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(54) **Titre : ALLIAGE NICKEL-COBALT**
(54) **Title: NICKEL-COBALT ALLOY**

(57) **Abrégé/Abstract:**

The invention relates to a Ni-Co alloy, comprising 30 to 65 wt% Ni, > 0 to max. 10 wt% Fe, > 12 to < 35 wt% Co, 13 to 23 wt% Cr, 1 to 6 wt% Mo, 4 to 6 wt% Nb + Ta, > 0 to < 3 wt% Al, > 0 to < 2 wt% Ti, > 0 to max. 0.1 wt% C, > 0 to max. 0.03 wt% P, > 0 to max. 0.01 wt% Mg, > 0 to max. 0.02 wt% B, > 0 to max. 0.1 wt% Zr, which fulfils the following requirements and criteria: a) 900°C < ?' solvus temperature < 1030°C with 3 at% < Al+Ti (at%) < 5.6 at% and 11.5 at% < Co < 35 at%; b) stable microstructure after 500 h of ageing annealing at 800°C with a ratio Al/Ti > 5 (on the basis of the contents in at%).

Abstract

The invention relates to a Ni-Co alloy, comprising 30 to 65 wt% Ni, > 0 to max. 10 wt% Fe, > 12 to < 35 wt% Co, 13 to 23 wt% Cr, 1 to 6 wt% Mo, 4 to 6 wt% Nb + Ta, > 0 to < 3 wt% Al, > 0 to < 2 wt% Ti, > 0 to max. 0.1 wt% C, > 0 to max. 0.03 wt% P, > 0 to max. 0.01 wt% Mg, > 0 to max. 0.02 wt% B, > 0 to max. 0.1 wt% Zr, which fulfils the following requirements and criteria: a) 900°C < γ' solvus temperature < 1030°C with 3 at% < Al+Ti (at%) < 5.6 at% and 11.5 at% < Co < 35 at%; b) stable microstructure after 500 h of ageing annealing at 800°C with a ratio Al/Ti > 5 (on the basis of the contents in at%).

Nickel-cobalt alloy

The subject matter of the invention relates to a nickel-cobalt alloy.

An important metallic material for rotating disks in gas turbines is the nickel-base Alloy 718. The chemical composition of Alloy 718 is listed in Table 1 of the AMS 5662 standard.

The requirements applicable to the mechanical properties that Alloy 718 must have in accordance with the AMS 5662 standard are listed in Table 2. Furthermore, for use as a rotating disk in an aircraft turbine, an elongation of < 0.2% is required after a creep test at a temperature of 650°C and a load of 550 MPa after a loading time of 35 h (or after 100 h in the case of even more stringent requirements), while high cycle numbers to failure are expected in the low cycle fatigue/LCF test. Depending on test condition, cycle numbers of several 10,000 cycles up to cycles of more than 100,000 are required, as specified on the basis of different disk designs. In accordance with the AMS 5662 standard, the mechanical requirements must be satisfied after a three-stage annealing process - one hour of solution annealing at an annealing temperature between 940 and 1000°C +

precipitation hardening at 720°C for 8 h + 620°C for 8 h.

Essentially two precipitation phases are responsible for the high strength properties of nickel-base Alloy 718. They are on the one hand the γ''-phase Ni_3Nb and on the other hand the γ'-phase $Ni_3(Al, Ti)$. A third important precipitation phase is the δ-phase, which limits Alloy 718 to a maximum temperature of 650°C, since above that temperature the metastable γ''-phase is transformed to the stable δ-phase. As a consequence of this transformation, the material loses its creep-strength properties. In the course of the process of manufacture of Alloy 718 material from the remelted ingot to the semifinished form of a forged billet, however, the δ-phase plays an important role in achieving a very fine-grained homogeneous grain structure during the forging process. During forging heats in the range of the precipitation temperature of the δ-phase, small proportions at precipitates of δ-phase result in grain refinement. This fine grain of the billet microstructure is preserved or becomes even more fine-grained due to hot forming during the manufacture in particular of turbine disks, even though forging in this case takes place at a temperature below the δ-phase solution temperature. The very fine-grained microstructure is a prerequisite for very high cycle numbers to failure in the LCF test. Since the precipitation temperature of the γ'-phase of Alloy 718 is very much lower than the δ-phase solution temperature of approximately 1020°C, Alloy 718 has a broad window of forming temperature, and so forging from ingot to billet or from billet to turbine disk is unproblematic as regards possible surface disruptions due to γ'-phase precipitates, which may occur during forging at very low temperatures. Thus Alloy 718 is very amenable to the hot-forming process. Nevertheless, one disadvantage is the relatively low application temperature of Alloy 718, up to 650°C.

Another nickel alloy known as "Waspaloy" is characterized by good microstructural stability at higher temperatures, up to approximately 750°C, and so its application temperature is approximately 100 K higher than that of Alloy 718. Waspaloy achieves its microstructural stability up to higher temperatures by higher alloying proportions of the elements Al and Ti. Herewith Waspaloy exhibits a high solution temperature of the γ'-phase, which in turn permits a higher application temperature. The chemical composition of Waspaloy is listed in Table 3 in accordance with the AMS 5704 standard.

The requirements imposed on the mechanical properties that Waspaloy must achieve in accordance with the AMS 5704 standard are listed in Table 4. Furthermore, for use as a rotating disk in an aircraft turbine, an elongation of < 0.2% is required after a creep test at a test temperature and a test load after a loading time of 35 h (or after 100 h in the case of even more stringent requirements), while high cycle numbers to failure are expected in the low cycle fatigue/LCF test. In this connection, depending on test condition, cycle numbers of several 10,000 cycles up to cycles of more than 100,000 are required, as specified on the basis of different disk designs. In accordance with the AMS 5704 standard, the mechanical requirements must be satisfied after a three-stage annealing process - four hours of solution annealing at an annealing temperature between 996 and 1038°C + stabilization annealing at 845°C for 4 h + precipitation hardening at 760°C for 16 hours.

However, the high γ' solution temperature of approximately 1035°C is also the cause of the poor hot formability of Waspaloy. At a surface temperature of approximately ≤ 980°C, deep discontinuities caused by γ'-phase precipitates may develop at the surface of the forged pieces during processes of forging from the remelted ingot to billets or from the billet to turbine disks. Thus the window of forming temperature for Waspaloy is relatively small, necessitating several forming heats due to multiple exposures in heating furnaces, in turn resulting in a longer process duration and therefore higher manufacturing costs. Because of the necessarily higher forging temperatures and the absence of a grain-refining δ-phase, a very fine grain microstructure in the billet forged from Waspaloy is not achievable, in contrast to what can be illustrated for Alloy 718.

For aircraft applications, Alloy 718 and Waspaloy are smelted as the primary heat in a VIM furnace then cast as round electrodes in chill molds. After further processing steps, either the electrodes are remelted in the ESR or VAR double-melt smelting process or VAR resmelted ingots are produced in the VIM / ESR / VAR triple-melt process. Before the resmelted ingots can be hot-formed, they are subjected to homogenization annealing. Thereafter the resmelted ingots are forged in several forging heats to billets, which in turn are used as forging stock for the manufacture, for example, of turbine disks.

US 6730264 discloses a nickel-chromium-cobalt alloy of the following composition: 12 to 20% Cr, up to 4% Mo, up to 6% W, 0.4 to 1.4% Ti, 0.6 to 2.6% Al, 4 to 8% Nb (Ta), 5 to 12% Co, up to 14% Fe, up to 0.1% C, 0.003 to 0.03% P, 0.003 to 0.015% B, the rest nickel.

DE 69934258 T2 discloses a process for manufacturing an object formed from Waspaloy, which process includes the following steps:

a) Preparing a batch of a material that consists, in wt%, of 18 to 21 Cr, 3.5 to 5 Mo, 12 to 15 Co, 2.75 to 3.25 Ti, 1.2 to 1.6 Al, up to 0.08 Zr, 0.003 to 0.010 B, the rest Ni and incidental impurities;

b) Smelting the batch of the material in a vacuum environment at a pressure of less than 100 μ (13.33 Pa) in a ceramic-free smelting system and heating the batch of the material to a limited superheat step within 200°F (93°C) above the melting point of the alloy;

c) Pouring the smelted batch of the material into a shot cylinder of a pressure die-casting apparatus in the vacuum environment, so that the molten material fills less than half of the shot cylinder; and

d) Injecting the molten material under pressure into a reusable mold.

The invention is based on the object of providing an alloy in which the previously described advantages of the two known alloys, Alloy 718 and Waspaloy, i.e., the good hot formability of Alloy 718 and the microstructural stability of Waspaloy up to higher temperatures of approximately 750°C, can be combined.

This task is accomplished by an Ni-Co alloy with 30 to 65 wt% Ni, > 0 to max. 10 wt% Fe, > 12 to < 35 wt% Co, 13 to 23 wt% Cr, 1 to 6 wt% Mo, 4 to 6 wt% Nb + Ta, > 0 to < 3 wt% Al, > 0 to < 2 wt% Ti, > 0 to max. 0.1 wt% C, > 0 to max. 0.03 wt% P, > 0 to max. 0.01 %wt Mg, > 0 to max. 0.02 %wt B, > 0 to max. 0.1 %wt Zr, which alloy satisfies the requirements and criteria listed below:

a) 900°C ≤ γ'-solvus temperature ≤ 1030°C at 3 at% ≤ Al + Ti (at%) ≤ 5.6 at% as well as 11.5 at% ≤ Co ≤ 35 at%;

b) stable microstructure after 500 h of aging annealing at 800°C and an Al/Ti ratio ≥ 5 (on the basis of the contents in at%).

Advantageous improvements of the inventive alloy are specified in the associated dependent claims.

On the basis of the parameters mentioned in claim 1, the inventive alloy no longer exhibits the disadvantages of Alloy 718, namely the relatively low application temperature, and of Waspaloy, namely the poor hot formability.

The inventive alloy preferably satisfies the requirement "945°C ≤ γ'-solvus temperature ≤ 1000°C".

It is of particular advantage when Co contents between 11.5 and 35 at% can be adjusted at a ΔT $(\delta - \gamma') \geq 80$ K and Al + Ti ≤ 4.7 atomic%.

The inventive alloy advantageously has a temperature interval between δ-solvus and γ'-solvus temperatures equal to or greater than 140 K and at the same time a Co content between 15 and 35 at%.

According to a further improvement of the invention, the Ti content in the alloy is adjusted to ≤ 0.8 atomic% and more preferably to a content of ≤ 0.65 atomic%.

Restricting the (Nb + Ta) contents to values between 4.7 and 5.7 wt% may also contribute to improving the good hot deformability of Alloy 718 and the microstructural stability of Waspaloy up to higher temperatures of approximately 750°C.

The value ranges for a ratio of two element contents are different when expressed in atomic and weight per cent. At the structural level, atomic proportions are essential. The contents of the elements essential for the inventive alloy, namely Al, Ti and Co, are presented in atomic% especially in Table 6a.

The inventive alloy may also contain the following elements as residual elements:

Cu	max. 0.5 wt%
S	max. 0.015 wt%
Mn	max. 1.0 wt%
Si	max. 1.0 wt%
Ca	max. 0.01 wt%
N	max. 0.03 wt%
O	max. 0.02 wt%

If appropriate for the respective application, the inventive alloy may if necessary also contain the following elements

V	up to 4 wt%
W	up to 4 wt%

In the inventive alloy, the elements listed below may be adjusted as follows:

0.05 at% ≤ Ti ≤ 0.5 at%,

3.6 at% ≤ Al ≤ 4.6 at%,

15 at% ≤ Co ≤ 32 at%.

Depending on area of application of the inventive alloy, it may be appropriate from cost viewpoints to substitute part of the elements Ni and/or Co with the less expensive element Fe.

The inventive alloy is preferably usable as a component in an aircraft turbine, especially a rotating turbine disk, as well as a component of a stationary turbine.

The alloy may be produced in the following semifinished forms: strip, sheet, wire, bar.

