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OXIDE DISPERSION-STRENGTHENED FERRITIC ALLOYS

DT02 data sheet

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October 1976

BLG 517

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OXIDE DISPERSION-STRENGTHENED FERRITIC ALLOYS
DTO2 data sheet

Summary. - This publication gives the available data on the DTO2 dispersion-strengthened ferritic alloy developed at C.E.N./S.C.K. Mol, Belgium. DTO2 is a Fe-Cr-Mo ferritic alloy, strengthened by addition of titanium oxide and of titanium leading to the formation of Chi phase. It was developed for use as canning material for fast breeder reactors.

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OXIDE DISPERSION-STRENGTHENED FERRITIC ALLOYS
DTO2 data sheet

Résumé. - DTO2 est un alliage ferritique renforcé par dispersion qui a été développé au C.E.N./S.C.K. Mol, Belgique et dont les données disponibles sont présentées dans ce rapport. Cet alliage ferritique Fe-Cr-Mo est non seulement renforcé par dispersion d'oxide de titane mais aussi par des additions de titane qui mènent à la formation de phase-Chi. Le domaine d'application est celui des gainages pour réacteurs rapides.

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OXIDE DISPERSION-STRENGTHENED FERRITIC ALLOYS
DTO2 data sheet

Samenvatting. - In dit dokument werden alle op dit ogenblik beschikbare gegevens samengebracht over de dispersie-verstevigde ferrietische legering DTO2. Deze ferrietische Fe-Cr-Mo-Ti legering wordt verstevigd door de aanwezigheid van een titaanoxide dispersie en een neerslag van Chi-phase. Deze legering werd op het S.C.K./C.E.N. Mol, België ontwikkeld als huls-materiaal voor snelle kweekreaktoren.

OXIDE DISPERSION-STRENGTHENED FERRITIC ALLOYS

DT02 data sheet

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Introduction

This publication gives the available data on the DT02 dispersion-strengthened ferritic alloys developed at C.E.N.-S.C.K. Mol, Belgium. It is intended to revise this text when new data will become available. Further information may be obtained from C.E.N.-S.C.K.
DT02 is a Fe-Cr-Mo ferritic alloy, strengthened by addition of titanium and of titanium oxide leading to the formation of Chi-phase. It was developed for use as canning material for fast breeder reactors. DT02 is produced by a powder metallurgy fabrication method. This method essentially entails intimately blending the elementary metallic and ceramic powders. The mixture is cold- and then hot-compacted. Finally, a hollow is hot-extruded and heat-treated to obtain the interdiffusion of the metallic powders. The final tube is obtained by cold drawing with intermediate annealings, as would be done for usual tube quality.

Available forms

DT02 is generally available in the form of bar, sheet and tube. Other forms may be supplied at special request.

Composition

A typical chemical composition is presented in Table 1.

Heat treatment

The heat treatments of reference materials are given in Table 2. To avoid the coalescence of the oxide dispersions, dispersion-strengthened alloys must be welded without bulk fusion. DT02 capsules have been successfully welded by using a slightly modified commercial resistance welding machine.

Physical properties

- Density at room temperature : 7.49.
  The exact density of DT02 is dependent on compositional variation, on shape and on heat treatment : a range of 7.45 to 7.52 has been recorded.
- Thermal conductivity at 40°C : 0.224 W cm^{-1} s^{-1}
- Mean thermal expansion as indicated in Table 3.
- Elasticity modulus versus temperature is depicted in Fig. 1.

Tensile properties

In Table 4,5,6 and Fig. 2,3,4 are given as a function of temperature :
$\sigma_{0.2}$: 0.2 % proof stress

UTS : ultimate tensile strength, i.e. maximum load divided by the original section

ε_{unif} : elongation at maximum load

ε_{tot} : total elongation

Dimensions of the specimens

Shape	Section	Gauge length
bar	3.2 mm Ø	21 mm
sheet	0.5 x 4.0 mm^2	21 mm
tube	6.0 mm outer Ø 5.2 mm inner Ø	41 mm

The tube specimens were resistance-welded to solid plugs in similar material.

Creep properties

In Tables 7,8 and Fig. 5,6 the creep properties are given as deduced from

- uniaxial creep test on specimens machined from swaged bars;
- the uniaxial creep test on tube specimens ;
- the biaxial tests on tube specimens closed under internal argon pressure ;
- uniaxial creep tests in flowing sodium.

The uniaxial creep tests are done in a vacuum of 10^{-4} torr, the biaxial tests are done in pure argon at 1 atm pressure. From the results, it can be concluded that the total elongation at rupture for DT02 ranges between 9 % for the lower stresses and 40 % for the highest stresses. From the limited amount of data, no temperature influence can be deduced.

Sodium corrosion

Exposure to dynamic sodium (oxygen content lower than 5 ppm and 4.5 m s^{-1} flow rate) under carburizing conditions causes a structural change of the alloy (χ-phase depletion). The extent of this effect at 700°C for different exposure times up to 15.000 h is being studied.
Creep tests at 700°C lasting up to 3.000 h did not reveal any significant effect of dynamic sodium exposure on the creep properties.

Compatibility with oxide fuel

Maximum reaction depths obtained when the DT02 alloy is exposed to hyper-stoichiometric oxide fuel ($UO_{2.08}$) with fission products added to simulate 10 and 20 % burn-up conditions are given in Table 9.

Exposure to $(U,Pu)O_{1.96}$ fuel (30 mol. % PuO_2) with 10% simulated burn-up gives rise to much smaller maximum reaction depths as can be seen in Table 10.

