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and EN45001 (1989)

Technology Services International

Chemical Technologies

CERTIFICATE OF ANALYSIS

To: *R LOOTS*

MATERIALS TECHNOLOGY
SCIENTIFIC SERVICES DEPARTMENT
TSI

Report No.: **100119771**
Logged on:
Reported on:

WELDING AT CRAP
AGED MATERIALS

These results are reported on an air-dried basis.

COMMENTS:

pp *Willie Delport*
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Report No.: 100119771

Logged on:
Reported on:

Sample ID:		200315390	200315392
Description:		1/2 1/2 1/4 NUUT	1/2 1/2 1/4 OUD
Component:	**Units**	**Value:**	**Value:**
CARBON	%	0.14	0.19
CHROMIUM	%	0.46	0.53
NICKEL	%	0.08	0.16
MANGANESE	%	0.51	0.54
MOLYBDENUM	%	0.51	0.54
VANADIUM	%	0.28	0.31
SULPHUR	%	0.01	0.012
PHOSPHORUS	%	0.008	0.014
SILICON	%	0.12	0.24
TITANIUM	%	0.01	0.01
COPPER	%	0.09	0.15
COBALT	%	0.01	0.02
NIOBIUM	%	0.005	0.005
TIN	%	0.01	0.02
TUNGSTEN	%	0.005	0.005

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Report No.: 100119771

Logged on:
Reported on:

Sample ID:		200315393	200315394
Description:		2 1/4 NUUT	2 1/4 OUD
Component:	**Units**	**Value:**	**Value:**
CARBON	%	0.11	0.10
CHROMIUM	%	2.41	2.57
NICKEL	%	0.05	0.17
MANGANESE	%	0.49	0.54
MOLYBDENUM	%	0.87	0.91
VANADIUM	%	0.01	0.02
SULPHUR	%	0.001	0.003
PHOSPHORUS	%	0.018	0.021
SILICON	%	0.11	0.04
TITANIUM	%	0.01	0.01
COPPER	%	0.04	0.12
COBALT	%	0.01	0.03
NIOBIUM	%	0.005	0.005
TIN	%	0.01	0.01
TUNGSTEN	%	0.005	0.02

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Report No.: 100119771

Logged on:
Reported on:

Sample ID:		200315395	200315396
Description:		X20 NUUT	X20 OUD
Component:	**Units**	**Value:**	**Value:**
CARBON	%	0.22	0.19
CHROMIUM	%	12.05	12.29
NICKEL	%	0.75	0.48
MANGANESE	%	0.59	0.45
MOLYBDENUM	%	0.82	0.78
VANADIUM	%	0.26	0.30
SULPHUR	%	0.004	0.013
PHOSPHORUS	%	0.016	0.020
SILICON	%	0.07	0.13
TITANIUM	%	0.01	0.01
COPPER	%	0.11	0.09
COBALT	%	0.01	0.01
NIOBIUM	%	0.01	0.005
TIN	%	0.01	0.01
TUNGSTEN	%	0.005	0.005

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Report No.: 100119771

Logged on:
Reported on:

Sample ID:		200315397
Description:		P91 NEW
Component:	**Units**	**Value:**
CARBON	%	0.22
CHROMIUM	%	9.19
NICKEL	%	0.19
MANGANESE	%	0.48
MOLYBDENUM	%	0.86
VANADIUM	%	0.24
SULPHUR	%	0.001
PHOSPHORUS	%	0.013
SILICON	%	0.27
TITANIUM	%	0.01
COPPER	%	0.05
COBALT	%	0.005
NIOBIUM	%	0.07
TIN	%	0.01
TUNGSTEN	%	0.005

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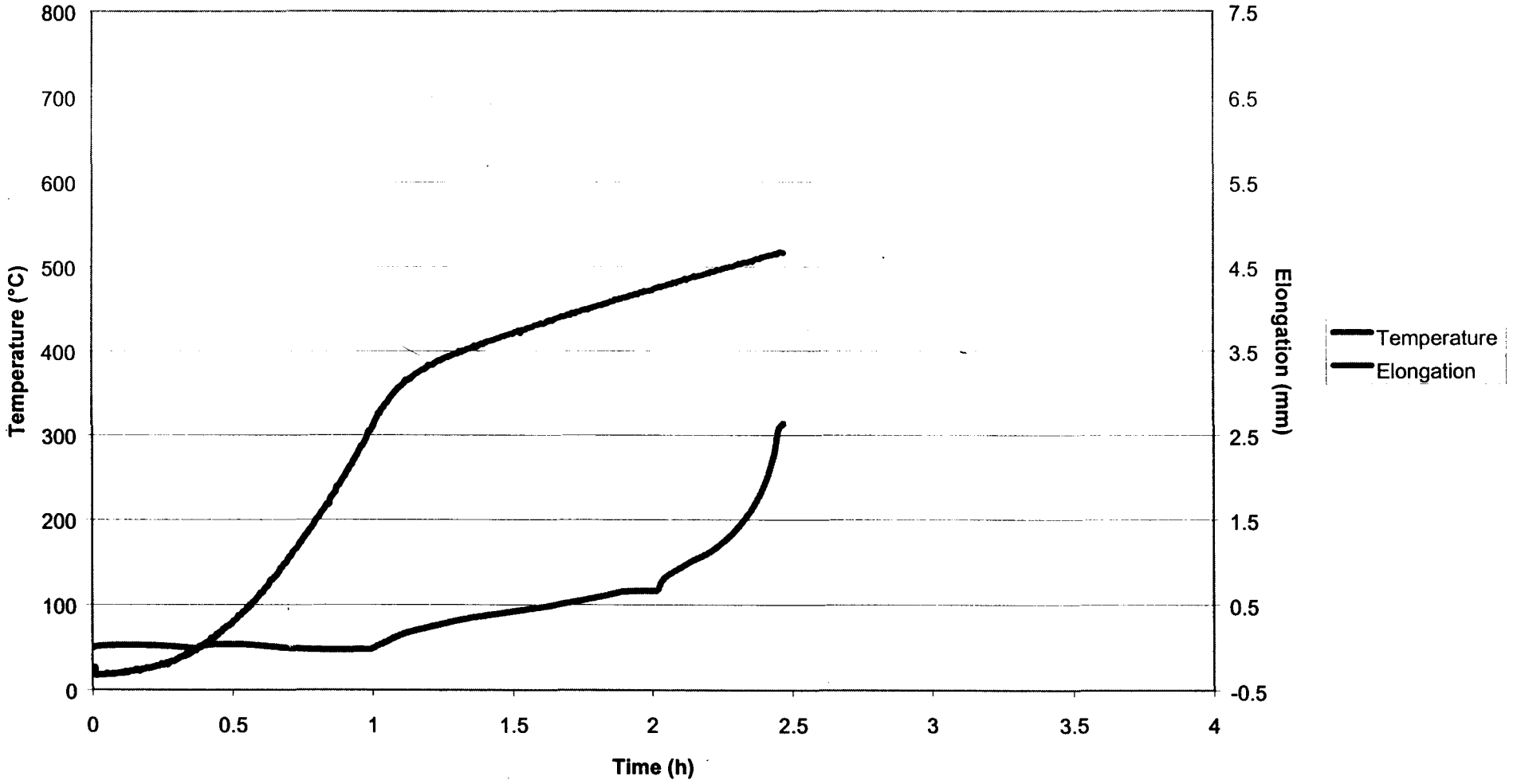
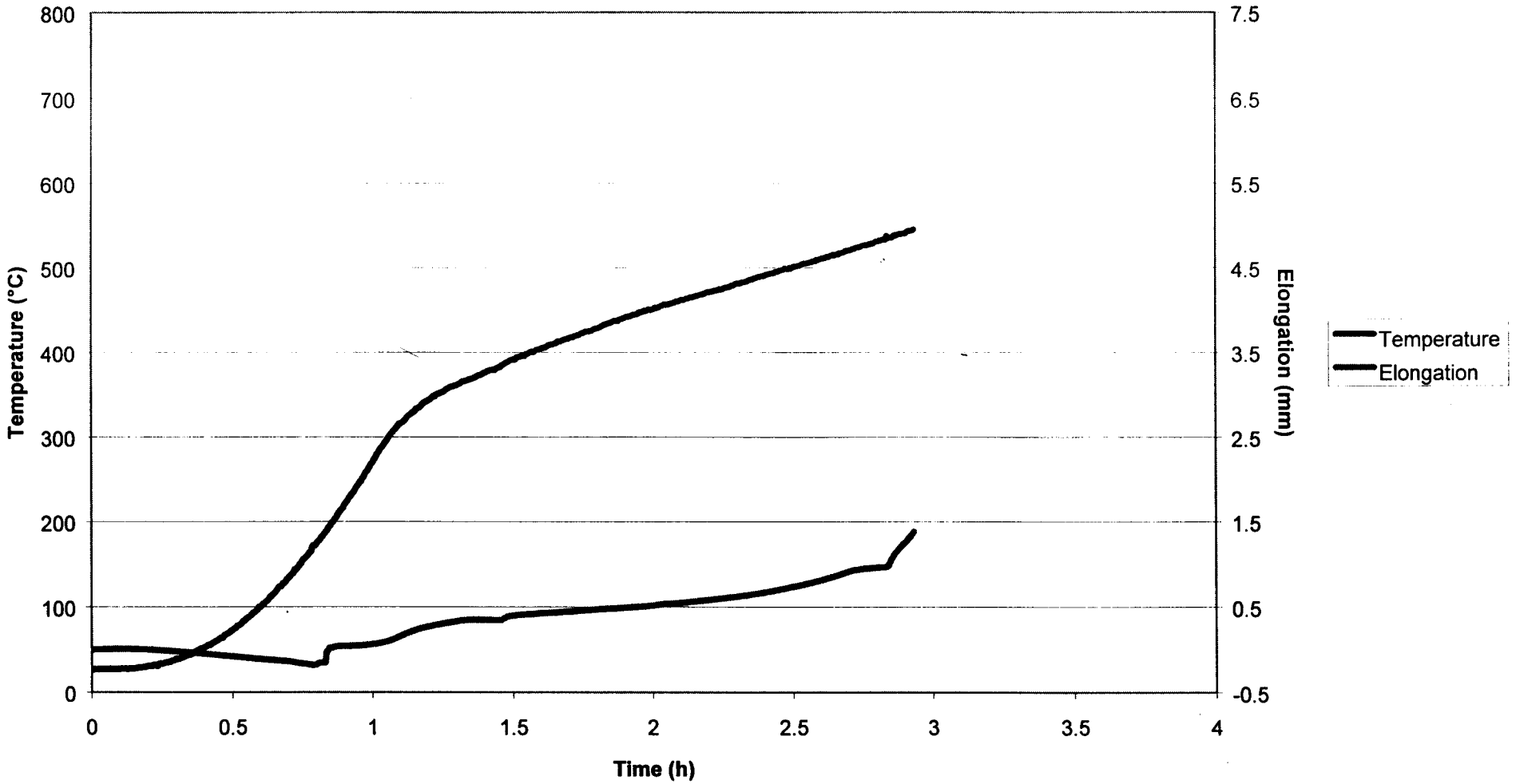
Logged on:
Reported on:

ALLOYING ELEMENTS IN STEEL ***ESKOM Method No 106 Rev 2 Accredited***
CARBON ***ESKOM Method No 119 Rev 1 Accredited***

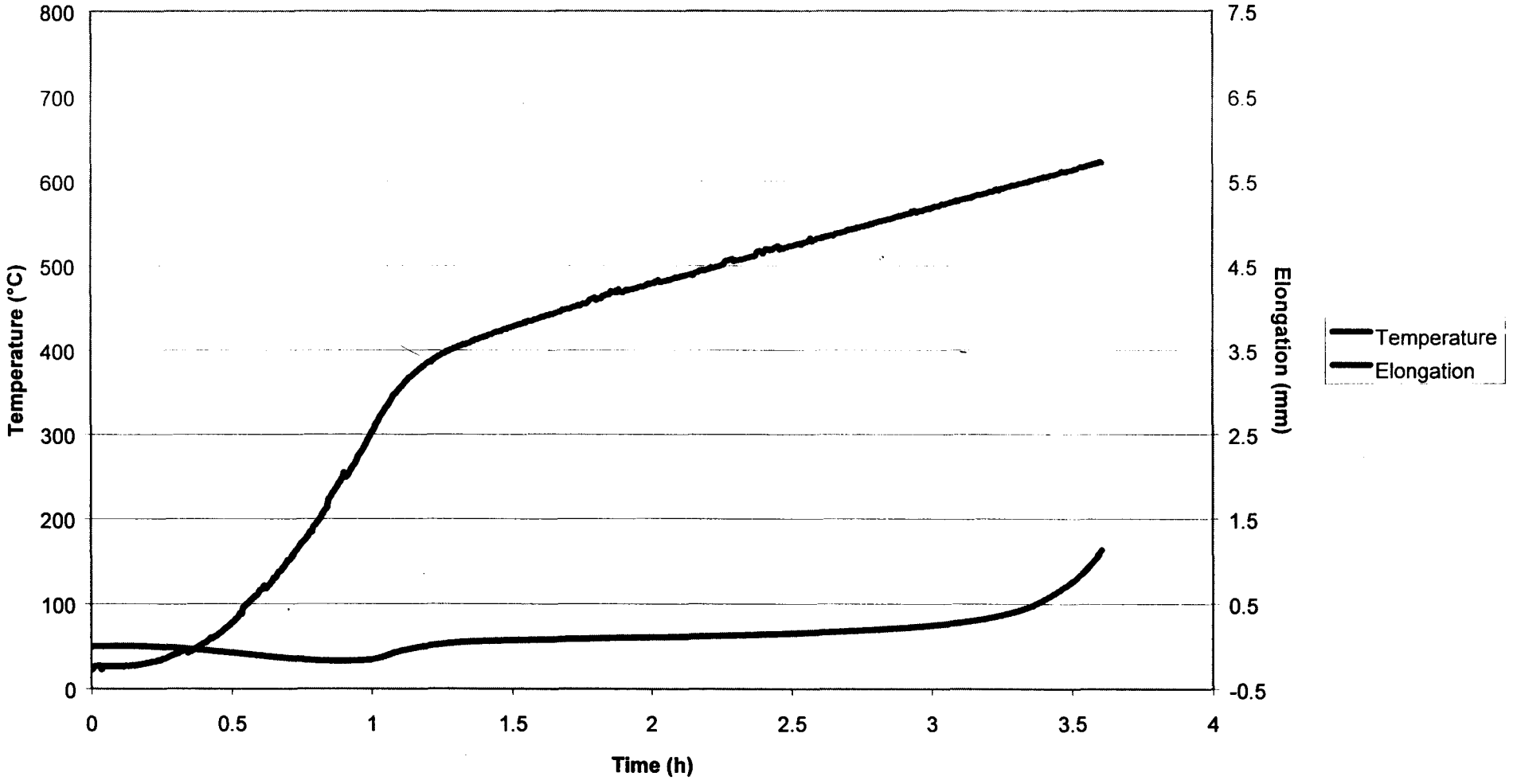
Appendix 2: Results from Spiral Notch Tests
½Cr-½Mo-¼V New: 356 MPa