The material is creep-resistant at high temperature and, besides the already mentioned applications, can also be used for the following service areas: in engine construction, in exhaust-gas systems, as heat shields, in furnace construction, in boiler construction, in power-plant construction, especially as superheater pipes, as structural parts in gas and oil extraction engineering, in stationary gas and steam turbines and also as a weld filler for all of the said applications.

The present invention describes a nickel alloy, especially for critical rotating components of an aircraft turbine. The inventive alloy has a high microstructural stability at high temperatures and therefore offers the possibility of application at thermal loads up to 100 K hotter than for the known nickel-base Alloy 718. Furthermore, the inventive alloy is characterized by better formability than the nickel alloy known as Waspaloy. The alloy of the present invention offers technological properties that permit applications in gas turbines in the form of disks, blades, holders, housings or shafts.

The present alloy describes the chemical composition, the technological properties and the processes for the manufacture of semifinished products made from the material of the inventive nickel-cobalt alloy.

The properties of the inventive alloy are discussed hereinafter:

Numerous laboratory heats with different chemical compositions were produced by means of a laboratory vacuum arc furnace.

Each heat was cast into a heavy-duty cylindrical copper chill mold with a diameter of 13 mm. During smelting, three bars with a length of approximately 80 mm were produced. All alloys were homogenized after smelting. The entire process took place in the vacuum furnace and consisted of 2 stages: 1140°C/6 h + 1175°C/20 h. This was followed by quenching in an argon atmosphere. Hot forming for the smelted alloys was carried out using a rotary swaging machine. The bars had a diameter of 13 mm at the beginning and were reduced in diameter by four rotary swaging operations of one millimeter each to obtain the final diameter of 9 mm.

Table 1 discloses the chemical composition of Alloy 718 corresponding to the prior art as specified by the valid AMS 5662 standard, while Table 2 presents the mechanical properties of that alloy.

Table 3 discloses the chemical composition of Waspaloy corresponding to the prior art as specified by the valid AMS 5662 standard, while Table 4 presents the mechanical properties of that alloy.

The inventive chemical compositions of the laboratory heats are listed in Table 5. At the bottom, the known alloys A718, A718 Plus and Waspaloy are also included as reference materials. In addition to the reference materials, the test alloys are identified with the letters V and L plus 2 numerals each. The chemical compositions of these test alloys include variations in the contents of the elements Ti, Al, Co and Nb.

When the contents of the elements Ti, Al and Co as well as the sum of Al + Ti and the Al/Ti ratio of the contents of the elements are expressed in atomic per cent, very good technological properties are obtained in selected ranges for the γ'-solvus temperature, the difference between δ-solvus and γ'-solvus temperatures, the absence of primary delta phase and absence of the η-phase, the microstructural stability at 800°C after aging annealing tests for 500 h and the mechanical hardness HV after a standard heat treatment comprising solution annealing and two-stage precipitation-hardening annealing for A718 (980°C/1 h + 720°C/8 h + 620°C/8 h, see the AMS 5662 standard).

Table 6a lists the contents in atomic per cent of the elements Al, Ti and Co as well as the sum of the Al + Ti contents (in atomic per cent) and the Al/Ti ratios for the test alloys and the 3 reference materials of Table 5.

Furthermore, Table 6b contains the calculated solvus temperatures of the δ-phase and of the γ'-phase as well as the temperature difference ΔT (δ - γ') calculated therefrom between the δ-solvus and γ'-solvus temperatures. Table 6b also indicates the mechanical hardness values 10 HV determined for the test alloys (after three-stage precipitation-hardening heat treatment of 980°C/1 h + 720°C/8 h + 620°C/8 h in accordance with the AMS 5662 standard for A718). Moreover, Table 6b indicates remarks on the occurrence of the η-phase (calculated or observed).

The criteria for selection of the inventive alloy are explained and exemplary test alloys are indicated in the following descriptions.

For reasons of strength and microstructural stability, the γ'-solvus temperature of the inventive alloy should be 50 K higher than that of alloy A718, which has a γ'-solvus temperature of approximately 850°C. On the other hand, the γ'-solvus temperature of the inventive alloy should be lower than or equal to 1030°C. This 1030°C corresponds approximately to the γ'-solvus temperature of Waspaloy. A higher γ'-solvus temperature would influence the hot formability very negatively since, in the forging process, for example, γ'-precipitates already lead to extensive precipitation hardening of the surface of the forged piece if the surface temperatures of the forged piece are slightly below the γ'-solvus temperature, and this in turn may lead to considerable disruptions of the surface of the forged piece during further forming by forging.

Thus the requirement 900°C ≤ γ'-solvus T ≤ 1030°C should be satisfied.

In Fig. 1, the γ'-solvus temperature of the test alloys is plotted against the sum of the Al + Ti contents (at%) of their chemical compositions.

From Fig. 1 it is evident that the requirement "900°C ≤ γ'-solvus T ≤ 1030°C" is satisfied by the restriction 3 at% ≤ Al + Ti (at%) ≤ 5.6 at%. The test alloys V12, V13, V14, V15, V16, V17, V20, V21, V22, L04, L07, L09, L15, L16, L17 and L18 are exemplary alloys for this range.

For even better hot formability, the γ'-solvus temperature of the inventive alloy should be < 1000°C, and for microstructural stability at even higher temperature it should be > 945°C. The test alloys V14, V16, V17, V20, V21, V22 L04, L15, L16, L17 and L18 are exemplary alloys for this range. The temperature range bounded between 945°C and 1000°C is evident from Fig. 2.

The Co content of the test alloys influences the δ-solvus and γ'-solvus temperatures and thus ΔT (δ - γ'). The Co content of the inventive alloy is not permitted to be too high, to ensure that no primary δ-phase develops. This restricts the Co content to < 35 at%. Exemplary alloys in which primary δ-phase develops are the test alloys L12 and L13, both of which have a Co content of approximately 50 at%.

Fig. 3, in which the occurrence of the η-phase is marked on the plots of the Co and Ti contents of the test alloys, shows that the Ti content of the inventive alloy must be limited to ≤ 0.8 at% in alloys with Co contents greater than 16 at%, in order to prevent the development of a stable η-phase. Exemplary alloys with Ti ≤ 0.8 at% are the test alloys V12, V13, V14, V15, V16, V17, V21 and V22. Preferred alloys have a Ti content of ≤ 0.65 at%. These are the exemplary test alloys V16, V17, V21 and V22.

During the forging process, minor proportions of δ-phase are consumed for grain refining of the microstructure. In other words, forging in the last forging heats is carried out starting from a temperature slightly below the δ-solvus temperature, in order to produce a very fine-grained microstructure of the respective forged piece. On the other hand, in order to make it possible to work with a sufficiently broad window of forging temperatures, the γ'-solvus temperature cannot be permitted to be too high, and it must lie well below the δ-solvus temperature of the inventive alloys. For the window of forging temperature to be sufficiently broad, it must be ≥ 80 K. Therefore the difference ΔT (δ - γ') between δ-solvus temperature and γ'-solvus temperature must be ≥ 80 K.

From Fig. 4, it can be seen that ΔT (δ - γ') is ≥ 80 K when the sum of the Al + Ti contents is ≤ 4.7 at% and the Co content is ≥ 11.5 at%. Even greater temperature intervals of ≥ 140 K between δ-solvus temperature and γ'-solvus temperature are possible if at the same time the Co content of the alloy is ≥ 15 at%.

A further criterion results from the requirement that states that the microstructure of the inventive alloy should be stable at an aging temperature of 800°C (after 500 h). This criterion is satisfied by the inventive alloys that have an Al/Ti ratio of ≥ 5.0. Exemplary alloys for this condition are the test alloys V13, V15, V16, V17, V21 and V22.

Table 7 lists exemplary test alloys for the requirement of the Al/Ti ratio of the inventive alloy.

Figs. 5a to 5e show exemplary SEM photographs for the test alloys L4, V10, V15, V16 and V17 after aging annealing for 500 h at 800°C.

Table 1: Chemical composition of Alloy 718 in accordance with the AMS 5662 standard

Element	Weight per cent

C	max. 0.08
Mn	max. 0.35
P	max. 0.015
S	max. 0.015
Si	max. 0.35
Cr	17 - 21%
Ni	50 - 55%
Fe	Rest
Mo	2.8 - 3.3%
Nb	4.75 - 5.5%
Ti	0.65 - 1.15%
Al	0.2 - 0.8%
Al + Ti	0.85 - 1.95%
Co	max. 1%
B	max. 0.006%
Cu	max. 0.3%
Pb	max. 0.0005%
Se	max. 0.0003%
Bi	max. 0.00003%

Table 2: Mechanical properties of Alloy 718 in accordance with the AMS 5662 standard

Mechanical properties	Test conditions	Requirements in accordance with AMS 5662
Offset yield strength Rp0.2	20°C	≥ 1034 MPa
Tensile strength Rm	20°C	≥ 1276 MPa
Elongation A5	20°C	≥ 12%
Hardness HB	20°C	≥ 331 HB
Offset yield strength Rp0.2	650°C	≥ 862 MPa
Tensile strength Rm	650°C	≥ 1000 MPa
Elongation A5	650°C	≥ 12%
Reduction of area at break Z	650°C	≥ 15%
Stress rupture test	650°C Load 725 MPa	
Time to break		≥ 23 h
Elongation A5		≥ 4%

Table 3: Chemical composition of Waspaloy in accordance with the AMS 5704 standard

Element	Weight per cent
C	0.02 - 0.10%
Mn	max. 0.1%
P	max. 0.015%
S	max. 0.015%
Si	max. 0.15%
Cr	18 - 21%
Fe	max. 2%
Mo	3.5 - 5.0%
Nb	
Ti	2.75 - 3.25%
Al	1,2 - 1,6%
Co	12 - 15%
Ni	Rest
B	0.003 - 0.01%
Cu	max. 0.1%
Zr	0.02 - 0.08%

Pb	max. 0.0005%
Bi	max. 0.00003%
Se	max. 0.0003%
Ag	max. 0.0005%

Table 4: Mechanical properties of Waspaloy in accordance with the AMS 5704 standard

Mechanical properties	Test conditions	Requirements in accordance with AMS 5662
Offset yield strength Rp0.2	20°C	≥ 827 MPa
Tensile strength Rm	20°C	≥ 1207 MPa
Elongation A5	20°C	≥ 15%
Hardness HB	20°C	≥ 341 HB and ≤ 401 HB
Offset yield strength Rp0.2	538°C	≥ 724 MPa
Tensile strength Rm	538°C	≥ 1069 MPa
Elongation A5	538°C	≥ 15%

Reduction of area at break Z	538°C	≥ 18%
Stress rupture test		
Time to break	732°C	≥ 23 h
Elongation A5	Load 552 MPa	≥ 5%
Stress rupture test		
Time to break	816°C	≥ 23 h
Elongation A5	Load 293 MPa	≥ 5%

Table 5: Chemical compositions (in weight per cent) of the test alloys (actual analysis). The C content of all alloys is approximately 0.025 wt%. If necessary, the respective alloy may contain the following elements as residual elements: Cu, S, Mn, Si, Ca, N, O. Depending on application, W up to 4 wt% and/or V up to 4 wt% may also be present in the respective alloy. The alloys A718Plus and Waspaloy respectively contain 1 wt% W.