Interactions with neutrons

- Neutronic calculations, based on the preliminary design for SNR 2, indicated that the use of ferritic steels as compared to the reference WN 1.4970 austenitic steel and for the same structural material volume fraction results in a 2 % lower fissile mass, an increase by 0.03 of the breeding ratio and a 18 % lower doubling time as indicated in Table 11.
- Post-irradiation tensile tests on DT02 sheets irradiated in BR2 at $0.8 \times 10^{22} n/cm^2$ (> 0.1 MeV) between 500 to 700°C indicate the low susceptibility of DT02 to neutron induced embrittlement (Fig. 8).
  - Neutron induced swelling

  a. Swelling of the metallic matrix

  At this moment only CT02, an alloy with slightly more Mo and Ti than DT02 has been irradiated in a fast reactor. After a dose of $5.2 \times 10^{22} n/cm^2$ (27 dpa) at 580°C in the Rapsodie reactor, this alloy showed no voids in the matrix or in the precipitates.

  b. Swelling of the oxide dispersion.

  The TiO_2 oxide dispersion particles in CT02 however showed, after the above-mentioned irradiation in Rapsodie a swelling of approximately 5 % leading to an overall swelling of 0.2 % for the DT02 alloy.
  Swelling of titanium oxide was also noticed after irradiation in the BR2 reactor to a dose of 0.8×10^{22} n/cm^2 (E > 0.1 MeV) at 700°C.
- Irradiation programme

  The present state of the irradiation programme is given in Table 12.

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Table 1

DT02 typical chemical composition (wt.%)

Ag	0.0010
Al	0.0010
B	0.0001
C	0.0206
Ca	0.0050
Cr	12.5
Cu	0.0050
Fe	balance
Mg	0.0075
Mn	0.0010
Mo	1.54
N	0.027
Na	0.0300
Ni	0.0020
O	1.36
Pb	0.0030
Sn	0.0150
Si	0.0030
Ti	4.73

Table 2

Heat treatment of DT02

Form	Forming method	Heat treatment
Bar	Hot swaging	1 d/800°C
	Cold swaging	15 min/1050°C + 1 d/800°C
Sheet	Cold rolled	15 min/1050°C + 1 d/800°C
Tube	Cold drawn	15 min/1050°C + straightening + 1 d/800°C

Table 3

Average thermal expansion of DT02

Temperature (°C)	$\alpha (10^{-6}/°C)$
200	10.8
400	11.4
600	11.9
800	12.3

Table 4

DT02 Tensile properties DT02 bar material

Temp. (°C)	$\sigma_{0.2}$ (N/mm^2)	UTS (N/mm^2)	ε_{unif} (%)	$\varepsilon_{tot.}$ (%)
20	380	630		15
200	365	600		8.5
400	355	555		9
500	400	470		15
600	270	300		30
700	120	130		45
800	60	65		42
900	30	35		32

Table 5

DT02 Tensile properties of DT02 sheet material

Temp. (°C)	$\sigma_{0.2}$ (N/mm^2)	UTS (N/mm^2)	ε_{unif} (%)	ε_{tot} (%)
20	380	605	9.6	10.0
	376	676	9.0	9.5
200	338	586	6.8	8.1
	348	605	6.2	8.1
400	360	546	6.0	7.1
	333	533	6.0	7.1
500	336	449	5.2	14.3
	319	450	5.3	10.0
600	257	301	2.1	21.9
	245	295	2.6	21.9
700	119	131	1.6	41.0
	131	140	0.8	36.6
800	54	61	2.0	60.4
	49	58	3.1	43.3

Table 6

DT02 Tensile properties of DT02 tube material

Temp. (°C)	$\sigma_{0.2}$ (N/mm^2)	UTS (N/mm^2)	ε_{unif} (%)	$\varepsilon_{tot.}$ (%)
20	506 446	838 721	7.3 6.9	10.2 11.0
200	388 377	657 641	6.3 6.8	6.6 9.0
400	386 390	605 598	5.1 4.8	9.9 9.7
500	372 350	510 498	4.7 5.8	15.4 15.6
600	293 244	336 312	1.8 3.4	31.7 30.5
700	122 125	149 139	2.2 1.1	52.6 49.0
800	62 60	68 66	2.9 3.0	54.8 49.5

Table 7

DT02 Creep-rupture properties of DT02 bar material

Test temp. (°C)	Stress (N/mm^2) for rupture in			
	300 h	1000 h	3000 h	10000 h
500	430	385	350	315
600	158	142	130	118
650	112	102	94	85
700	80	73	66	60

Table 8

Total plastic strain data of DT02 bar material

Test temp. (°C)	Stress (N/mm^2) for 2 % elongation in	
	1000 h	10000 h
600	110	85
650	75	60
700	60	45

Table 9

Maximum depth (µm) of the reaction layers (shown in Fig.7) after 1000 h compatibility tests on DT02 in contact with $UO_{2.08}$ and fission products to simulate 10 % or 20 % burn-up

	550°C		650°C		750°C	
	10% B.U.	20% B.U.	10% B.U.	20% B.U.	10% B.U.	20% B.U.
Continuous oxide layer	7	50	12	16	12	30
Intergranular oxidation	23	62	62	66	138	175
Te-rich intergranular phase			72	115	152	195
Chi-phase depletion					172	225