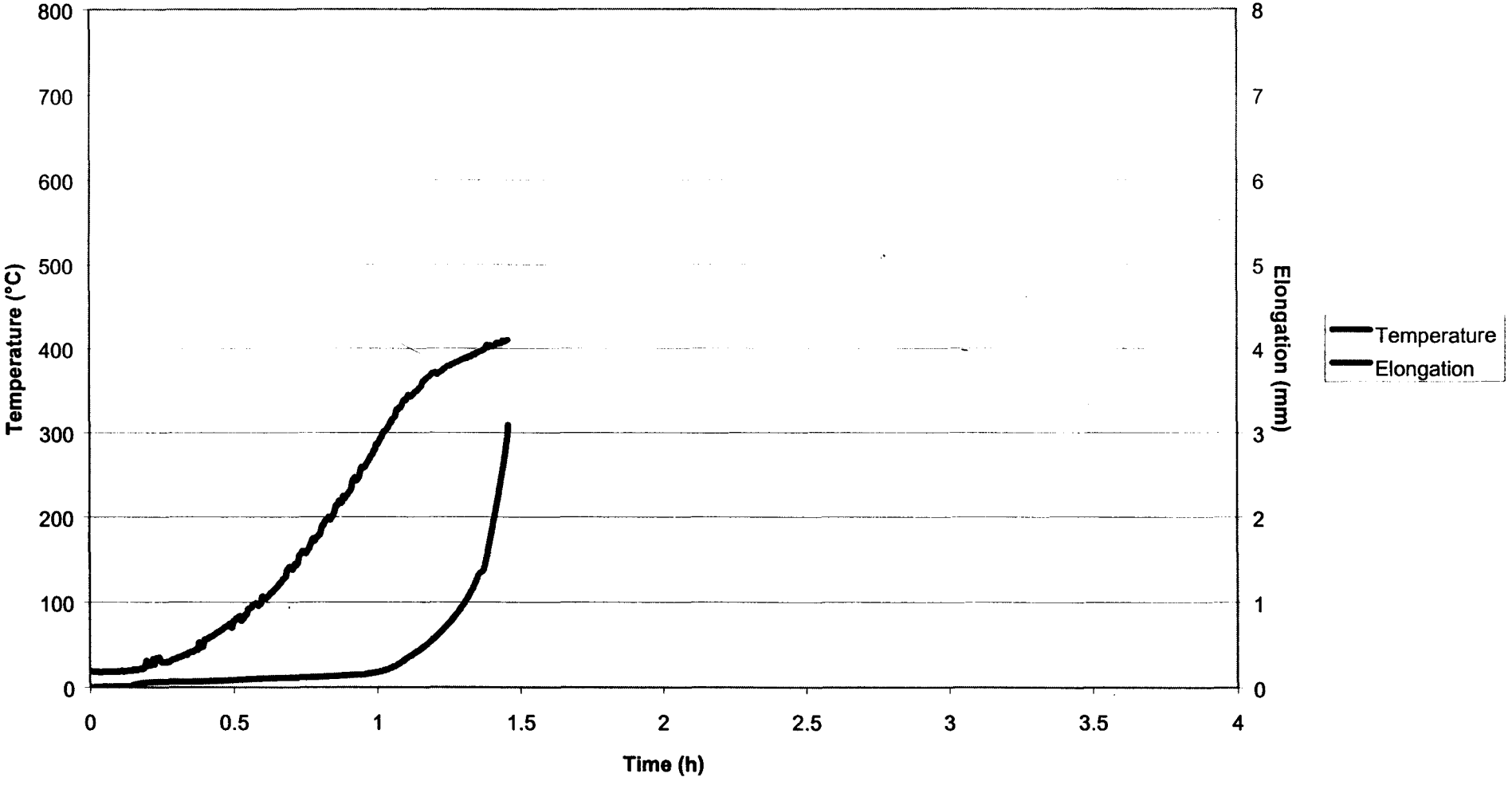
Appendix 2 (Continued)
½Cr-½Mo-¼V New: 305 MPa



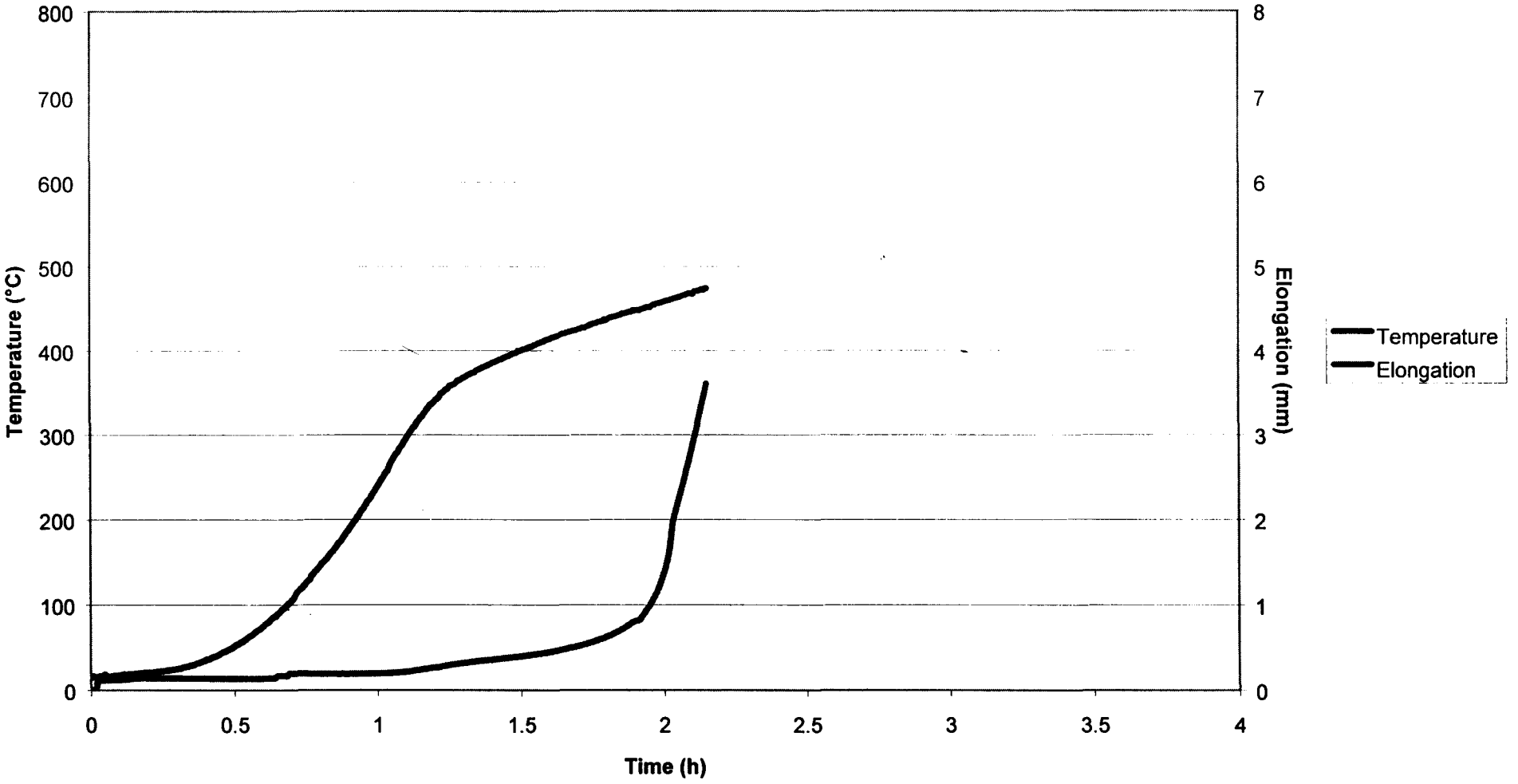
Appendix 2 (Continued)
½Cr-½Mo-¼V New: 204 MPa



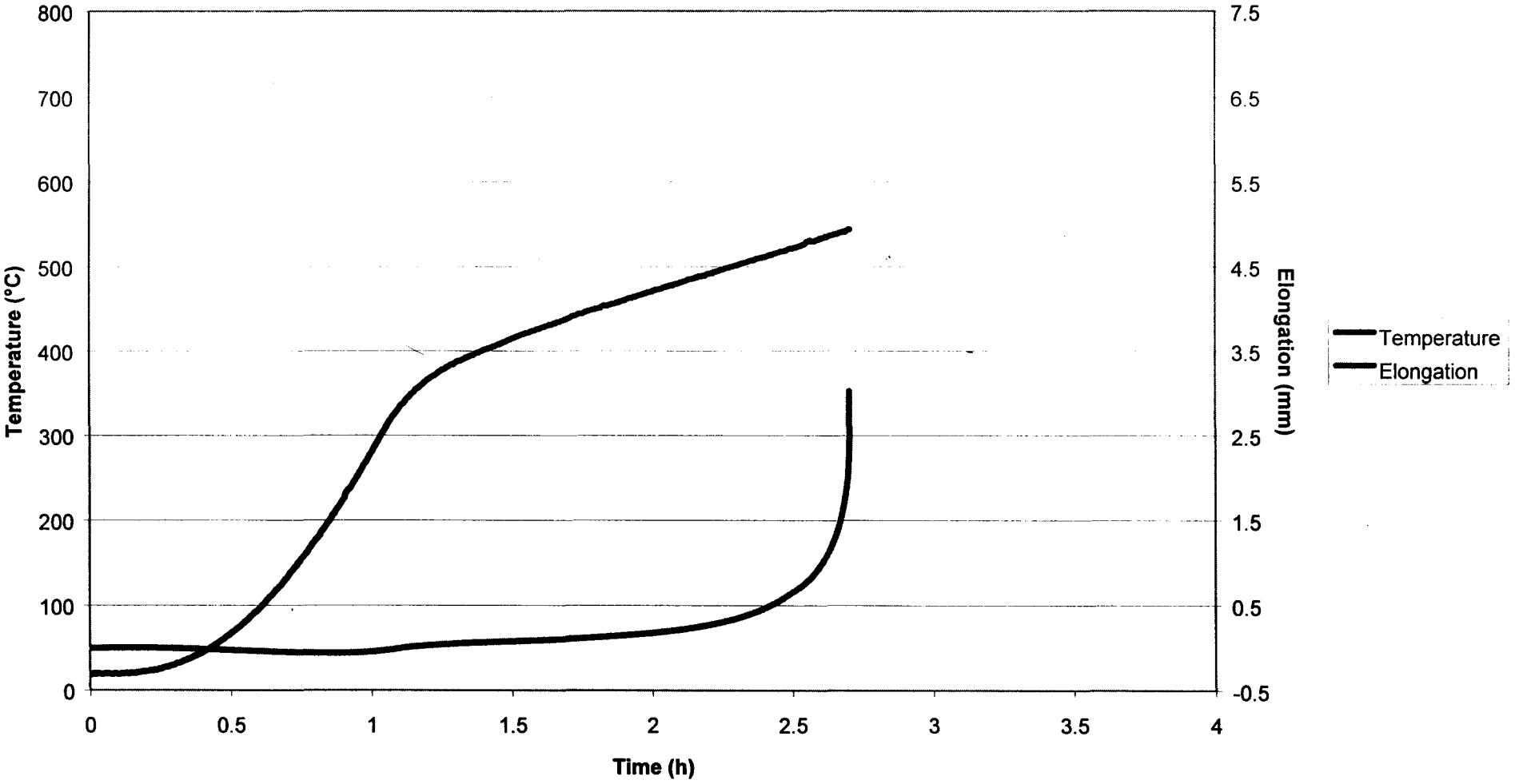
Appendix 2 (Continued)
½Cr-½Mo-¼V Service Exposed: 356 MPa



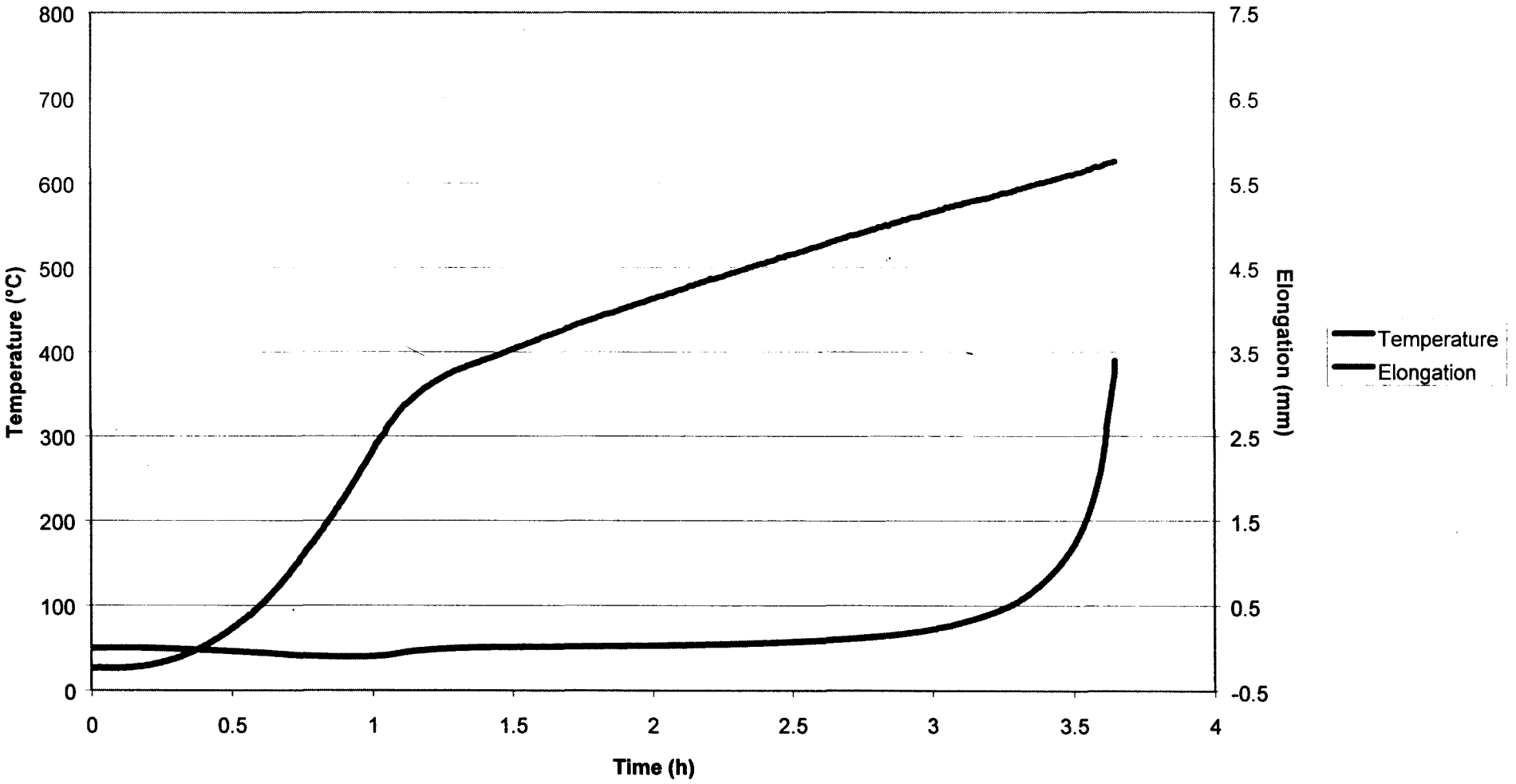
Appendix 2 (Continued)
½Cr-½Mo-¼V Service Exposed: 305 MPa



