6 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

6.1 CONCLUSIONS

(i) Tough Fe-40Cr alloys can be produced by suitable heat treatment and processing: rolling between 1050 and 750 °C and annealing at 950 °C for 1 hour,

(ii) Despite a large grain size and high interstitial contents, the Fe-40Cr alloys achieve excellent toughness (200J) and an adequate DBTT (-10 °C),

(iii) REM additions are useful for the development of isotropic toughness properties and the maintainance of good toughenss at high temperatures (>1000 °C),

(iv) Sigma phase which is produced through cold-work is stable to high temperatures (up to 1050 °C) in the Fe-40Cr alloys,

(v) Intragranular precipitates separate from the matrix and have little or no role in the fracture process, and

(vi) Excessive grain boundary precipitation (carbide or σ-phase) is responsible for embrittlement.

In summary the Fe-40Cr alloy is very promising since it is fairly tolerant of impurities and when suitable fabrication procedures are used, embrittlement is fairly easily avoided. In addition, the excellent corrosion resistance of the alloy[91] makes it good potential replacement for the more expensive austenitic stainless steels.

6.2 RECOMMENDATIONS FOR FUTURE WORK

Further work in the laboratory is required for quantifying the effect of interstitials (especially oxygen) and REMs on the behaviour of Fe-40Cr. However, a detailed economic survey of the industrial viability and the determination of the applications and market for wrought Fe-40Cr is a priority, if further and more in-depth research on the alloy is warranted. This section suggests particular areas to be developed and new directions of investigation.

6.2.1 **Economic survey**

This would include information on the kind of tonnages required for the profitable production of Fe-40Cr. The necessity for pure base materials would have to be taken into account.

The availability of melt techniques such as vacuum oxygen decarburisation (VOD) and argon - oxygen decarbonisation (AOD), and the associated technical expertise in South Africa is another important consideration.

Finally the economic survey must include an investigation of the potential market, local and international, for Fe-40Cr. All the possible applications of the alloy must be identified and assessed in terms of the cost and properties of materials currently in use in the areas of application of interest.

6.3.1 **Laboratory work**

The analytical techniques for determining the interstitial contents and REM yields need to be assessed critically. The techniques should either be improved through the establishment of proper standards, or a quantitative assessment of their accuracy should be made.

The method by which REMs are added should be standardised so that yields are predictable. Additions can then be tailored to 'getter' the amount of nitrogen and oxygen present.

The relationship between the DBTTs determined in the Charpy impact and slow bend tests does not follow that predicted by theoretical considerations. The slower strain rates associated with the slow bend tests should result in lower DBTTs and not vice versa as this study has indicated. This trend could be investigated under more rigorous conditions.

Other techniques, such as the compact tension fracture toughness test, should be used to assess the toughness of the Fe-40Cr alloys. Results which are more quantitative and predictive in engineering terms can thus be obtained. The behaviour of the alloy can also be determined at low temperatures and in different media as required by different applications.

Further investigation of grain boundary film thickness in relation to ductility and toughness should also be carried out in order to develop a more suitable model for fracture in these alloys. The Cottrell[8] and Almond et al[87] models for brittle fracture are heavily influenced by the grain size term, $d^{1/2}$. This term has less importance at the large grain sizes obtained in these alloys.

Finally, more detailed TEM studies should be undertaken. In this way the contribution of dislocation density to ductile behaviour can be assessed. The pinning of dislocations by interstitials can also be evaluated and its contribution to brittle behaviour clarified.

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APPENDICES

APPENDIX A

Computer programme for the calculation of areas below the slow bend test load vs stroke curves.

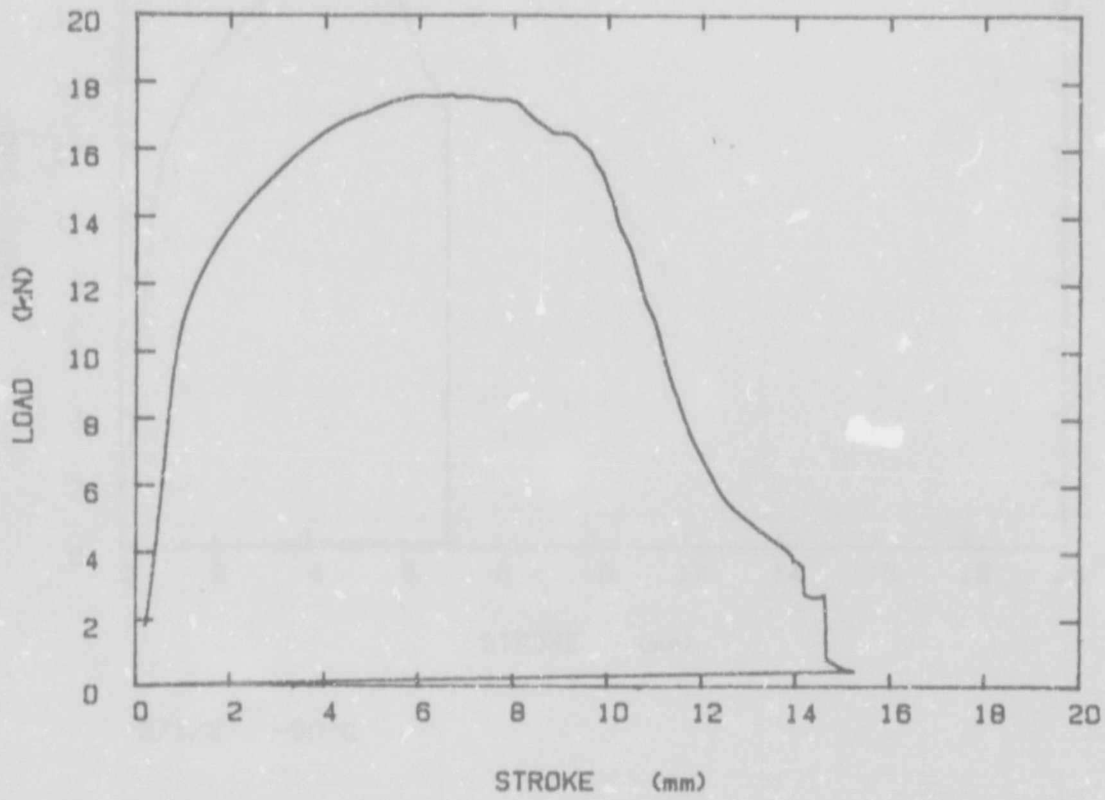
```
READY.

 5 DIMX(2000),Y(2000)
 6 PRINT"[illegible]!!"
 8 FOR A=1 TO1000:NEXTA
 10 PRINT""
 20 INPUT"NTER FILE TO BE INTEGRATED :";NA$
 30 DOPEN£1,(NA$)
 31 IF DS>0 THEN  DCLOSE£1:GOTO20
 32 INPUT£1,D
 33 FOR A=1 TO D
 40 INPUT£1,X(A):INPUT£1,Y(A)
 45 NEXT A
 50 MM=1: MAX=Y(1):FOR A=1TOD:IFY(A)>MAXTHEN MAX=Y(A):MM=A
 51 NEXT A
 52 PRINT"PEAK AT "MM"      LAST POINT AT"D-1
 53 PRINT"LIST Y/N"
 54 GET A$:IF A$="" THEN 54
 55 IF A$="N" THEN 59
 56 FORA=1 TO D:IF Y(A)=MAX THEN PRINT"";
 57 PRINTA;")    ";X(A);TAB(25)Y(A)
 58 NEXTA
 59 INPUT"NTEGRATE TO WHICH NUMBER :";D
 60 REM------------------
 70 REM
 80 REM  INTEGRATE DATA
 90 REM
 100 REM----------------
 110 SUM=0
 111 PRINT"NTEGRATING...";
 120 FOR A=2TOD
 125 X=X(A)-X(A-1):Y=Y(A-1)
 126 A1=X*Y:A2=(Y(A)-Y(A-1))*X/2
 130 AREA=A1+A2
 140 SUM=SUM+AREA
 141 PRINT".";
 150 NEXTA
 170 PRINT"NTEGRAL IS :";SUM
 180 OPEN 4,4
 200 PRINT£4,"NTEGRAL TO POINT ";D;" OF SAMPLE NO. ";NA$;" IS  :";SUM
 210 PRINT£4,"-----------------------------------------------------------";
 211 PRINT£4
 250 CLOSE 4,4
 260 INPUT"EW DATA (Y/N) :";C$:IF C$="N"THEN 52
 300 RUN
```