Alloy	Ni	Fe	Cr	Mo	Ti	Al	Nb + Ta	Co
V05	Rest	0.05	18.17	2.96	2.00	1.96	5.50	17.03

V07	Rest	0.06	18.40	2.96	2.01	1.97	5.45	29.95
V10	Rest	0.05	18.48	3.03	1.11	2.04	5.38	17.03
V11	Rest	0.06	18.50	3.05	1.11	2.03	5.39	30.04
V12	Rest	0.05	18.40	2.97	0.50	1.23	5.53	17.04
V13	Rest	0.04	18.41	2.99	0.49	1.97	5.50	16.98
V14	Rest	0.04	18.43	2.99	0.49	1.60	5.52	17.01
V15	Rest	0.04	18.50	2.96	0.50	2.33	5.45	17.05
V16	Rest	0.05	18.25	2.98	0.17	1.90	5.51	17.25
V17	Rest	0.05	18.48	2.96	0.17	1.90	5.40	24.98
V20	Rest	0.05	18.70	2.99	0.52	2.04	5.60	30.10
V21	Rest	0.04	18.70	2.96	0.20	2.04	5.58	25.06
V22	Rest	0.04	18.70	2.96	0.20	2.04	5.40	30.10
L03	Rest	0.18	18.20	2.90	0.75	0.63	5.49	16.98
L04	Rest	0.04	18.45	3.06	1.09	1.24	5.46	17.05
L06	Rest	0.21	18.40	2.91	0.73	0.64	5.49	30.00
L07	Rest	0.38	18.32	2.93	1.07	0.92	5.49	17.04
L09	Rest	0.46	18.40	2.94	1.46	1.23	5.60	16.90
L12	Rest	0.34	18.50	2.90	0.72	0.61	5.36	49.76
L13	Rest	0.45	18.32	2.90	1.48	0.69	5.59	49.88
L15	Rest	0.03	18.47	3.03	1.09	1.25	5.38	13.99
L16	Rest	0.03	18.46	3.02	1.64	0.92	5.40	12.00

L17	Rest	0.04	18.42	3.04	1.12	1.23	5.41	25.14
L18	Rest	0.05	18.49	3.04	1.11	1.24	5.38	30.01
A718	Rest	17.06	18.71	2.93	0.99	0.48	5.32	0.02
A718Plus	Rest	10.00	18.00	2.75	0.70	1.45	5.45	9.00
Waspaloy	Rest	0.20	19.5	4.25	3.00	1.30	0	13.5

Table 6a: Element contents in atomic per cent or ratios of element contents of the test alloys

Alloy at%	Al/Ti	Al + Ti	Ti	Al	Co
V05	1.74	6.58	2.40	4.18	16.65
V07	1.73	6.62	2.42	4.20	29.27
V10	3.28	5.69	1.33	4.36	16.65
V11	3.24	5.68	1.34	4.34	29.40
V12	4.36	3.27	0.61	2.66	16.85
V13	7.15	4.81	0.59	4.22	16.65
V14	5.83	4.03	0.59	3.44	16.75
V15	8.28	5.57	0.60	4.97	16.64
V16	20.35	4.27	0.20	4.07	16.94
V17	20.35	4.27	0.20	4.07	24.52

V20	20.00	4.64	0.62	4.02	29.58
V21	18.10	4.61	0.24	4.37	24.49
V22	18.17	4.60	0.24	4.36	29.48
L03	1.49	2.29	0.92	1.37	16.94
L04	2.02	3.99	1.32	2.67	16.83
L06	1.55	2.30	0.90	1.40	29.93
L07	1.53	3.31	1.31	2.00	16.96
L09	1.49	4.44	1.78	2.66	16.75
L12	1.51	2.21	0.88	1.33	49.73
L13	0.83	3.33	1.82	1.51	49.83
L15	2.04	4.01	1.32	2.69	13.80
L16	0.99	3.99	2.00	1.99	11.87
L17	1.95	4.01	1.36	2.65	24.83
L18	1.98	4.02	1.35	2.67	29.63
A718	0.86	2.55	1.37	1.18	0.02
A718Plus	3.66	4.43	0.95	3.48	9.00
Waspaloy	0.77	6.3	3.56	2.74	13.5

Table 6b: Solvus temperatures of the δ-phase and of the γ'-phase, difference ΔT (δ - γ') of the solvus

temperatures of the δ- and γ'-phases, hardness 10 HV (after precipitation-hardening heat treatment 980°C/1 h + 720°C/8 h + 620°C/8 h in accordance with the AMS 5662 standard for A718) and remarks on the η-phase for the test alloys.

Alloy	δ-solv. T (°C)	γ'-solv. T (°C)	ΔT (δ-γ') (K)	Hardness 10 HV	Remarks on the η-phase (calculated or observed)
V05	1080	1077	3	506	Large amounts of η-phase
V07	1157	1037	120	539	η-Phase
V10	1090	1050	40	491	No η-phase
V11	1180	1037	143	486	η-Phase stable from 1127°C
V12	1097	917	180	415	No η-phase
V13	1087	1027	60	426	No η-phase
V14	1097	967	130	417	No η-phase
V15	1077	1027	50	470	No η-phase
V16	1097	997	100	442	No η-phase

V17	1152	957	195	448	No η-phase
V20	1162	950	212	446	Small amounts of η-phase; if necessary after aging at 800°C
V21	1127	952	175	455	No η-phase
V22	1177	952	225		No η-phase
L03	1117	887	230	396	η-Phase stable from 937°C
L04	1100	977	123	410	Small amounts of η-phase, stable from 950°C to 910°C
L06	1200	700	500	473	η-Phase stable from 1050°C
L07	1100	900	200	442	η-Phase stable from 1050°C
L09	1100	950	150	488	η-Phase more stable than δ
L12	1250	none		530	η-Phase primary, δ-phase

					primary, Laves phase
L13	1240	none		503	η-Phase primary, δ-phase primary, Laves phase
L15	1077	977	100	423	η-Phase stable
L16	1070	977	93	450	η-Phase stable
L17	1152	952	200	464	η-Phase stable from 1097°C
L18	1157	977	180	452	η-Phase stable from 1047°C
A718	1027	847	180	441	No η-phase
A718Plus	1027	976	51		η-Phase $Nb_3Al_{0.5}Nb_{0.5}$
Waspaloy		1035			No η-phase, no γ''-phase

Table 7: Exemplary test alloys for the requirement of the Al/Ti ratios for inventive alloys.

Alloy	Al/Ti	Microstructural stability after 500 h at 800°C	Notes
L04	2.02	Not satisfied	Exemplary alloy that does not satisfy the requirement
V13	7.15	Satisfied	Exemplary alloy that satisfies the requirement, but at a relatively high γ'-solvus temperature
V15	8.28		
V16	20.35	Satisfied	Exemplary alloys that satisfy the requirement
V17	20.35	Satisfied	

Table 8

Mechanical test values for A780 in comparison with A718

tested on upsetting-test specimens (solution-annealed + precipitation-hardened)

	Tension test at 20°C				Hot tension test at 650°C				Hot tension test at 700°C				Hot tension test at 750°C			
	20 °C	20 °C	20 °C	20 °C	650 °C	650 °C	650 °C	650 °C	700 °C	700 °C	700 °C	700 °C	750 °C	750 °C	750 °C	750 °C
Batch	Rp0.2 (MPa)	Rm (MPa)	A5 (%)	Z (%)	Rp0.2 (MPa)	Rm (MPa)	A5 (%)	Z (%)	Rp0.2 (MPa)	Rm (MPa)	A5 (%)	Z (%)	Rp0.2 (MPa)	Rm (MPa)	A5 (%)	Z (%)
25	1179	1495	24	32	1046	1388	12	15	1000	1245	11	13	908	1075	15	13
26	1191	1521	26	37	1015	1292	12	17	984	1203	10	10	910	1057	6	8
27	1222	1556	23	38	1055	1363	11	14	1032	1255	8	9	943	1109	11	12
A718 (420159)	1262	1494	16	29	1031	1231	23	59	958	1100	25	72	729	865	34	87

By way of further description of the subject matter of the invention, Figs. 6 and 7 are considered in conjunction with Table 8.

Figs. 6 and 7 show diagrams containing data on strength tests at 20°C, 650°C, 700°C and 750°C on the new alloy (VDM Alloy 780 Premium), in this case batches 25, 26 and 27, in comparison with Alloy 718 (batch 420159) belonging to the prior art. From the diagrams it is evident that A 780, even when subjected to higher test parameters in hot tension tests, achieves higher Rp 0.2 strength values (measured on upsetting-test specimens in the precipitation-hardened condition) than A 718.

Furthermore, it was observed that, in the creep and stress rupture test at 700°C, A 780 also achieves the desired mechanical properties of creep elongation much smaller than 0.2% as well as much longer times to failure of > 23 h in the stress rupture test - under otherwise identical test conditions where these properties are achieved by A 718 only at test temperatures up to 650°C.

Table 8 shows the batches 25 to 27 indicated in Figs. 6 and 7 in comparison with A 718. Here it is evident that especially the tensile strength Rm of A 780 batches 25 to 27 achieves higher values than A 718 at higher temperatures (700°C and 750°C) in the hot tension tests.

Description of the figures

Fig. 1: γ'-Solvus temperatures of the test alloys versus the sum of the Al + Ti contents (atomic%) of the chemical compositions.

Fig. 2: γ'-Solvus temperatures of the test alloys versus the sum of the Al + Ti contents (at%) of the chemical compositions with the restricted temperature range between 945°C and 1000°C.

Fig. 3: Occurrence of the η-phase versus the plots of the contents of Co and Ti of the test alloys.

Fig. 4: Difference between δ-solvus and γ'-solvus temperature of the test alloys versus the sum of the Al + Ti

contents (at%). Open squares: Co < 11.5 at%, open diamonds: 11.5 at% ≤ Co ≤ 18 at%, closed diamonds: Co > 18 at%.

Fig. 5: Exemplary SEM photographs for test alloys L4, V10, V15, V16 and V17 after aging annealing for 500 h at 800°C.

Fig. 6: A 780 variants in comparison with Alloy 718 (tension test: Rp 0.2)

Fig. 7: A 780 variants in comparison with Alloy 718 (tension test: Rm)

Claims

1. Ni-Co alloy with 30 to 65 wt% Ni, > 0 to max. 10 wt% Fe, > 12 to < 35 wt% Co, 13 to 23 wt% Cr, 1 to 6 wt% Mo, 4 to 6 wt% Nb + Ta, > 0 to < 3 wt% Al, > 0 to < 2 wt% Ti, > 0 to max. 0.1 wt% C, > 0 to max. 0.03 wt% P, > 0 to max. 0.01 %wt Mg, > 0 to max. 0.02 %wt B, > 0 to max. 0.1 %wt Zr, which alloy satisfies the requirements and criteria listed below:
   a) 900°C ≤ γ'-solvus temperature ≤ 1030°C at 3 at% ≤ Al + Ti (at%) ≤ 5.6 at% as well as 11.5 at% ≤ Co ≤ 35 at%;
   b) stable microstructure after 500 h of aging annealing at 800°C and an Al/Ti ratio ≥ 5 (on the basis of the contents in at%).

2. Alloy according to claim 1, which satisfies the requirement "945°C ≤ γ'-solvus temperature ≤ 1000°C".

3. Alloy according to claim 1 or 2, with $\Delta T\ (\delta - \gamma') \geq 80$ K and Al + Ti ≤ 4.7 at% as well as with Co contents ≥ 11.5 at% and ≤ 35 at%

4. Alloy according to one of claims 1 to 3, which has a temperature interval between δ-solvus and γ'-solvus temperatures equal to or greater than 140 K and a Co content ≥ 15 at% and ≤ 35 at%.

5. Alloy according to one of claims 1 to 4, with a Ti content of ≤ 0.8 at%.

6. Alloy according to one of claims 1 to 5, with a Ti content of ≤ 0.65 at%.

7. Alloy according to one of claims 1 to 6, with a content of 4.7 ≤ Nb + Ta ≤ 5.7 wt%.

8. Alloy according to one of claims 1 to 7, if necessary containing residual elements:

max. 0.5 wt% Cu
max. 0.015 wt% S
max. 1.0 wt% Mn
max. 1.0 wt% Si
max. 0.01 wt% Ca
max. 0.03 wt% N

max. 0.02 wt% O.

9. Alloy according to one of claims 1 to 8, if necessary also containing

up to 4 wt% V

up to 4 wt% W

10. Alloy according to one of claims 1 to 9, with contents of Ti, Al and Co in accordance with the following limit values:

0.05 at% ≤ Ti ≤ 0.5 at%,

3.6 at% ≤ Al ≤ 4.6 at%,

15 at% ≤ Co ≤ 32 at%.

11. Alloy according to one of claims 1 to 10, characterized in that, if necessary, part of the elements Ni and/or Co may be substituted by the element Fe.

