

https://dspace.org/

The development of a tough high chronmium ferritic stainless steel

Hermanus, Mavis Ann

2015-01-27
http://hdl.handle.net/10539/16775

Downloaded from a DSpace repository. https://dspace.org/

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 ductiltity 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.

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 ductiltity 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.

REFERENCES

1. Rodrigues M. 'Fracture initiation studies in 540°C aged Fe-29Cr-4Mo-2Ni and Fe-26Cr-3Mo-2Ni ferritic stainless steels.' MSc. Thesis. Rensselaer Polytechnic Institute, New York. August 1984.

2. Grubb J F. 'Brittle fracture of ferritic stainless steels.' PhD Thesis. Rensselaer Polytechnic Institute, New York. April 1982.

3. Honeycombe R [illegible] Steels. Microstructure and Properties.' Metallurgy and Materials Science Series. Edward Arnold Publishers. 1981.

4. Demo J J. 'Structure, constitution and general characteristics of wrought ferritic steels.' American Society for Testing and Materials. STP 619. 1977, p 1.

5. Lula R A. 'Ferritic stainless steels: Corrosion resistance and economy.' Metals Progress. July 1976, Vol.110, No.2, p 24.

6. Baerleken E B, Fischer W A and Lorenz K. Stahl und Elsen. 1961, Vol.81, No.12, p 768.

7. Petty E R. 'Physical Metallurgy of Engineering Materials.' George Unwin, Publishers. 1970.

8. Wright R N. 'Toughness of ferritic stainless steels.' Toughness of Ferritic Stainless Steels. Lula R A, Ed. American Society for Testing and Materials. STP 706. 1980, p 2.

9. Lawn B R and Wilshaw T R. 'Fracture of brittle solids.' Cambridge Solid State Science Series. Cambridge University Press. 1975.

10. Dieter G E. 'Mechanical metallurgy.' Second Edition. Mcgraw - Hill International Book Company. 1981.

11. Cottrell A H. 'An Introduction to Metallurgy.' Second Edition. Edward Arnold Publishers. 1979.

12. Loomis B A and Carlson O N. Reactive Metals, Wiley (Interscience) Publishers. 1959.

13. Stroh A N. Advanced Physics. 1957, Vol.6, p 418.

14. Cottrell A H. Transactions of the Metallurgical Society. AIME. 1958, Vol.212, p 192.

15. Zener C. 'The micro-mechanism of fracture.' Fracturing in Metals. ASM. Metals Park, Ohio, 1948.

16. Eshelby J D, Frank F C and Nabarro F R N. 'The equilibrium linear arrays of dislocations.' Philosophy Magazine. 1951, Vol.42, p 351.

17. Meakin J D and Wildorf H G F. Transactions of the Metallurgical Society. AIME. 1960, Vol.218, p 737.

18. Tetelman A S and McEvily A J, Jr. 'Fracture of structural Materials.' John Wiley and Sons, Publishers. 1967, Chapter 6.

19. Petch N J. Journal of the Iron and Steel Institute, London. 1953, Vol.174, p 25.

20. Grubb J and Wright R. 'The role of C and N in the brittle fracture of Fe-26Cr.' Metallurgical Transactions A. September 1979, Vol.10A, p 1247.

21. Lemay I. 'Principles of Mechanical Metallurgy.' Elsevier North Holland Inc., Publishers. 1981.

22. Kay D A R and Kumar R V. 'Role of calcium, magnesium and rare earth additions in ferrous ladle metallurgy.' Centenary Conference of the University of Sheffield's Department of Metallurgy: 'Perspectives in Metallurgical Development.' Metals Society, London. 1984, p 64.

23. Kelly M J and Stoloff N S. Metallurgical Transactions. 1976, Vol.7A, p 331.

24. Newell H D. Metals Progress. May 1946, p 977.

25. Zapffe C A and Worden C O. Welding Journal. Research Supplement. 1951, Vol.30, p 47.

26. Heger J J Metals Progress. August 1951, p 55.

27. Houdremont E. Handbuch der Sonderstahlkunde. Springer Verlag, Berlin, Germany, 1943.

28. Williams R O and Paxton H W. 'The nature of ageing of binary iron-chromium alloys around 500°C.' Journal of the Iron and Steel Institute. 1957, Vol.1, No.185, p 358.

29. Courtnall M and Pickering F B. 'The effect of alloying on 485°C embrittlement.' Metals Science. August 1976, p 273.

30. Grobner P J. 'The 885°F (475°C) embrittlement of ferritic stainless steels.' Metallurgical Transactions. January 1973, Vol.4, p 251.

31. Grobner P J and Steigerwald R F. 'Effect of cold work on the 885°F (475°C) embrittlement of 18Cr-2Mo ferritic stainless steels.' Journal of Metals. July 1977, p 17.

32. Nichol T J, Datta A and Aggen G. 'Embrittlement of ferritic stainless steels.' Metallurgical Transactions A. April 1980, Vol.11A, p 573.

33. Plumtree A and Gullberg R. 'Influence of interstitial and some substitutional alloying elements.' Toughness of Ferritic Stainless Steels. Lula R A, Ed. American Society for Testing and Materials. STP 706. 1980, p [illegible].

34. Chevenard P. Travaux et memoires du bureau international des poids et mesures. 1927, Vol.17, p 90.

35. Bain E C and Griffiths W E. Transactions of the American Institute of Mining and Metallurgical Engineers. 1927, Vol.75, p 166.

36. Shortsleeve F J and Nicholson M E. Transactions of the American Society for Metals. 1951, Vol.43, p 142.

37. Binder W and Spendelow H R. 'The influence of chromium on the mechanical properties of plain chromium steels.' Transactions of the American Society for Metals. 1951, Vol.43, p 211. (Hoffmans results are appended to this paper.)

38. Onashi N, Ono Y, Kinoshita N and Yoshioka K. 'Effects of metallurgical and mechanical factors on charpy impact toughness of low interstitial ferritic stainless steels.' Toughness of Ferritic Stainless Steels. Lula R A, Ed. American Society for Testing and Materials. STP 706. 1980, p 202.

39. Tomashov N D. 'Corrosion resistant alloys and prospects for their development.' Zasch Met. 1981, Vol.17, No.1, p 16.

40. Lena A J and Hawkes M F. Transactions AIME, Journal of Metals. 1954, Vol.200.

41. Demo J J. 'Mechanism of high temperature embrittlement and loss of corrosion resistance in AISI type 446 stainless steels.' Corrosion. December 1971, p 531.

42. Senchyshen M, Bond A P and Dundas H J. 'Effects of composition on ductility and toughness of ferritic stainless steels.' Towards Improved Ductility and Toughness. Conference proceedings. Kyoto International Conference Hall. October 25th and 26th 1971, p 239.

43. Pollard B. 'Ductility of ferritic stainless weld metal.' Weld Research Supplement. April 1972, p 222.

44. Demo J J. 'Weldable and corrosion resistant ferritic stainless steels.' Metallurgical Transactions. November 1974, Vol.5, p 2253.

45. Plumtree A and Gullberg R. 'Embrittlement of a continuously cooled Fe-26Cr alloy.' Metallurgical Transactions A. September 1976, Vol.7A, p 1451.

46. Deverall H E. 'Toughness properties of induction melted high chromium ferritic stainless steels.' R A Lula Editor. American Society for Testing and Materials. STP 706. 1980, p 184.

47. Saito S, Takuro H, Shimura M, Tanaka E, Kataura Y and Ototani T. 'On the embrittlement and toughness of high purity Fe-30Cr-2Mo alloy.' Toughness of Ferritic Stainless Steels. Lula R A, Ed. American Society for Testing and Materials. STP 706. 1980, p 77.

48. Pickering F B. 'Some aspects of the physical metallurgy of the stainless steels.' Centenary Conference of the University of Sheffield's Department of Metallurgy: 'Perspectives in Metallurgical Development.' Metals Society, London. 1984, p 201.