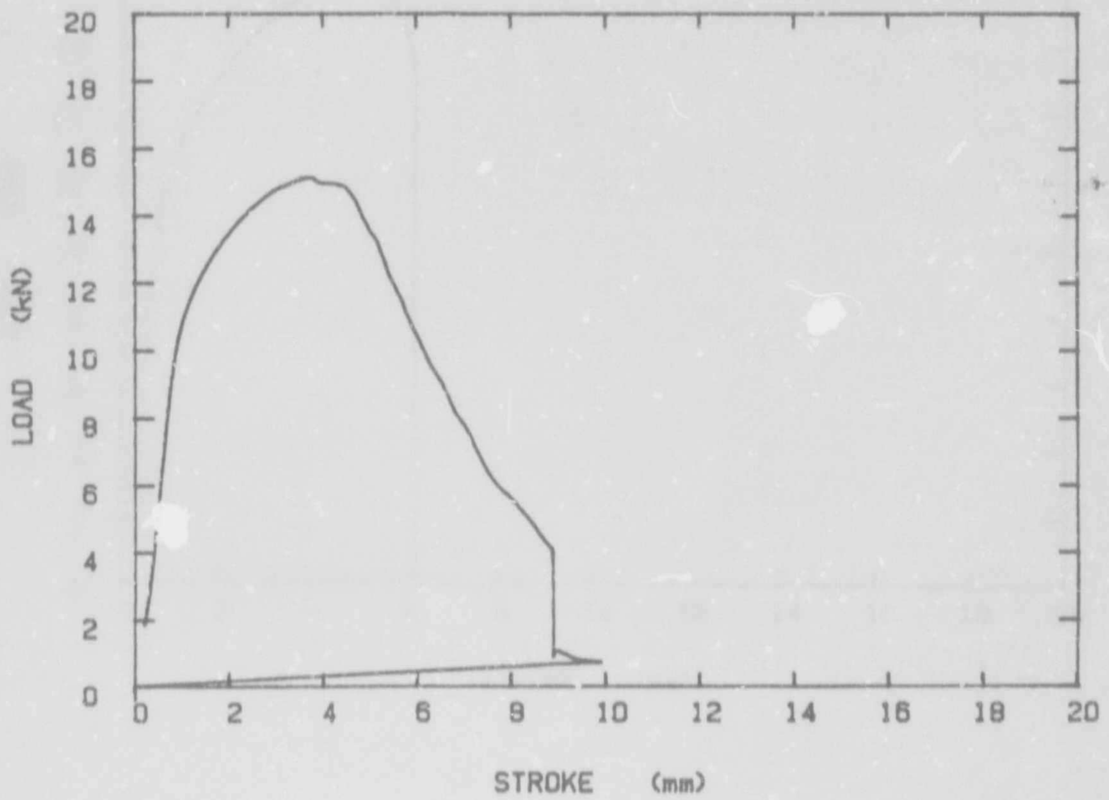
APPENDIX B

Slow bend test curves (load vs stroke)