Table 10

Maximum reaction depths (µm) after compatibility tests on DT02 in contact with $(U,Pu)O_{1.96}$ and fission products to simulate 10 % burn-up

	550°C	650°C	750°C
1000 h	1	20	8
4000 h	3	20	8

Table 11

Comparison of SNR 2 core nuclear characteristics for ferritic alloys or PE-16 replacing the reference WN 1.4970 material for the same structural material volume fraction, as deduced from calculations using the KFK/INR or ENDF/B-4 data sets

	WN 1.4970 Reference	Ferritic alloys KFK/INR	Ferritic alloys ENDF/B-4	PE - 16 KFK/INR	PE - 16 ENDF/B-4
adjustment of fissile mass needed (%)	100	-2.0	- 2.7	+2.3	+ 2.3
change of breeding ratio	0.18	+0.034	+ 0.043	-0.039	- 0.039
change in doubling time (%)	100	-18	- -	+31	- -

Table 12

Present state of the irradiation programme of dispersion-strengthened ferritic alloys

	Type of samples		Reactor	Start of irradiation	Scheduled completion P.I.E. of post irradiation examinations	Irradiation temperature (°C)	Total fast neutron fluence $10^{23} n/cm^2$ (> 0.1 MeV)
1.	Disp. 04	tension	BR2	7.74	12.76	300 - 420	0.1
2.	Ripcex 1	tension, swelling	Rapsodie	4.74	12.76	400 - 510	1
3.	CFC 4D	1 UO_2 fuel capsule	BR2	7.74	12.76	700	0.05
4.	Rag party	tension, swelling	Rapsodie	6.74	6.77	500 - 700	0.3
5.	Monitor Rapsodie	swelling	Rapsodie	12.75	3.79	400 - 510	1
6.	Ripcex 2	swelling neutron induced creep	Rapsodie	4.77	6.80	400 - 510	1
7.	Carafe	3 UO_2 - PuO_2 fuel pins	Rapsodie	10.77	12.80	400 - 510	1
8.	M.1	swelling	P.F.R.	-	-	450 - 650	1

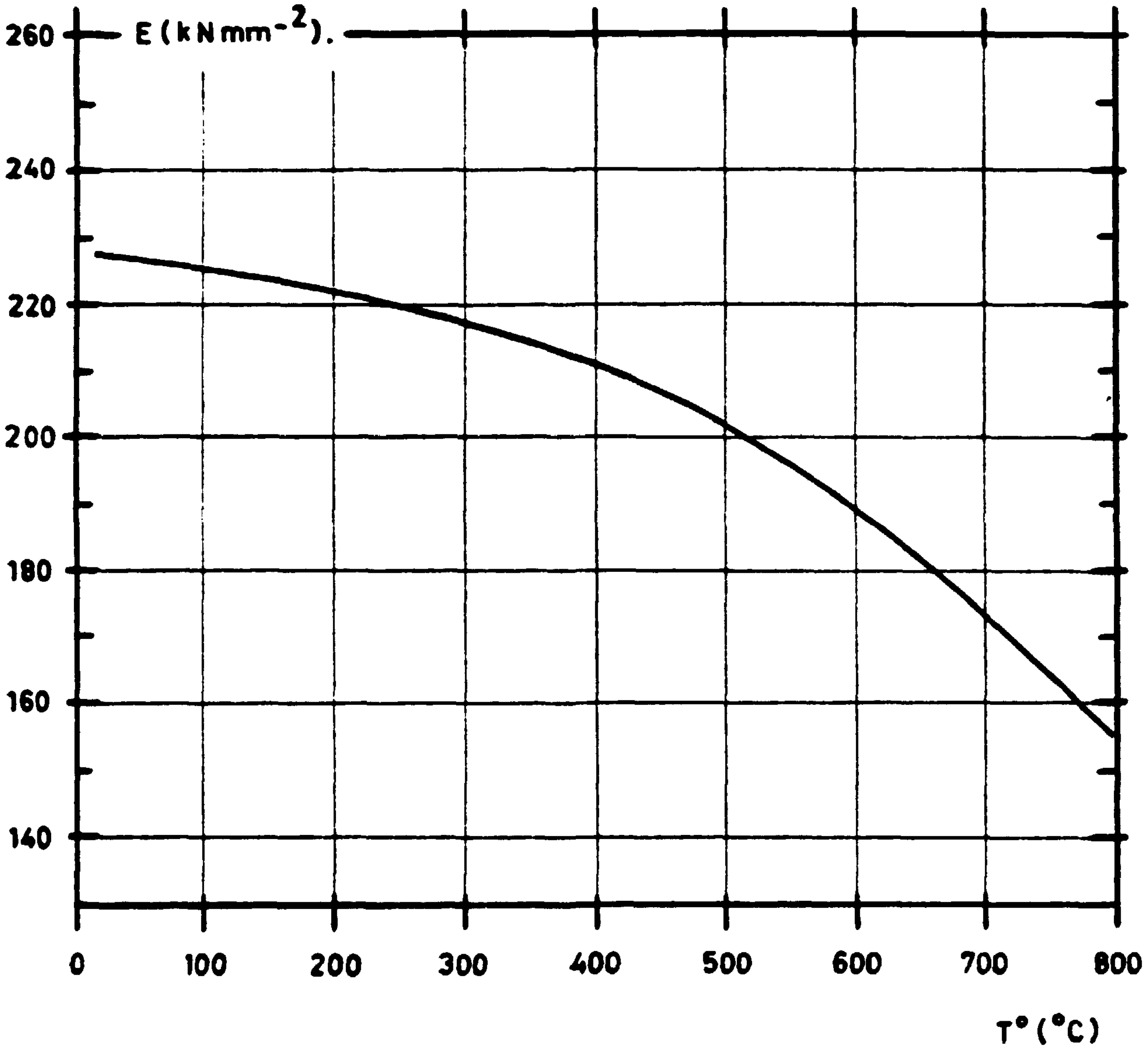


Fig.1 _ DTO 2 modulus of elasticity versus temperature.

