

Федеральное государственное бюджетное образовательное учреждение
высшего профессионального образования
«Южно-Уральский государственный университет»
(национальный исследовательский университет)

На правах рукописи



Маковецкий Александр Николаевич

ВЛИЯНИЕ ТЕРМИЧЕСКОЙ ОБРАБОТКИ В МЕЖКРИТИЧЕСКОМ
ИНТЕРВАЛЕ ТЕМПЕРАТУР НА СВОЙСТВА НИЗКОЛЕГИРОВАННЫХ
ТРУБНЫХ СТАЛЕЙ

Специальность:

05.16.01 – «Металловедение и термическая обработка металлов и сплавов»

Диссертация на соискание ученой степени
кандидата технических наук

Научный руководитель:
доктор физико-математических наук,
профессор Мирзаев Джалал Аминович

Челябинск - 2016

.....

1.14

1.1 . ,14

1.230

1.3 -40

.....40

1.452

253

2.153

2.253

2.354

2.455

2.557

2.657

359

3.159

3.259

3.364

3.465

3.5

.....69

3.6

.....70

3.7 « »73

.....73

3.879

481

4.181

4.2 ...82

4.383

4.4103

4.5 -

20.....104

4.6105

4.7107

4.8117

4.9

.....118

4.10119

4.11128

5

20 13130

5.1130

5.2130

5.3134

5.4 -143

5.5150

5.6151

5.7

(+)

.....152

5.7.1	.....	152
5.7.2	.....	152
5.7.3	13 .	.....159
5.7.3.1	.....	159
5.7.3.2	13	184
5.7.3.3	13	198
5.7.3.3.1	13 :1050 ° - ; 900 ° - , 830° 0,5	198
5.7.3.3.2	13 :1050 ° - ; 900 ° - , 800° 0,5	208
5.7.3.3.3	13 :1050 ° - ; 900 ° - , 800 ° 0,5	222
5.7.3.3.4	13 : 1050 ° - ; 900 ° - , 760 ° 0,5	228
5.7.4	.....	242
6	13 ,	.....245
6.1	.....	246
6.2	.....	256
7	20 2	258
7.1	20 2 .	

		.....	263
7.1.1		.....	263
7.1.2		.....	266
7.2	20 2	.....	286
7.2.1	20 2	: 900° 0,5 ,	286
7.2.2	20 2	: 1050° 0,5 , ; 900° 0,5 ,	..290
7.3		.....	311
8		-	313
8.1		13	
	16	.....	313
8.2		20	318
8.2.1		.....	321
8.2.2		.....	321
8.2.3		.....	325
8.3		.....	326
8.3.1		.....	327
8.3.2		.....	328
8.4		-	
	20 2	.....	333
8.4.1		.....	334
8.4.2		.....	335

.....340

.....343

.353

... , ... , ... , ... , ... ,
... , ... ,

.

,

.

.

,

.

,

.

,

.

,

.

-60° (KCV-60 50 / ²),

.

.

,

,

(

,

)

.

,

,

.

-

,

,

,

.

.

:

-

;

-

;

-

;

-

;

-

.

:

-

,

,
 , ;
 - ,
 ,
 -
 : ()
 1;
 .
 15—
 20° 1, (σ ,σ)
 ;
 - KCV ,
 ;
 - ;
 - ;
 , -
 , , ;
 - , 0,009%
 ,
 KCV, ,
 - ,
 ;
 - Fe₃C,
 .
 , :
 - ,
 ,

KCV-60

1.

2.

3.

(Mathcad)

· , ,

,

·

· · - · ·

· · ·

:

:

- XVI - « -

2008» (, 2008 .);

- XVII - « -

2009» (, 2009 .);

- VII «

» (, 2012 .);

- XXI - « -

2014» (, 2014 .).

8 , 7

,

·

·

5 1 « ».

·

2015 20 · ·

·

,

· · -

· · - · ·

. . . , . . .
 . . . , ,
 « » , :
 . . . , . . . , . . . , . . . , . . .
 , . . . , . . . , . . . ,
 - .
 .
 , 8 ,
 112 , 27 , 188 1
 . 353 .

1.

1.1

, Pcm (0,12%), ≤43% Pcm ≤ 0.23%.

$$C = + \frac{Mn}{6} + \frac{(Cr+Ni+Cu)}{5} + \frac{Mo}{4}, \% \quad (1.1)$$

$$Pcm = C + \frac{Si}{30} + \frac{Mn+Cu+Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B, \% \quad (1.2)$$

C, Mn, Si, Cr, Ni, Cu, Mo, V, B –

, .%.

($\sigma = 338,1 \dots 560$),

(KCV-50 29,4 / 2 ,

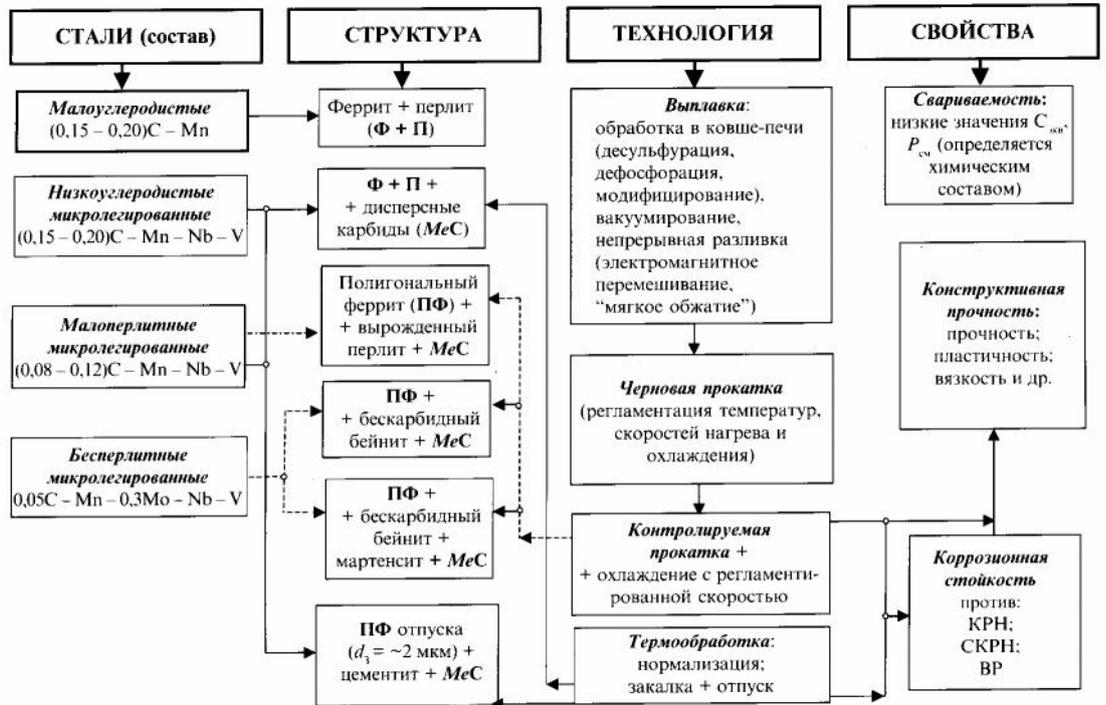
KCV-60 29,4 / 2),

- (

50%

),

[1].



. 1.1 -

[2]

Рсм

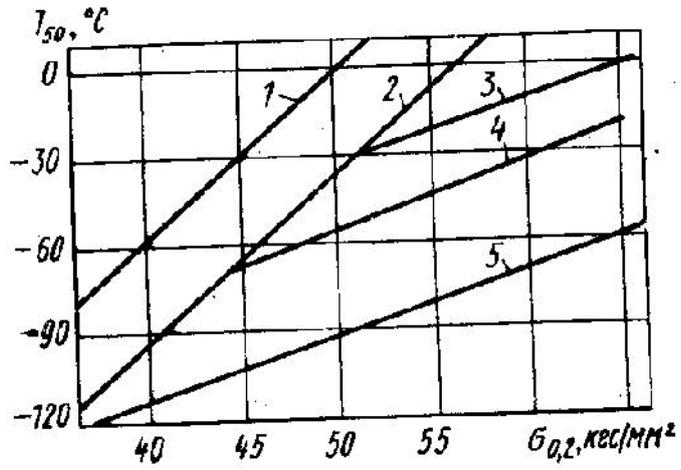
55-60 / 2

[3,

4].

[5-7],

[3]



. 1.2 -

1 -

; 2 -

; 3 -

; 4 -

; 5 -

[10-13, 16-22]

[14, 15]

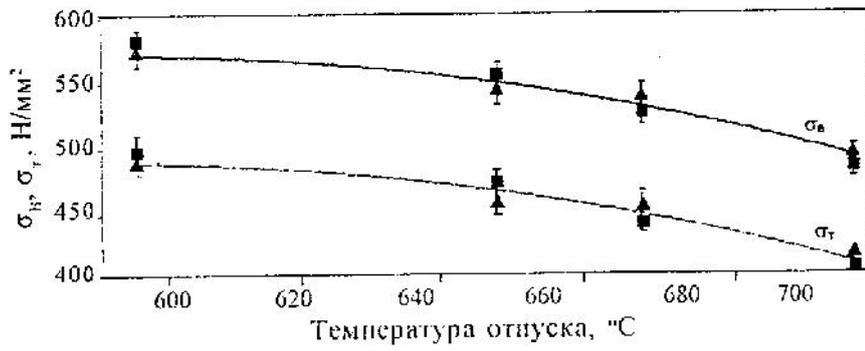
[12]

σ_{th}

NACE TM 0177

Ø168,3 12,7

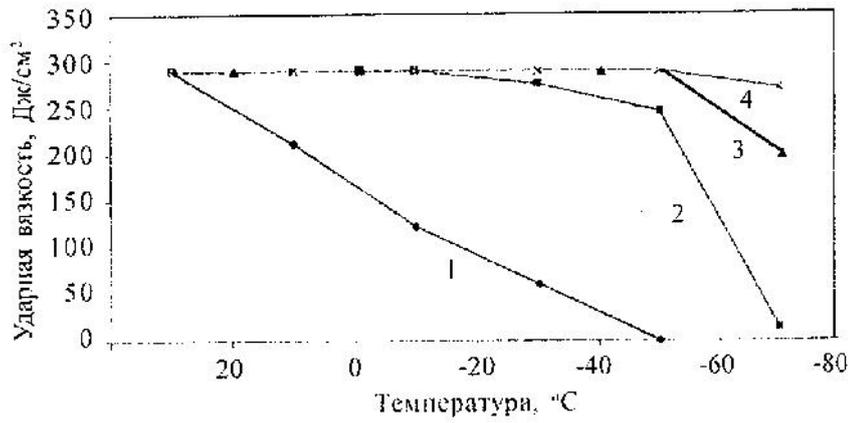
13



13

1.3 -

920 (■) 1000° (▲)



1.4 -

V 13, 1 - ; 2 -

; 3 - 920°, 670° ; 1000° ,

670° .

, [12]

σ_{th}

670°

1 . , 1000°

13

, 920°

($\sigma_{th}=0,95\sigma$

720

392

).

,

,

1000°

[14]

Ø219,1 15,4

Ø304,5 34 .

Ø219,1 15,4

10 ,

Ø304,5 34

10 .

10

10

.

,

,

10

$\sigma =460...560$

, $\sigma =540...630$

, $\delta=36...44\%$.

10

: $\sigma =463...569$

, $\sigma =561...633$

, $\delta=22...48\%$.

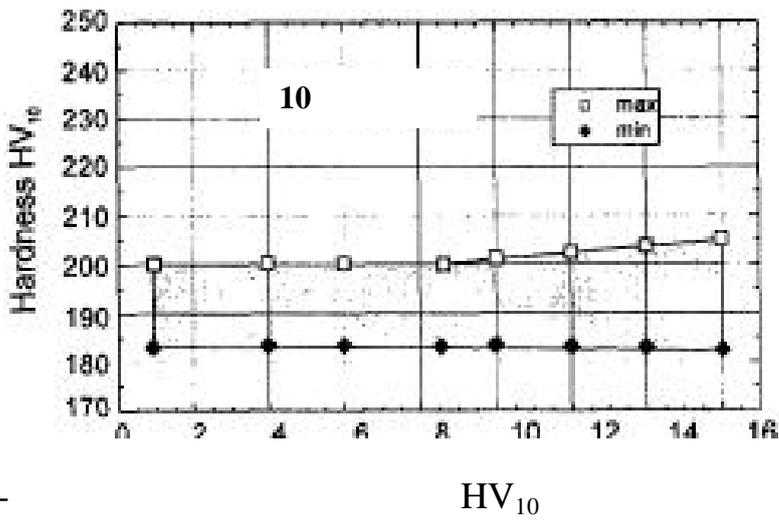
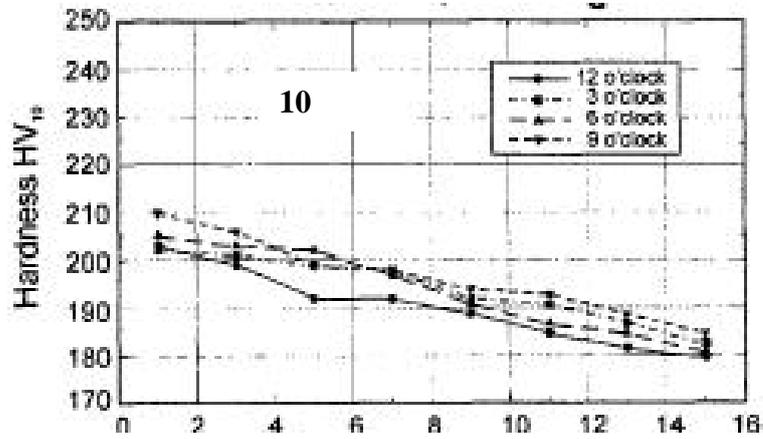
TM0284-96

10

10

, CLR=6.0%,

CTR=0.28%.



. 1.5 -

HV₁₀

(10 Ø219,1 15,4 ,

10 Ø304,5 34 ,).

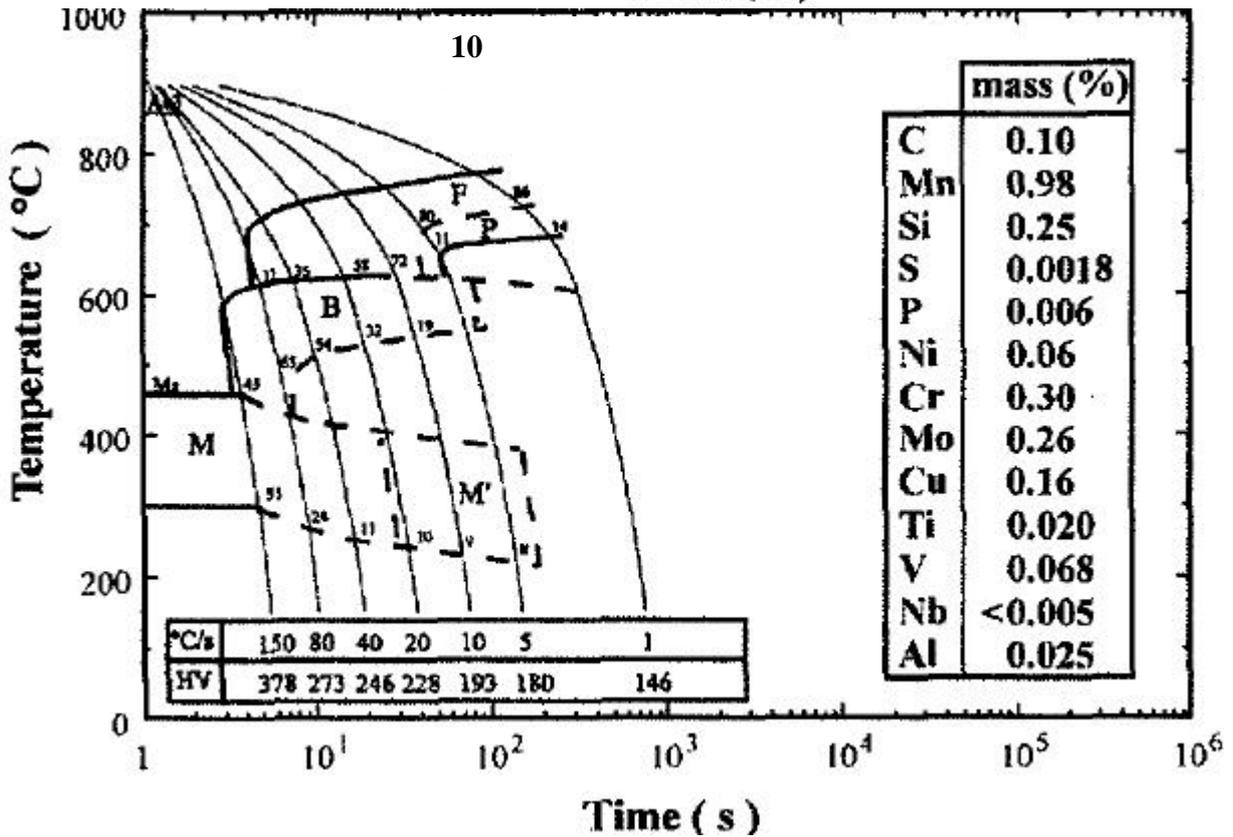
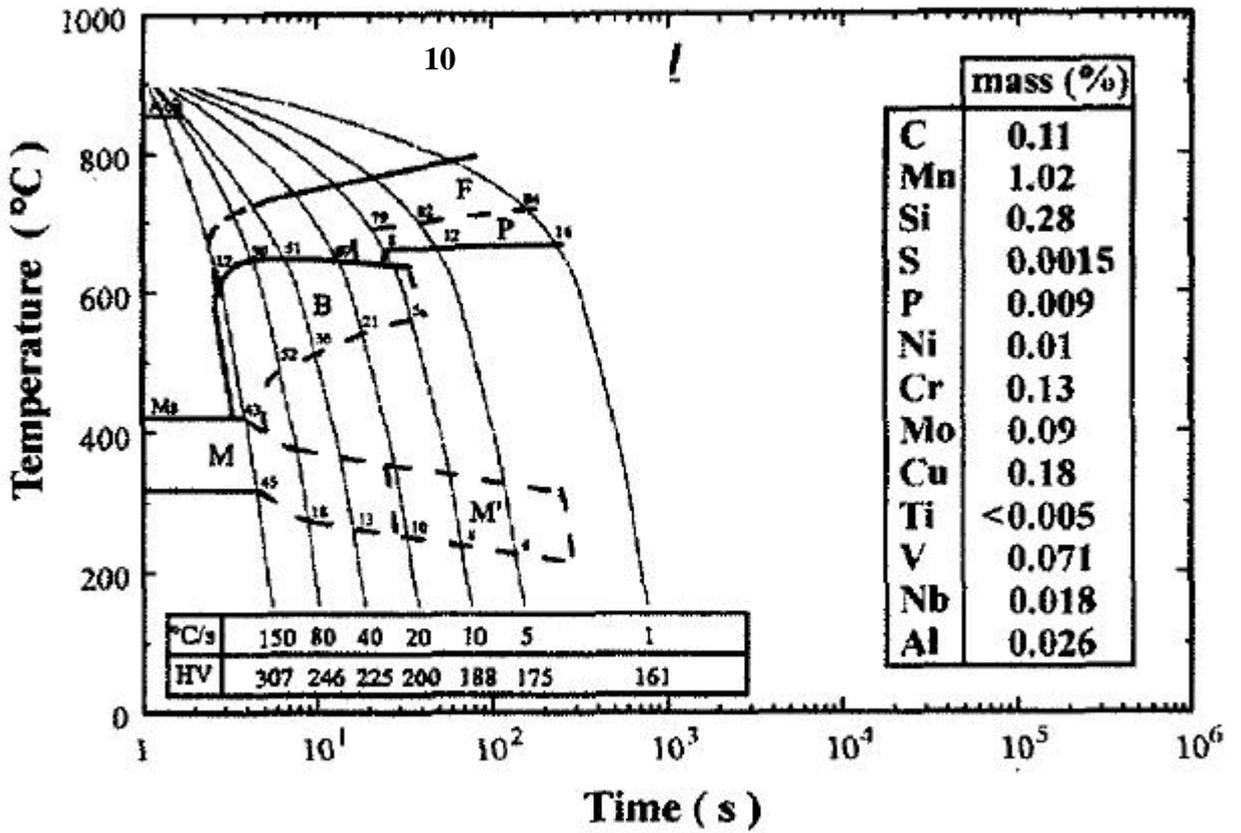
10

12 , 3 , 6

, 9 .

10

-



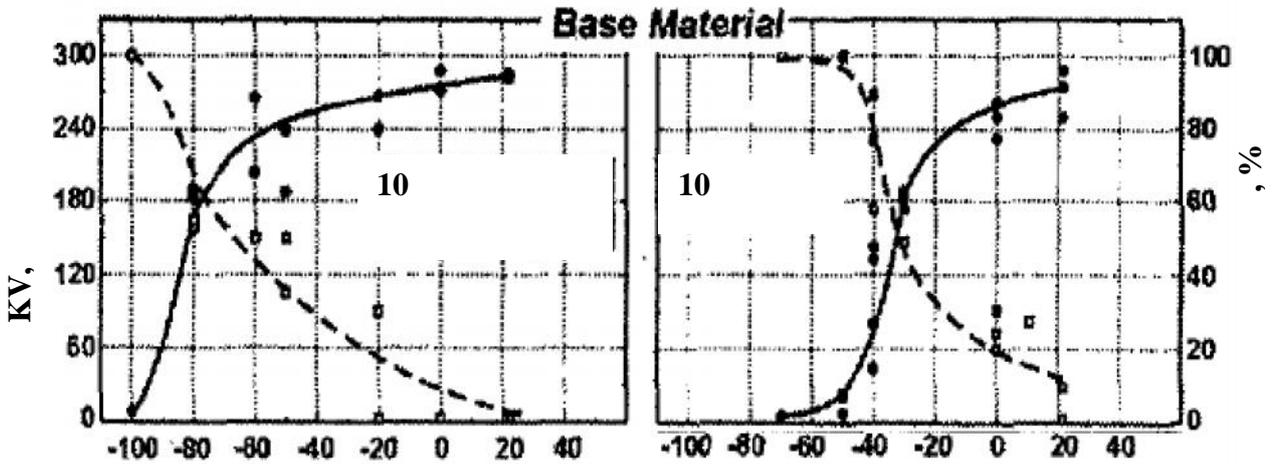
. 1.6 -

10 10

1.5 1.6 ,

20° / .

10%,



. 1.7 -

KV (•)

(o)

10

10

. 1.7

10

[10]

10

20

1200° ,

900° ,

(

)

660° .

273 18

-60°

900° ,

900°

900° .

[10]

· , «
 ,
 ...

— ». [10]

: « 1⁻ 3
 α- γ- Mn, C, Al, S

, , — .
 , ...

».

[11, 13]

, + ,
 , KCV-70,
 ,

20

Ø114 9 .

(
). [11, 13]

($\sigma = 365$, $\sigma = 539$, $\delta_5 = 32,5\%$, $KCV-70 = 251$ / 2 ,

, $\sigma_{th} = 0,8\sigma$, $K_{1ssc} = 51 \pm 6,2$) ,

($\sigma = 397$, $\sigma = 560$, $\delta_5 = 29,7\%$, $KCV-70 = 251$ / 2 ,

, $\sigma_{th} = 0,75\sigma$, $K_{1ssc} = 43 \pm 6,7$). [11, 13]

, [10],

,

. [11]

[9]

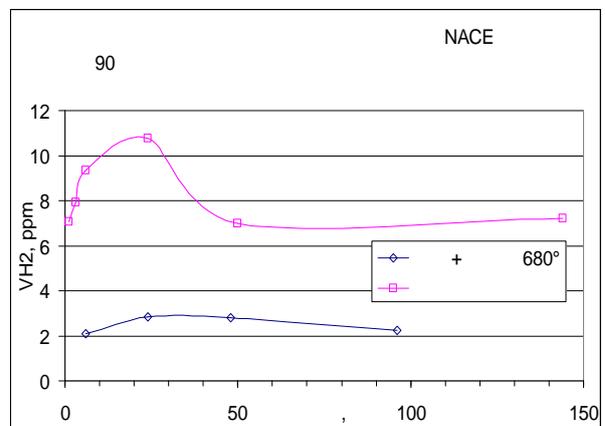
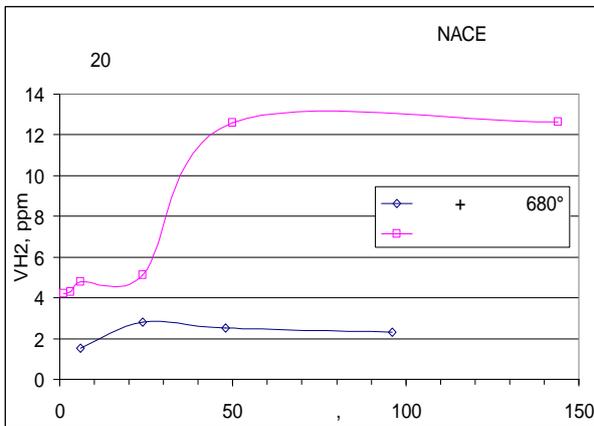
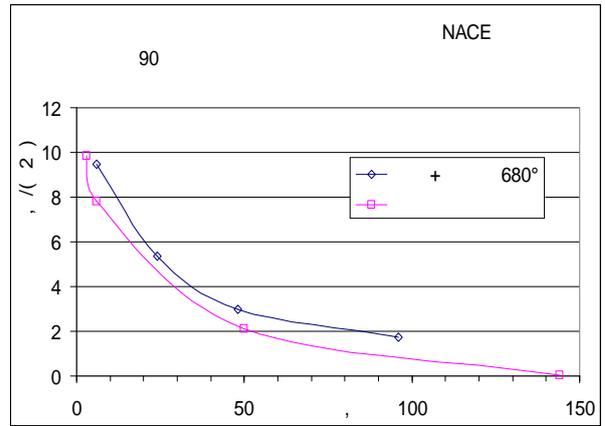
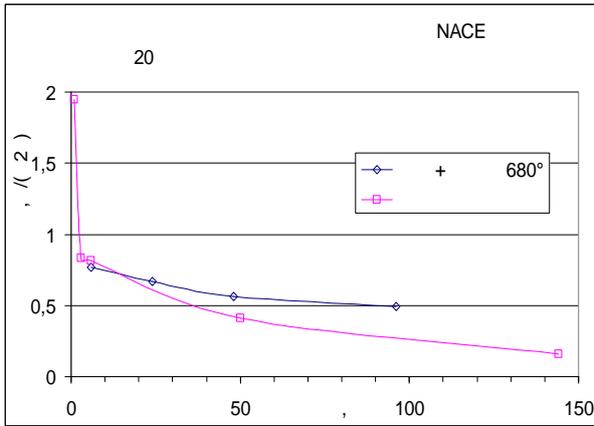
20

770°)

680° .

NACE (5%NaCl, 0.5%CH₃COOH).

. 1.8.



. 1.8 -

NACE

[9]

3

)

)

3-5

;

;

)

,

.

- [15]

65

API 5L [1].

40

:

0.05-0.14% , 0.15-0.35 %Si, 1.0-1.5 %Mn, 0.25% Mo, 0.01-0.04% Al,

0.08 %V, 0.04 %Nb, 0.25 %Ni, 0.25 %Cu, 0.005 %S, 0.020 %P,

 ≤ 0.38 ,

KV-40

150

80%.

-

25 : $\sigma_{th} 0,85\sigma$,25 : $\sigma_{th} 0,72\sigma$.CLR \leq 10%, CTR \leq 3%.

,

,

,

-

650-800

,

KCV-20 -

80-

100 / ².

[16]

-

,

,

,

Ø1020 9...11

() .

180-250 ^{3/}0,35...0,50 / ² (3,5-5) .

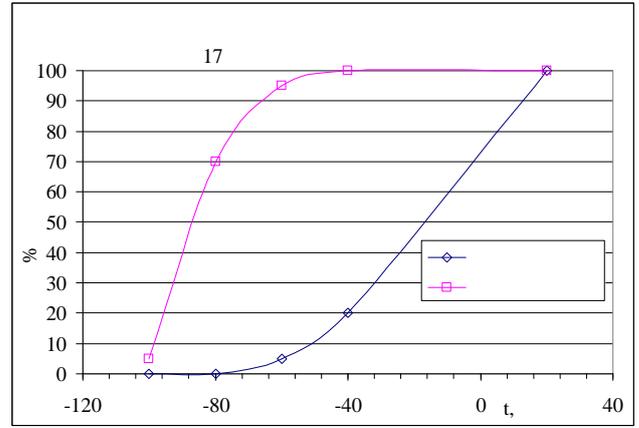
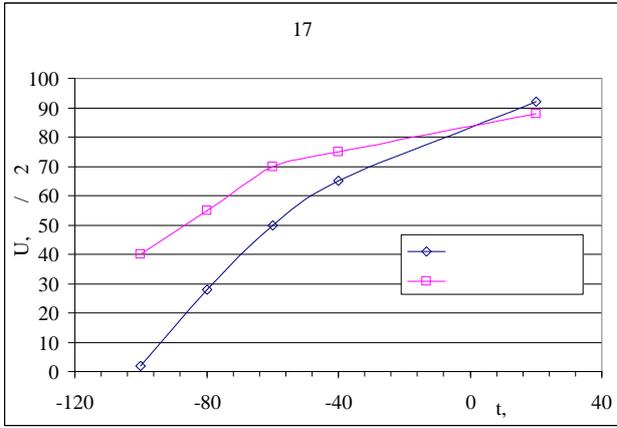
17 .

870-

1040° ,

530-630° .

: σ 412-431 (11-10
), σ 627 , δ_5 16%, KCU-40 40 / 2 .



. 1.9 -

17

50%

60° .

16 , 17 1

[16,

17, 18].

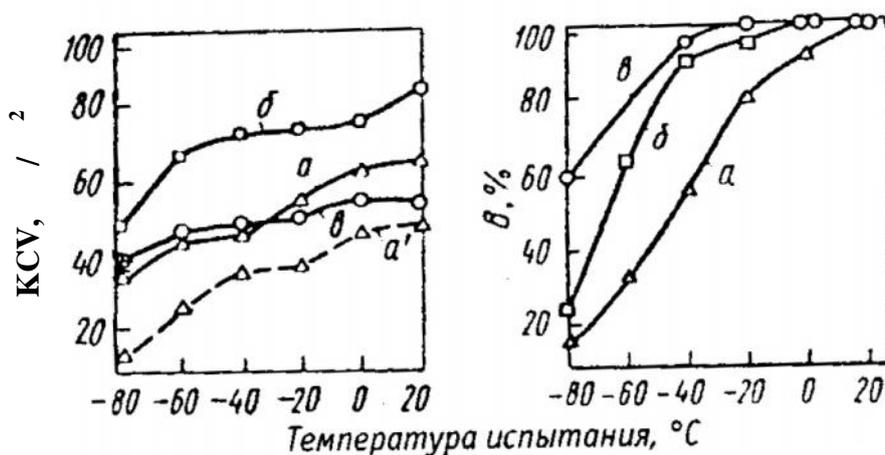
720 3 /

\varnothing 820...1420 8...15

17 1

σ =420...500 ,

σ =650...720 , δ_5 =16...18%, KCV-15...-40=130...200 / 2 [16].



. 1.10 -

17 1

, (KCV) - C = 0,37%; 0,01% Al; - = 0,37%; 0,06% Al; - = 0,46; 0,06% Al

17 1

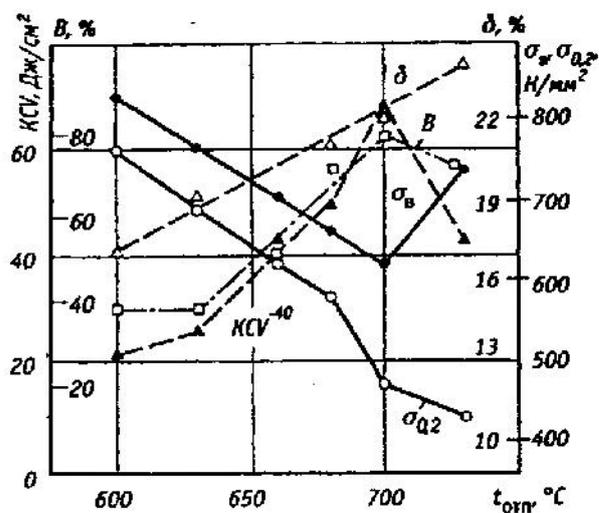
[19]

16

920°

600-730°

1



. 1.11 -

KCV-40,

sigma,

sigma_0,2

delta

[5, 20, 21]

Ø1420 14

16

900-940°

650-660°

2 .

:

$\sigma = 637...647$, $\sigma = 735...764$, $\delta_5 = 21...23\%$, $KCV-15 = 147...169$ / 2 ,
100%.

17 1 , 16 . ,

[10, 22, 23]

17 , 13 1 - , 10 2 , 09 2

[10],

[22].

[9]

1%

[10, 11]. ,

(- , - , , ,)

(0.9-1.8% Mn)

API 5L

1.65% [1].

, 80 ppm, 20 ppm

[1, 14, 15].

[11].

450°)

[20],

(

[17].

90°

550

,

,

,

.

1.2

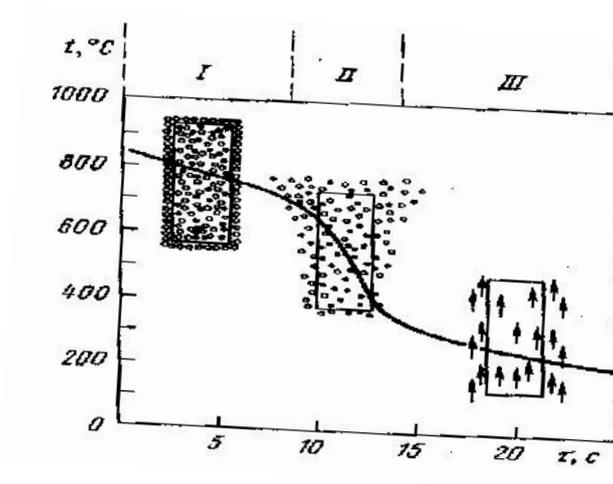
[24].

48- 60 [13].

48- 60

[25].

[25].



. 1.2.1 -

[25]. I -

, II -

, III -

:

$$-\} \frac{\partial T}{\partial r} = r(T - T_s); \tag{2.1}$$

} - ; - ; r - ; r -
 ; - .
 [24, 26, 27],

=f(T) ,
 , . . .
 .
 .
 , ,
 ,

1

1.2.1

, $\frac{\quad}{2}$

Mitsutsuka	$r = 2,292 \cdot 10^8 \cdot W^{0.616} \cdot [s]^{-2.445}$	[28]	$W, \frac{\quad}{2}$ (10÷2000) $[s, ^\circ C (400 \div 800)]$

Sasaki	$r = (708 \cdot W^{0.75} \cdot [t_s]^{-1.2} + 0,116) \cdot 1163$	[29]	$W, \frac{---}{2} (2 \div 42)$ $[t_s, ^\circ C ($ $1200)$
Ishiguro	$r = 0,581 \cdot W^{0.451} \cdot (1 - 0,0075 \cdot [t_w]) \cdot 1163$	[30]	$W, \frac{---}{2}$ $[t_w, ^\circ C$
Nozaki	$r = 1,57 \cdot W^{0.55} \cdot (1 - 0,0075 \cdot [t_w]) \cdot \frac{1}{a} \cdot 1163$	[31]	$W, \frac{---}{2}$ $[t_w, ^\circ C$ $a=4$
Bolle	$r = 0,423 \cdot W^{0.556} \cdot 1163$	[32]	$W, \frac{---}{2}$
Shimada, Mitsutsuka	$r = 1,57 \cdot W^{0.55} \cdot (1 - 0,0075 \cdot [t_w]) \cdot 1163$	[33]	$W, \frac{---}{2}$ $[t_w, ^\circ C$
Bolle, Moreau	$r = 0,360 \cdot W^{0.556} \cdot 1163$	[34]	$W, \frac{---}{2}$
Mizikar (1)	$r = 0,0776 \cdot W \cdot 1163$	[35]	$W, \frac{---}{2} (3 \div 23,3)$ $[t_s, ^\circ C ($ $1094)$
Mizikar (2)	$r = 0,1 \cdot W \cdot 1163$	[35]	$W, \frac{---}{2} (3 \div 23,3)$ $[t_s, ^\circ C ($ $1094)$
Hodgson	$r = 3,15 \cdot 10^6 \cdot W^{0.616} \left(700 + \frac{[t_s] - 700}{\exp\left(\frac{[t_s] - 700}{10}\right) + 1} \right)^{-2.455} \times$	[36]	$W, \frac{---}{2} (0,16 \div 62)$ $[t_s, ^\circ C (150 \div 900)$

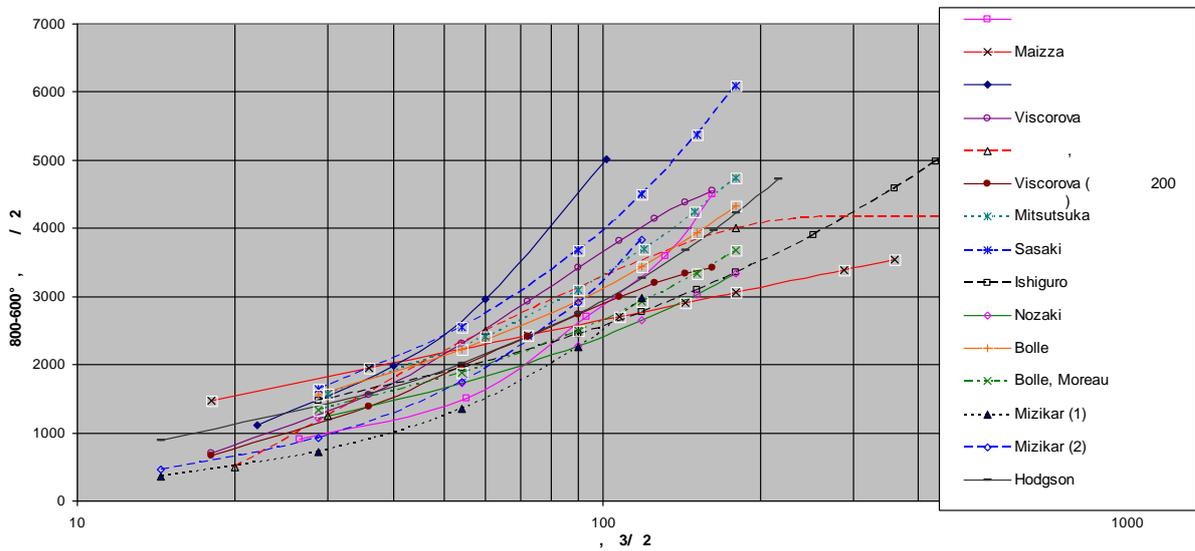
	$\times \left(1 - \frac{1}{\exp\left(\frac{[L_s - 250]}{40}\right) + 1} \right) \cdot 1163$		
Viscorova	$r = [190 + \tanh\left(\frac{W}{8}\right) + (140 \cdot W \cdot (1 - \frac{W \cdot \Delta T}{72000}) + 3.26 \cdot \Delta T^2 \cdot (1 - \tanh\left(\frac{\Delta T}{128}\right)))] \cdot 1,163$	[37]	$W, \frac{1}{2} (3,8 \div 30)$ $\Delta, ^\circ$

: W -

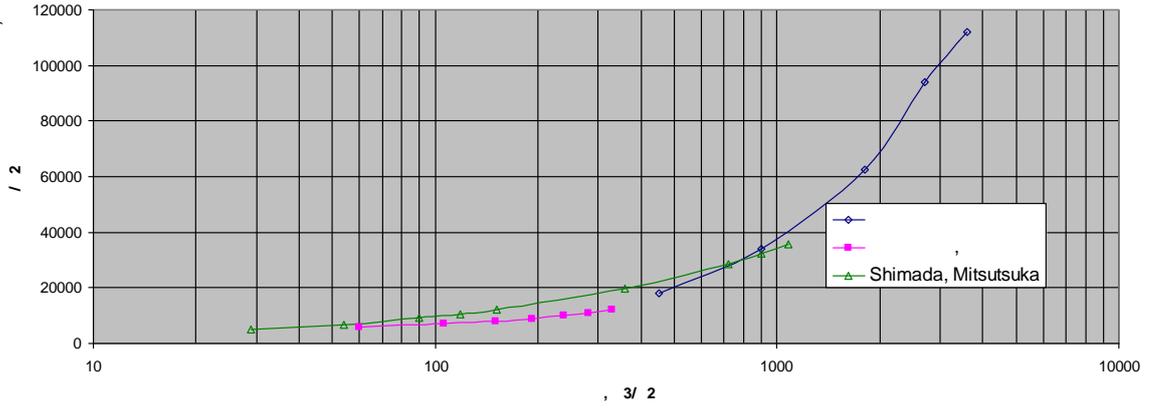
; [L_s, [L_w, Δ -

,
:
1163 (1 / =1,163*10³) 1,163 (1 / =1,163).

. 1.2.2 , .



)



)

. 1.2.2 -

$$(1 \quad / \quad = 1,163 \cdot 10^3 \quad)$$

[24,28-39]

$$900-600^\circ \quad 40-200 \quad \frac{3}{2} \quad (1,5 \div 7) \times 10^3$$

$$\frac{1750 \div 8140}{2} \quad (\quad . \quad 13).$$

$$r, (4 \div 15) \times 10^3 \quad \frac{4652 \div 17445}{2} \quad [40,41]$$

$$(\quad . \quad 13 \quad).$$

$$r \quad [42].$$

[42-47]

[43]

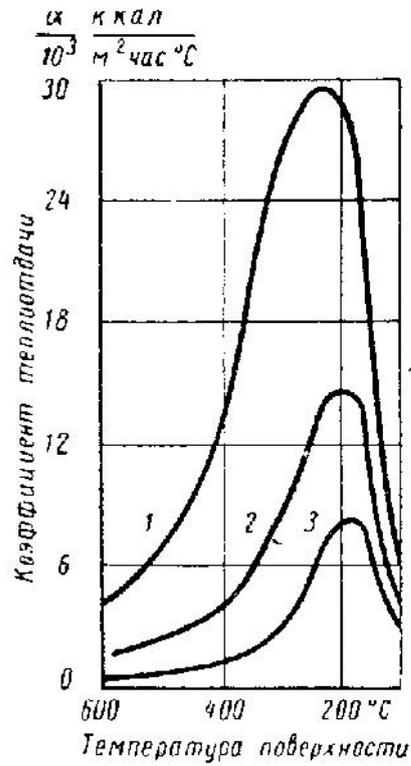
$$860-900^\circ \quad 150-80^\circ$$

$$r \approx 3,35 \cdot 10^5 R, \quad 2.2$$

, R -

$$\frac{3}{2}; \Gamma -$$

$\frac{3}{2}$.



. 1.2.3 -

[43]

:

$$1 - 0,06-0,064; 2 - 0,033-0,042; 3 - 0,014-0,017 \frac{3}{2}.$$

[43]

0,06-0,064

$$\frac{3}{2}$$

:

[44]

36 2 40 Ø63-73 3,5...11

[44]

$r, \frac{1}{2 \cdot 0}$

:

$$r = \frac{3 \cdot g \cdot c_p \cdot \ln \frac{t_0 - t}{t_k - t}}{3 \cdot \left\{ - \frac{g \cdot c_p \cdot u}{t_k - t} \cdot \ln \frac{t_0 - t}{t_k - t} \right\}}, \quad 2.3$$

$g -$

$; c_p -$

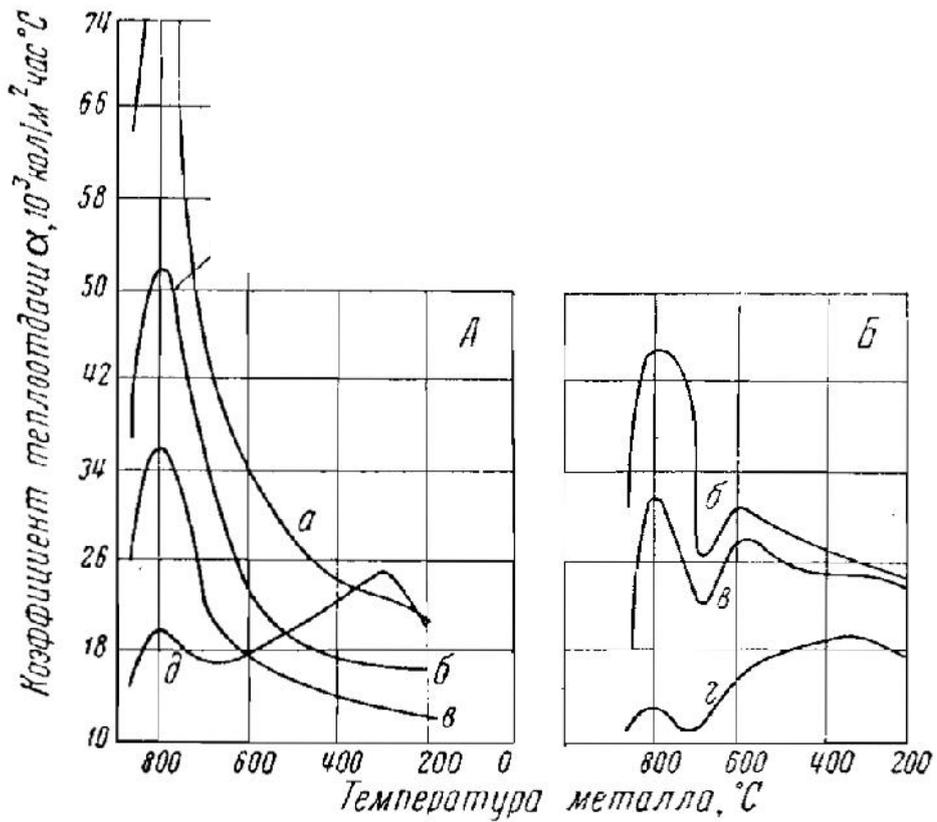
$; \ddagger -$

$; \} -$

$; u -$

$; t_0 \quad t_k -$

$; t -$



. 1.2.4 -

9() 11()

[44] (1 / =1,163*10³):

-3,0; -2,2; -1,5; -0,8; -0,8-0,6 / ².

[45]

,

3

5,8*10⁵

:

$$\frac{\partial T}{\partial \ddagger} = a \cdot \frac{\partial^2 T}{\partial h^2},$$

2.4

T - ; † - ; h -

$$, a = \frac{\}}{c \cdot \dots} -$$

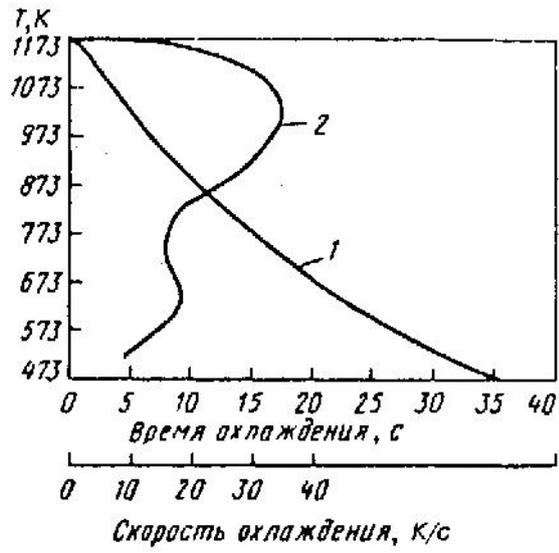
; -

; ... -

720-360°

$$- 2,8 \cdot 10^3 \frac{\quad}{2} .$$

$$6 \cdot 10^3 \frac{\quad}{2} .$$



. 1.2.5 -

Ø1420 14

1 -

:
; 2 -

[46]

2-2,5

r

1.3

,

,

,

[9, 10, 11,

13]

(1... 3)

[11, 48].

[49].

[11, 50, 51]

[50, 52]

[53]

, 40-100%

30

3. [54]

28

3,

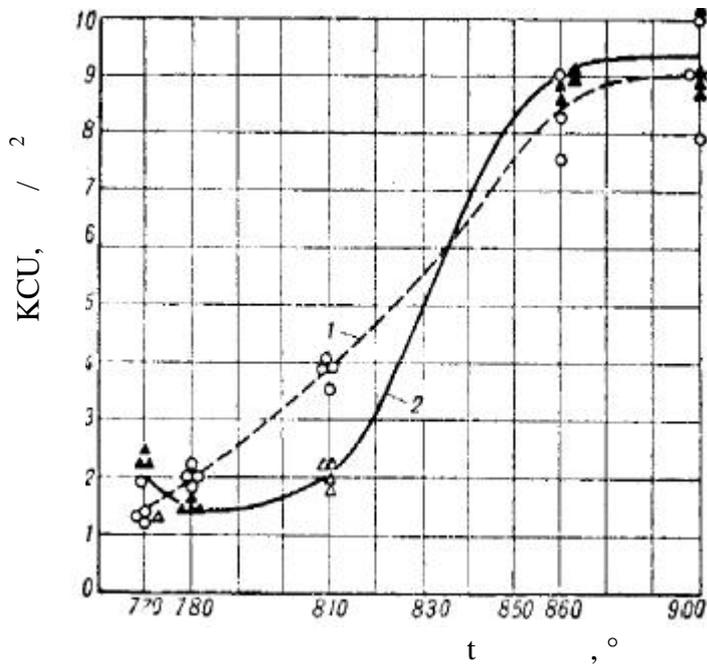
(36°)

50%

[55].

15 .

900° ,



. 1.3.1 -

15 ,

1 -

-

, ; 2 -

-

(. 1.3.1)

1

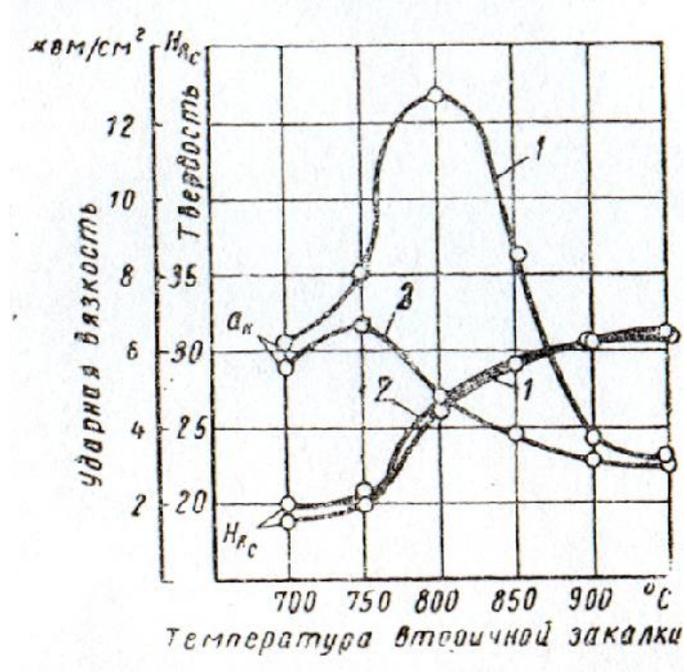
3 -

[55]

30 .

+

,
 .
 .
 +
 .
 ,
 .
 . .
 30 [56].
 , [56] , «
 ,
 ».
 . [57]
 35 :



1.3.2 -

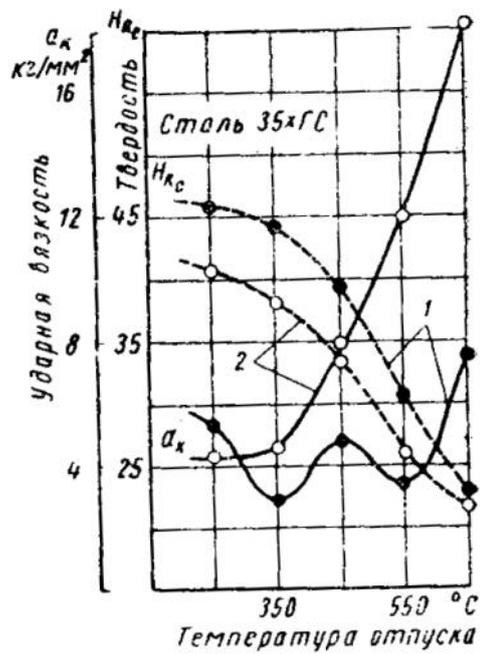
35

550° (4)

: 1 -

930° ; 2 -

930° .



1.3.3 -

35

: 1 -

900° ; 2 -

900°

800°

26 2

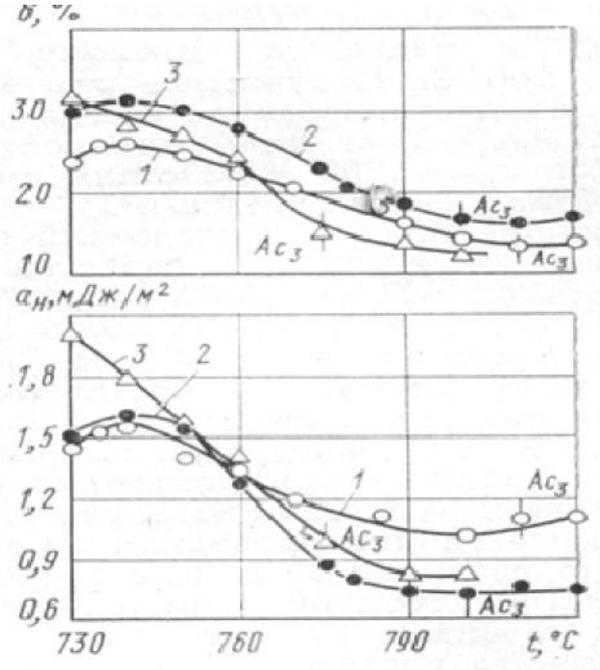
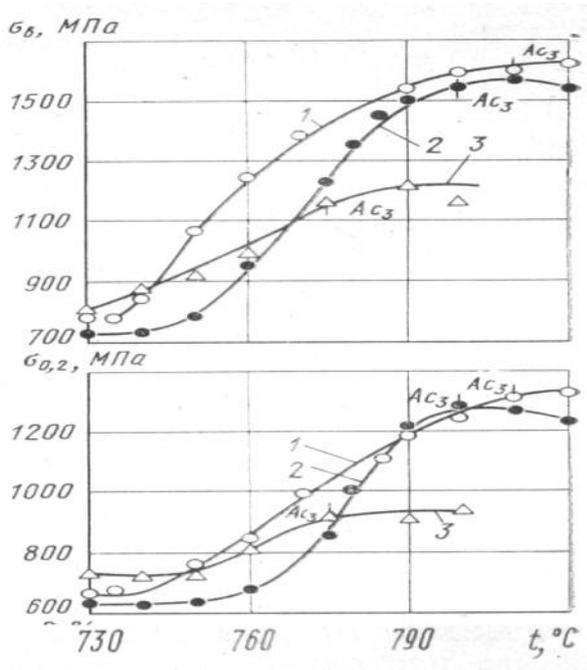
[58].

[58]

26 2

2

° / 300 ° /



. 1.3.5 -

930°

26 2

[58]. 1 -

300 ° /

; 2 - 200 ° /

; 3 - 2

° /

[59]

3,

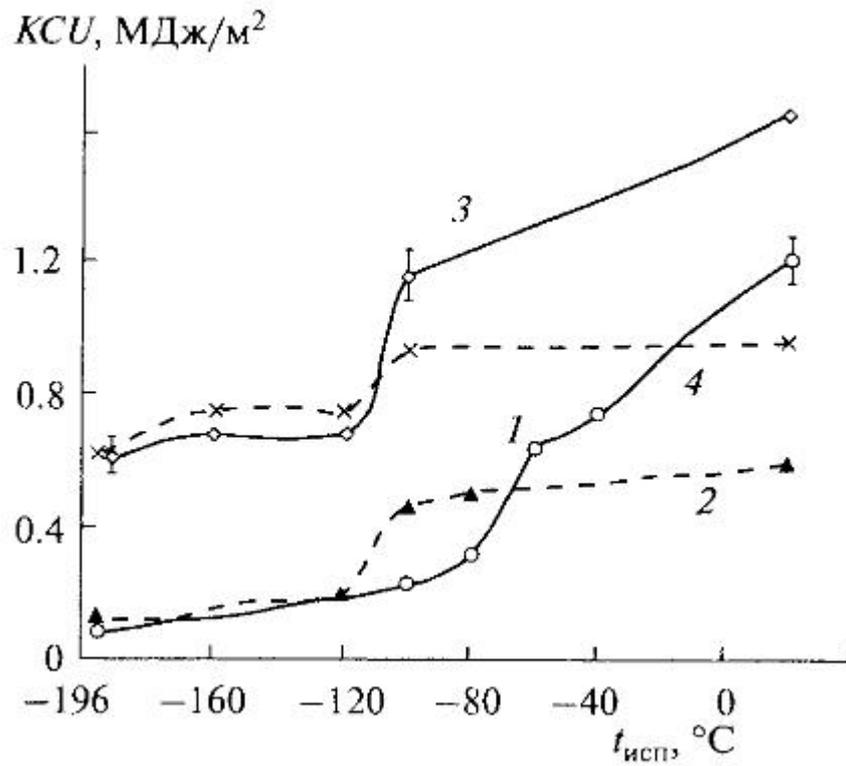
3. ,

15 [60]. ,

[61]

10 7,

+



. 1.3.4 -

10 7

[61]: + (1, 2)

(3,

4);

(+) .

. . . .

[62]

(r₃+100)-(r₃+150)^o ,

3

(r₁+80)-(r₃-30)^o

(500- r₁)^o

[62]

60-90%

[51].

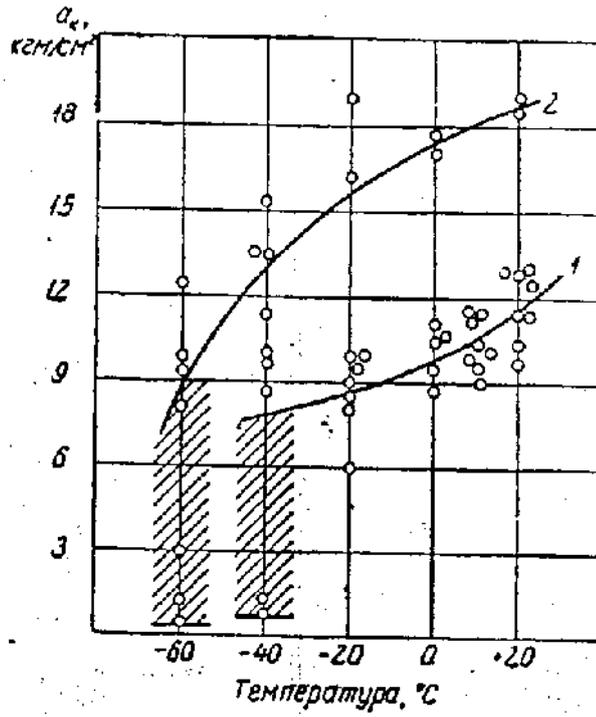
[51]

08 2

c

(0,12-0,15%).

15% « » .



.1.3.6 -

08 2,

.1 - 30% « »

(950°); 2

- 15% « » (975°).

[11, 63]

20,

, 750-830° . 20

[49]

40...60 %

[64]

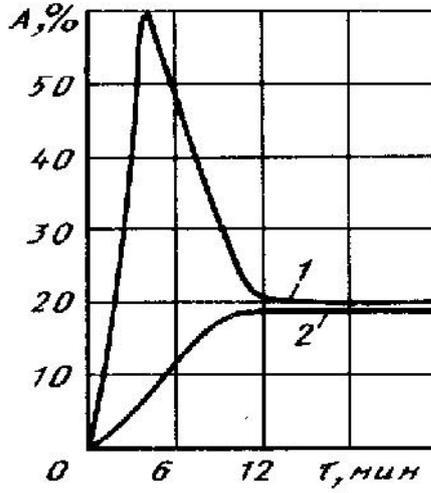
09 2

, 20-22% (780-810°).

[49]

Fe-C -

[65, 66]



1.3.7 -

750°

250° /

:

(1)

+

600° (2)

[65].

[67]

→

3, 09 2, 09 2, 16 2

(920° , 20 ,

,

300° ,

)

(

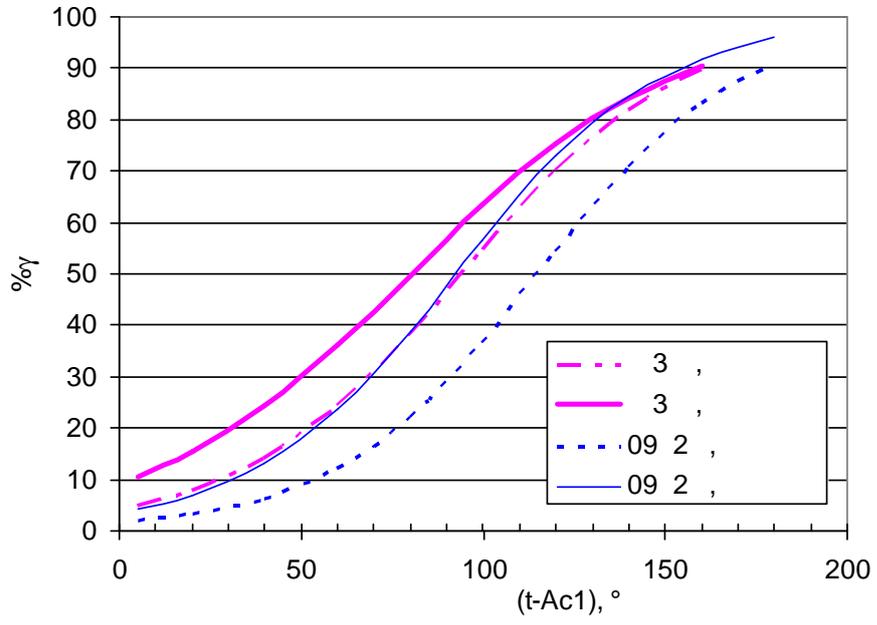
920°

20

).

5...90%

-



. 1.3.8 -

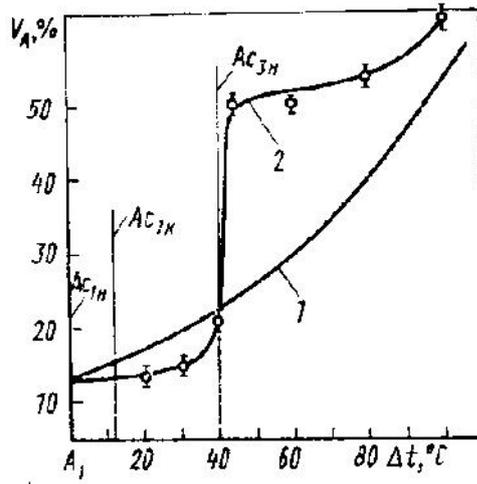
35° / [67]

[68]

30 2 30 2 .