49. Vigor C W. 'Effect of cold-working on impact transition temperature of E-4 stainless steels.' Toughness of Ferritic Stainless Steels. Lula R A, Ed. American Society for Testing and Materials. STP 706. 1980, p 255.

50. Krivcbok V N. Transactions. American Society for Testing and Materials. 1935, p 1.

51. Thielsch H. Welding Journal. Research Supplement. 1951, Vol.30, p 209.

52. Hochmann J. Revue de Metallurgie. 1951, Vol.48, p 734. (Brutcher Translation No.2981.)

53. Houdremont E and Tofaute W. Stahl und Eisen. 1952, Vol.72, p 539.

54. Lula R A, Lena A J and Kiefer G C. Transactions. American Society for Testing and Materials. 1954, Vol.46, p 167.

55. Baumel A. Archiv fur das Eis en hu Henwesen. 1963, Vol.34, p 135. British Iron and Steel Industry. Translation No.3287, London. 1963.

56. Demo J J. 'Effect of high temperature exposure on the corrosion resistance and ductility of AISI 466 Stainless Steel. Conference, Cleveland. National Association of Corrosion Engineers. 1968, NACE reprint No 23.

57. Bond P A. 'Mechanisms of intergranular corrosion in ferritic stainless steels.' Transactions of the Metallurgical Society of AIME. 1969, Vol.245, No.8, p 2127.

58. Hodges R J. 'Intergranular corrosion in high purity ferritic stainless steels: isothermal time-temperature sensitization measurements.' Corrosion. April 1977, Vol.27, No.4, p 164.

59. Sims C. 'The case for chromium.' Journal of Metals. February 1963, p 127.

60. Smithells C J. 'Metals Reference Book.' 5th Edition. Butterworth and Company Publishers Ltd. 1976.

61. Stephens H R and Klopp W D. 'Enhanced ductility in binary chromium alloys.' Transactions of the Metallurgical Society of the AIME. September 1968, Vol.242, p 1837.

62. Geach G A and Hughes J E. Plansee Proceedings. Pergamon Press. 1956, p 245.

63. Klopp W D. 'A review of chromium, molybdenum and tungsten alloys.' Journal of [illegible]ommon Metals. 1975, Vol.42, p 261.

64. Barrett W, Bee J V and [illegible] G G. 'The influence of rare earth elements on [illegible] temper embrittlement behaviour and mechanical properties of a low alloy steel.' Speciality Steels and Hard materials. Comins N R and Clark J B, Eds. CSIR. Materials development, 1982. Pergamon Press. 1983, p 239.

65. Kovrigin V A, Gladkov M I, Kobzistyi V V, Mostovoi A B and Polyakov O A. 'Improving structure and properties of tool steel using rare earth metals and argon injection.' Steel in the USSR. December 1983, Vol.13, p 548.

66. Mikadze O I, Rakitskii A N, Tavadze F N and Trefilov V I. 'Mechanism of the influence of rare earth metals on the heat resistance of chromium.' Fiz. Metal. Metalloved. 1975, Vol.39, No.2, p 430.

67. Rakitskii A N and Trefilov V I. 'Effects of chromium and chromium alloys containing REMs.' Translated from Metallofizica. 1974, Vol.50, p 31.

68. Rakitskii A N and Trefilov V I. 'Effects of REM on the structure and properties of chromium.' Translated from Metallofizica. 1974, Vol.51, p 97.

69. Rakitskii A N and Trefilov V I. 'Optimum alloying of chromium with highly active elements. A survey.' Soviet Powder Metallurgy and Metal Ceramics. 1977, Vol.16, p 703.

70. Rakitskii A N and Trefilov V I. 'The effects of REMs on the structure and properties of recrystallised chromium.' Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, September 1979, p 44.

71. Tkachenko V G and Trefilov V I. 'Impurity effects in chromium and an alloy of chromium with 1% Yttrium.' Translated from Fiz. metal. metalloved. 1971, Vol.31, No.3, p 567.

72. Barrett W 'Molybdenum replacement and the resistance of low alloy steels to temper embrittlement.' M.Sc. Thesis. Department of Metallurgy, University of the Witwatersrand. 1982.

73. Winkler O and Bakish R. 'Vacuum metalurgy.' Elsevier Book Publishers, New York, 1971.

74. Wolff I. 'Melting problems in high chromium ferritic irons.' Final year project. Department of Metallurgy, University of the Witwatersrand. September, 1985.

75. Edwards B C, Eyre B L and Gage G. 'Temper embrittlement of low alloy Ni-Cr steels - I. The susceptibility to temper embrittlement and the influence of intermediate tempering treatments.' Acta Mettalurgica. 1980, Vol.28, p 735.

76. Gulyaev A P and Ul'yanin E A. 'Rare earth metals in structural steels'. Metal Science and Heat Treatment. 1963, Vol.8, p 242.

77. Luyckx L and Jackman J R. Proceedings of the 31st Electric Furnace Conference. AIME. 1973.

78. Hertzberg R W. 'Deformation and fracture mechanics of engineering materials.' John Wiley and Sons Publ. 1976.

79. Van Zwieten A C. 'The effect of hot work and heat treatment on the impact energy of Fe-40Cr.' 4th year project. Department of Metallurgy. University of the Witwatersrand. October 1985.

80. De Marsh E. 'A study of the embrittlement and toughening of the Fe-40Cr alloy.' MSc. Thesis. Department of Metallurgy. University of the Witwatersrand. May 1986.

81. Lawn B R and Wilshaw T R. 'Fracture of brittle solids.' Cambridge solid state science series. Cambridge University Press. 1975.

82. Rolfe S T and Barson J M. 'Fracture and fatigue control in structures.' Applications of fracture mechanics. Prentice-Hall Inc. Publishers. 1977.

83. Gowne D T and Lewis G M H. 'Strengthening mechanisms in high-strength microalloyed steels.' Materials Science and Technology. March, 1985. Vol.1, p 183.

84. Edelson B and Baldwin W. Transactions. American Society for Metals. 1962. Vol.55, p 230.

85. Mintz B. 'Importance of k_y (Hall-Petch slope) in determining strength of steels.' Metals Technology. July, 1984. Vol.11, p 265.

86. Li J C M. Transactions. AIME. 1963. Vol.227, p 239.

87. Almond E A and Embury J D. Metal Science Journal. 1968. Vol.2, p 194.

88. Mintz B, Morrison W B and Cochrane R C. 'Influence of grain boundary carbide thickness and grain size on the impact properties of steels.' Proceedings of the product technology conference on 'Controlled processing of HSLA steels'. York University. 1976. British Steel Corporation. Paper No.1.

89. Gladman T. 'The effects of inclusions on mechanical properties.' Inclusions. Ed. Pickering F B. The Institution of Metallurgists(Britain). 1979. Monograph No 3, p 157.

90. Pickering F B. 'Inclusion shape control.' Inclusions. Ed. Pickering F B. The Institution of Metallurgists (Britain). 1979. Monograph No 3, p 108.

91. Higginson A. 'The spontaneous passivation of Fe-Cr-Ru alloys in acidic solution.' Mintek (SA) Technical Memorandum. Division No15053. October 21, 1985.