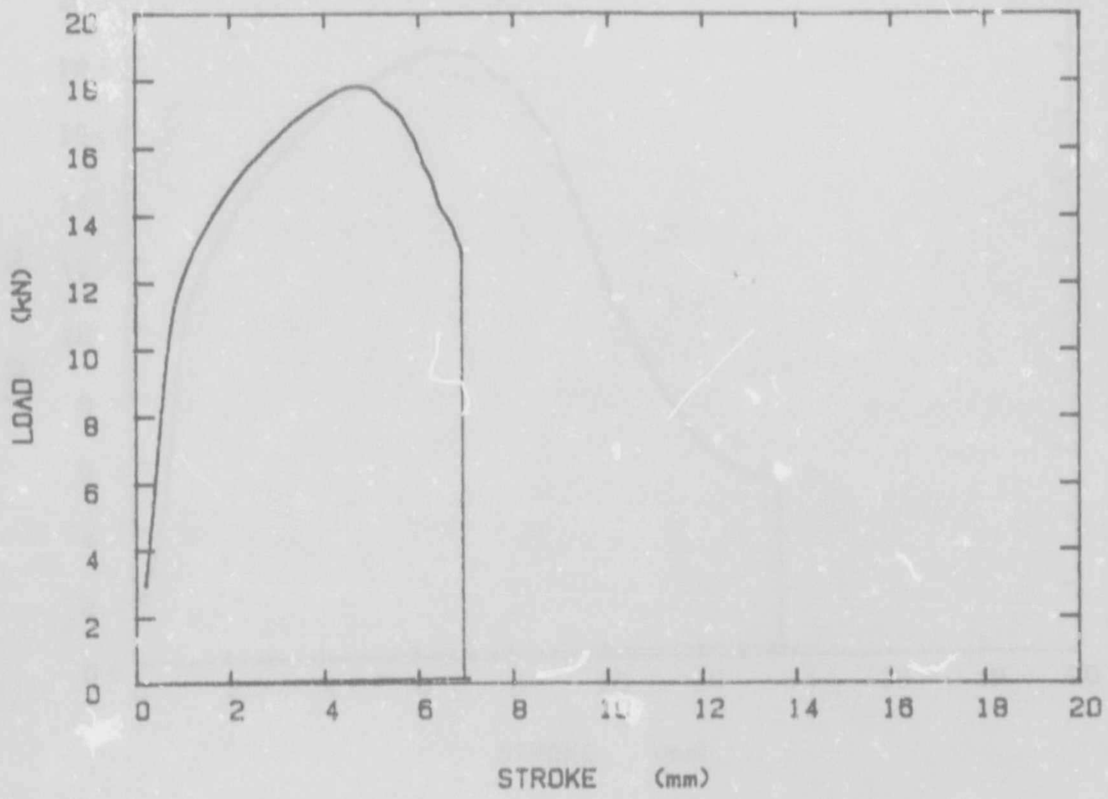
v2/1/2 32 °C



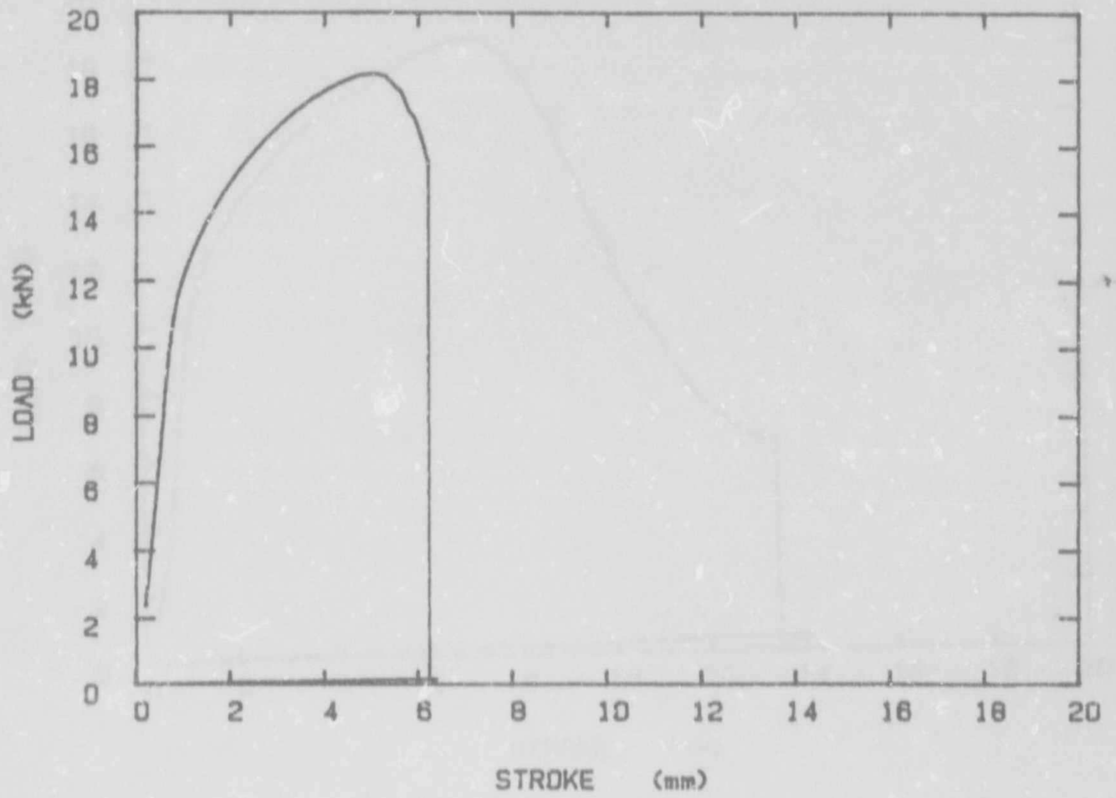
v2/1/2 0 °C

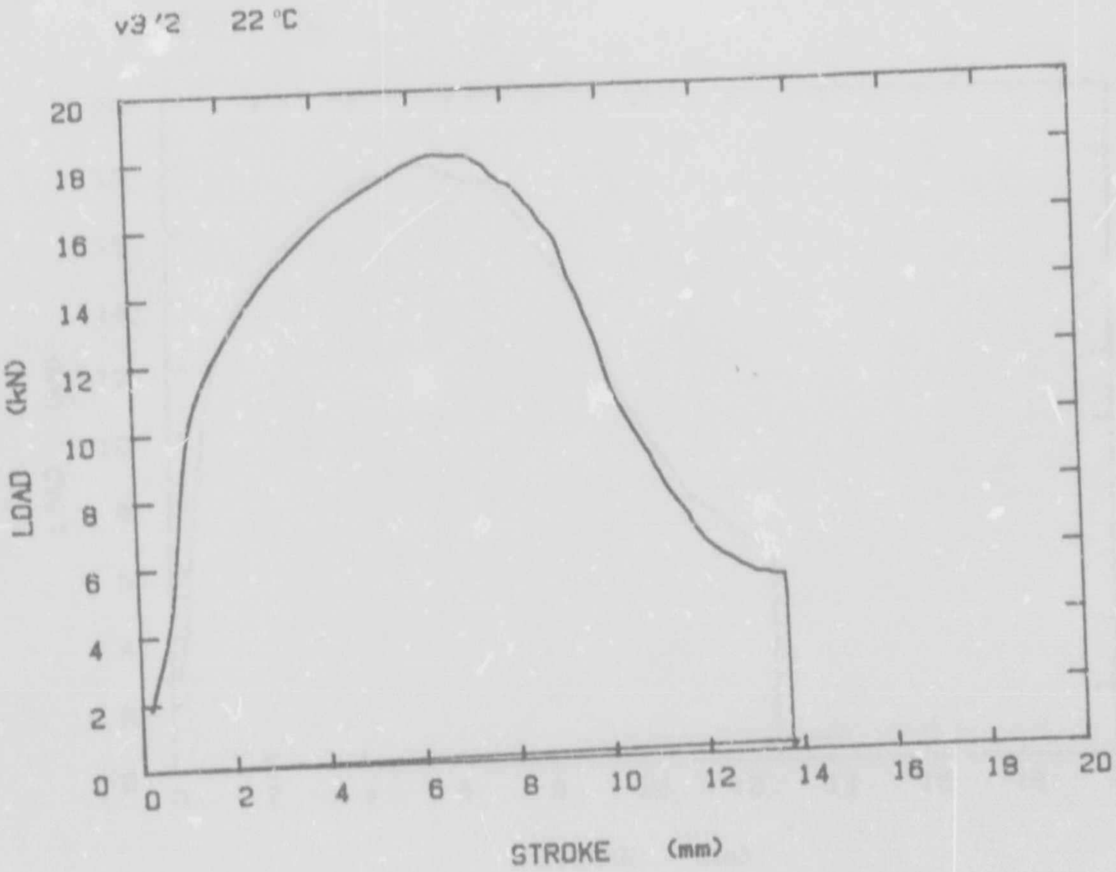