[69]

10



. 1.3.9 -

(V_A)

10

1... 3: 1 -

; 2 -

(Δt -

1).

[49, 65, 66, 67, 69]

$r \rightarrow x$

$r -$

« » « »

[49]

06

[70,

71],

13

[8, 9, 10, 11,

12, 13, 62, 63, 72, 73, 74].

1.4

,

,

.

,

.

:

-

-

;

-

;

-

,

,

;

-

;

-

.

2

2.1

. C

2.1.1

		, %										
		C	Si	Mn	S	P	Cr	Ni	Cu	Al	N	Nb
20		0,17	0,17	0,45	0,015	0,015	0,25	0,25	0,25	0,02	0,008	0,01
		0,24	0,37	0,65						0,05		0,03
13		0,13	0,17	0,45	0,015	0,015	0,25	0,25	0,25	0,02	0,008	-
		0,17	0,37	0,65						0,05		
20	2	0,17	0,17	1,3	0,015	0,015	0,8	0,25	0,25	0,02	0,008	0,03
		0,22		1,6			1,3			0,05		0,06

2.2

1.

U-40

30 / . ² 1497,

5- ;

2.

5003-0,3

10 10 55 V-

9454;

3. 4543

;

4. -

5004 9012;

5. -

500 9013;

6. -3

100 9450;

2.3

,

,

500/12- .

$\pm 0,5^\circ$.

20 ,

13 20 2 :

1) 1050 ° , 30 , ();

2) 900 ° , 30 ,, .

3) 13 900 °

.

13 20 2

12 12 70 ,

.

, 900° 1050°

40-

$\pm 1^\circ$.

755, 770, 800, 830

,

860 ° , 40

; 600° 1 ,

454 24

20 2

24 150 150 .

$920 \pm 10^\circ$,

(740, 750, 760, 780, 800, 820, 840, 860°) $\pm 10^\circ$,

$600 \pm 10^\circ$

2.4

«Linseis L78 R.I.T.A.».

700 °

$10^\circ /$,

700 °

$0,1^\circ /$.

:

- (900, 830, 800, 760 755 °);

- 5 30 ;

-

$5...70^\circ /$,

5,

10, 20 40 ° /

3

10 .

$70^\circ /$

4 10

0,5 .

$r \rightarrow x$

L .

r -

L_0 ,

:

$$L_0 = L \cdot (1 + s \cdot (-)) , \tag{2.4.1}$$

s -

r -

%

$\Lambda \cdot L_0$,

Λ -

1% x -

L .

, :

$$L_0 - L = \Lambda \cdot L_0 \tag{2.4.2}$$

:

$$= \frac{L_0 - L + L \cdot s \cdot (-)}{\Lambda \cdot L_0} , \% \tag{2.4.3}$$

3

$100 \cdot \Lambda \cdot L_0$

r -

100%

x -

$L_{100\%}$,

$$\Lambda \cdot L_0 = \frac{L_0 - L_{100\%}}{100} ,$$

2.4.4

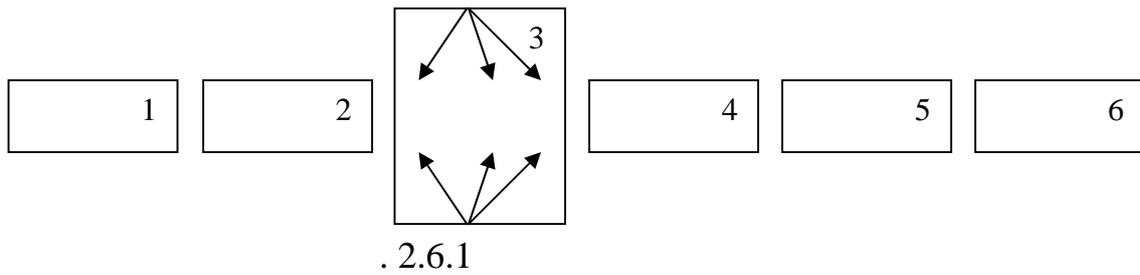
2.5

30», , , « -
4-% HNO₃.
-
JEM 200CX.

5639
5639 Thixomet.
5640.

2.6

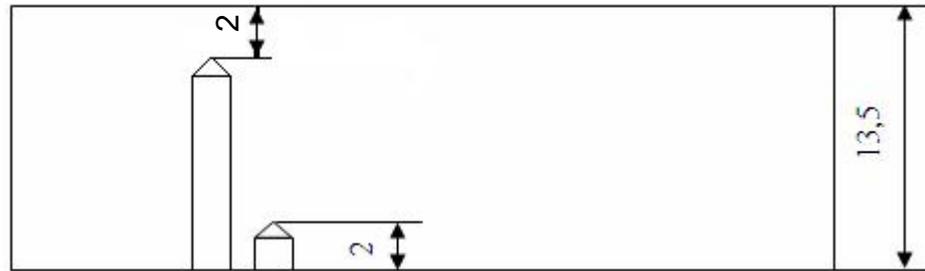
3 « » (. 2.6.1).



1, 2 - ; 3 - ; 4, 5, 6 -

13 325 12 ((13,5) 2

2.6.2).



. 2.6.2

« -600»

820±15° .

« -4» .

$$150 \frac{3}{2} ,$$

3 .

0,06 ⁻¹ .

« » ,

3

(r), (T_0) (T_f)
 }, r

3.1

13

3.1.1.

3.1.1

	, %						
		Mn	Si	S	P	Cr	V
13	0,15	0,6	0,2	0,005	0,010	0,6	0,05

15 ,

[75]

15 .

3.2

:

$$\frac{\partial^2}{\partial r^2} + \frac{1}{r} \frac{\partial}{\partial r} = \frac{1}{a} \frac{\partial}{\partial t}, \tag{3.2.1}$$

— , r — — ;
 — , = } — ; } —
 ; — ; ... — .

(r = r₁):

$$\frac{\partial}{\partial r} \Big|_{r=r_1} = 0; \tag{3.2.2}$$

(r = r₂)

$$- \} \frac{\partial}{\partial r} \Big|_{r=r_2} = r ((r_2, \ddagger) - f), \tag{3.2.3}$$

f — , ;
 r — .
 ,
 :

$$(r, \ddagger = 0) = 0, \tag{3.2.4}$$

T₀ — .

(3.2.1)

[76]:

$$\frac{T(r, \ddagger) - T_f}{T_0 - T_f} = \sum_{n=1}^{\infty} C_{2,n} e^{-\alpha_n F_0} (I_1(\alpha_n \frac{r_1}{r_2}) Y_0(\alpha_n R) - Y_1(\alpha_n \frac{r_1}{r_2}) I_0(\alpha_n R)) \frac{1}{I_1(\alpha_n R)}, \tag{3.2.5}$$

I₀(z) I₁(z) «0» «1»

, Y₀(z) Y₁(z) -

[77], R — : R = $\frac{r}{r_2}$; Fo = $\frac{a\ddagger}{r_2^2}$ -

; Bi = $\frac{\Gamma}{\} r_2$ - ,

~_n .

Bi

$$(3.2.5)$$

n .

n

μ_n ,

:

$$\frac{V_0(\sim n)}{W_0(\sim n)} = \frac{\sim n}{Bi}, \tag{3.2.6}$$

$$V_0 \quad W_0 \quad :$$

$$V_0(\sim n R) = \left(Y_0(\sim n R) I_1\left(\sim n \frac{r_1}{r_2}\right) - I_0(\sim n R) Y_1\left(\sim n \frac{r_1}{r_2}\right) \right) \tag{3.2.7}$$

$$W_0(\sim n R) = \left(Y_1(\sim n R) I_1\left(\sim n \frac{r_1}{r_2}\right) - I_1(\sim n R) Y_1\left(\sim n \frac{r_1}{r_2}\right) \right) \tag{3.2.8}$$

$$(7) \quad (8) \quad (6)$$

$R=1$.

$$(5.5)$$

$2n$:

$$C_{2n} = \frac{2Bi \cdot V_0(\sim n)}{\left(Bi^2 + \sim n^2 \right) \cdot V_0^2(\sim n) - 4/f^2}, \tag{3.2.9}$$

$$(5.1)$$

n ,

$$(1)$$

:

$$T_{i,k} = T_{i,k-1} + a \cdot \Delta t \cdot \left(\frac{T_{i+1,k-1} - 2 \cdot T_{i,k-1} + T_{i-1,k-1}}{\Delta x^2} + \frac{1}{D - i \cdot \Delta x} \cdot \frac{T_{i+1,k-1} - T_{i-1,k-1}}{2 \cdot \Delta x} \right), \tag{3.2.10}$$

$i=1 \dots n -$

,

$-$

, $n -$

,

, $\Delta x -$

, $D -$

, $\Delta t -$

:

$$T_{i,0} = T_0$$

$$(3.2.11)$$

:

$$T_{n,k} = T_{n,k-1} + a \cdot \Delta t \cdot \left(\frac{T_{k-1} - 2 \cdot T_{n,k-1} + T_{n-1,k-1}}{\Delta x^2} + \left(\frac{D}{2} \right) \cdot \frac{T_{k-1} - T_{n-1,k-1}}{2 \cdot \Delta x} \right), \quad (3.2.12)$$

T -

$$T_{k-1} = T_{n-1,k-1} - 2 \cdot \Delta x \cdot \frac{\Gamma}{\Delta x} \cdot (T_{n,k-1} - Tf) \quad (3.2.13)$$

$$T_{1,k} = T_{1,k-1} + a \cdot \Delta t \cdot \left(\frac{T_{2,k-1} - 2 \cdot T_{1,k-1} + T_{k-1}}{\Delta x^2} + \left(\frac{D}{2} - s \right) \cdot \frac{T_{2,k-1} - T_{k-1}}{2 \cdot \Delta x} \right) \quad (3.2.14)$$

s -

, T -

:

$$T_{k-1} = T_{2,k-1} \quad (3.2.15)$$

, (15) (2).

[78]:

$$\Delta t \leq \frac{\Delta x^2}{2 \cdot a} \quad (3.2.16)$$

(8)

(10)-(15)

«Mathcad».

«MS Excel».

15 [75].

, (3.2.5), (3.2.10)

}, , ..., r .

3.2.1 ,

426 9

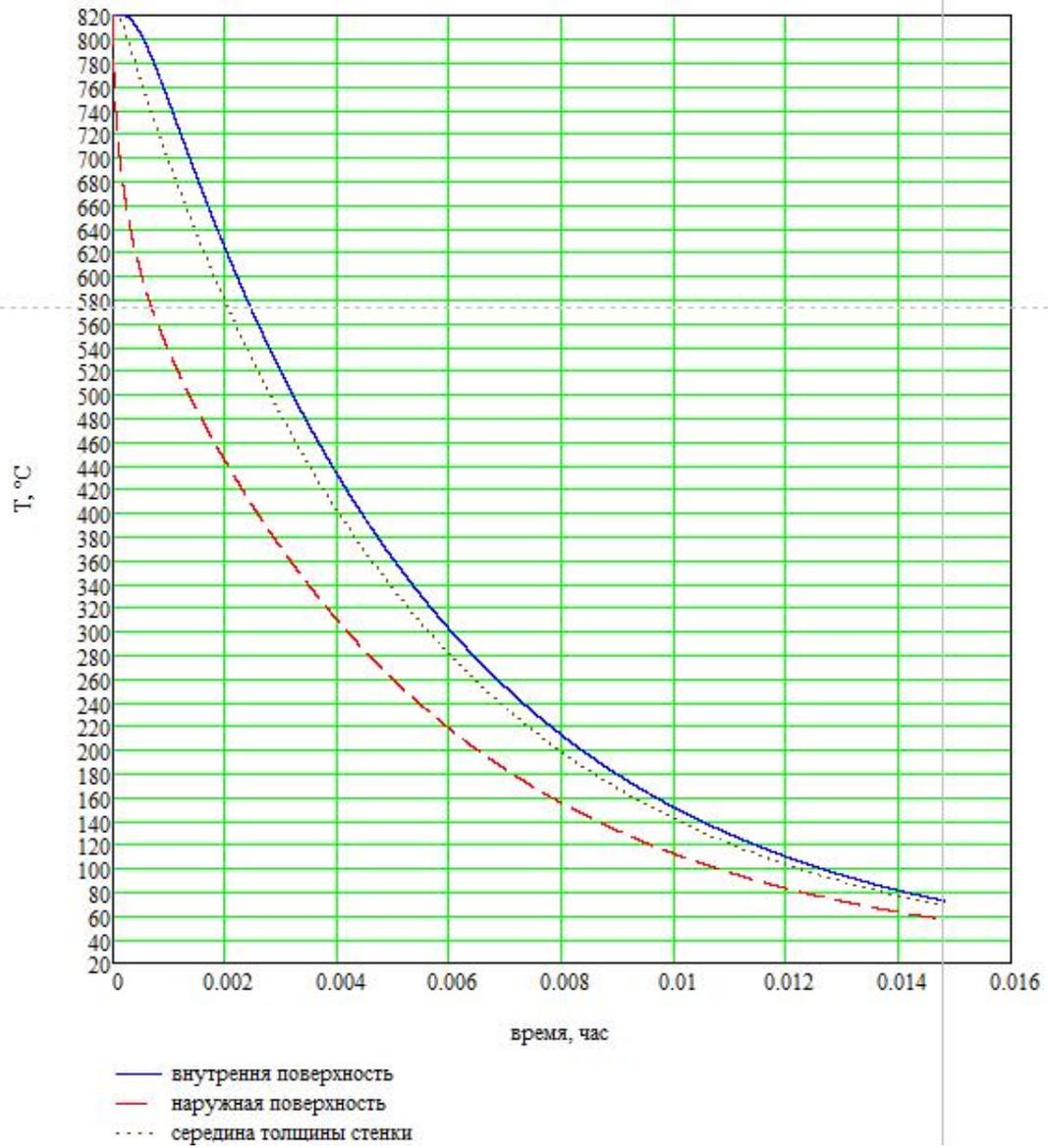
=27,52

_____ ; =7860 _____ ; =0,152 _____ ; =2500 _____ (1 / =1,163*10³

).

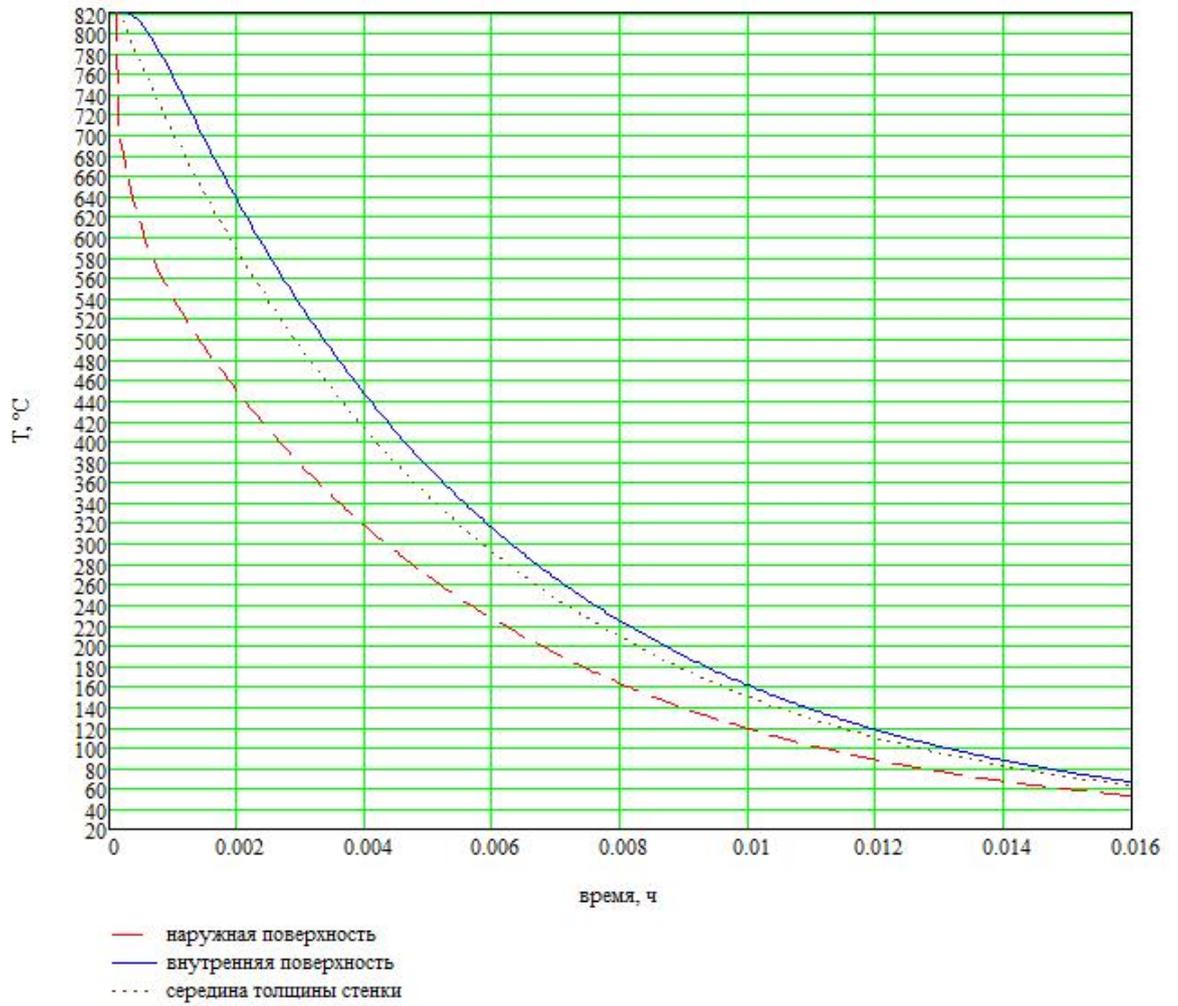
(15)

40 .



. 3.2.1

(3.2.10).



. 3.2.1 .

$$(3.2.5)$$

3.3

$$(3.2.5)-(3.2.10)$$

() . :

$$(3.2.5) \quad r$$

$$r = r_2 - 2 \quad r = r_1 + 2 \quad ()$$

, ... (

r 820-700° , 700-600° 600-400°) [79].

[24, 79]

(5.5).

r . . [24]:

$$r = G \frac{C_1 \cdot T_{m1} - C_2 \cdot T_{m2}}{F \cdot \Delta t \cdot \left(\frac{T_{n1} - T_{n2}}{2} - T_f \right)}, \tag{3.3.1}$$

G - , T_{m1} , T_{m2} -

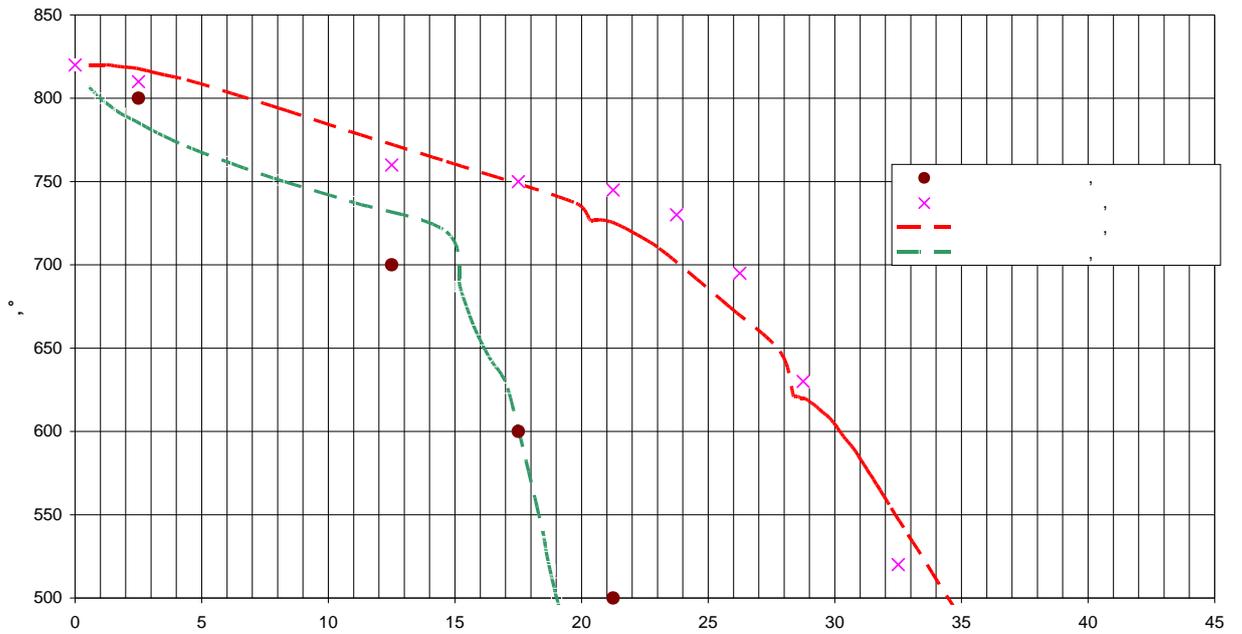
, 1 , 2 -

, F -

, - , T_1 , T_{n2} -

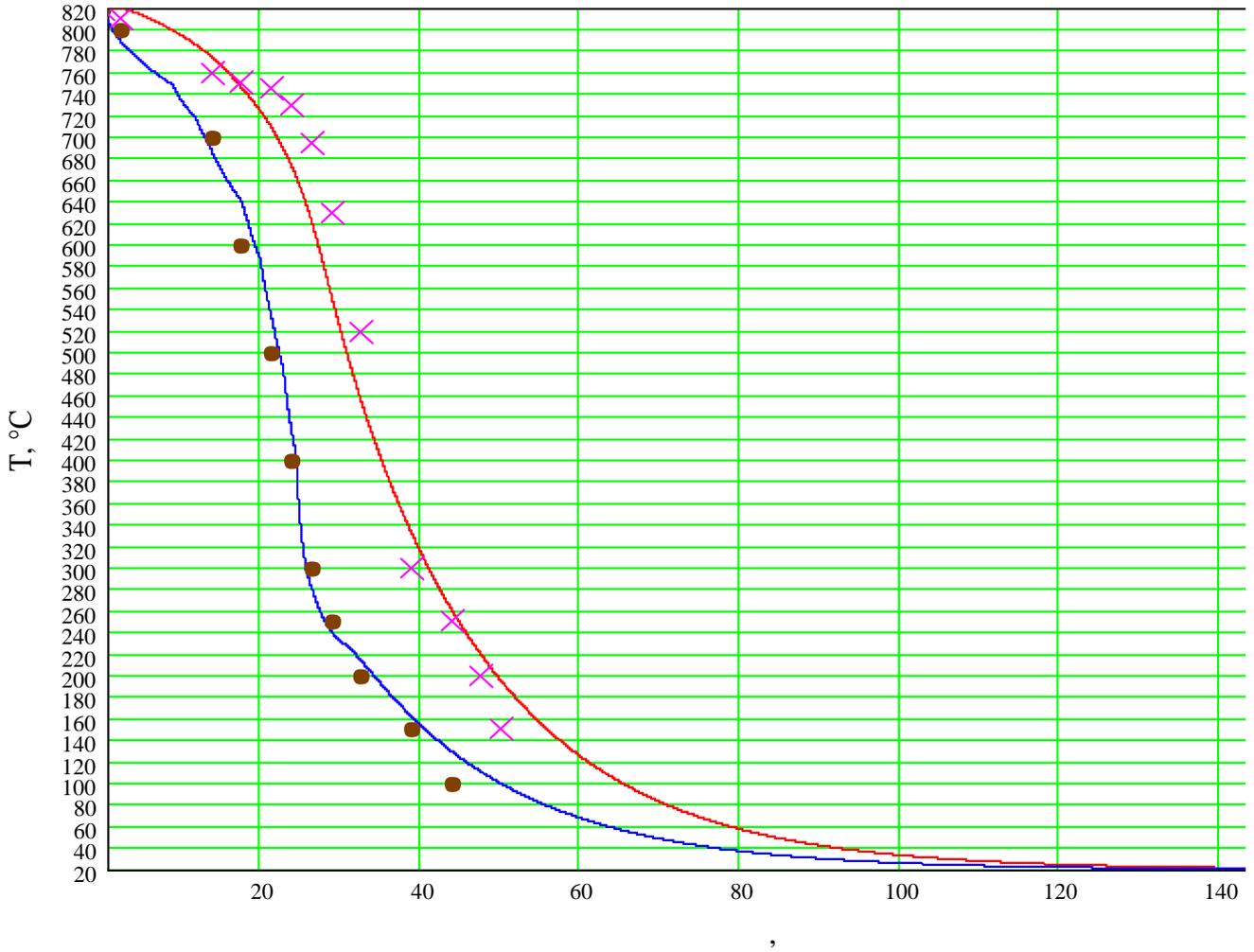
3.4

. 3.4.1.



. 3.4.1

(3.2.5)



. 3.4.2

(3.2.10)

(3.2.5)

800-500°

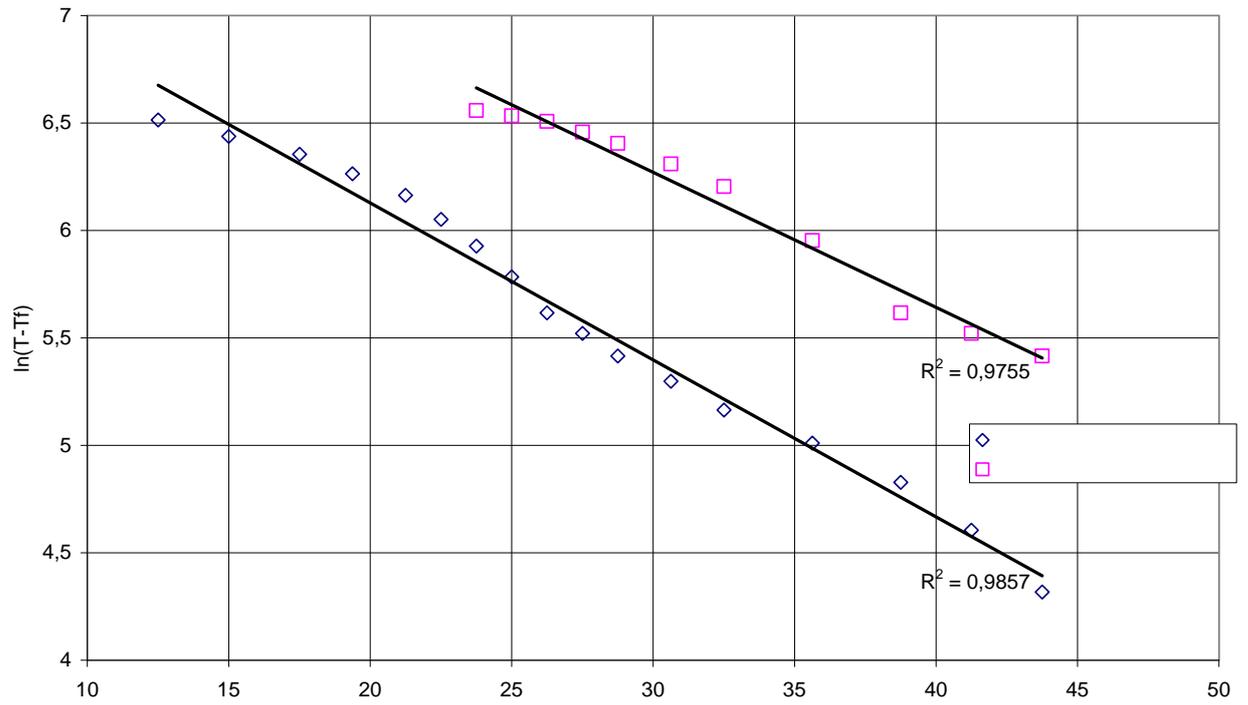
1800 $\frac{\text{---}}{2 \cdot \cdot}$ (2093 $\frac{\text{---}}{2 \cdot}$).

(3.3.1)

750-500°

2000 $\frac{\text{---}}{2 \cdot \cdot}$ (2326 $\frac{\text{---}}{2 \cdot}$).

. 3.4.3

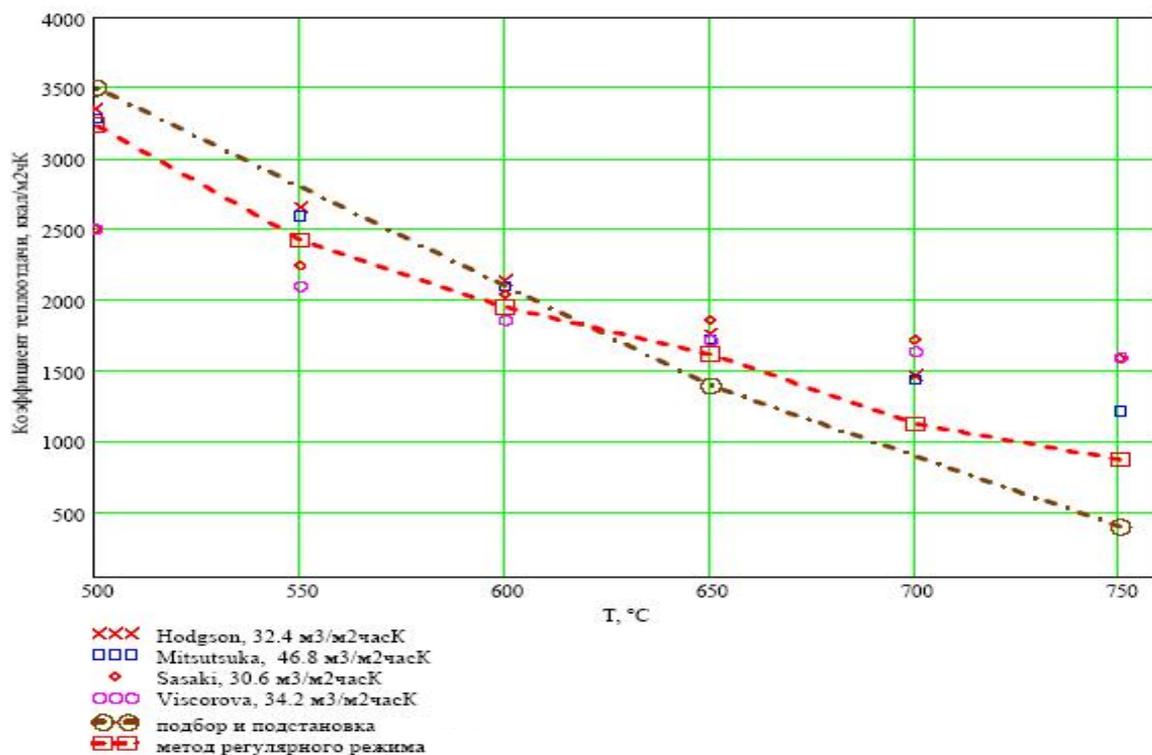


.3.4.3

. 3.4.4

(3.3.1)

(3.2.5).



. 3.4.4

$$(1 / =1,163)$$

750°

r (3.3.1)

(3.3.1)

750-500°

$$2000 \frac{2}{2} (2326 \frac{2}{2})$$

[26],

2000

. 3.4.4

[36, 28, 29, 37].

30,6-46,8 $\frac{3}{2}$, ... 3,2-4,9

,

,

[35, 39,

80],

1,3-2

[92].

3.5

(3.2.1)

n

(3.2.1)

$$T_{i,k} = T_{i,k-1} + a \cdot \Delta t \cdot \left(\frac{T_{i+1,k-1} - 2 \cdot T_{i,k-1} + T_{i-1,k-1}}{\Delta x^2} + \frac{1}{D - i \cdot \Delta x} \cdot \frac{T_{i+1,k-1} - T_{i-1,k-1}}{2 \cdot \Delta x} \right) \quad (3.5.1)$$

$$T_{i,0} = T_0 \quad (3.5.2)$$

$$T_{n,k} = T_{n,k-1} + a \cdot \Delta t \cdot \left(\frac{T_{k-1} - 2 \cdot T_{n,k-1} + T_{n-1,k-1}}{\Delta x^2} + \frac{1}{(D/2)} \cdot \frac{T_{k-1} - T_{n-1,k-1}}{2 \cdot \Delta x} \right), \quad (3.5.3)$$

T -

$$T_{k-1} = T_{n-1,k-1} - 2 \cdot \Delta x \cdot \frac{r}{\Delta x} \cdot (T_{n,k-1} - Tf); \quad (3.5.4)$$

$$T_{1,k} = T_{1,k-1} + a \cdot \Delta t \cdot \left(\frac{T_{2,k-1} - 2 \cdot T_{1,k-1} + T_{k-1}}{\Delta x^2} + \frac{1}{\left(\frac{D}{2} - s\right)} \cdot \frac{T_{2,k-1} - T_{k-1}}{2 \cdot \Delta x} \right), \quad (3.5.5)$$

s -

, T -

,

.

:

$$T_{k-1} = T_{2,k-1} - 2 \cdot \Delta x \cdot \frac{r}{\Delta x} \cdot (T_{1,k-1} - Tf) \quad (3.5.6)$$

3.6

$$(3.2.5) \quad (3.2.10)$$

.

273 9

20

.

« ».

—

,

.

[26].

$$r = \frac{1,2}{D^{0,25}} \cdot (T0 - Tf)^{0,25} + v \cdot \frac{71 \cdot \left(\frac{T0 + 273}{100} \right)^4 - \left(\frac{Tf + 273}{100} \right)^4}{T0 - Tf}, \quad (3.6.1)$$

$$v = - \quad , \quad = 4,9$$

$$, D -$$

$$r \quad 86 \frac{\quad}{2} .$$

$$= + \frac{\Delta H}{\Delta T}, \quad (3.6.2)$$

$$- \quad ; \Delta H - \quad ;$$

$\Delta T -$

[26] $\Delta H = 14 \dots 18$ — .

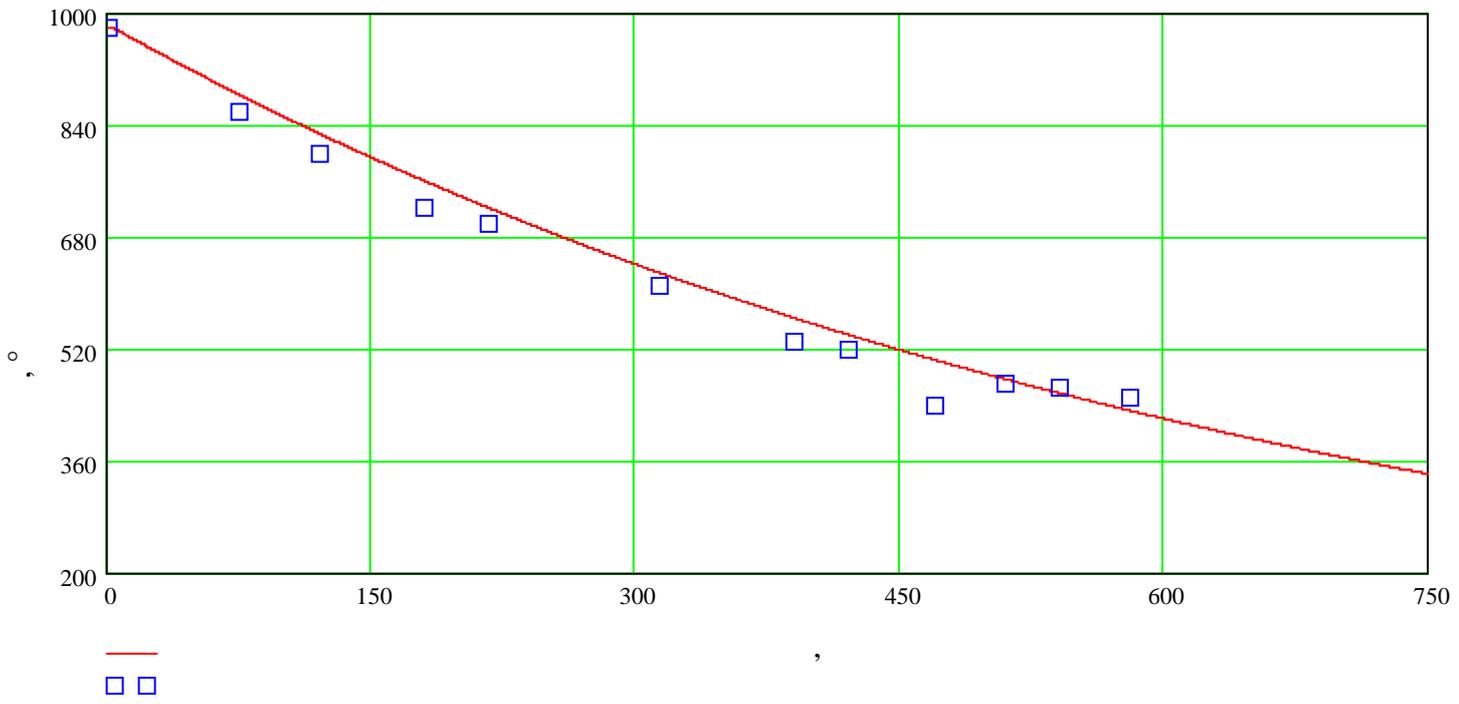
[81] $\Delta H = 10-20$ — .

$\Delta H = 16$ — (67 —) .

(3.2.5), (3.2.10)

(3.2.10), (3.6.1)

3.6.1.



. 3.6.1

$$Bi = \frac{r}{r_2} = \frac{86}{34,7} \cdot \left(\frac{0,273}{2} \right) = 0,338 \tag{3.6.3}$$

980-500 °

1° / .

[16]

20 15 (20 13)

3.7

« »

Bi→)

Bi>100 [82].

Bi→

=0.150 — λ=37.80 — .

10-15%

900° .

900-500° .

2

Mathcad –

(3.2.10),

30 ,

(3.2.5).

150000 — ,

Bi>>100.

3.7.1

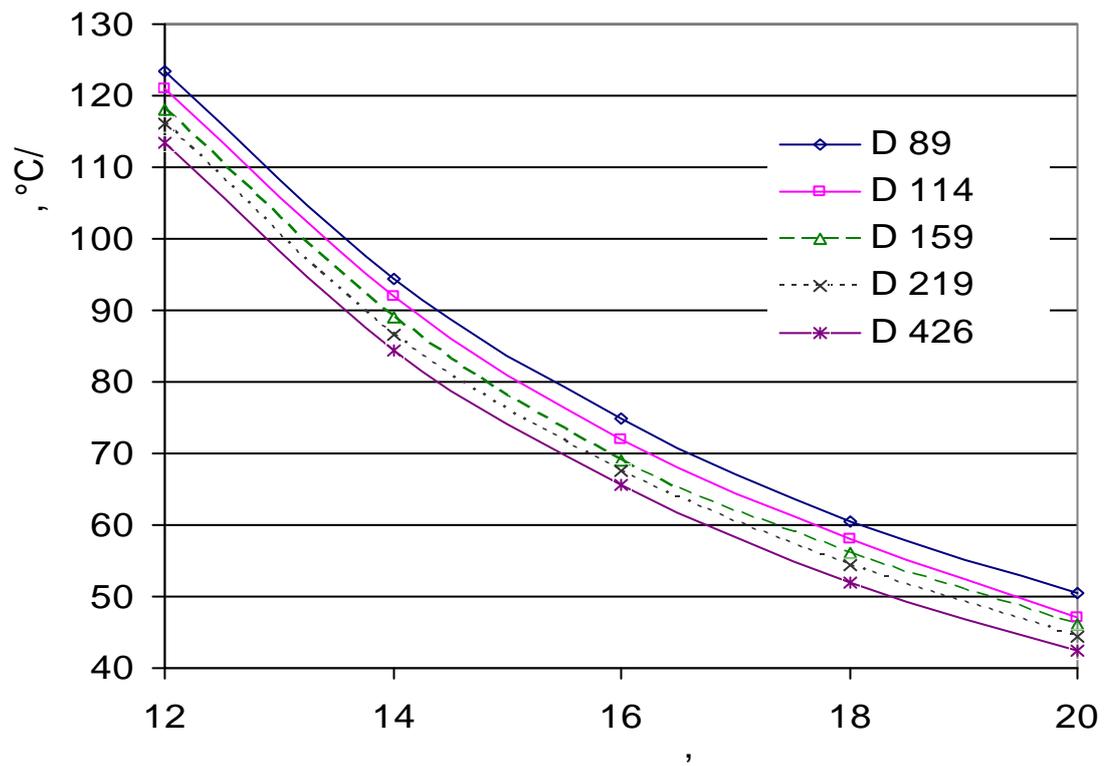
3.7.1

3.7.1

° /

→

	89	114	159	219	426
12	124/123	121/121	118/118	116/116	114/113
14	95/94	92/92	89/89	87/86	85/84
16	75/75	72/72	69/69	68/67	65/66
18	61/60	58/58	56/56	55/54	52/52
20	51/50	49/48	46/46	45/44	42/43



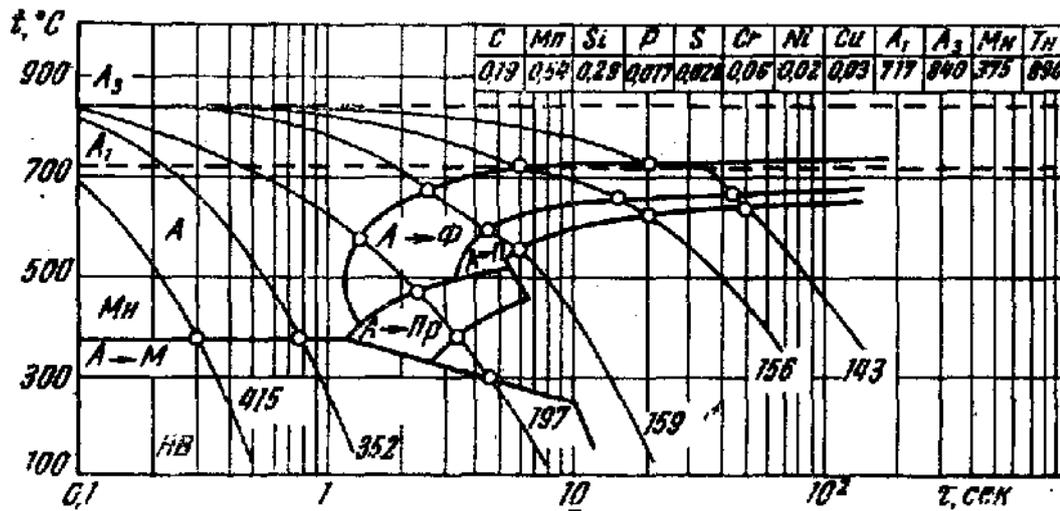
. 3.7.1

20 20

20 15 [16],

20

14 (. 3.7.2).

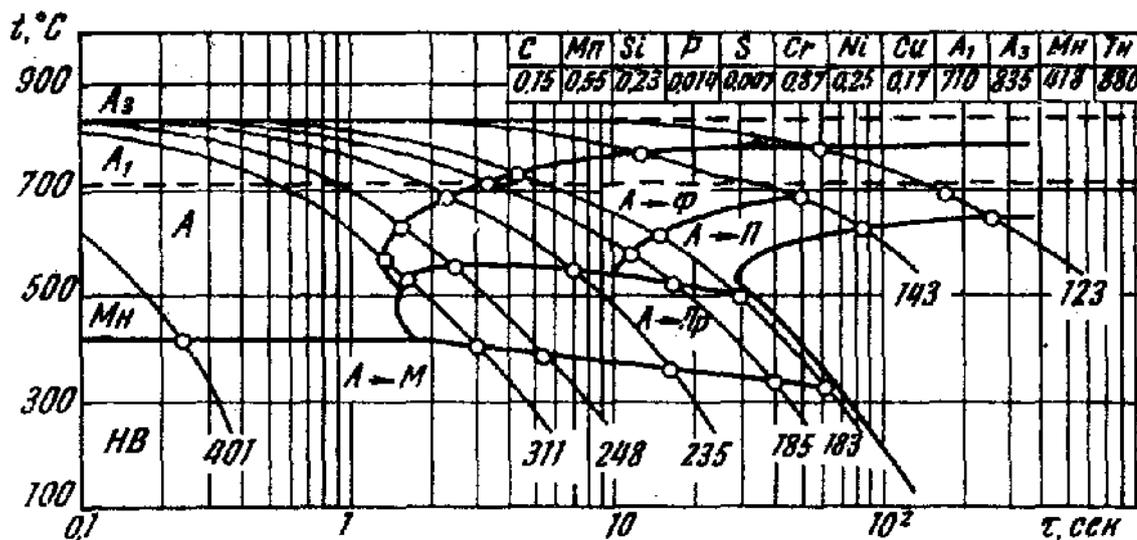


. 3.7.2

20,

[16]

[8, 48]



. 3.7.2

15 ,

[16]

15 (

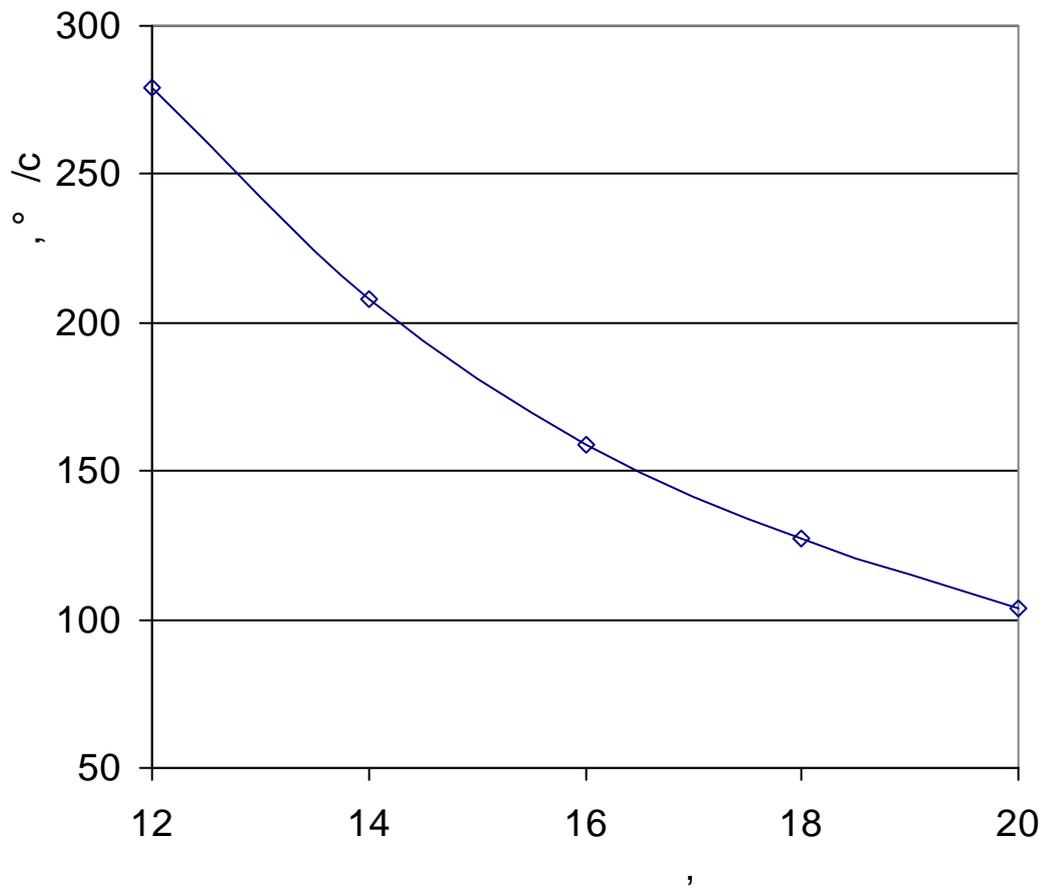
13)

Mathcad

(3.2.10),

(

).



. 3.7.3

20

13

20

(. 5).

(2000 $\frac{\quad}{2}$).

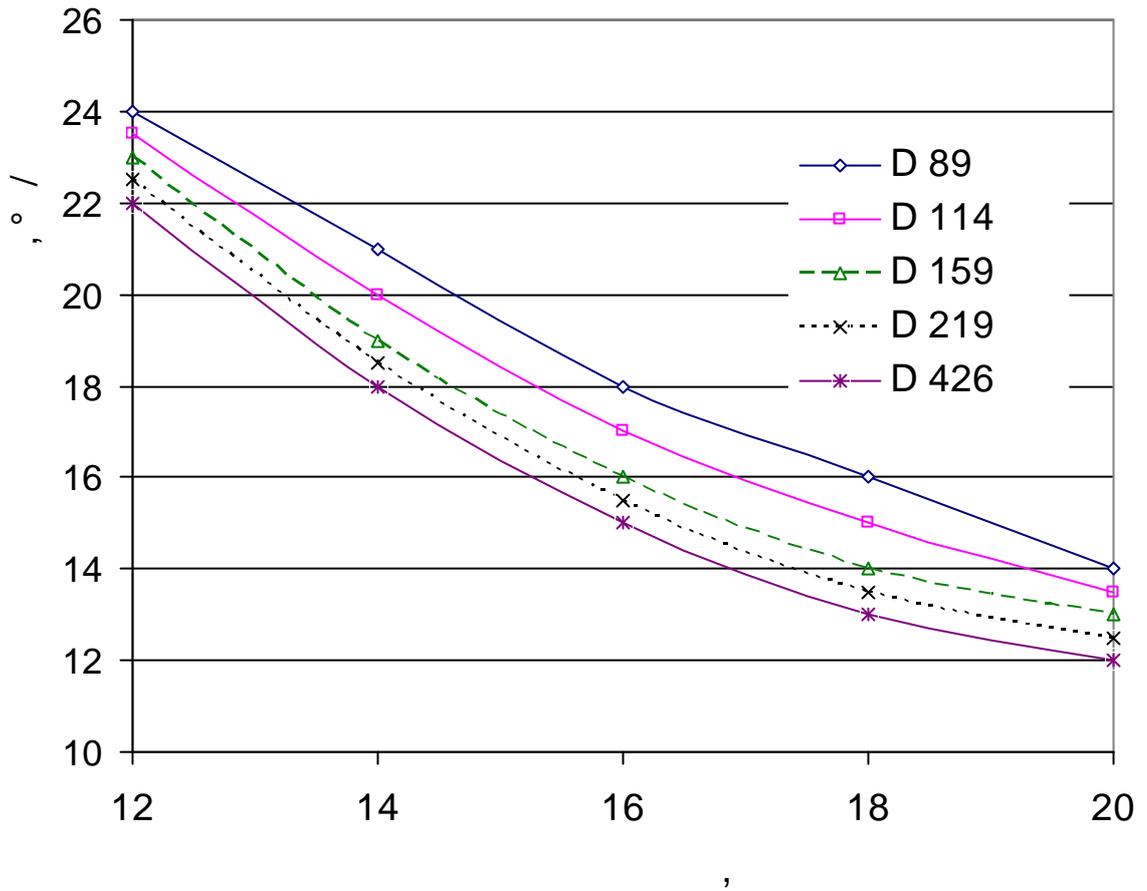
3.7.2 . 3.7.4.

3.7.2

o /

$$r = 2000 \frac{\quad}{2} - (2326 \frac{\quad}{2})$$

	89	114	159	219	426
12	24	23,5	23	22,5	22
14	21	20	19	18,5	18
16	18	17	16	15,5	15
18	16	15	14	13,5	13
20	14	13,5	13	12,5	12



. 3.7.4

$$r = 2000 \frac{\quad}{2}$$

- , 20 13

« »,

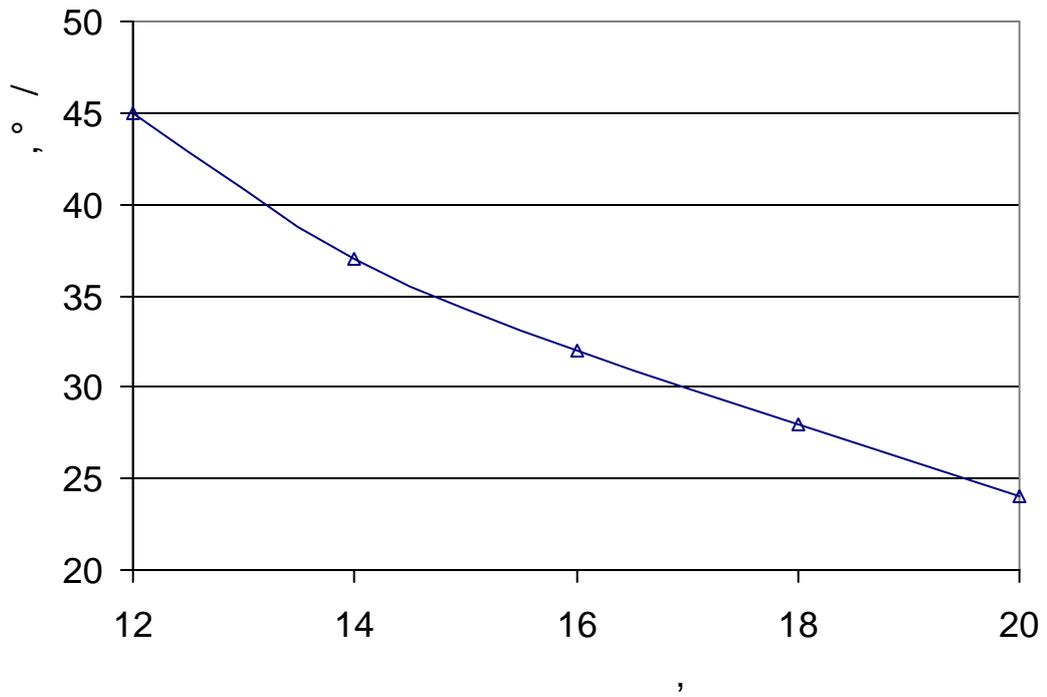
20 - ,

, 13 $r = 2000 \frac{\quad}{2}$ (

)

3.7.5

$$r = 2000 \frac{1}{2}$$



.3.7.5

$$r = 2000 \frac{1}{2} (2326 \frac{1}{2})$$

3.8

1.

2.

3.

4.

 $(+)-$.

-

4

4.1

, .

,
($\alpha+\gamma$) .

, . . . ,
, . . . , . . . [49-51, 56, 57, 59-68,

70-74].

, ,

(KCV-60).

, , ,

, , (

), ,

, : -

, , ,

[66, 83]

(

3)

.
,

, , , .

-60° .

KCV-60.

« » « »

1

, , , , .

+ [84].

4.2

13 ,

4.2.1.

4.2.1

13

, %										
C	Si	Mn	S	P	Cr	Ni	Cu	Al	N	V
0.16	0.3	0.53	0.012	0.007	0.60	0.05	0.06	0.04	0.007	0.06

900°

1050°

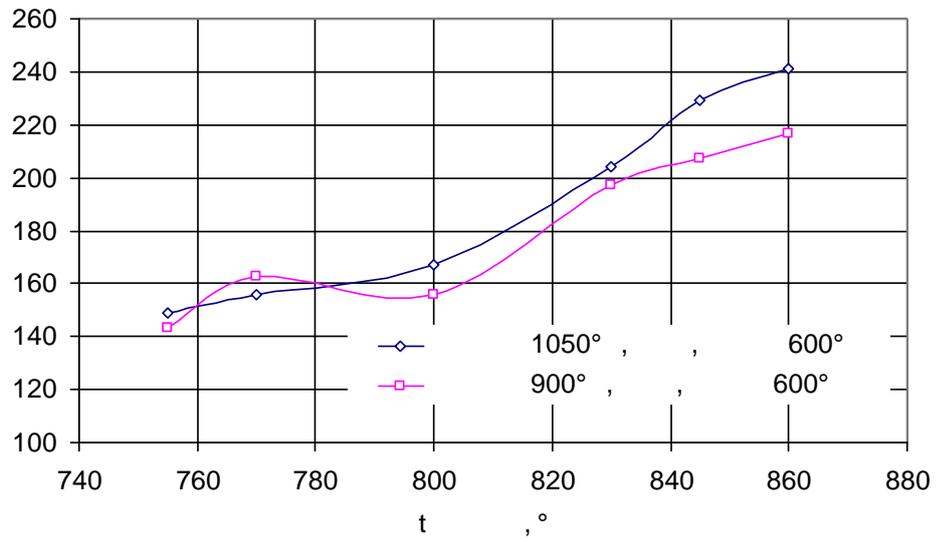
40-

».

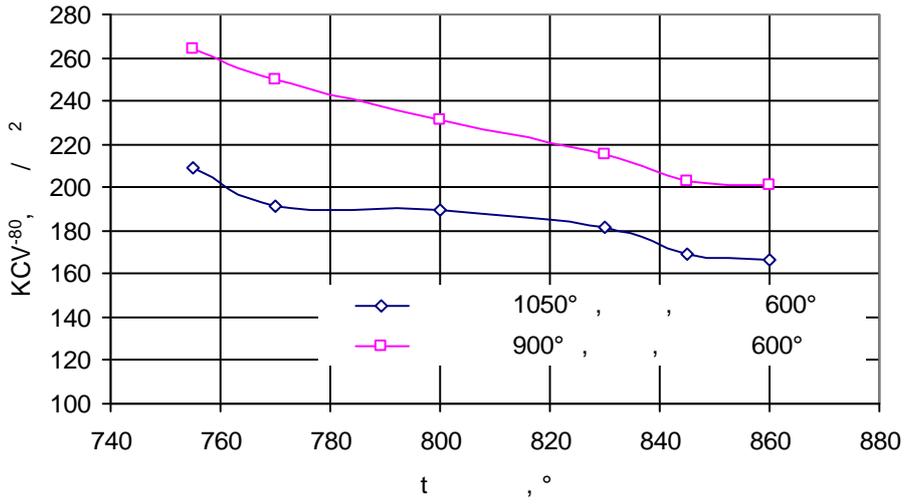
«

4.3

. 4.3.1.



)



)
 .4.3.1.

() ()
 600° .

.4.3.2. 1050 900°

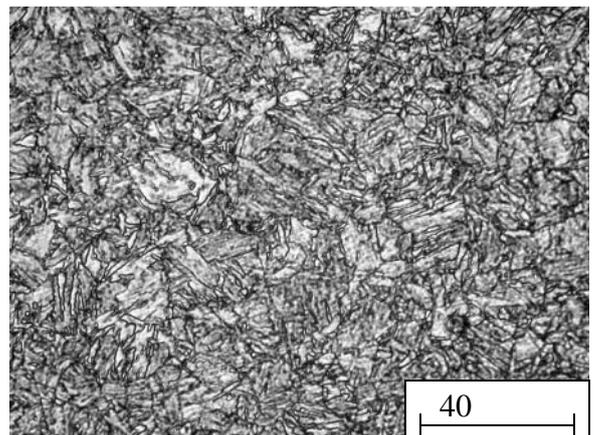
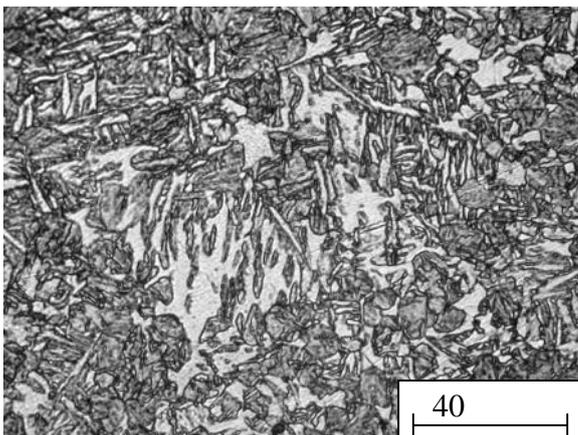
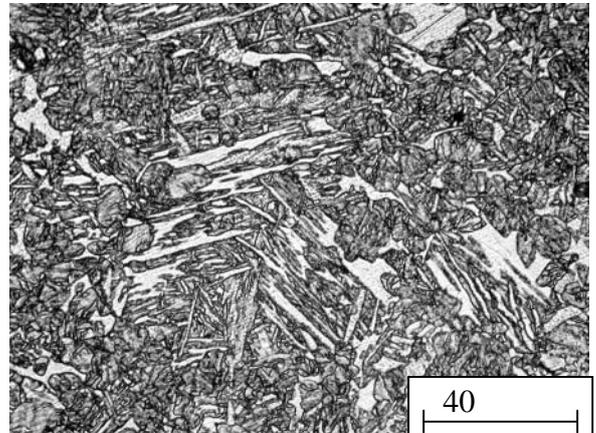
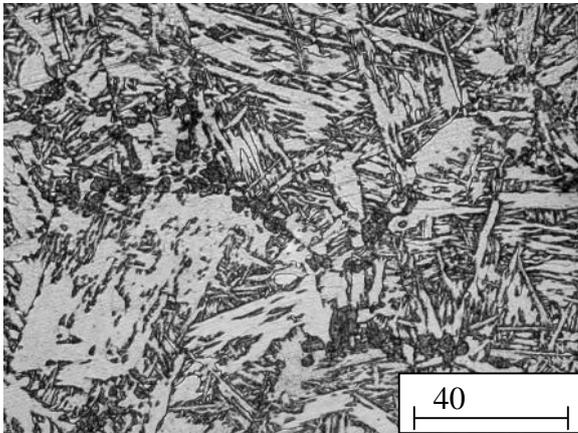
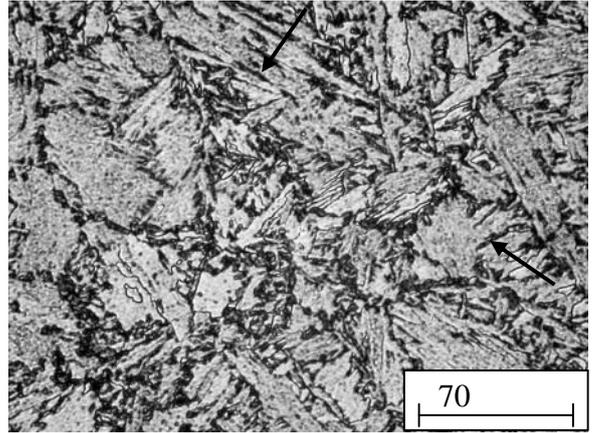
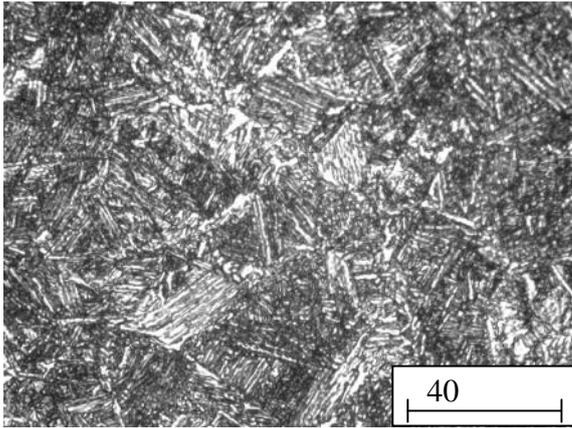
[85, 86].