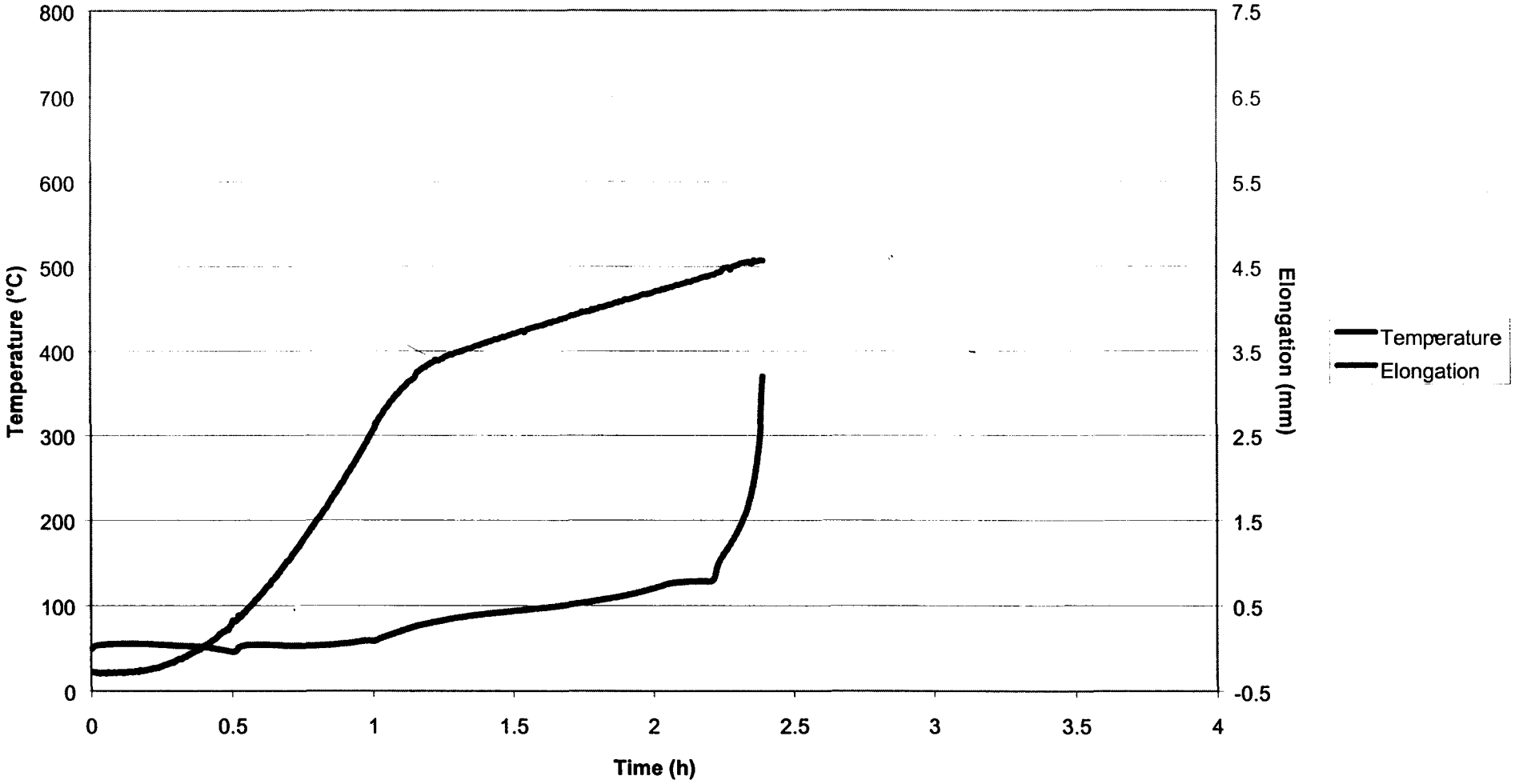
Appendix 2 (Continued)
½Cr-½Mo-¼V Service Exposed: 204 MPa



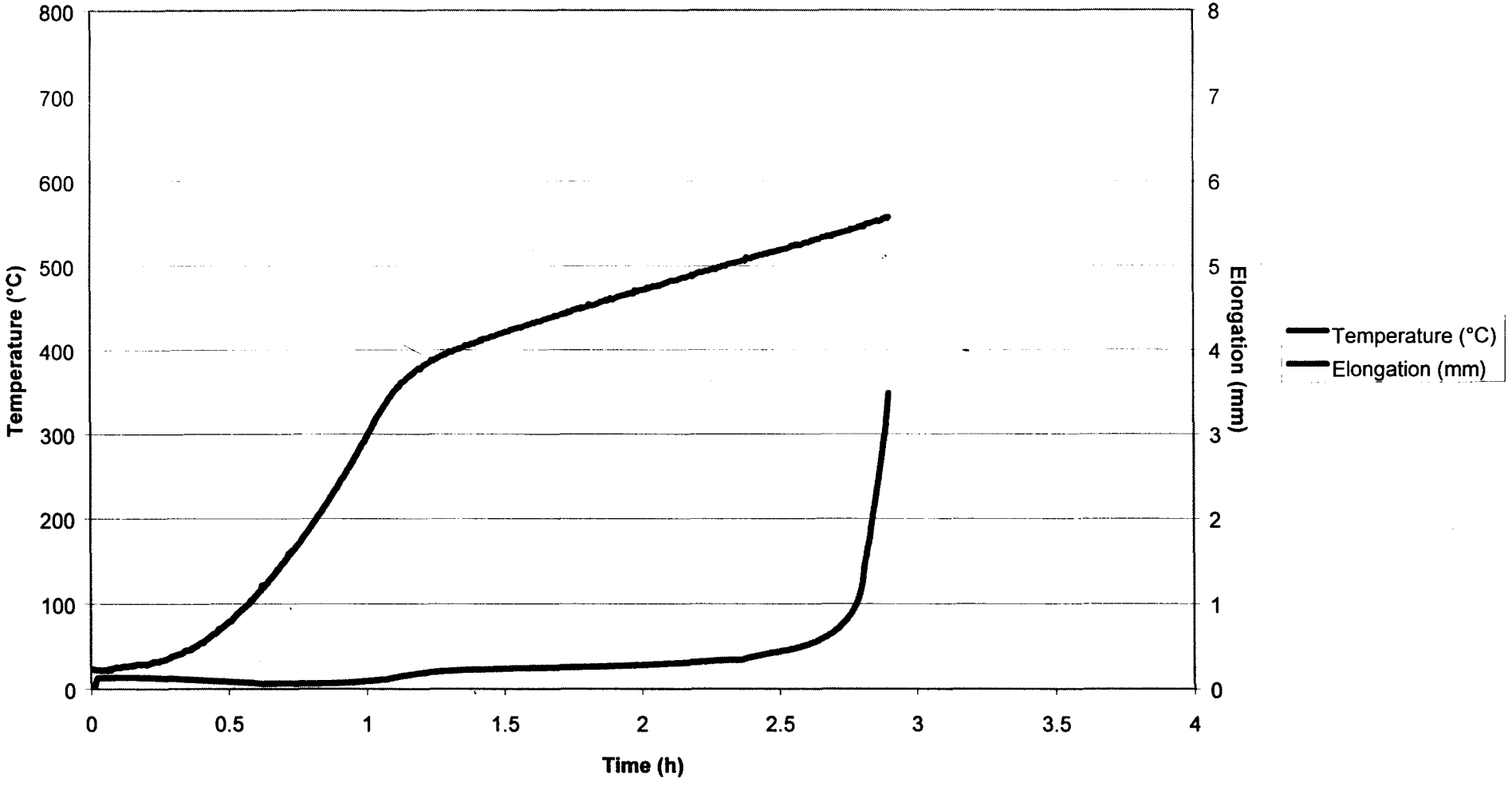
Appendix 2 (Continued)
½Cr-½Mo-¼V Service Exposed: 153 MPa



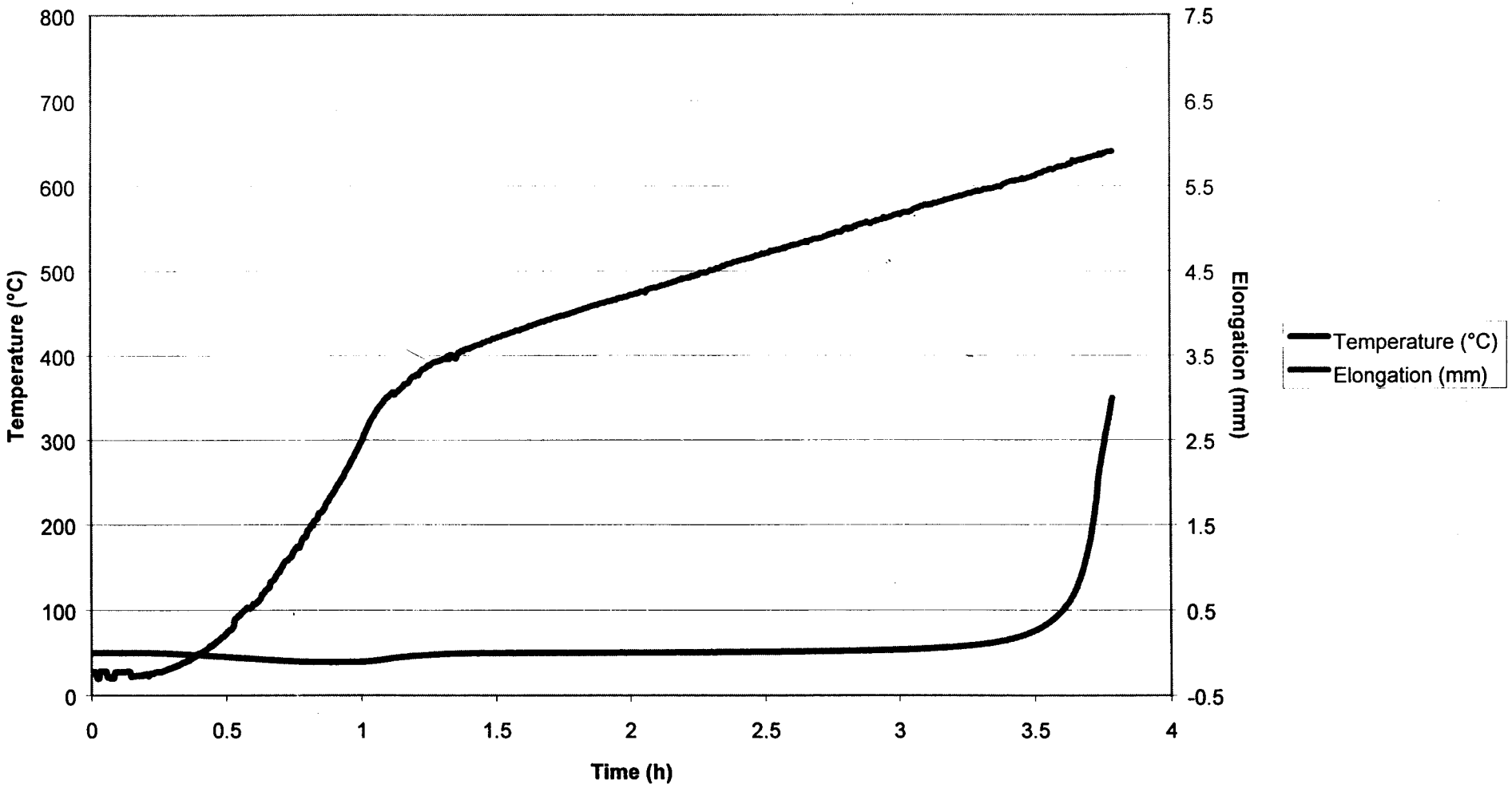
Appendix 2 (Continued)
2¼Cr-1Mo New: 356 MPa



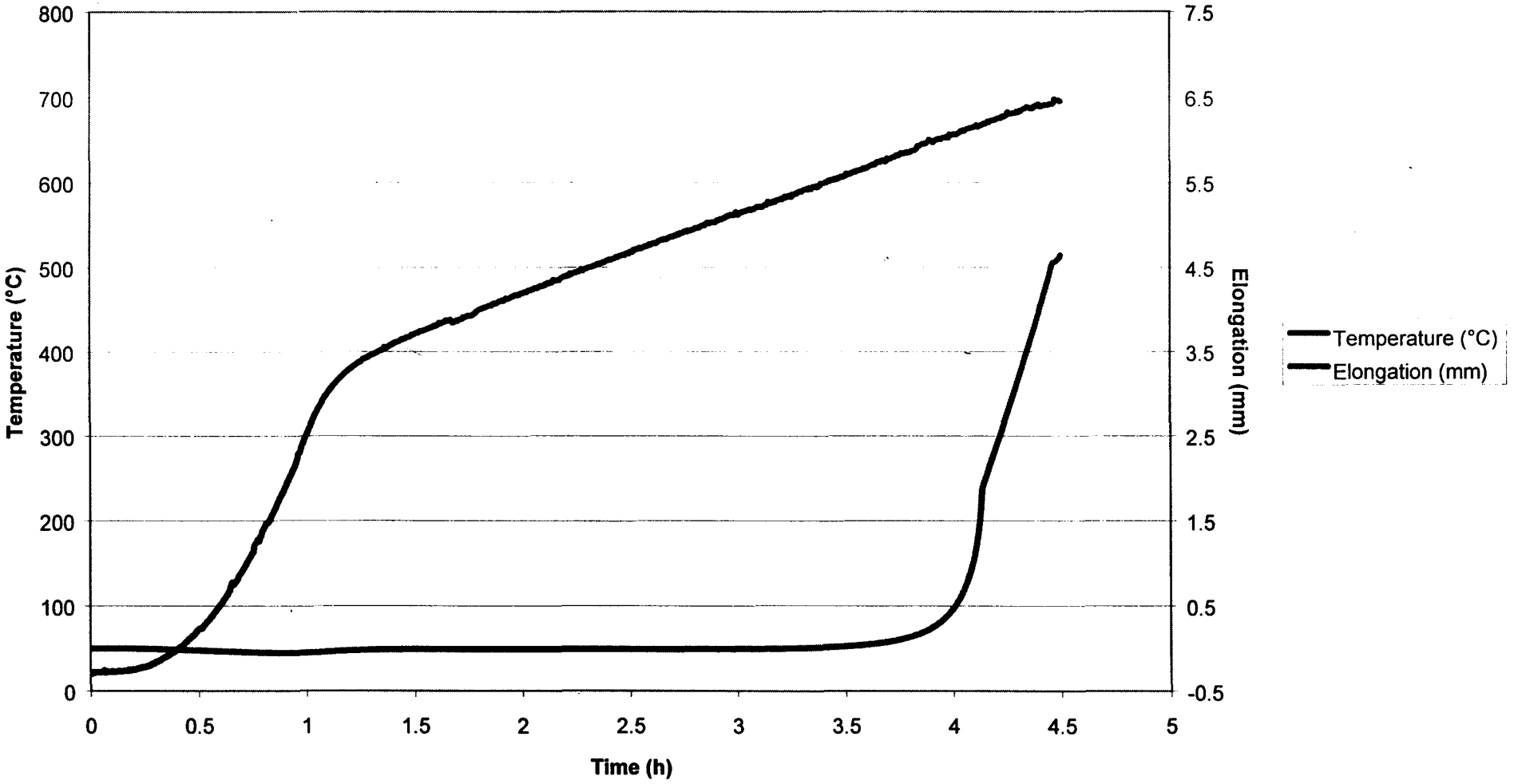
Appendix 2 (Continued)
2¼Cr-1Mo New: 305 MPa