APPENDICES

APPENDIX A

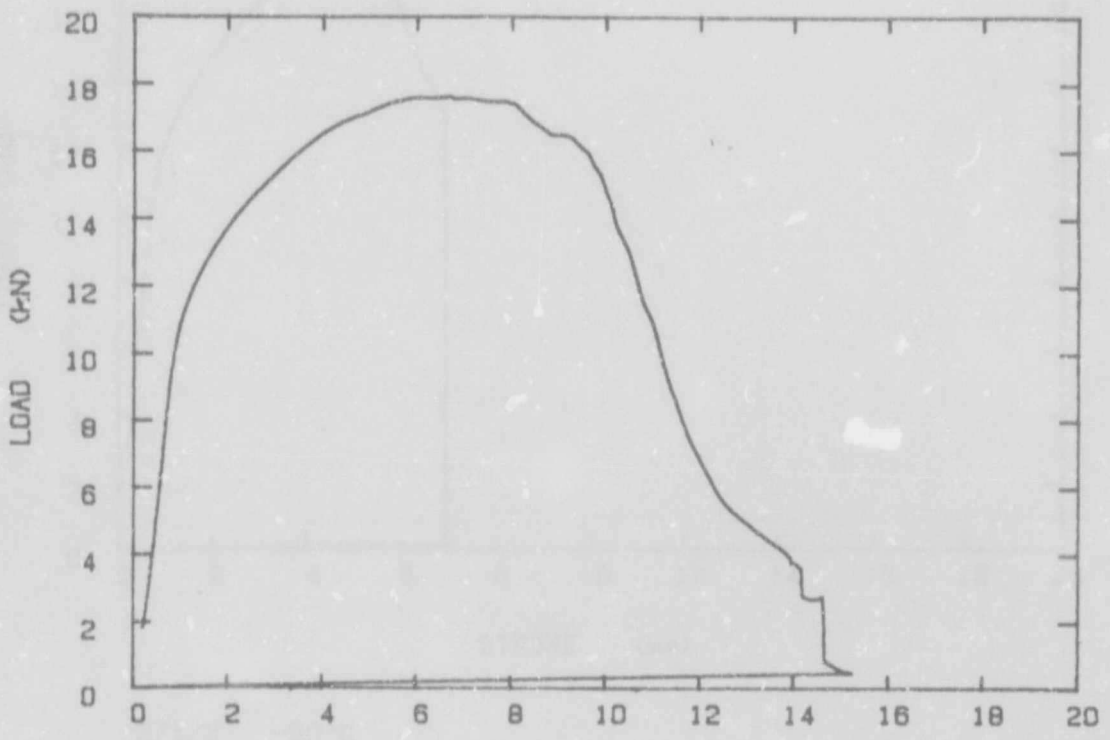
Computer programme for the calculation of areas below the slow bend test load vs stroke curves.

```
READY.
 5 DIMX(2000),Y(2000)
 6 PRINT"[illegible]!!"
 8 FOR A=1 TO1000:NEXTA
 10 PRINT""
 20 INPUT"ENTER 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"INTEGRATE TO WHICH NUMBER :";D
 60 REM--------------------
 70 REM
 80 REM  INTEGRATE DATA
 90 REM
 100 REM------------------
 110 SUM=0
 111 PRINT"INTEGRATING...";
 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"INTEGRAL IS :";SUM
 180 OPEN 4,4
 200 PRINT£4,"INTEGRAL TO POINT ";D;" OF SAMPLE NO. ";NA$;" IS  :";SUM
 210 PRINT£4,"----------------------------------------------------------";
 211 PRINT£4
 250 CLOSE 4,4
 260 INPUT"NEW DATA (Y/N) :";C$:IF C$="N"THEN 52
 300 RUN
```

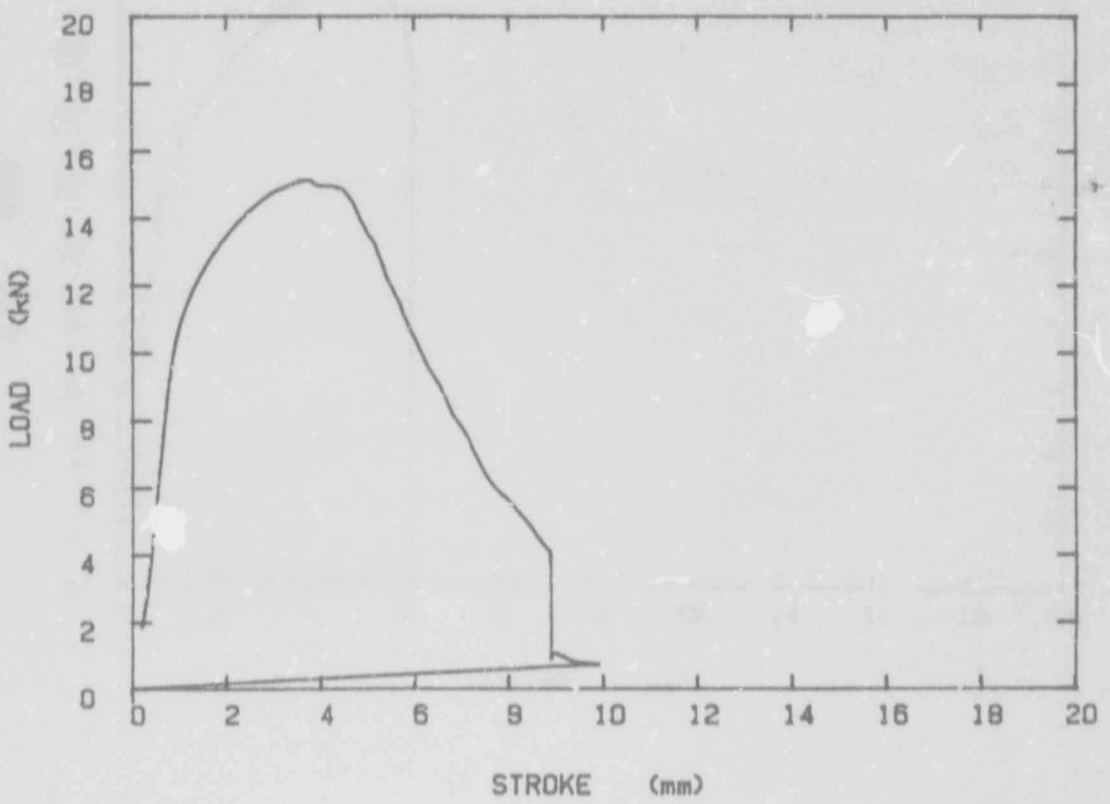
APPENDIX B

Slow bend test curves (load vs stroke)