12. Alloy according to one of claims 1 to 11, characterized in that it is usable for the following semifinished forms: strip, sheet, wire, bar.

13. Use of the alloy according to one of claims 1 to 12 as

components of an aircraft turbine, especially rotating turbine disks, as well as components of a stationary turbine.

14. Use of the alloy according to one of claims 1 to 12, in engine construction, in in furnace construction, in boiler construction, in power-plant construction.

15. Use of the alloy according to one of claims 1 to 12, as a structural part in oil and gas extraction engineering.

16. Use of the alloy according to one of claims 1 to 12, as a structural part in stationary gas and steam turbines.

17. Use of the alloy according to one of claims 1 to 12, as a weld filler material.

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Fig. 1

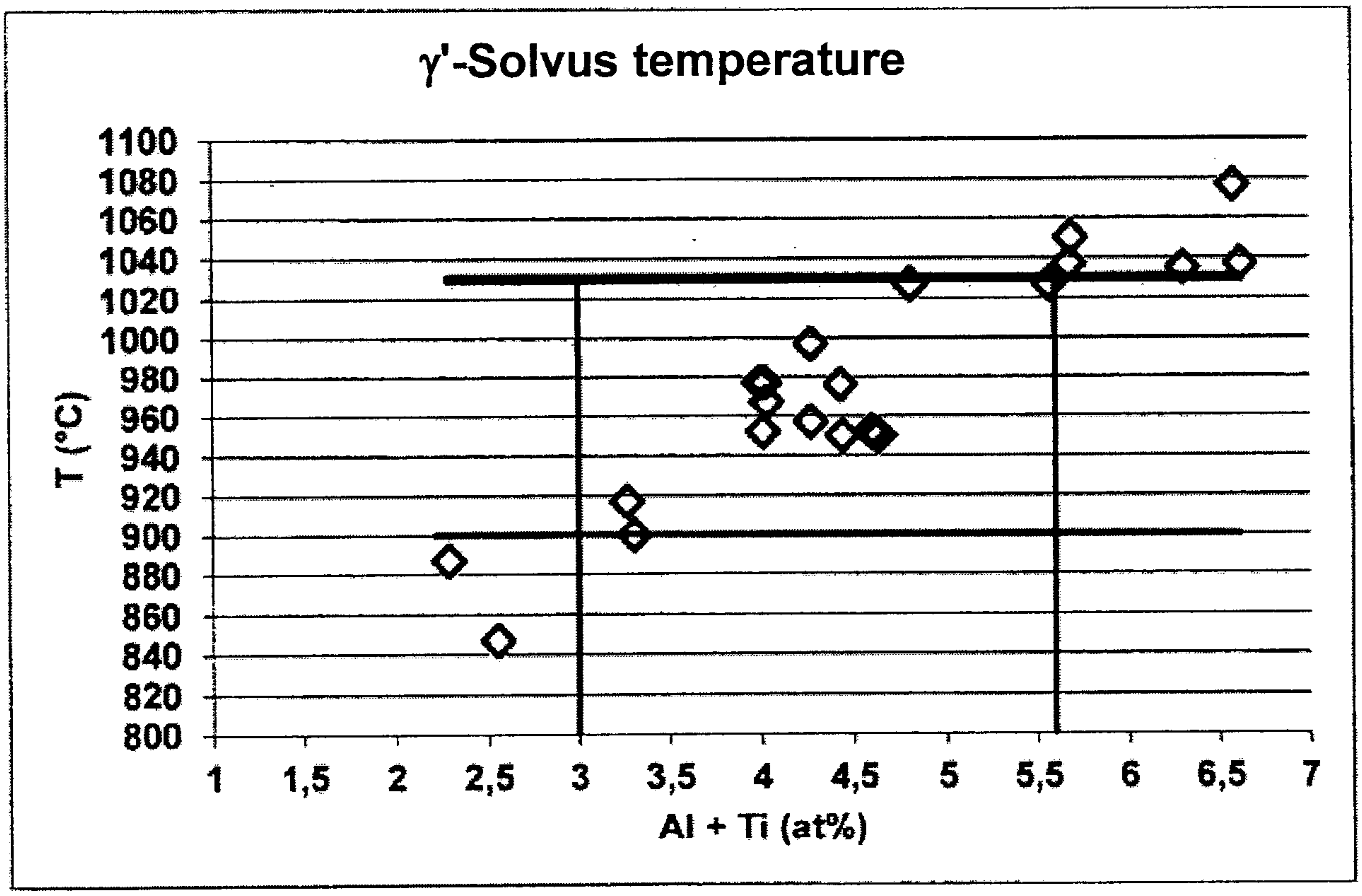

γ'-Solvus temperature
T (°C)
1100
1080
1060
1040
1020
1000
980
960
940
920
900
880
860
840
820
800
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
6,5
7
Al + Ti (at%)

Fig. 2

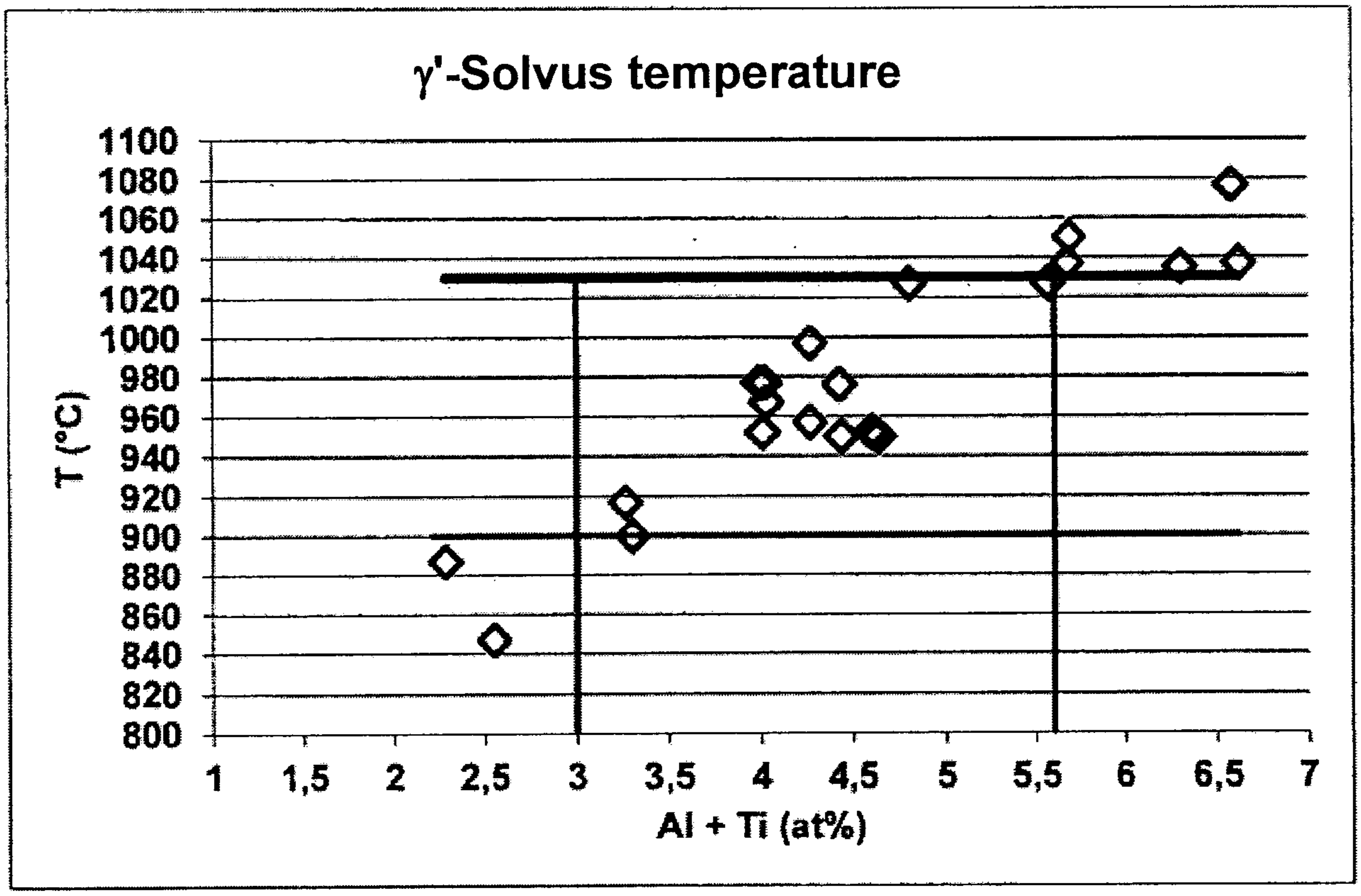

γ'-Solvus temperature
T (°C)
1100
1080
1060
1040
1020
1000
980
960
940
920
900
880
860
840
820
800
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
6,5
7
Al + Ti (at%)

Fig. 3

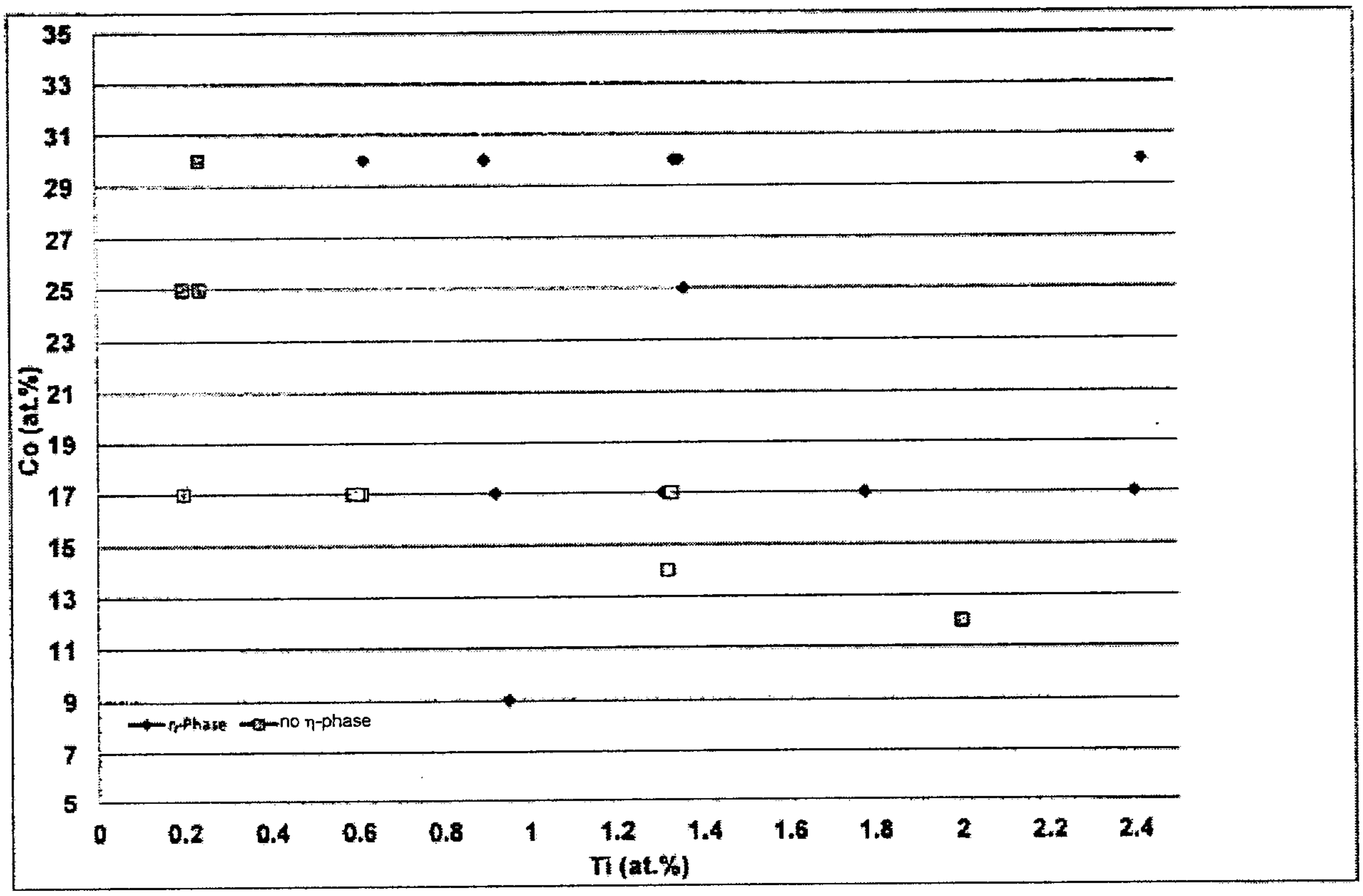

35
33
31
29
27
25
23
21
19
17
15
13
11
9
7
5
Co (at.%)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
Ti (at.%)
η-Phase
no η-phase

