 10110
```

```
10090 IF NS► = 500 THEN PRINT cl$":F3" ELSE PRINT
  ucl$":F3"
10100 pcl$ = ":F3"
10110 IF TP = -10 AND jnt = 2 THEN GOTO 10120 ELSE
  10140
10120 IF NS► = 500 THEN PRINT cl$":F4" ELSE PRINT
  ucl$":F4"
10130 pcl$ = :F4"
10140 IF TP = -20 AND jnt = 2 THEN GOTO 10150 ELSE
  10180
10150 IF NS► = 500 THEN PRINT cl$":F5" ELSE PRINT
  ucl$":F5"
10160 pcl$ = ":F5"
10180 RETURN
10200 REM ****************** END ******************
```