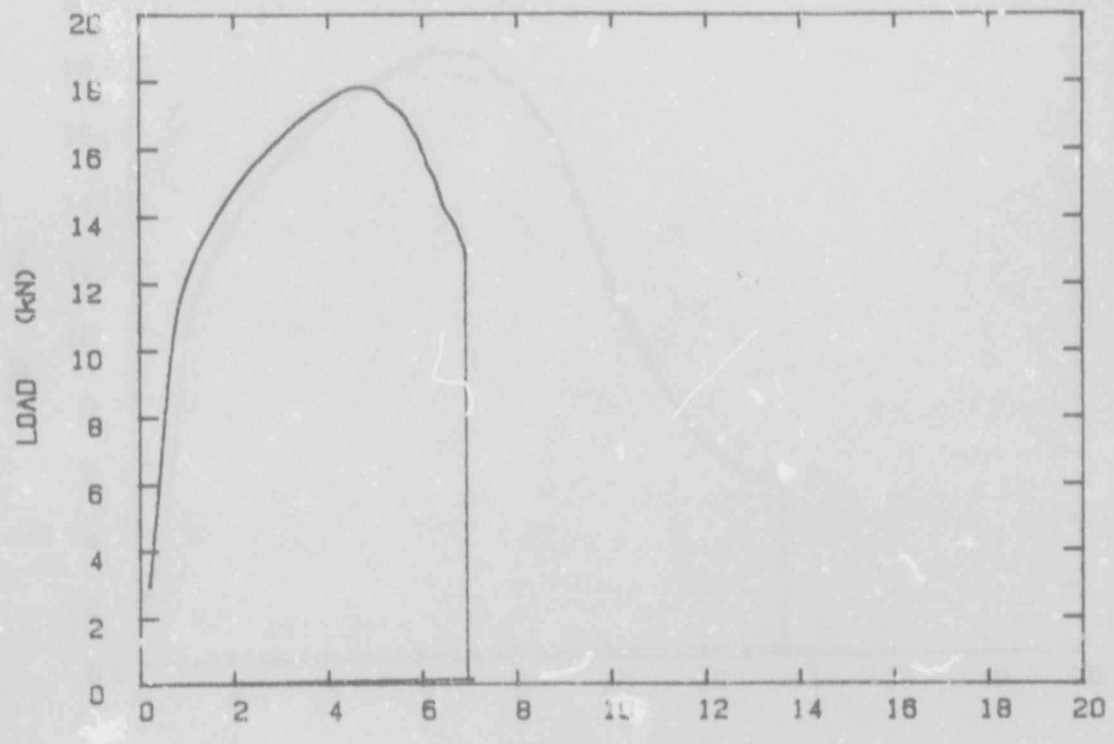
v2/1/2 32 °C



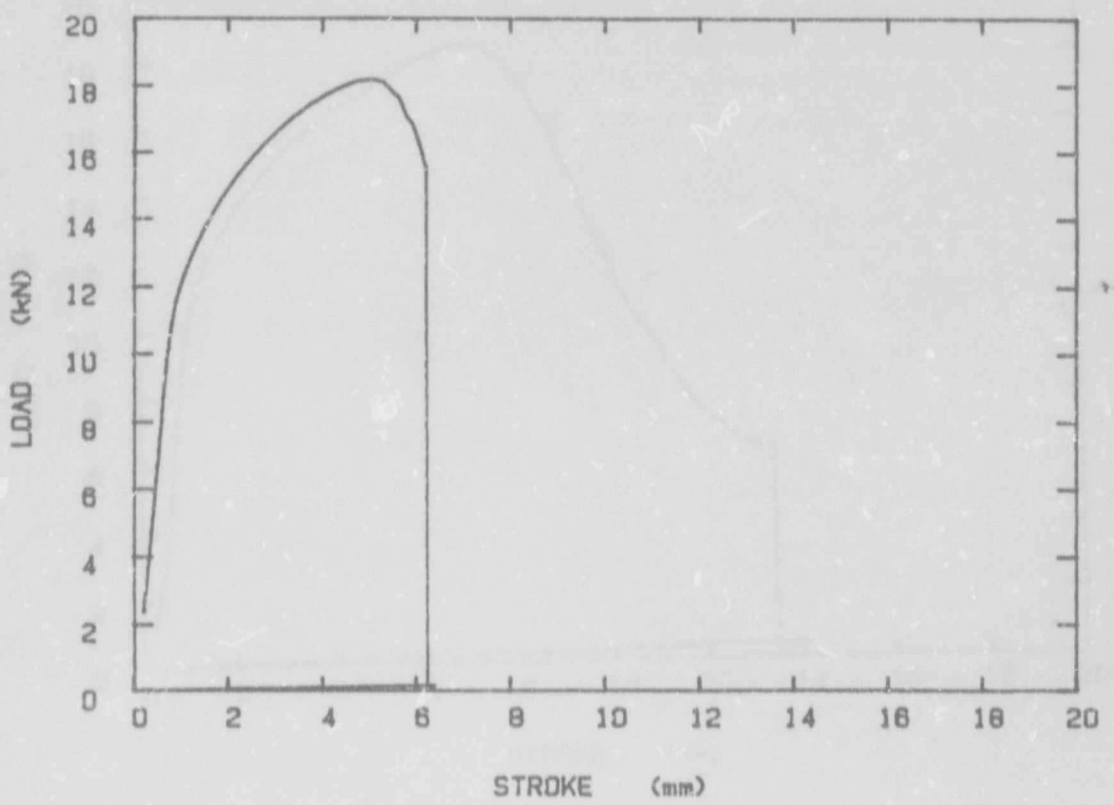
v2/1/2 0 °C



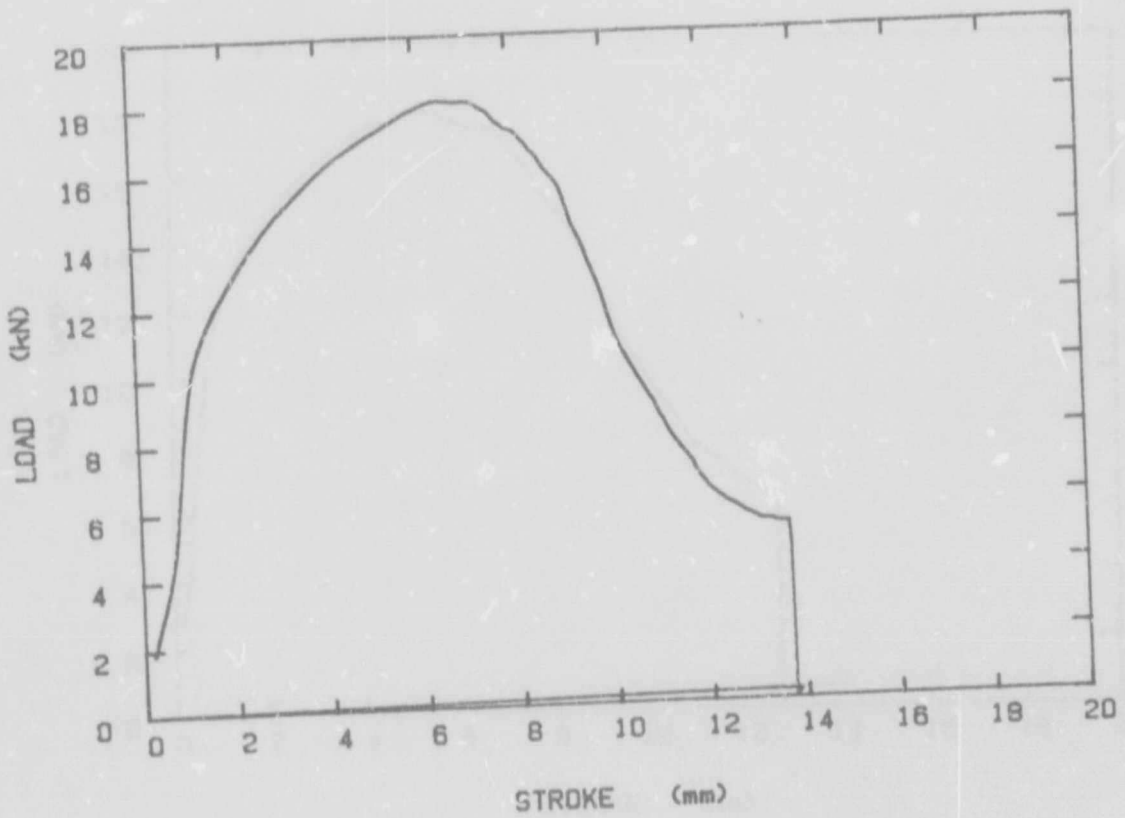
v2/1/2 -15 °C