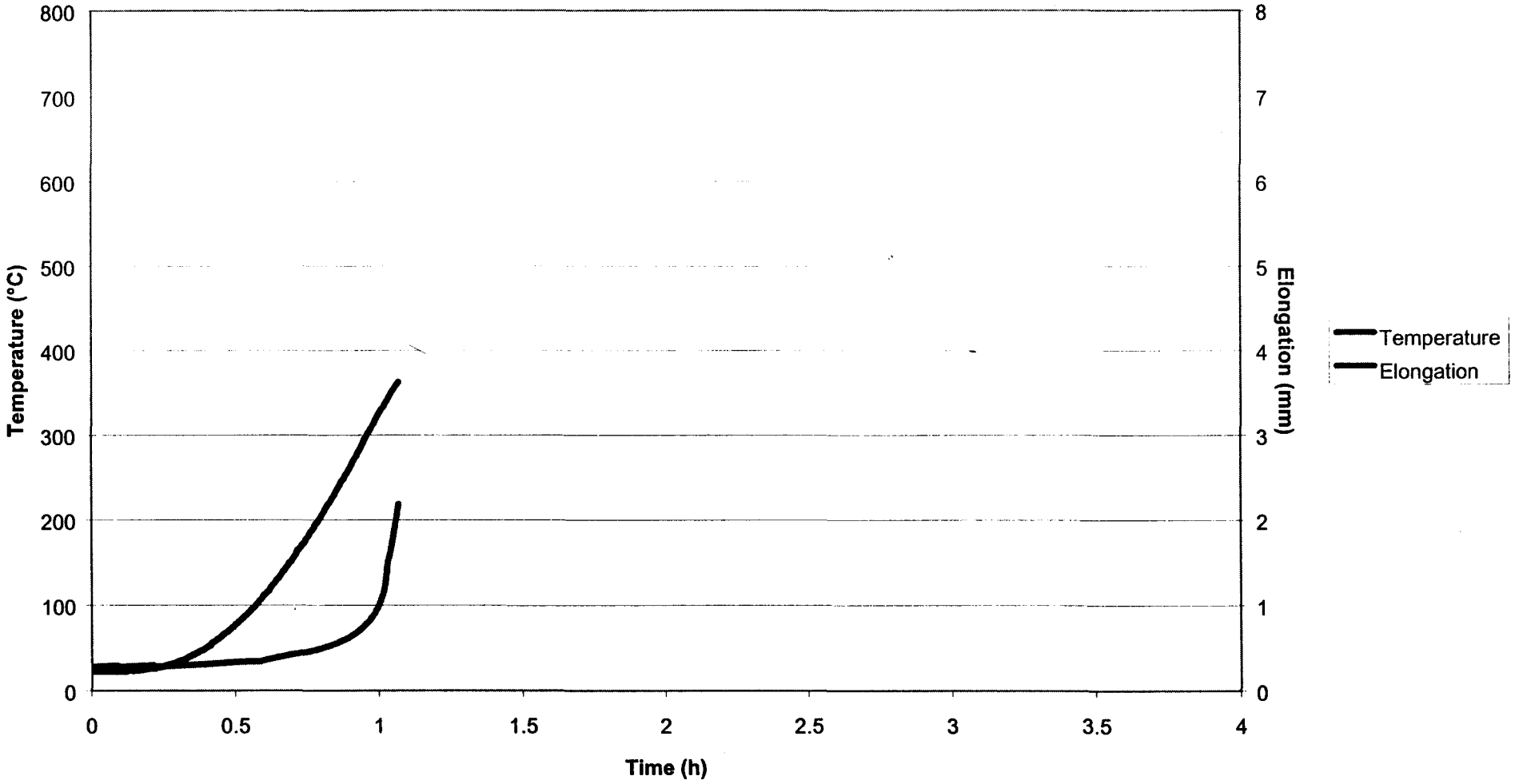
Appendix 2 (Continued)
2¼Cr-1Mo New: 204 MPa



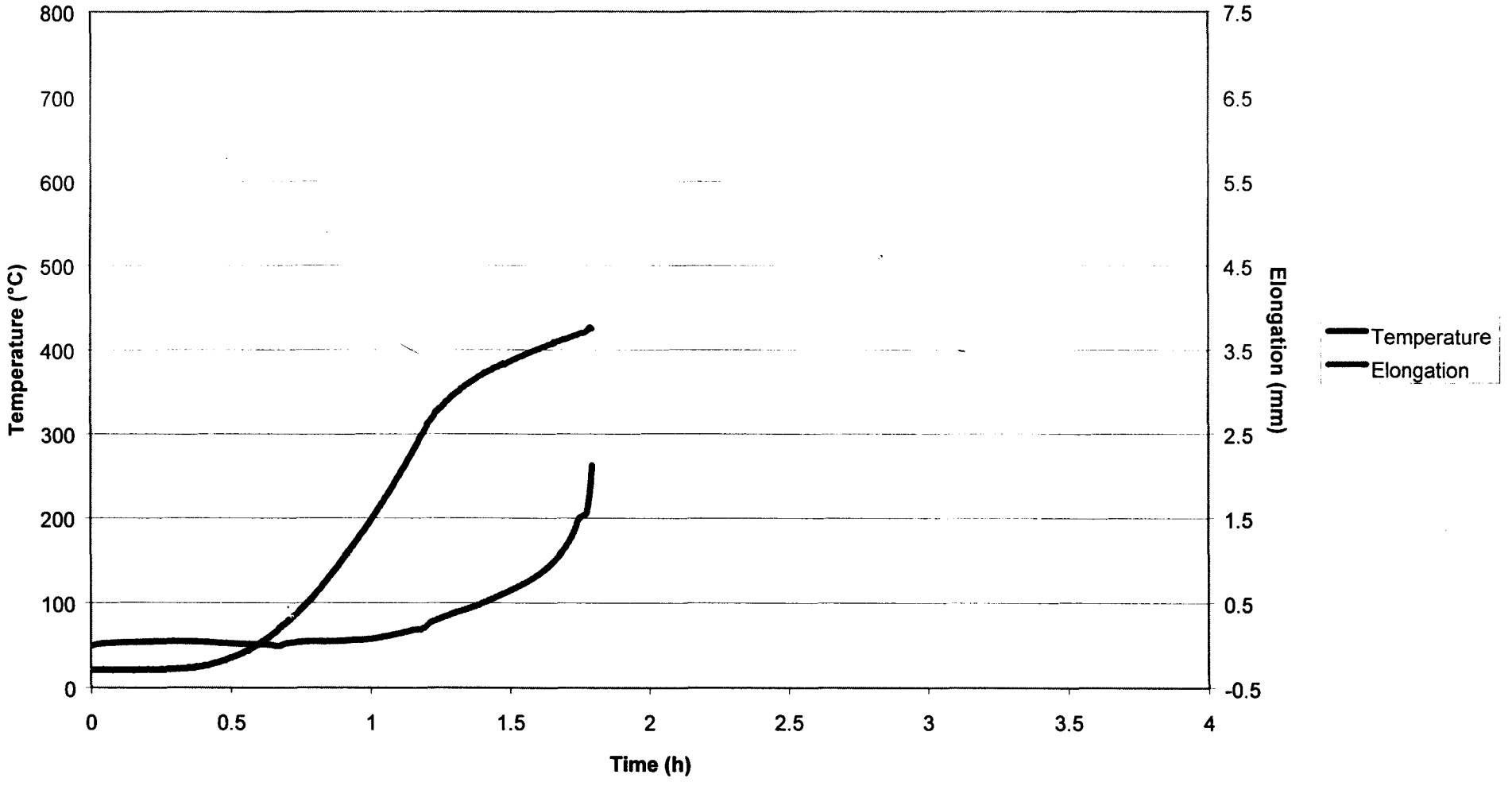
Appendix 2 (Continued)
2¼Cr-1Mo New: 153 MPa



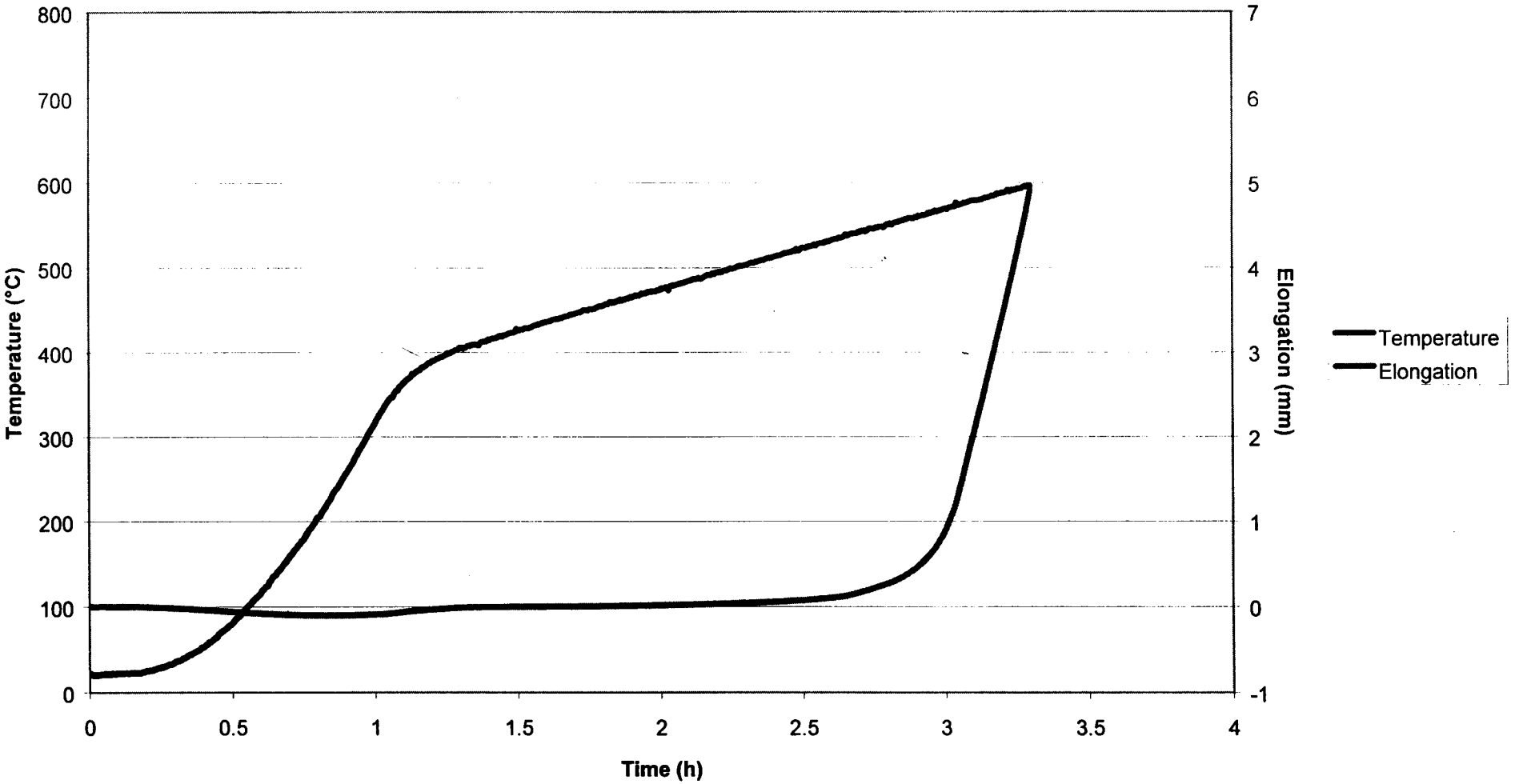
Appendix 2 (Continued)
2¼Cr-1Mo Service Exposed: 356 MPa



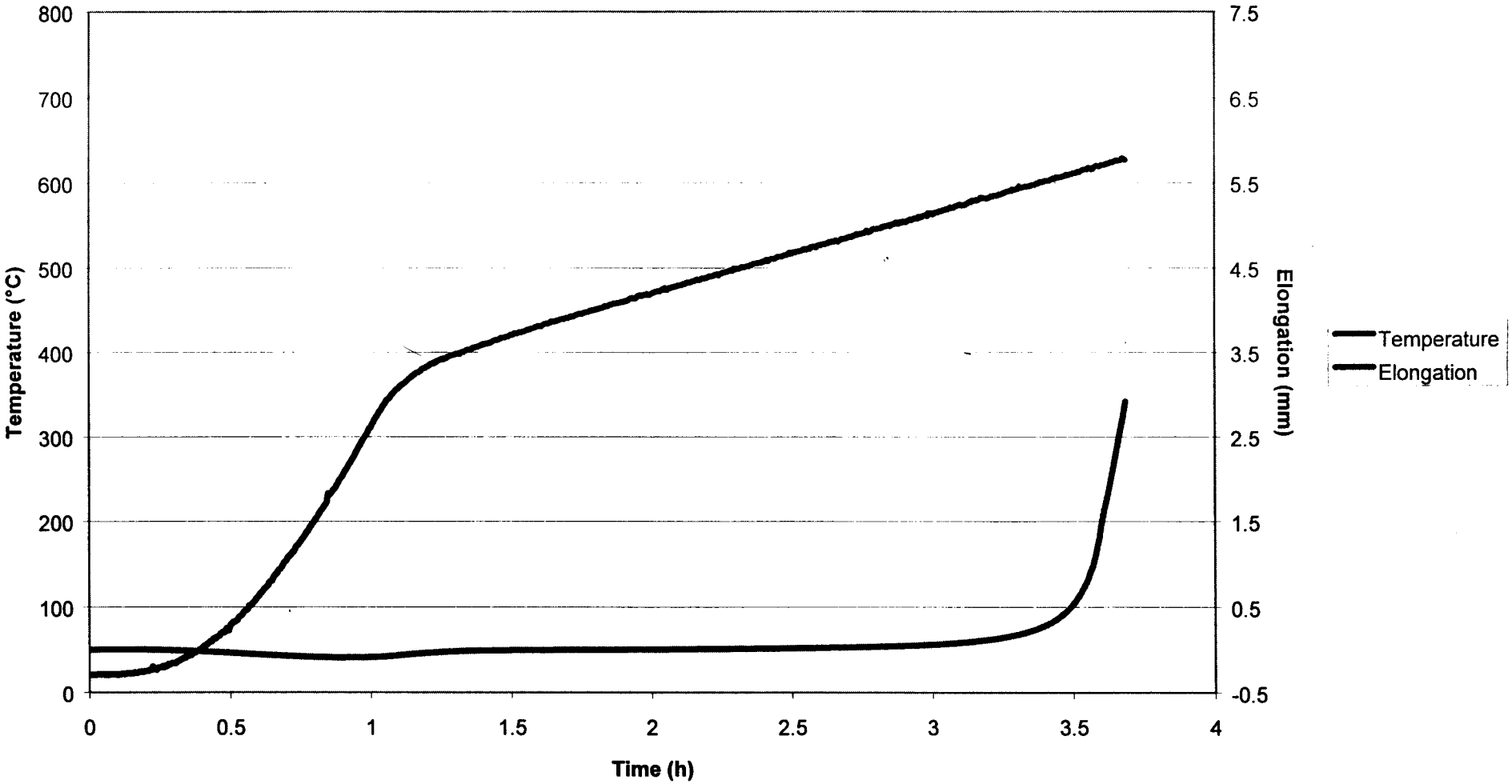
Appendix 2 (Continued)
2¼Cr-1Mo Service Exposed: 305 MPa