Fig. 4

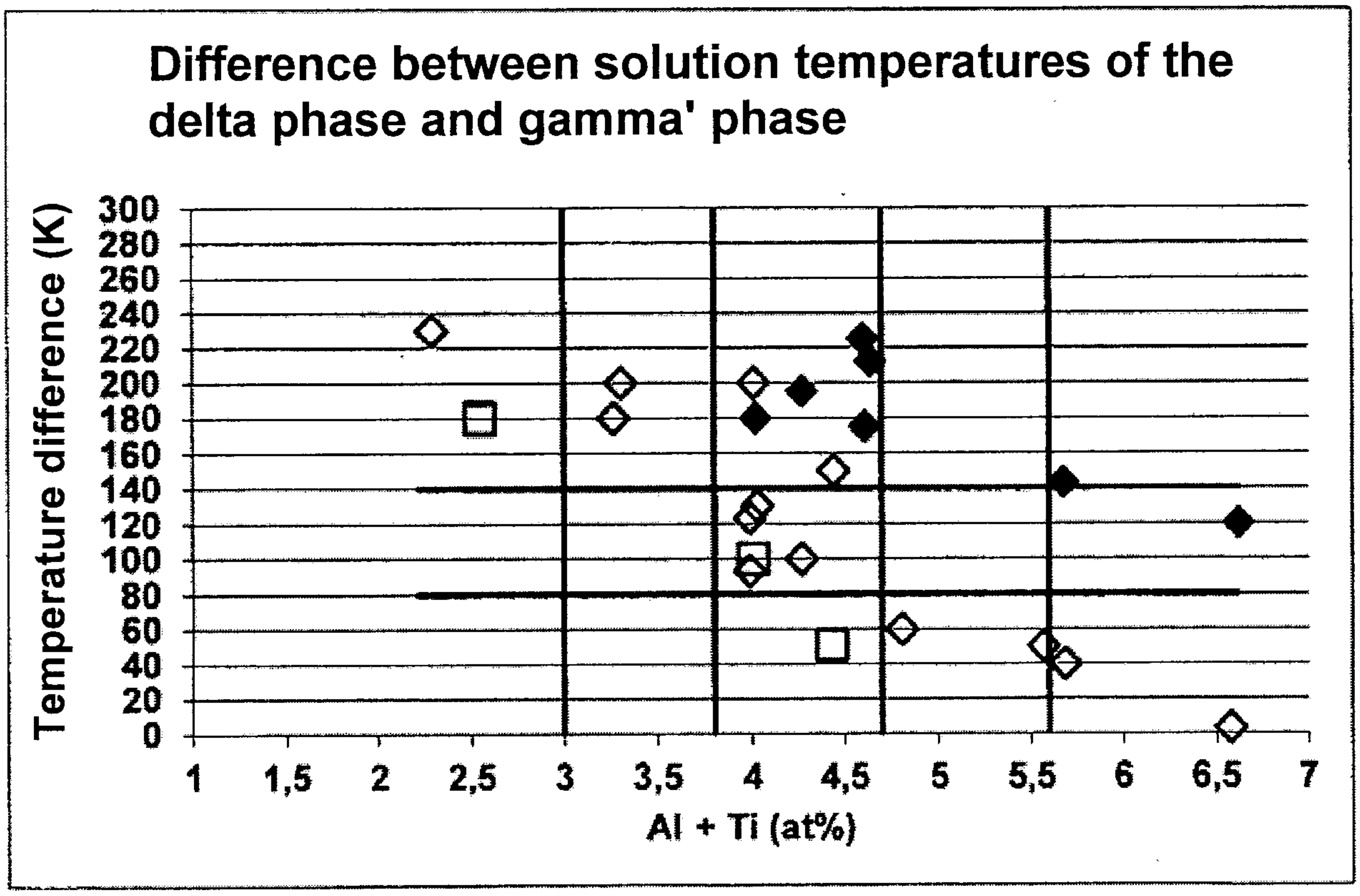

Difference between solution temperatures of the delta phase and gamma' phase
Temperature difference (K)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
6,5
7
Al + Ti (at%)

Fig. 5a L4 after 500 h / 800°C (top part of the figure)

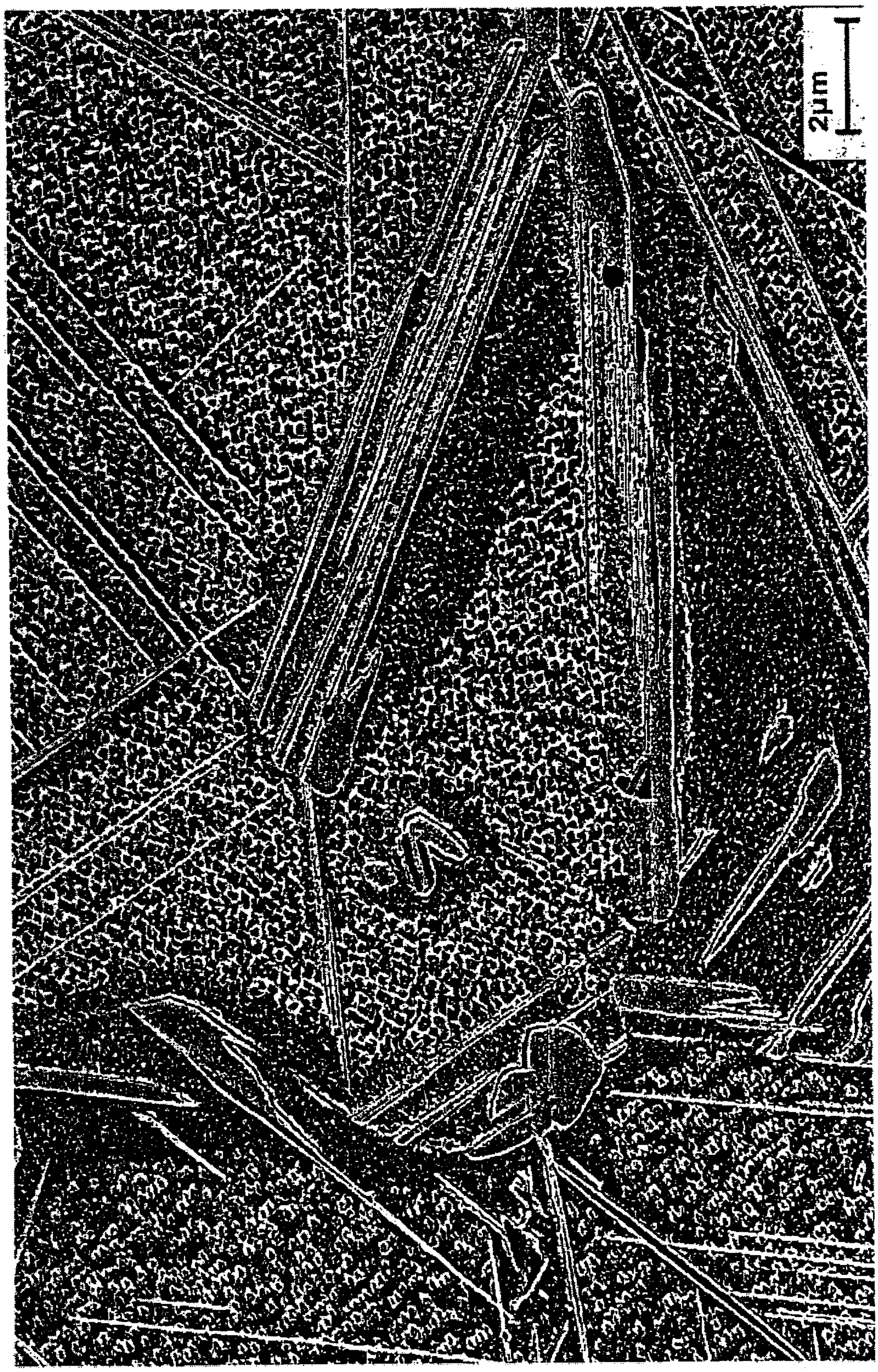


Fig. 5a L4 after 500 h / 800°C (bottom part of the figure)

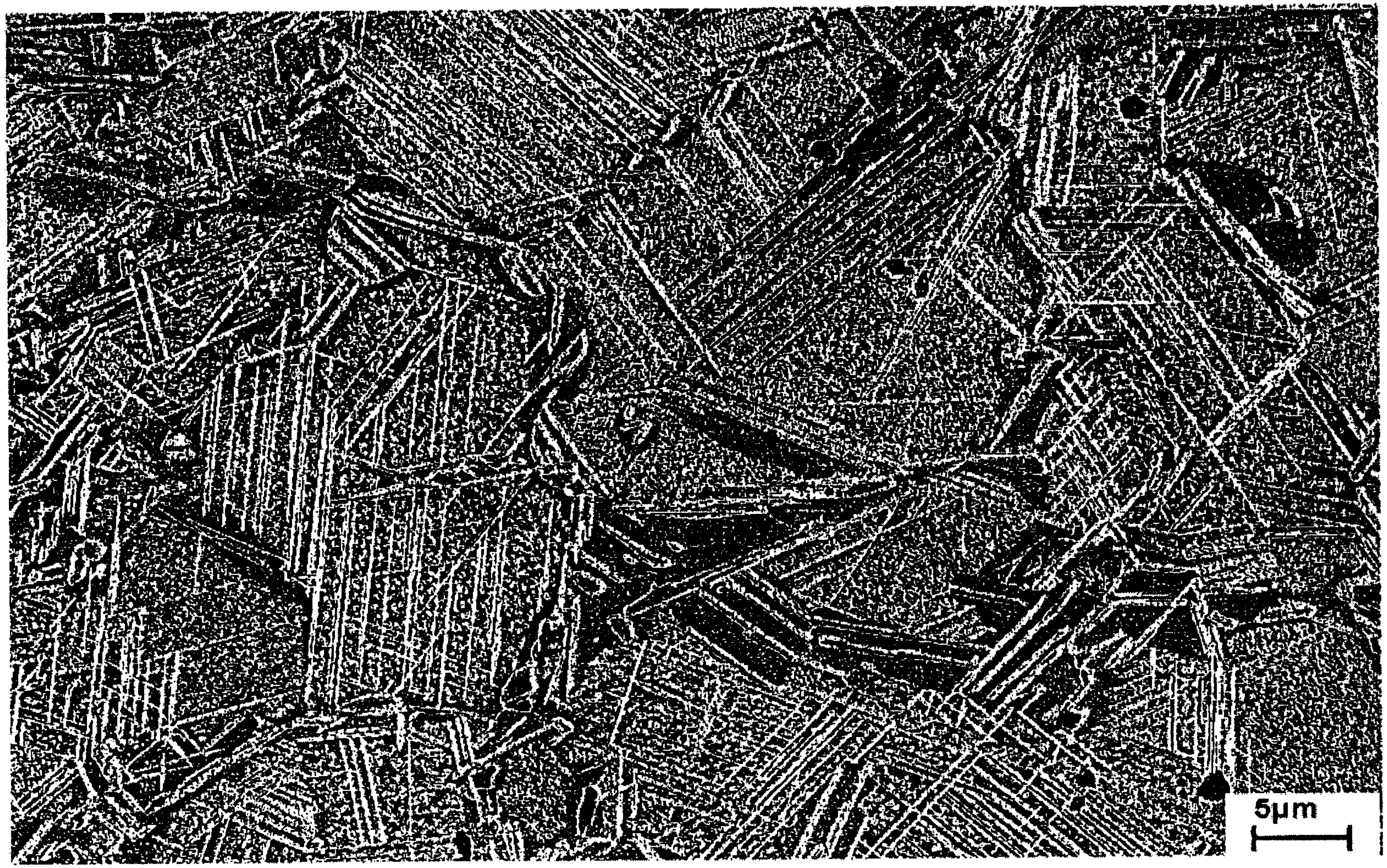


Fig. 5b V10 after 500 h / 800°C (top part of the figure)