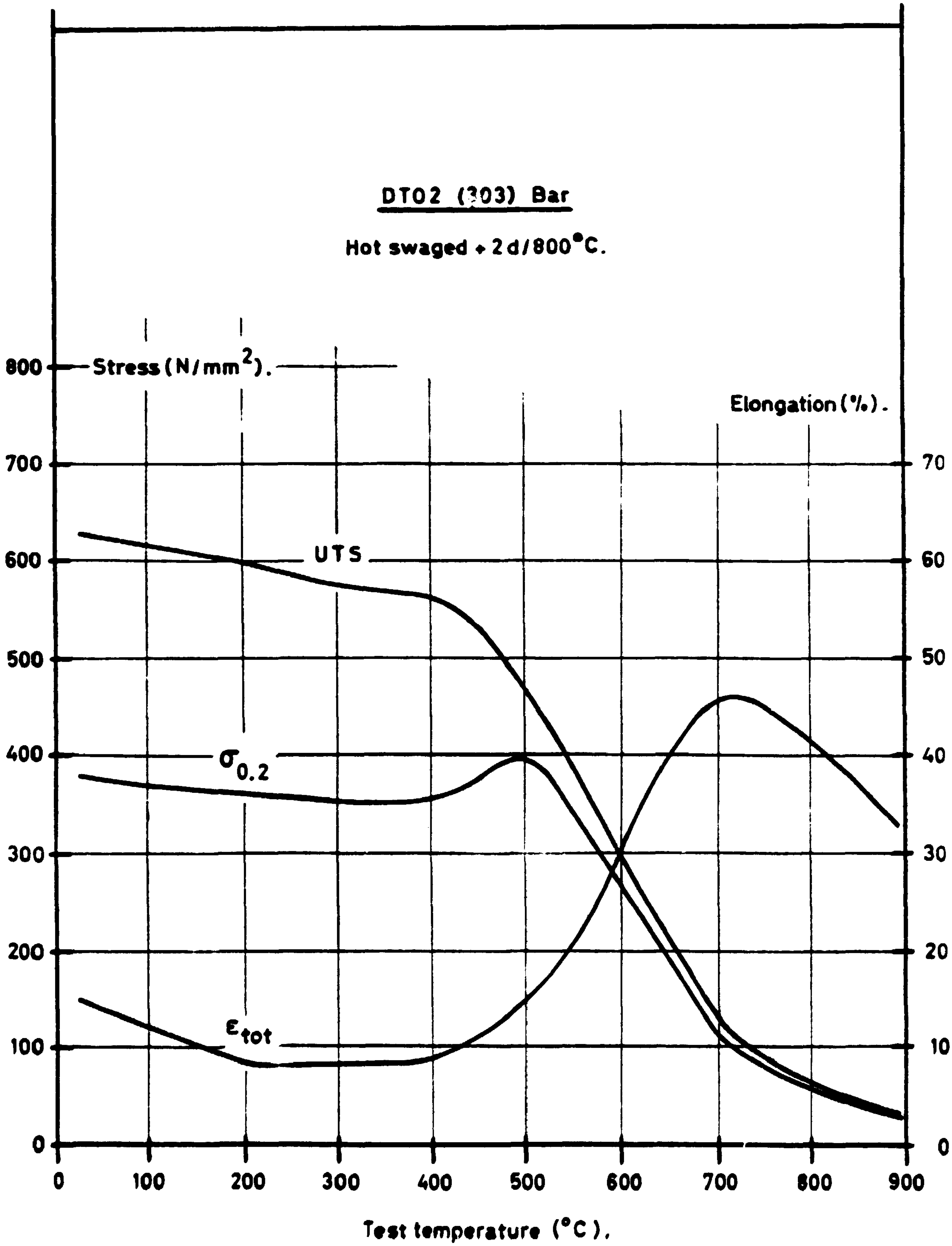
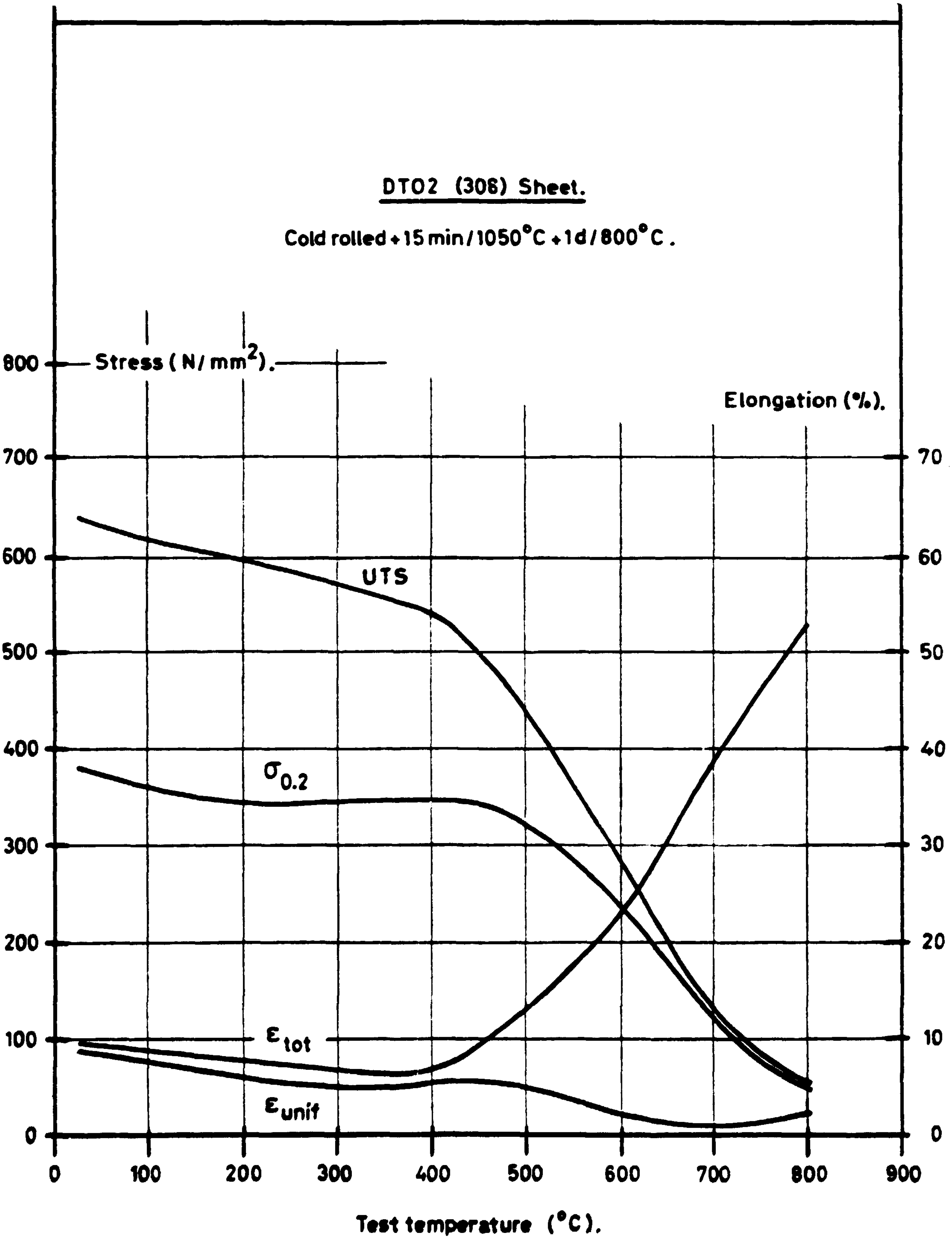