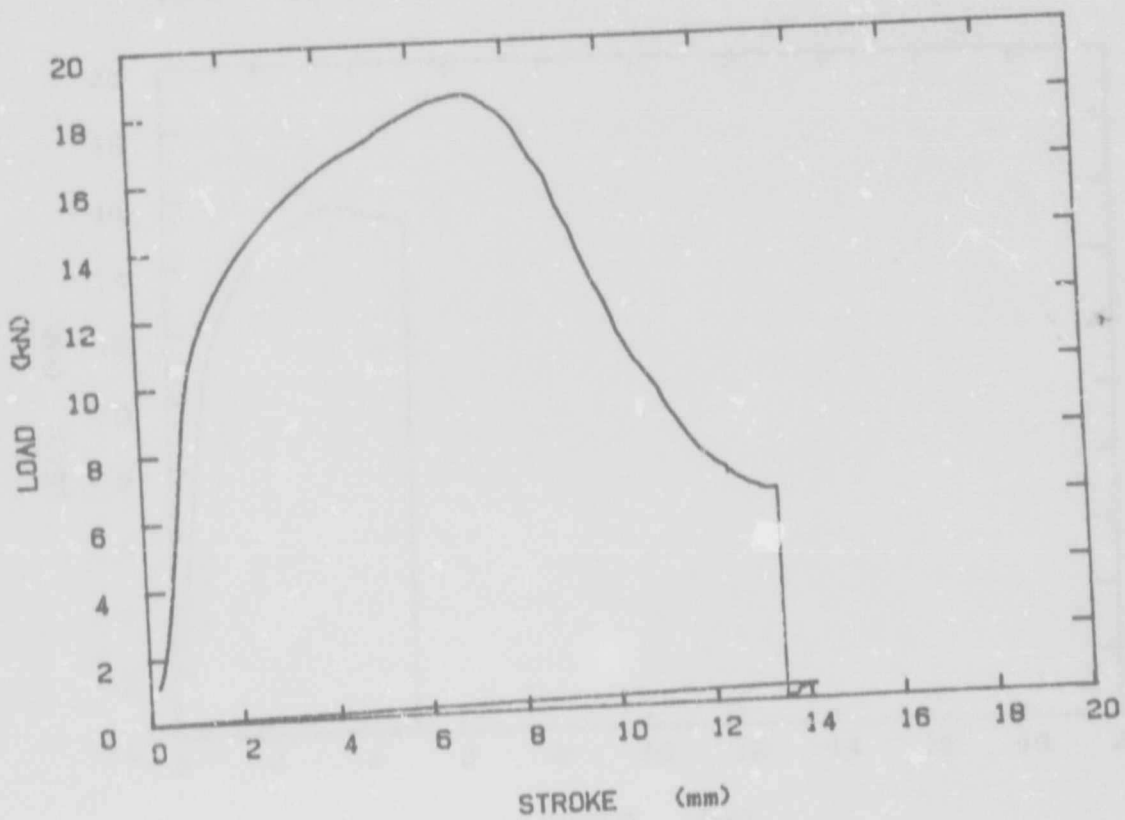
v2/1/2 -30 °C



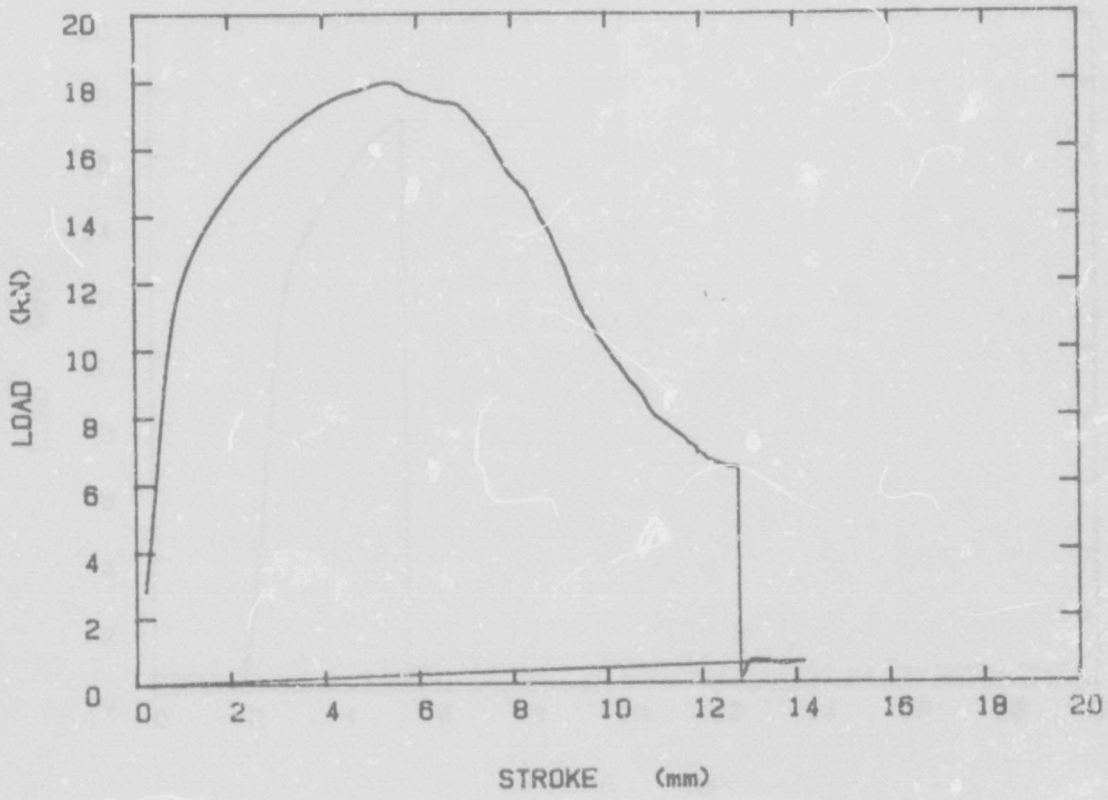
v3'2 22 °C



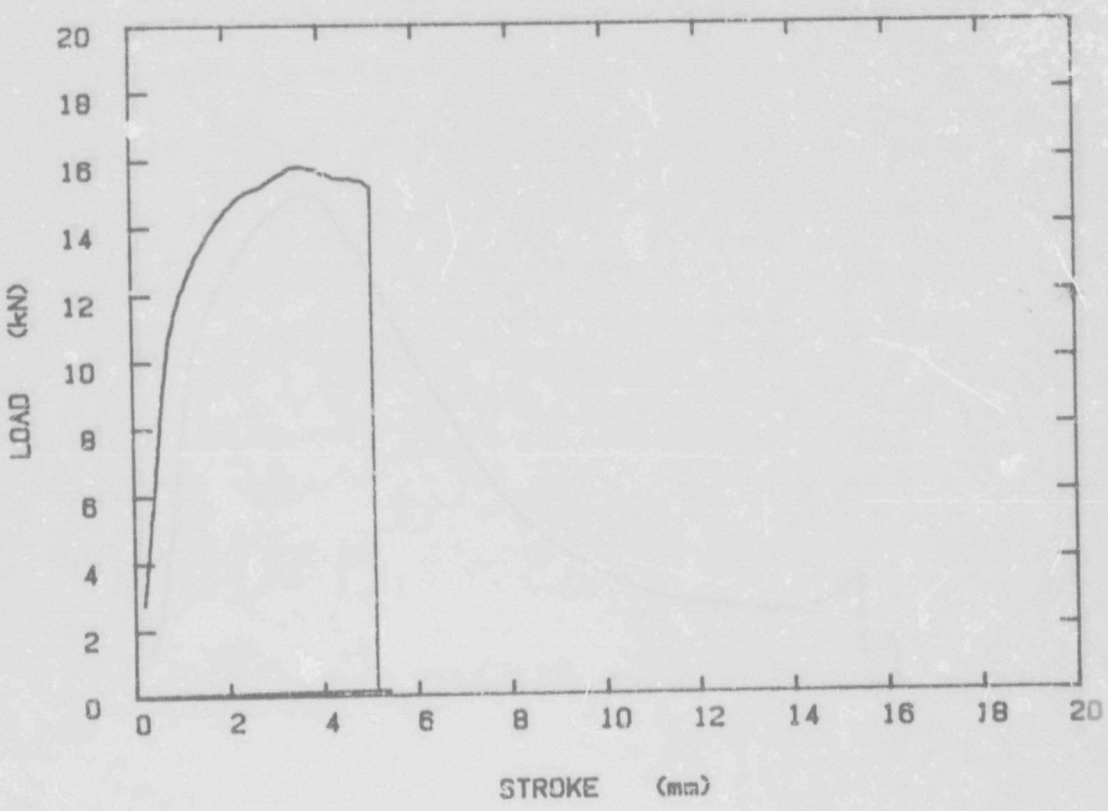
v3/2 10 °C