0.15-0.6 .

120°:

6 .

[87],



.4.3.2.

13

1050° (),

755 (), 770 (), 800 (), 830 () 860 ()

600° , 1 .

(. 4.3.2)

1050° ,

755°

(. 4.3.2),

800°

5

5 70° / .

760 715, 660 615° .

$\alpha_1=746\pm 5^\circ$.

[49]

40

12

100° / , . .

755°,

1)

2)

3)

. 4.3.2

[88, 85]

3)

« »,

770 (. 4.3.2) 800° (. 4.3.2)

1,

γ-

740° (1)

1

755°

()

(. 4.3.2 ,)

770 800°

755° .

755°

770°

γ-

() .

830°

(. 4.3.2 ,) .

()

« » , . .

γ-

860° ,

()

(. 4.3.2) .

900° ,

600°

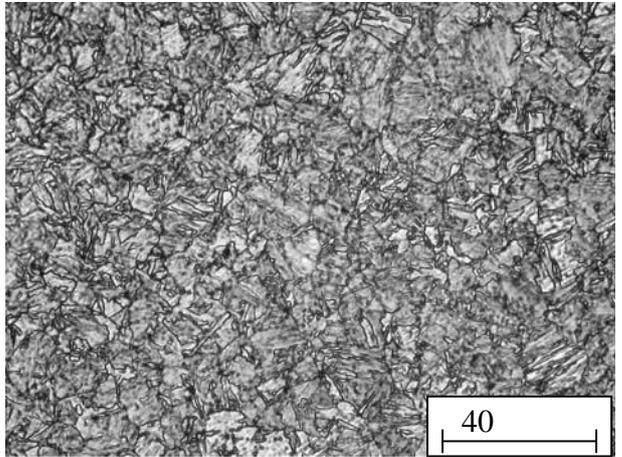
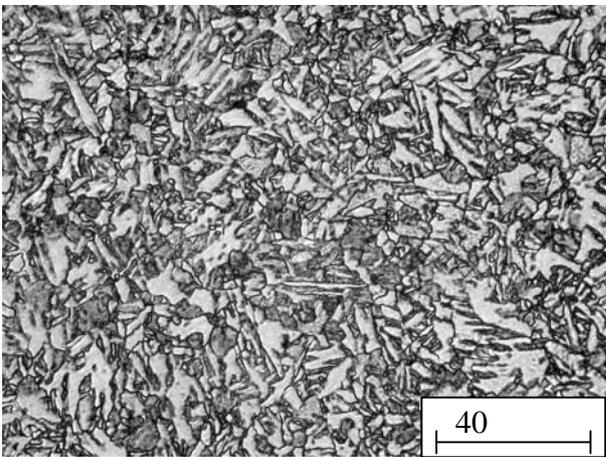
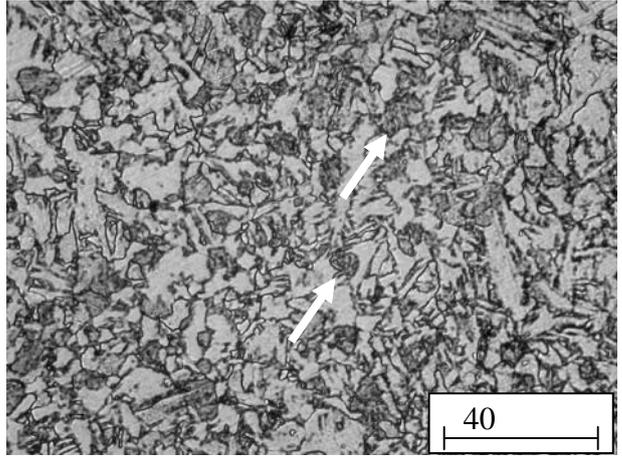
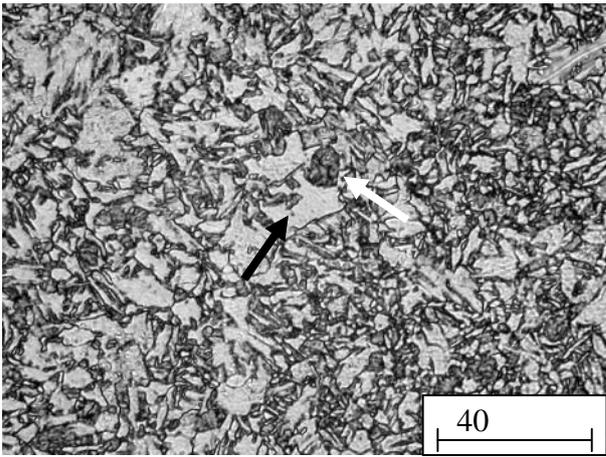
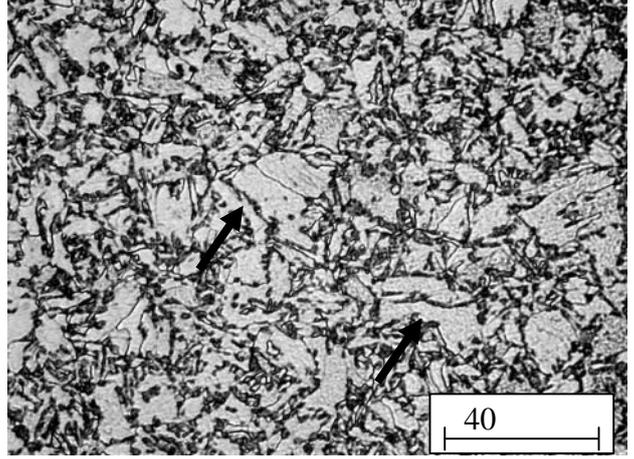
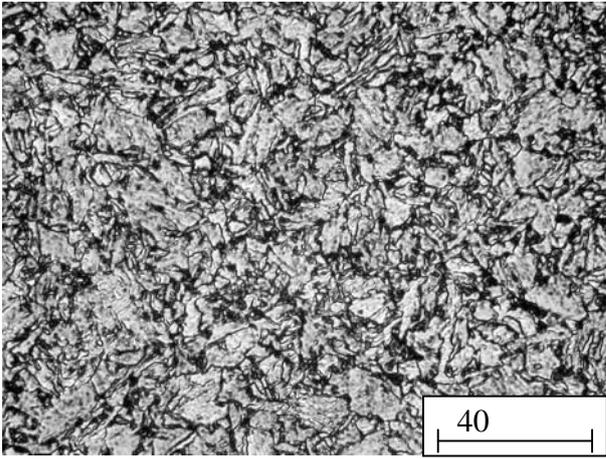
1050° .

755°

(. 4.3.3) ,

() (

. 4.3.3 ,) .



.4.3.3.

900° ,

600° , 1 : - 755, - 770, - 800, - 830, - 845, - 860.

γ -

(

. 4.3.3 ,),

γ -

770, 800, 830 845°

(4.3.3 , , ,),

1050° .

860°

(. 4.3.3)

. ,

. 4.3.4,

770°

« » - ,

,

- .

770°

(. 4.3.4),

,

γ -

[88, 85],

«

».

« »

- (. 4.3.4).

(.

4.3.4 ,)

- [001]₁, [111]₂,

[$\bar{9}$ 11]₃

[22 $\bar{1}$].

: ($\bar{2}$ 20) ||(011) .

, 770° .

(. 4.3.4),

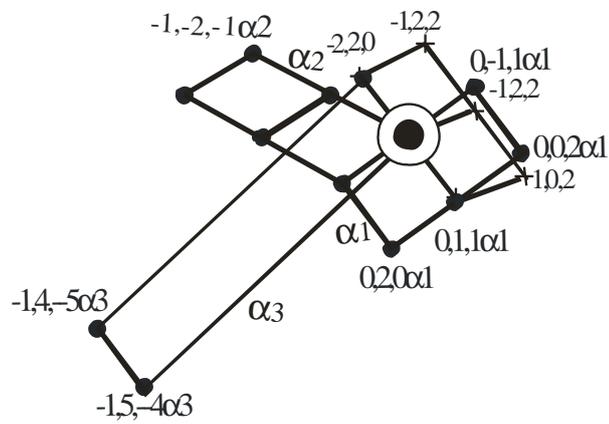
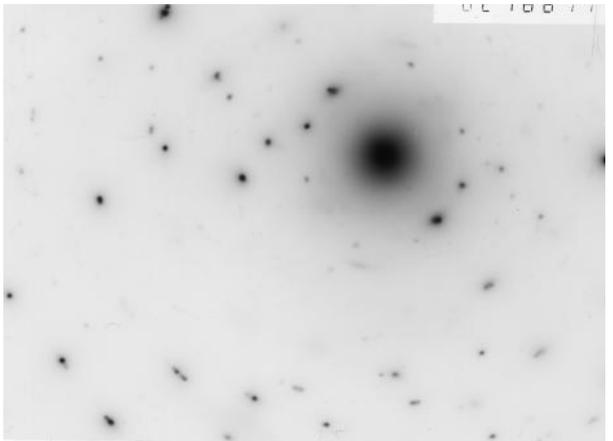
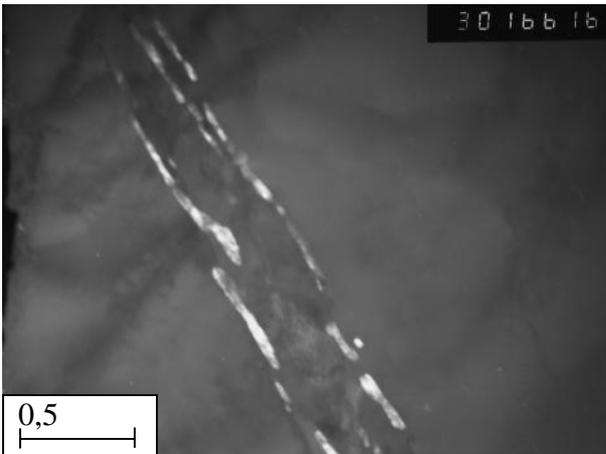
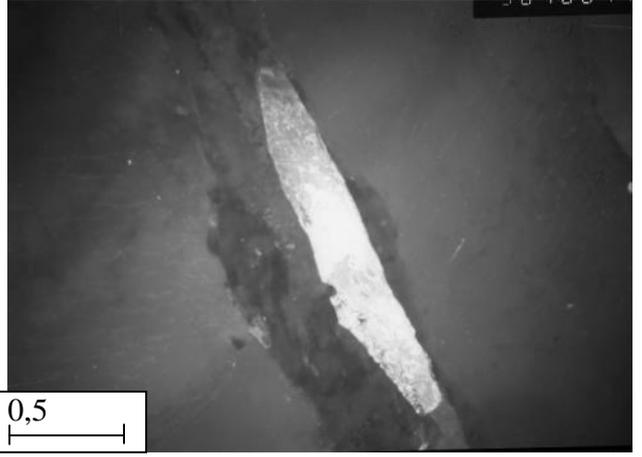
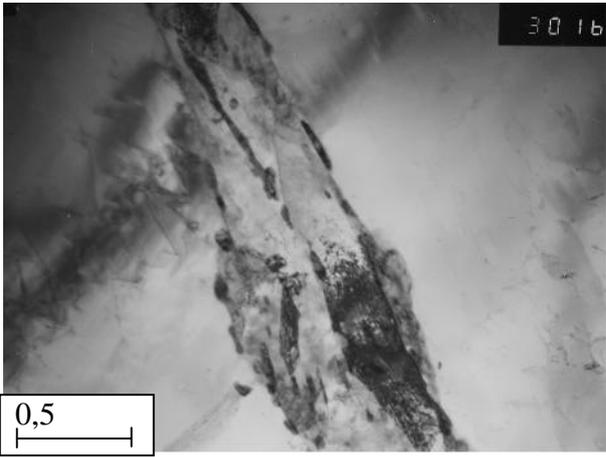
,

,

,

,

.



. 4.3.4.

13

1050° ,

, 770°

600° , 1 : -

; -

(110) ; -

(102); -

« », -

.

4.3.5

,

(

. 4.3.5)

.

- .

-

(. 4.3.5

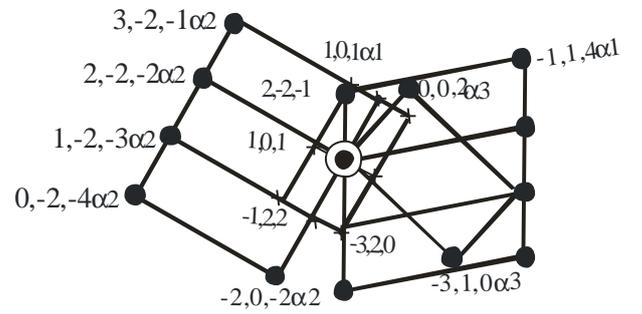
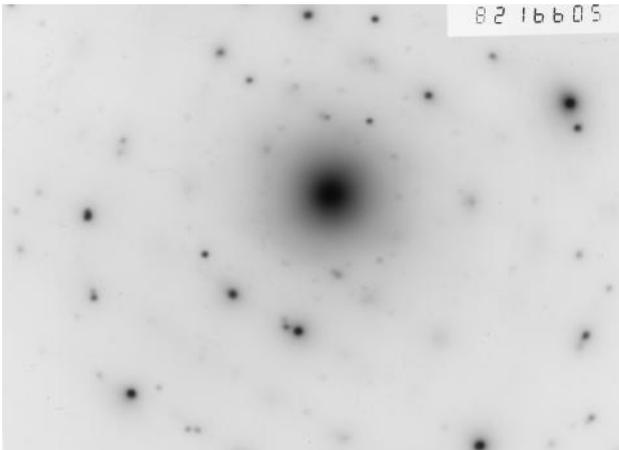
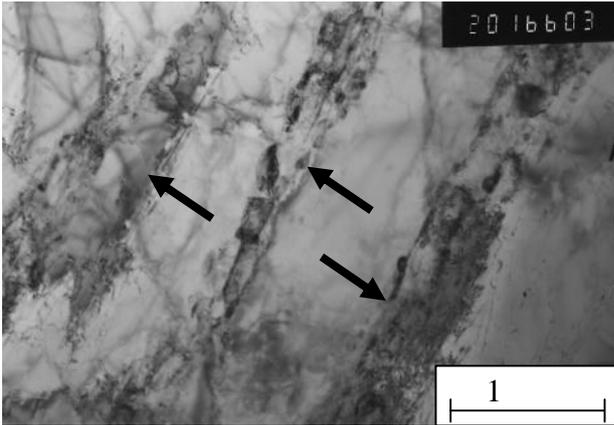
, ,). - ,

2 « »

. ,

« »,

- (221) ||(101)



.4.3.5.

13

1050° ,

, 770°

600° , 1 : -

; -

(101); -

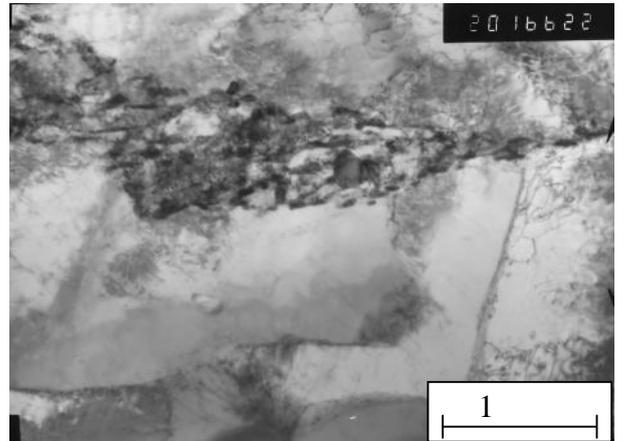
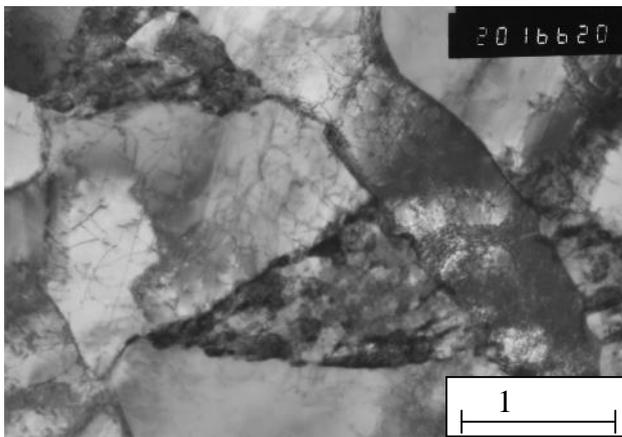
« ».

[88]. .4.3.6 (,)
770°

[88],

0.06 -

0.2



.4.3.6.

13

1050° ,

600° , 1 : , -

770°

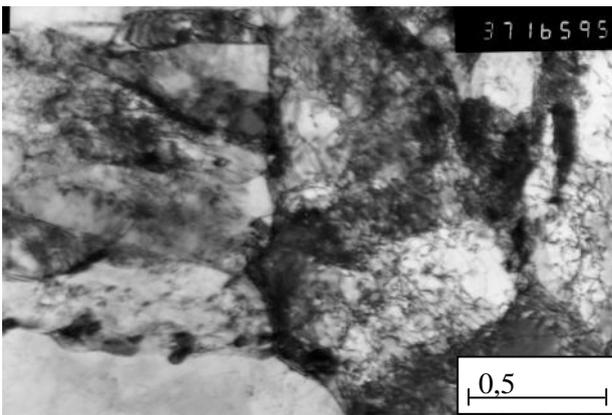
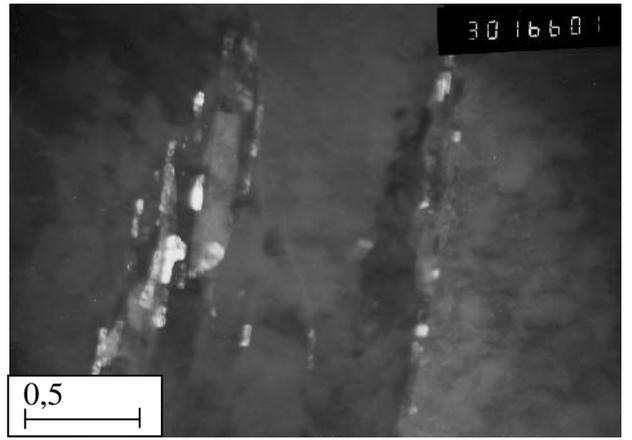
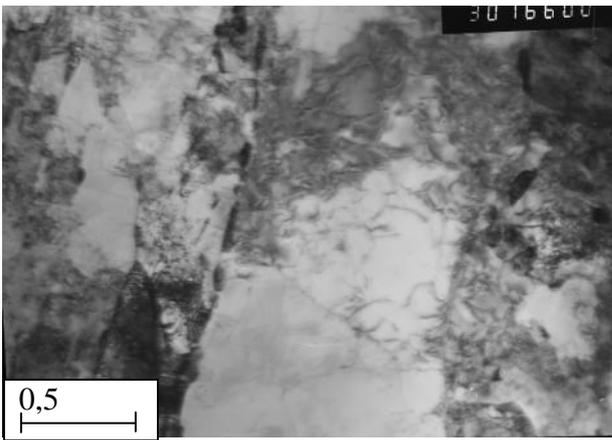
830° -

(. 4.3.7)

(. 4.3.7).

(. 4.3.7

).



.4.3.7.

13

1050° ,

600° , 1 : -

, 830°

; -

, 30000; -

900° ,

755-830° ,

1050° .

,

,

.

. 4.3.8 ,

,

,

.

.

(. 4.3.8)

-

,

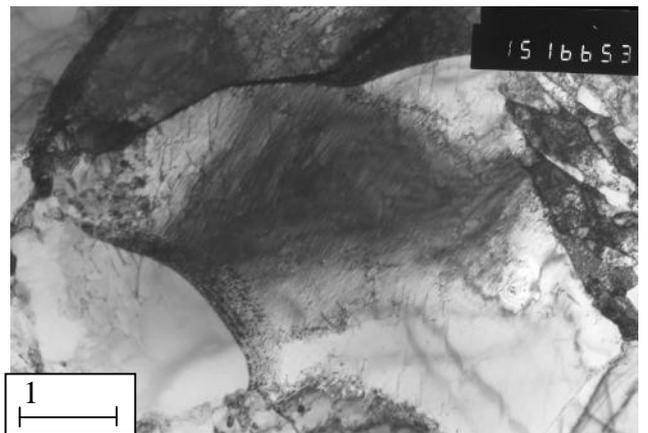
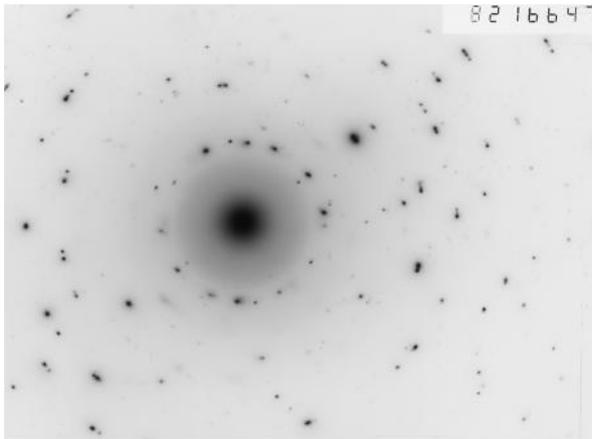
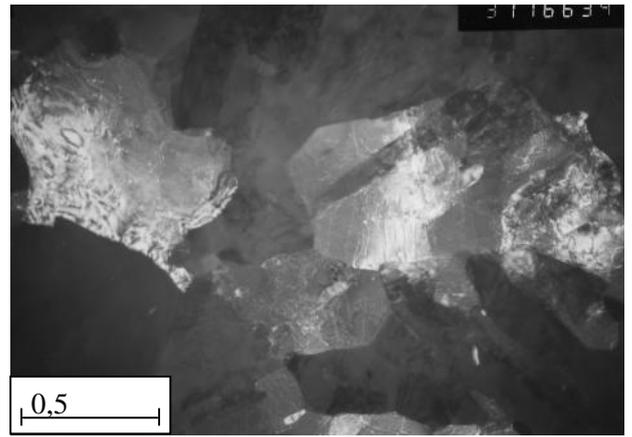
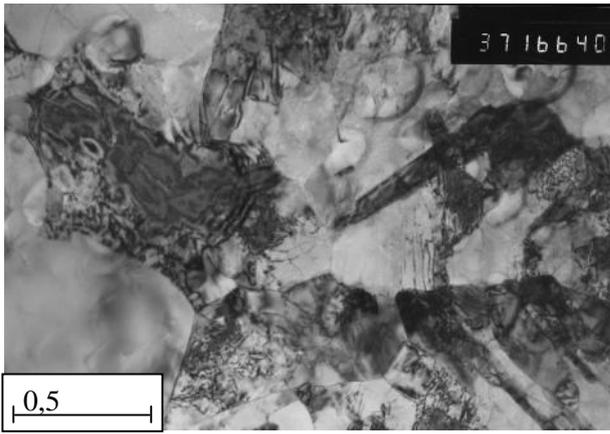
.

(

)

()

. 4.3.8 .



.4.3.8.

13 900° ,

, 770°

600° , 1 : - ; -

(110) ; - « ».

, 830° ,

,

« ».

,

(. 4.3.9).

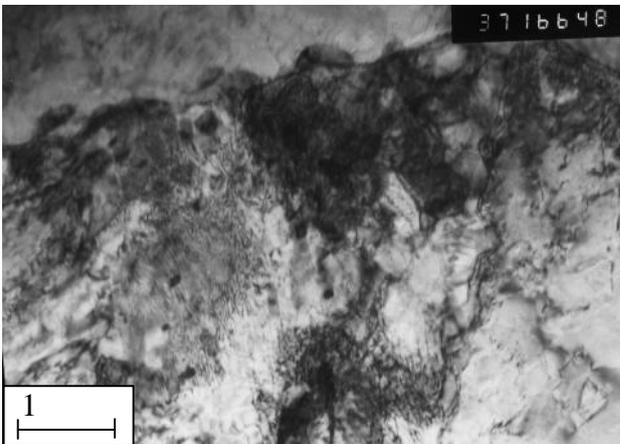
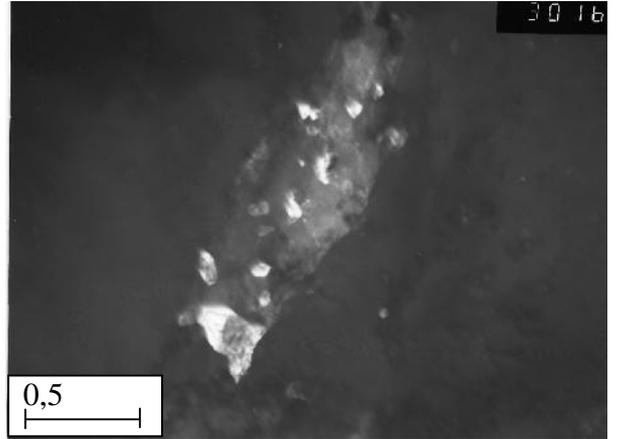
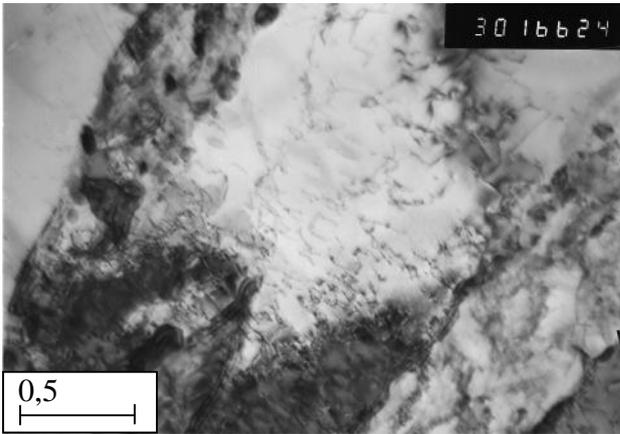
, ,

,

- (. 4.3.9). . 4.3.9

()

(),



.4.3.9.

13

900° ,

600° , 1 : -

, 830°

, -

,

-

13

KCV⁸⁰.

740° (KCV⁸⁰=270 / 2), . . .

40

900° .

800° ,

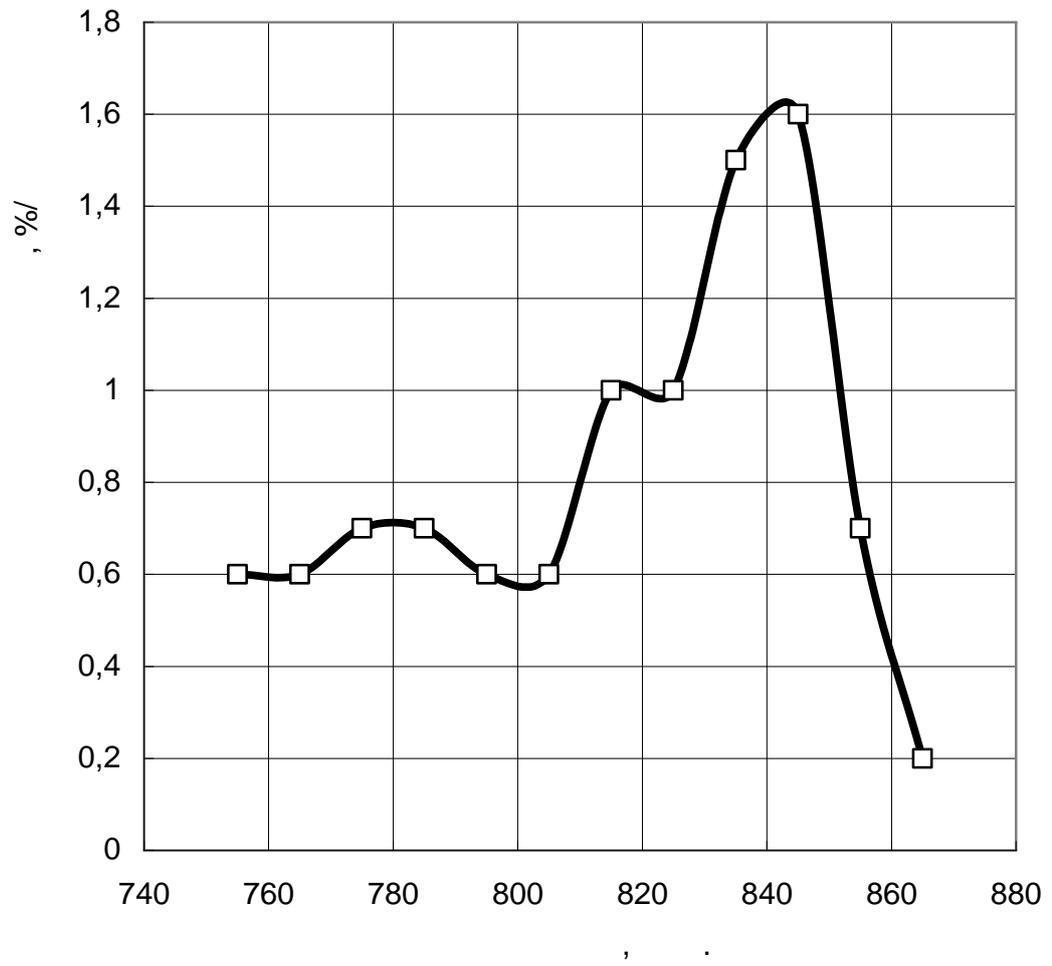
4.3.10)

. 4.3.1 .

(. 4.3.1)

800°

1050°



. 4.3.10.

4.4

1.

600°

1050

900°

13

3.

KCV⁻⁸⁰

1...800° ,

2.

)

)

)

)

1050°

900° - 770° ;

(-)

;

-

.

,

.

,

,

.

4.5

-
20

219

12 .

(+)

4.5.1

4.5.1

14-158- 113-99	, %										
	C	Si	Mn	S	P	Cr	Ni	Cu	Al	N	V
	0,18	0,27	0,46	0,003	0,008	0,17	0,11	0,13	0,031	0,009	0,04

«

».

4.6

4.6.1

4.6.1

σ , 338-470	σ , 502-627	δ , % ≥ 25	KCV-50, / ² () $\geq 39,2$., % ≥ 50
-----------------------	-----------------------	---------------------------	---	-------------------

4.6.2 .

4.6.2

I	σ ,	σ ,	δ , %	KCV-50, / ²	., %	
	1: 920° ,40 + 780° ,30 + 690° ,40 .					
	338	510	32	160±120		8
	2: 760° ,30 + 690° ,40					
	329	510	29	14±2		6
	3: 780° ,30 + 730° ,40					
	314	495	31	13±2		6-5
	4: 820° ,30 + 690° ,40					
				94±25	50	7-6

– 50 °

13-14 / ² . ,

760-780 820°

/ ² . ,

106
160 / ².

- 50°

50%.

4.6.3

4.6.3

II	σ , / ²	σ , / ²	δ , %	KCV-50, / ²	., %	
	5:		780° , 15	+	690° , 40	
	309	471	29,5	14±0,03		6
	6:		780° , 30	+	690° , 40	
	343	520	30	13±1		6
	7:		780° , 1,5	+	690° , 40	
	343	510	31,5	30±6		6-7
	8:		780° , 3	+	690° , 40	
	314	500	31	18±4		6

α-

V-50.

13 30

/ ²,

4.6.4

III	σ , / 2	σ ,	δ , %	KCV-50, / 2	., %	
	9:		840° , 30	+	690° , 40	
	412	559	29,5	284±50	85	11
	10:		900° , 30	+	690° , 40	
	422	554	28	265±25	85	10

4:

3

4.

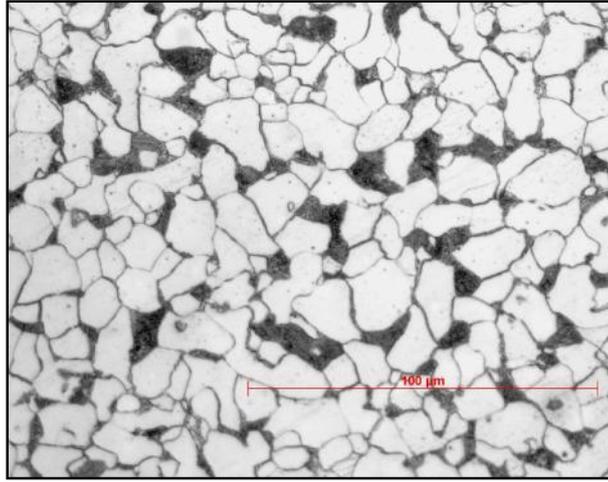
4.7

PS

Fe-C,

“ ”

(.4.7.1).



500

4.7.1

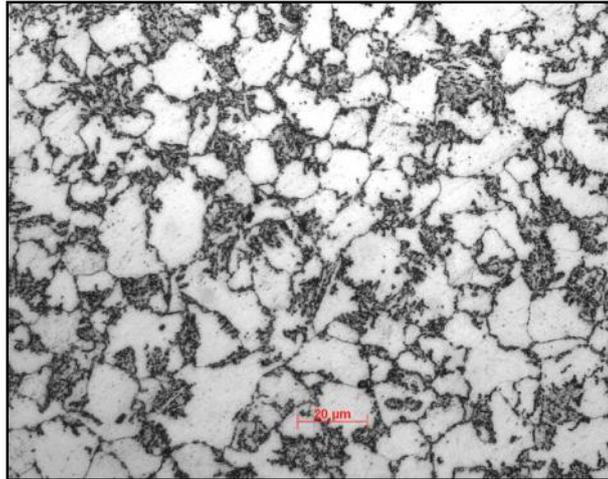
20

920°

920° (.4.7.1)

(.4.7.2),

780°



500

4.7.2

20

920° ,

780° ,

690°

Fe-C,

,

,

,

-

),

,

, . . .

,

.

,

,

780°

,

,

.

(

)

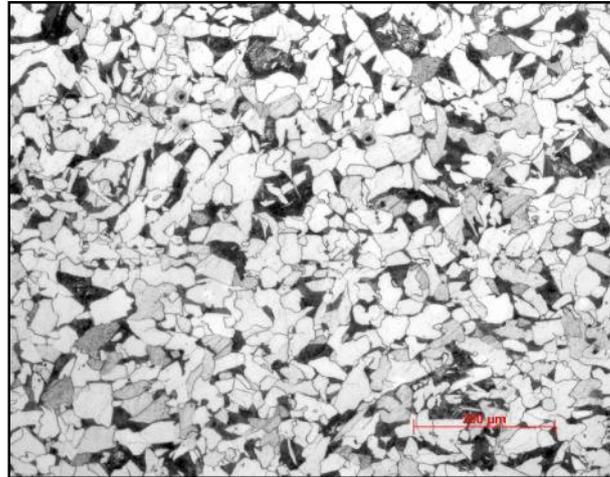
50° .

20

(. 4.7.3)

760°

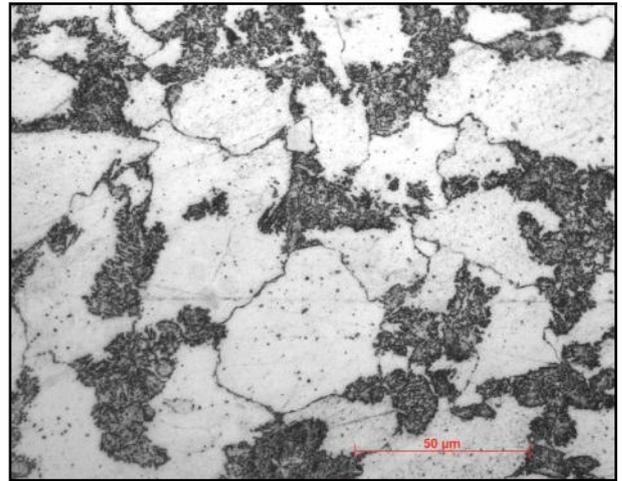
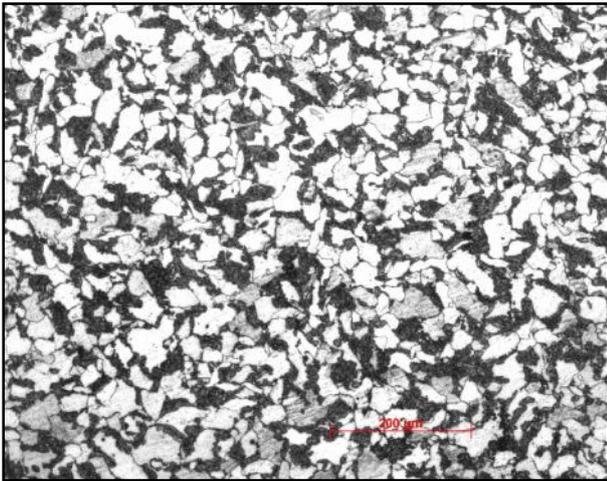
690° (. 4.7.4).



100

4.7.3

20



) 100

) 500

4.7.4

20

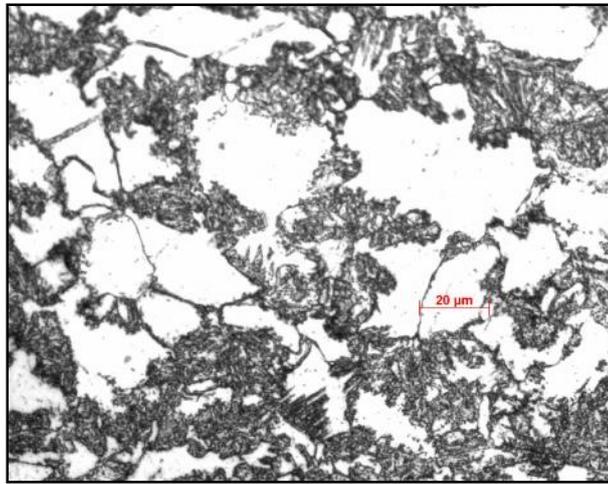
760° ,

690°

760°

4.7.5
690° .

820°



500

4.7.5

820°

690°

780° ,

- 690° ,

(15 , 30 , 1,5

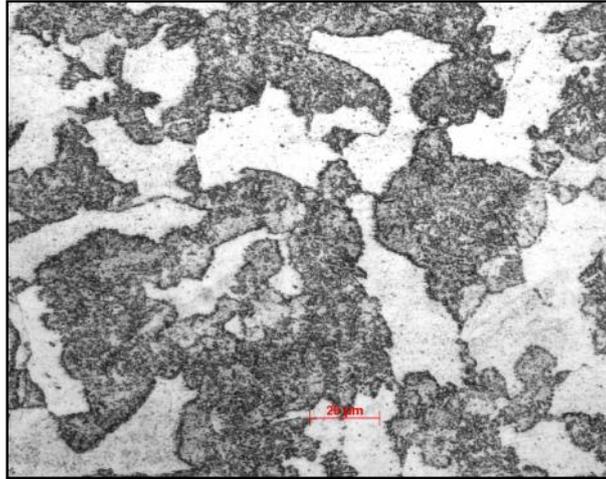
).

780°

: 4.7.6, 4.7.7, 4.7.8.

5

()



500

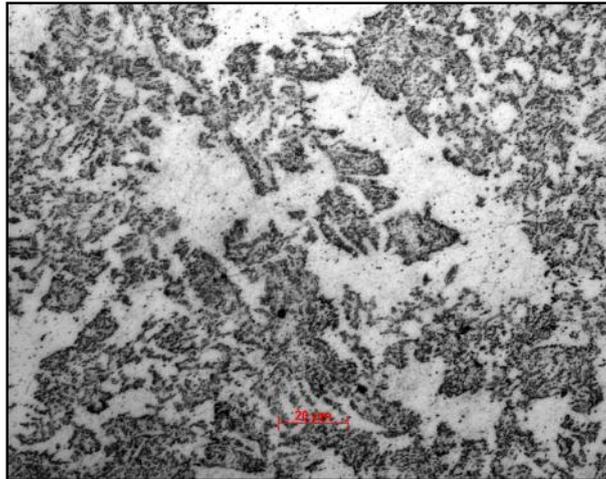
4.7.6

20

780°

15

690°



500

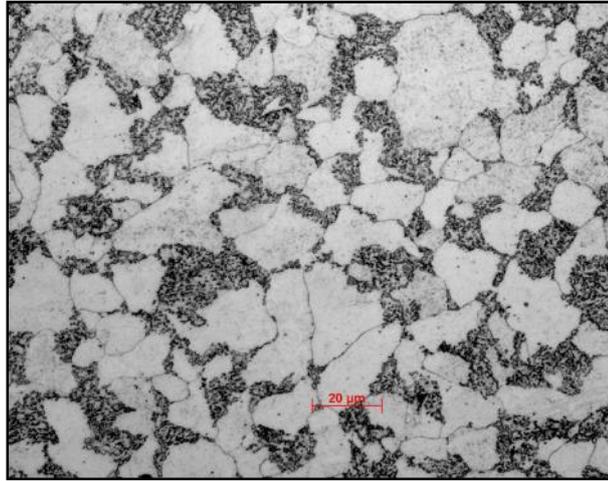
4.7.7

20

780°

30

690°



500

4.7.8

20

780°

1,5

690°

,

-

- 50 °

.

-

840° (. 4.7.9).

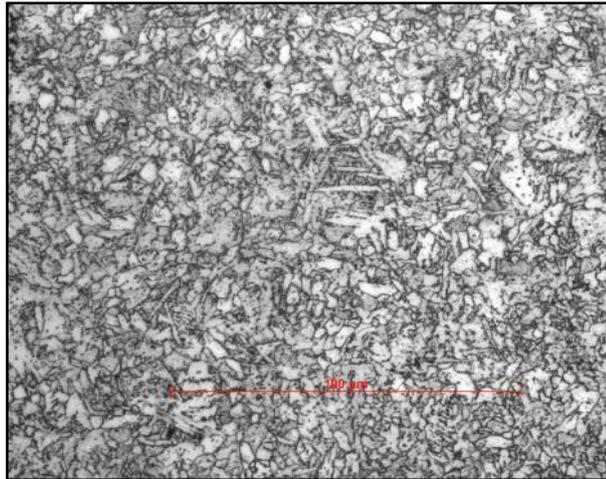
,

.

,

,

r → x



500

4.7.9

20

840°

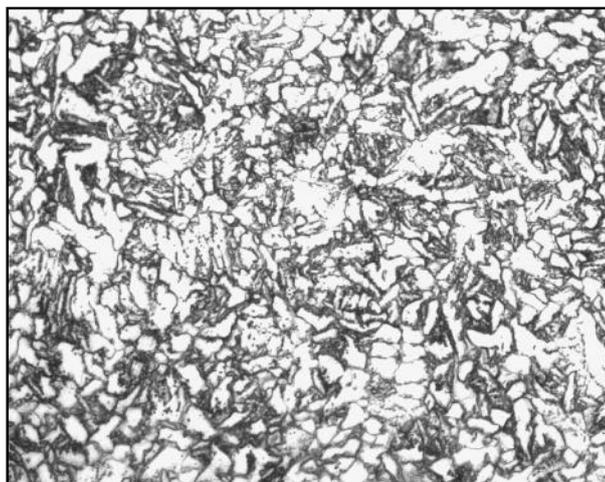
690°

50°

(. 4.6.4)

900°

(. 4.7.10).



500

4.7.10 –

20

900°

690°

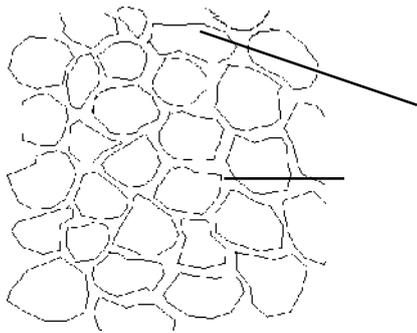
840° .

950° [89],

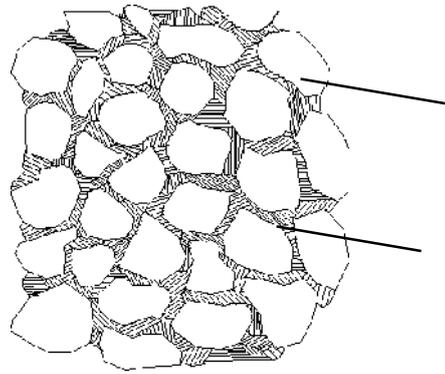
950° ,

900°

840°



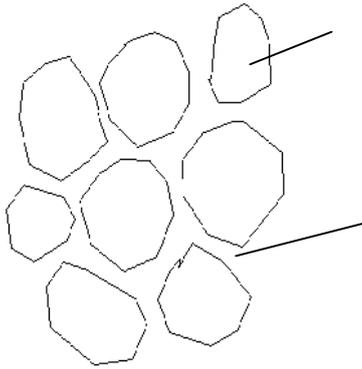
4.7.11 -



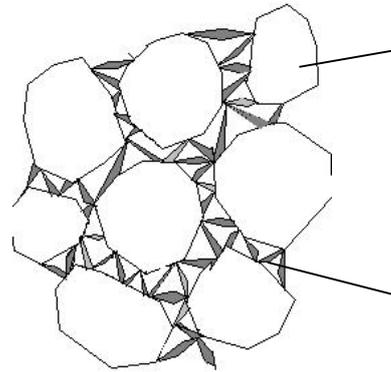
4.7.12 -

4.7.11

(. 4.7.12)



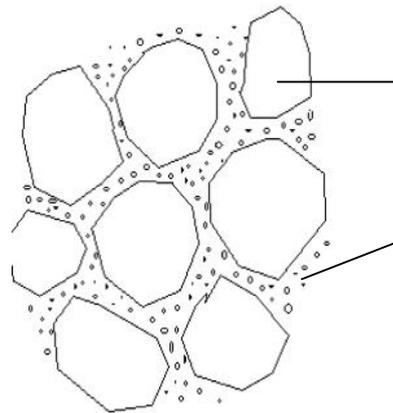
4.7.13 –



4.7.14 –

, (. 4.7.13).

(. 4.7.14).



4.7.15 –

Fe₃C,

,

4.7.15). . . [56], (.

[84].

4.8

20.

1)

2)

KCV-50=30 / ²

3)

760-780° 820° , . .

3

4)

3

265-285 / ²,

5)

4.9

·
 ,
 20 13 .

13 .

4.9.1.

12 12 70 ,

4.9.1

	, %										
	C	Si	Mn	S	P	Cr	Ni	Cu	Al	N	V
13	0,16	0,30	0,53	0,012	0,007	0,60	0,05	0,06	0,04	0,007	0,06

c

13 , 40-

1050°

, .

900° .

755, 770,

800, 830, 845 860 ° ,

40

,

600°

HB₃₀₀₀,

KCV-80,

-

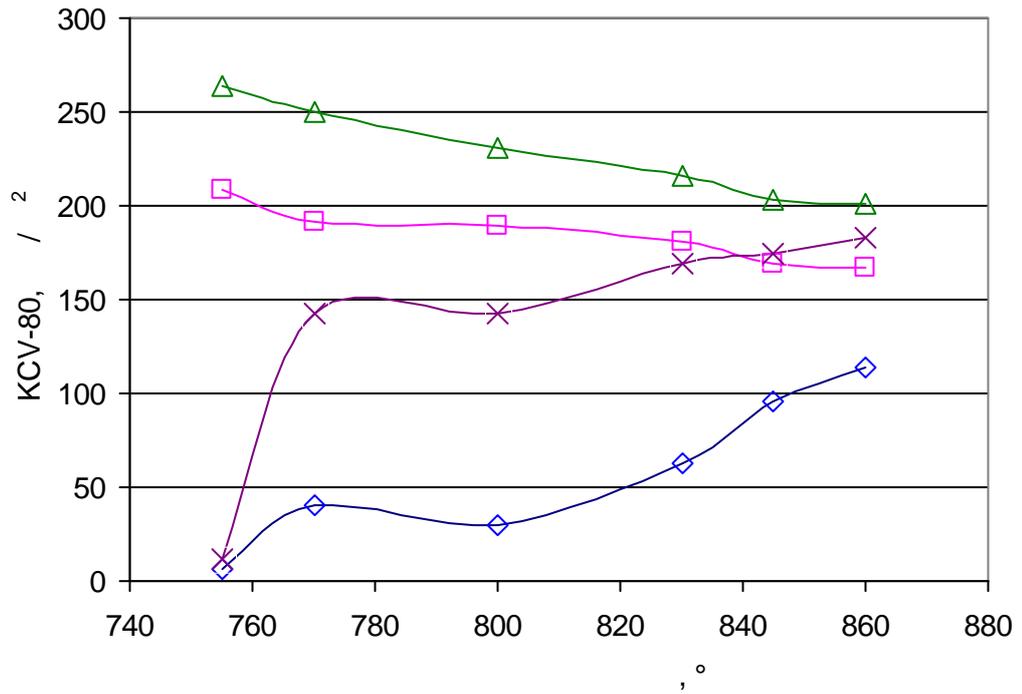
.

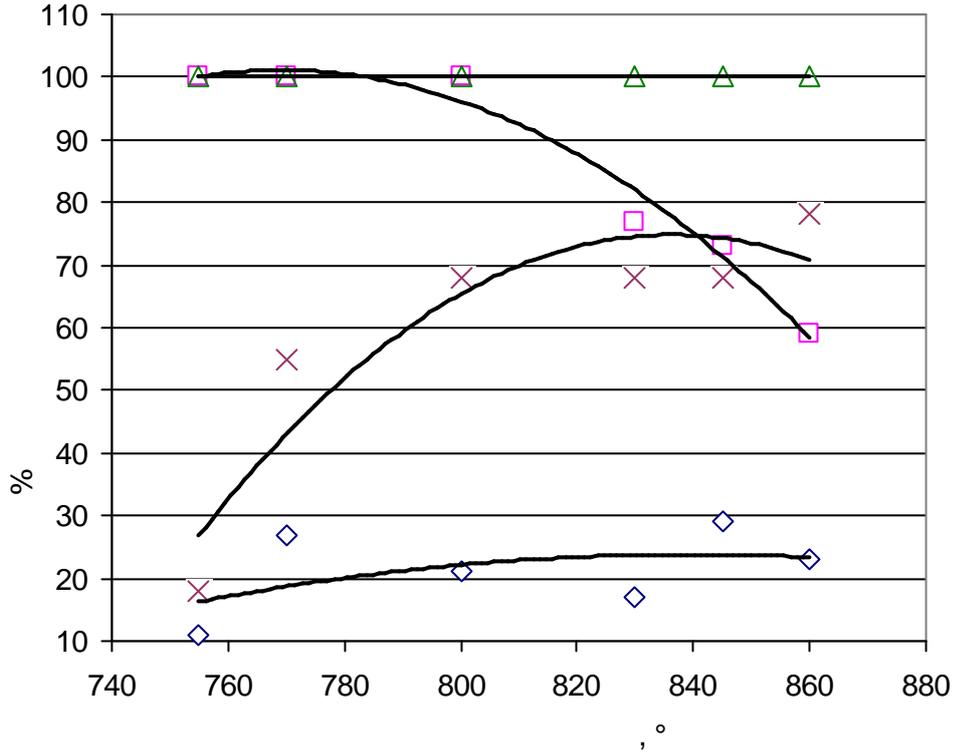
4.10

. 4.10.1 ,

13 . , . 4.10.1

13 .



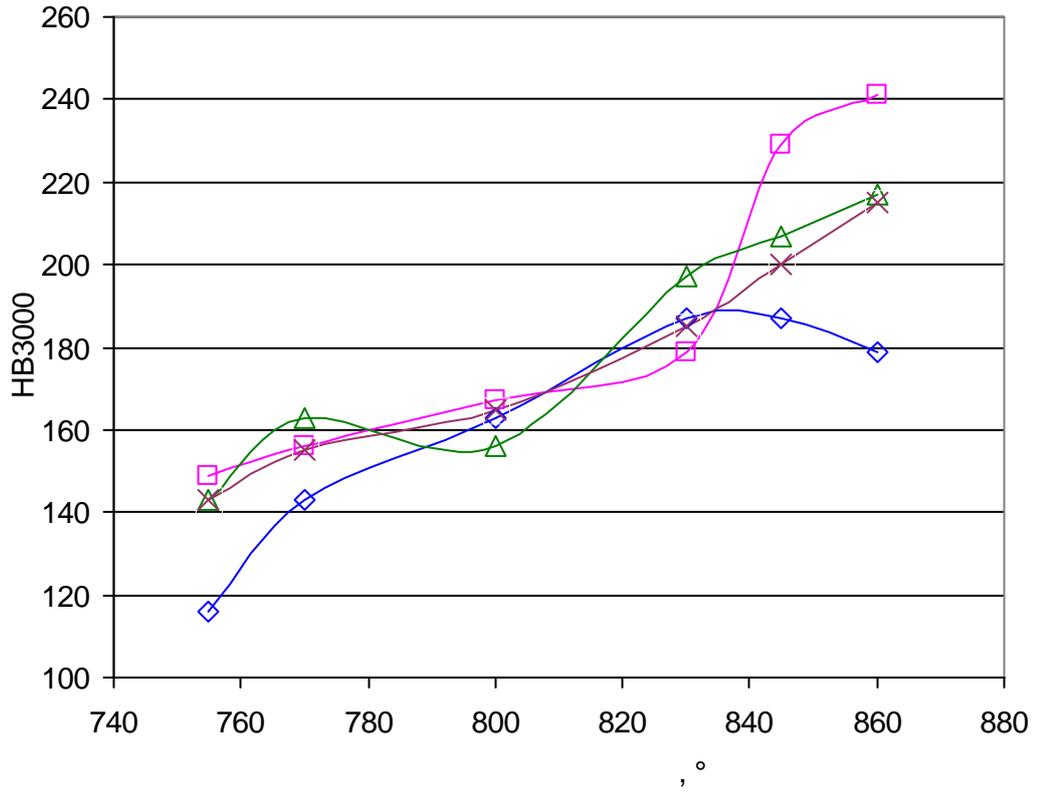


. 4.10.1 — () ()

- , - , -), 900° - Δ, 1050° (600° , 1

. 4.10.2

. 4.10.1 ,



4.10.2 —

— , —), 900° - Δ , 1050° (- , 600° , 1 .

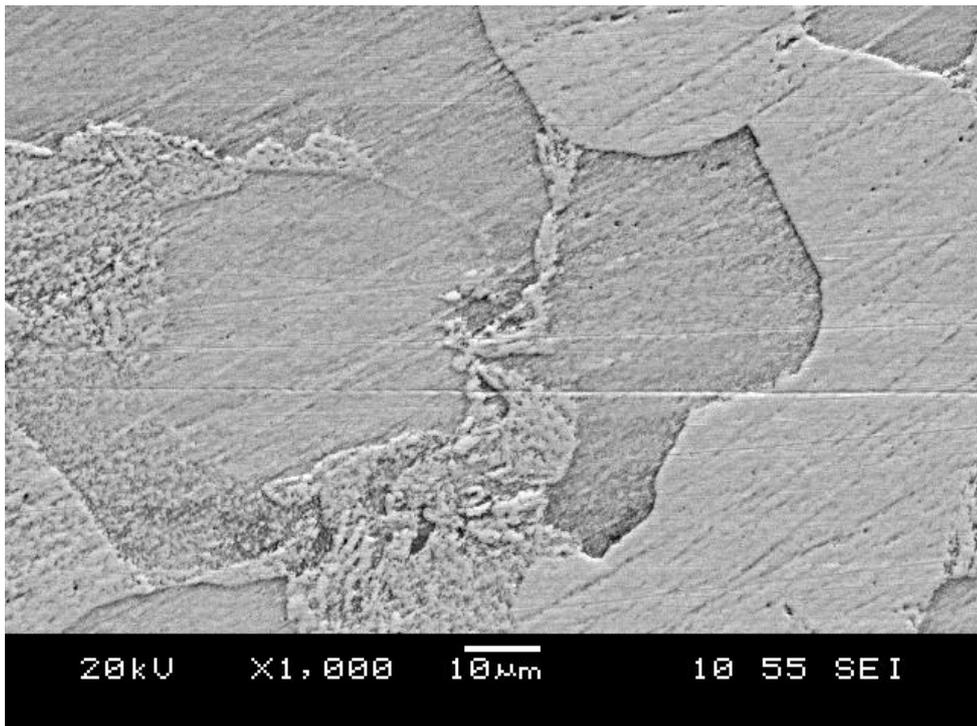
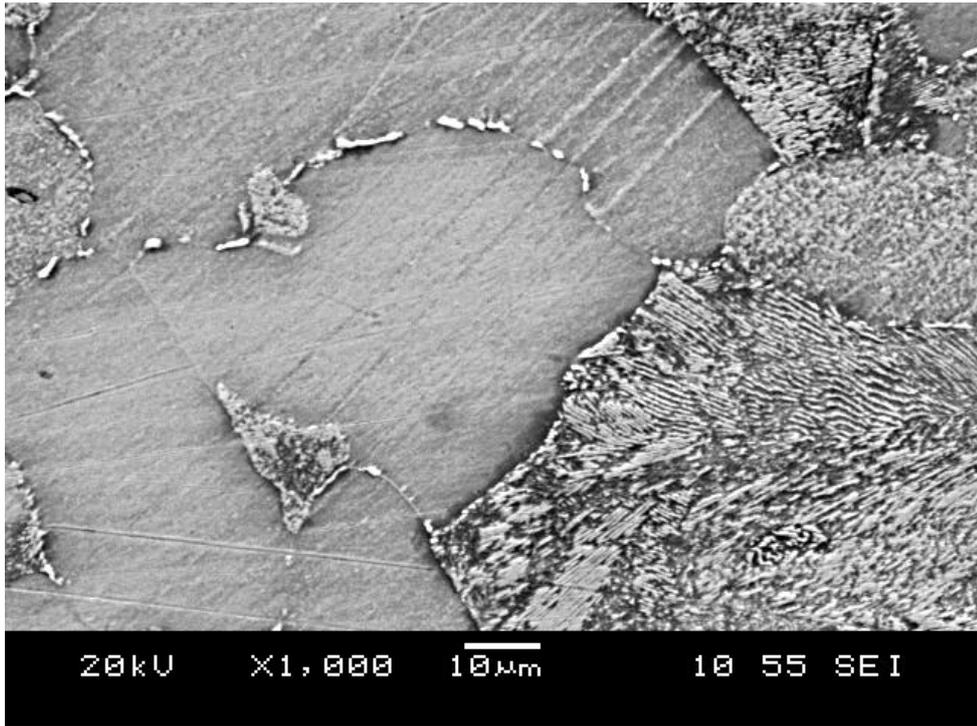
1 3

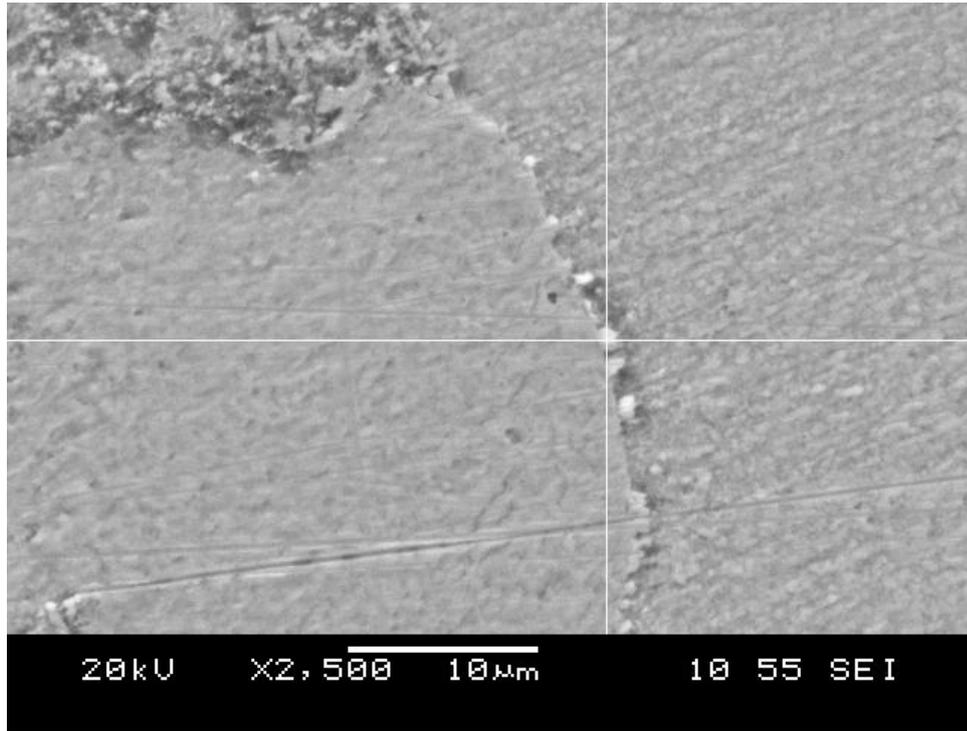
13

1050°

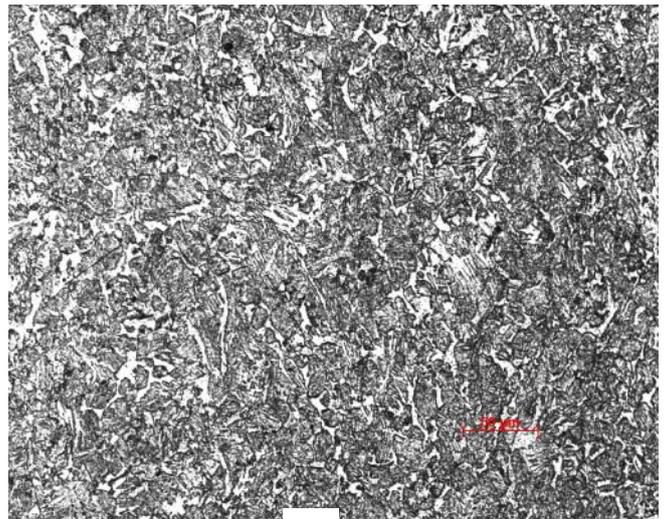
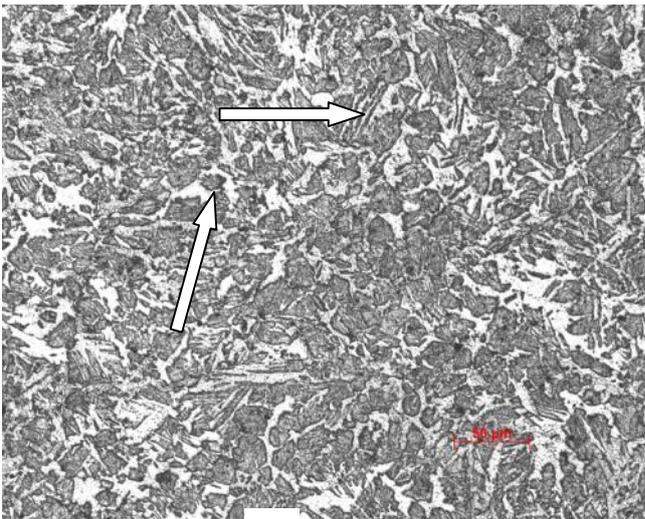
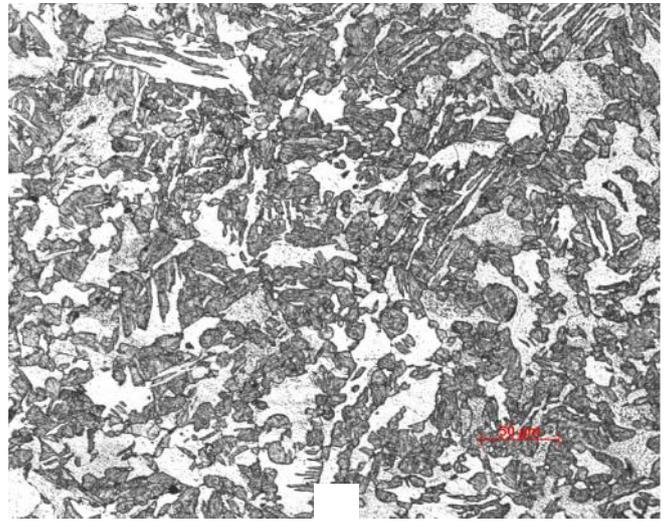
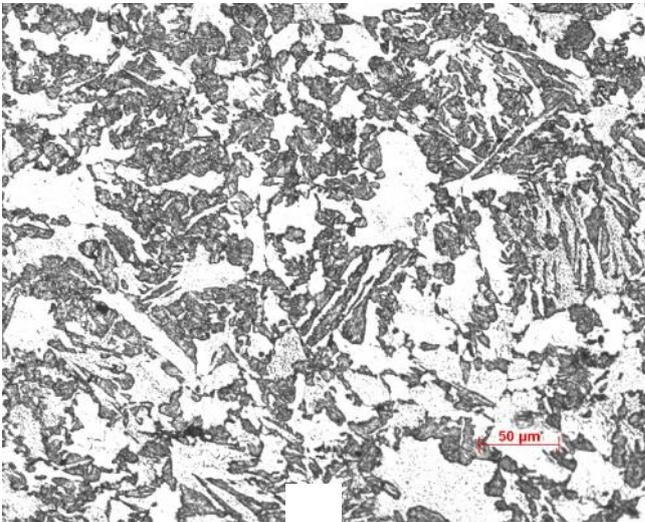
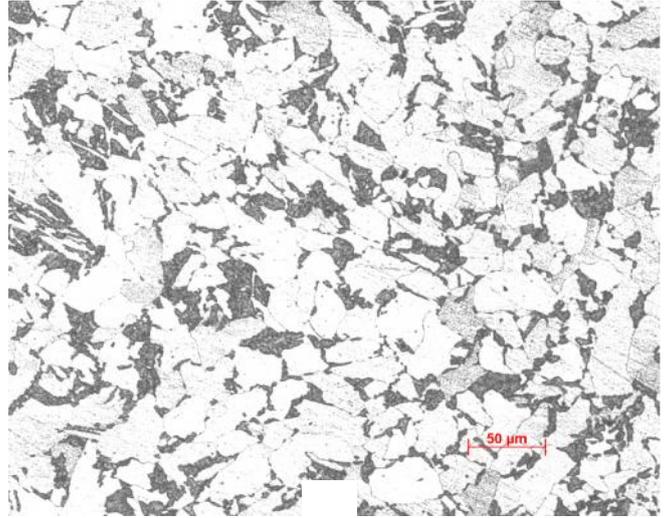
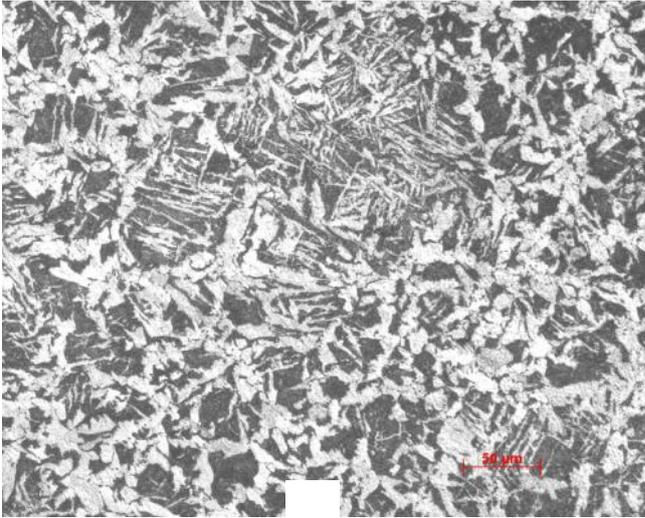
755° 13

(4.10.3).