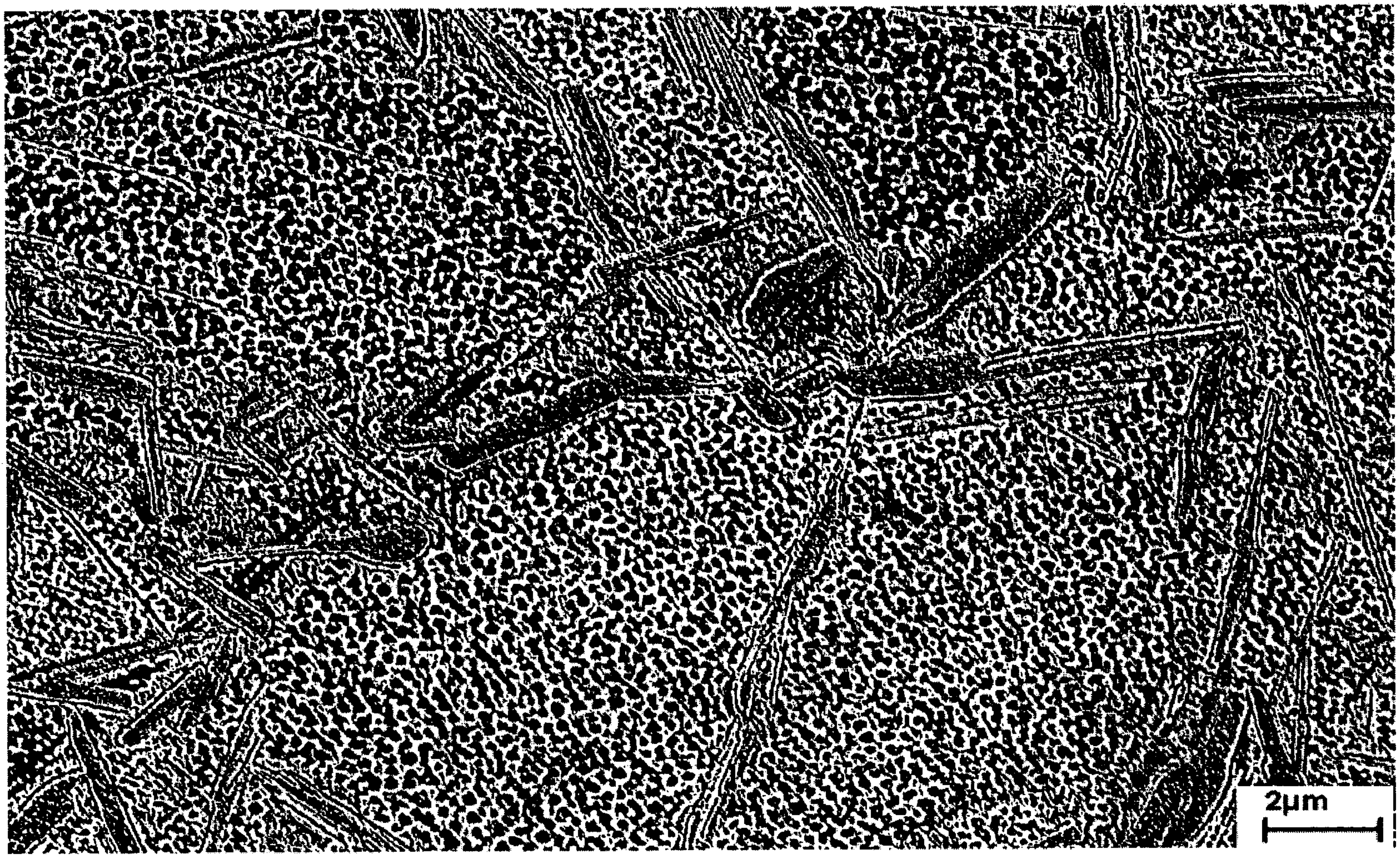


Fig. 5b V10 after 500 h / 800°C (bottom part of the figure)

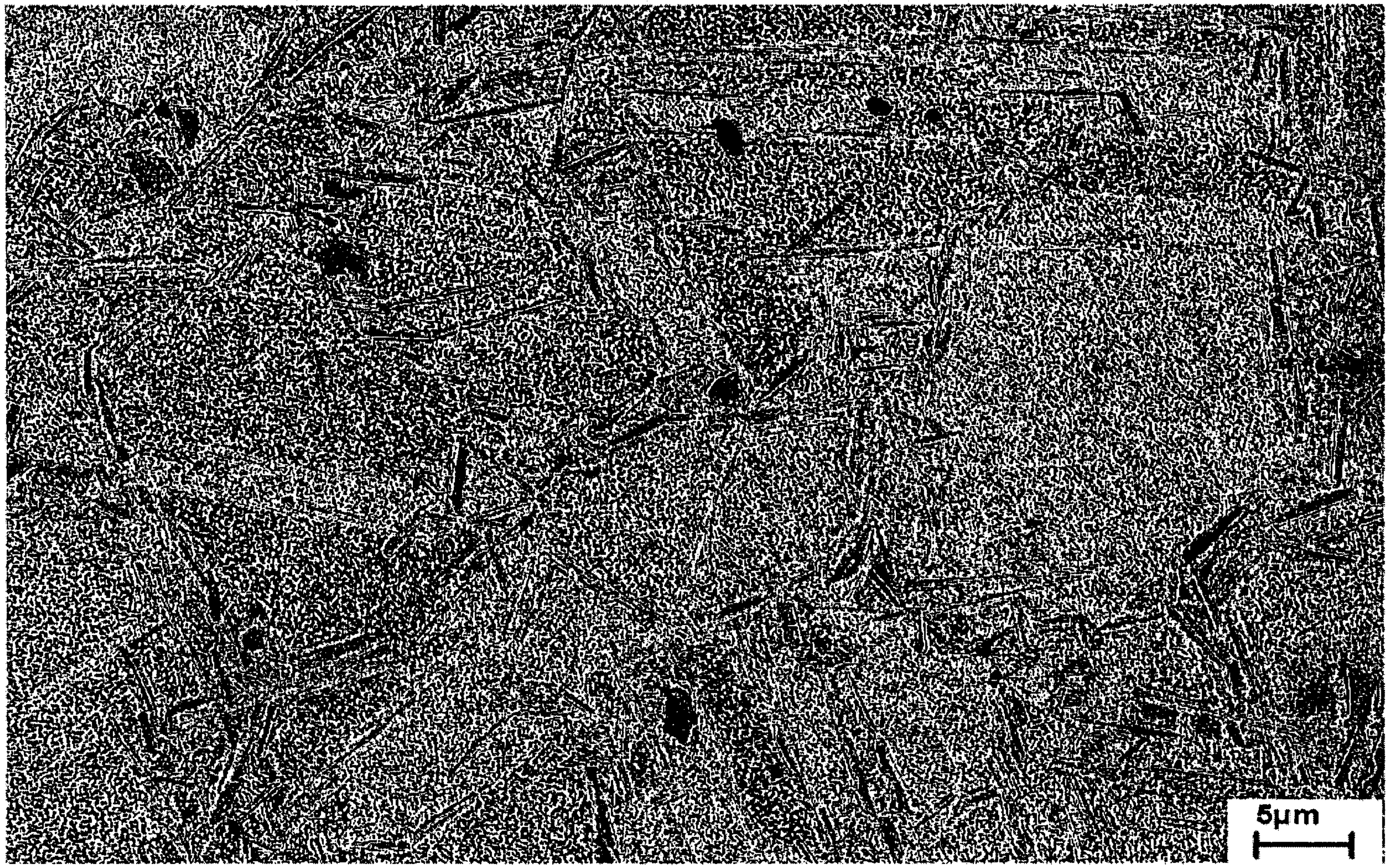
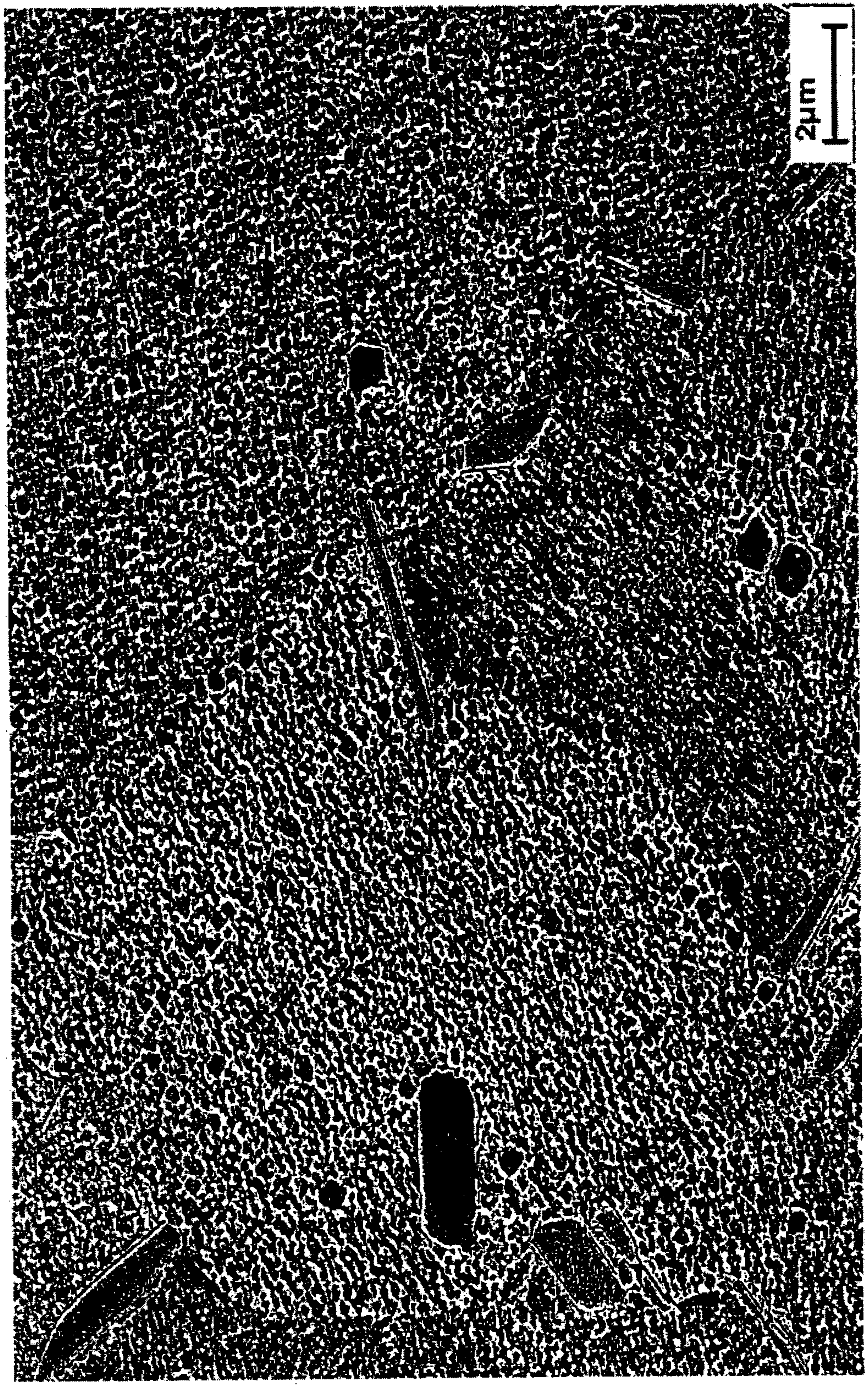