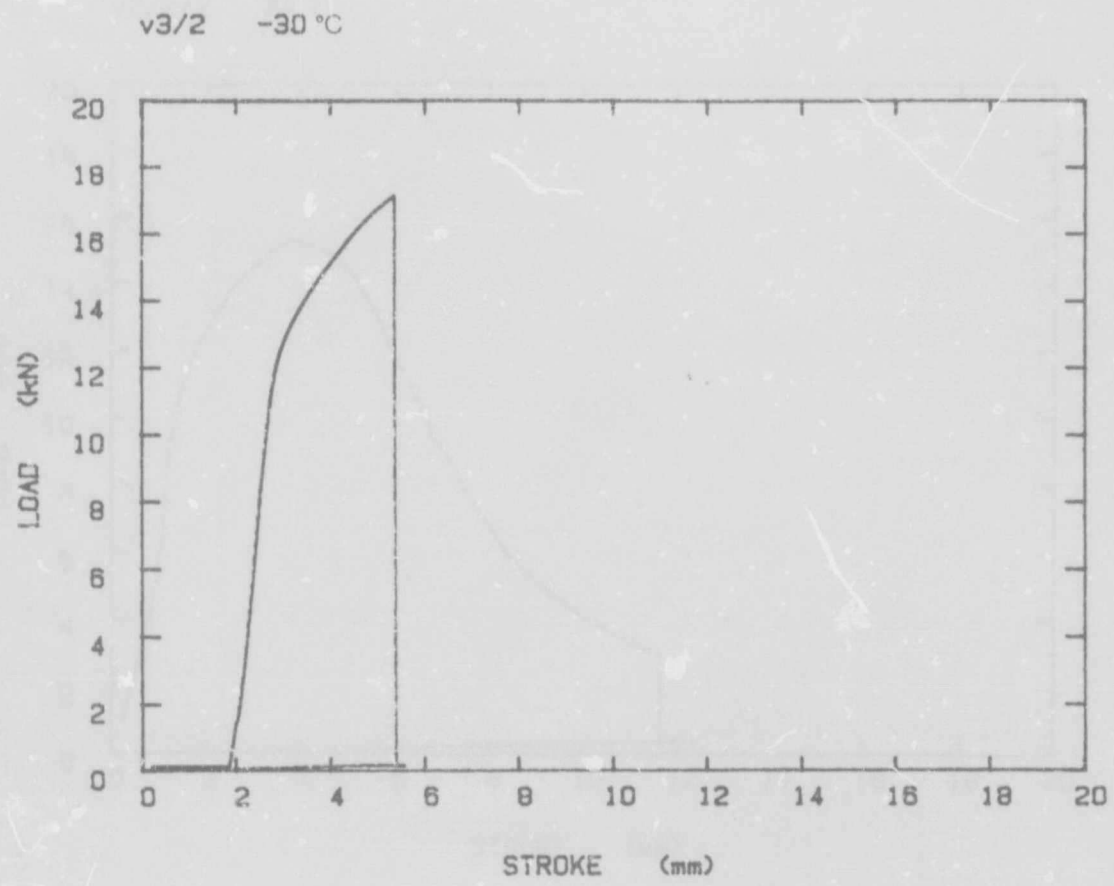


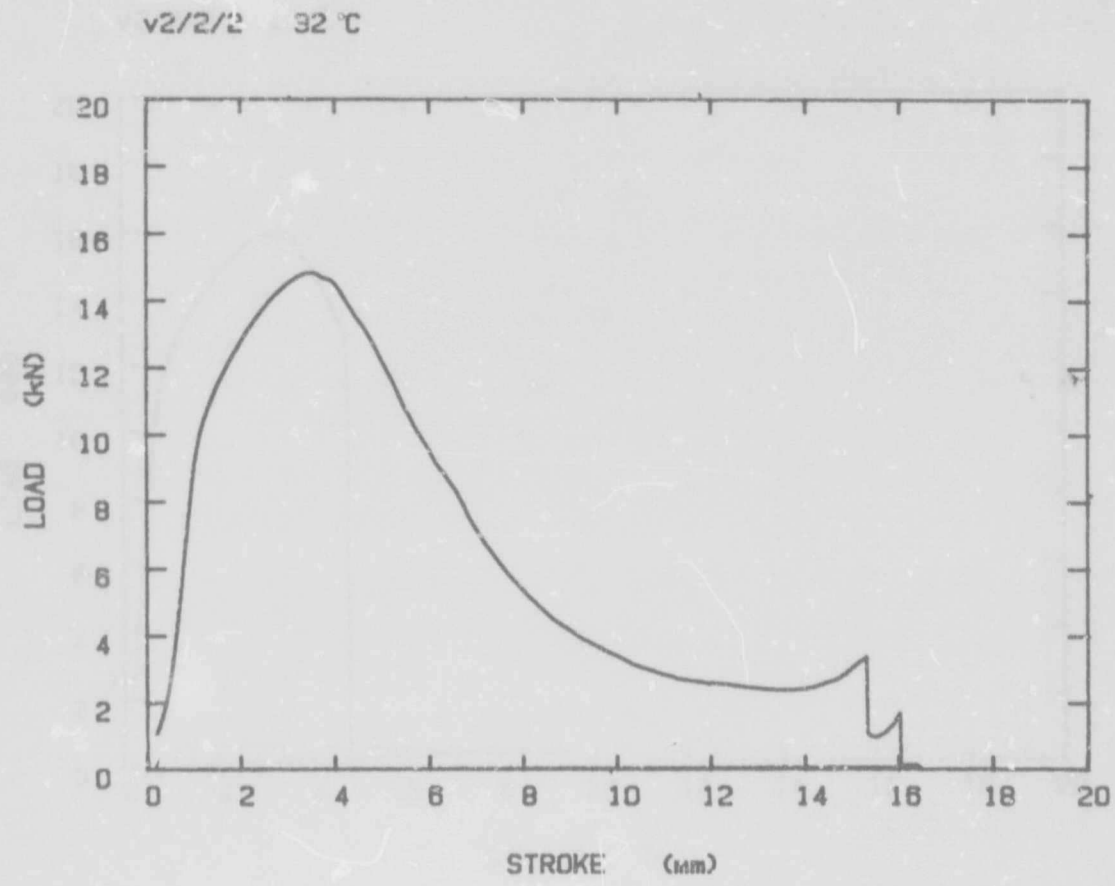
v3/2 0 °C

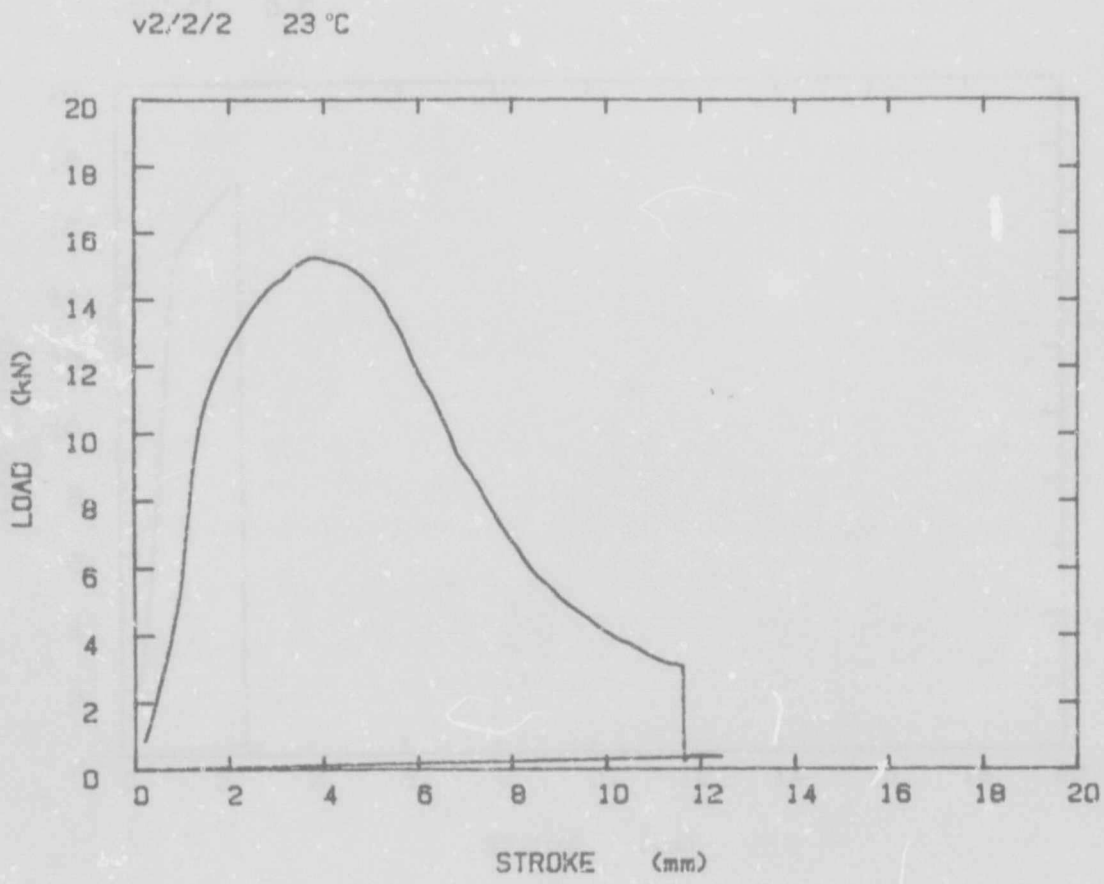


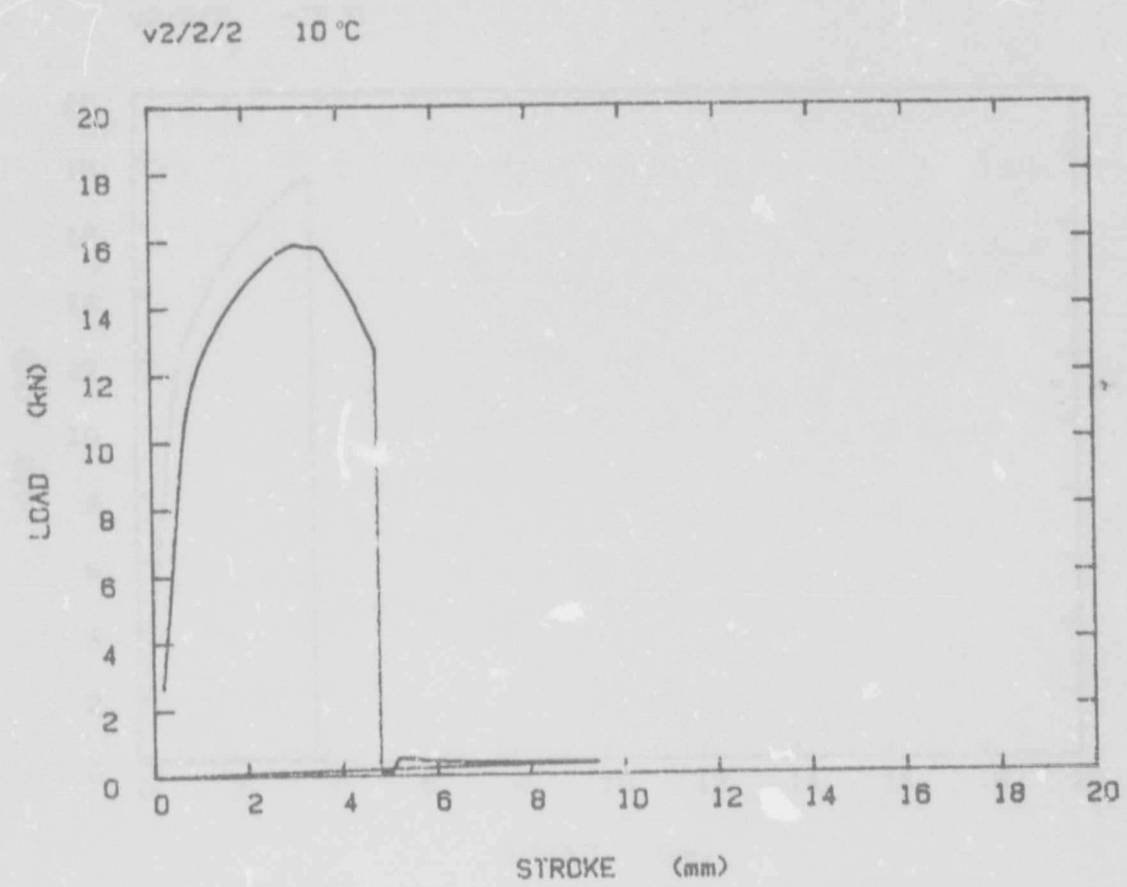
v3/2 -15 °C