. 4.10.3 — 13 - 770 800° 755° 600° 1050° 600° ; , - , 1000, - , 1050° , 770-800° () (. 4.10.3 ,). , γ- . (. 4.10.4 ,).

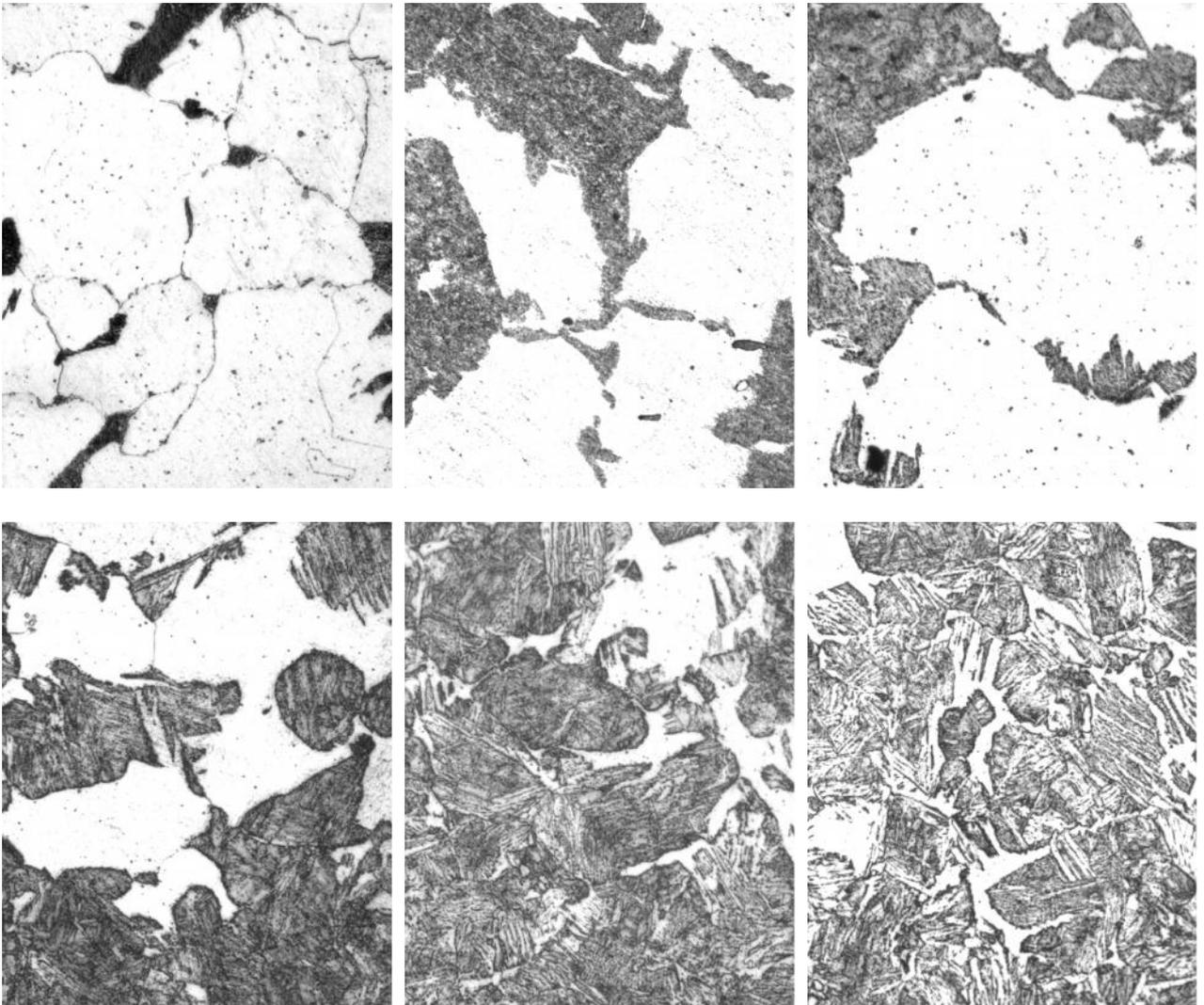


. 4.10.4 —
 1050 °
 770° , - 800° , - 830° , - 845° , - 860° , 500.

13

755° , -

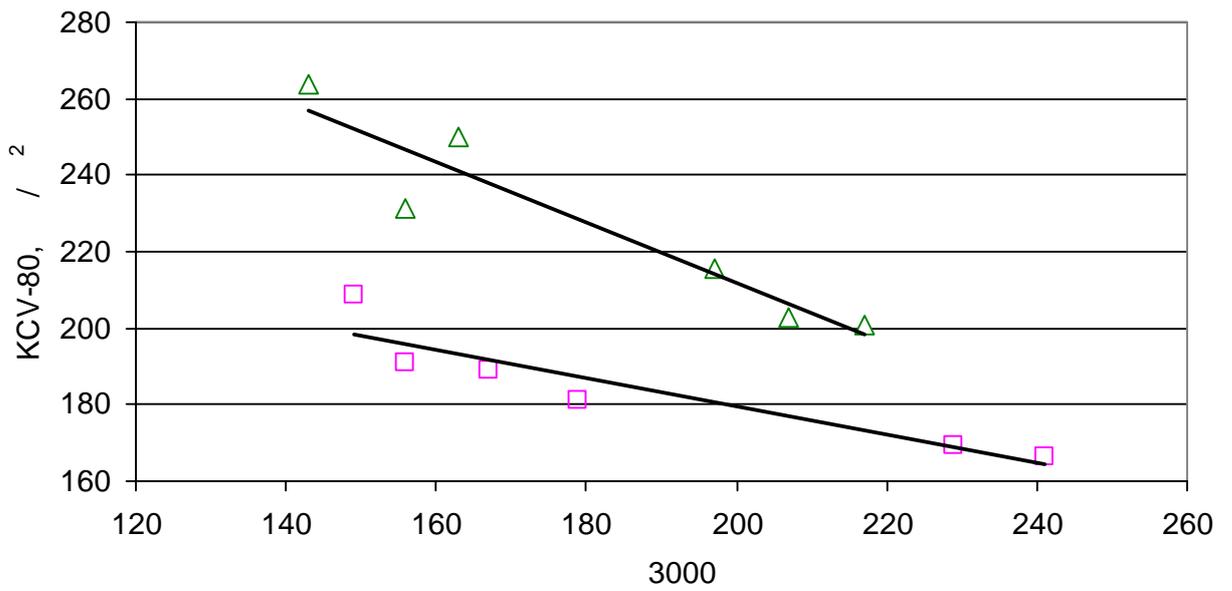
, , α - , ,
 () (. 4.10.4 ,
 ; 4.10.5 ,),
 (800°)
 [90]. . 4.10.4

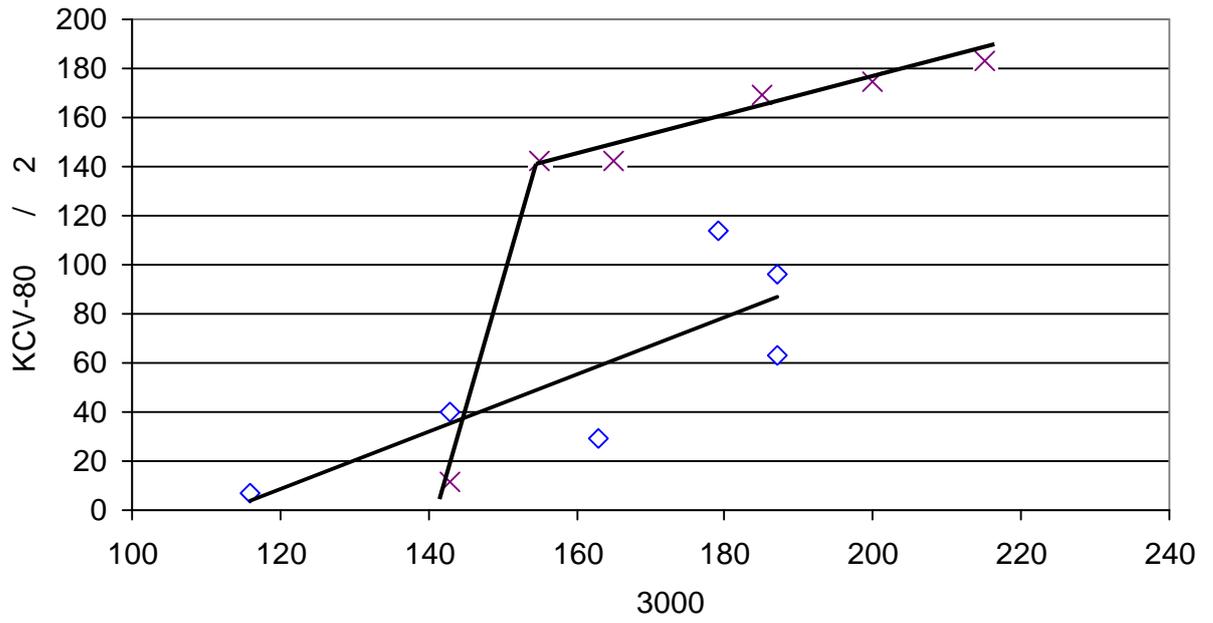


. 4.10.5 — 13
 1050° , —
 -800° , -830° , -845° , -860° , 500.

755° , -770° ,

γ- ,
(.4.10.4 , ;4.10.5 ,).
. 4.10.6 ,





4.10.6

), 900° - Δ, 1050° (- , - 600° , 1 .

() 600°

$$KCV = f(HB)$$

KCV - 80

KCV

1.

[88, 91]

$$KCV = f(HB).$$

4.11

1)

1050°

13

2)

3)

4)

1050 900° ,

,

1, . . .

,

.

5)

.

6)

.

.

1050° ,

,

-

,

.

5

20 13

5.1

13 20 ,

5.1.1.

5.1.1

13 20

	, %											
	C	Si	Mn	S	P	Cr	Ni	Cu	Al	N	V	Nb
13	0,13	0,25	0,51	0,012	0,006	0,65	0,05	0,05	0,04	0,006	0,04	-
20	0,2	0,2	0,55	0,015	0,012	0,10	0,05	0,05	0,04	0,008	0,04	0,02

900 °

2.4.

5.2

1

13

131

$$_1=746\pm 5 \text{ } ^\circ ,$$

$$_3=863\pm 5 \text{ } ^\circ \text{ (. 5.2.1).}$$

5.2.1

900 ° , 5-70 ° / 13 ,

/ ,						
900 °						
5	741,6	868,3	126,7	770,4	608,8	161,6
10	747,5	860,1	112,6	773,0	613,7	159,3
20	743,8	856,6	112,8	774,0	544,0	230,0
40	750,7	867,9	117,2	761,7	464,3	297,4
70	740,3	871,1	130,8	730,0	357,7	372,3

. 5.2.1.

117 °

, 0,85 %/° . .

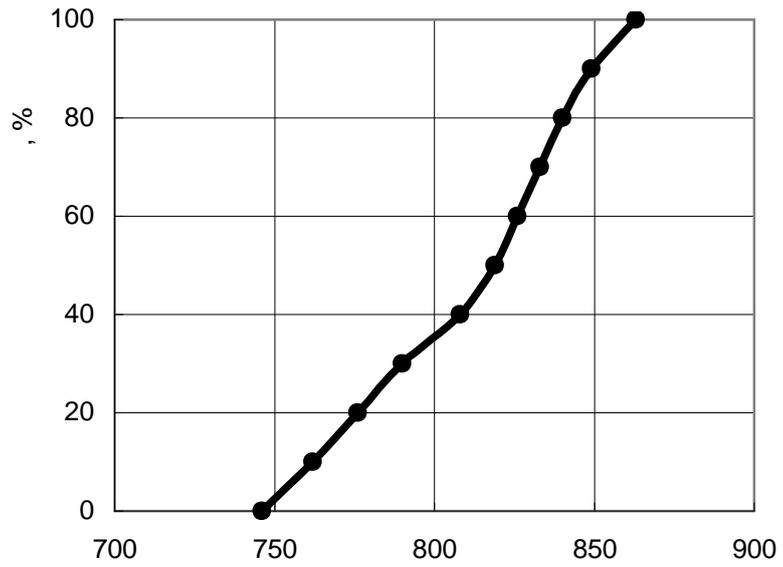
5.2.1 ,

800 °

13

40 % ,

863 °



. 5.2.1

13

20

13

110 °

;

1

3

727±5 °

837±5 °

(. 5.2.2).

5.2.2

(°),

20 ,

900 °

5-70 ° /

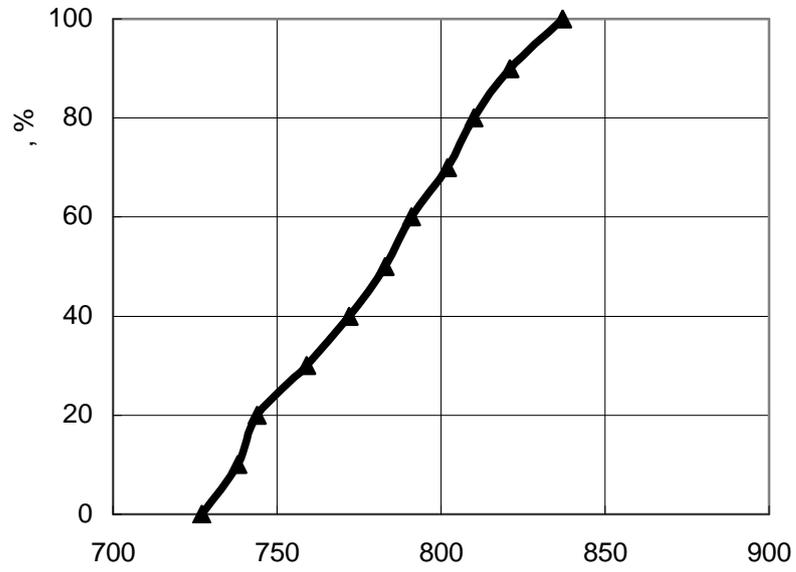
° /						
900 °						
5	729,9	835,2	105,3	767,3	606,2	161,1
10	730,1	836,6	106,5	734,6	593,4	141,2
20	730,2	839,7	109,5	730,3	567,6	162,7
40	728,0	836,4	108,4	730,0	542,4	187,6
70	729	841	112	707,2	507,0	199,8

0,9 %/° .

800°

70 % (. 5.2.2).

900°



. 5.2.2

20 .

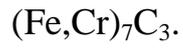
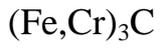
$\alpha \rightarrow \gamma$

13 .

20

$\alpha \rightarrow \gamma$

VC.



3

5.3

900°

3

α↔γ

(

0,25

/1%)

900 °

. 5.3.1, 5.3.3.

13

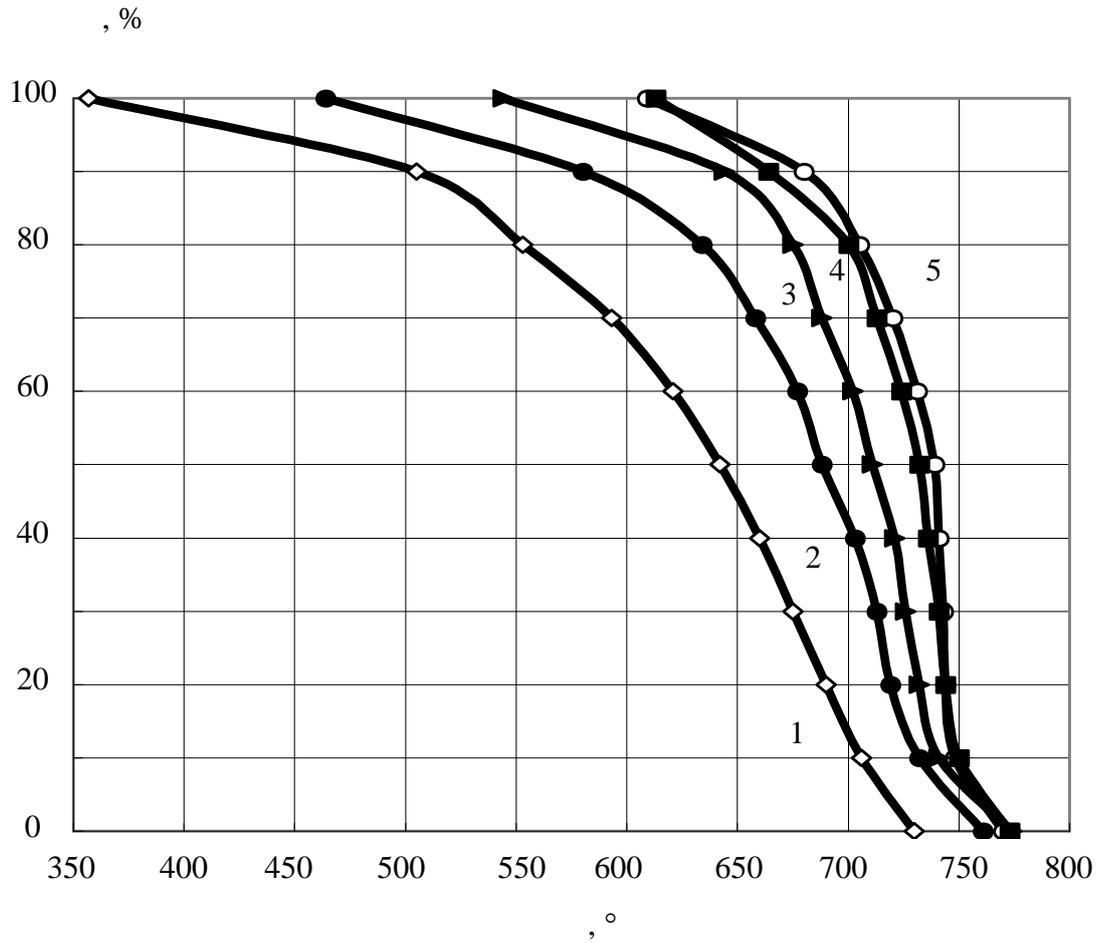
(. 5.3.1, . 5.2.1)

γ→α

44 °

774 730 ° ;

r₃



. 5.3.1
 13
 : 1 - 70° / , 2 - 40° / , 3 - 20° / ,
 4 - 10° / , 5 - 5° / .

10 %

30°

Γ₃;

(750—650)°

5-10 ° /
 700
 (. 5.3.1, 4, 5)
 ° 80 %, 20, 40 ° / (. 5.3.1,
 3, 2) 60 40 %
 70 ° / (. 5.3.1,
 1)
 700 ° 10 %.

50 % 5-10 ° /
 r_3 31-41 .., 73-88° .
 40-70 ° /

200 ° (161 373 ° .)
 r_1 ,

(70 ° /)

600° .

. 5.3.1,

70 ° / 90 %

500° ,

150°

10 % .

r_1

100 %

5.3.2

13

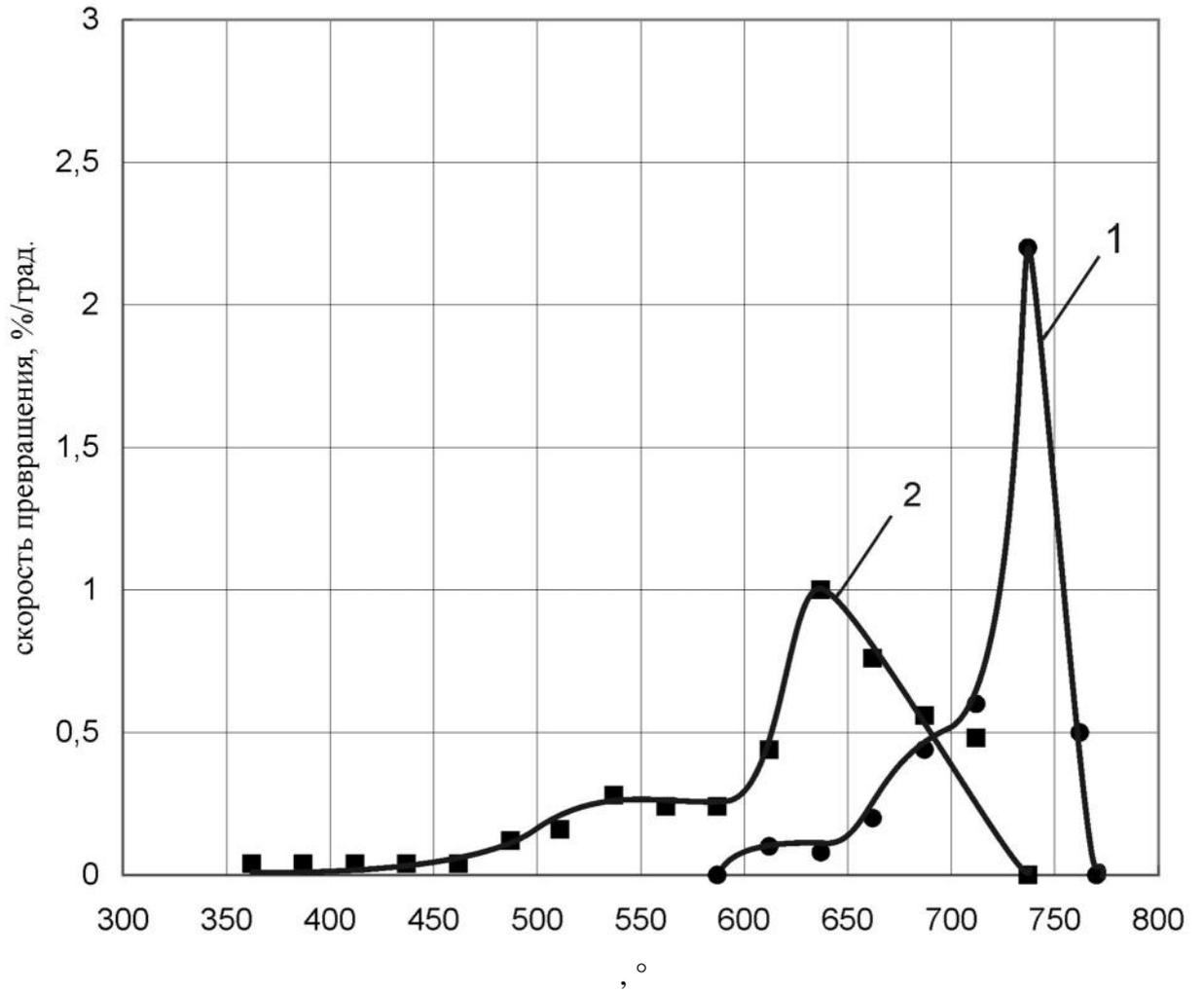
(5 ° /),

1,

(70 ° /),

2,

900 ° .



5.3.2

13

900 ° .

1 –

5 ° / ;

2 –

70

° / .

730° ,

450° . () 600

,
,
, r₁,

[93]

13

:

, ° = 520 - 320·0,13 - 45·0,51 - 30·0,65 - 20·0,05 - 5(0,25+0,05) =

433° .

20 :

, ° = 520 - 320·0,2 - 45·0,55 - 30·0,1 - 20·0,05 - 5(0,2+0,05) = 426° .

r₁

,

70 ° /

,

,

,

,

,

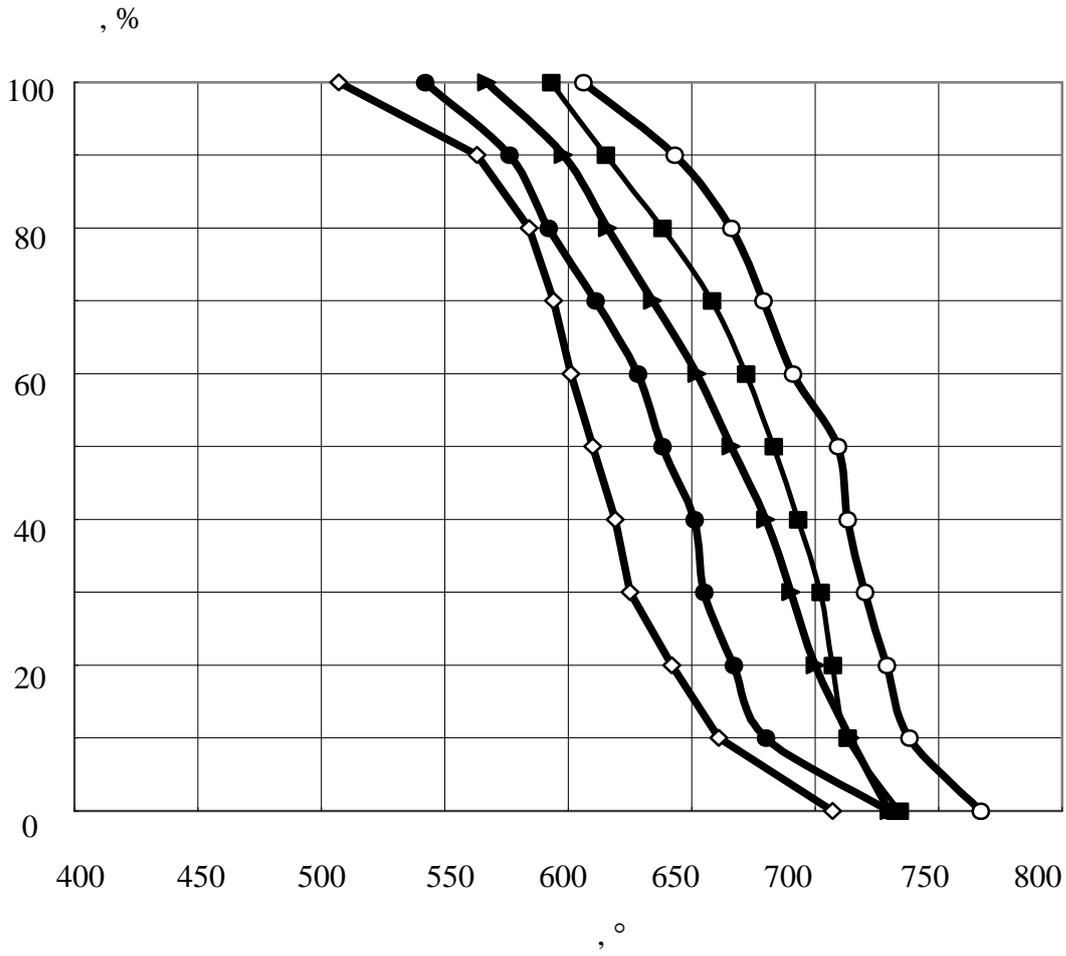
20

900°

.5.2.2

. 5.3.3,

5.3.4.



. 5.3.3
 20 900 °
 : 1 - 70 ° / , 2 - 40 ° / , 3 - 20 ° / ,
 4 - 10 ° / , 5 - 5 ° / .

20

r₃

767-707 °

13

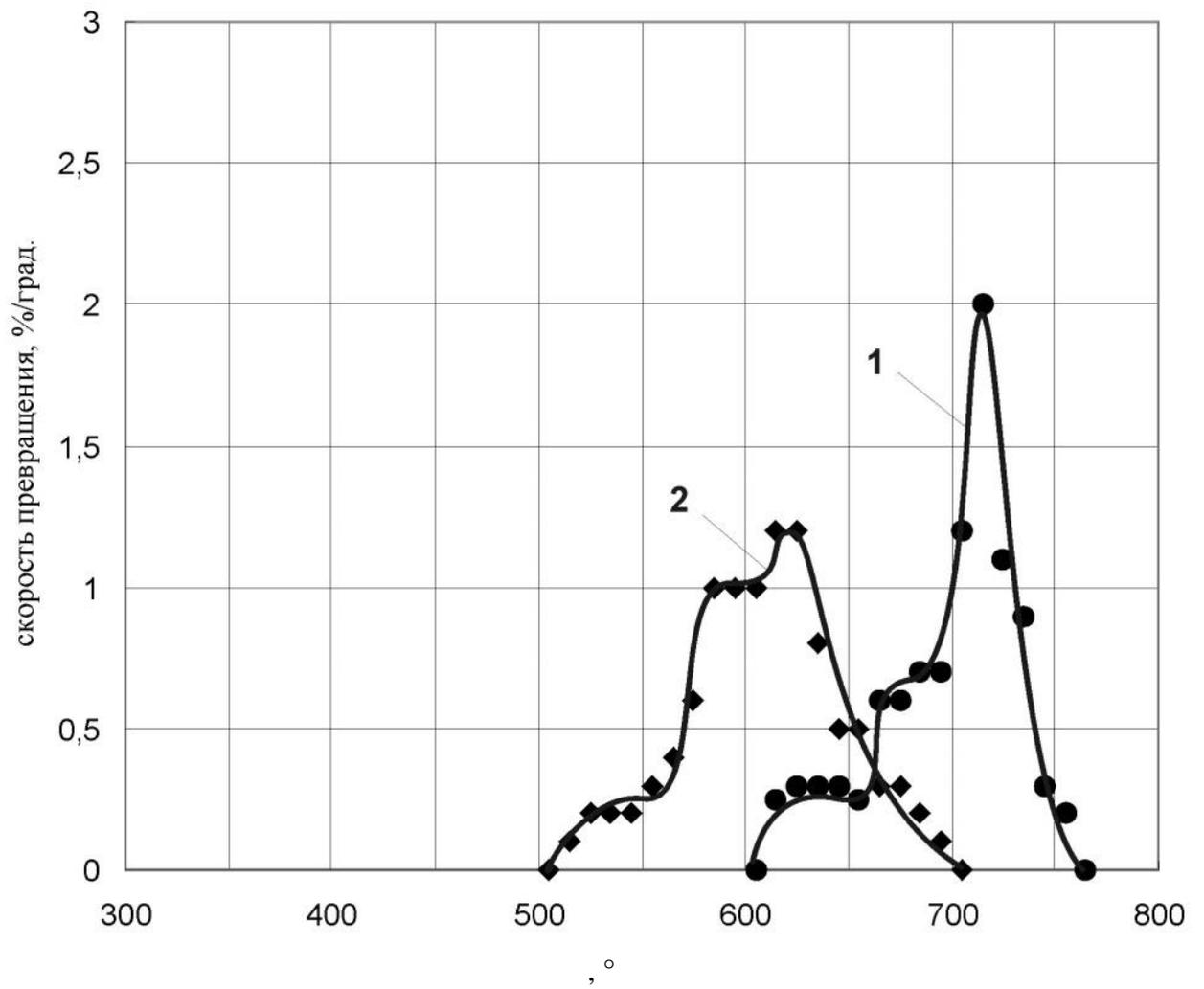
140
30-40 °

ГЗ.

(160° 5

° / 199° 70 ° /)

606 ° 507 ° ,



.5.3.4

20

900 ° .

1 -

5 ° / ;

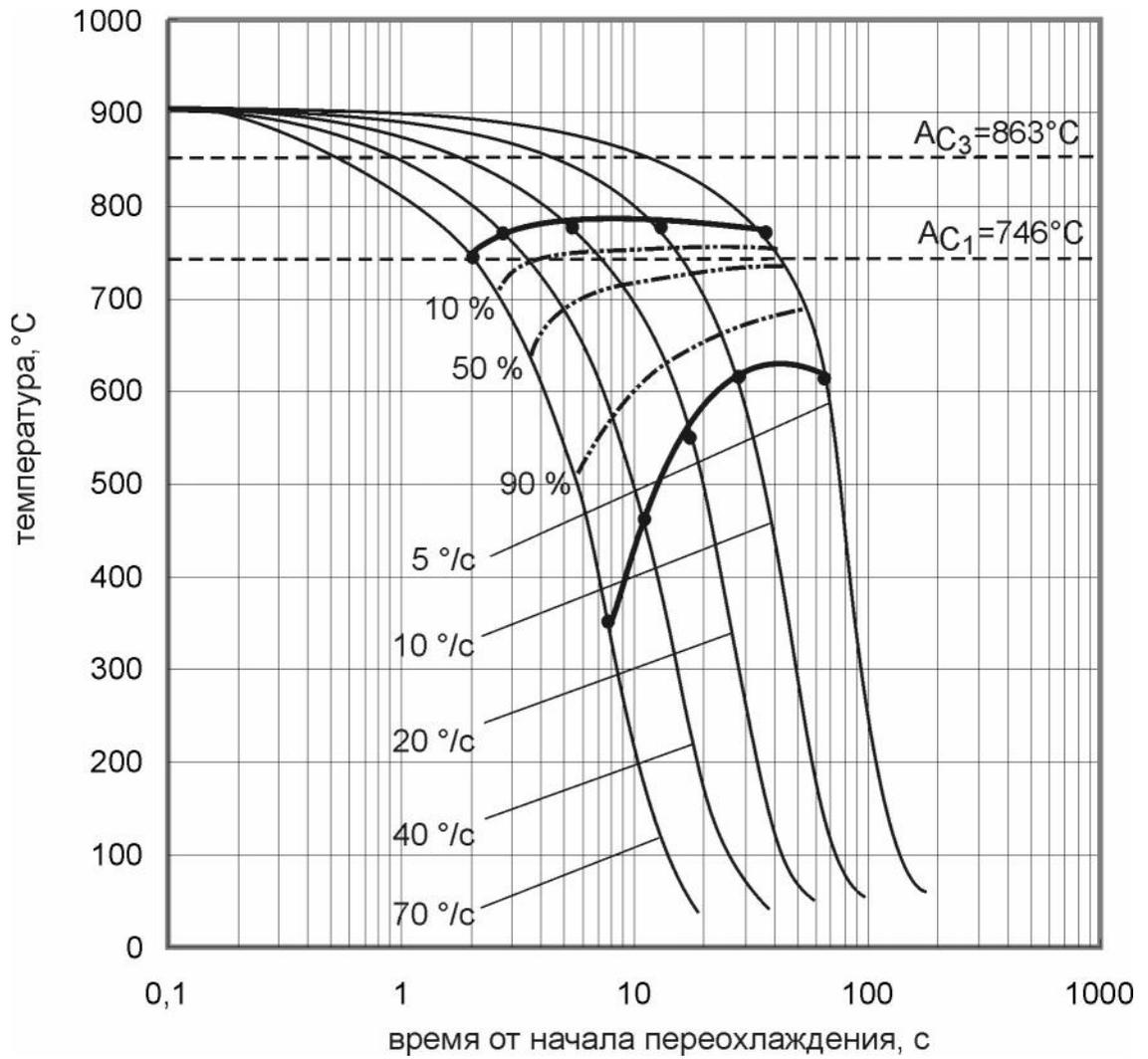
2 -

70

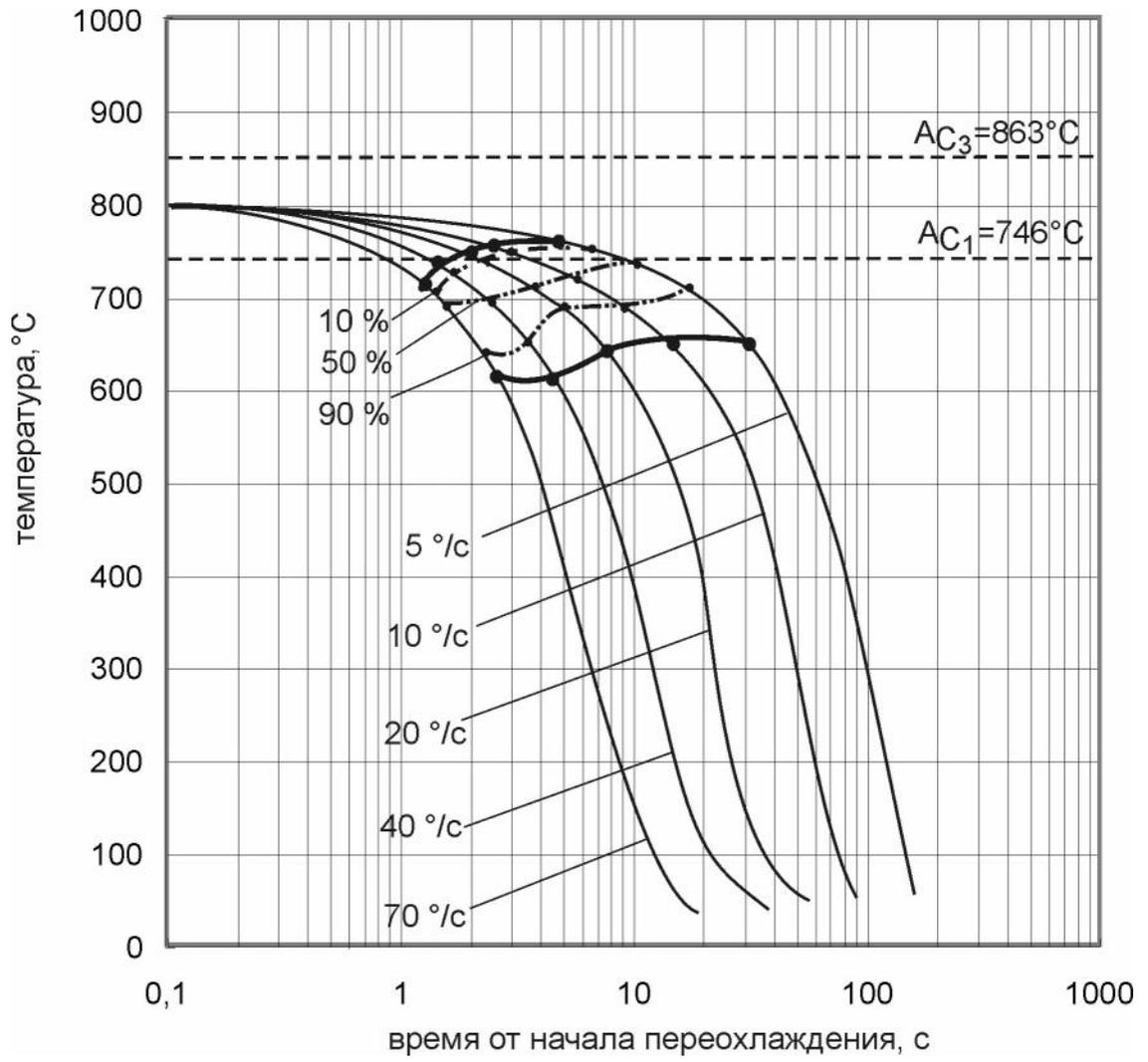
° / .

900 ° , (. 5.3.5, 5.3.6).

5-70 ° /



.5.3.5



. 5.3.6

20

900 °

, Γ_1 Γ_3 , ,

, ,

(5 ° /).

20

13

. ,

. 20

.

, , ;
 70 ° / .
5.4 -
 13
 20 ,
 900° . ,
 .
 .
 5 ° / -
 , , ,
 (. 5.4.1 , 5.4.2). 20-30 .
 13 ~15%, 20 -
 20% .
 10 ° /
 (. 5.4.1 , 5.4.2),
 - . 20 ° /
 ,
 13 20 25-30% (. 5.4.1 , 5.4.2).
 60-65% .
 .
 40 ° /
 ~40%
 (. 5.4.1 , 5.4.2). ,
 10-15 .
 .
 ,
 ,

.

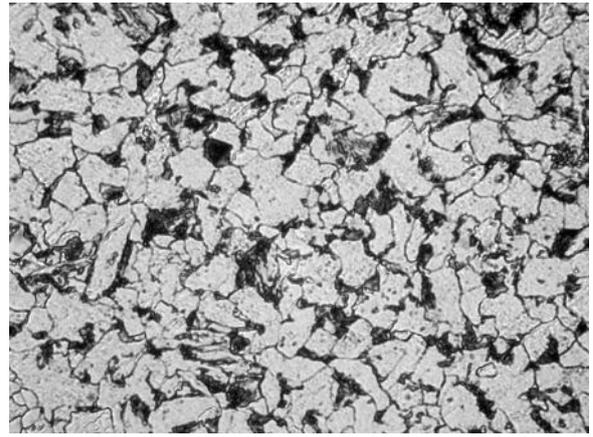
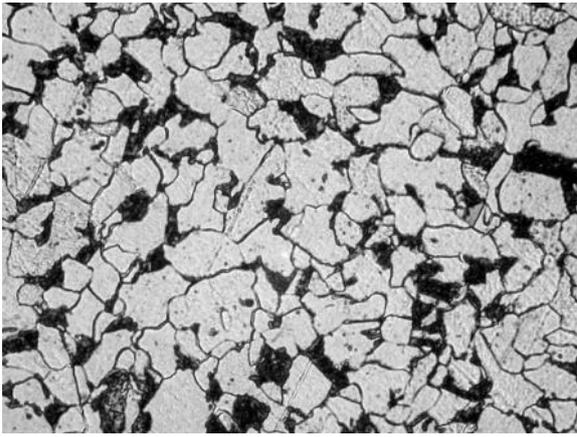
,

70 ° /

80-85%, 10-15% (. 5.4.1 ,

5.4.2).

(. 5.4.1 , 5.4.2).



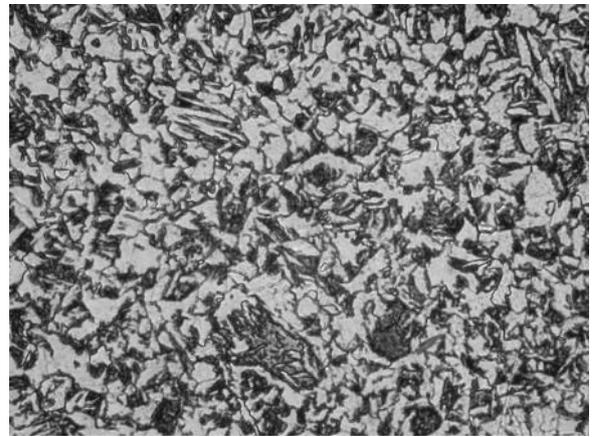
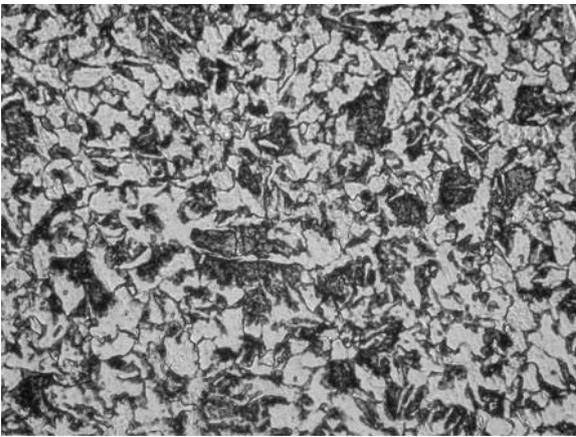
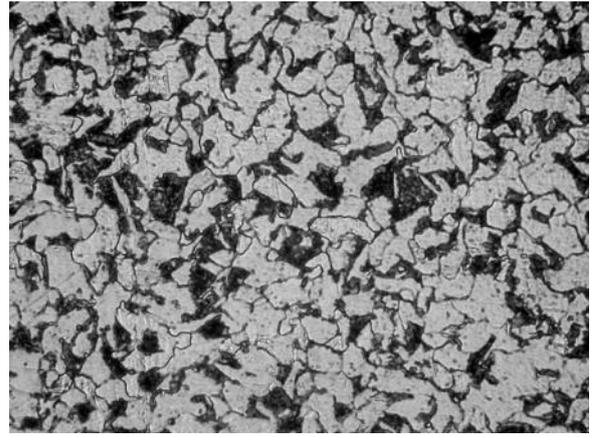
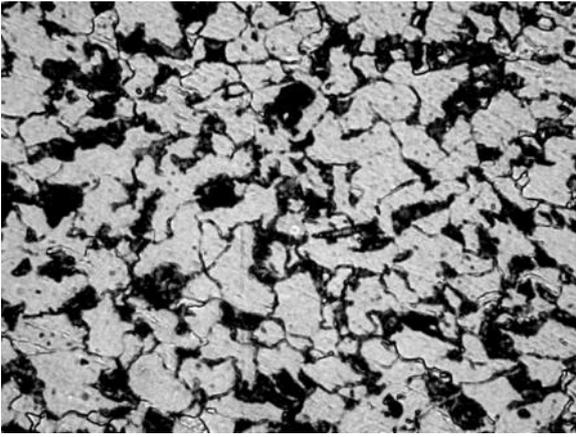
.5.4.1

-

13

900°
40° / , -70° / ; 500

: -5° / , -10° / , -20° / , -



. 5.4.2

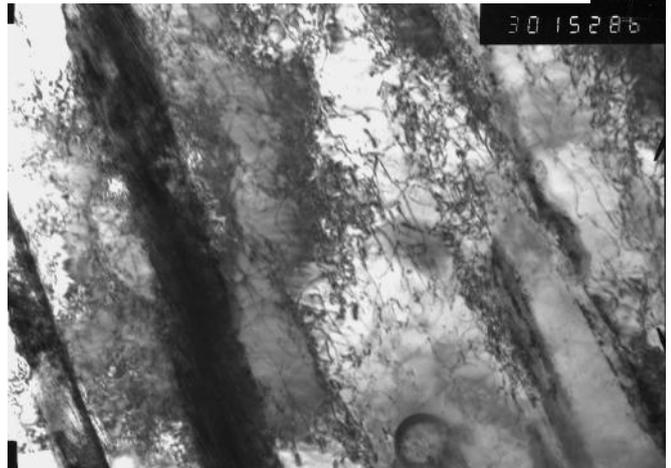
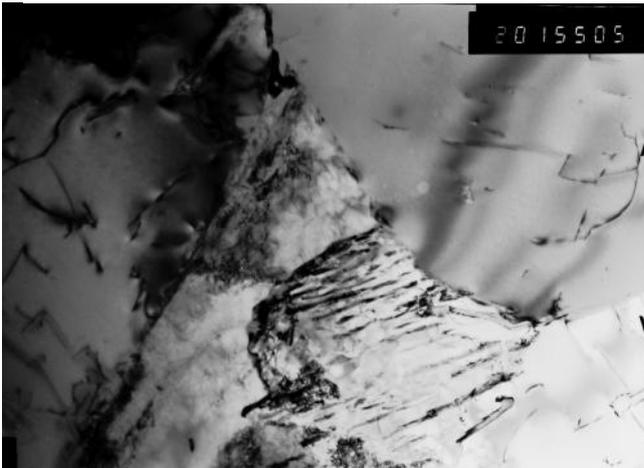
20

900°

: - 5 ° / , - 10 ° / , - 20 ° / , - 40

° / , - 70 ° / ; 500

5.4.3 . 900° 5 ° / 13 .
 5.4.3 . 40 ° / 13 .
 (. 5.4.3),



5.4.3 13 900° -)
 5 °C/ , 20000;) 40 °C/
 , 30000.

13 900° $70^\circ /$.

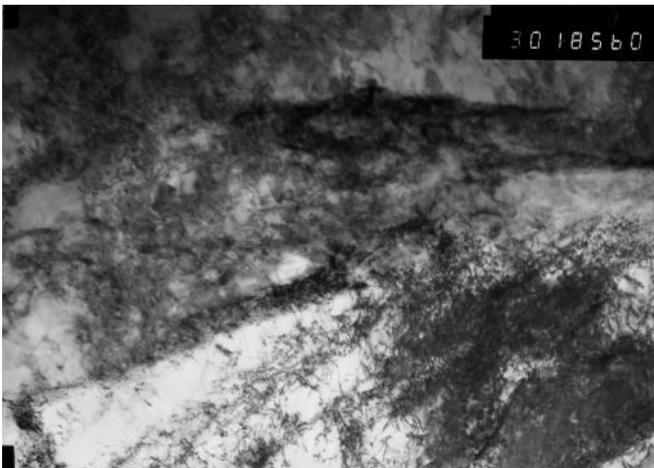
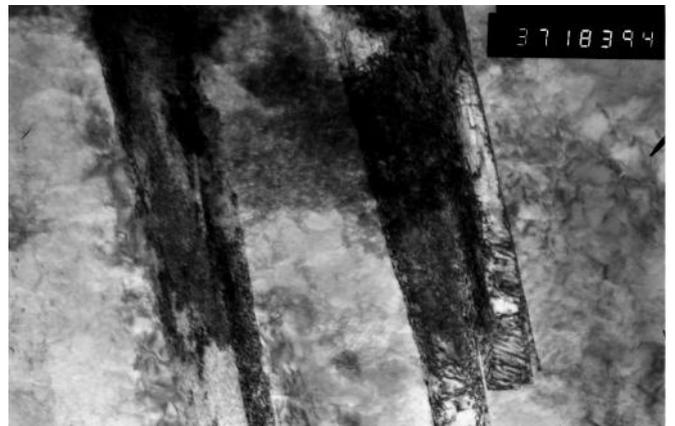
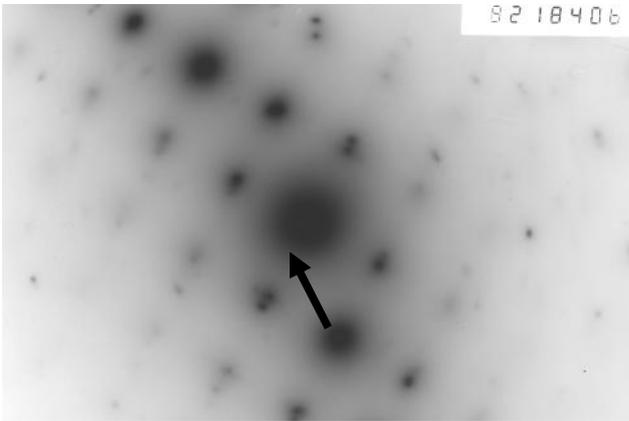
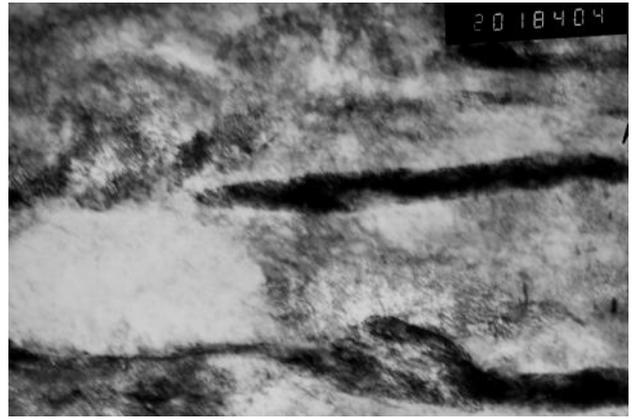
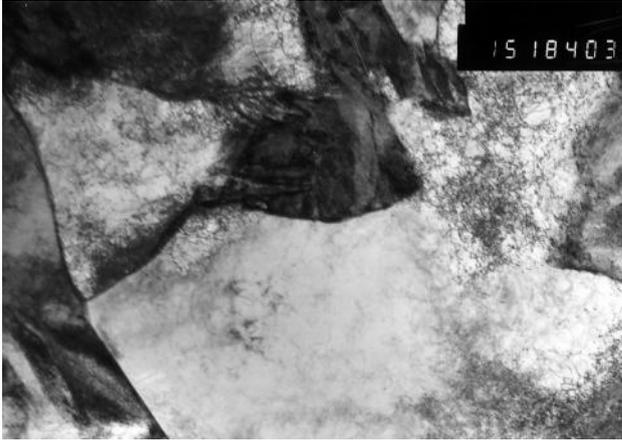
(. 5.4.4).

(. 5.4.4) , ;

(. 5.4.4).

13 , $70^\circ /$ 900° .

5.4.4) - (.



5.4.4

13 (, , ,) 20 ()
 900° 70 °C/ . , , - - 15000,
 - 20000, - 37000

150
20 900° 5 °C/ ,
13 , - .
40 °C/ 20
- , ,
5-10%.
13 .
,
70 °C/ 20 , 900°
-
(<5%). 13

13 20 .

5.5

5.5.1.

,
. 13 ,
900 °
154 / ² (5
%/) 204 / ² (70 ° /). 20
900 °
159 / ² (5 ° /) 208 / ²
(70 ° /).

, ,

,

.

13

70° / ,

.

5.5.1

13 20

900°

	, ° /				
	5	10	20	40	70
13	154	167	194	203	204
20	159	165	183	201	208

5.6

20

13

-

13

70° /

5-10%,

20

-

5%.

5.7

(+) .

5.7.1

4.5 «

20»,

13

+

13 .

5.7.2

13

900 °

(. 5.7.2.1).

5.7.2.3-5.7.2.5.

, . 5.7.2.3 , , .

- , . 5.7.2.3 .

1 ,

. 5.7.2.5

(101) Fe₃C.

900°

15-20 %, . 5.7.2.2

- .

, ,

, 1-2 , ,
. 5.7.2.6 , . ,
, . 5.7.2.6 .

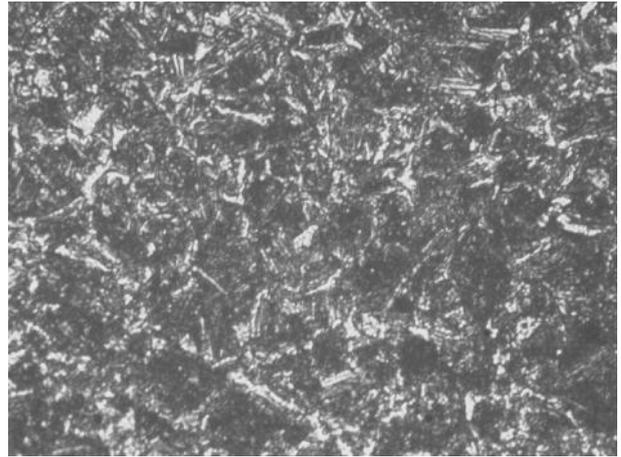
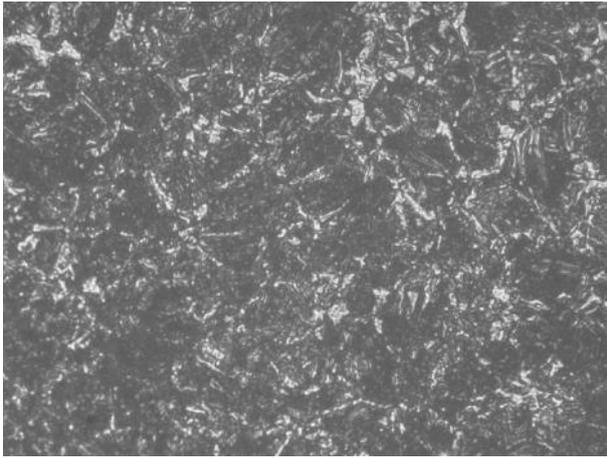
,

13 .