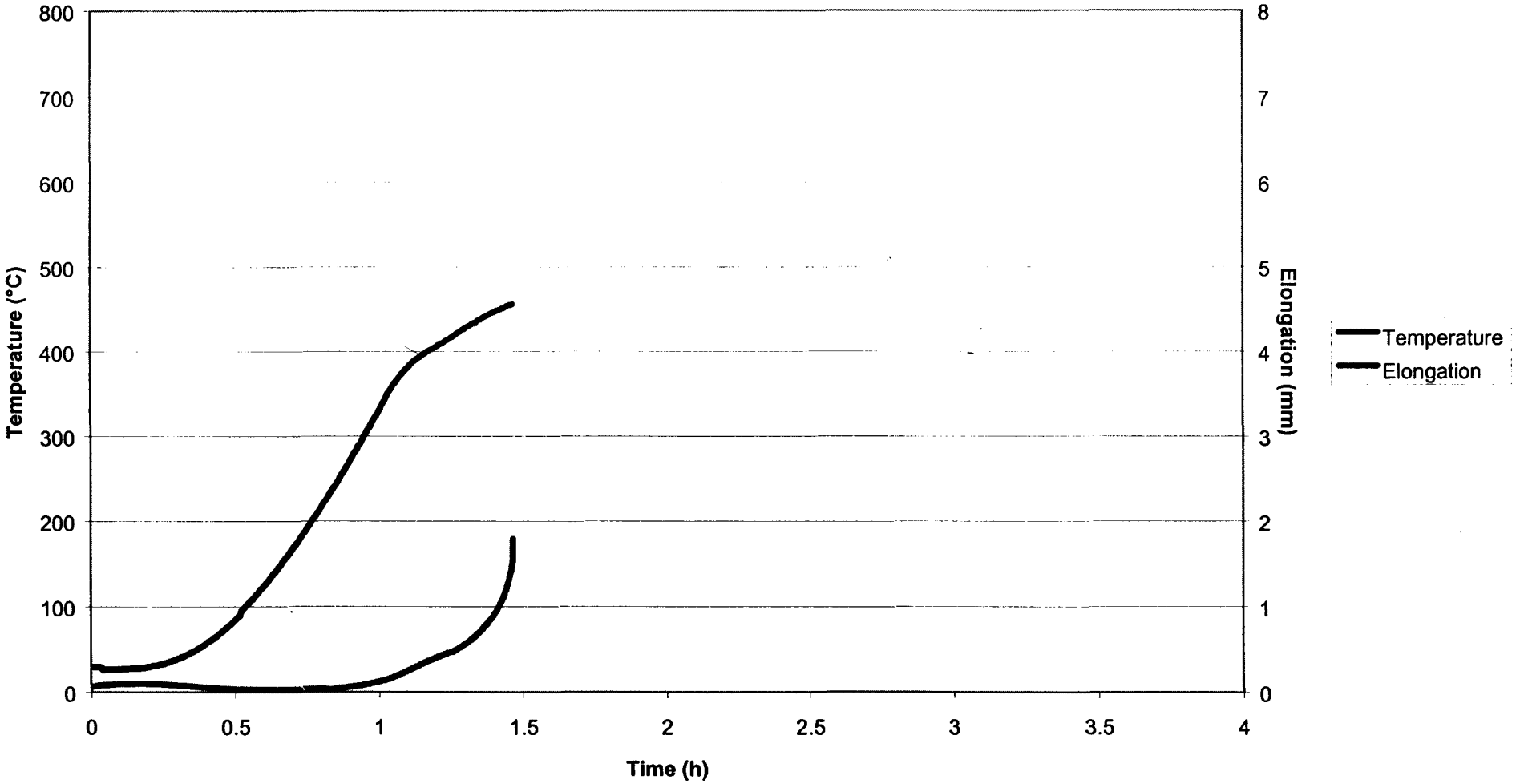
Appendix 2 (Continued)
2¼Cr-1Mo Service Exposed: 204 MPa



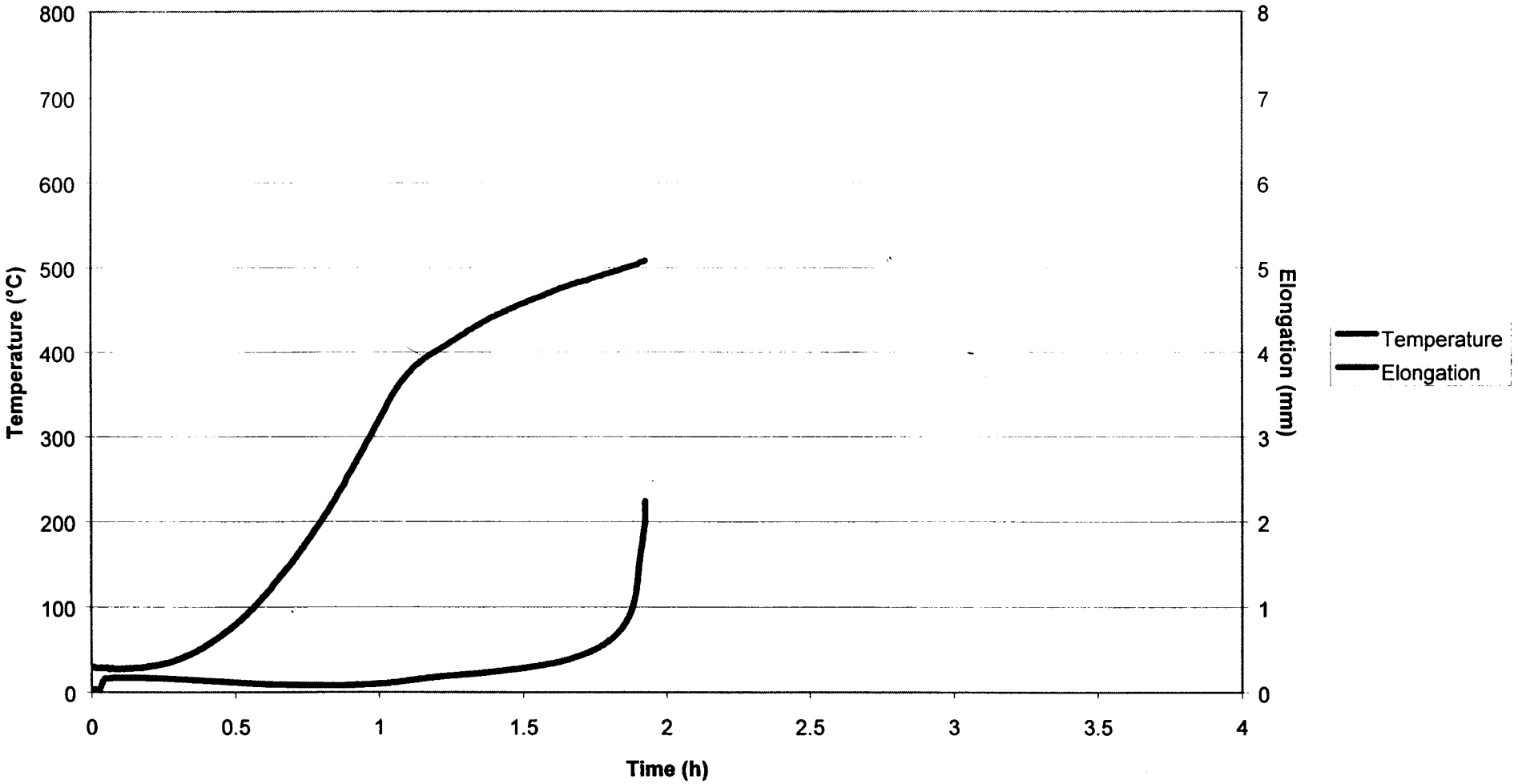
Appendix 2 (Continued)
2¼Cr-1Mo Service Exposed: 153 MPa