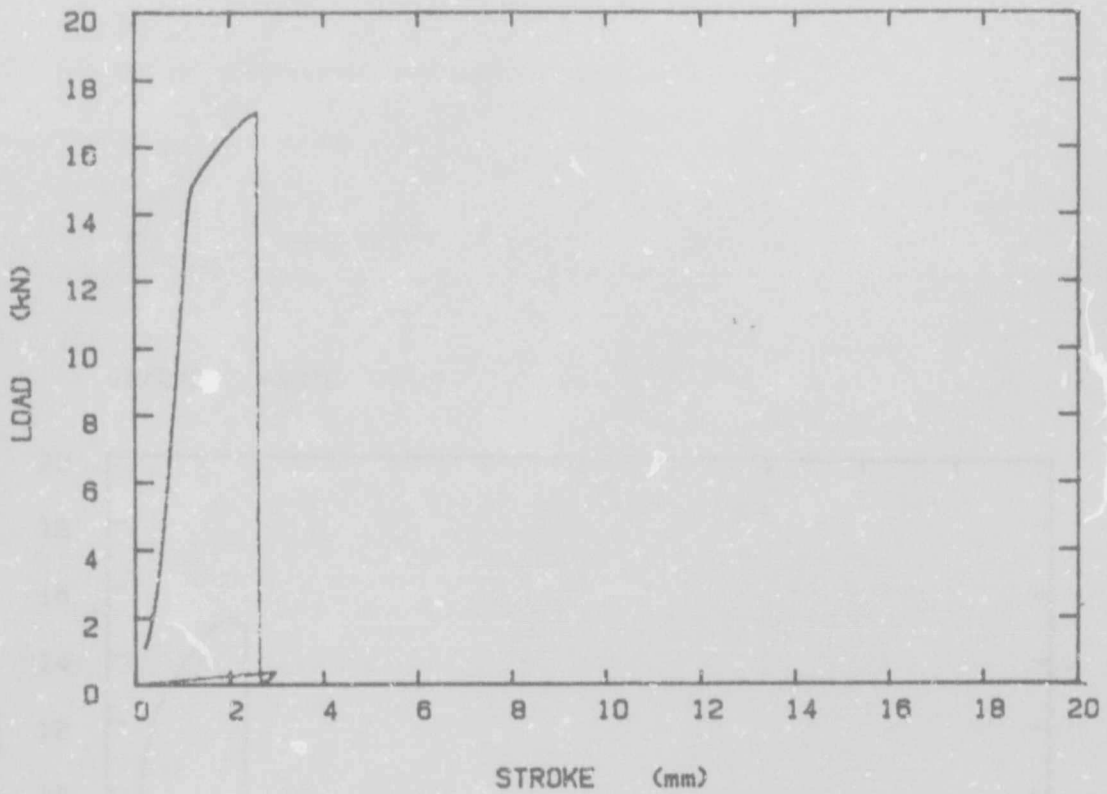

v3/2 -30 °C
LOAD (kN)
0
2
4
6
8
10
12
14
16
18
20
STROKE (mm)


v2/2/2 32 °C
LOAD (kN)
0
2
4
6
8
10
12
14
16
18
20
STROKE (mm)