900 °

13

-



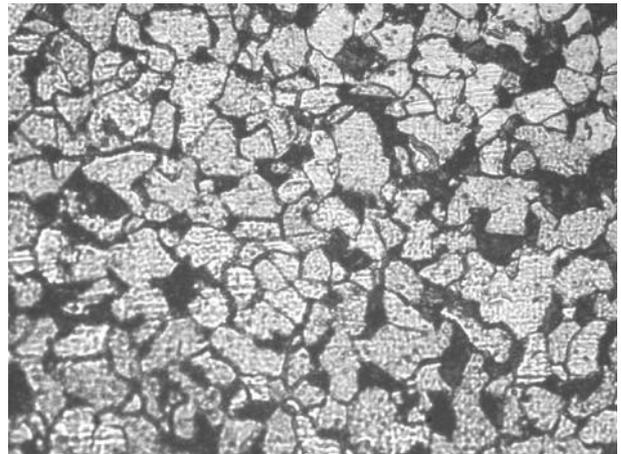
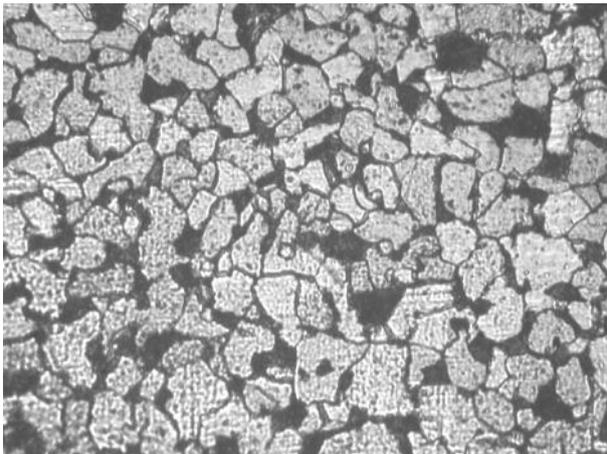
.5.7.2.1-

13

500

900°

,



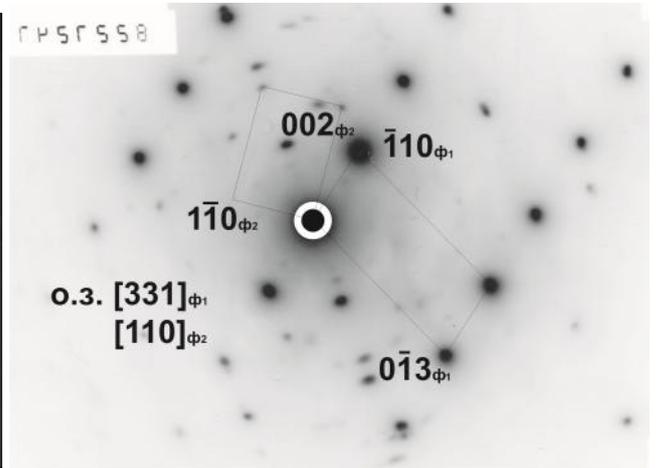
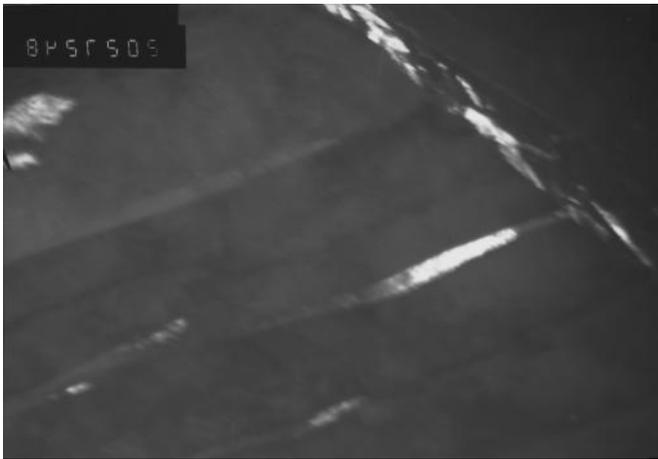
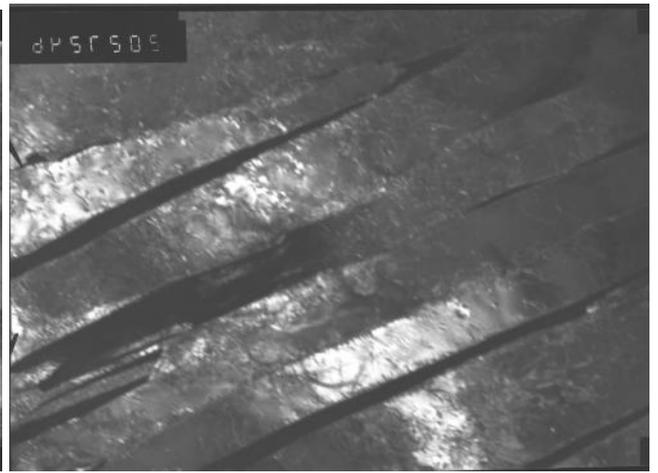
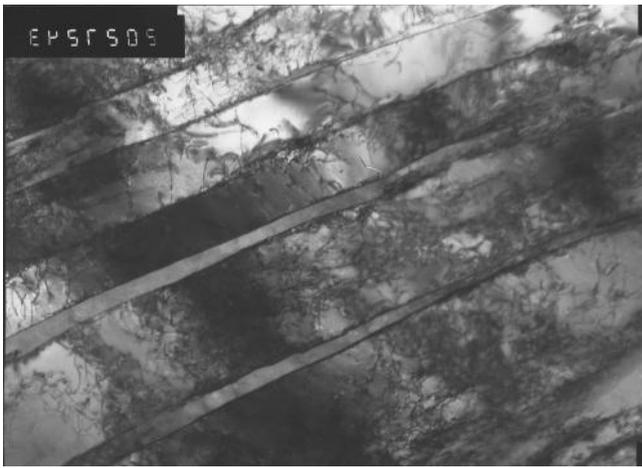
.5.7.2.2-

13

500

900°

,

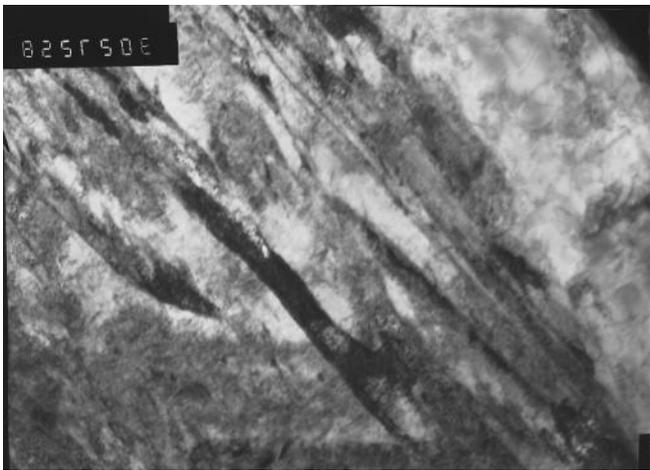
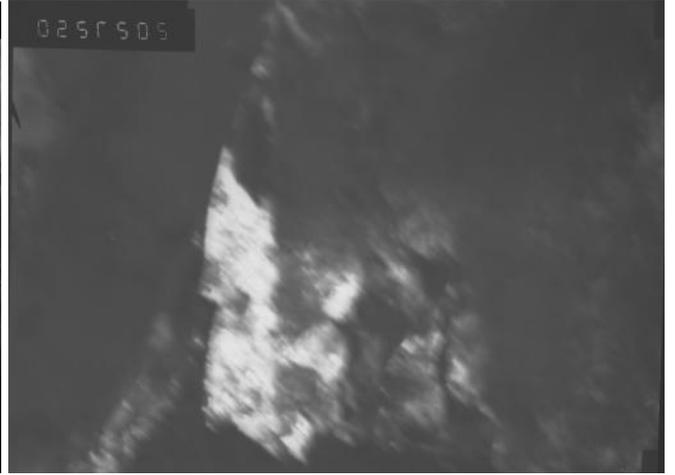
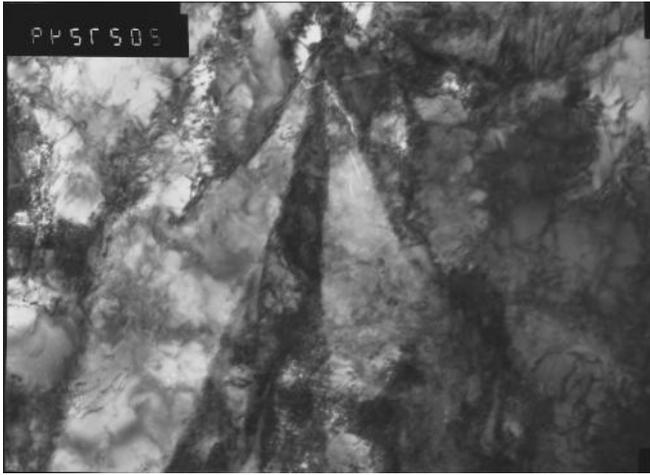


- , 20000;
- (110) , 20000;
- (10-1) , 20000;
- ;

.5.7.2.3 -

13

900°



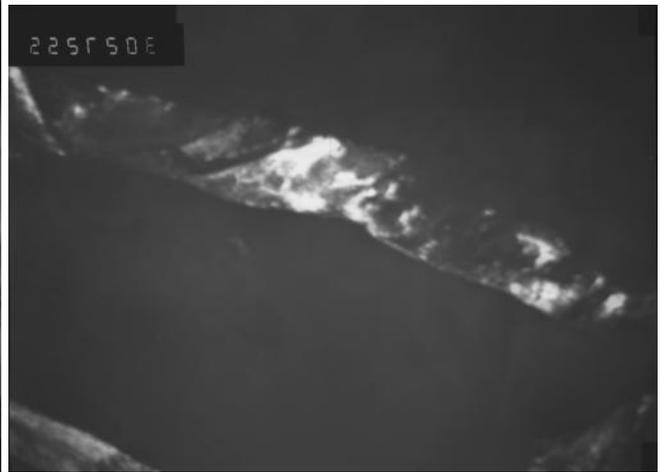
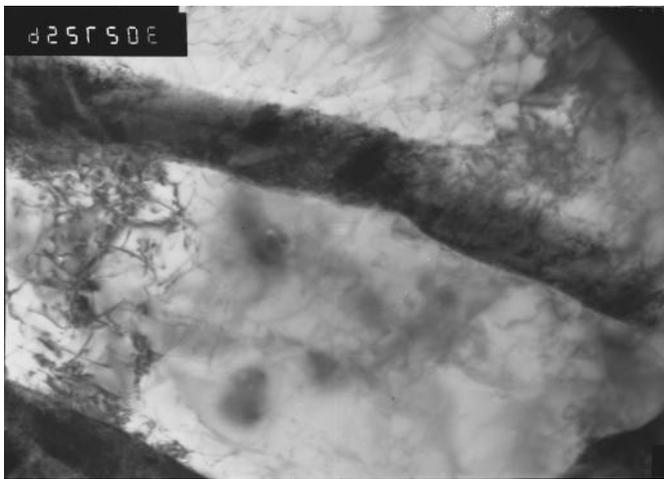
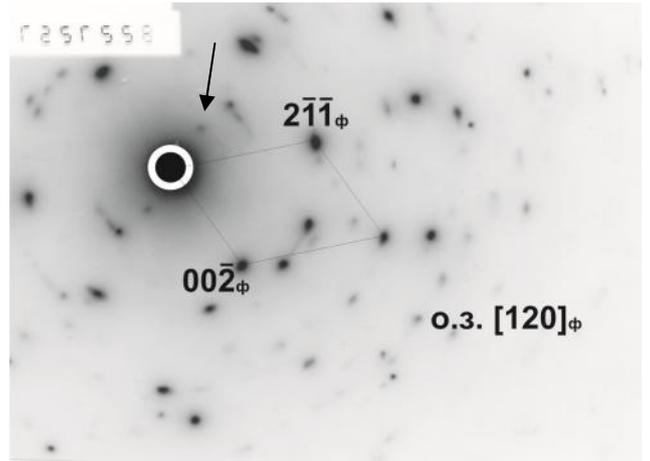
- , 20000;
 - (112) , 20000;
 - , 20000;
 - (013) , 20000;

.5.7.2.4 -

13

900°

.



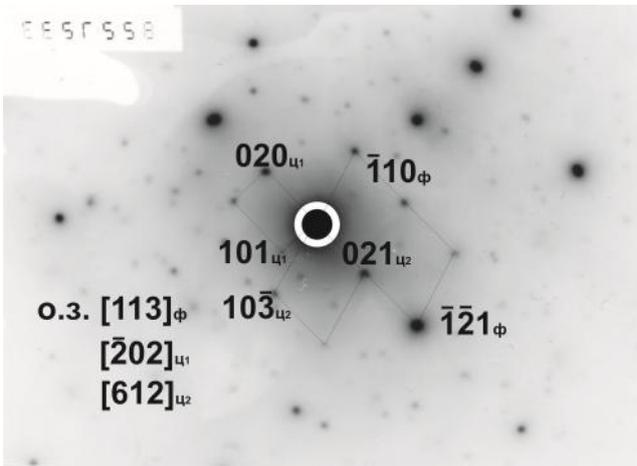
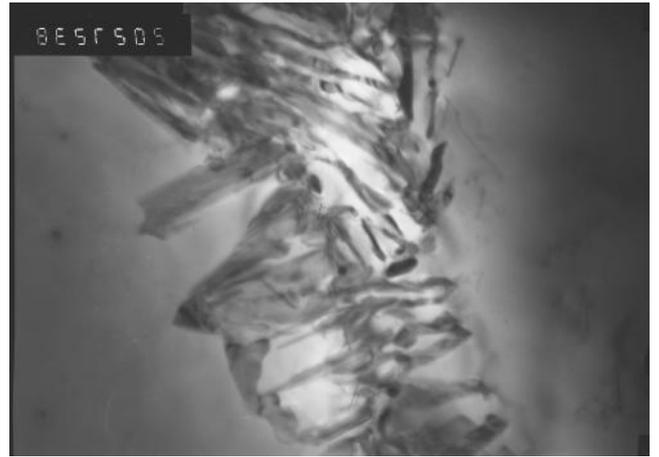
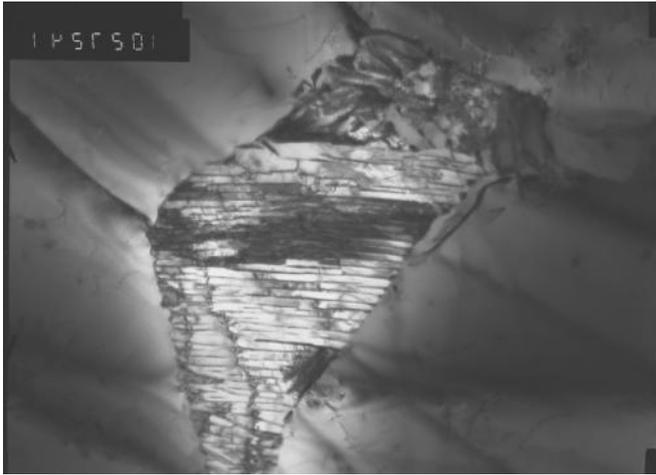
- ; , 15000;
 - ; , 30000;
 - , 30000;

. 5.7.2.5 -

13

900°

.



- , 10000;
 - , 20000
 - ;
 - , 15000;

.5.7.2.6 -

13

900°

5.7.3

13 .

5.7.3.23,
5.7.3.2.1.

. 5.7.3.1-

$\alpha \leftrightarrow \gamma$

5.7.3.1

13
745) ° .

$1 = (727-$

738 ° .

3

863 ° ,

830 °

$\gamma-$

5.7.3.22, 5.7.3.23

$\alpha \rightarrow \gamma$

900 ° 13

-

5.7.3.1).

(.
(760, 800

830 °)

1- 3

1

22, 62 92 ° . . 5.7.3.23

760 ° , 800 ° 830 °

,

,

,

1 (,

-

160

).

γ -

13

1.

30

$\alpha \rightarrow \gamma$

760 °

13 %,

43 %, .

5.7.3.22 .

$\alpha \rightarrow \gamma$

760 °

:

15-20

. $\alpha \rightarrow \gamma$

3

$\alpha \rightarrow \gamma$

13

830 °

: 72 96 %, . 5.9.1.22 .

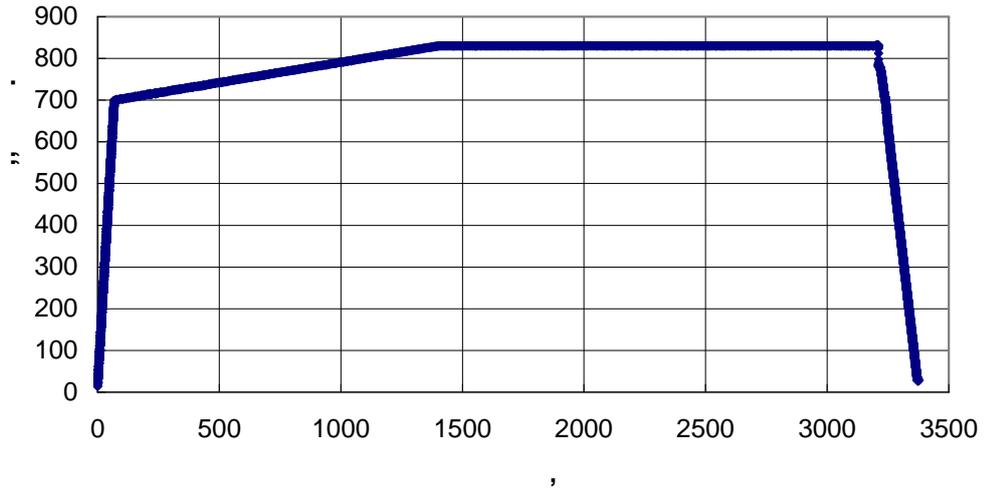
760, 800 830 °

13

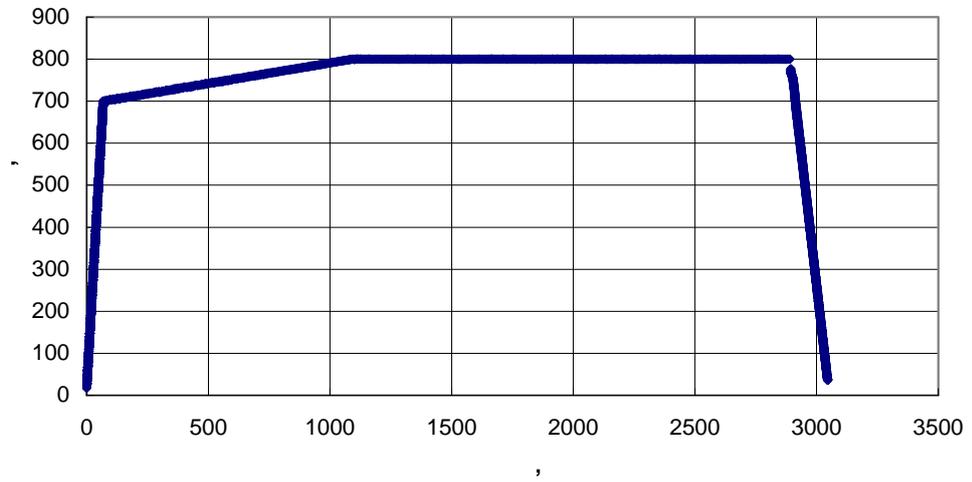
40, 74 100 %

, . 5.7.3.23.

13 900 830 5



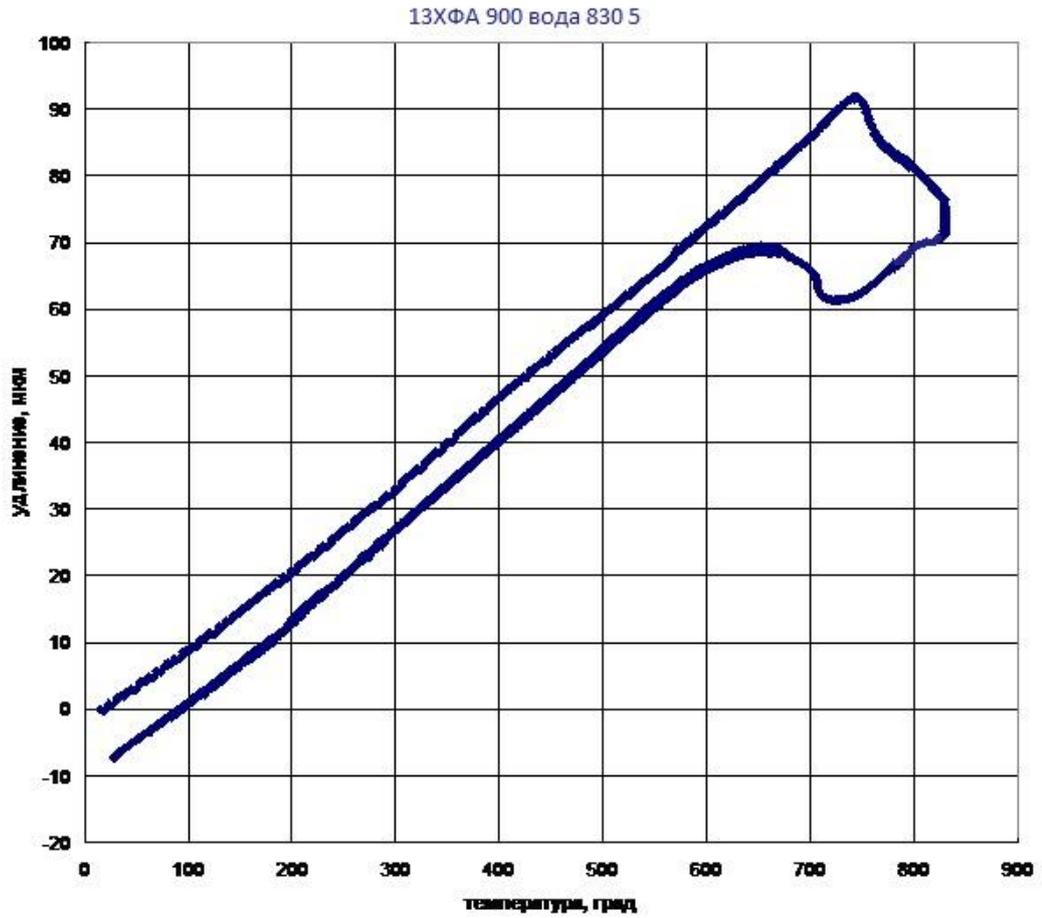
13 900 800 5



13 900 760 5



830 ° ; - 800 ° ; - 760 °

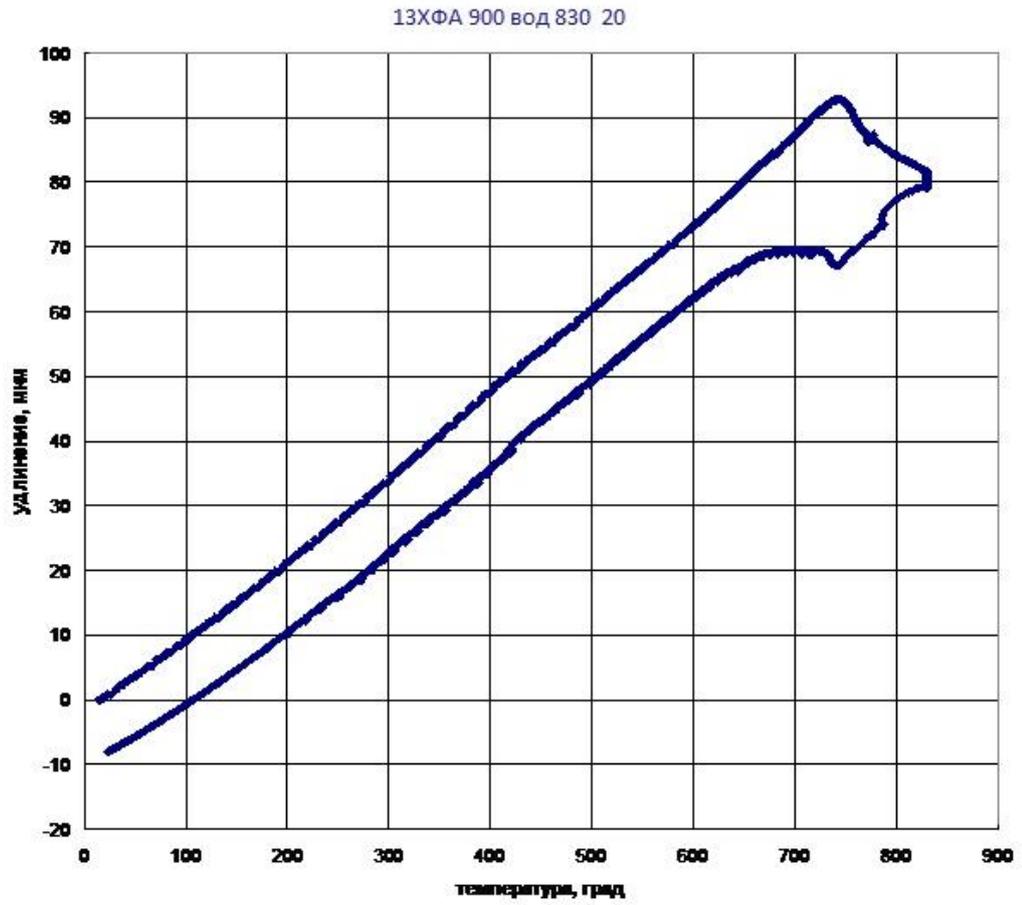


. 5.7.3.2 -

830° ,

13 .

900°
5° /

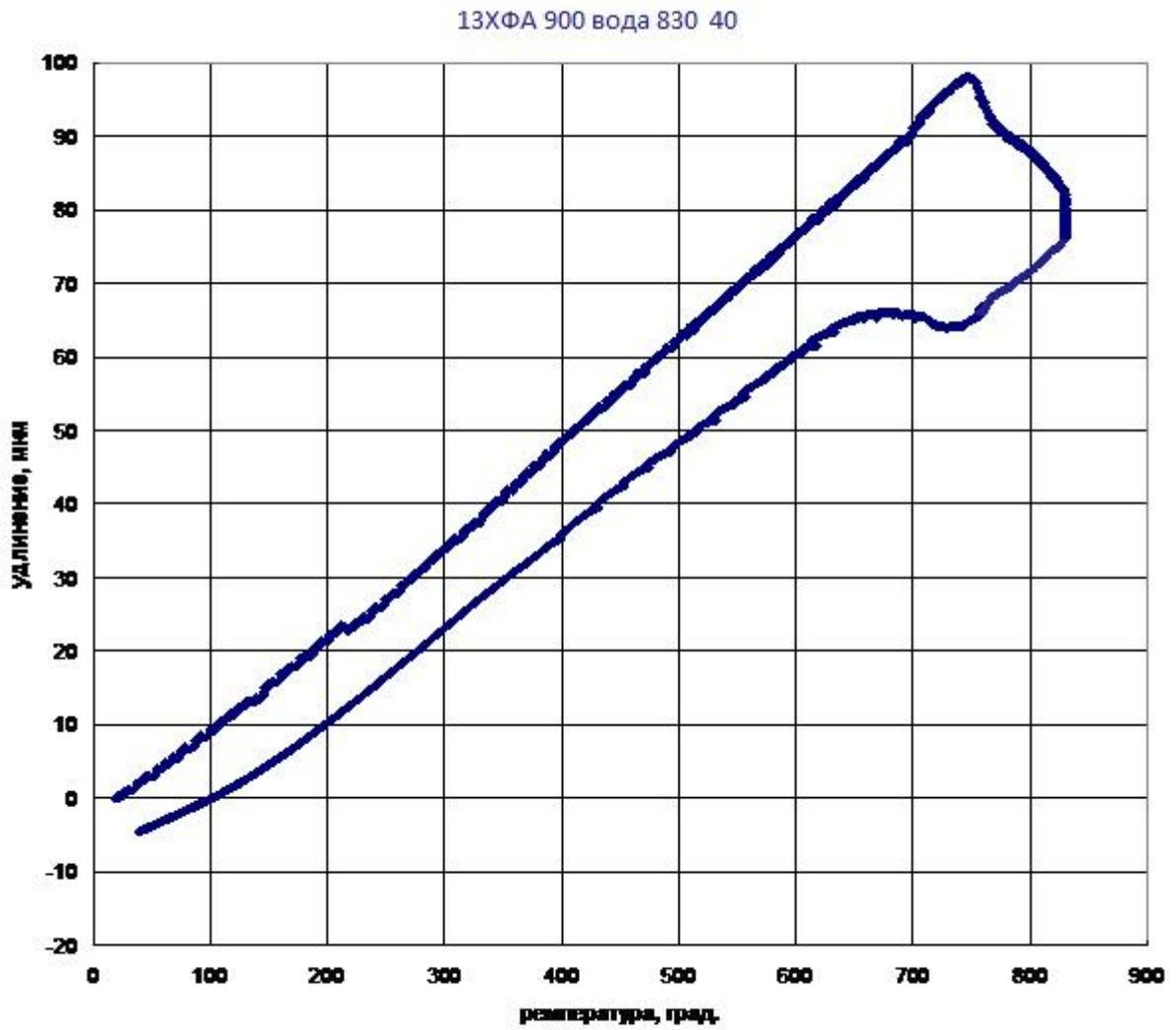


. 5.7.3.3 -

830° ,

13

900°
20° /

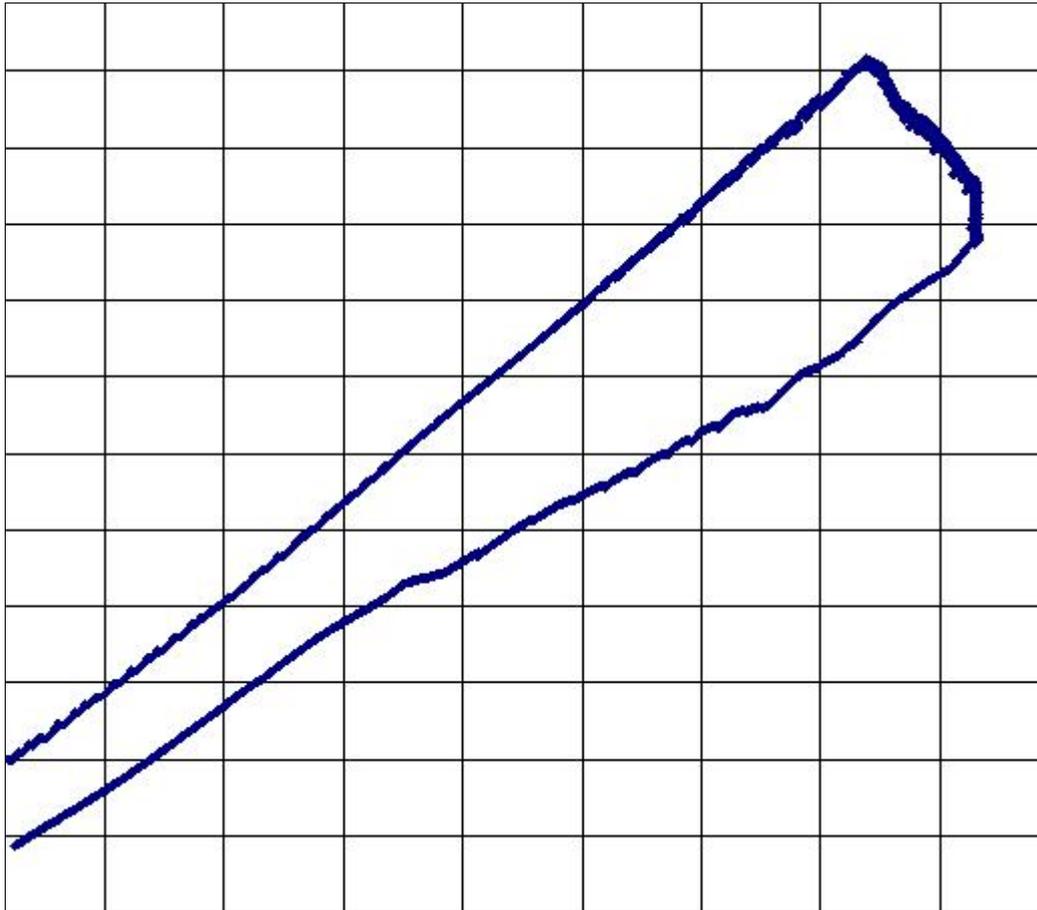


. 5.7.3.4 -

830° ,

13

900°
40° /



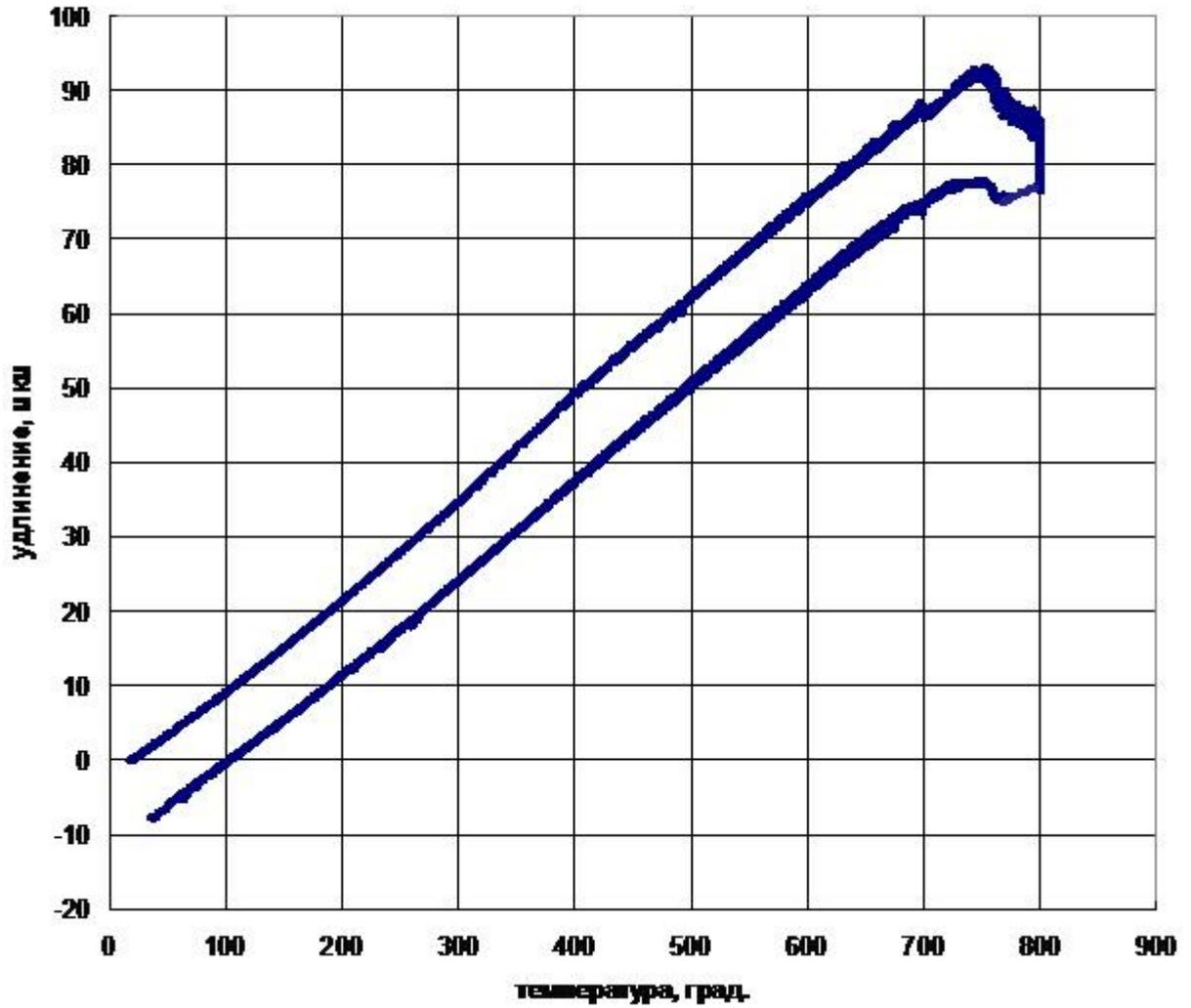
.5.7.3.5 -

830° ,

13

900°
70° /

13ХФА 900 вода 800 5

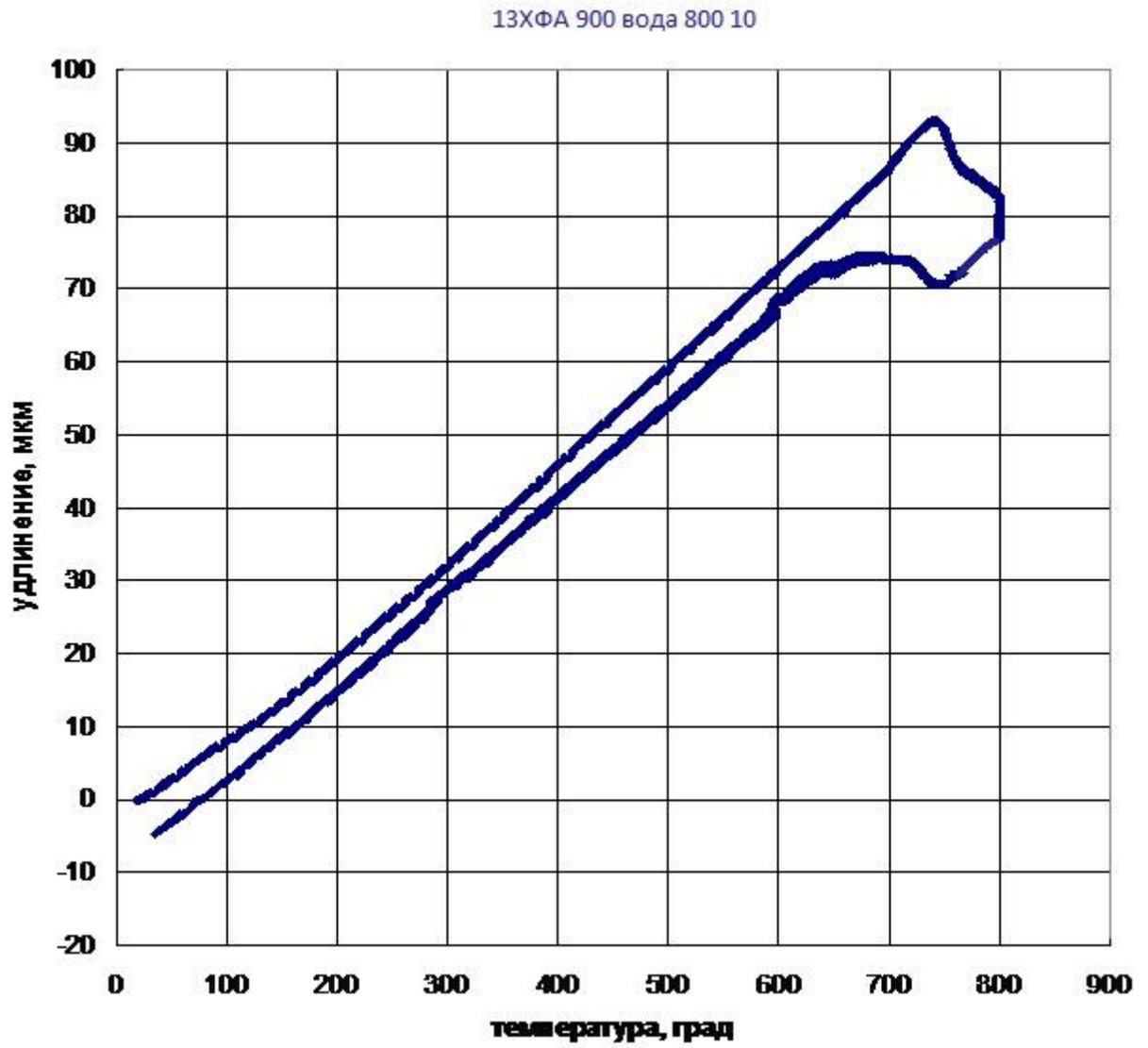


.5.7.3.6 -

800° ,

13

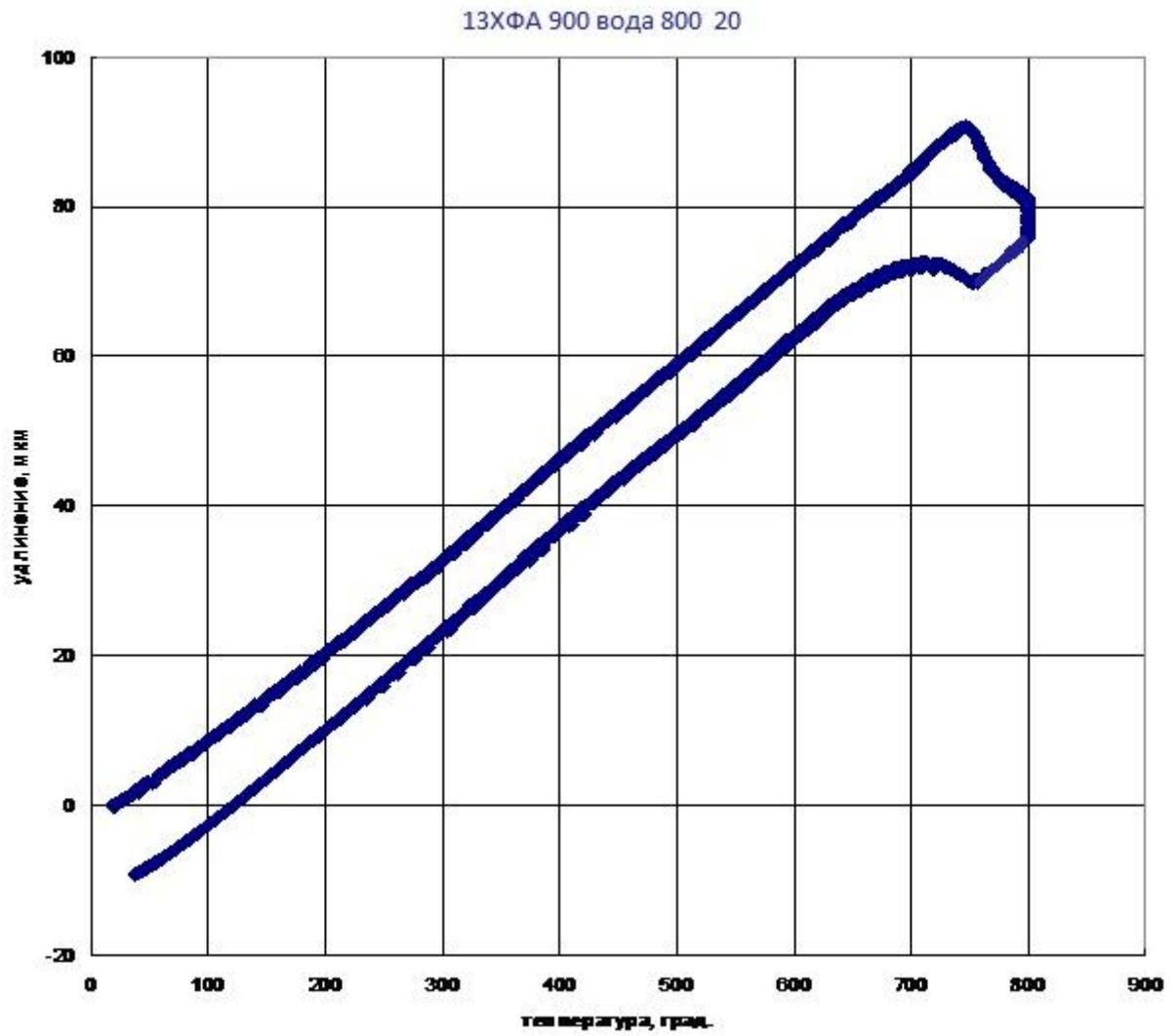
900°
5° /



5.7.3.7 -

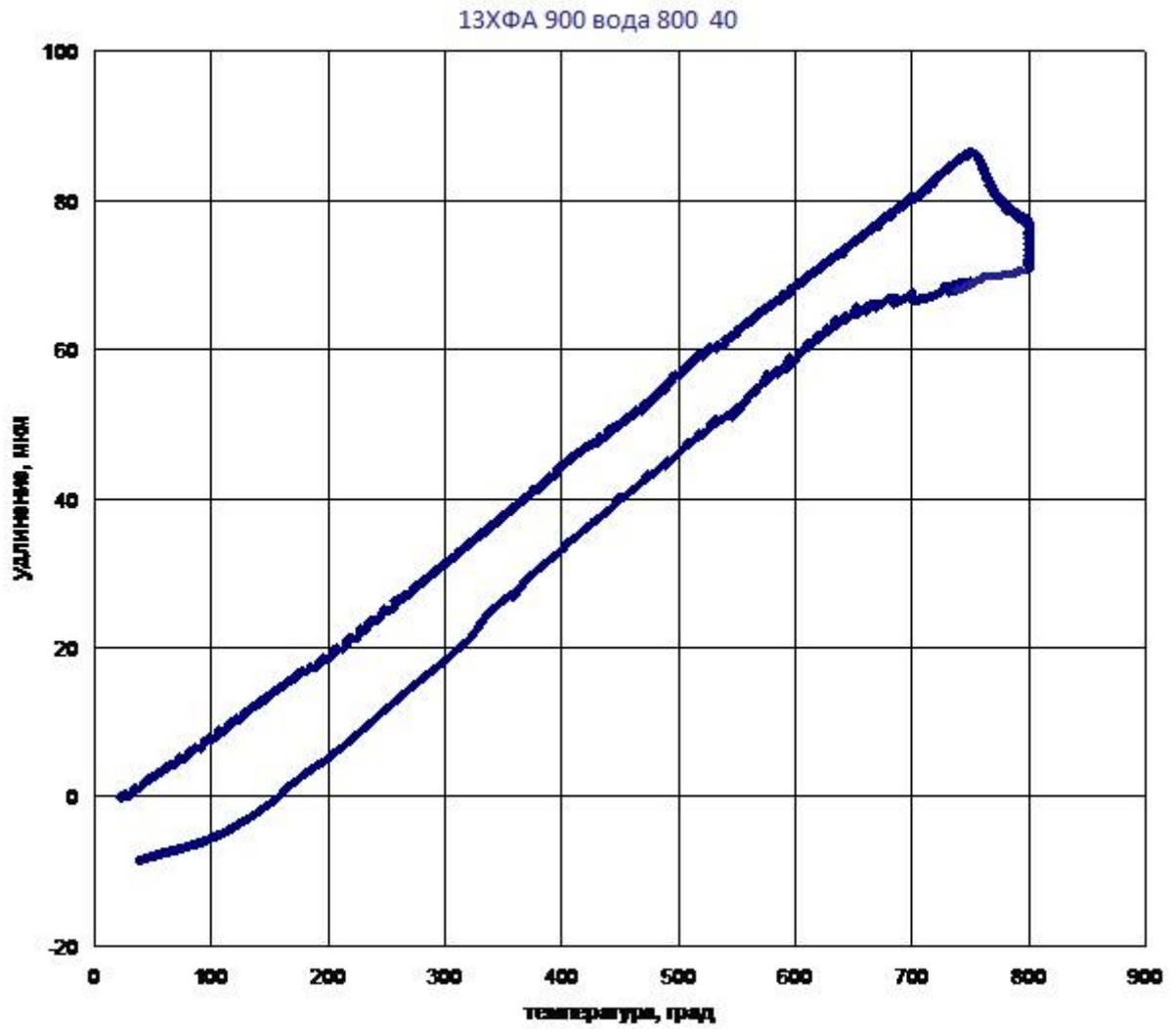
800° , 13

900°
10° /



.5.7.3.8 -

13 . 900° .
800° , 20° /

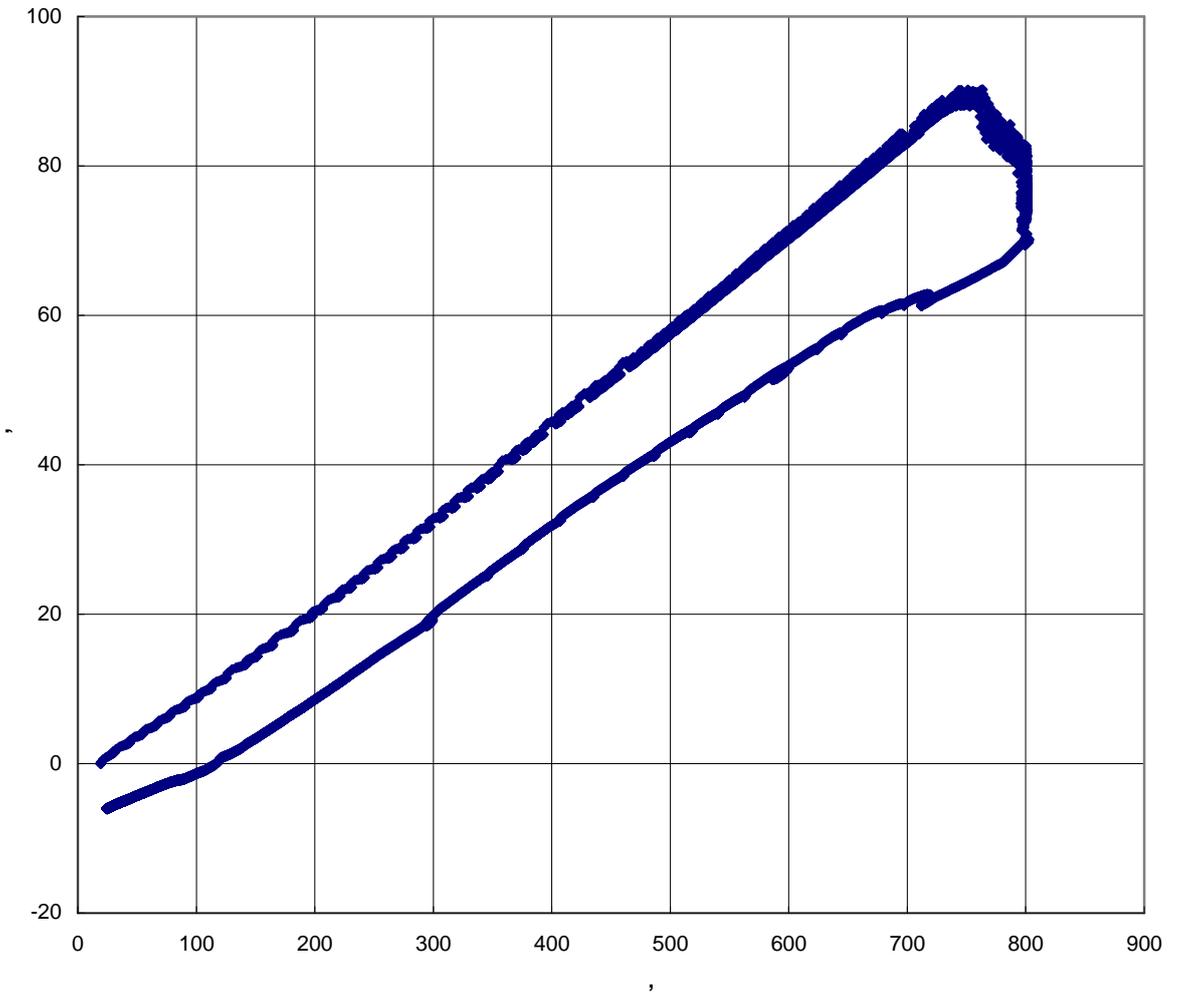


.5.7.3.9 -

800° , 13 .

900° .
40° /

13 900 800 70



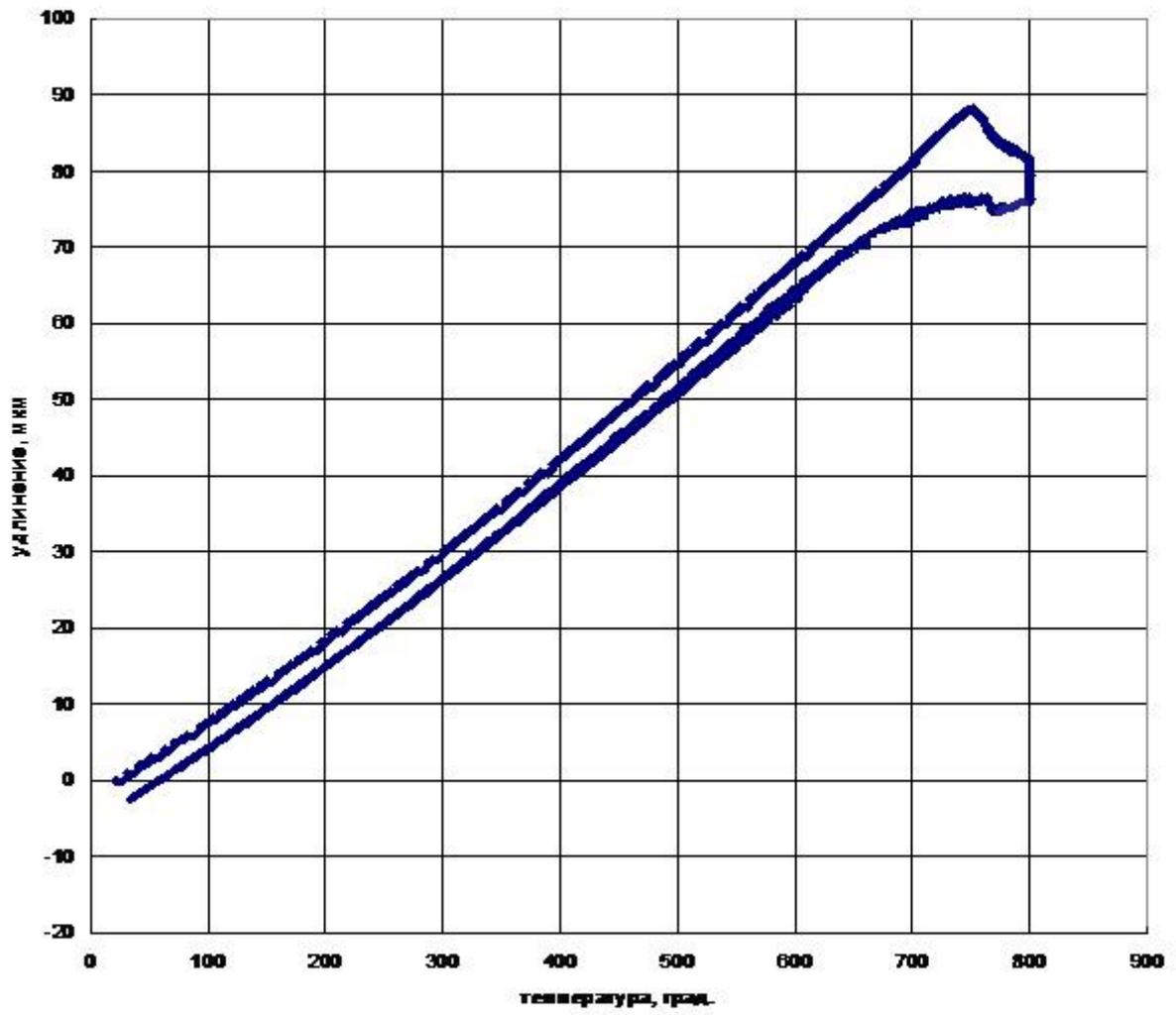
. 5.7.3.10 -

800° ,

13 .

900°
70° /

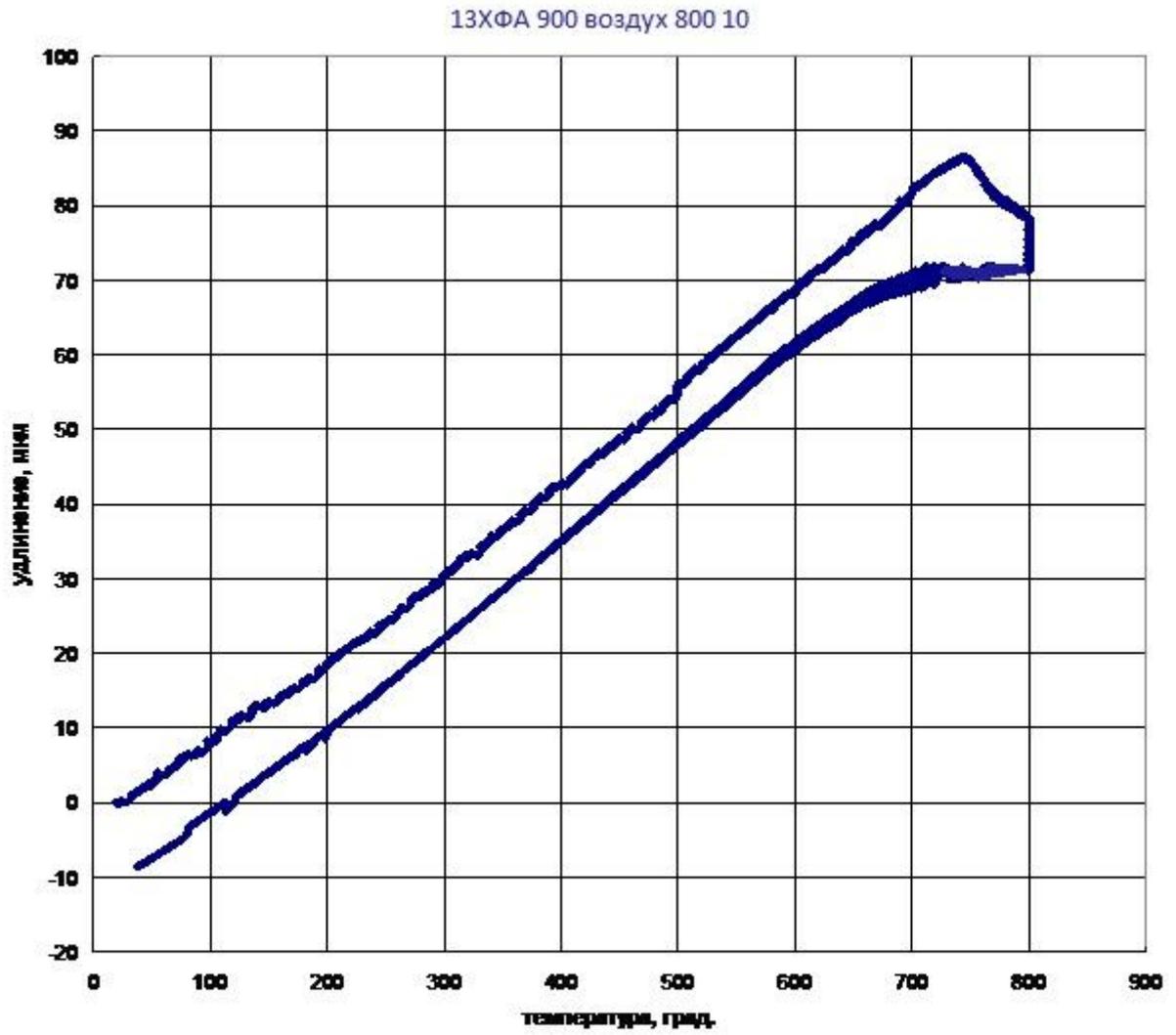
13ХФА 900 воздух 800 5



. 5.7.3.11 -

800° , 13

900°
5° /

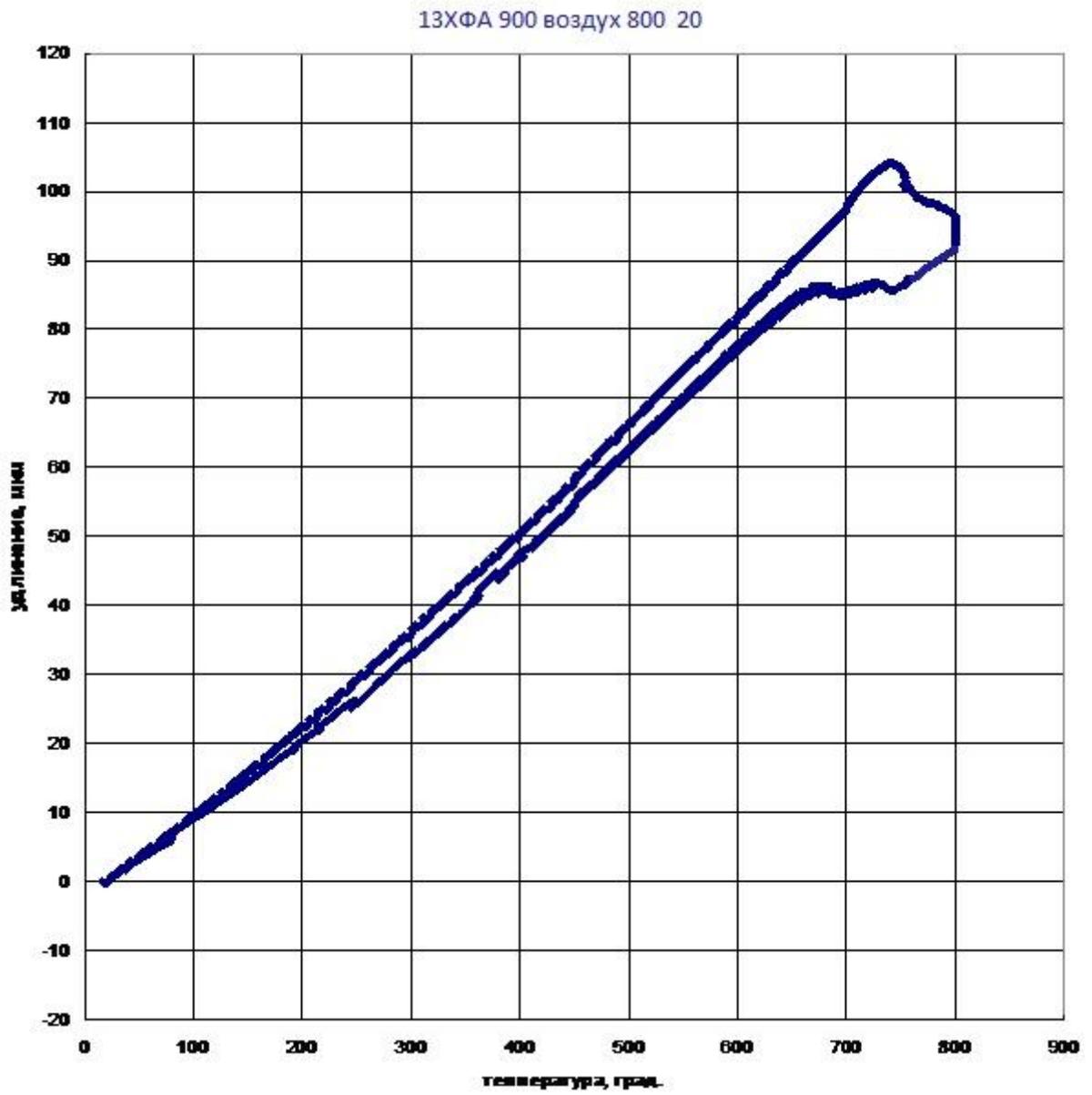


.5.7.3.12 -

800° ,

13

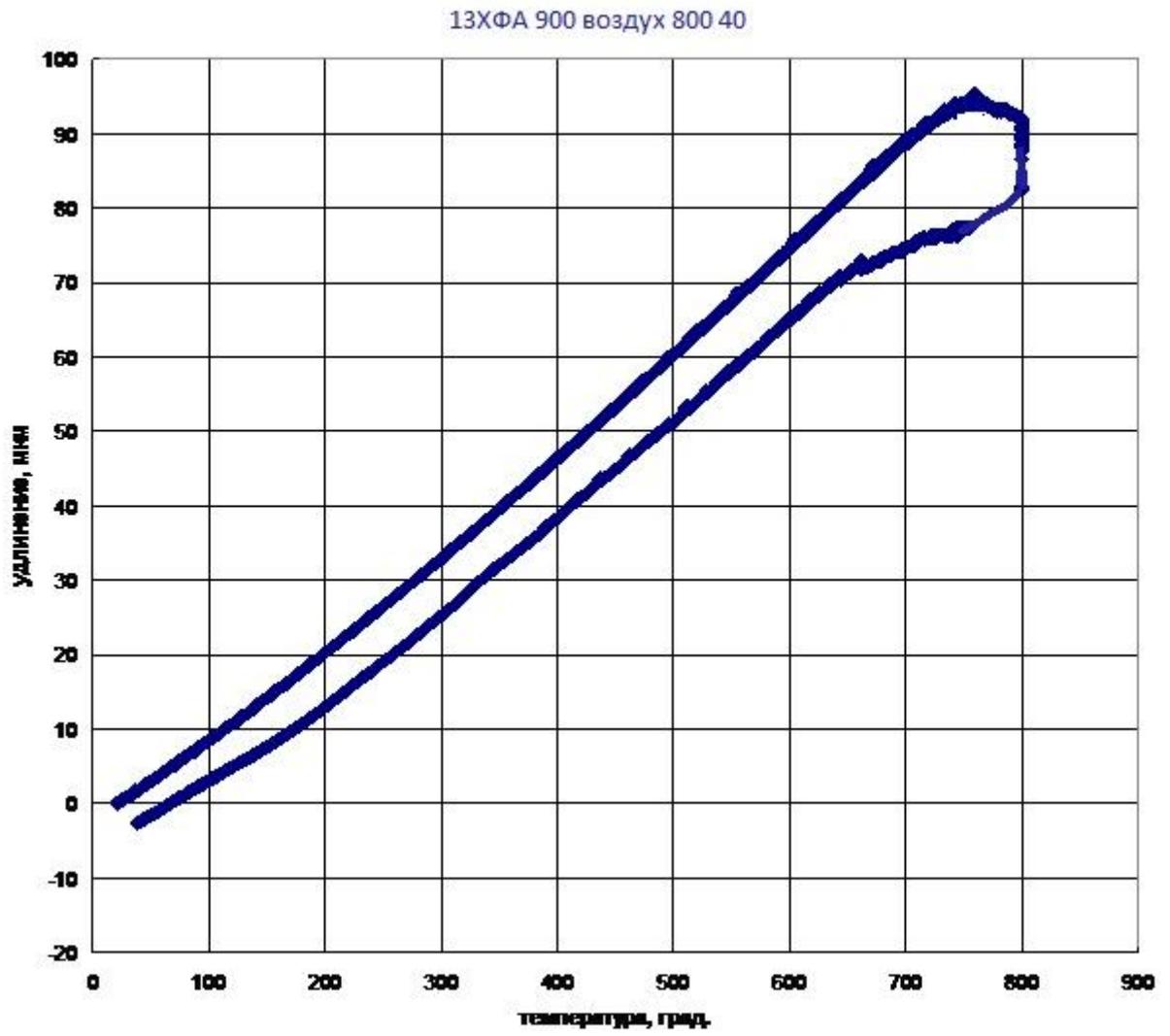
900°
10° /



. 5.7.3.13 -

800° , 13 .