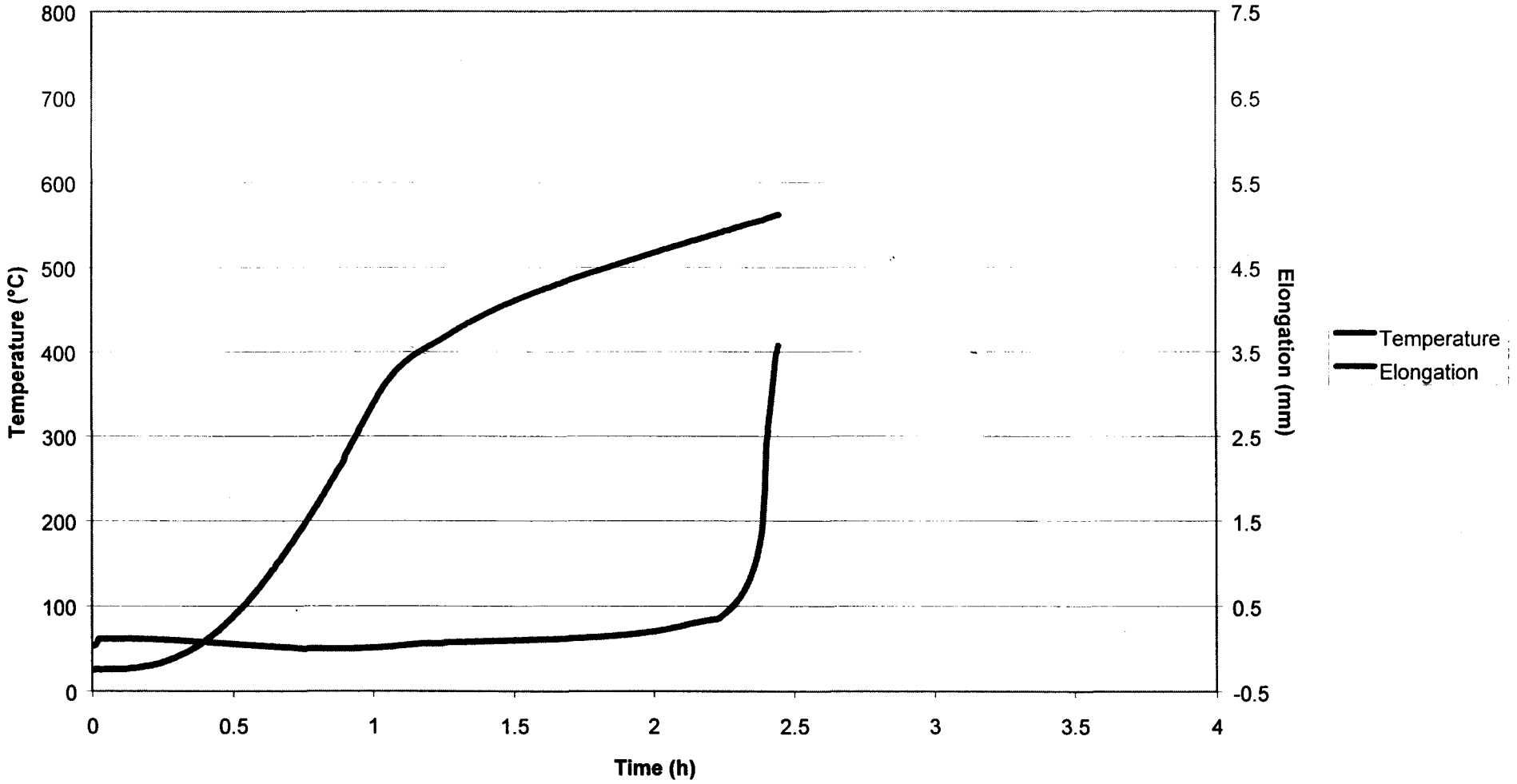
Appendix 2 (Continued)
X20 New: 407 MPa



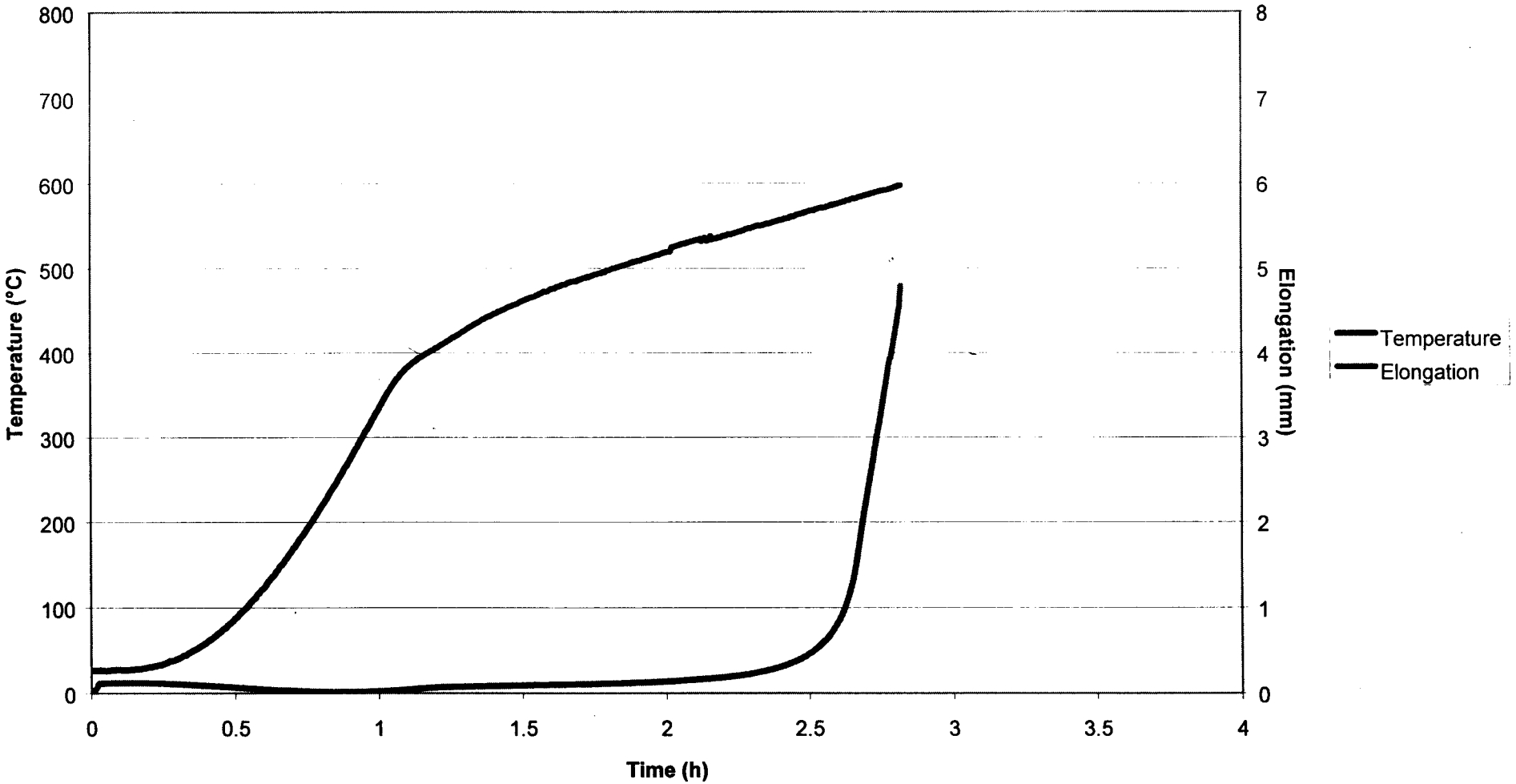
Appendix 2 (Continued)
X20 New: 356 MPa



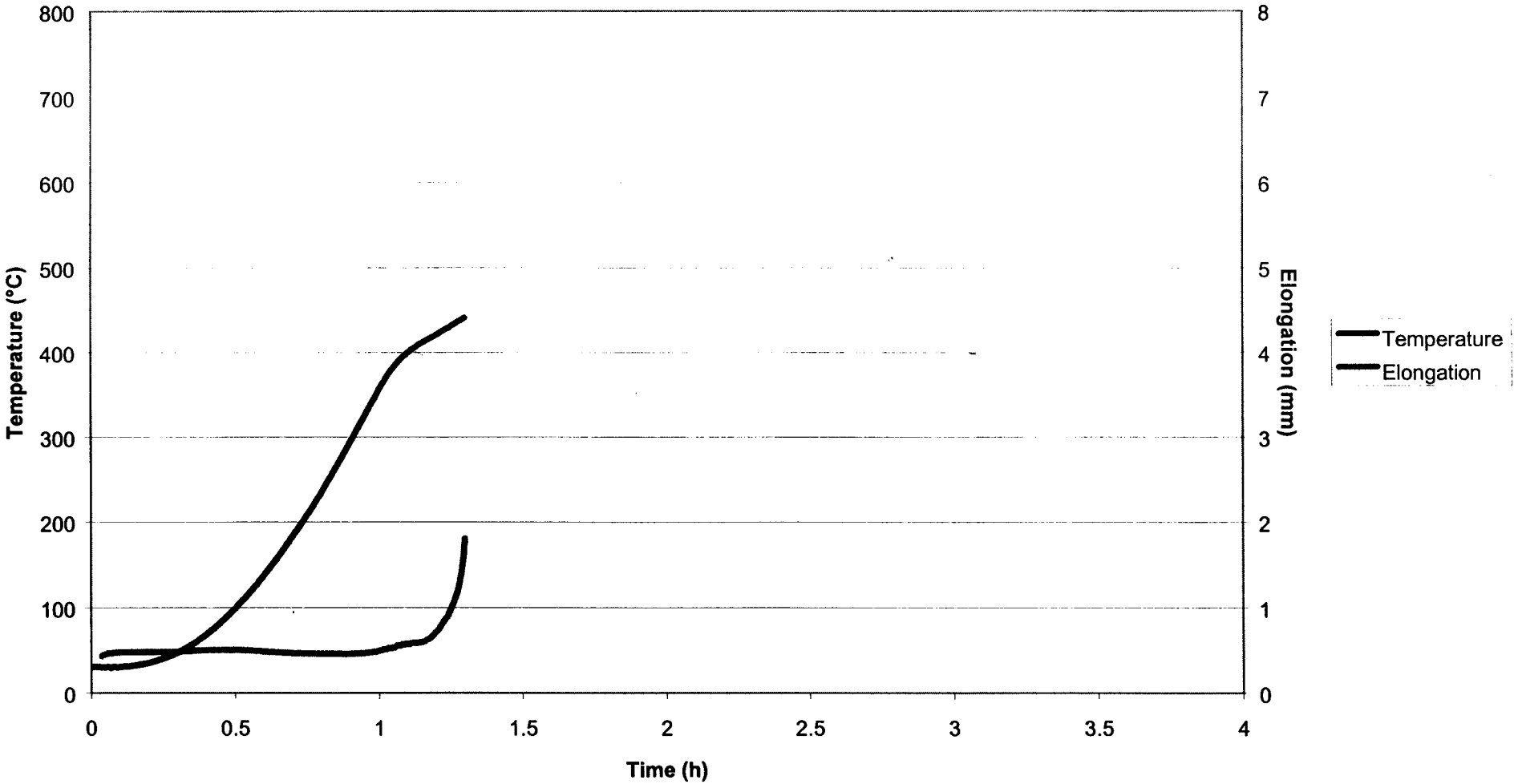
Appendix 2 (Continued)
X20 New: 305 MPa



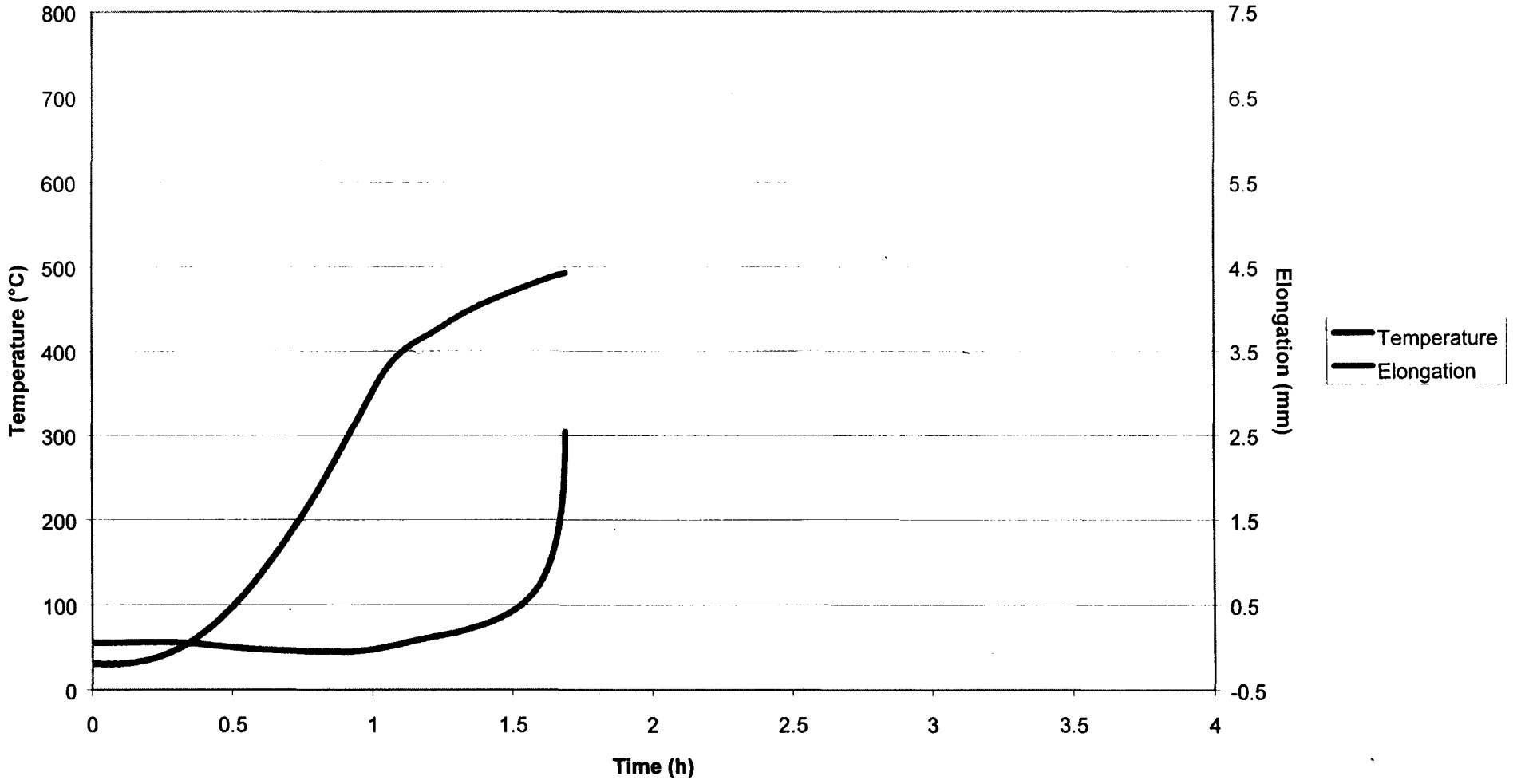
Appendix 2 (Continued)
X20 New: 254 MPa



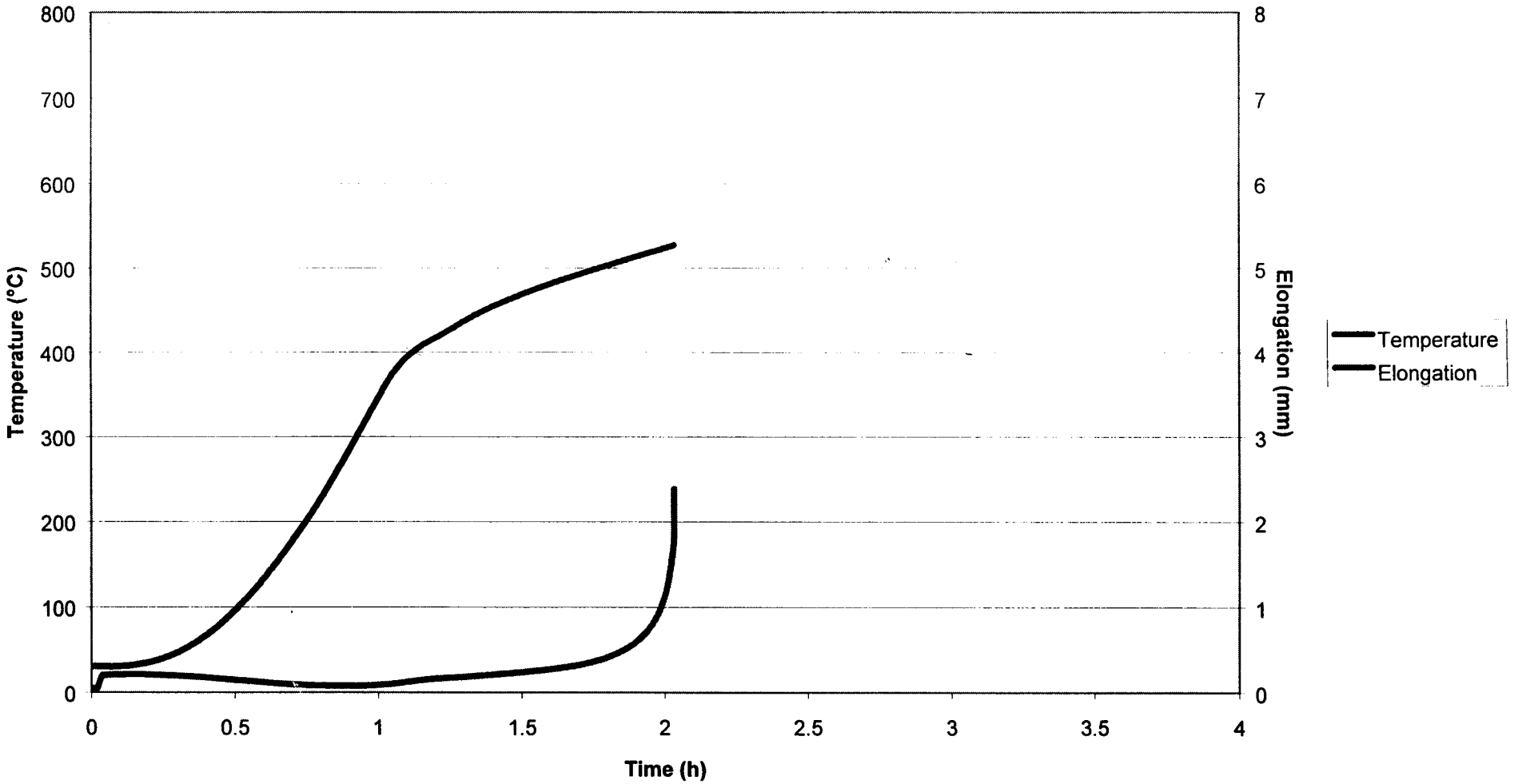
Appendix 2 (Continued)
X20 Service Exposed: 407 MPa



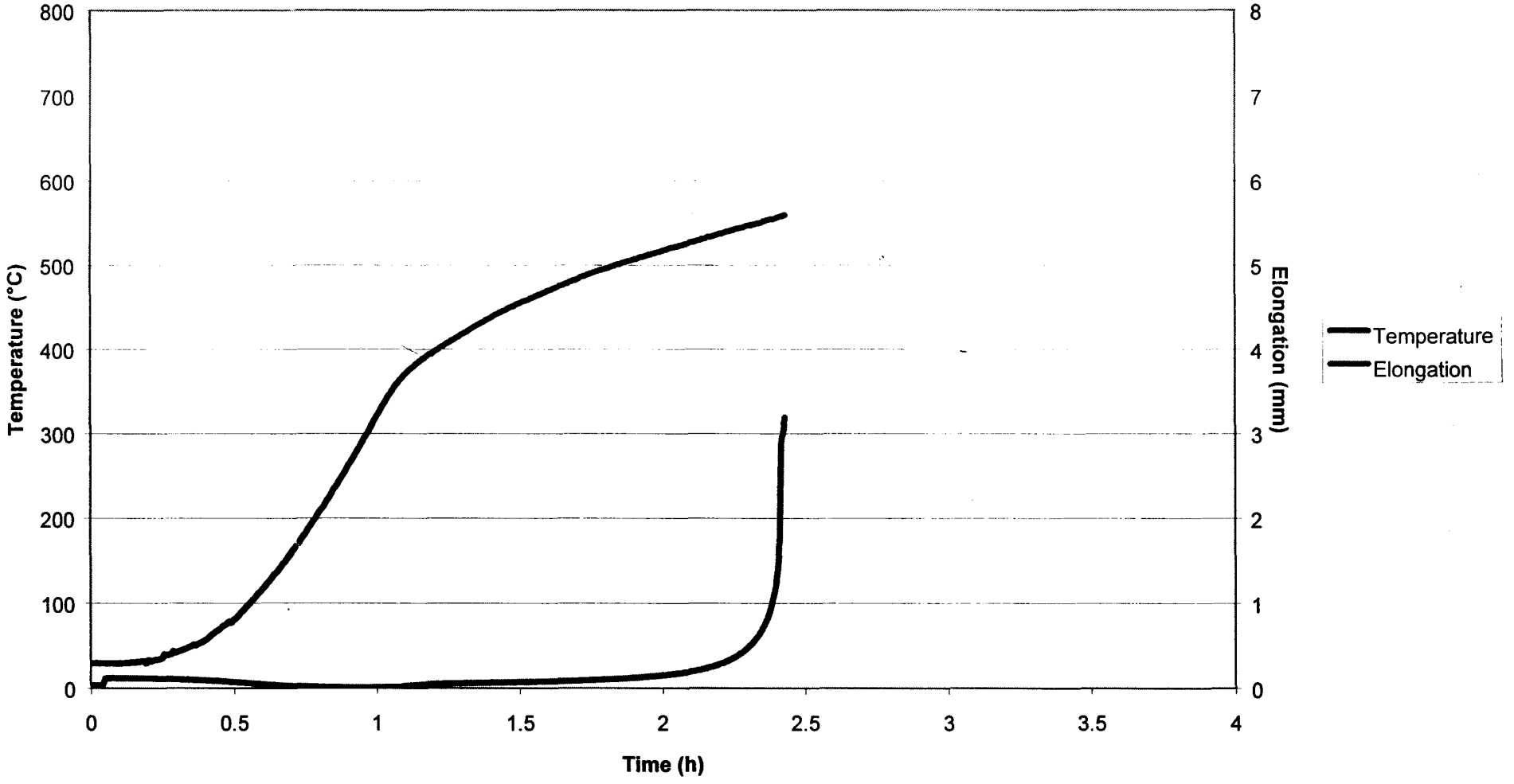
Appendix 2 (Continued)
X20 Service Exposed: 356 MPa



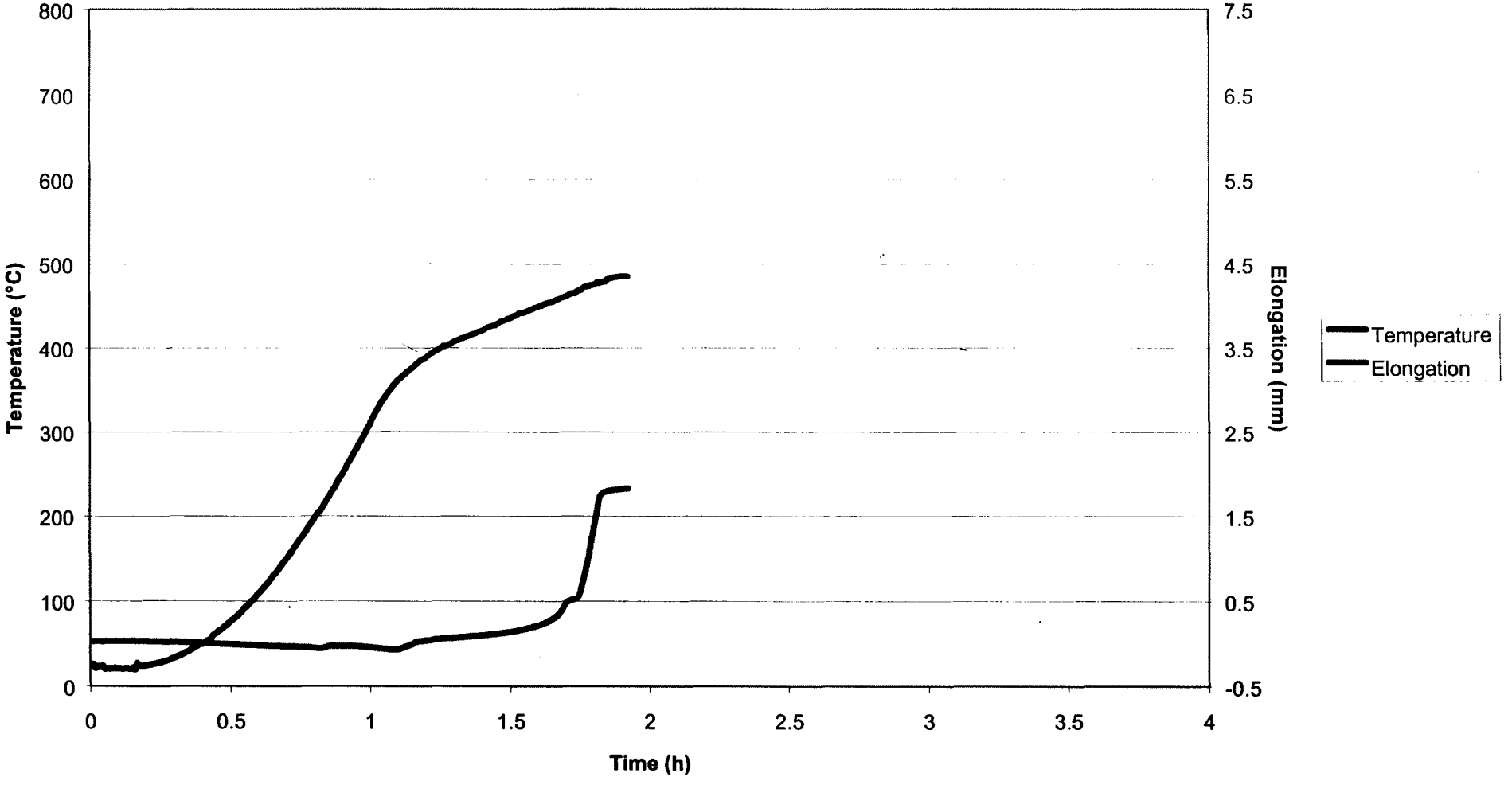
Appendix 2 (Continued)
X20 Service Exposed: 305 MPa