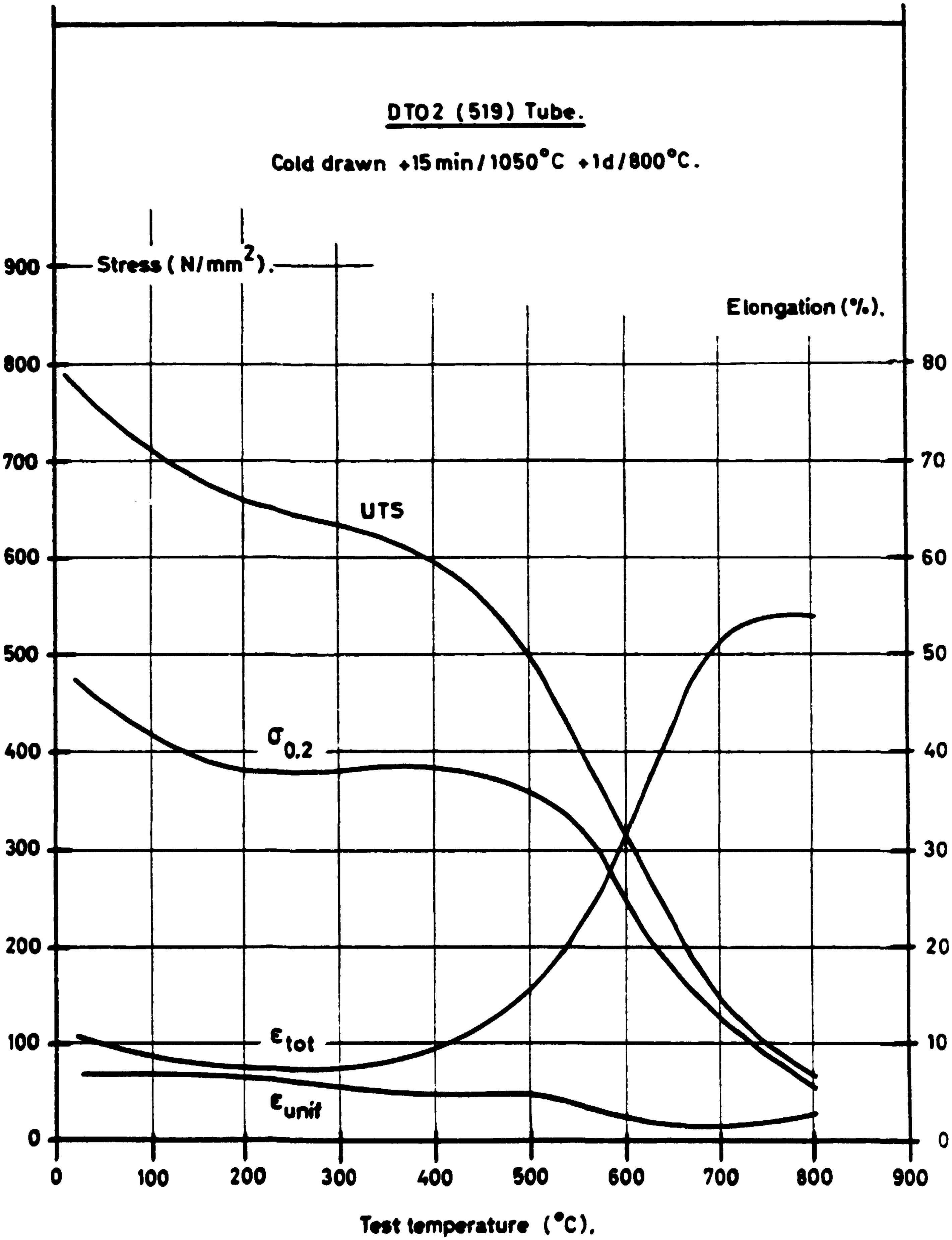