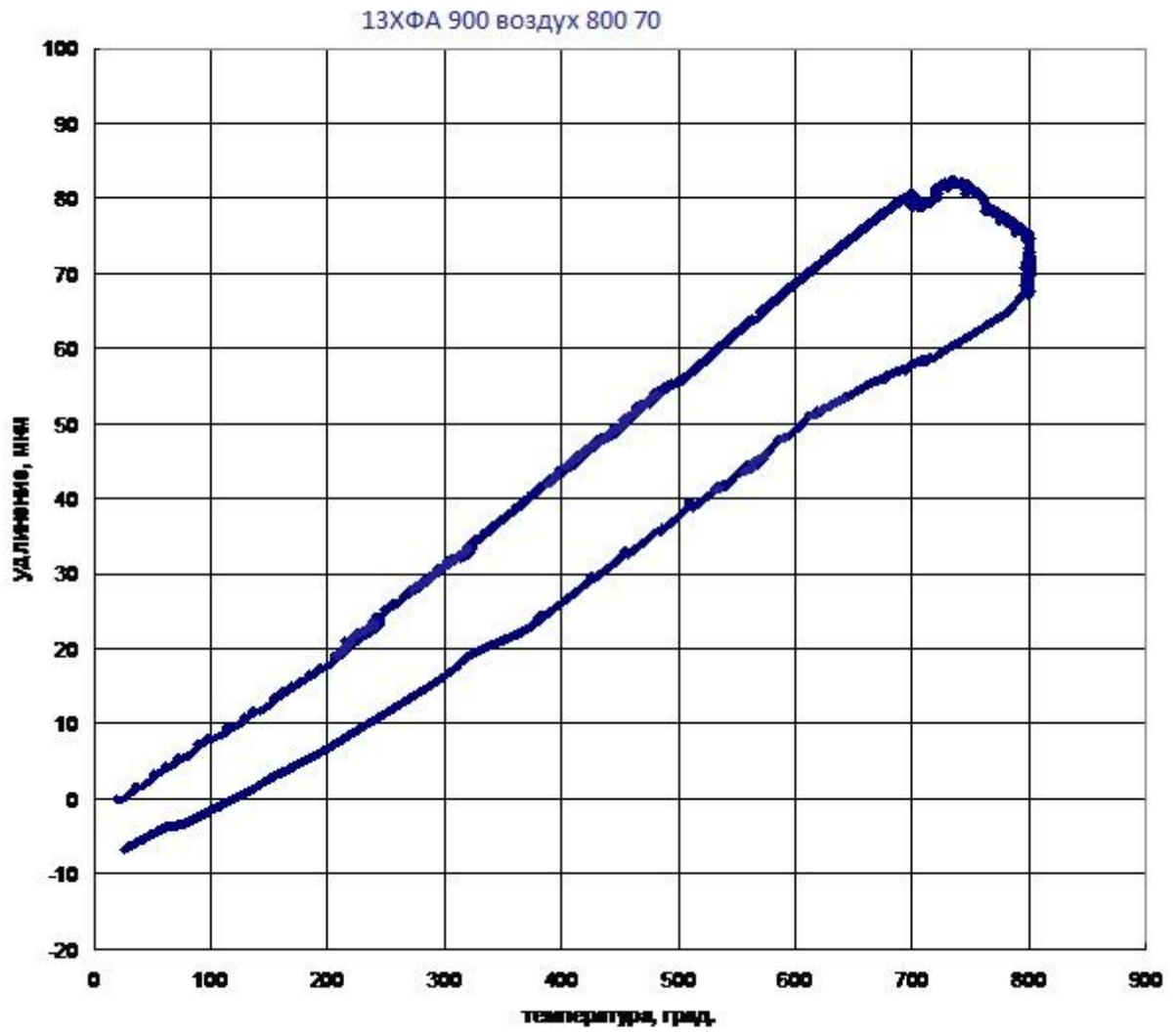
900°
20° /



.5.7.3.14 -

13
800° ,

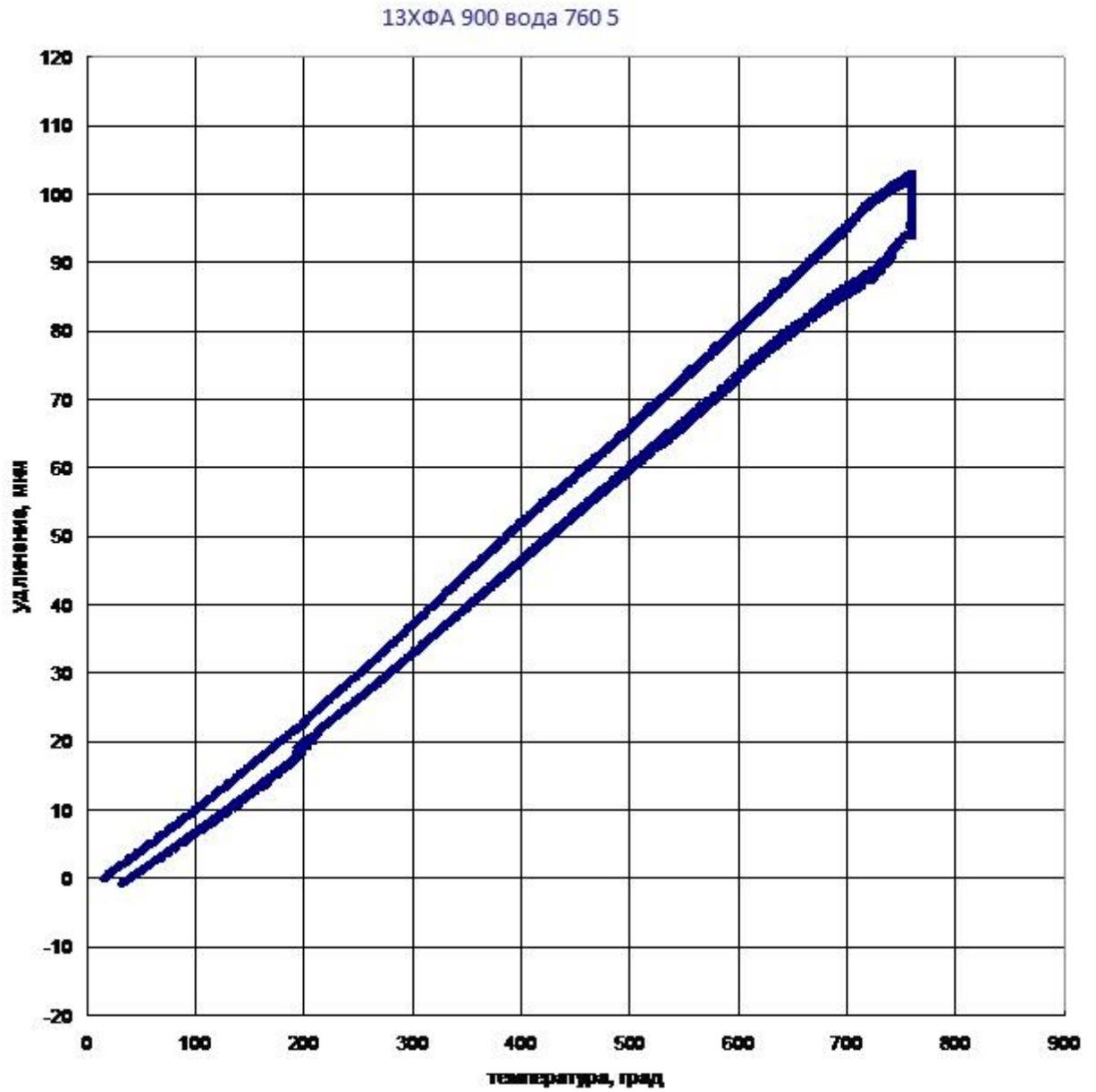
900°
40° /



5.7.3.15 -

800° , 13

900°
70° /

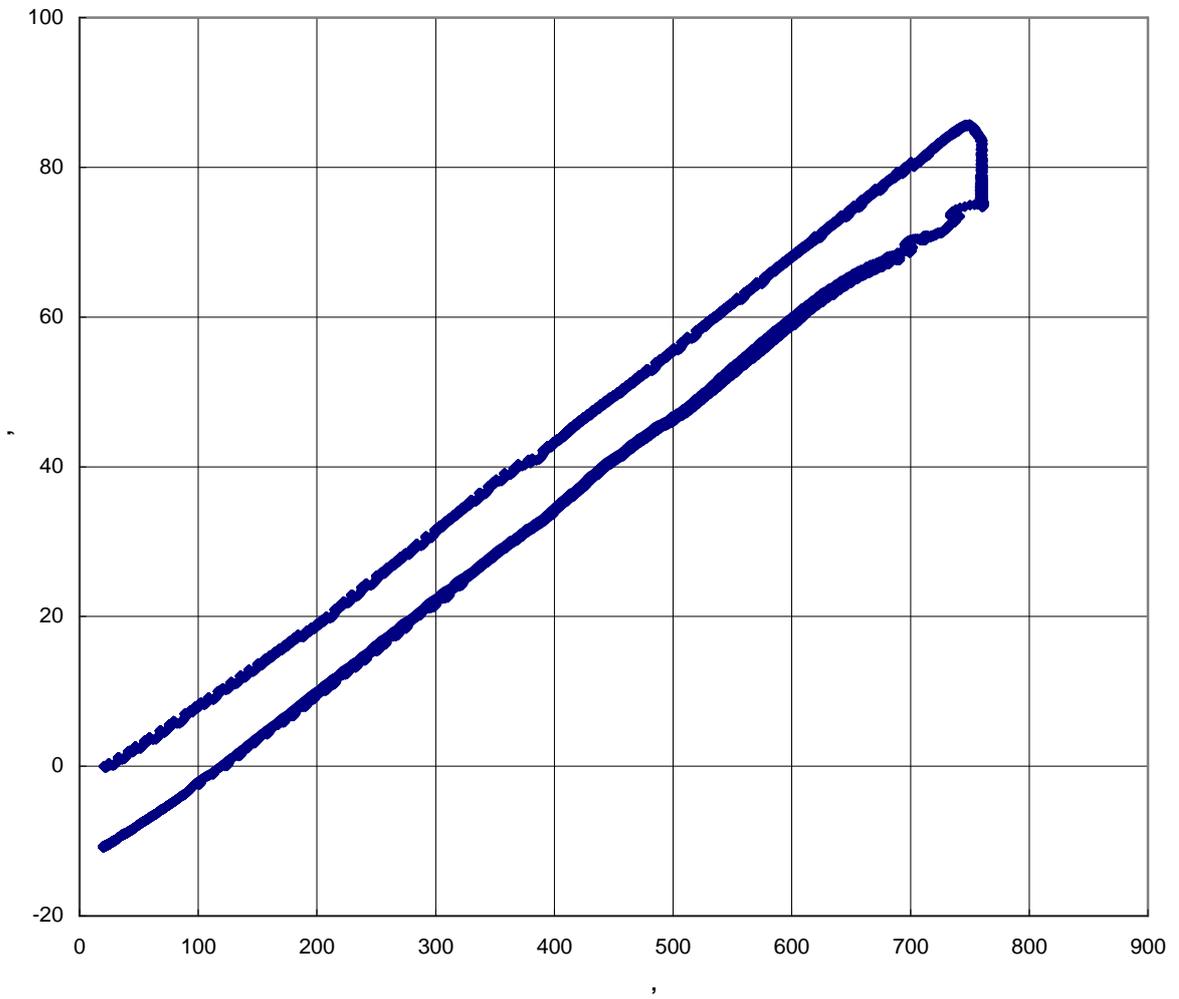


. 5.7.3.16 -

760° , 13

900°
5° /

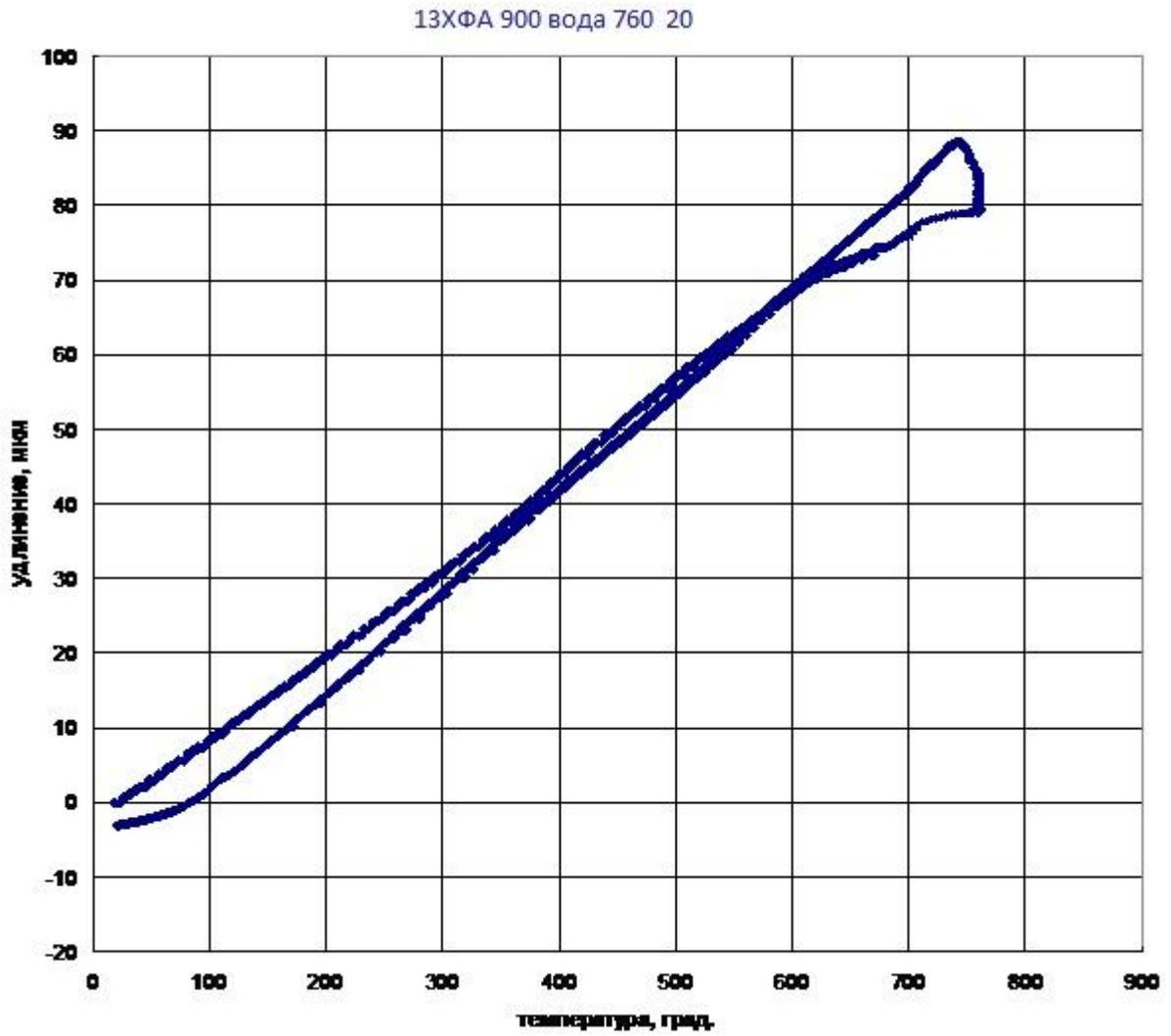
13 900 760 10



. 5.7.3.17 -

760° , 13 .

900°
10° /

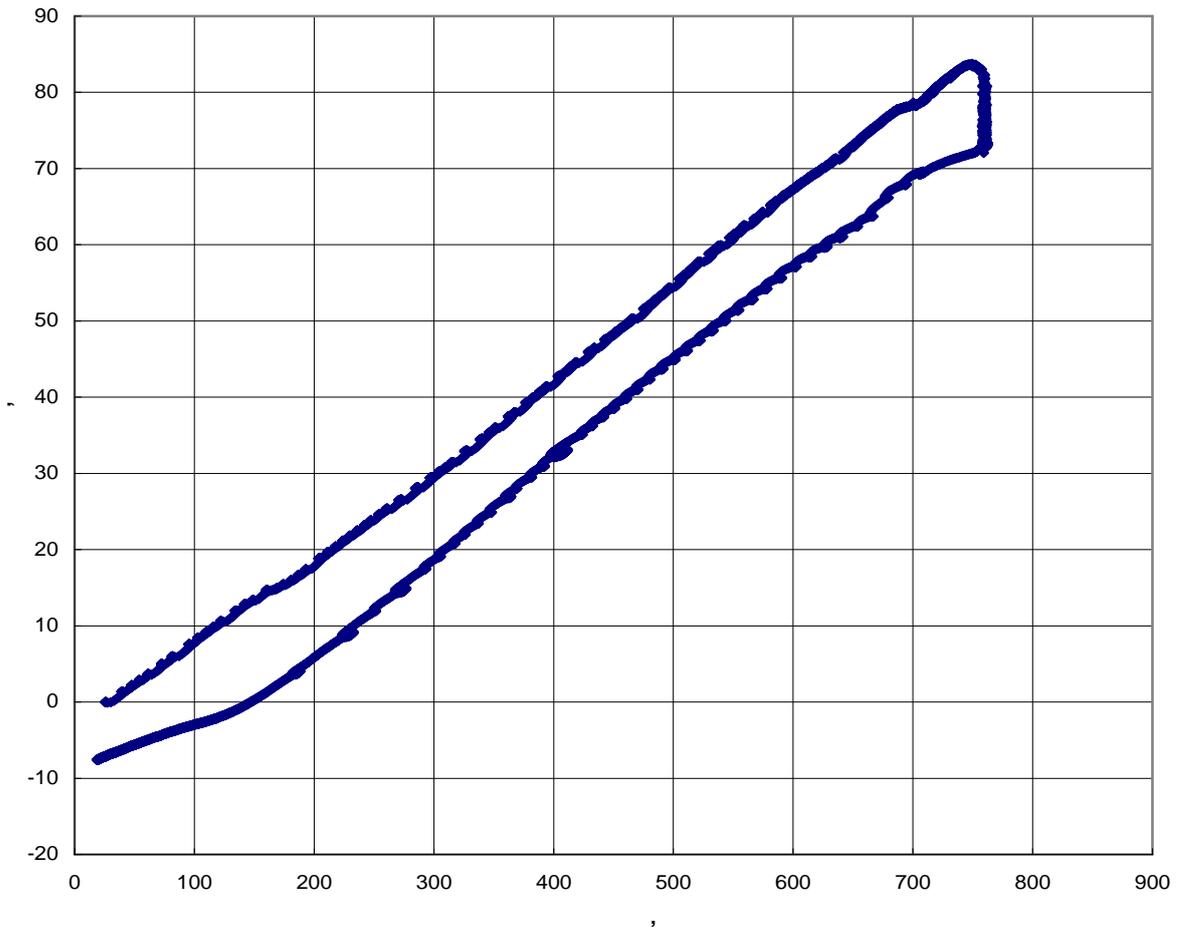


. 5.7.3.18 -

760° , 13

900°
20° /

13 900 760 40

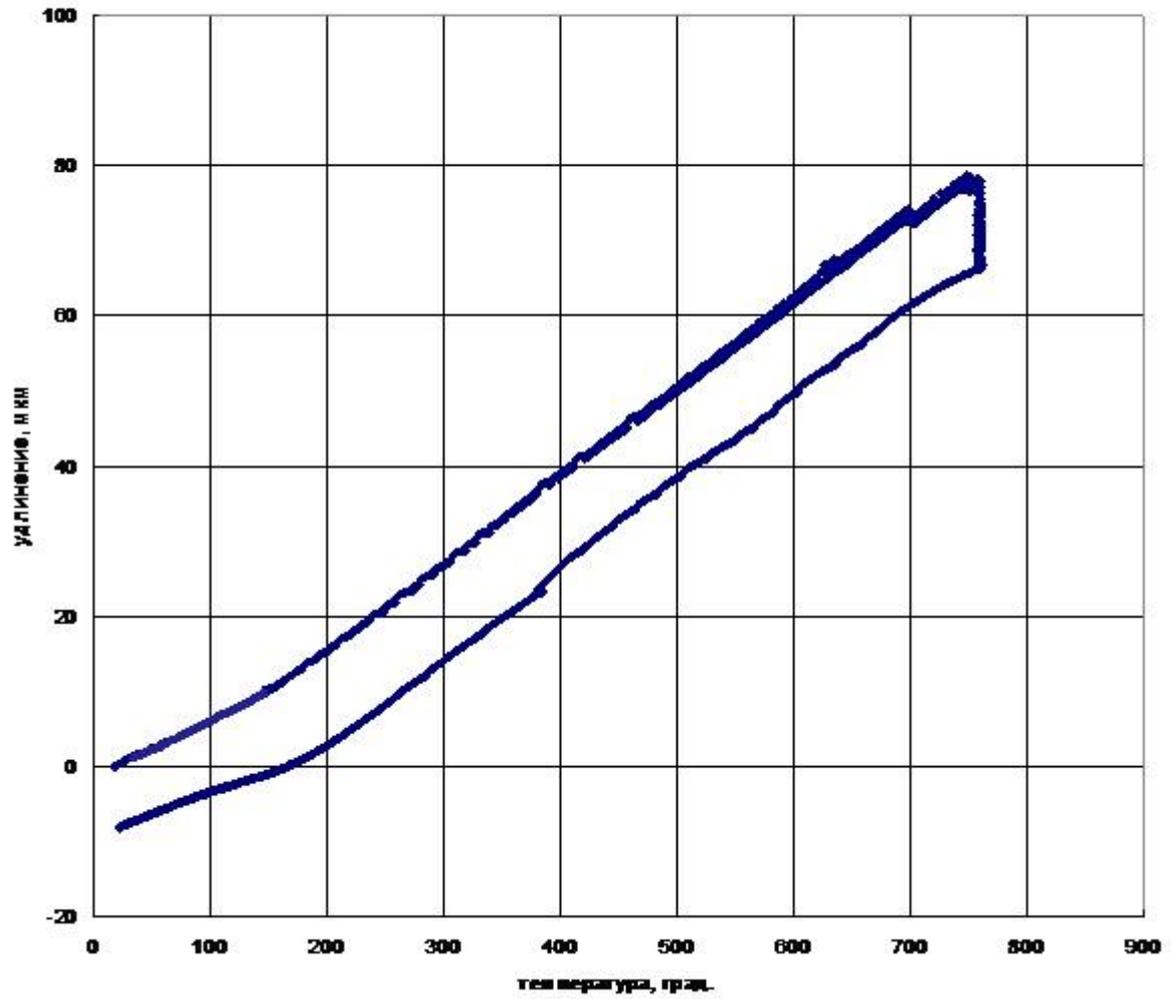


. 5.7.3.19 -

760° , 13

900°
40° /

13ХФА 900 вода 760 70

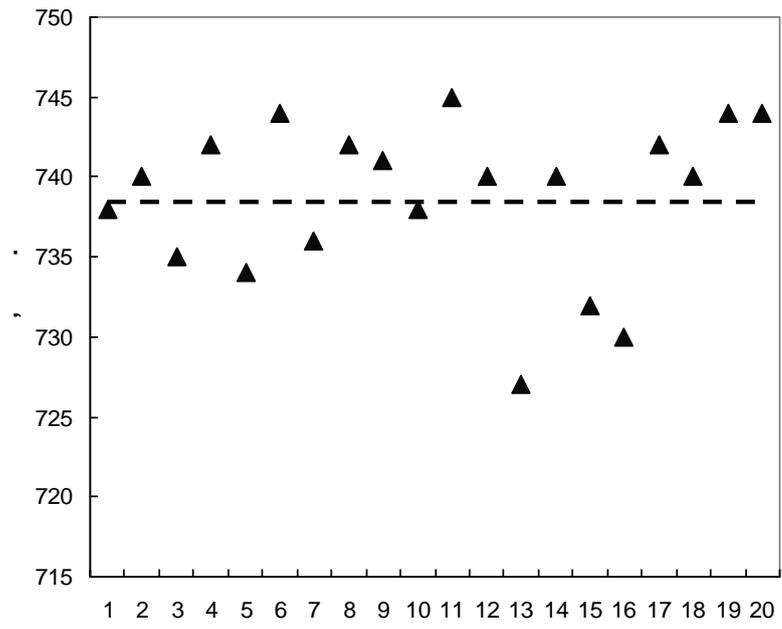


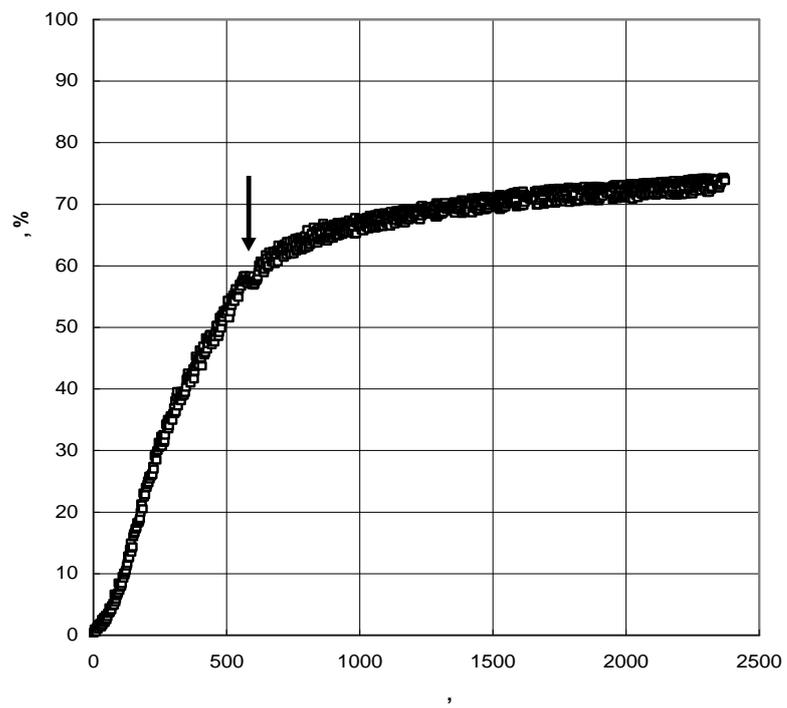
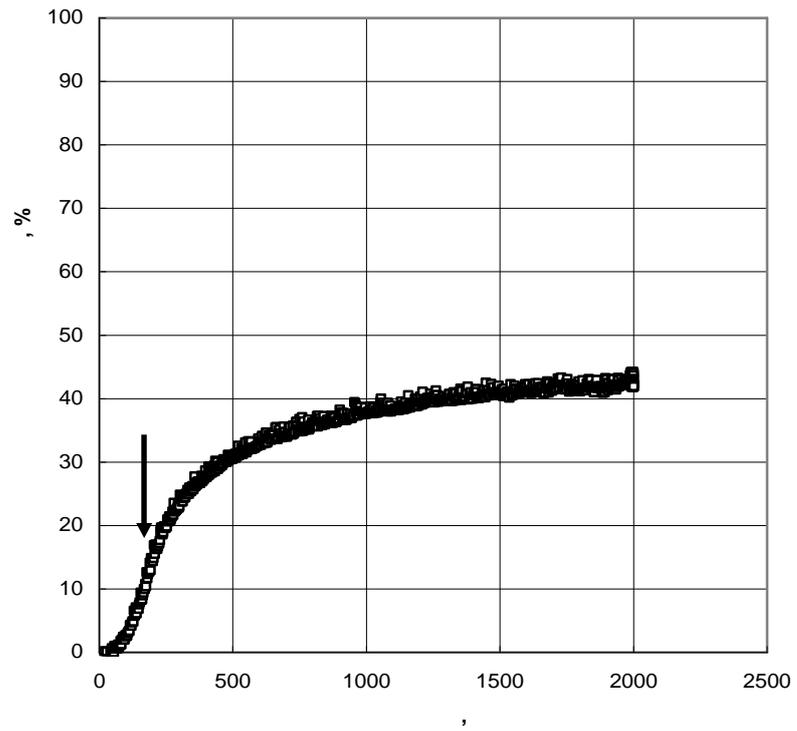
. 5.7.3.20 -

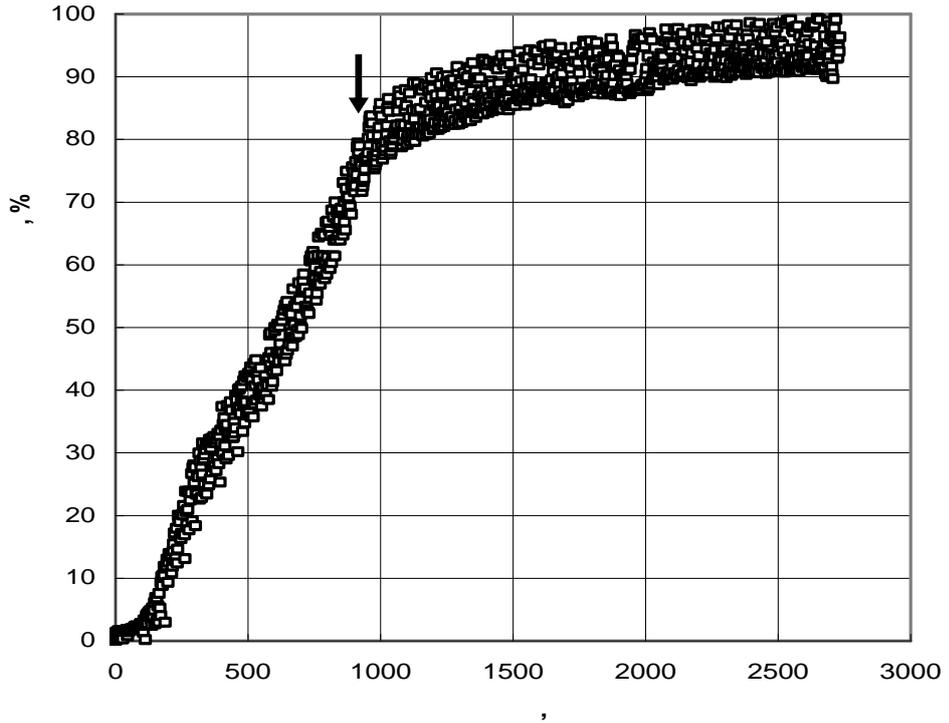
760° ,

13 .

900°
70° /

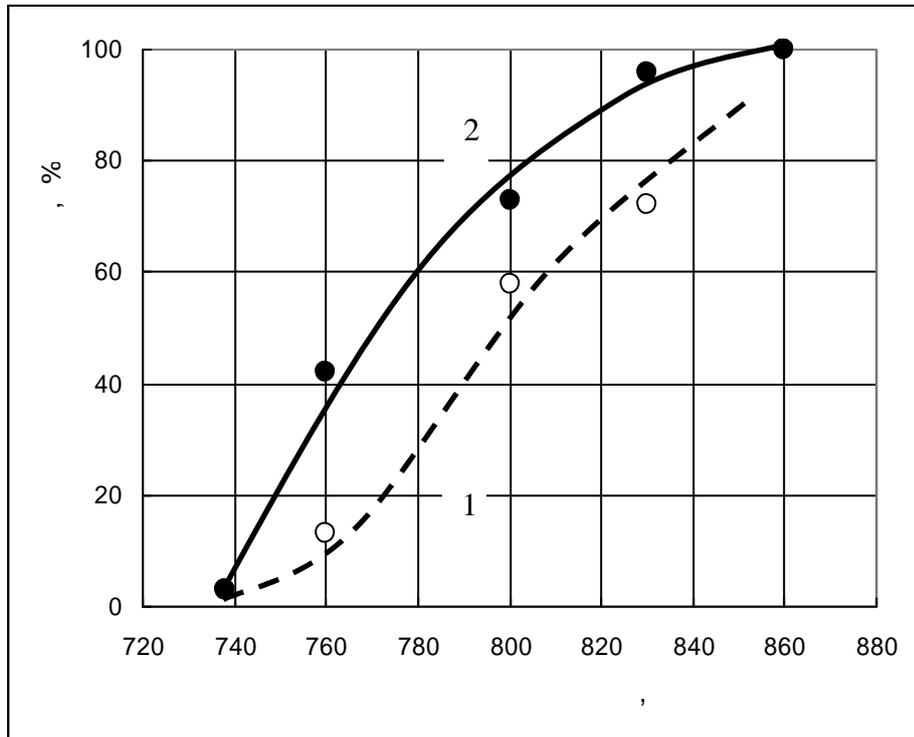






- 760 ° , (185 ; 13 %);
 - 800 ° ; (572 ; 58 %);
 - 830 ° ; (935 ; 72 %).
 . 5.7.3.22. - 13

1



. 5.7.3.23 -

13

: 1 -
 2 -

30

;

5.7.3.2

13

830 °

. 5.7.3.2.1.

,

754 - 715° ,

. 5.7.3.2-5.7.3.5,

5.7.3.2.1.

r₁

(30 °)

,

70 ° / .

5-40° / .

(150-110°).

,

5.7.3.2.6

,

20 ° /

r₁.

(5 ° /)

700 °

(70 %),

20 ° /

40 %

,

1 2

. 5.7.3.2.6.

,

20 ° /

.

,

50 %

.

5 40 ° /

(601 630-615 °)

,

.

(70 ° /)

r₃ (280 °)

.

3, . 5.7.3.2.6

500 ° ,

.

800°

, . 5.7.3.11-5.7.3.15.

830 ° γ- ,
800 ° ,

· ,
· ,
;

13 ,
900 ° (

), . 5.7.3.2.2 5.7.3.2.4

830° ,

770 720 ° , r₁

r₁, °

800 ° . , 830 °
5 ° / 60 ° ,

(. 5.7.3.2.1 5.7.3.2.2).

800 °

(40-70 ° /)

800 °

830 °

70 ° /

5.7.3.2.2, 5.7.3.2.4

800 °

830

800 °

900 °

900 °

° /).

(355 246 °

70

5.7.3.2.7

13

800 °

5 30

(10 70 ° /).

1

5-

(50 %

)

760-662 ° .

30-

2.

1 2

,

.

,

2

1

.

2

70 %

;

$\alpha \rightarrow \gamma$

.

10

70 ° /

5-

,

40

° ,

1 3.

,

600 °

.

4

30-

.

1-3

γ -

,

.

,

600 °

,

40-45 %

.

.

,

,

.

;

70 ° /

13

.

$\gamma \rightarrow \alpha$

$\alpha \rightarrow \gamma$

800 °

13

760

. 5.7.3.16 – 5.7.3.20

. 5.7.3.2.5.

40 %,

5

20 ° /

830 800 ° (5.7.3.2.1).

r₁

5 ° / 722 ° .

r₁

5 20 ° / .

40-70 ° /

$\gamma \rightarrow \alpha$

189

760 800 °

,

,

γ-

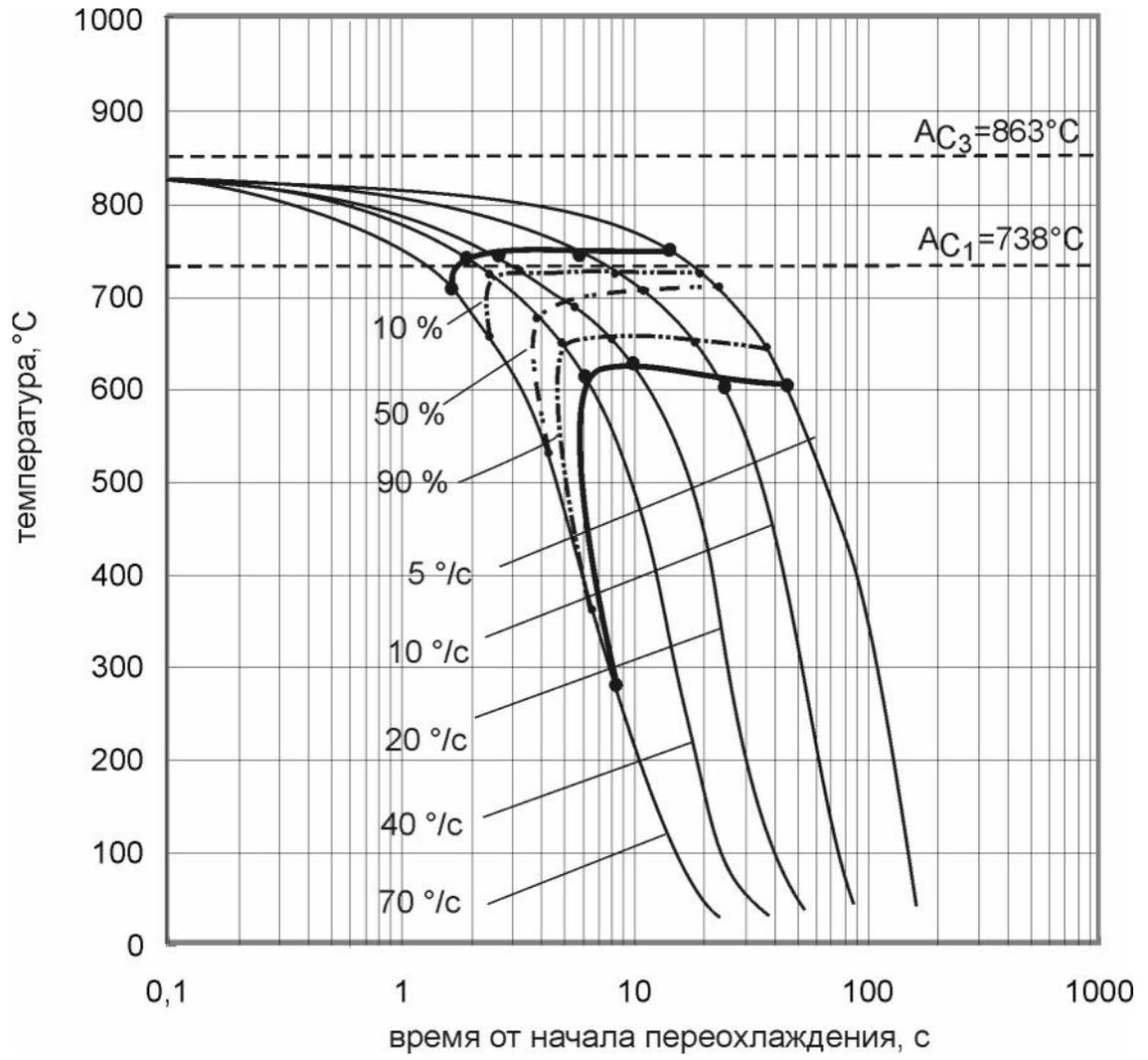
.

5.7.3.2.1

13

830 ° , 800 ° 760 ° 5-70 ° /

° /	°	°							
		800-700	700-600	600-500	500-400	400-300	300-200	200-100	100-20
		900 °				830 °			
5	738	754	601						
10	740	750	601						
20	735	743	630						
40	742	746	615						
70	734	715					280		
		900 °				800 °			
5	744	767	661						
10	736	751	644						
20	742	750	636						
40	741	745	634					195	
70	738	738		529			246		
		900 °				800 °			
5	745	770	629						
10	740	760	625						
20	727	745	646						
40	740	735	644					198	
70	732	720	565			355			
		900 °				760 °			
5	730	722	640						
10	742	725	643						
20	740	695	612						
40	744	691					212		
70	744	701					220		

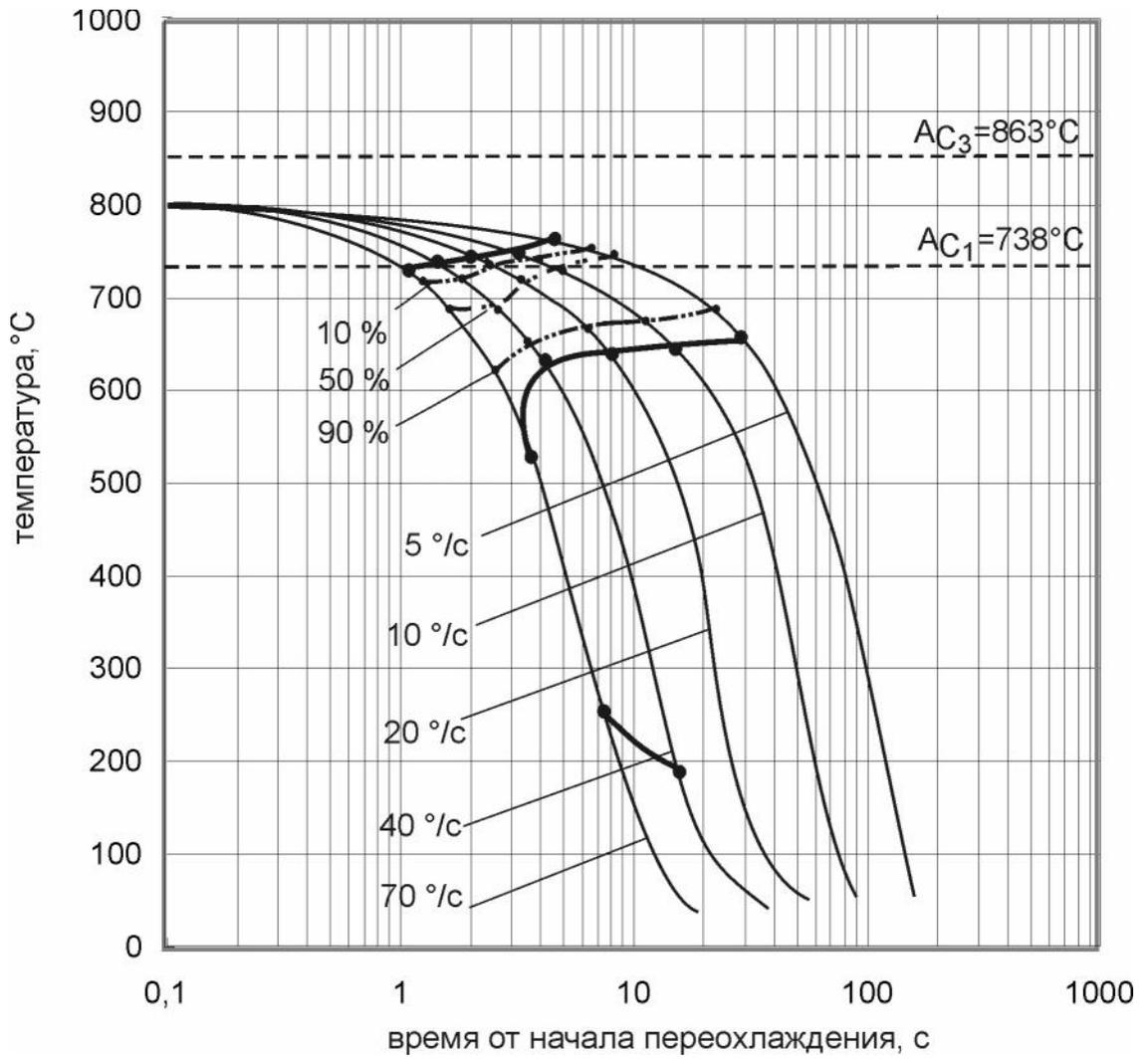


. 5.7.3.2.1–

13

900° , 0,5 .,

, 830° , 0,5 .

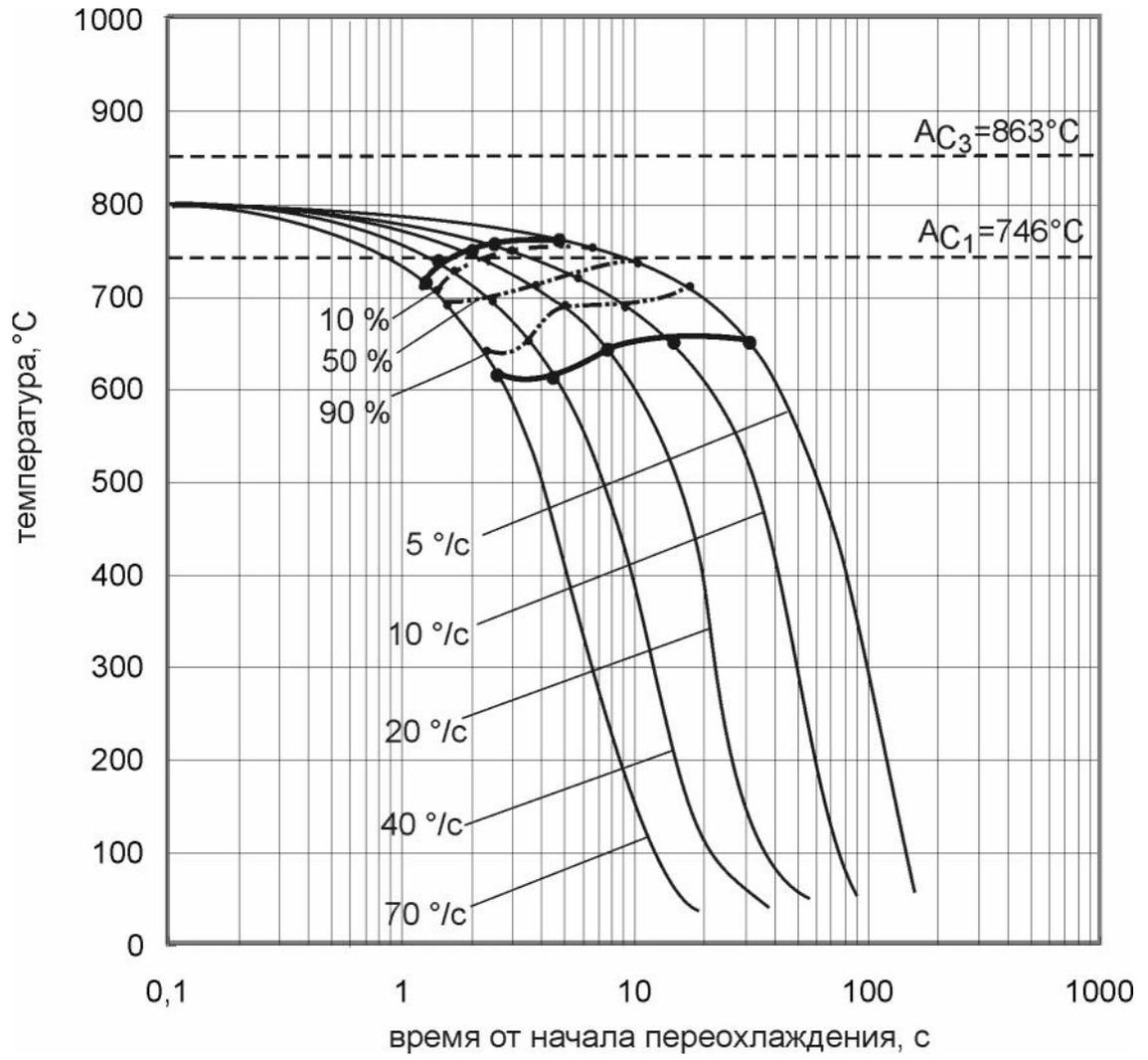


. 5.7.3.2.2 -

13

900° , 0,5 ..

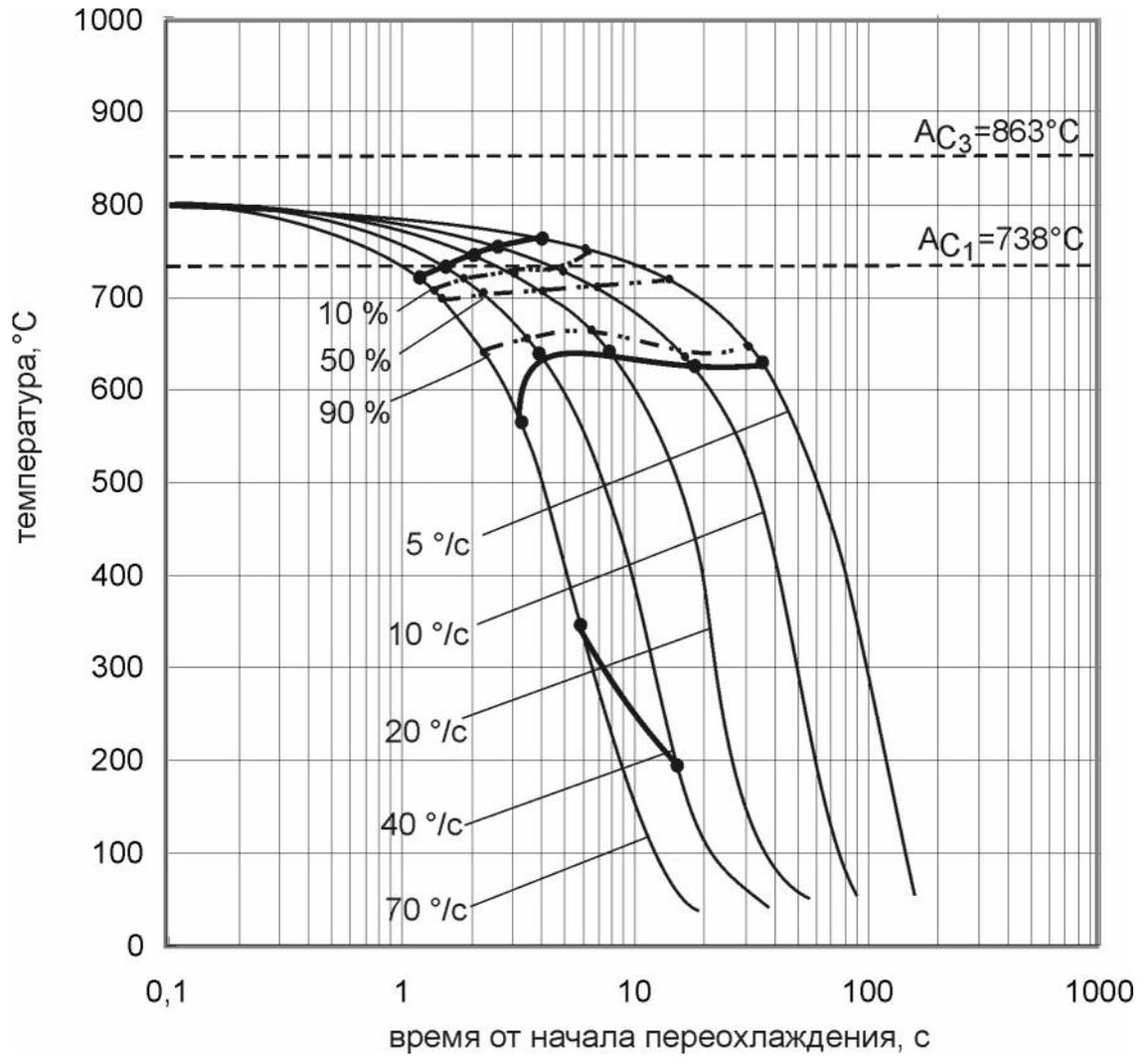
, 800° , 0,5 .



. 5.7.3.2.3 -
13

900° , 0,5 ..

, 800° , 5 .

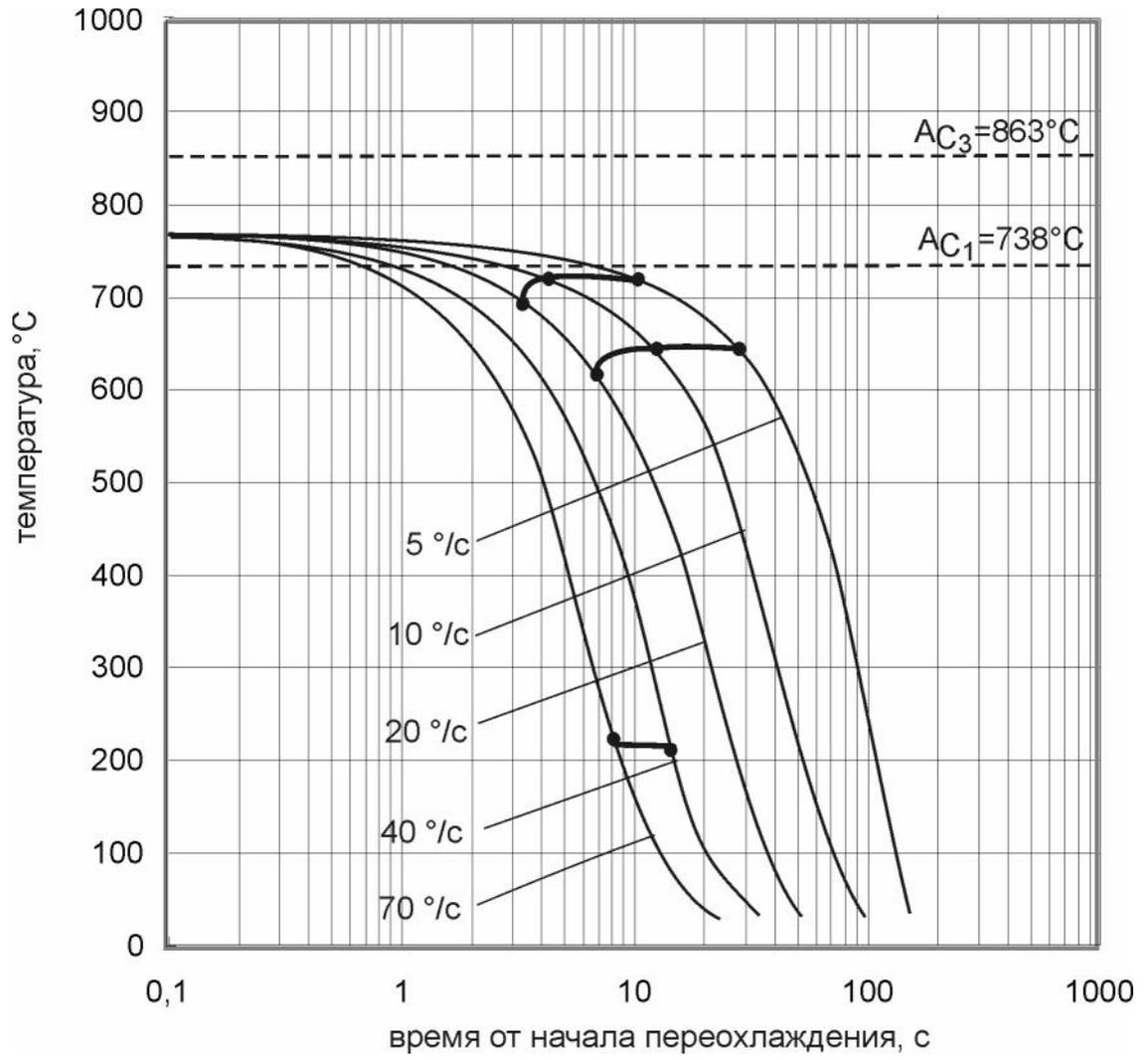


.5.7.3.2.4 –

13

900° , 0,5 .,

800° , 0,5 .

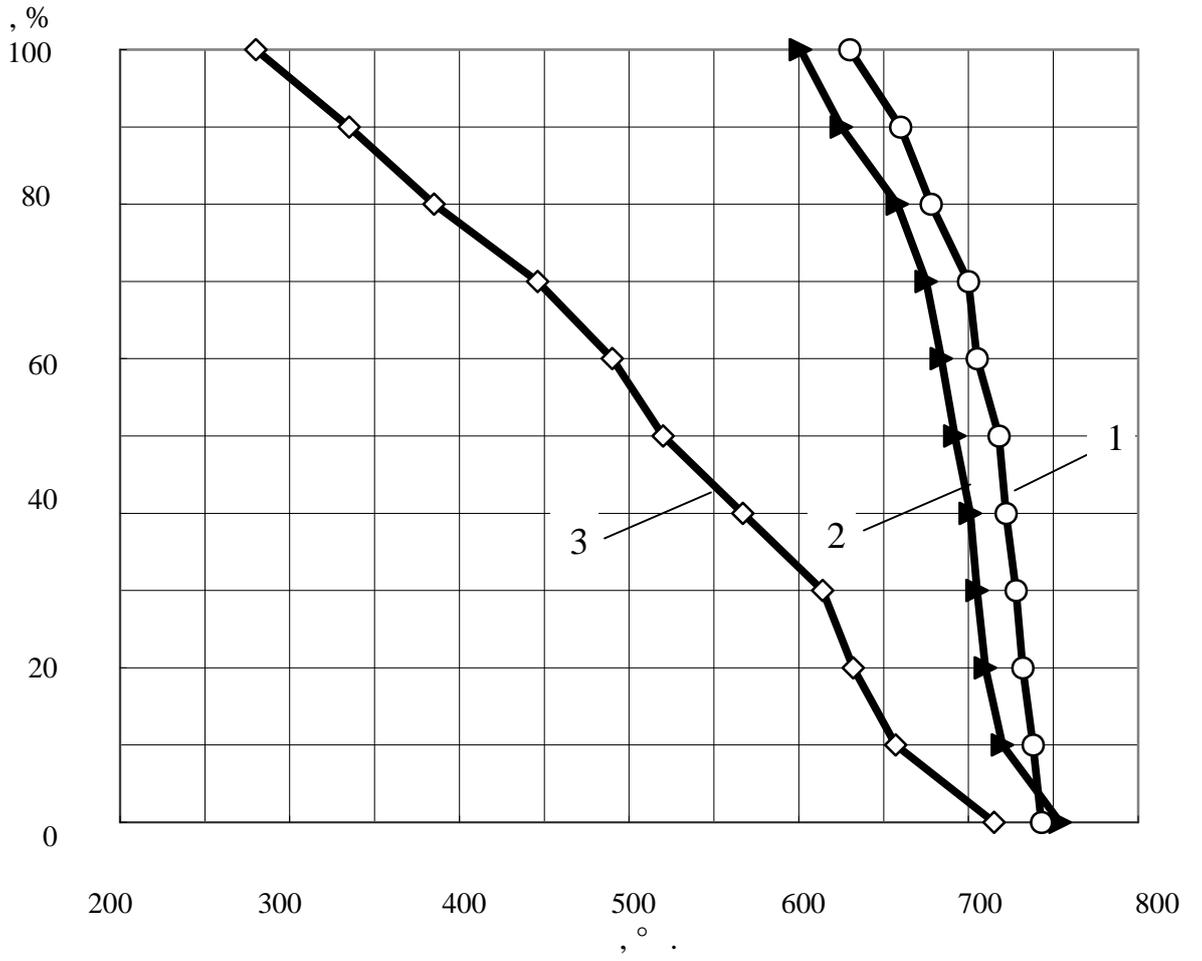


.5.7.3.2.5 –

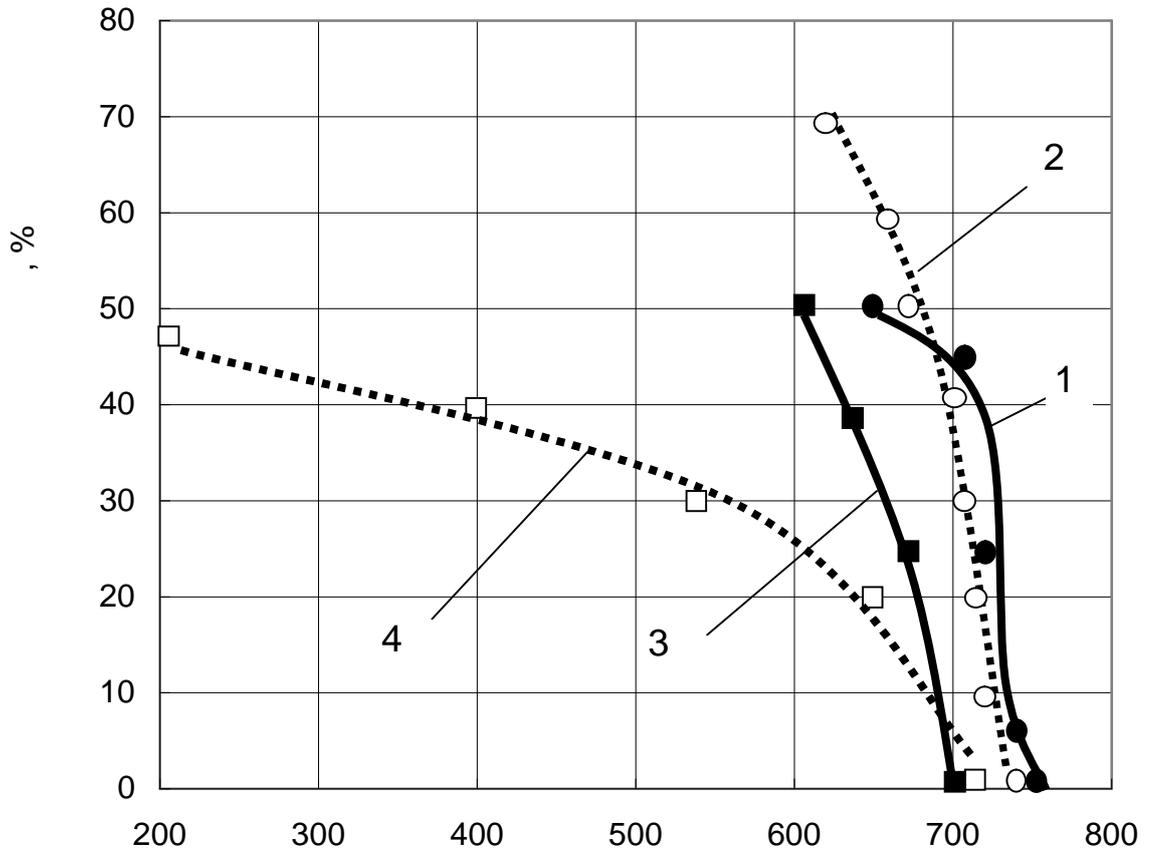
13

900° , 0,5 .,

, 760° , 0,5 .



.5.7.3.2.6 – 13 :
 900 ° , 830 ° (0,5) ,
 1 – 5 ° / , 2 – 20 ° / , 3 – 70 ° /



. 5.7.3.2.7 –

13

800 ° :

- 1 – 800 ° 5 .. 10 ° / ;
- 2 – 800 ° 30 .. 10 ° / ;
- 3 – 800 ° 5 .. 70 ° / ;
- 4 – 800 ° 30 .. 70 ° / ;

5.7.3.3

13

5.7.3.3.1

13

:

1050 Ê -

; 900 Ê -

,

830 Ê

0,5 .

830 ° α→γ-

80 %

0,5

. 5.7.3.3.1.1.

5 10 ° /

(. 5.7.3.3.1.1 ,).

3-5 ,

20 ° /

13

(. 5.7.3.3.1.1).

40 ° /

(. 5.7.3.3.1.1).