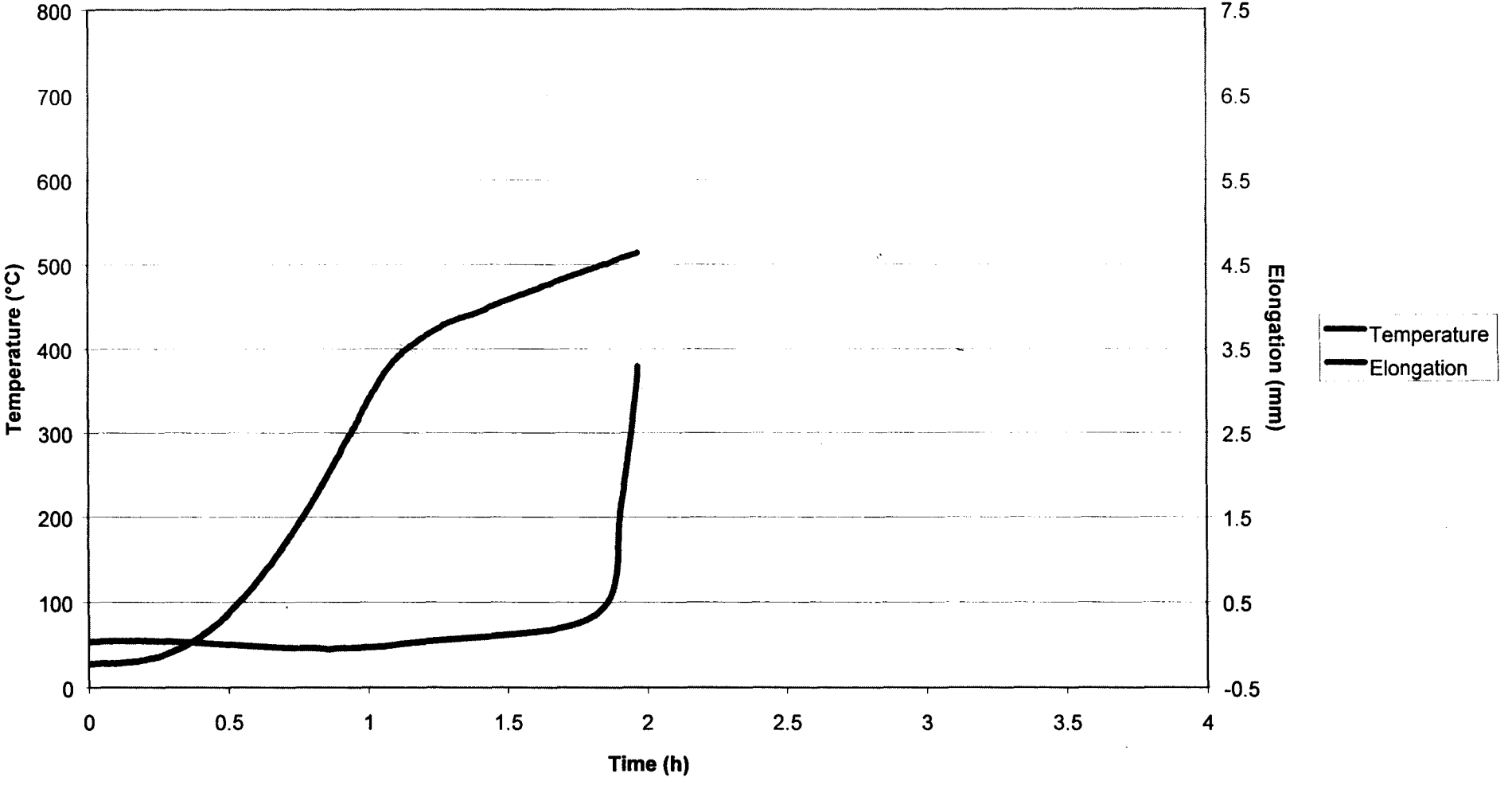
Appendix 2 (Continued)
X20 Service Exposed: 254 MPa