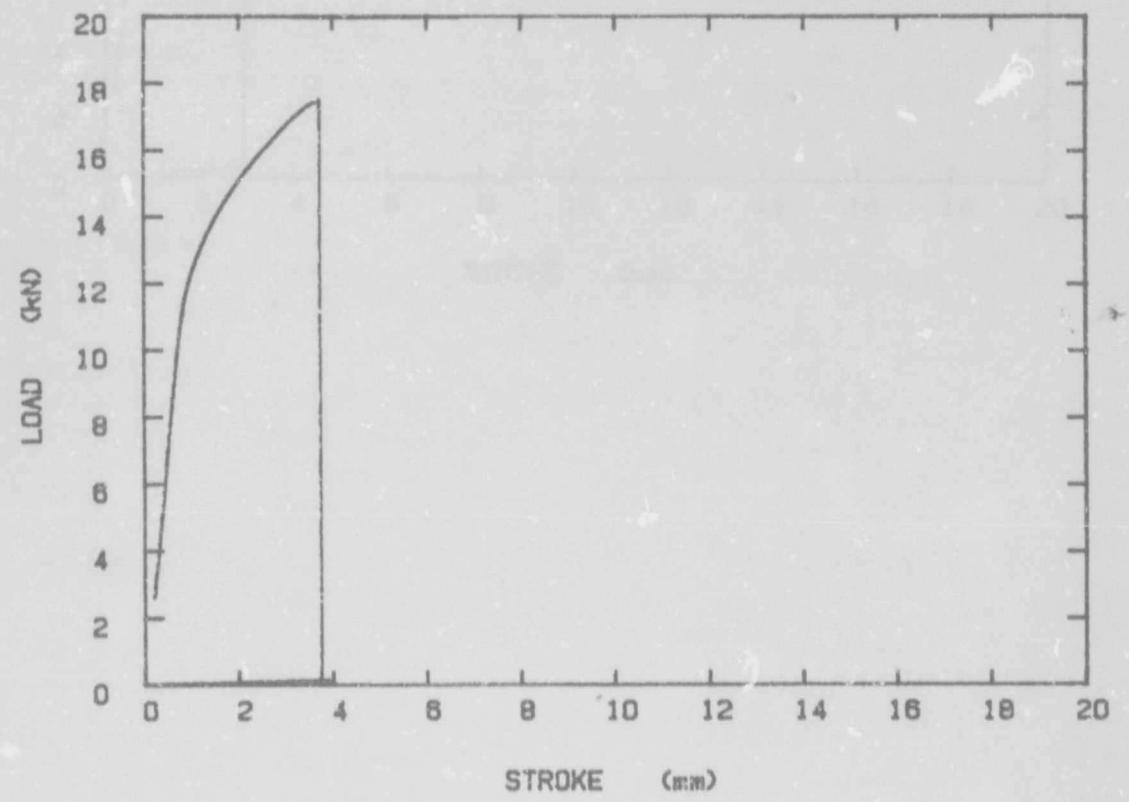

v2/2/2 23 °C
LOAD (kN)
0
2
4
6
8
10
12
14
16
18
20
STROKE (mm)

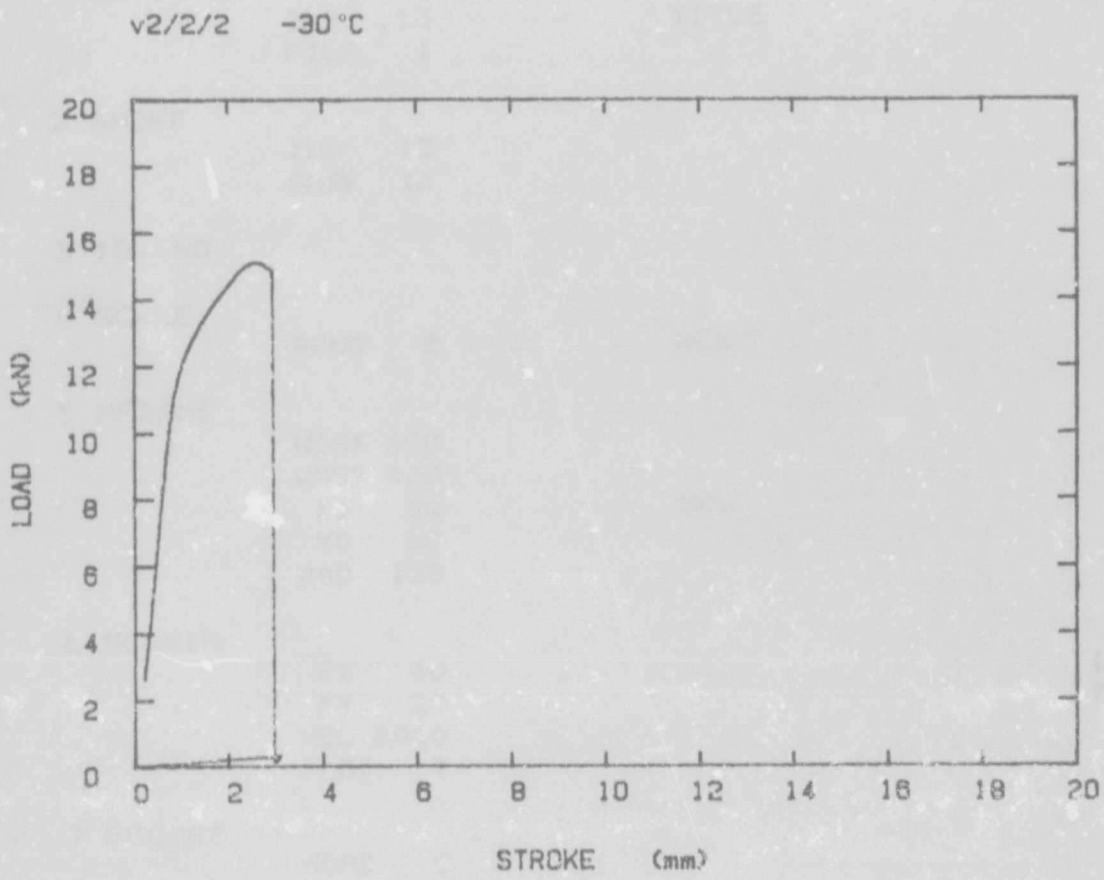

v2/2/2 10 °C
LOAD (kN)
0
2
4
6
8
10
12
14
16
18
20
STROKE (mm)

v2/2/2 0 °C



v2/2/2 -15 °C




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

APPENDIX C

Computer programme for image analysis

MEASUREMENT OF PPTS 105X OIL / MAY & DAPHNE

FUNCTION	INTEGER		VARIABLES: 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	1.000
	MODY	1				
10 AREA						
	NCLS	40			LOW	0.00
	MODX	1		CLASS	HIGH	20.0
	MODY	1				
11 AREA%						
	NCLS	60			LOW	0.00
	MODX	1		CLASS	HIGH	3.00
	MODY	1				

Author Hermanus Mavis Ann
Name of thesis The development of a tough high chronmium ferritic stainless steel. 1986

PUBLISHER:

University of the Witwatersrand, Johannesburg
©2013

LEGAL NOTICES:

Copyright Notice: All materials on the University of the Witwatersrand, Johannesburg Library website are protected by South African copyright law and may not be distributed, transmitted, displayed, or otherwise published in any format, without the prior written permission of the copyright owner.

Disclaimer and Terms of Use: Provided that you maintain all copyright and other notices contained therein, you may download material (one machine readable copy and one print copy per page) for your personal and/or educational non-commercial use only.

The University of the Witwatersrand, Johannesburg, is not responsible for any errors or omissions and excludes any and all liability for any errors in or omissions from the information on the Library website.