Fig. 5c V15 after 500 h / 800°C (top part of the figure)



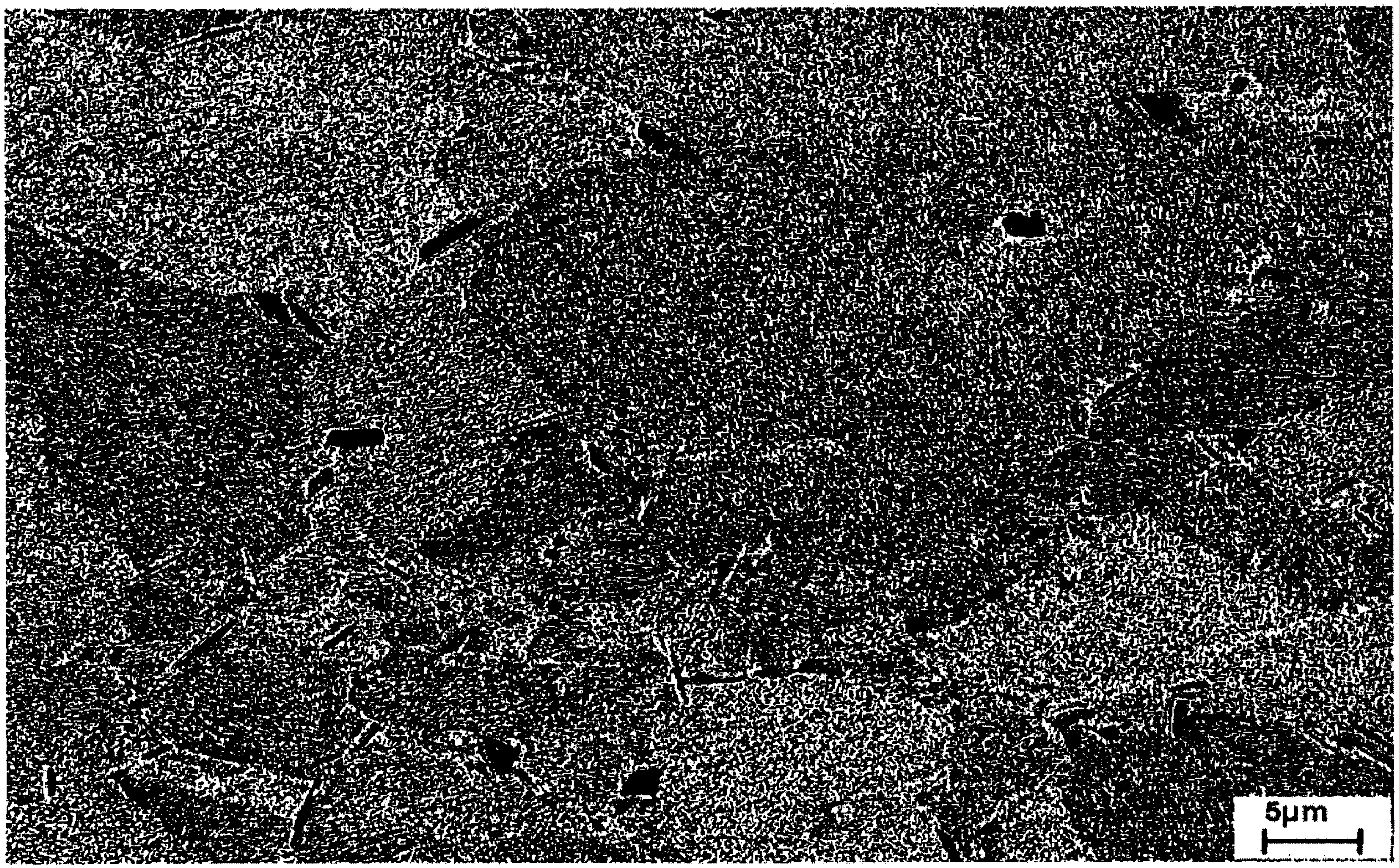


Fig. 5c V15 after 500 h / 800°C (bottom part of the figure)

Fig. 5d V16 after 500 h / 800°C (top part of the figure)

Fig. 5d V16 after 500 h / 800°C (bottom part of the figure)

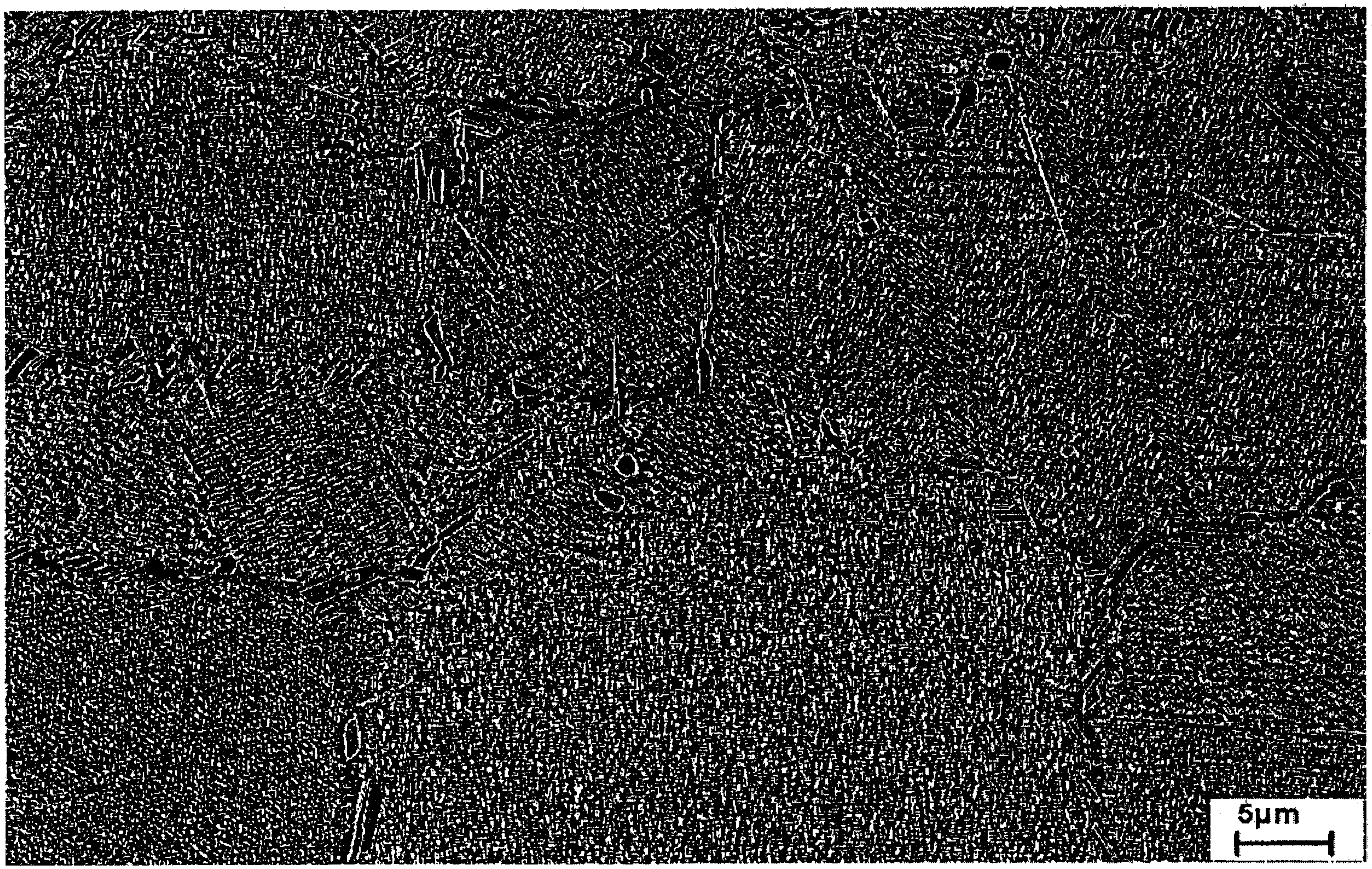


Fig. 5e V17 after 500 h / 800°C (top part of the figure)

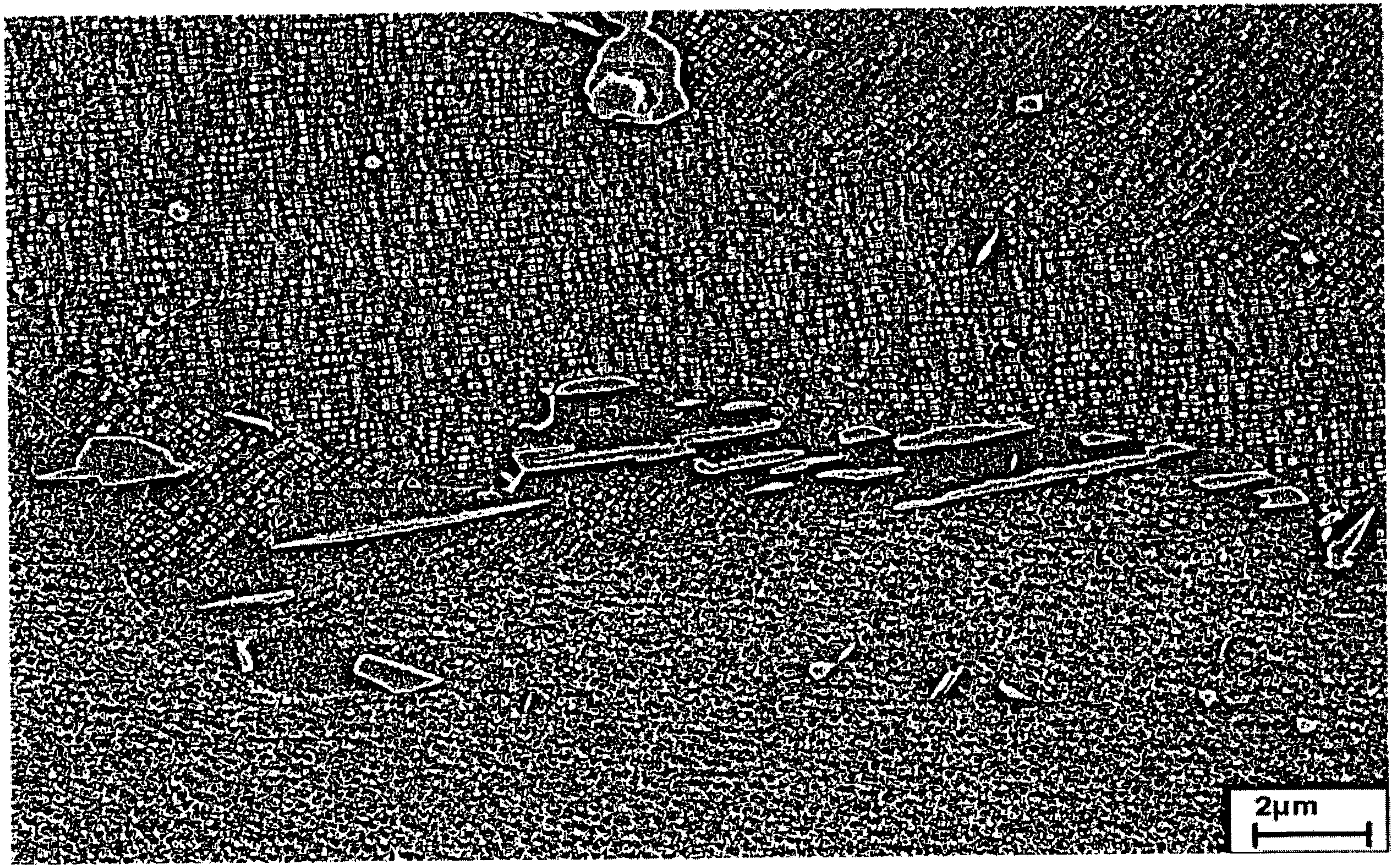
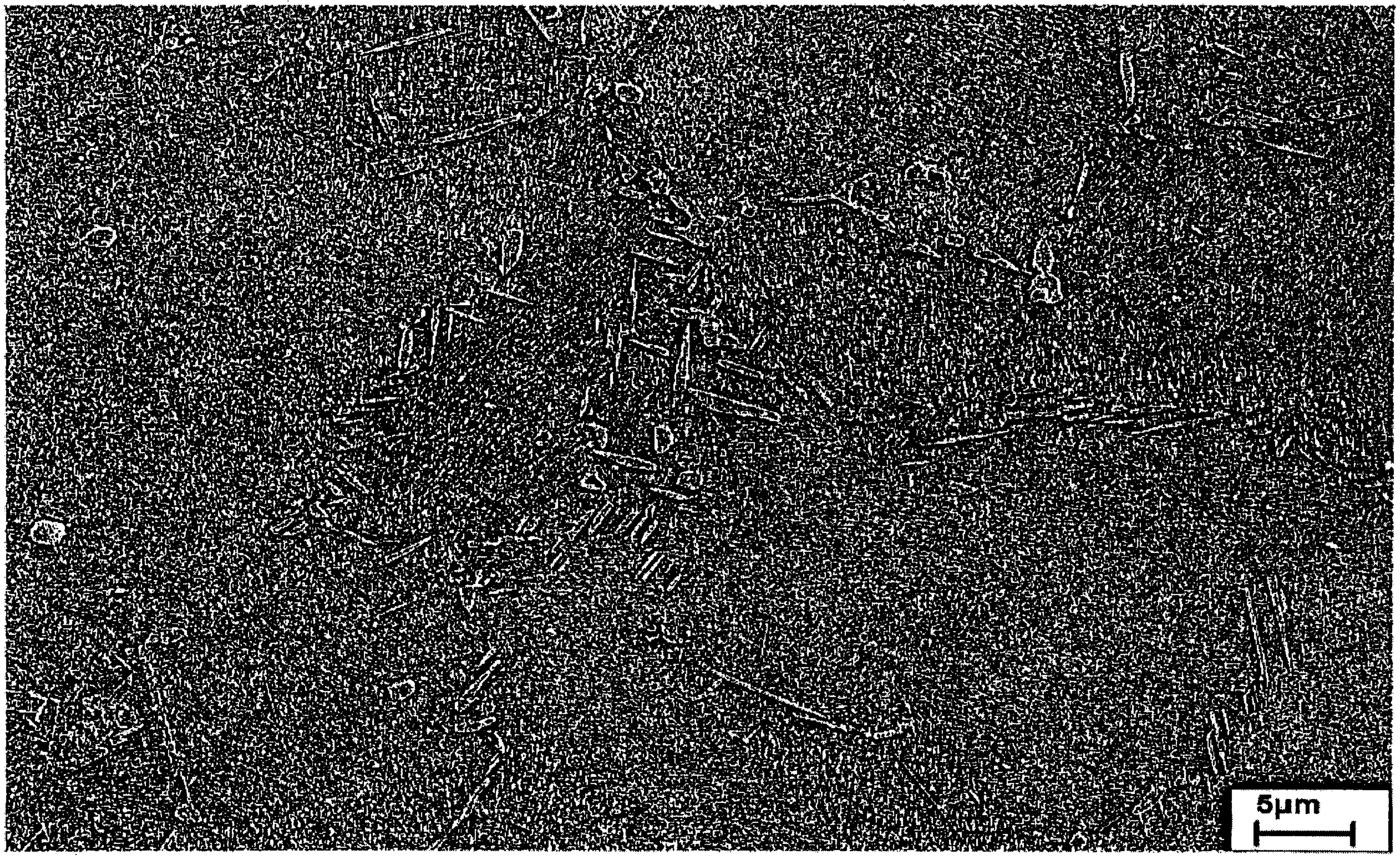