80%.

(. 5.7.3.3.1.1).

10 ° /

,
 ,
 - -
 ,
 , 5.7.3.3.1.2 .
 - .
 .
 0,1-0,15 (. 5.7.3.3.1.2).
 ,
 (. 5.7.3.3.1.2 -).
 ,
 Fe₃C, . 5.7.3.3.1.2 .
 20 ° /
 . . 5.7.3.3.1.3
 .
 (. 5.7.3.3.1.3).
 ,
 (. 5.7.3.3.1.4).
 ,
 . 5.9.3.3.1.4 (200),
 .
 - ,
 , 0,2-0,3 (. 5.9.3.3.1.4 , ,).
 ,
 ,
 (. 5.7.3.2 ,

5.7.3.3, 5.7.3.4).

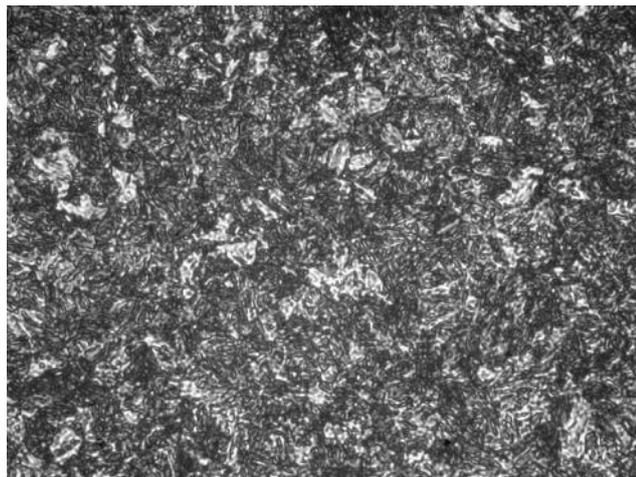
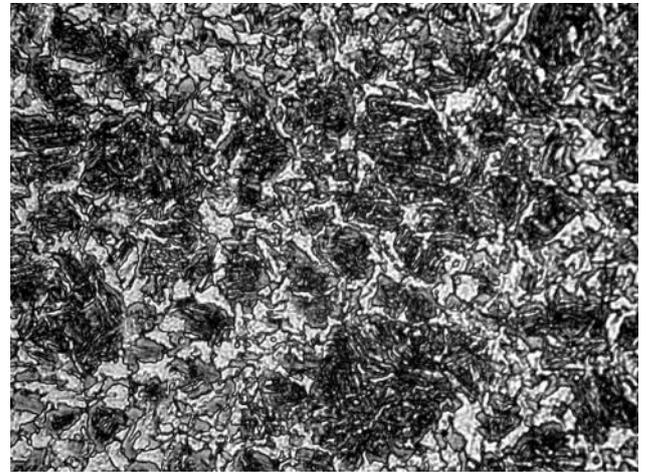
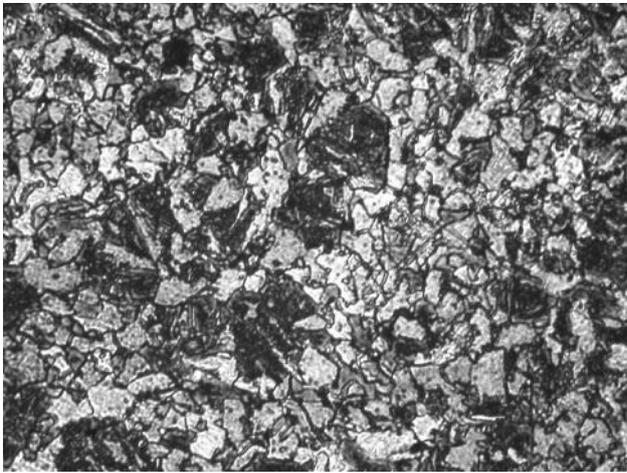
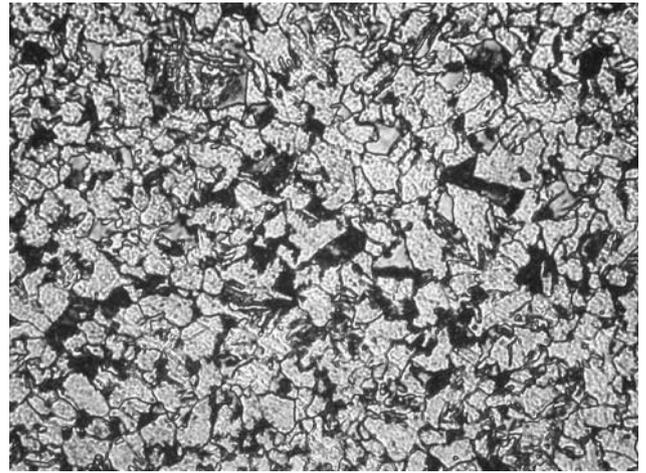
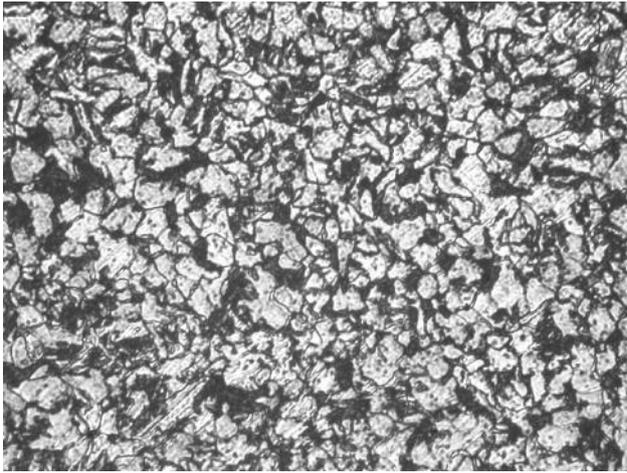
·
 $70^\circ /$
 $\theta_1 = 715^\circ$, 30° . $40^\circ /$
 (. . 5.7.3.2.1). $\gamma \rightarrow \alpha$ -
 · (-
) · -

(. 5.7.3.3.1.5).
 , (. . 5.7.3.3.1.5
 . 5.7.3.3.1.2).

(280°),
 (. 5.7.3.3.1.6, 5.7.3.3.1.7).

·
 (. 5.7.3.3.1.7).
 ()
 · . 5.7.3.3.1.6 ,

·
 ,
 ,
 Fe_3C .



-5 ° / , 500; -10 ° / , 500; -20 ° / , 500; -40 ° / , 500
 -70 ° / , 500

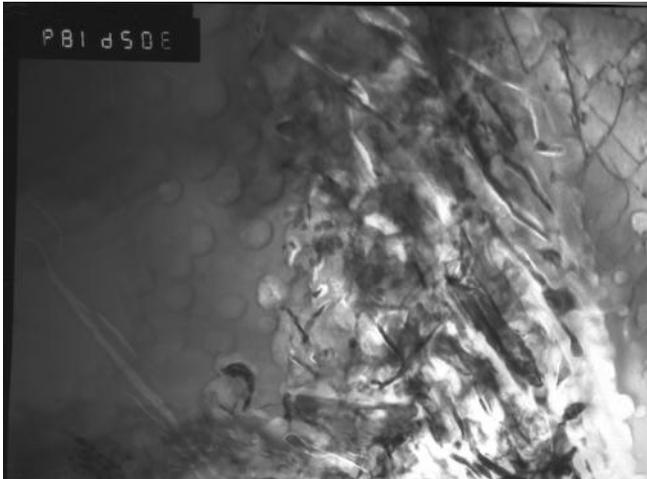
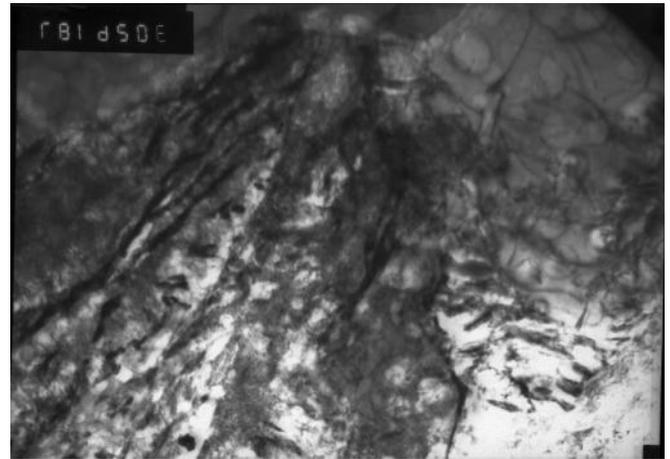
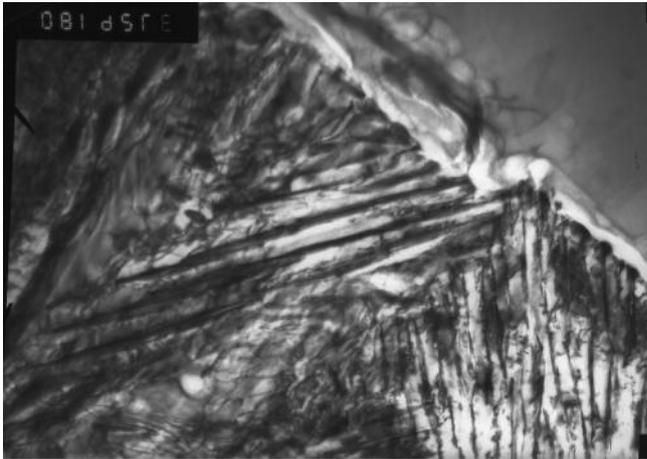
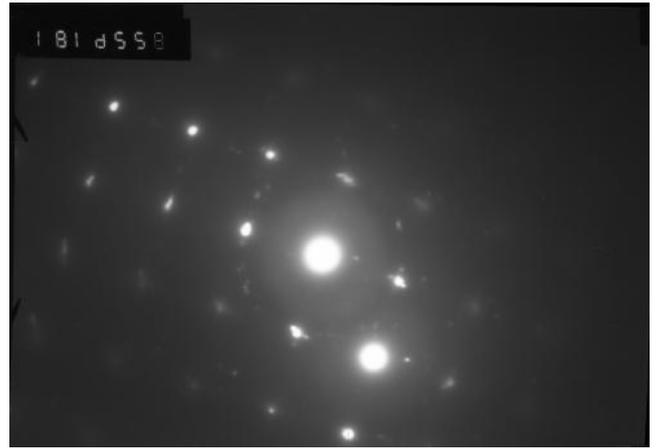
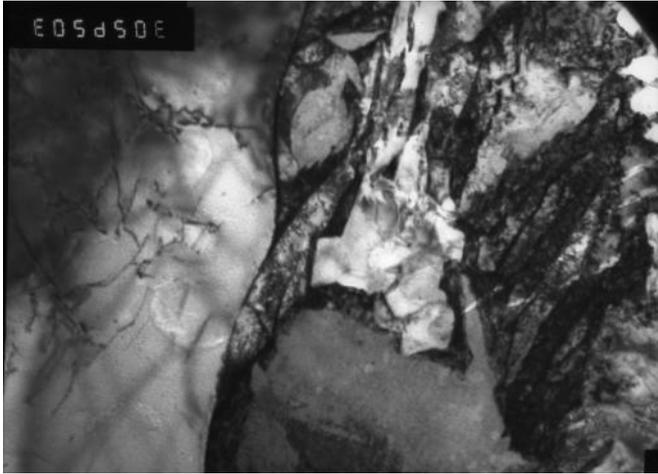
5.7.3.3.1.1-

13

900° ,0,5 .,

,830° ,0,5 .

.



— , 30000; — , .30000; —
30000

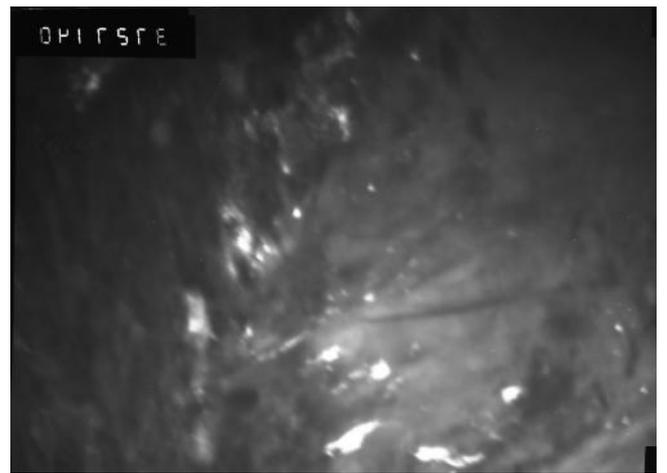
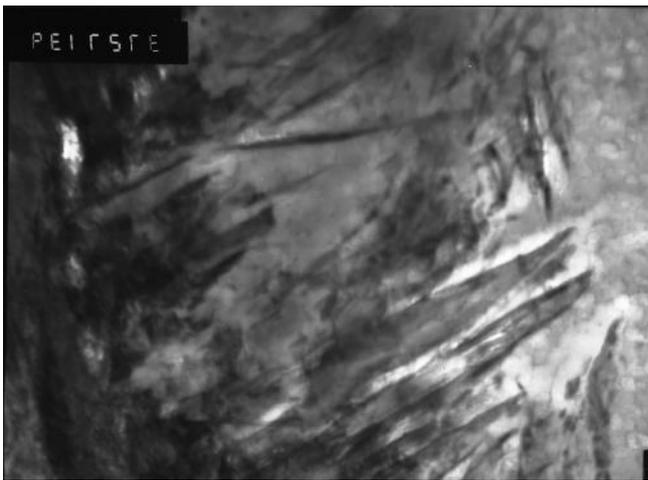
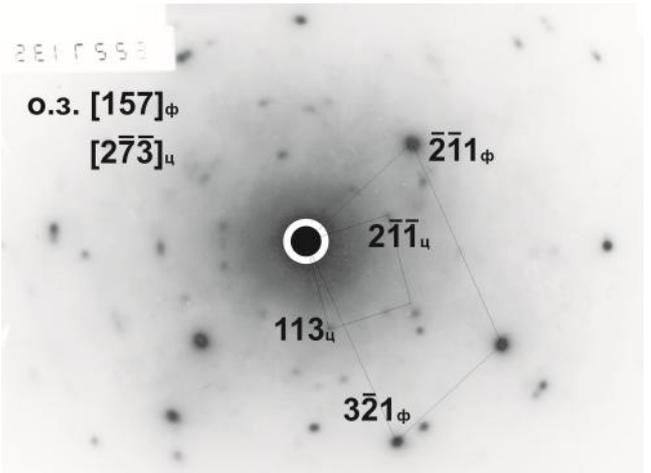
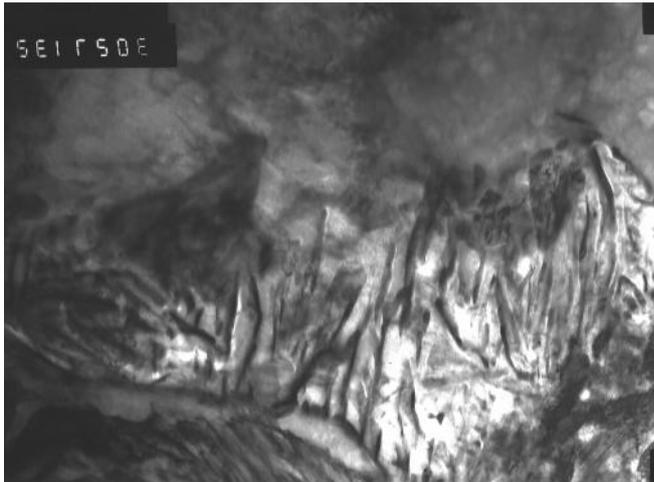
; , , , -
.5.7.3.3.1.2 ,

.5.7.3.3.1.2 -

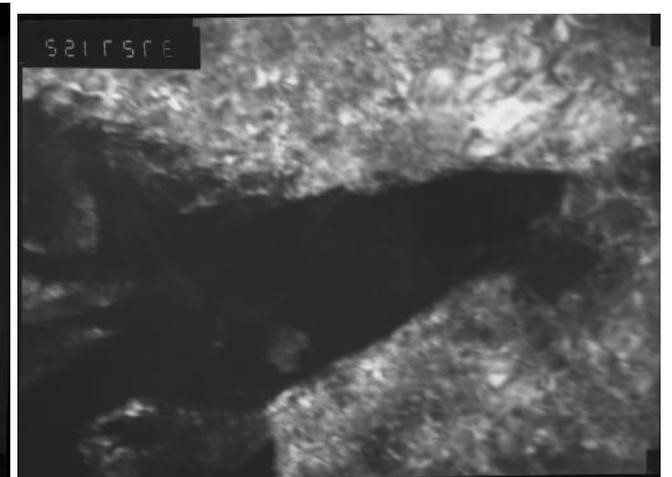
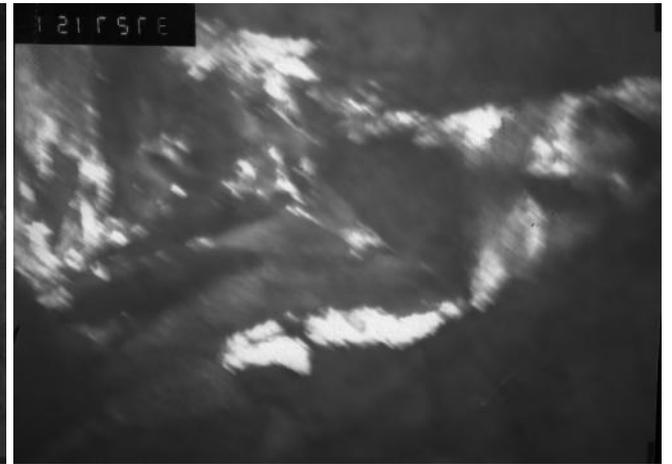
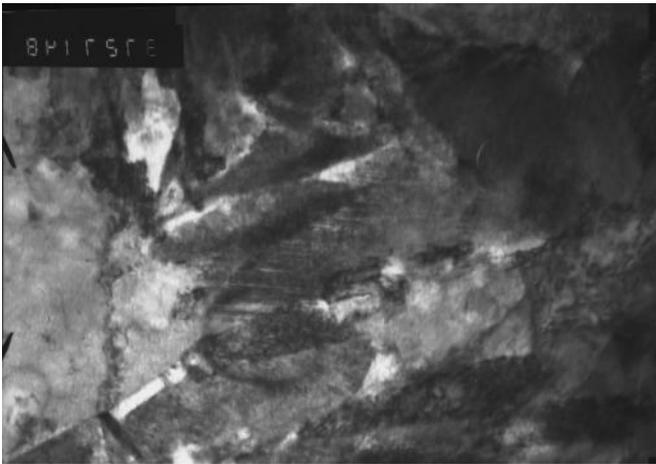
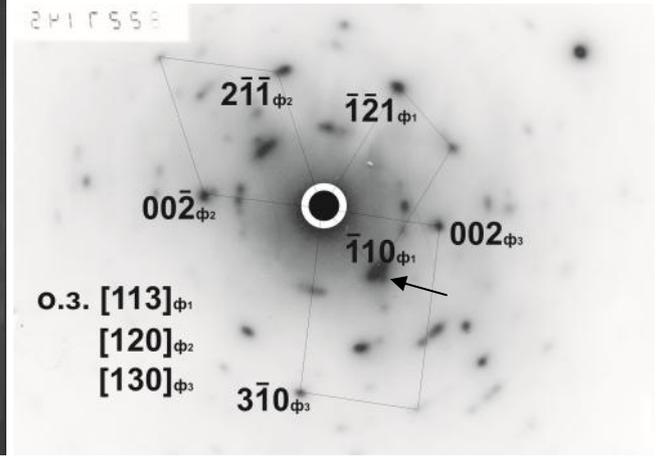
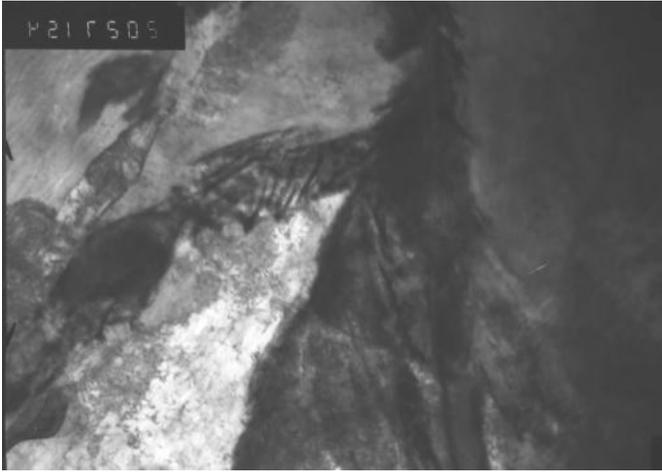
13

830 °

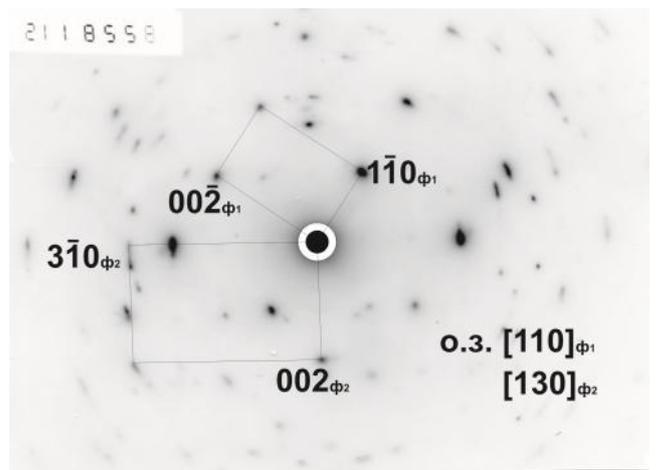
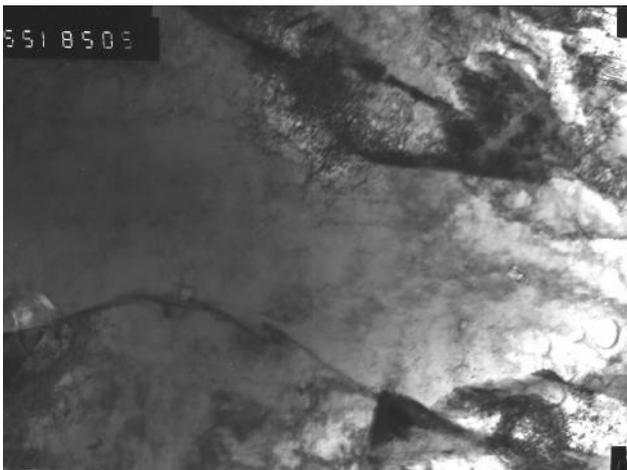
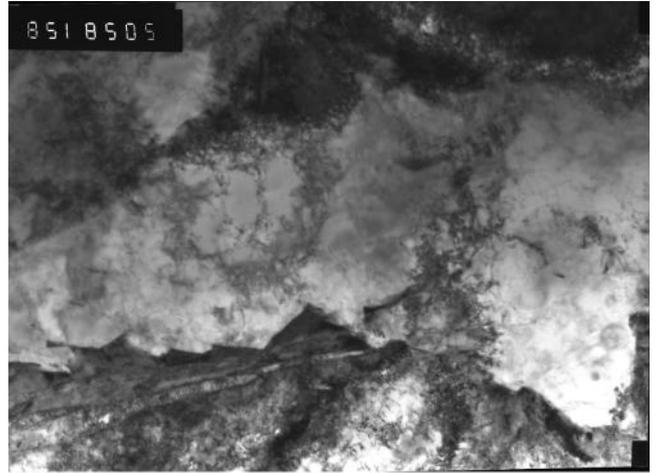
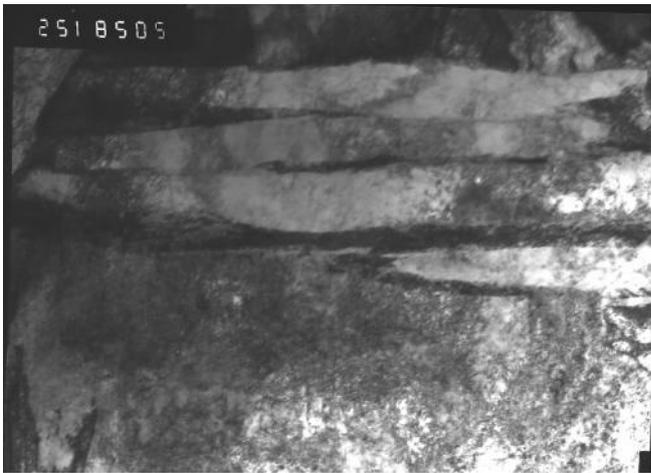
10 ° /



- , 30000;
 - ;
 - , 37000;
 - . 5.7.3.3.1.3 (211), 37000
 . 5.7.3.3.1.3 - 13 830 ° 20 ° /



- , 20000;
 - ;
 - , . 37000;
 , , - . 5.7.3.3.1.4 -
 (110), 37000;
 . 5.7.3.3.1.4 - 13 830 ° 20 ° /



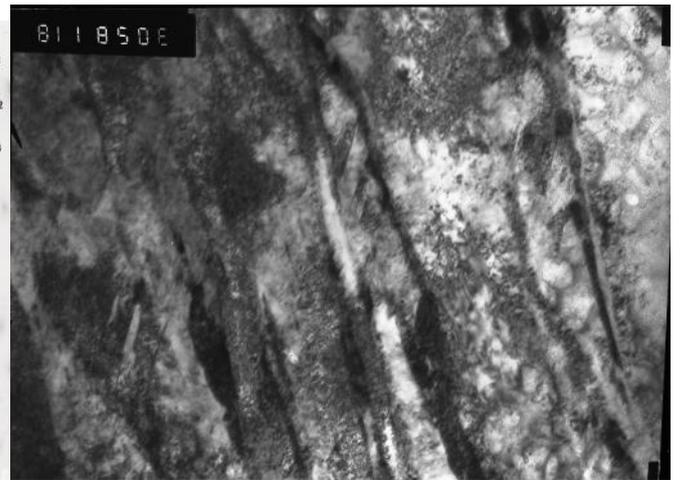
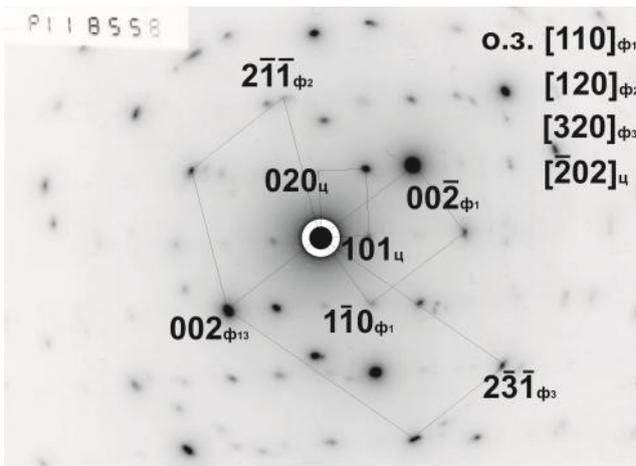
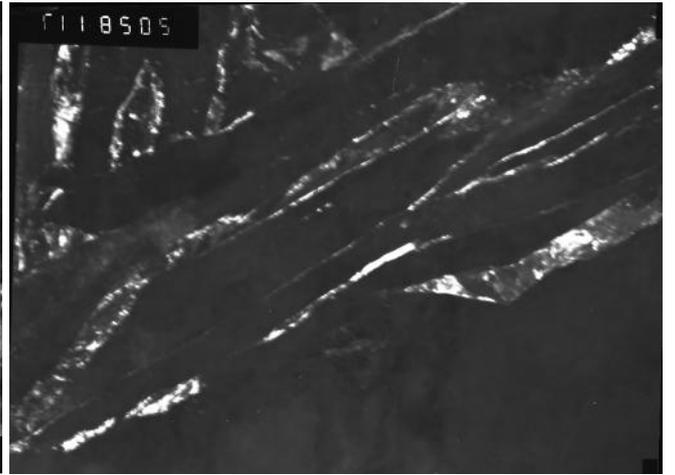
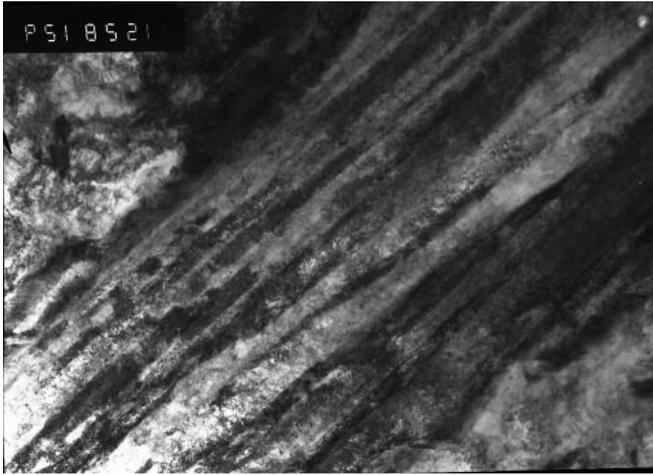
, , - ; , 20000;
-

.5.7.3.3.1.5 -

13

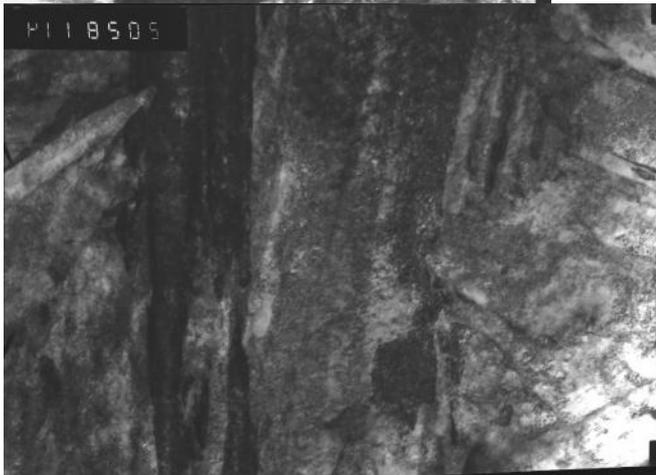
830 °

70 ° /



- , 15000;
 - .5.9.3.1.6 (101), 20000;
 - .5.7.3.3.1.6 ;
 - , 30000;

.5.7.3.3.1.6 - 13 830 ° 70 ° /



- , 20000;
- .5.7.3.3.1.7

, 20000;

.5.7.3.3.1.7 -

13

830 °

70 ° /

5.7.3.3.2

13

:

1050 Ê -

; 900 Ê -

,

800 Ê

0,5 .

800 °

13

.

,

800 °

$\alpha \rightarrow \gamma$

,

0,5

70 %.

800 °

(

)

.

,

. 5.7.3.3.2.1,

,

5 70 ° / .

(

5-10 ° /)

(. 5.7.3.3.2.1 ,).

,

.

,

,

,

.

,

.

,

20 ° / (. 5.7.3.3.2.1).

-

(

.

5.7.3.3.2.1)

,

-

,

.

,

«

»,

.

-

-

.

-

()

().

,

.

-

.

40 ° /

,

, , ,

(.5.7.3.3.2.1).

70 ° /

-

,

(.5.7.3.3.2.1).

13 ,

10 ° / ,

. 5.7.3.3.2.2, 5.7.3.3.2.3.

,

,

(.5.7.3.3.2.2).

.

900°

,

(.5.7.3.3.2.2 ,).

,

-

(.5.7.3.3.2.3 ,

).

-

13

,

-

,

,

«

»

(

),

«

»

,

α-

,

(.5.7.3.3.2.3 ,).

,

,

«

»

.

,

, « »,

20 ° /

5.7.3.3.2.4

1 ,

(. 5.7.3.3.2.4).

20 ° / ,

0,1-0,2 (. 5.7.3.3.2.5),

(. 5.7.3.3.2.6)

« »

5.7.3.3.2.6

1,5-2

α-

, . 5.7.3.3.2.5 .

γ-

. 5.7.3.3.2.5).

5 30

40 ° /

(. 5.7.3.3.2.7 - , 5.7.3.3.2.8).

(. 5.7.3.3.2.7).

(. 5.7.3.3.2.8).

20 ° / ,

(. 5.7.3.2.2)

50- %

40 ° . ,

20 ° / .

30

5

70 ° /

13

40 ° / .

(. 5.7.3.3.2.9 -).

(. 5.7.3.3.2.9).

(. 5.7.3.3.2.10).

10-20 %.

800 °

5 30

(. 5.7.3.2.3

.5.7.3.2.2).

5

30

(

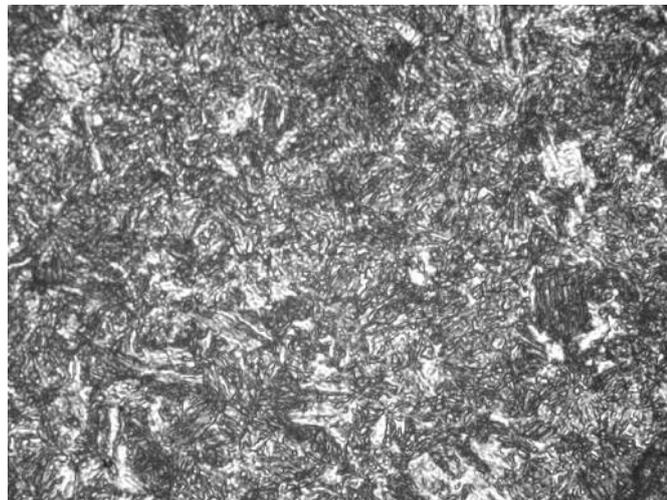
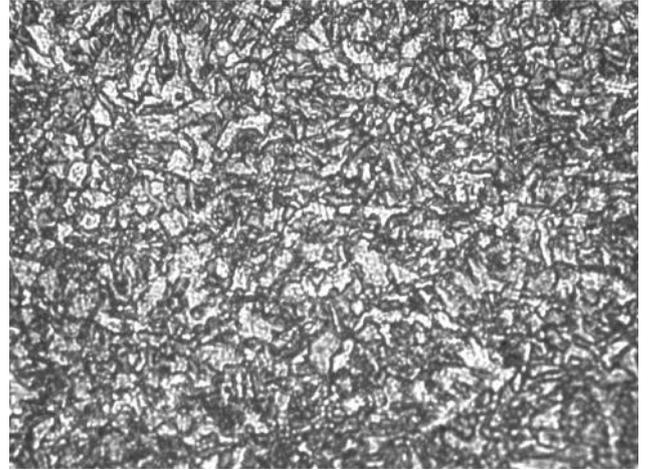
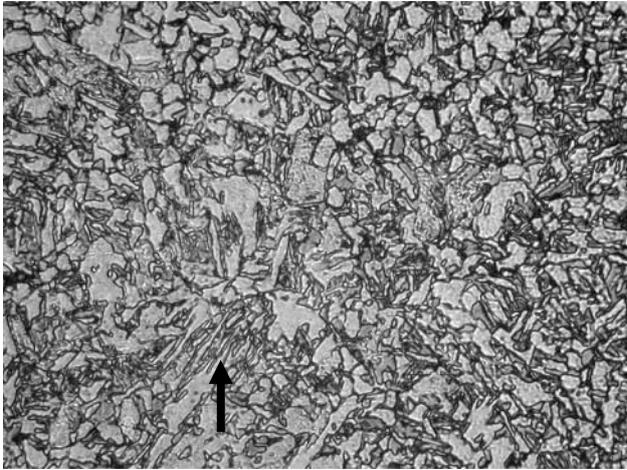
70 ° /)

r₃

615 °

529 ° . ,

= 246 ° .

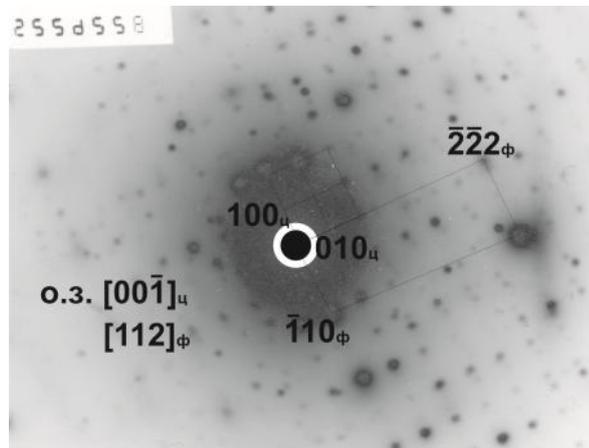
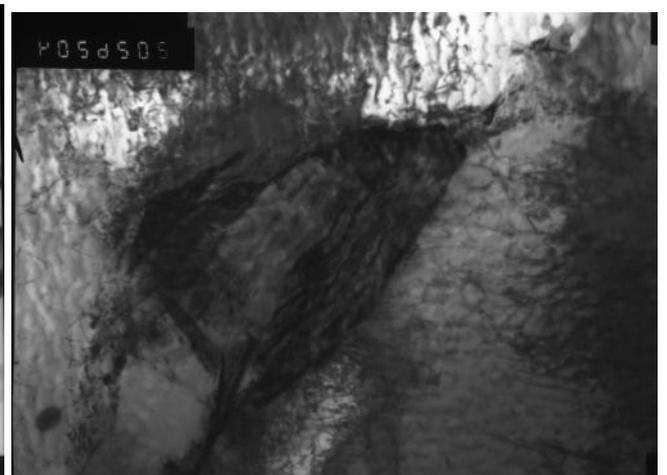
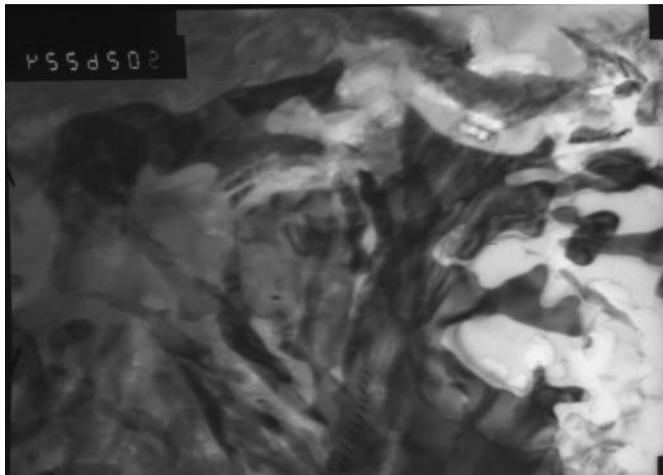
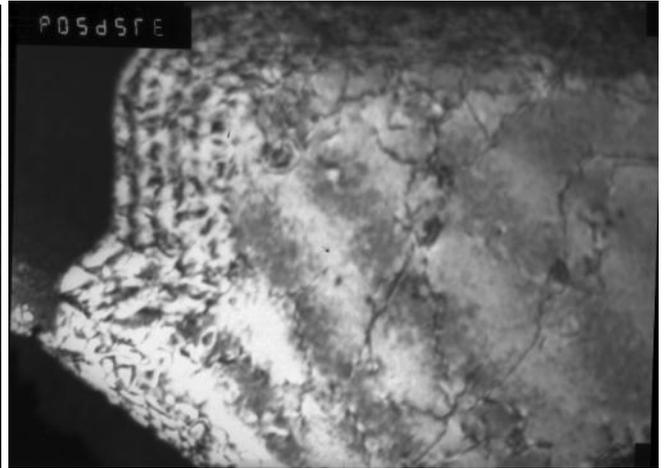


$-5^\circ / , 500$; $-10^\circ / , 500$; $-20^\circ / , 500$; $-40^\circ / , 500$;
 $-70^\circ / , 500$

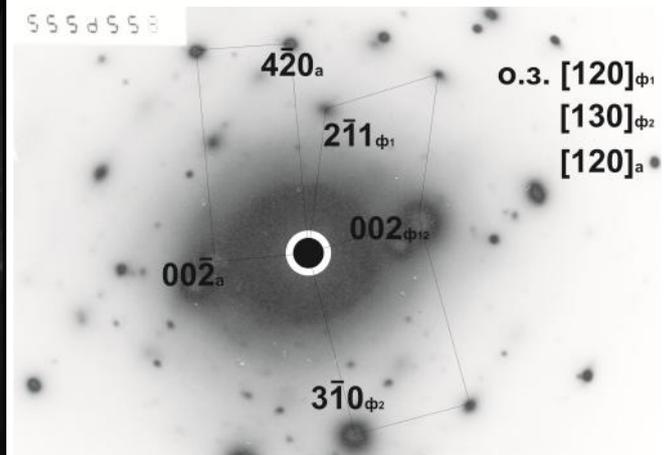
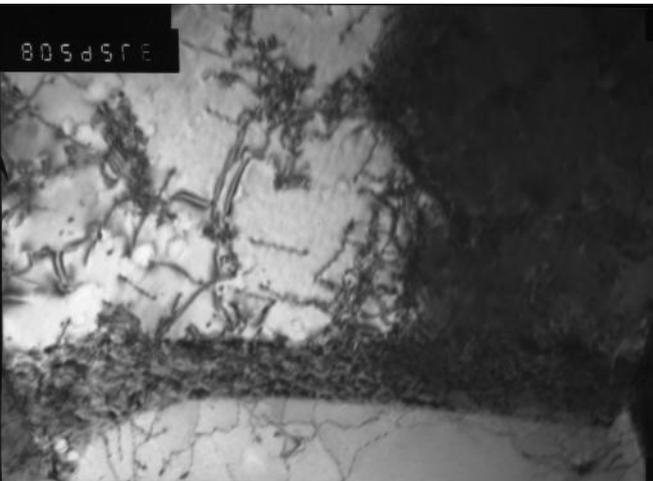
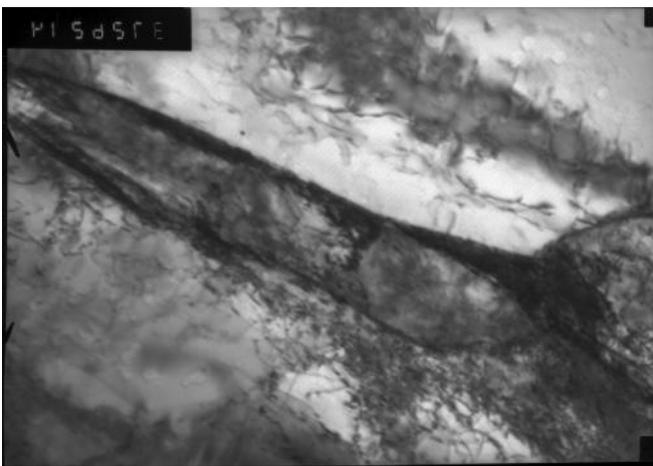
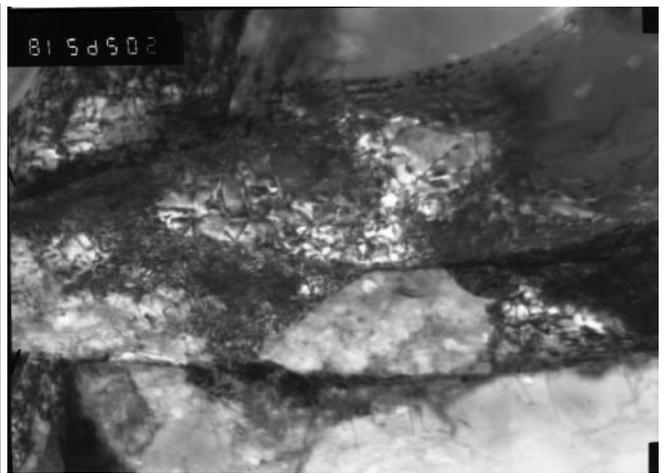
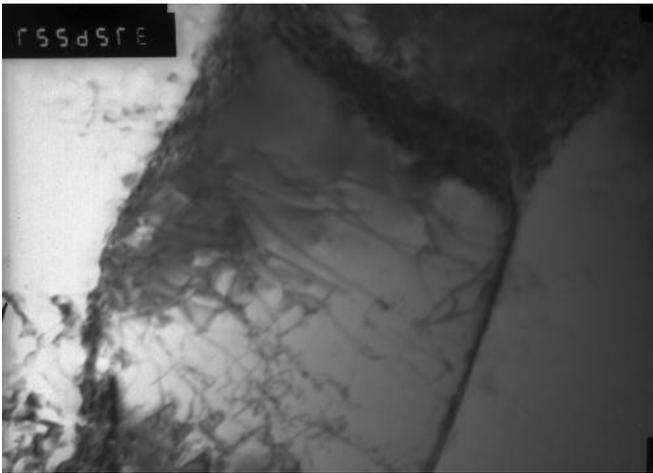
.5.7.3.3.2.1-

13
 $, 800^\circ , 0,5 .$

$900^\circ , 0,5 .,$

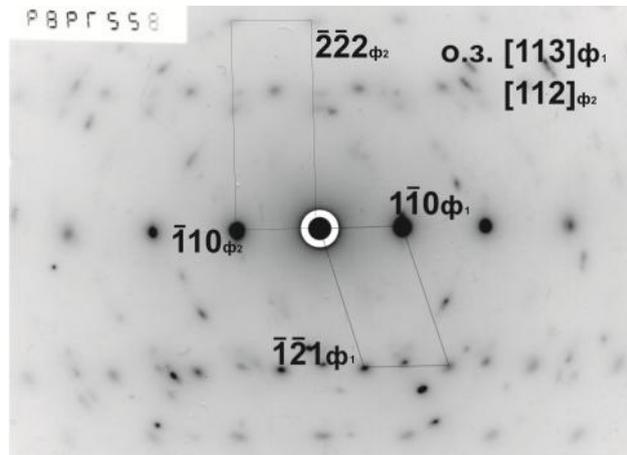
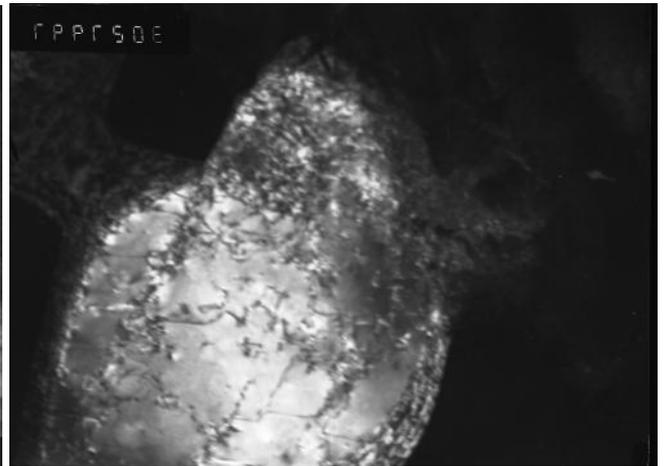
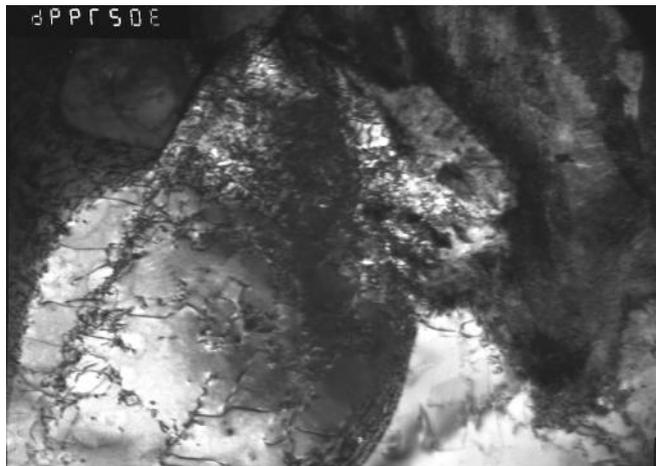
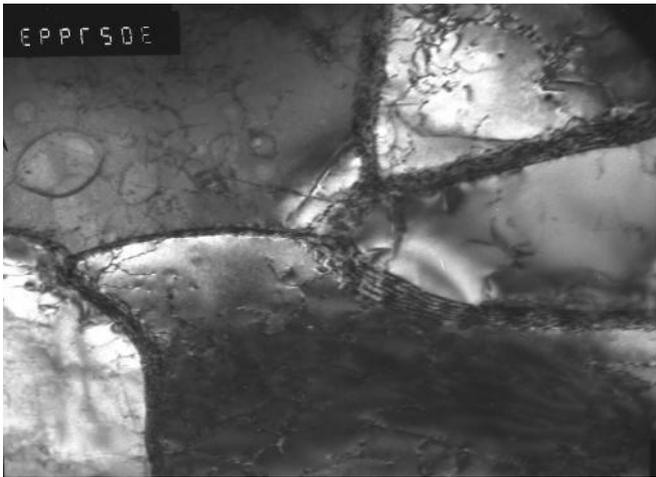


— , 30000;
 — . 5.7.3.3.2.2 , 37000;
 — , 50000;
 — , 20000;
 — 3.9 ;
 . 5.7.3.3.2.2— 13 900° , 0,5 . ,
 800° , 0,5 . , 10° /

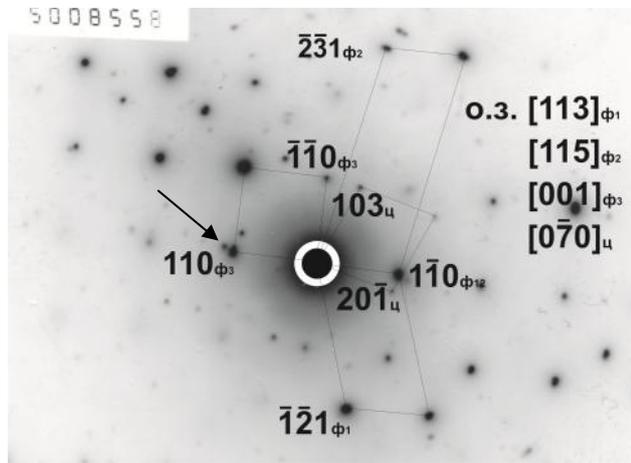
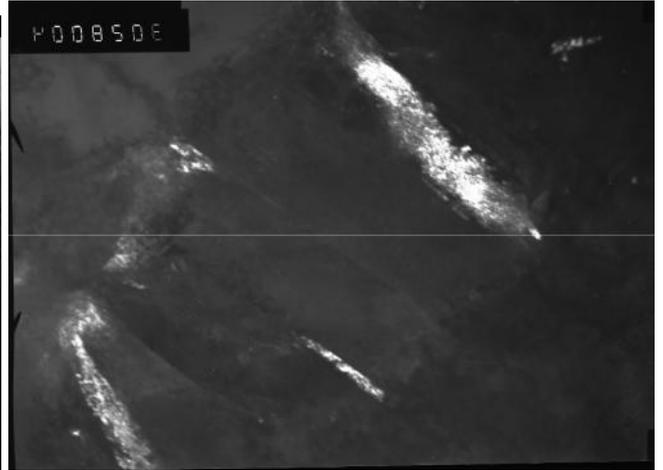
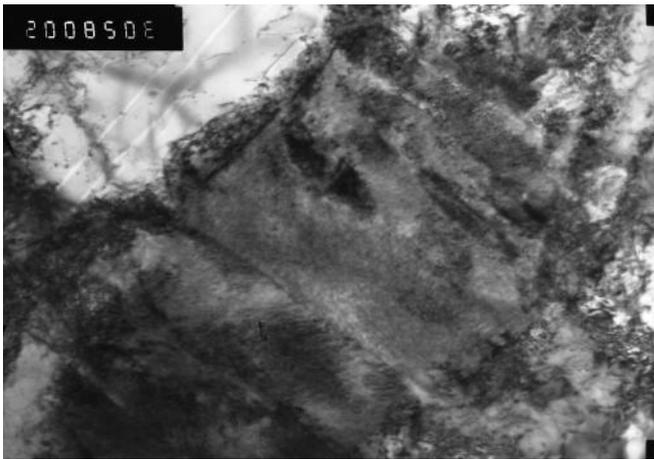


- , 37000;
- , 50000;
- , 37000;
- . 5.7.3.3.2.3 - 211, 37000;
- , 37000;
- 3.10 ;

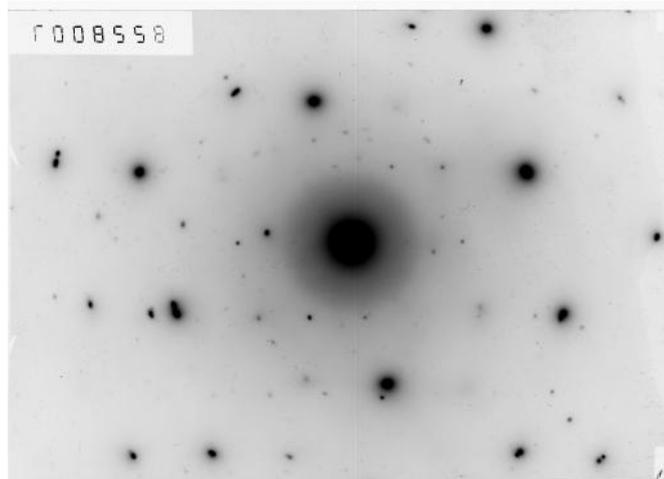
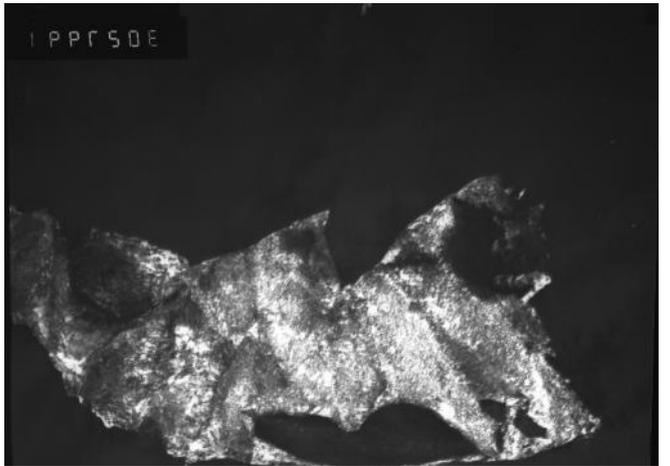
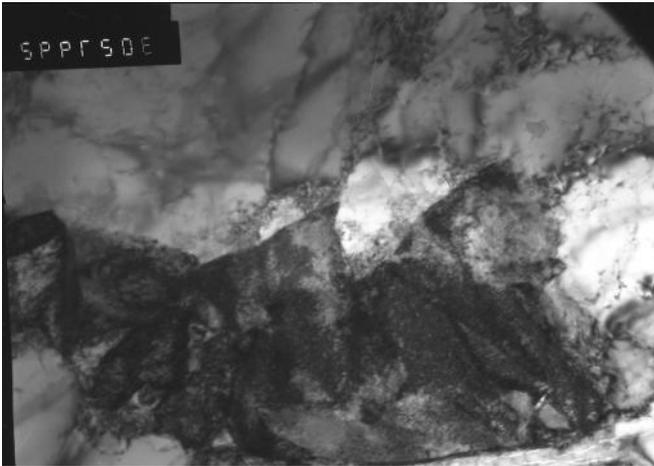
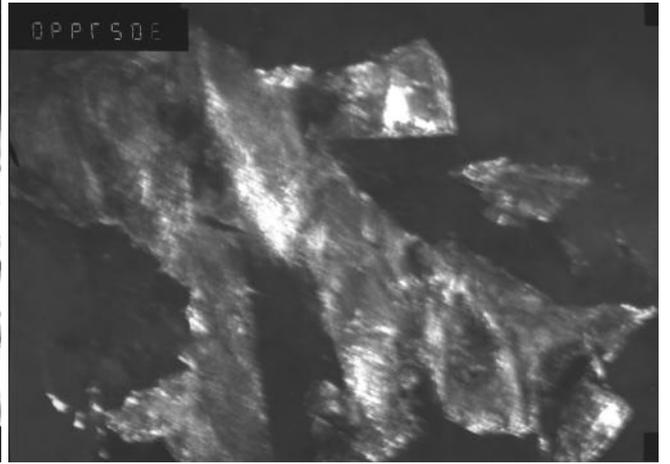
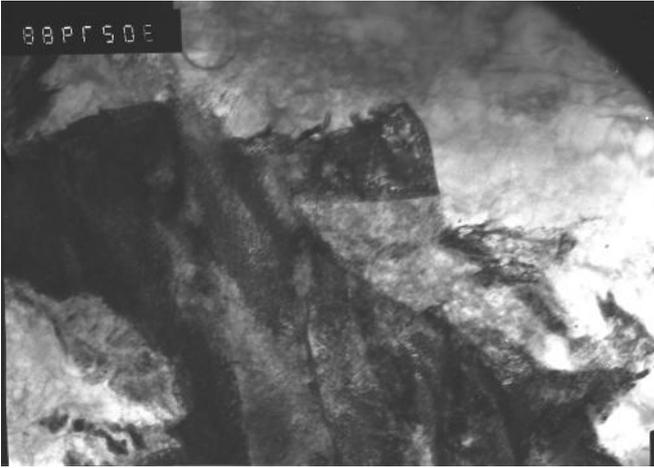
. 5.7.3.3.2.3- 13 900° , 0,5 . ,
 800° , 0,5 . , 10° /



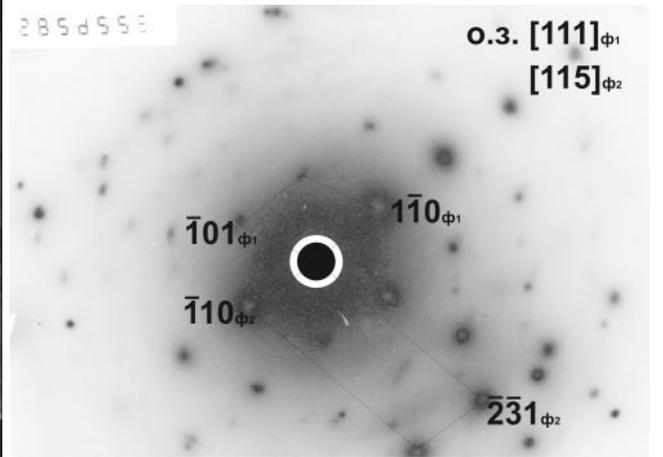
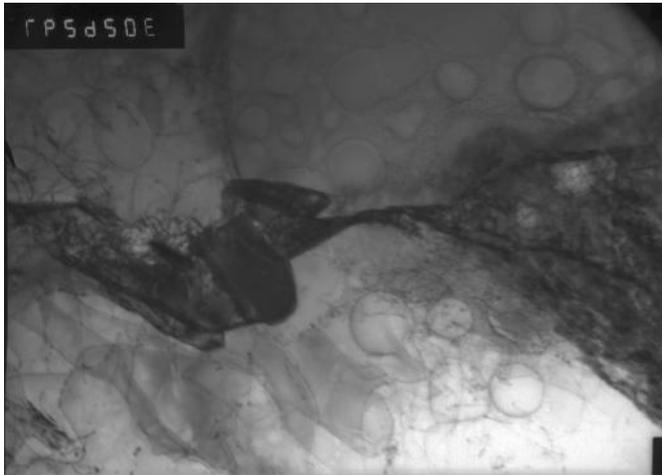
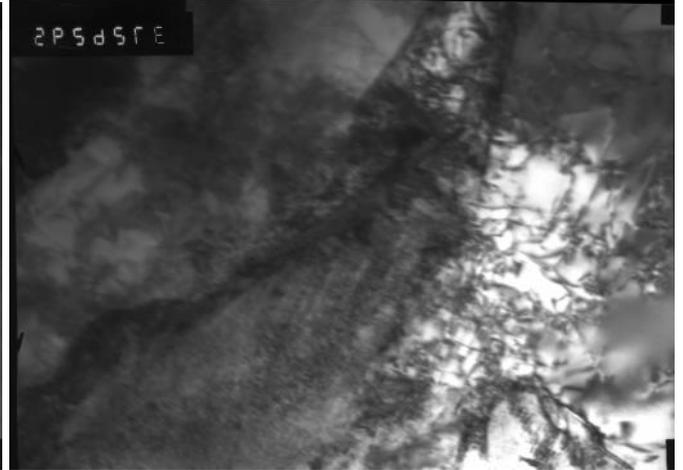
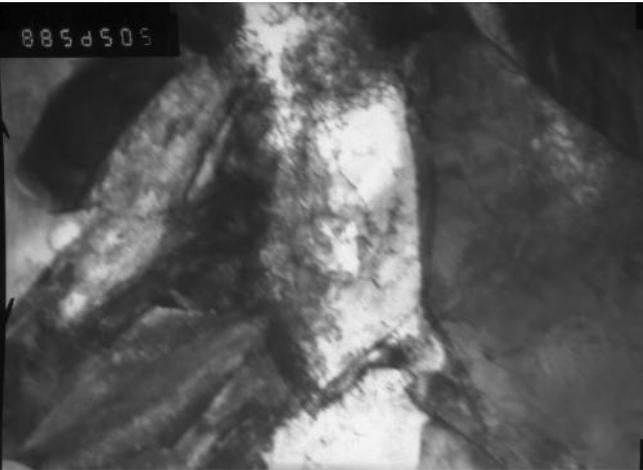
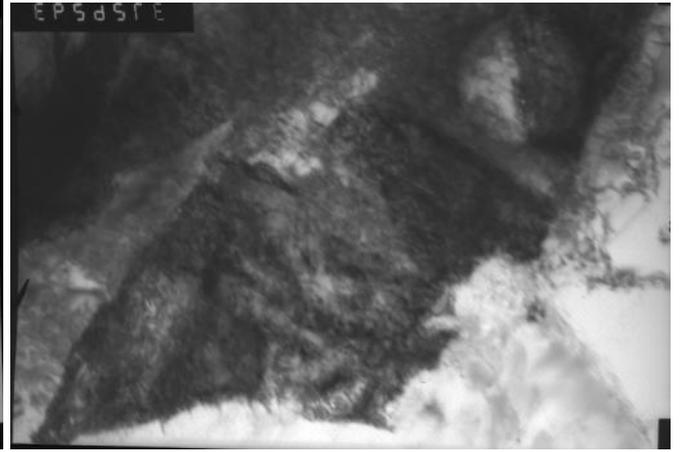
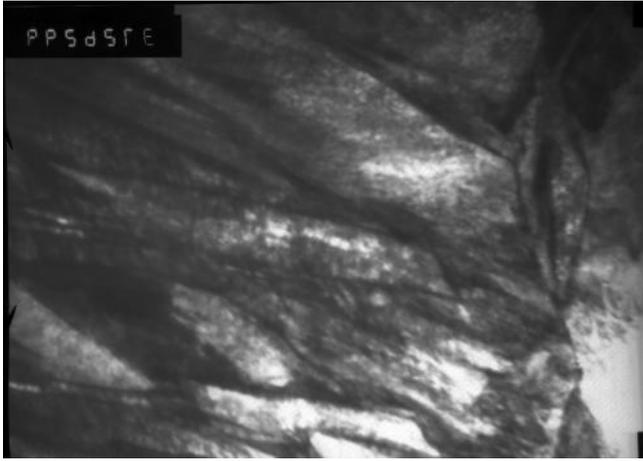
— , 30000;
 — , 37000;
 - , 30000
 - . 5.7.3.3.2.4 — 121, 30000;
 - . 5.9.3.2.4 — 110, 37000;
 - . 5.9.3.2.4 ;
 . 5.7.3.3.2.4— 13 900° , 0,5 . ,
 800° , 0,5 . , 20° /



— , 30000;
 — . 5.7.3.3.2.5 110, 30000;
 — ;
 . 5.7.3.3.2.5— 13 900° , 0,5 .. ,
 800° , 0,5 .. 20° /

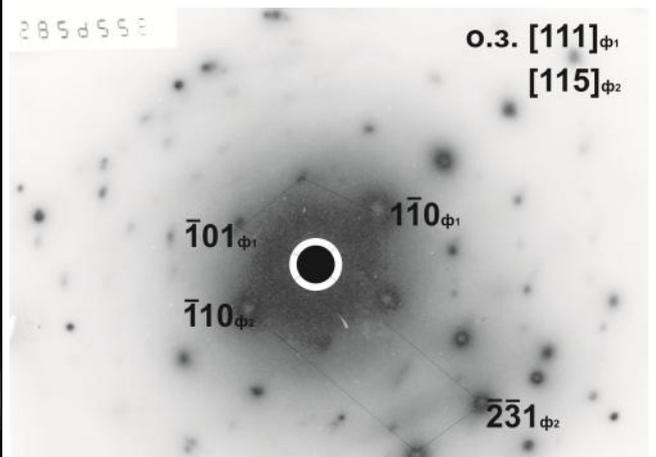
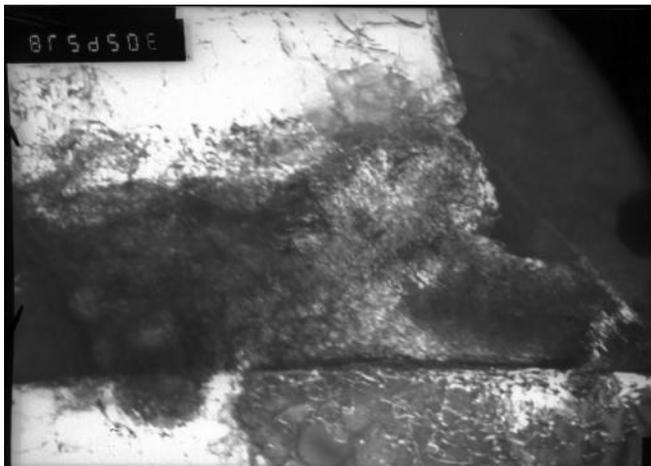
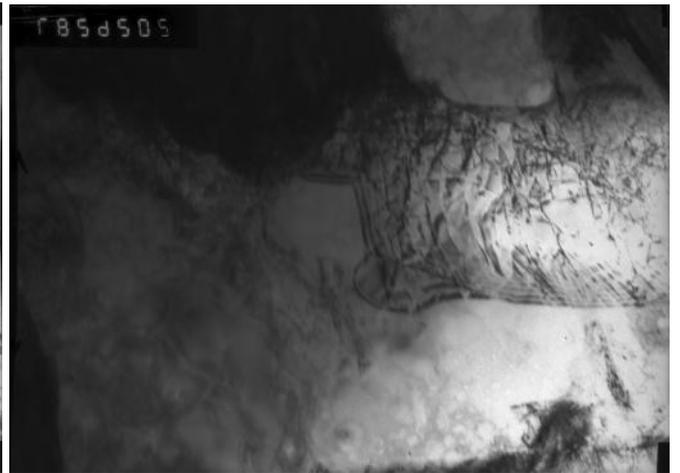


— , 30000;
 — . 5.7.3.3.2.6 , 30000;
 — , 30000
 — . 5.7.3.3.2.6 , 30000;
 — ;
 . 5.7.3.3.2.6— 13 900° , 0,5 .. ,
 800° , 0,5 .. 20° /



, , - , 370000;
 - , 20000;
 - , 300000;
 -

.5.7.3.3.2.7- 13 900° , 0,5 , ,
 800° , 0,5 , 40° /



, - , 30000;
 -
 - ;

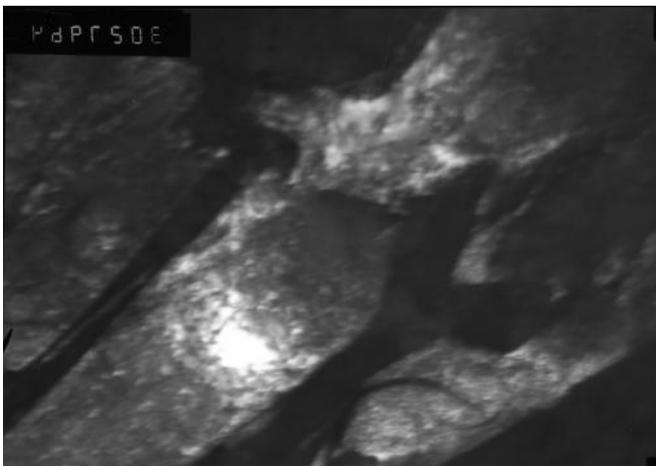
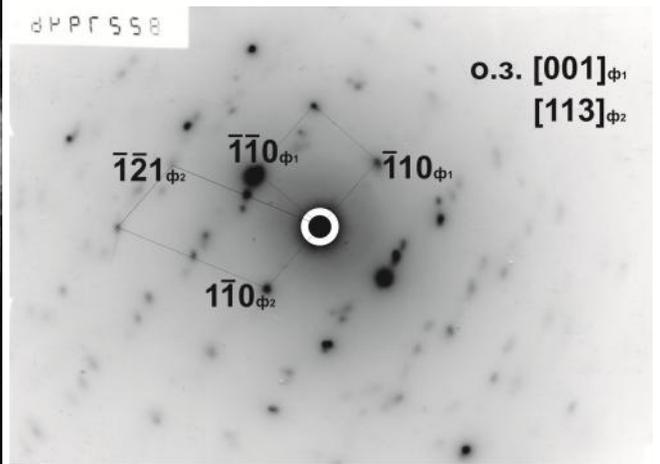
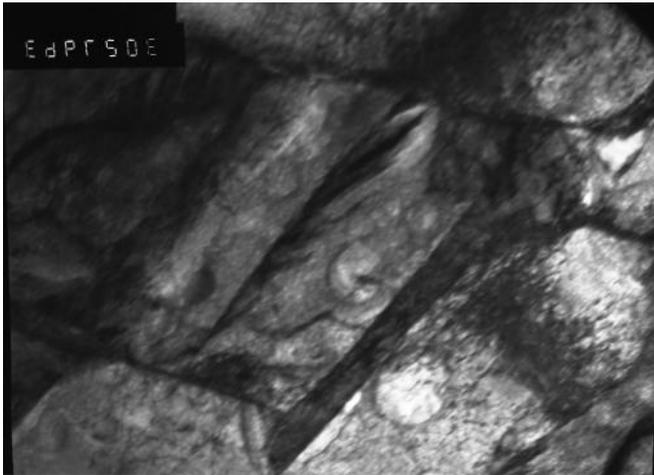
$\bar{1}01$, 30000

.5.7.3.3.2.8-
 800° , 0,5 ..