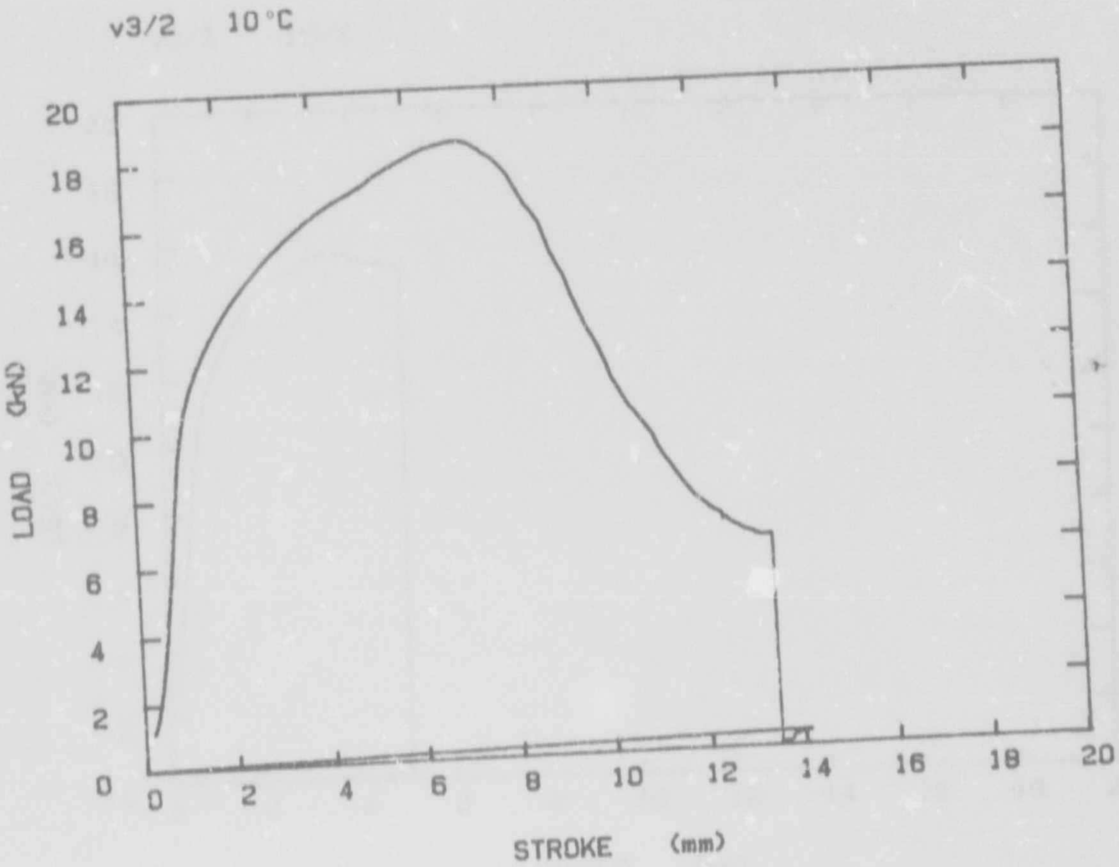
v2/1/2 -15 °C



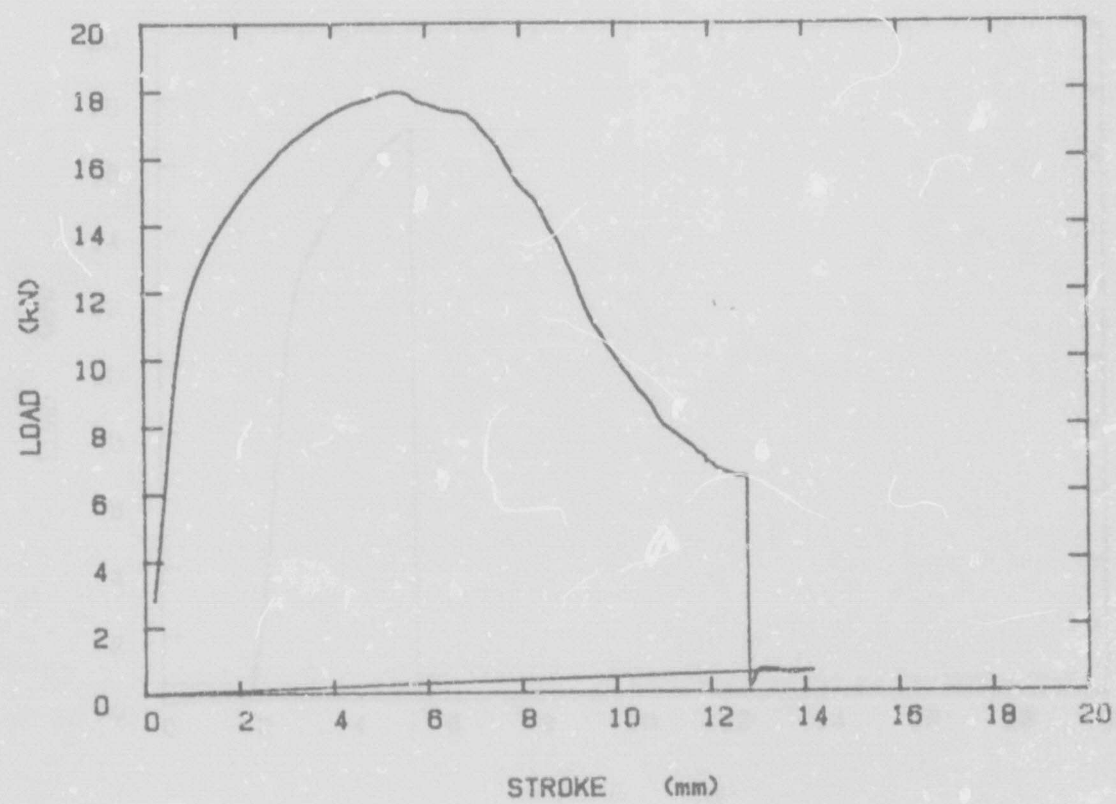
v2/1/2 -30 °C



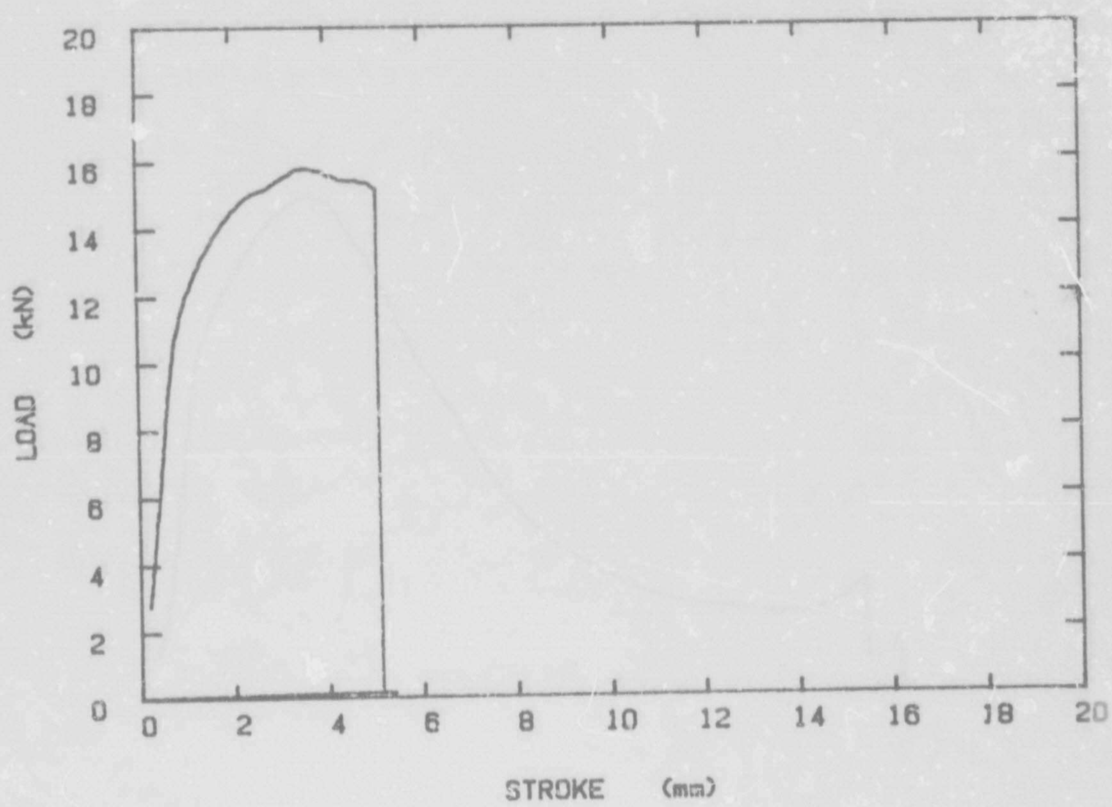

v3/2 22 °C
20
18
16
14
12
10
8
6
4
2
0
LOAD (kN)
0 2 4 6 8 10 12 14 16 18 20
STROKE (mm)


v3/2 10 °C
20
18
16
14
12
10
8
6
4
2
0
LOAD (kN)
0 2 4 6 8 10 12 14 16 18 20
STROKE (mm)