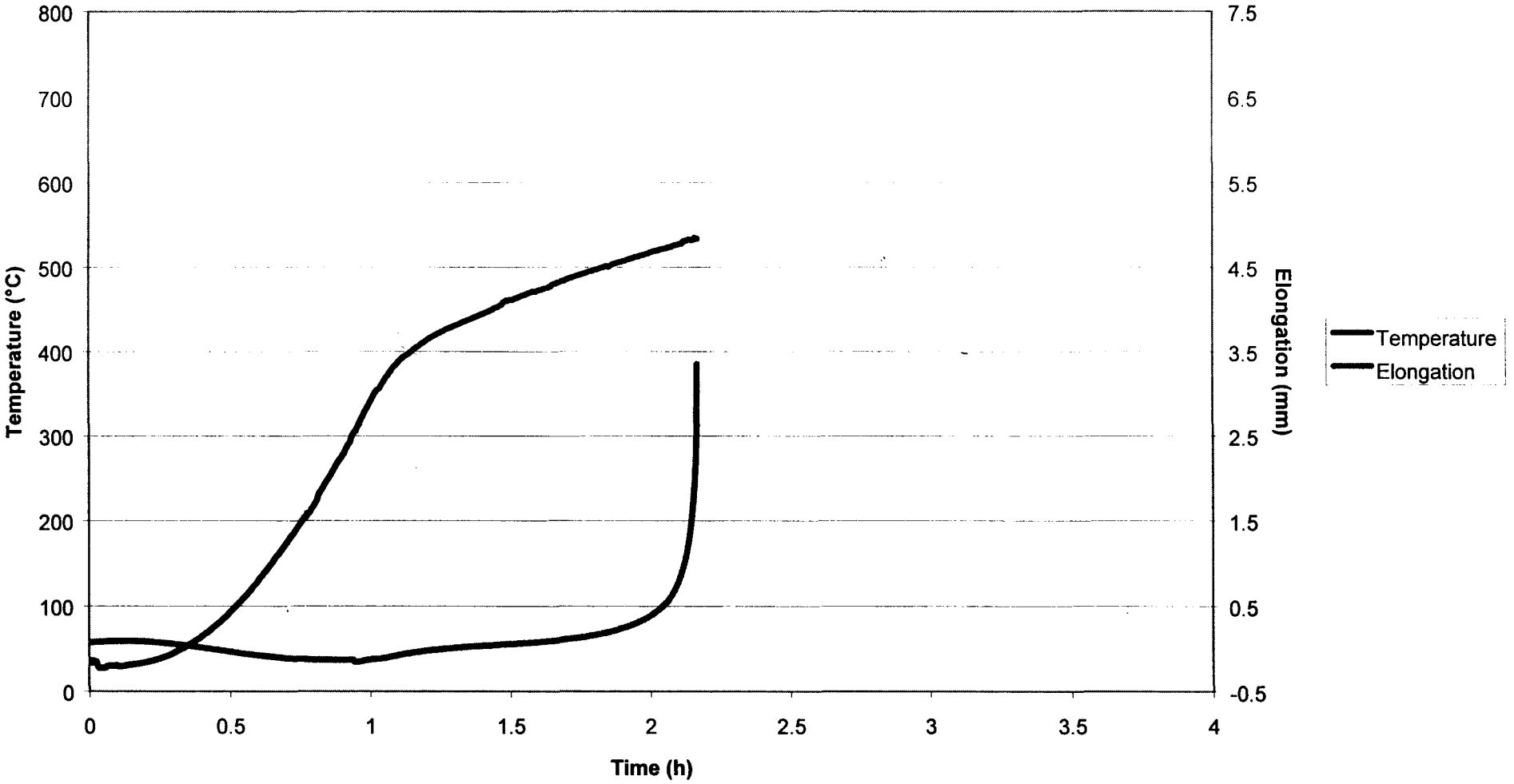
Appendix 2 (Continued)
P91 New: 407 MPa



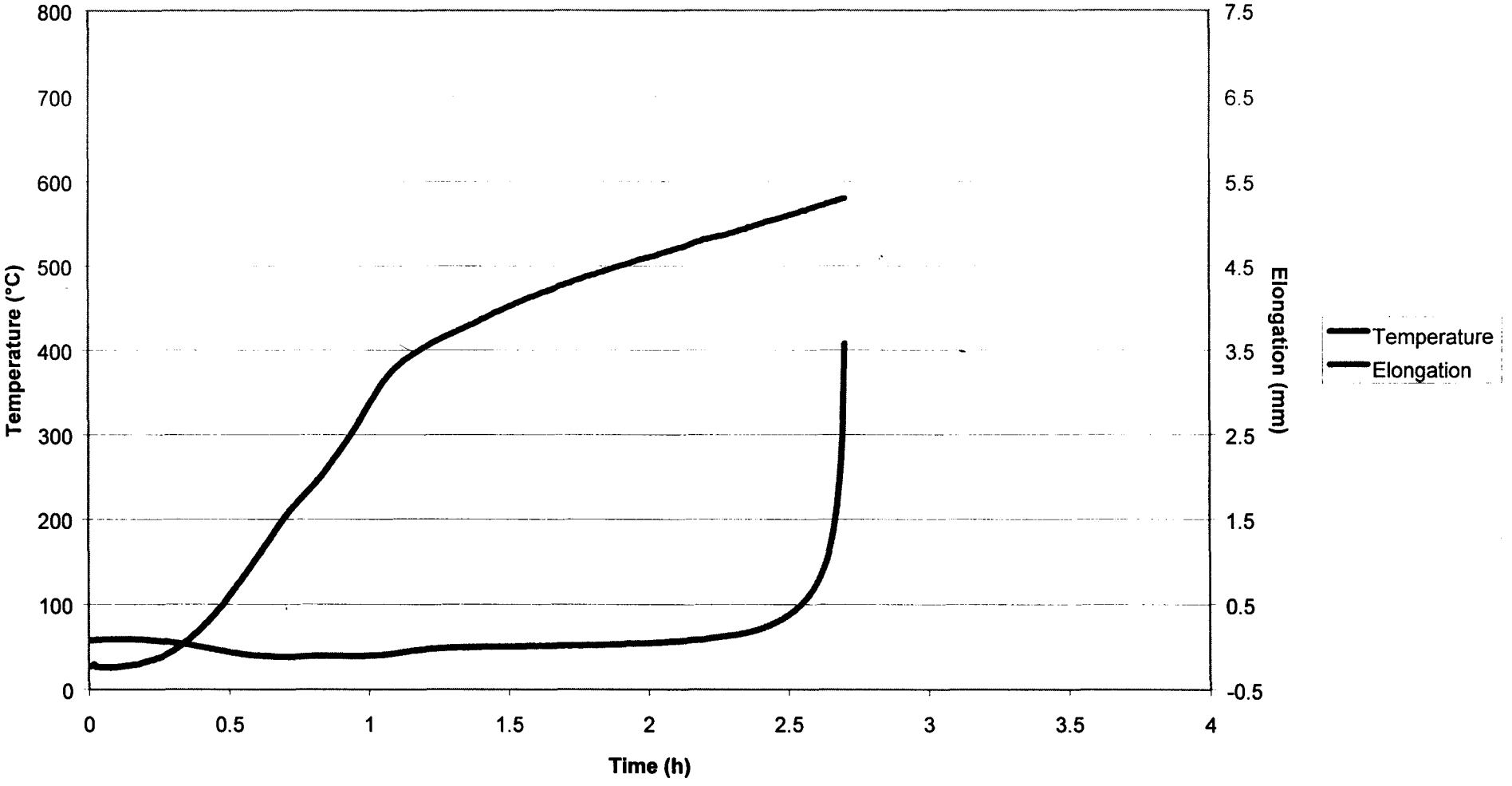
Appendix 2 (Continued)
P91 New: 356 MPa



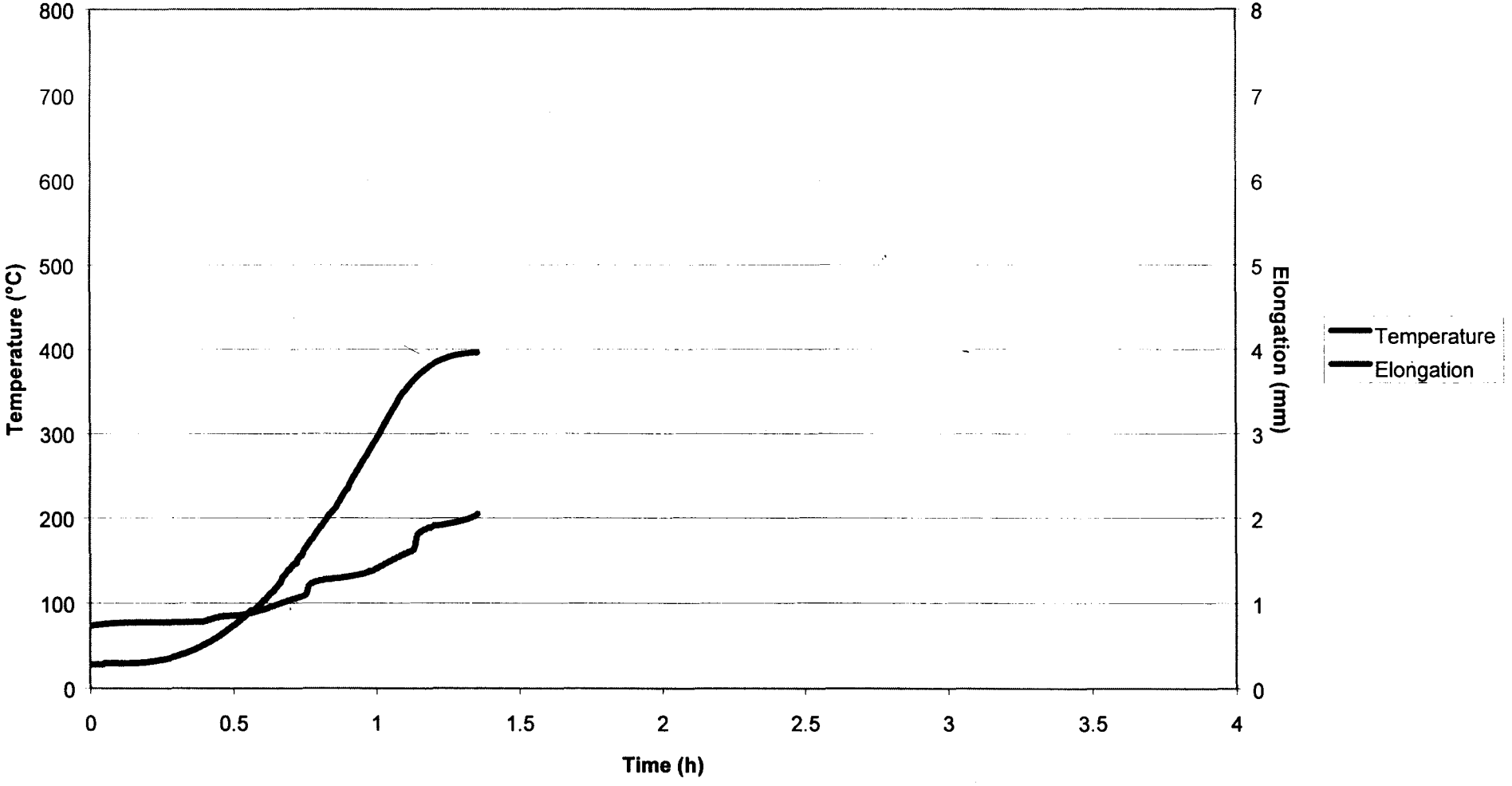
Appendix 2 (Continued)
P91 New: 305 MPa



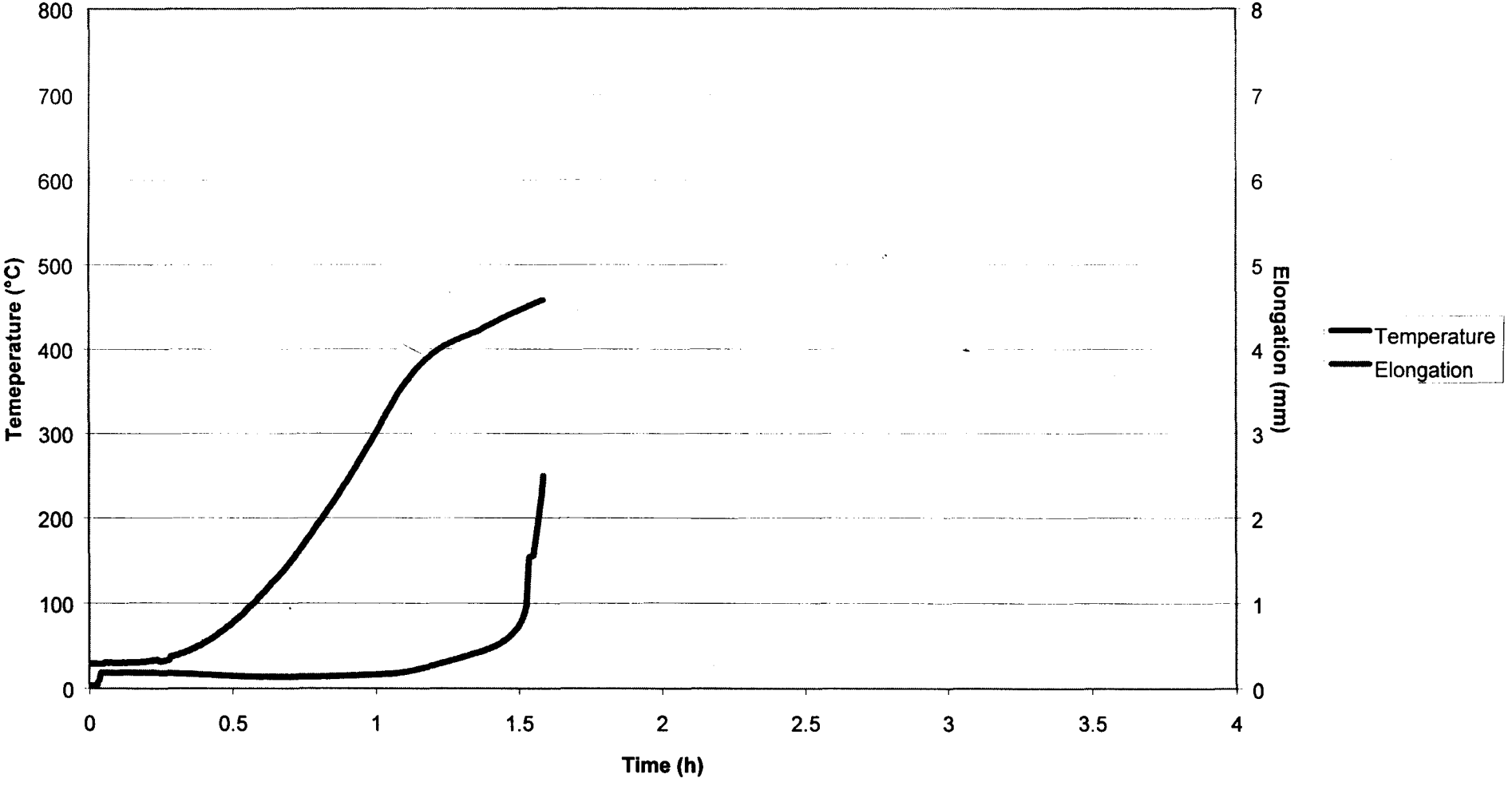
Appendix 2 (Continued)
P91 New: 254 MPa



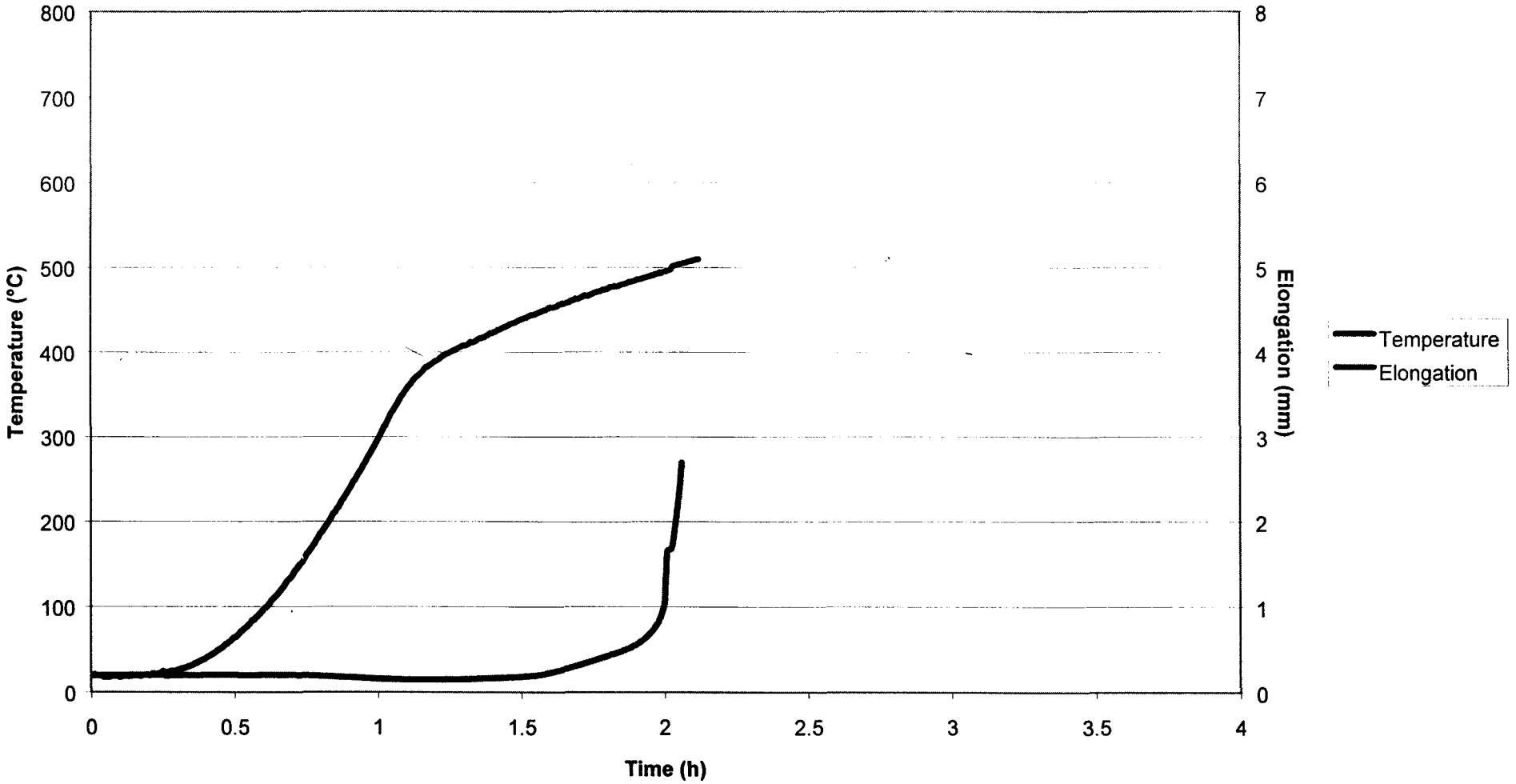
Appendix 2 (Continued)
P91 Artificially Aged: 407 MPa



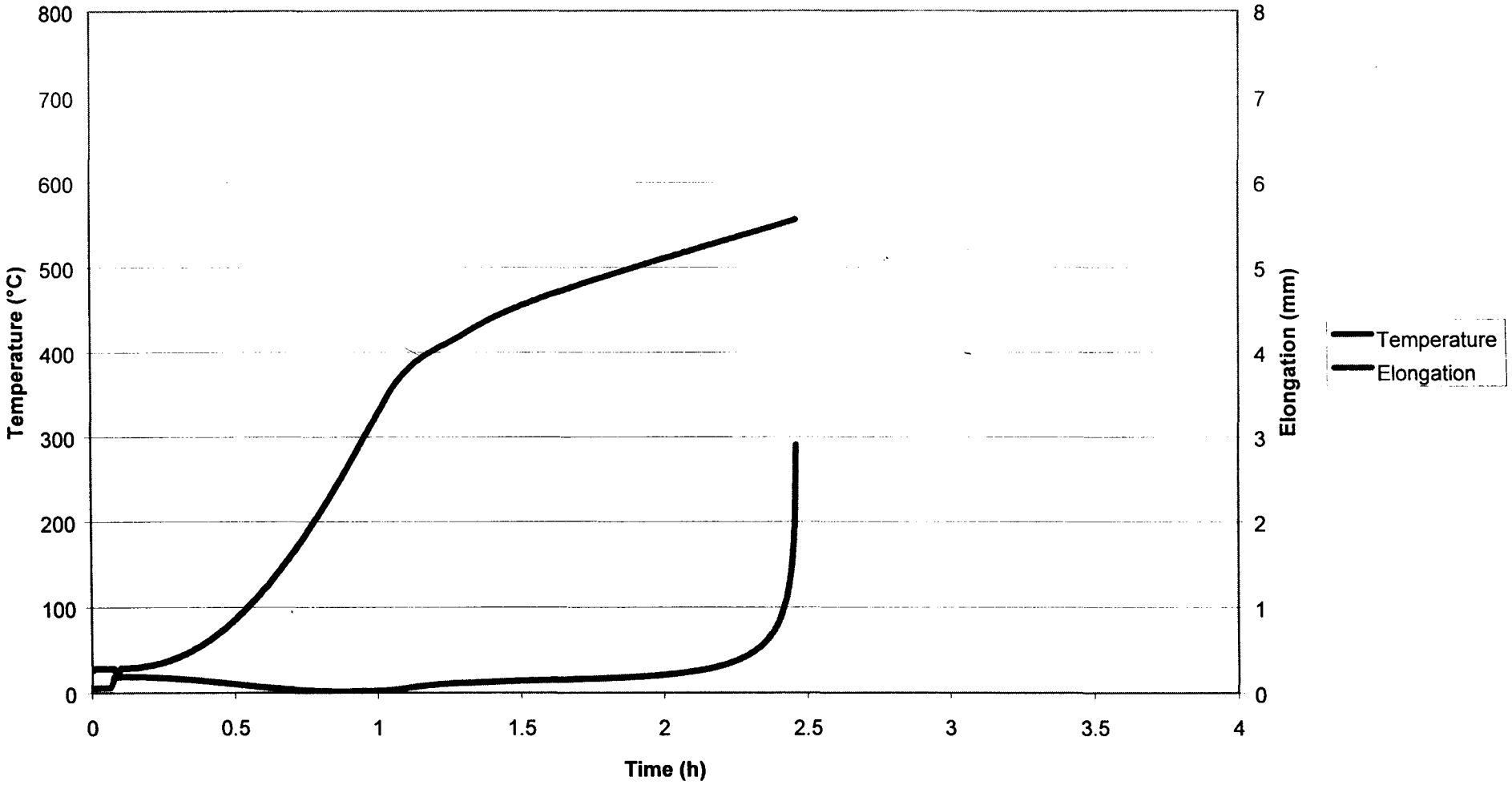
Appendix 2 (Continued)
P91 Artificially Aged: 356 MPa



Appendix 2 (Continued)
P91 Artificially Aged: 305 MPa



Appendix 2 (Continued)
P91 Artificially Aged: 254 MPa



the high amount of chromium that is present in the structure as chromium carbides as well as molybdenum carbides.

From the SEM photographs it is evident that both the new and service-exposed material failed due to a ductile fracture mechanism. Due to the notch a stress concentration is present and the yield strength of the base metal is lower than the HAZ during the PWHT. The base metal will be the primary region where creep deformation occurs under the influence of a tensile stress up to the point of failure.

The structure of the base metal in the service-exposed condition is such that it will be softer than the base metal of the new material. This leads to the failure in the base metal areas because the yield strength for the base metal is lower than that of the CGHAZ. CGHAZ simulation resulted in similar structures of partly tempered martensite. This is due to the very high hardenability of X20. A fully martensitic structure can thus be obtained in these materials with slower cooling rates in comparison with that of to the two ferritic grades (½Cr-½Mo-¼V and 2¼Cr-1Mo). During cooling of materials with a high hardenability the martensite that formed first is still at a relatively high temperature and longer periods of time and undergoes auto-tempering as the work piece cools down to room temperature. The structure of the sample that underwent PWHT (spiral notch test) showed a tempered structure due to the thermal cycle as expected.

The hardness profiles showed the service-exposed material base metal had a lower hardness than the new material. The hardness of the HAZ's showed some difference. After PWHT the hardness of the HAZ is significantly reduced as toughness and ductility are restored due to the tempering of the hardened structure. The hardness (yield strength) is still higher than that of the base metal, which points to the fact that the base metal is the area where creep deformation was concentrated during PWHT.

X20 material creep strength is obtained due to the high content of chromium as alloying element with molybdenum in small quantities. The hardenability of the steel is very high. PWHT restores toughness and ductility and does not seem to increase the strength, as is the case with ½Cr-½Mo-¼V. Due to the high hardenability, a X20 component during welding operations is held at a certain temperature before PWHT. This could prevent full transformation of the HAZ to martensite and retained austenite could be present before PWHT. The temperature before PWHT must be such that it prevents cracking due to the high hardenability and also to allow almost full transformation. The yield strength of the base metal for new and service-exposed material will always be lower than the HAZ making it the primary region for creep deformation during PWHT to allow stress relief to occur.

6.9 REFERENCES

1. Stahlschlüssel – Key to Steel, 1998