Fig. 5e V17 after 500 h / 800°C (bottom part of the figure)



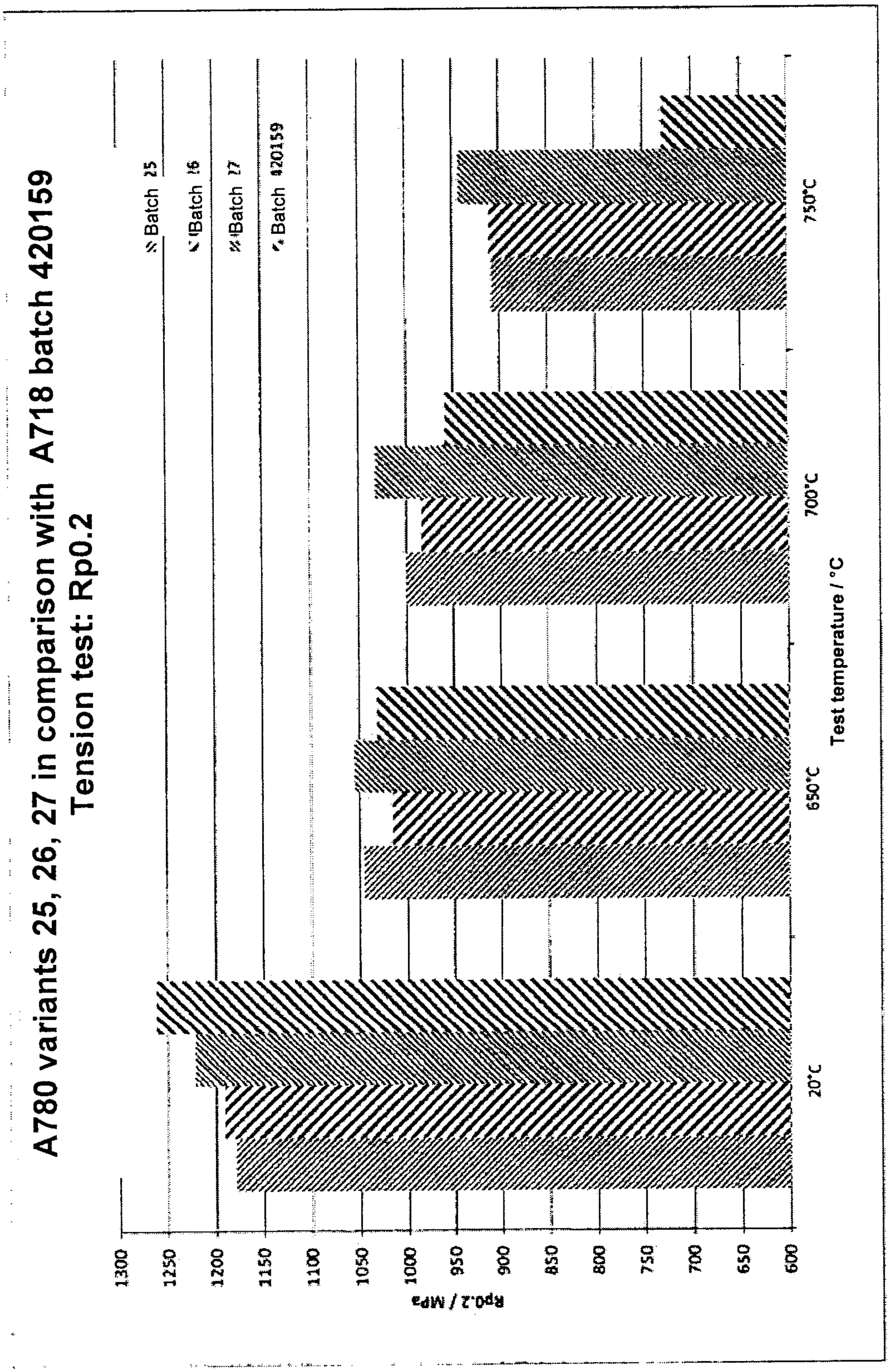

A780 variants 25, 26, 27 in comparison with A718 batch 420159
Tension test: Rp0.2
Batch 25
Batch 26
Batch 27
Batch 420159
Rp0.2 / MPa
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
20°C
650°C
700°C
750°C
Test temperature / °C

Fig. 6

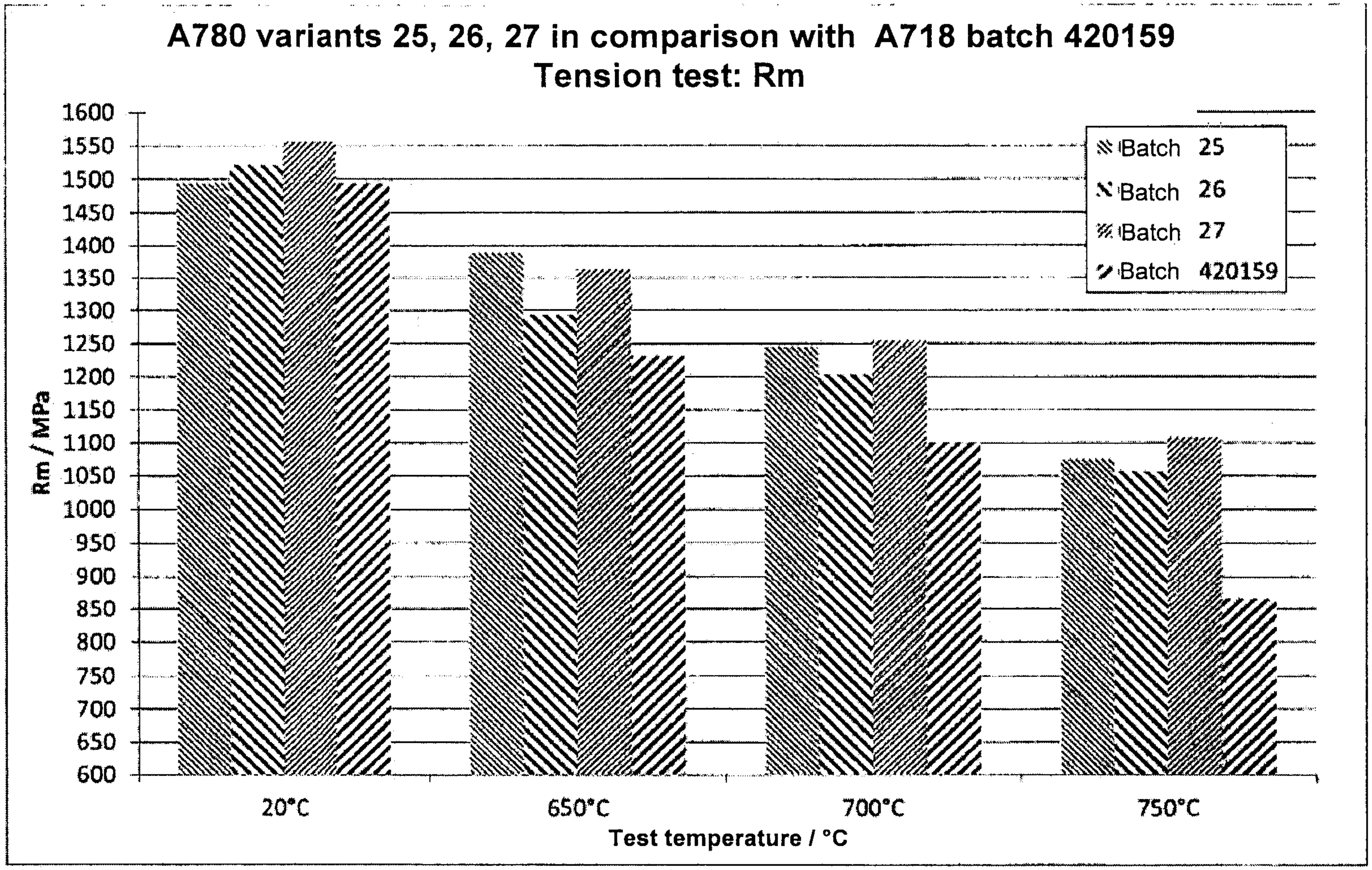

A780 variants 25, 26, 27 in comparison with A718 batch 420159
Tension test: Rm
Rm / MPa
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
20°C
650°C
700°C
750°C
Test temperature / °C
Batch 25
Batch 26
Batch 27
Batch 420159

Fig. 7