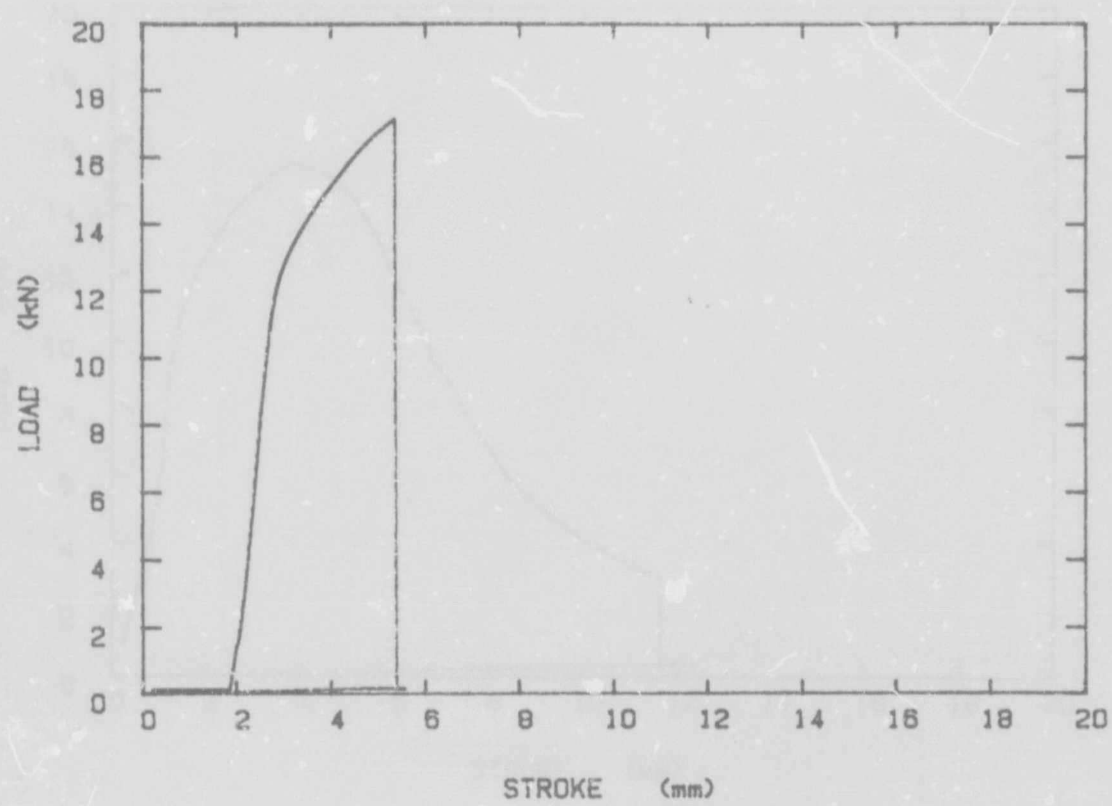
v3/2 0 °C



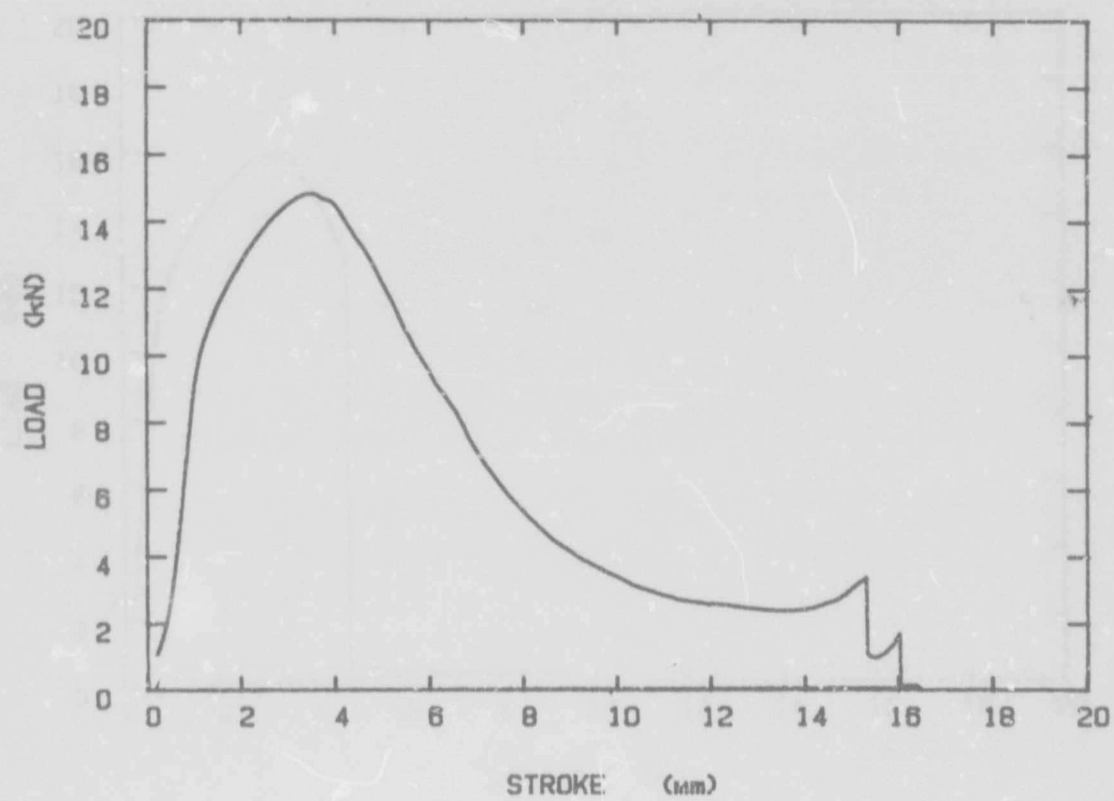
v3/2 -15 °C



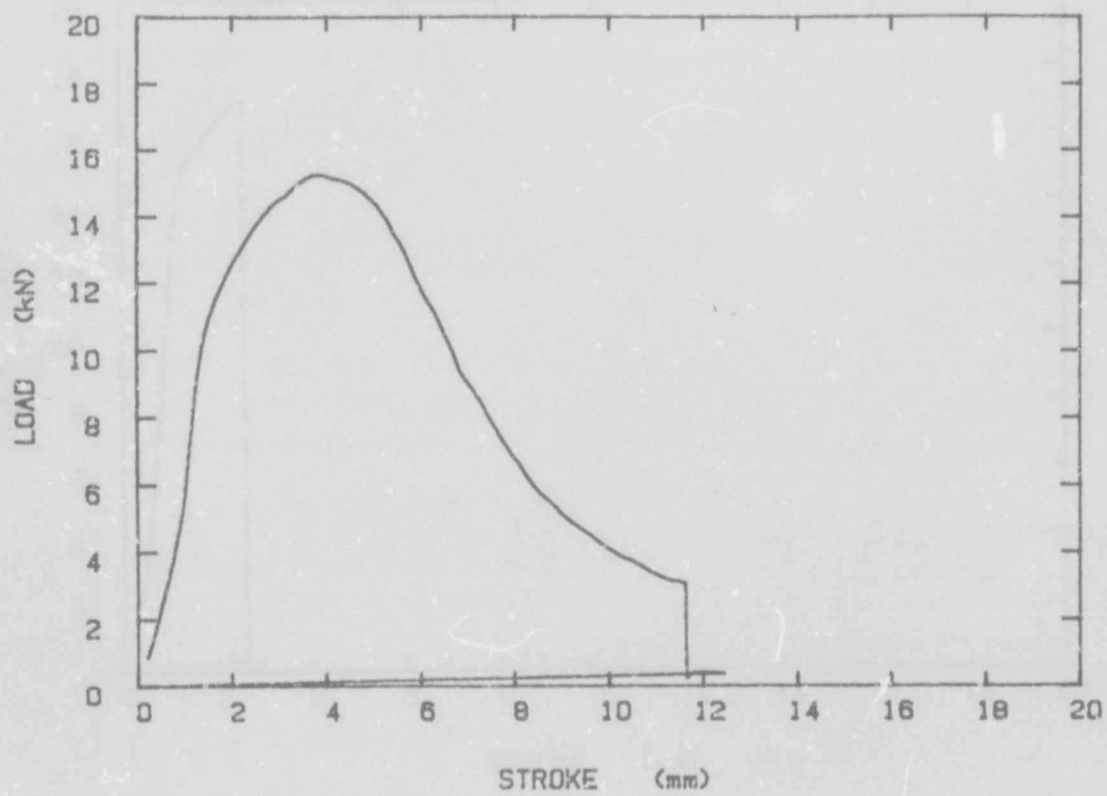
v3/2 -30 °C



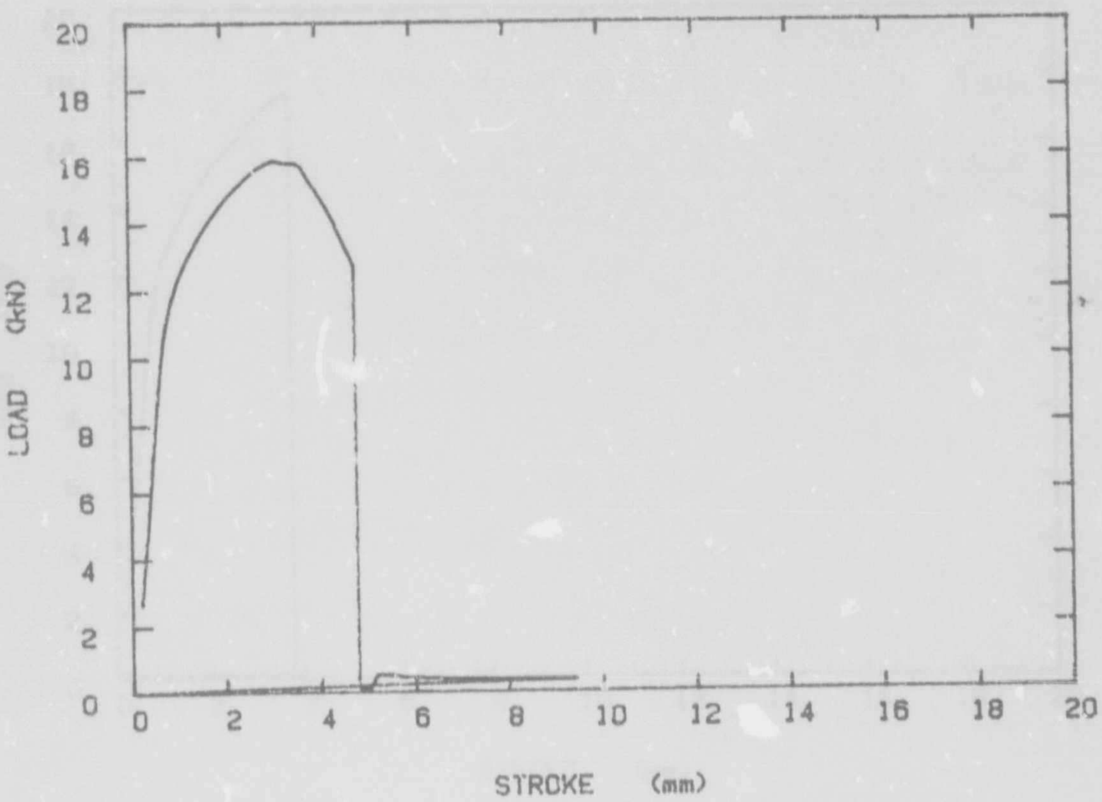
v2/2/2 32 °C



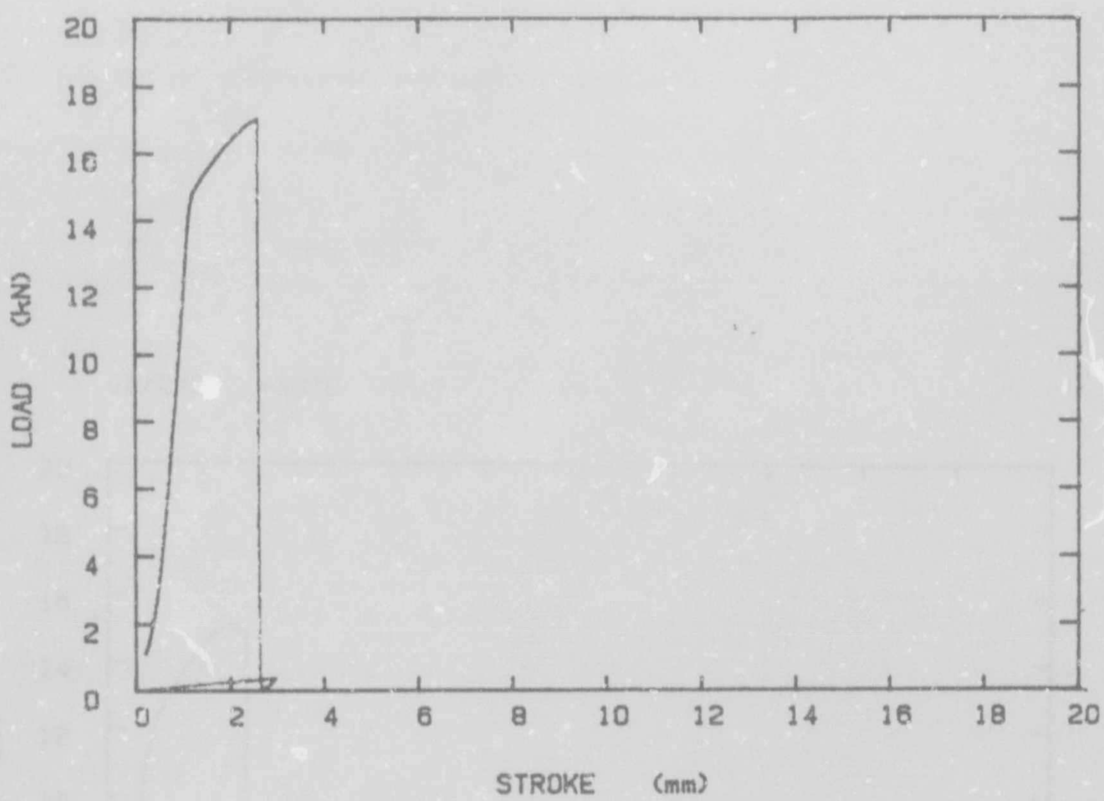
v2/2/2 23 °C



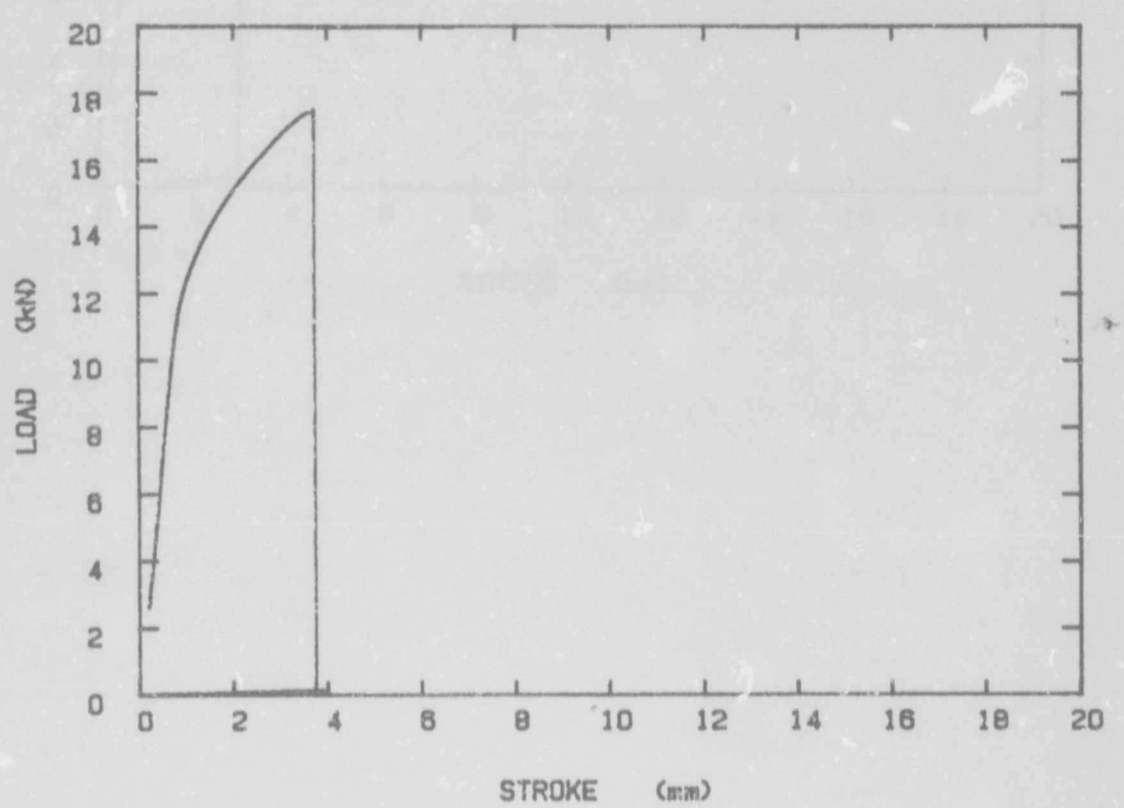
v2/2/2 10 °C

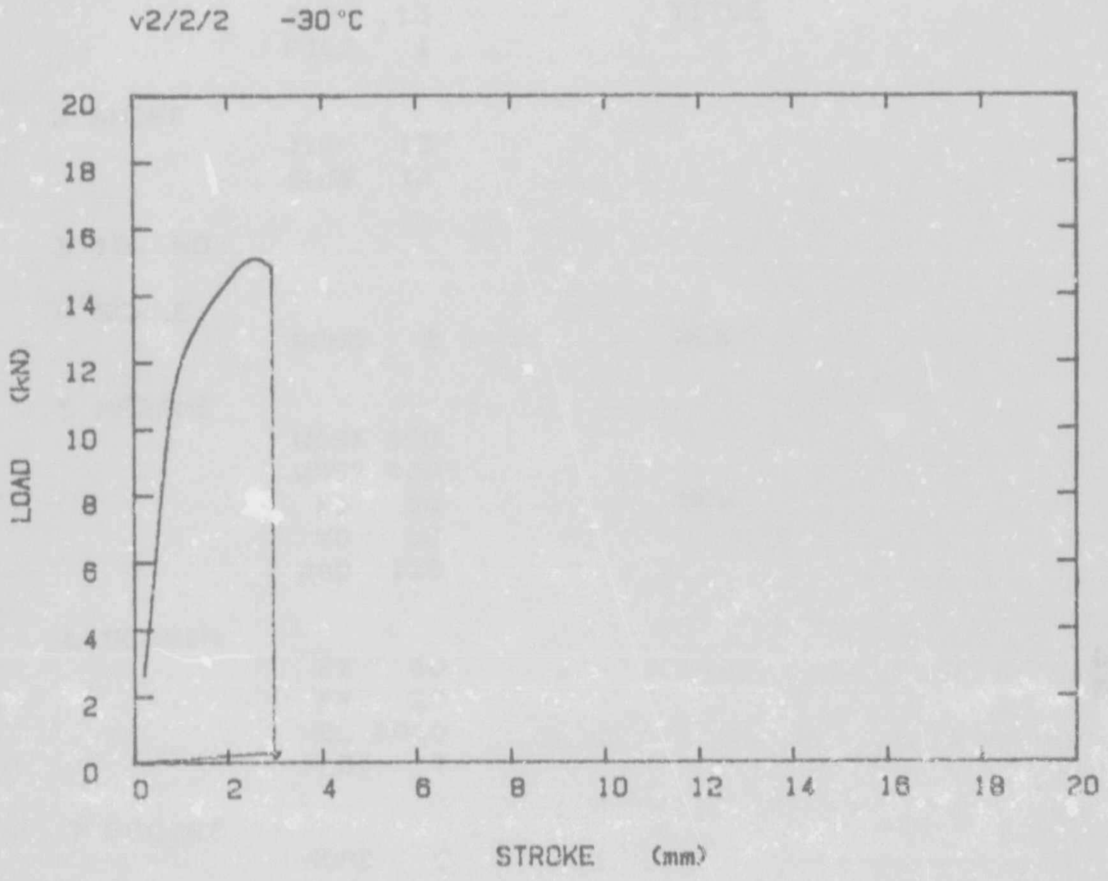


v2/2/2 0 °C