DT02 (303) Bar
Hot swaged + 2d/800°C.
Stress (N/mm²).
Elongation (%).
UTS
σ0.2
εtot
800
700
600
500
400
300
200
100
0
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
900
Test temperature (°C).

Fig. 2



DT02 (308) Sheet.
Cold rolled + 15 min/1050°C + 1d/800°C.
Stress (N/mm2).
Elongation (%).
UTS
σ0.2
ε tot
ε unif
800
700
600
500
400
300
200
100
0
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
900
Test temperature (°C).

Fig. 3



DT02 (519) Tube.
Cold drawn +15 min / 1050°C +1d / 800°C.
Stress (N/mm²).
Elongation (%).
UTS
σ0.2
εtot
εunif
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
Test temperature (°C).

Fig. 4

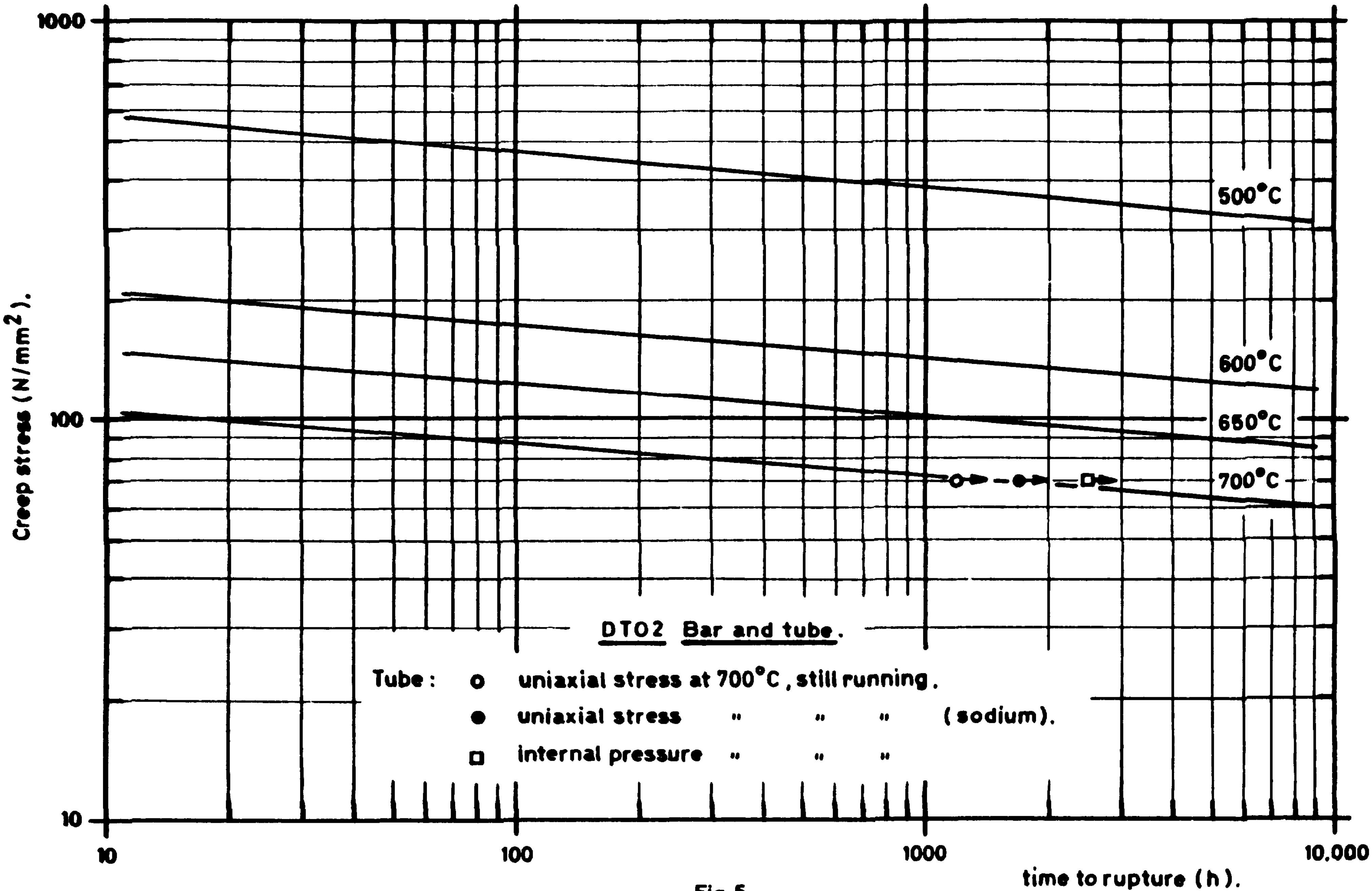
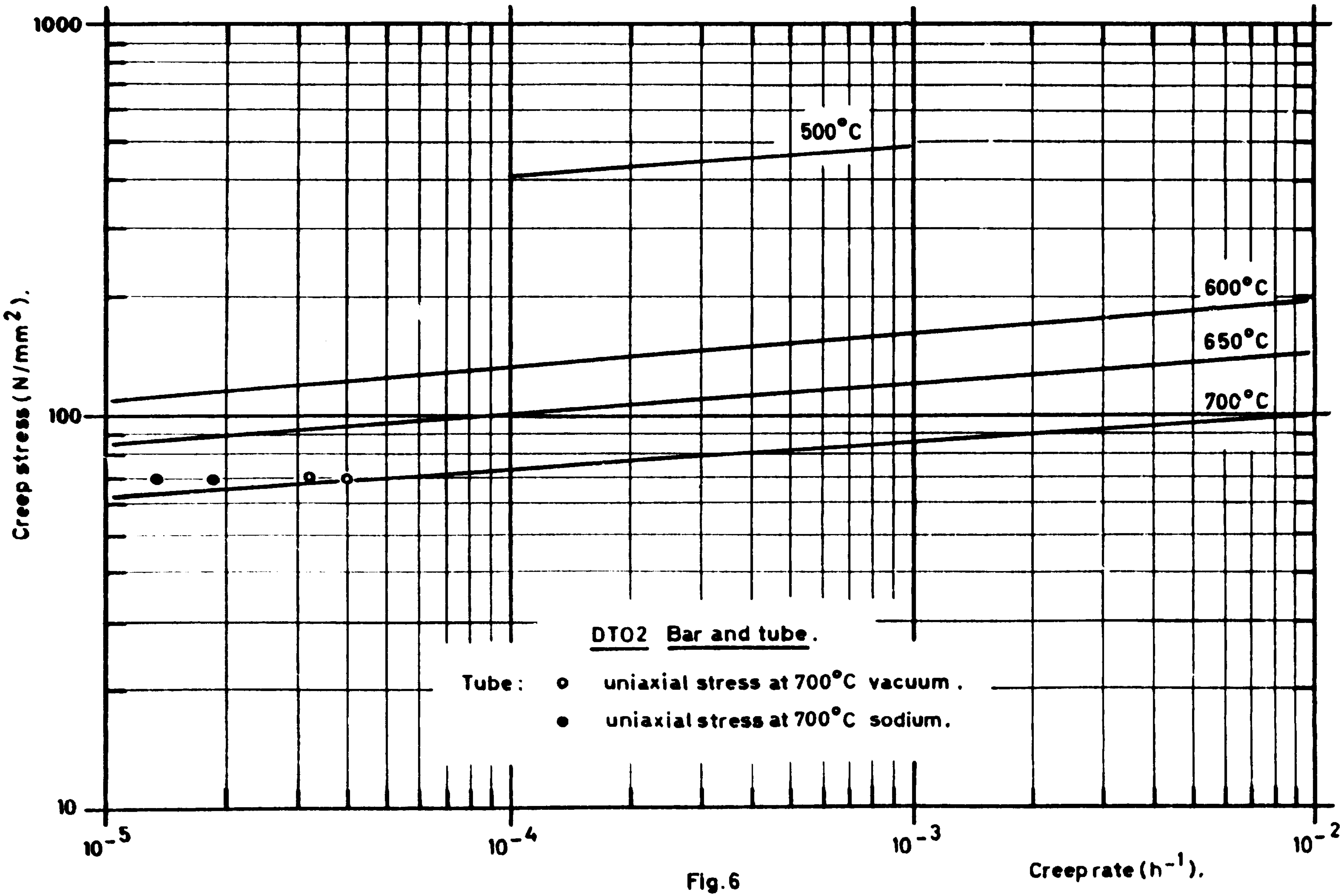
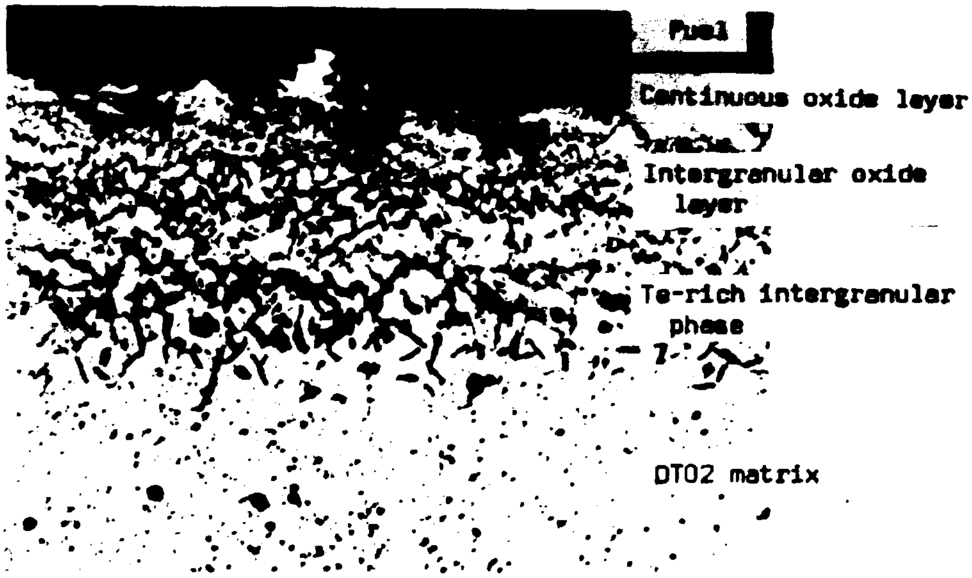