v2/2/2 -15 °C




v2/2/2 -30°C
LOAD (kN)
STROKE (mm)
0
2
4
6
8
10
12
14
16
18
20

APPENDIX C

Computer programme for image analysis

MEASUREMENT OF PPTS 105X OIL / MAY & DAPHNE

FUNCTION	VARIABLES: INTEGER		LOGICAL	REAL	
1 GETIM					
	INP	13	TITLE		
	FILE	1			
2 SHDEF					
	INP	13			
	SHRF	14			
3 ID. NO					
4 SCALE					
	SCNO	2	NEW		
5 MFRAME					
	WDSX	400			
	WDSY	400			
	XO	50	NEW		
	YO	50			
	RAD	128			
6 SCANIN					
	FX	40		DX	2050.
	FY	20		DY	2050.
	VEL	6000			
	FLG#	9			
7 FOCSET					
	RGMD	2			
	FLG#	8			
8 MVSCAN					
	IFOC	1			
	RFIL	0			
	WFIL	0			
	SNMD	1			
9 CIRSF					
	NCLS	50		LOW	0.000
	MODX	1	CLASS	HIGH	1.0000
	MODY	1			
10 AREA					
	NCLS	40		LOW	0.000
	MODX	1	CLASS	HIGH	20.00
	MODY	1			
11 AREA%					
	NCLS	60		LOW	0.000
	MODX	1	CLASS	HIGH	3.000
	MODY	1			