1000
100
10
Creep stress (N/mm²).
500°C
600°C
650°C
700°C
DTO2 Bar and tube.
Tube : ○ uniaxial stress at 700°C, still running.
● uniaxial stress " " " (sodium).
□ internal pressure " " "
10
100
1000
10.000
time to rupture (h).

Fig.5



1000
100
10
Creep stress (N/mm²).
500°C
600°C
650°C
700°C
DTO2 Bar and tube.
Tube : o uniaxial stress at 700°C vacuum.
• uniaxial stress at 700°C sodium.
10⁻⁵
10⁻⁴
10⁻³
10⁻²
Creep rate (h⁻¹).

Fig. 6



<u>Fig. 7</u> Reaction of $UO_{2.08}$ fuel, with fission proaucts added to simulate 10% burn-up, with DT02 cladding material after 1000 hour exposure at 650°C.
Magnification : 500 x

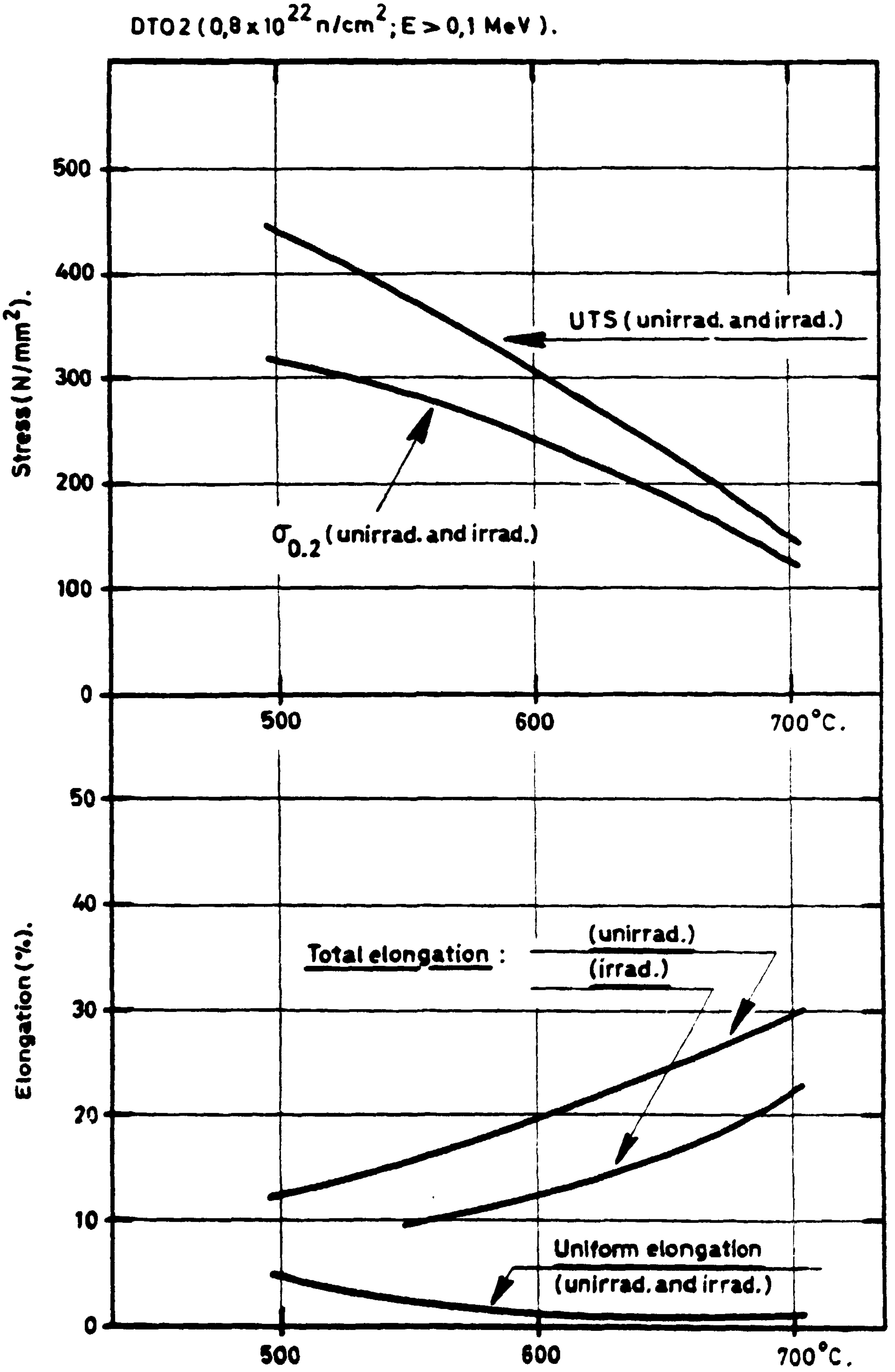


Fig.8 – Irradiation and test temperature.