13 40° /

900° , 0,5 ..

,

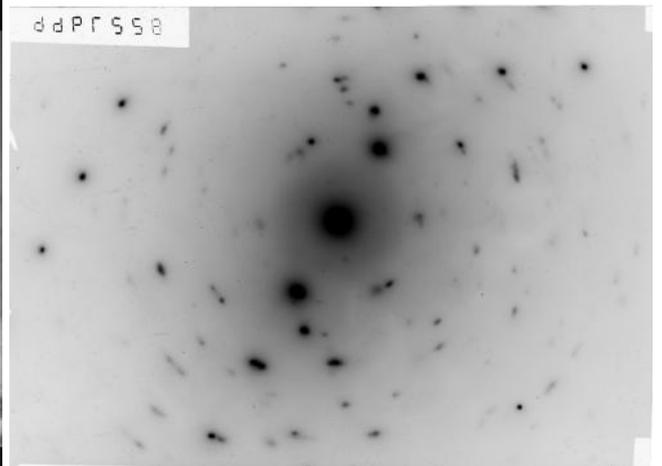
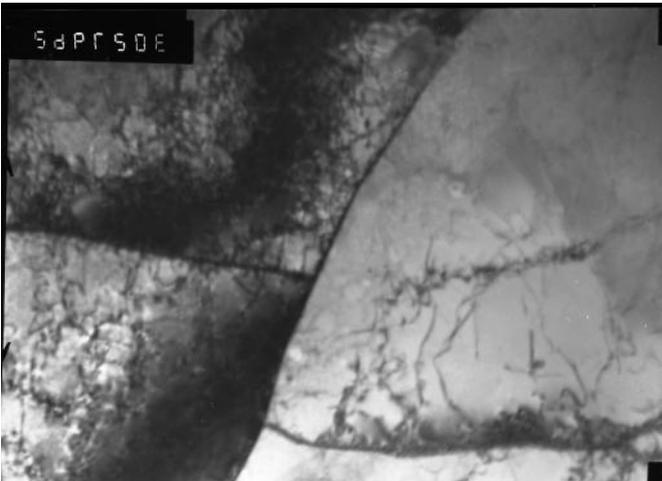
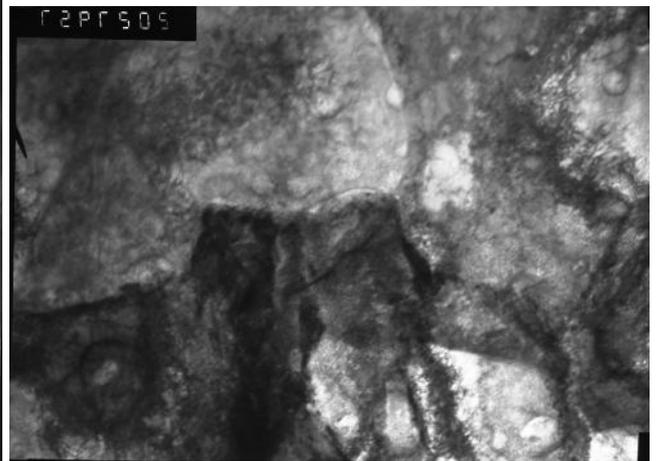
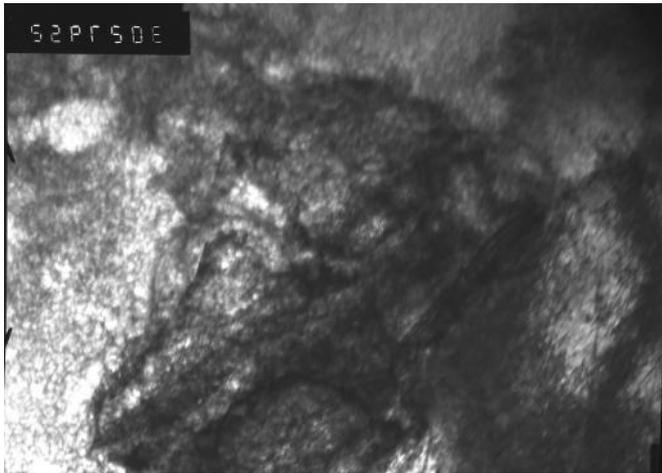
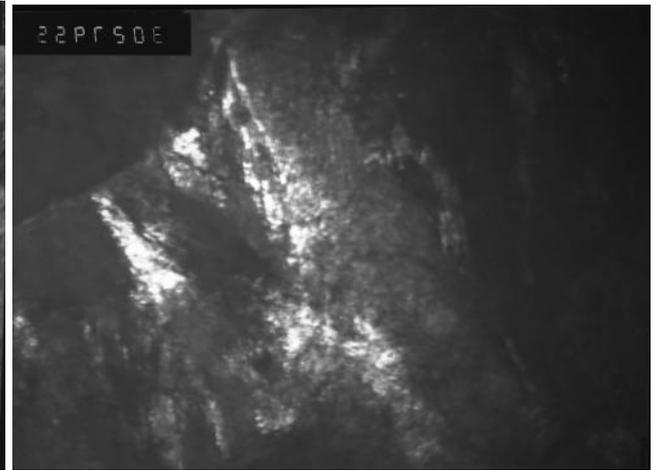
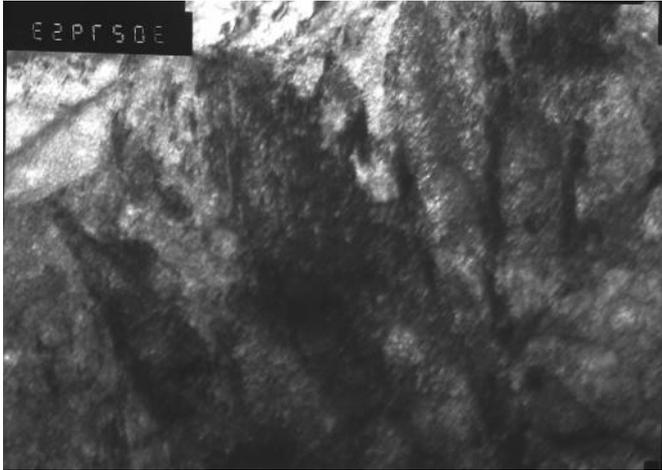


, - ; , 30000;
 - ;
 , -

α - $\bar{1}10$, 30000

.5.7.3.3.2.9- 13 70° /
 800° , 0,5 .,

900° , 0,5 .,



, , , , - , 30000;
- ;

.5.7.3.3.2.10- 13 900° ,0,5 . ,
800° ,0,5 . , 70° /

5.7.3.3.3 **13** :
1050 E^- - ; **900** E^- - ,
800 E^- **0,5** .

800 $^\circ$

,

900 $^\circ$ 900 $^\circ$ ()

(. 5.7.3.2.2 5.7.3.2.4).

,

13

- (. 5.7.2.2).

13 900 $^\circ$, 0,5 .,

800 $^\circ$, 0,5 . 5 10 $^\circ$ /

(. 5.7.3.3.3.1). 5 30 ,

.

20 $^\circ$ /

(. 5.7.3.3.3.1).

- ,

10 $^\circ$ / , ,

(. 5.7.3.3.3.2),

(. 5.7.3.3.3.2). ,

,

Fe₃C (. 5.7.3.3.3.2).

.

40 $^\circ$ / ,

,

.

« »

(. 5.7.3.3.3.1).

- ,
(. 5.7.3.3.3.3).

,
(. 5.7.3.3.3.3).

α - ,
(. 5.7.3.3.3.4 , 5.7.3.3.3.4).
(. 5.7.3.3.3.4)
, (. 5.7.3.3.3.4).

5.7.3.3.3.4). ~0,1 (.

13 , 900 °

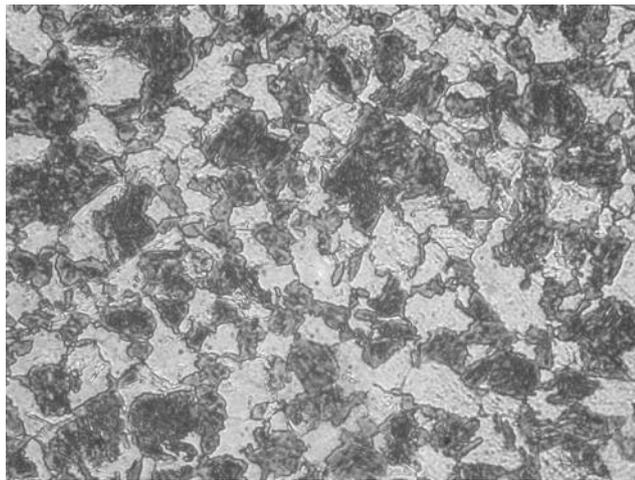
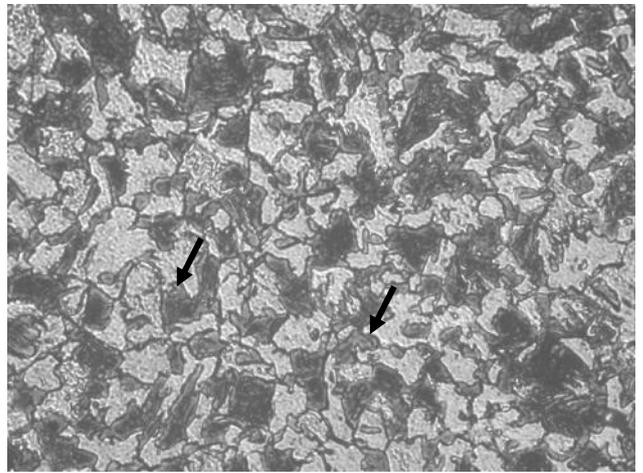
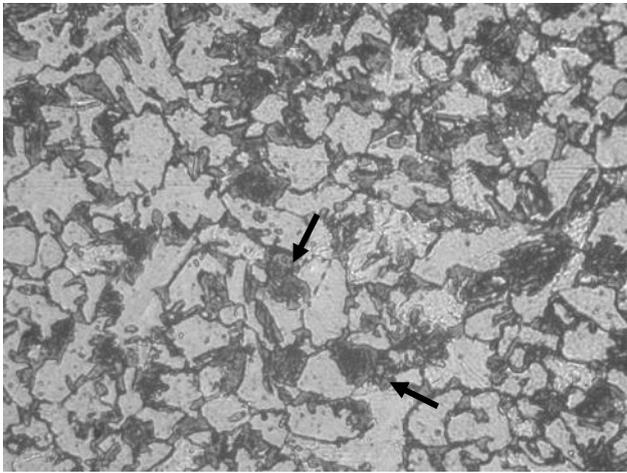
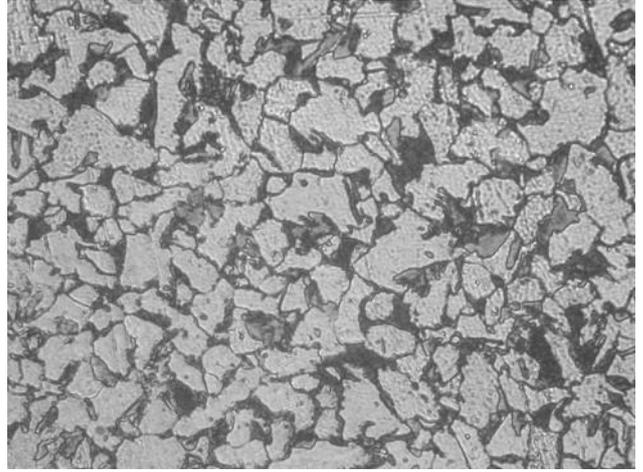
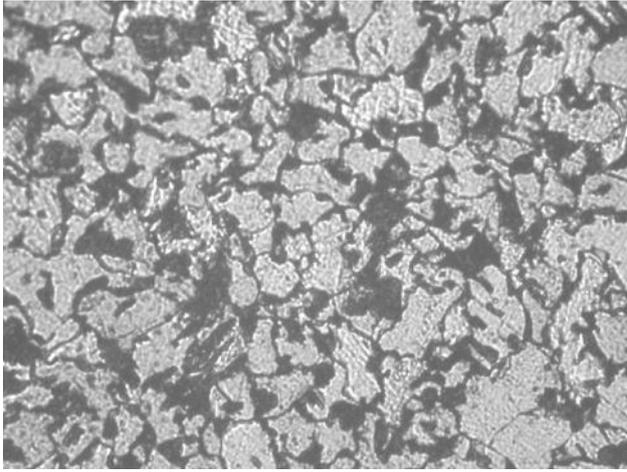
, , ,
()

(10 ° /)

, (40
° /) , ,

, -

.

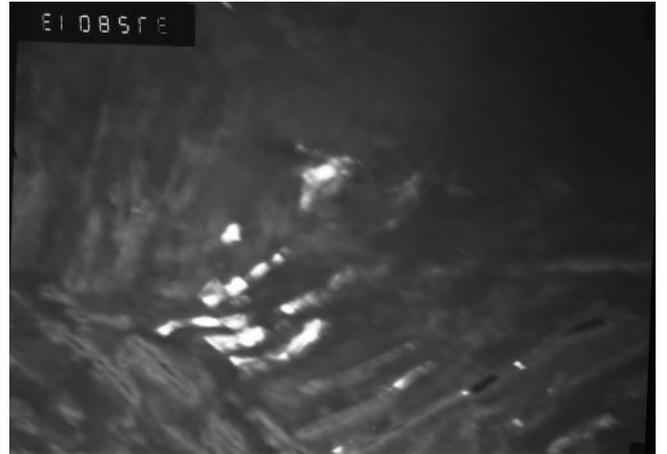
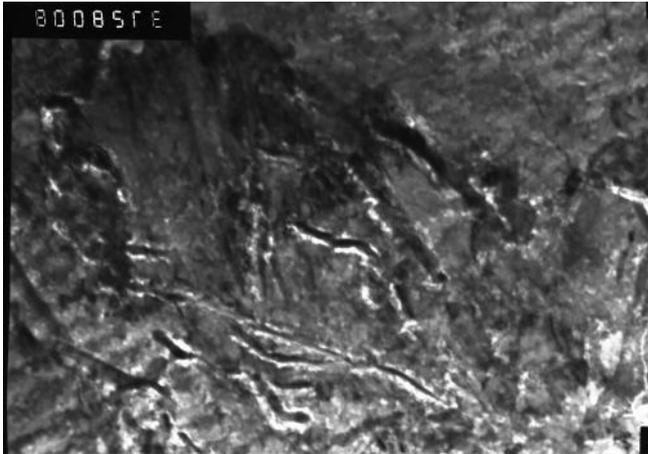
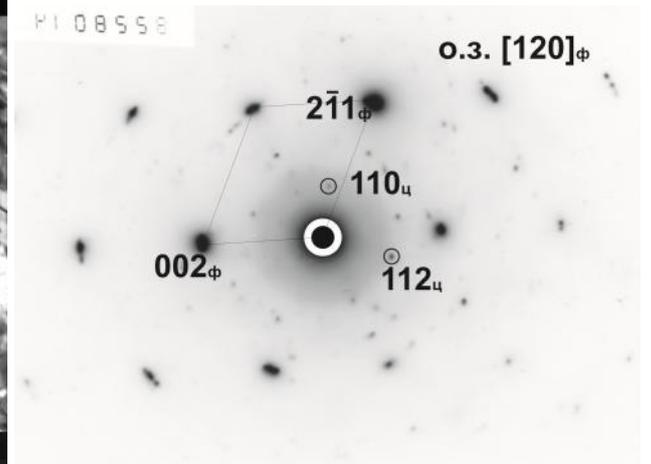
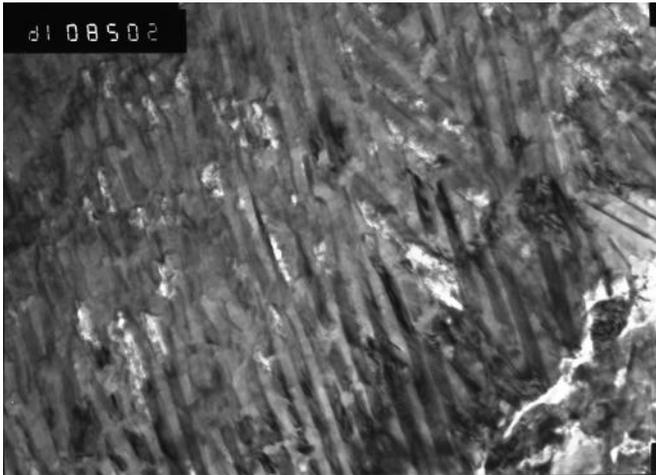


-5° / ; -10° / , -20° / , -40° / ; -70° / , 500

. 5.7.3.3.3.1 -

13
800° , 0,5 .

900° , 0,5 .
.

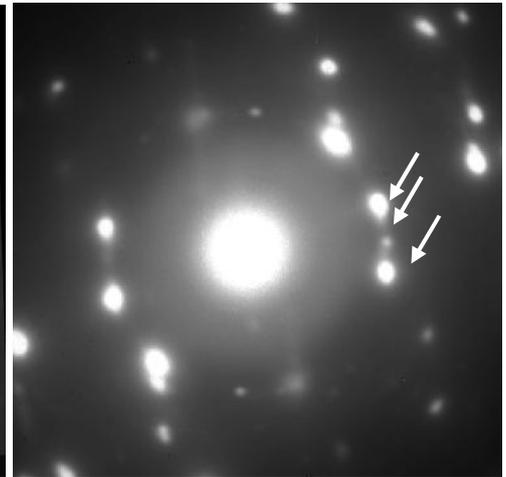
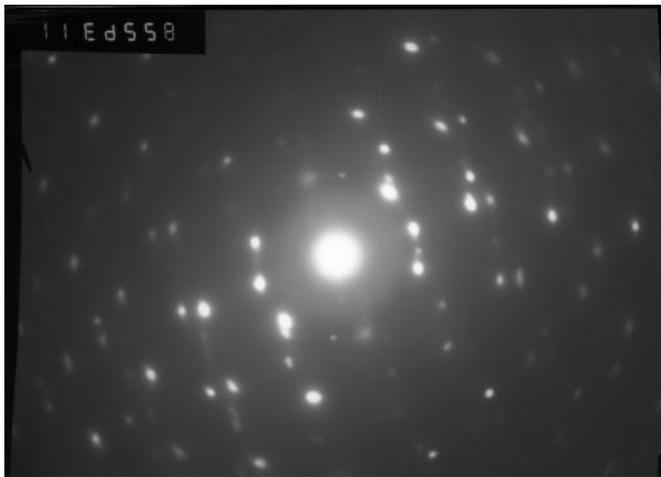
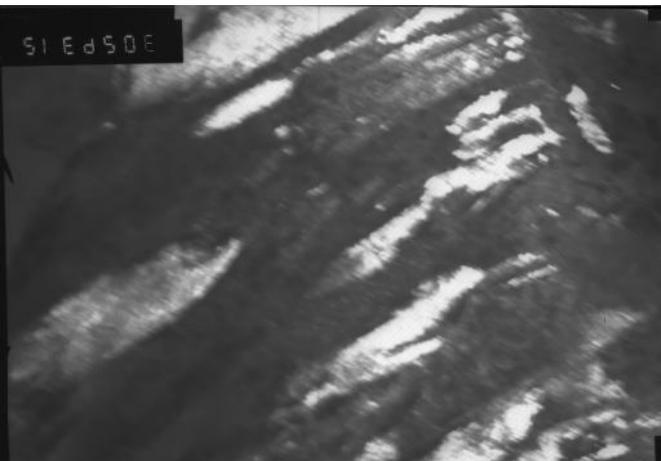
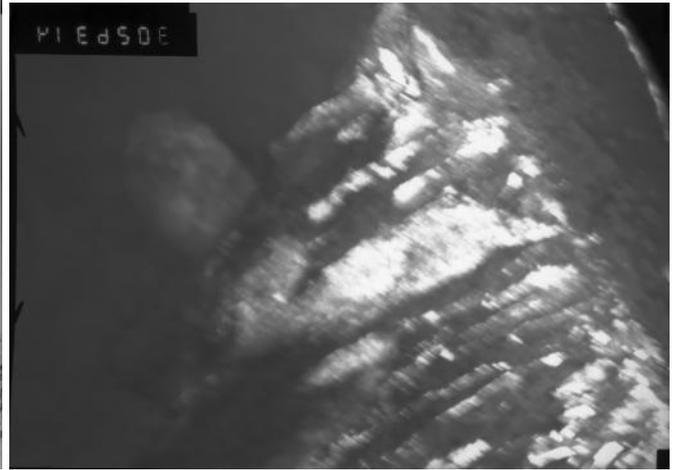
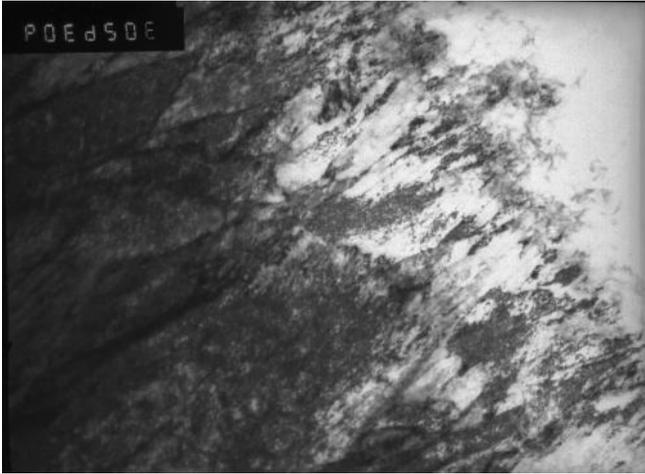


- , 50000;
- ;
- , 37000;
-

112 .5.7.3.3.3.2 , 37000.

.5.7.3.3.3.2 – 13
 , 800° , 0,5 .,

900° , 0,5 .,
 10° /

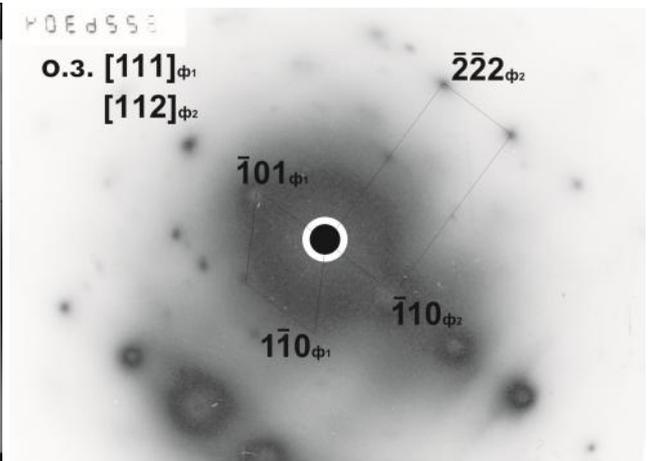
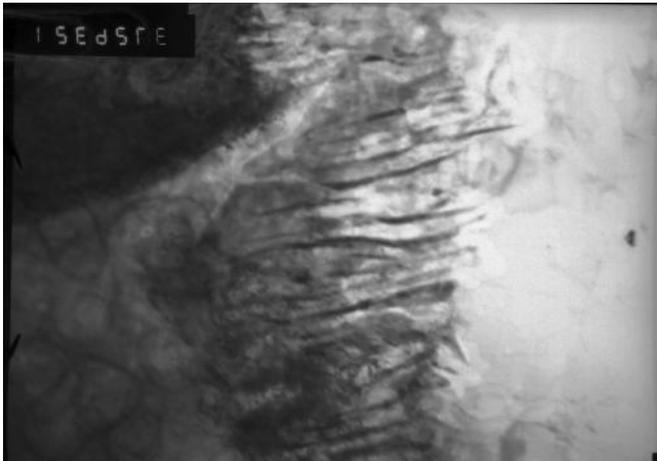
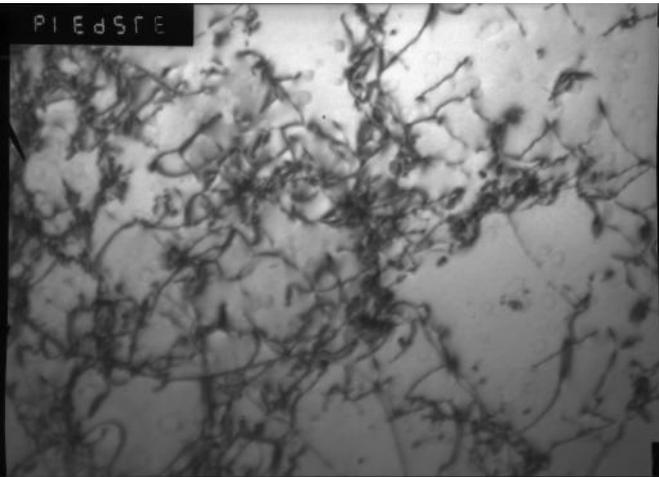
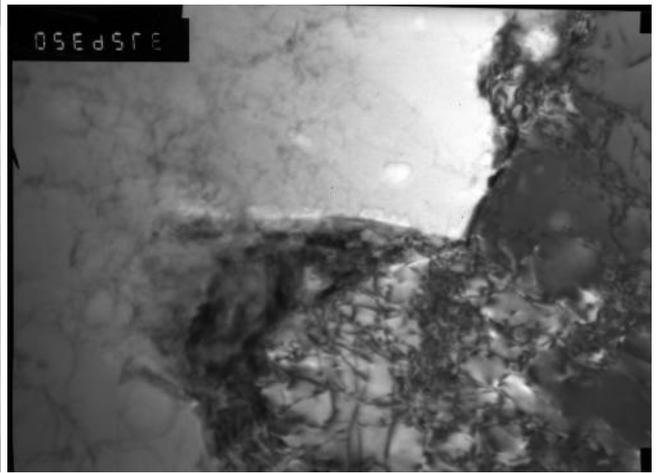
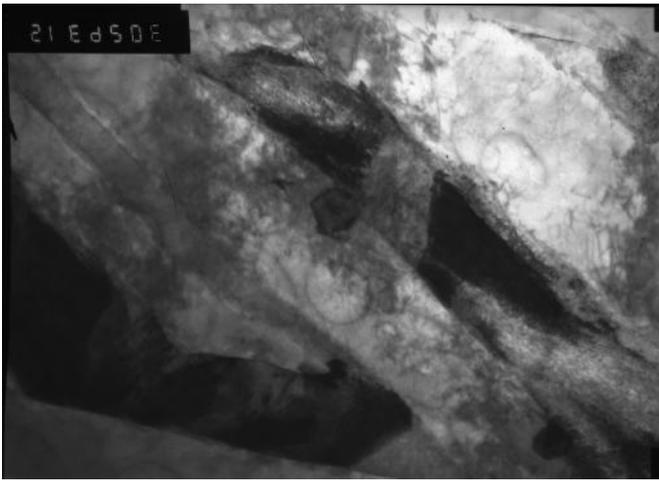


— , 30000;
 , , —
 — ;

. 5.7.3.3.3.3
 , 30000;

. 5.7.3.3.3.3 — 13
 , 800° , 0,5 ..

900° , 0,5 ..
 40 ° /



— , 30000;
 , , - , 37000
 — , 50000
 — ;

.5.7.3.3.3.4 – 13 900° , 0,5 .,
 , 800° , 0,5 ., 40 ° /

5.7.3.3.4

13

:

1050 Ê -

; 900 Ê -

,

760 Ê

0,5 .

13

760 °

30 .

$\alpha \rightarrow \gamma$

.

,

,

- 800 830° .

4 [90],

760°

«

»,

-

.

,

« » (

)

«

» (

)

. « »

.

,

« »

,

-

.

30

760°

«

»

,

,

,

,

,

.

,

,

,

,

,

,

,

-

,

(

. 5.7.3.3.4.1 ,).

,

13

5 10 ° /

,

« »

,

«

»,

(. 5.7.3.2.5)

5 20 ° / . 5.7.3.3.4.2 ,

760°

(760°)

(. 5.7.3.3.4.3 ,). . . 5.7.3.3.4.2 -

α-

760°

()

(. 5.7.2.3, 5.7.2.4)

760 °

5.7.3.3.4.3 , , 5.7.3.3.4.2 -)

(. 5.7.3.3.4.3 ,) .

:

(. 5.7.3.3.4.4, 5.7.3.3.4.5),

40 ° /

(. 5.7.3.3.4.6 , 5.7.3.3.4.7 ,) .

(200) (

. 5.7.3.3.4.6 , 5.7.3.3.4.7) .

. 5.7.3.3.4.8

0,2

0,1-

(. 5.7.3.3.4.8) .

. 5.7.3.3.4.9 , ,

(. 5.7.3.3.4.10 , ,) .

5.7.3.3.4.10),

, 5-10 ° .

, 13

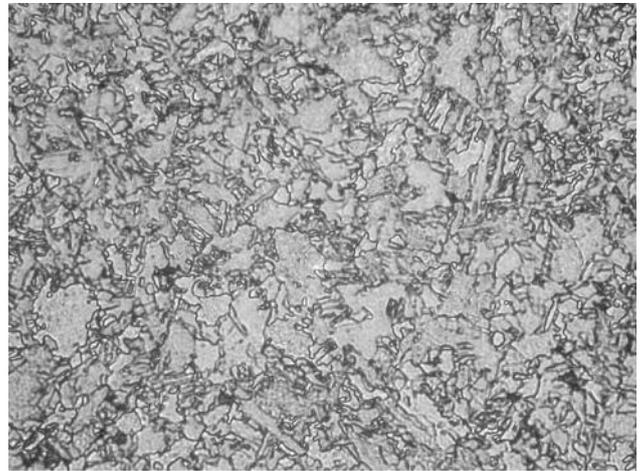
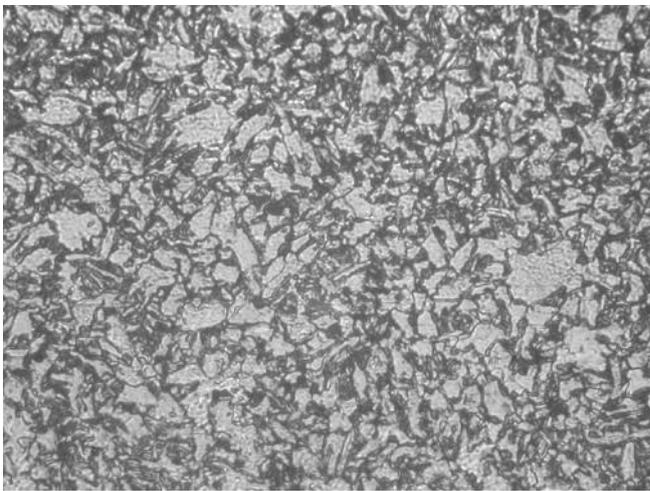
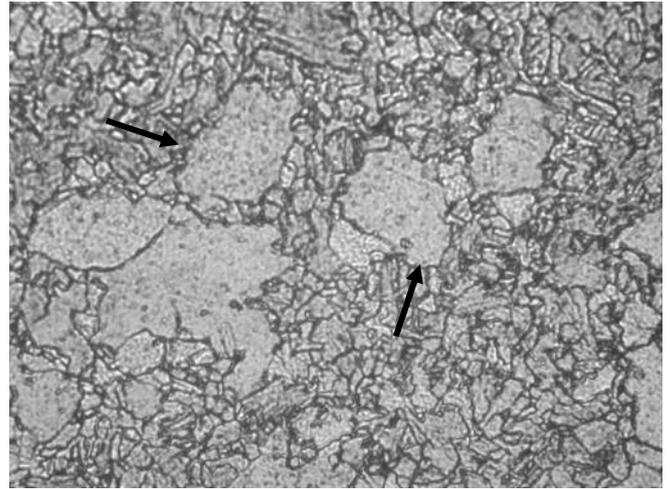
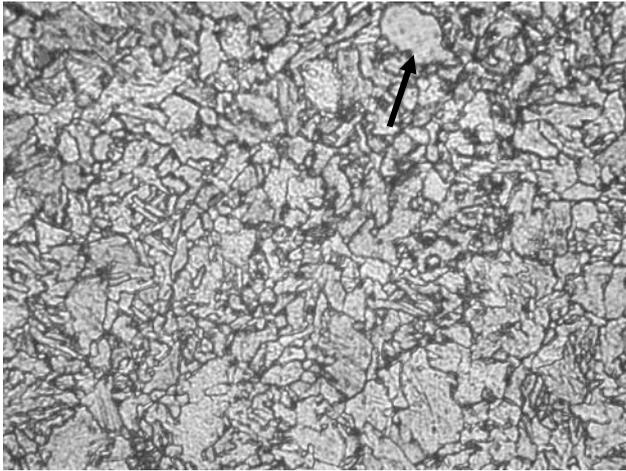
760°

- ,

,

α-

.

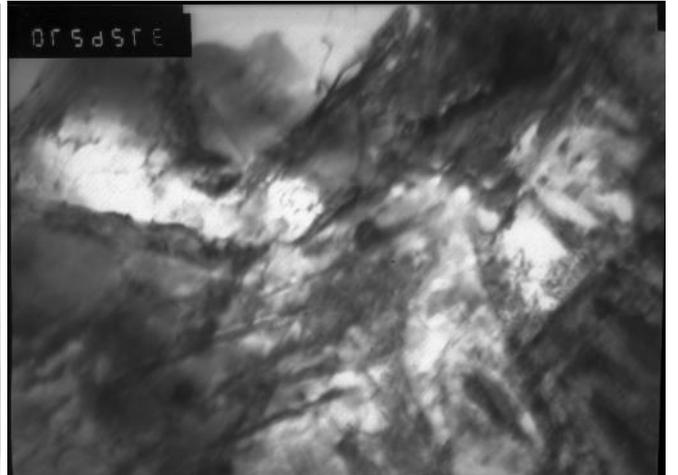
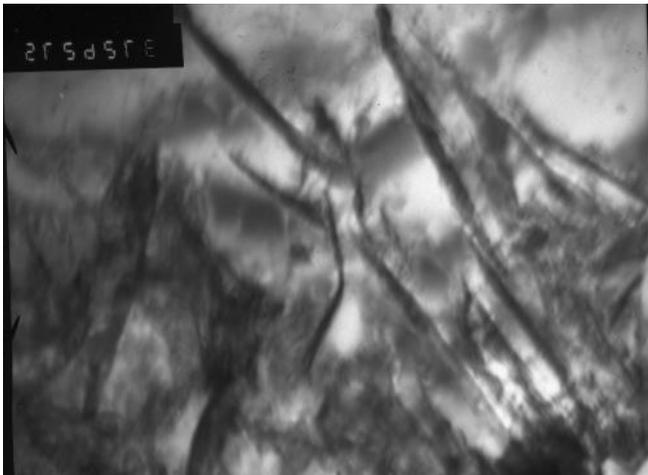
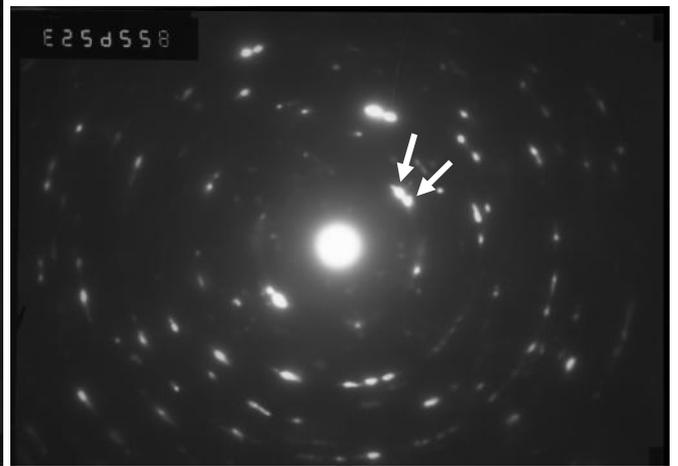
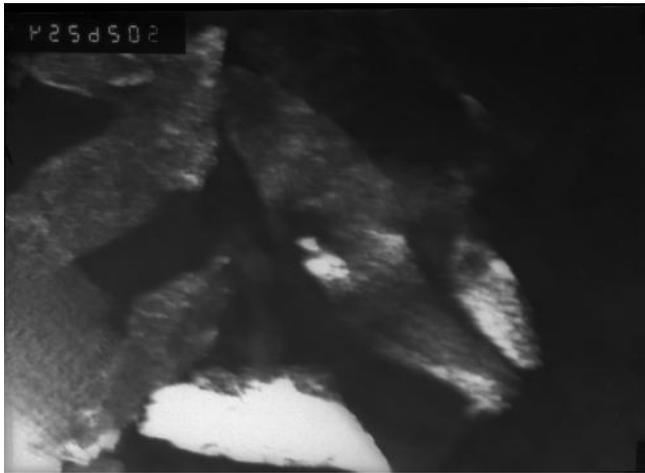
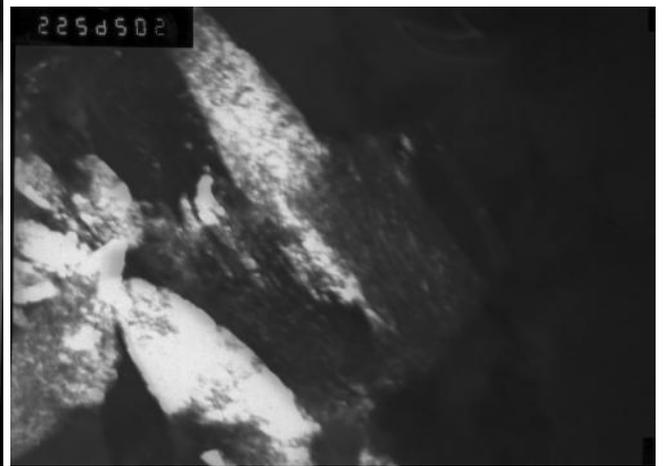
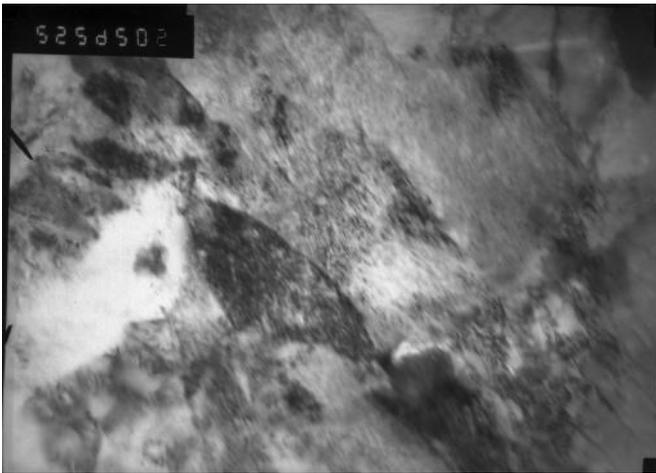


, -5° / , -10° / , -20° /

.5.7.3.3.4.1 -
 , 760° , $0,5$.

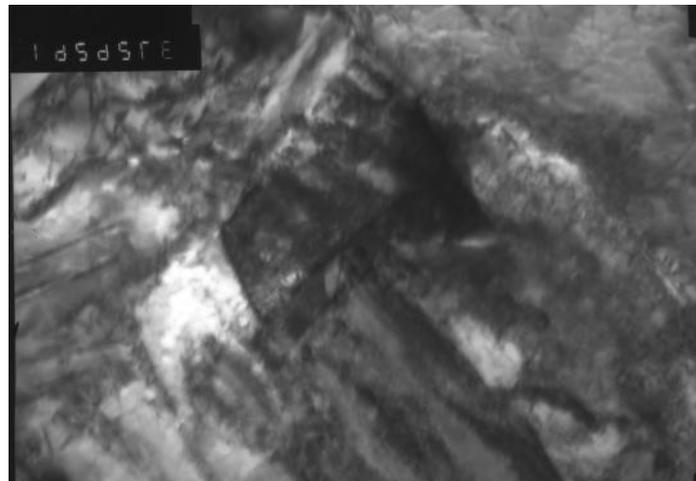
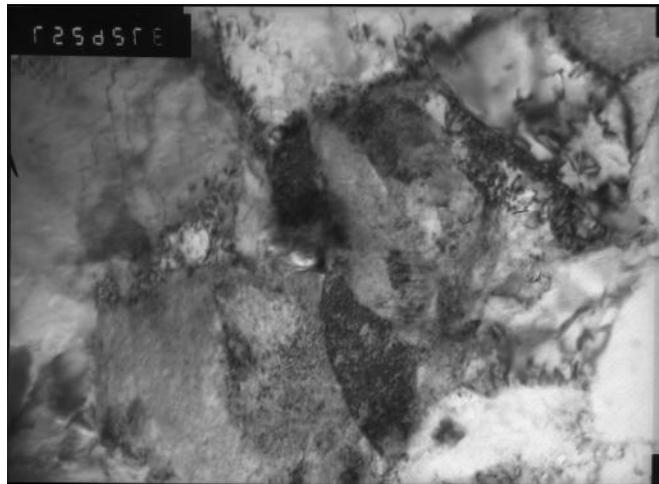
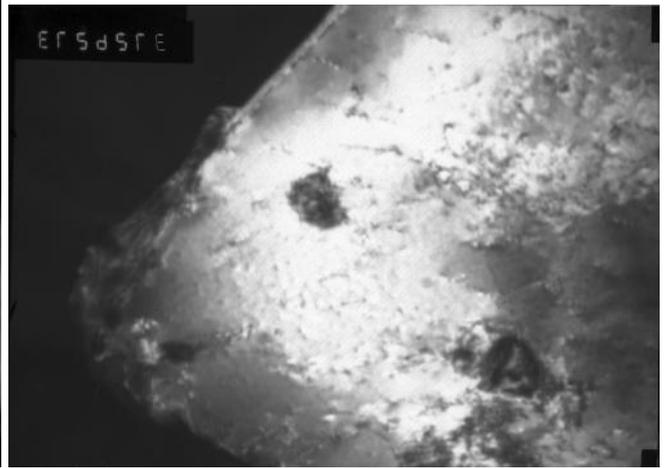
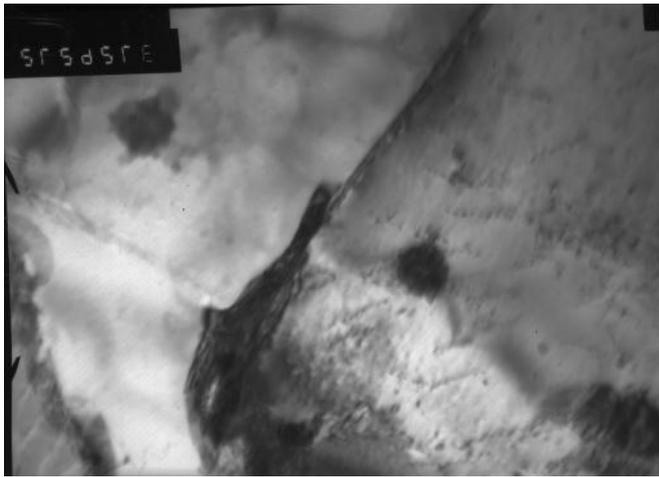
13

900° , $0,5$.,



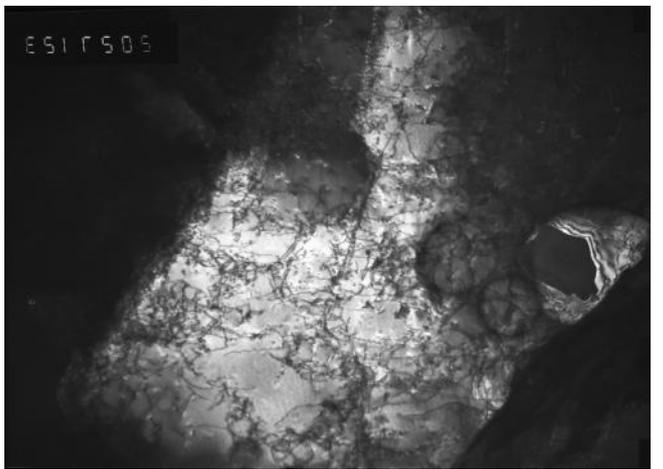
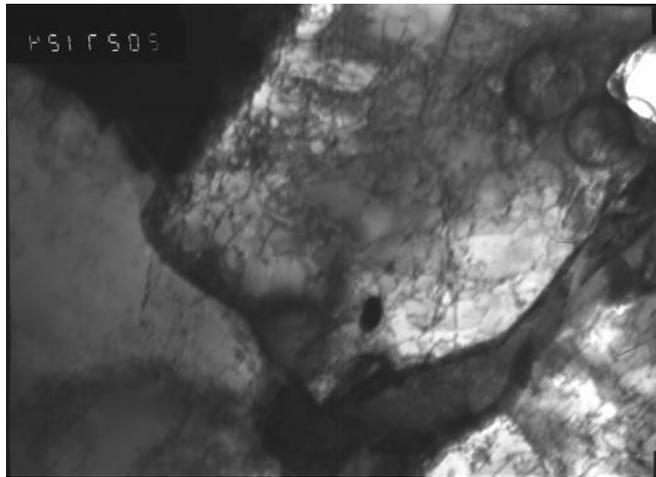
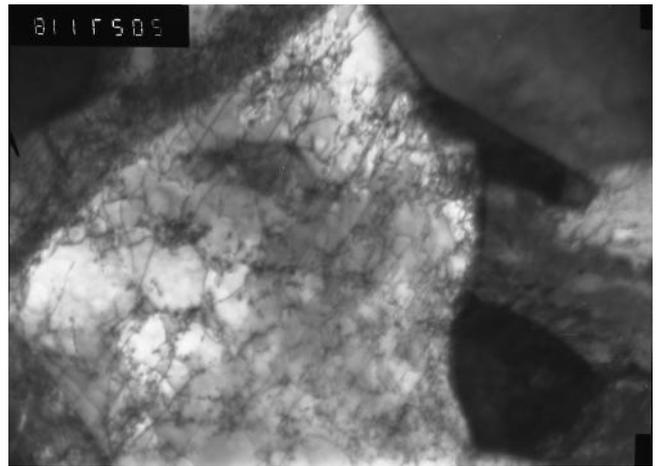
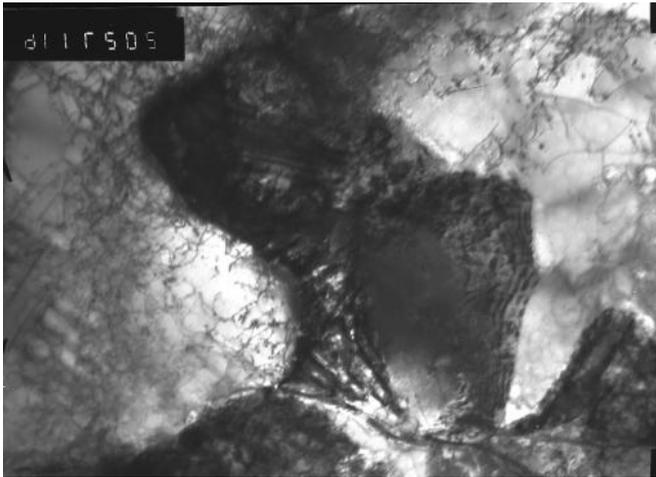
- , 50000;
 - . 5.7.3.3.4.2 , . 50000;
 - . 5.7.3.3.4.2 , 50000
 , - , . 37000

 . 5.7.3.3.4.2 - 13
 760° , 0,5 .. 900° , 0,5 .. ,
 10° /

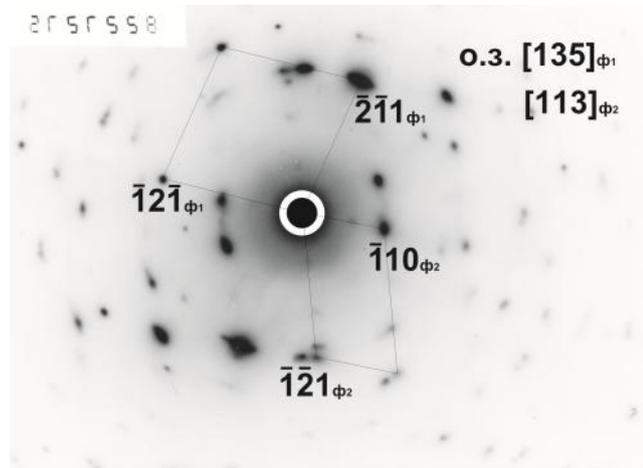
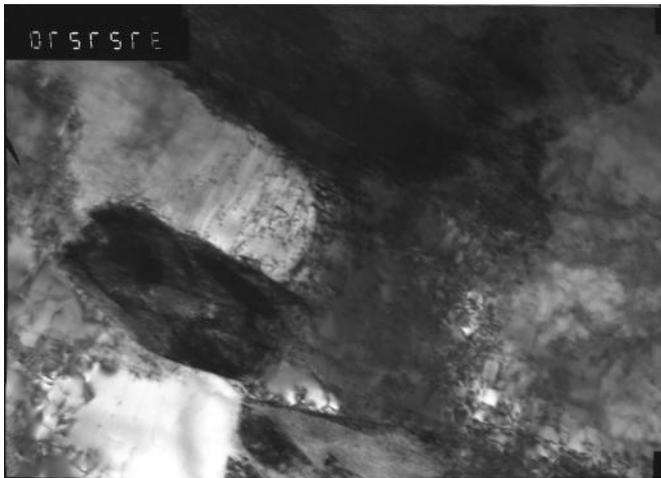
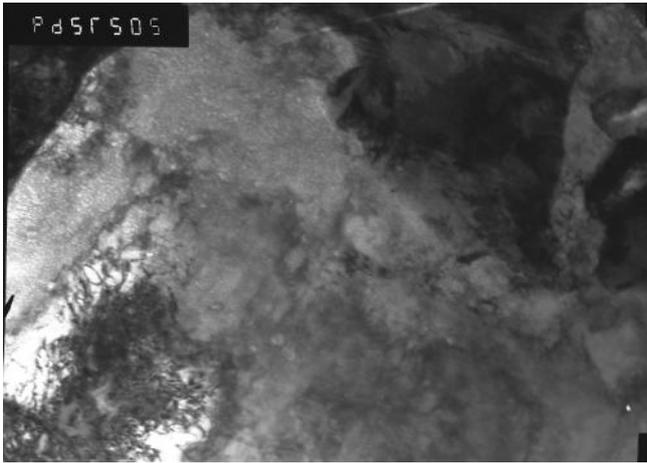


- , 37000;
 - . 5.7.3.3.4.3 , 37000;
 - , 37000;
 - . 5.7.3.3.4.3 , 37000
 - , 37000

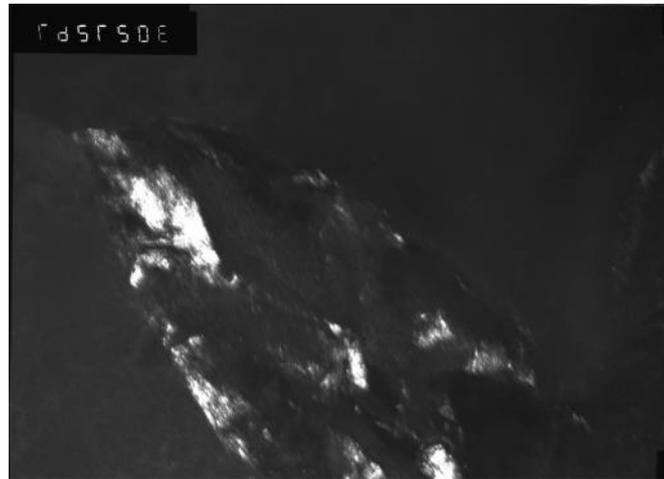
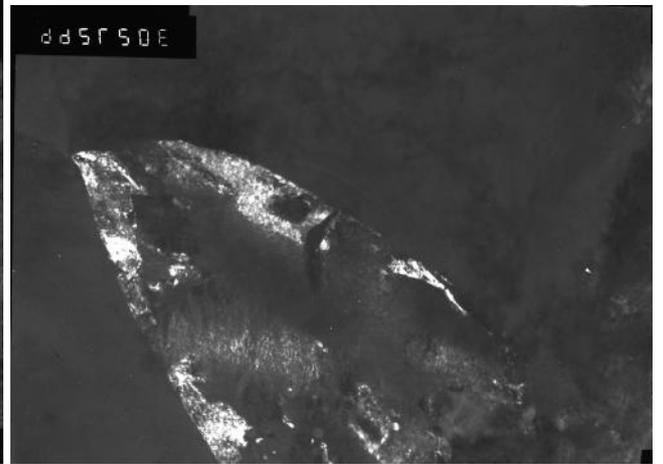
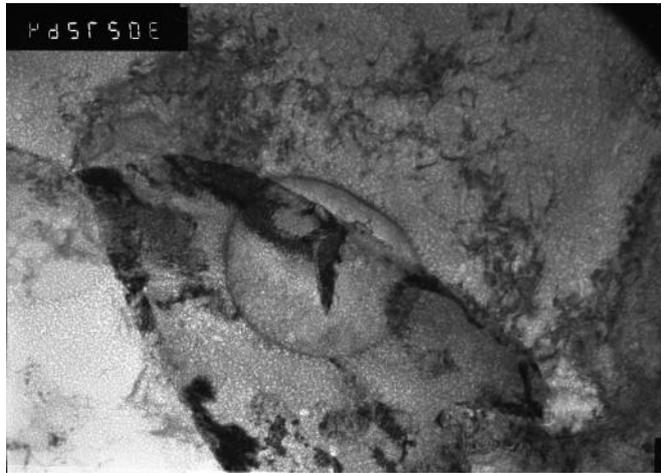
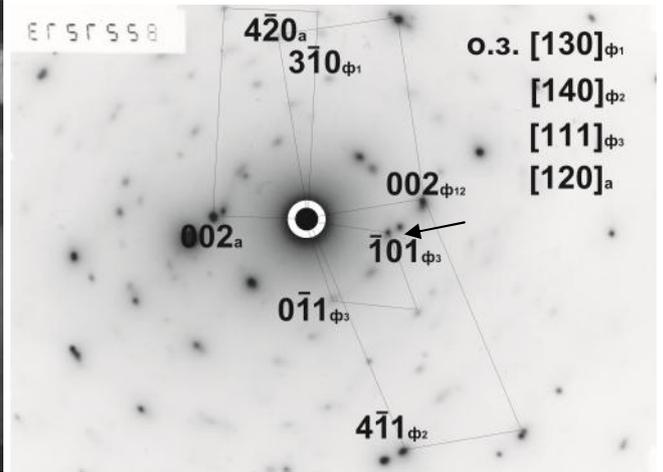
. 5.7.3.3.4.3 - 13 900° , 0,5 .. ,
 760° , 0,5 .. 10° /



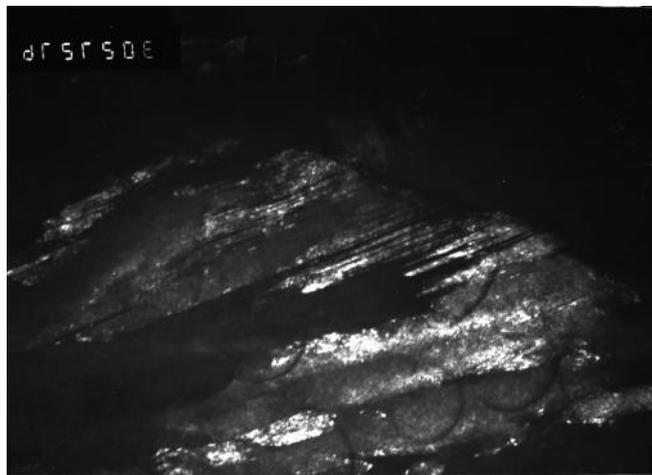
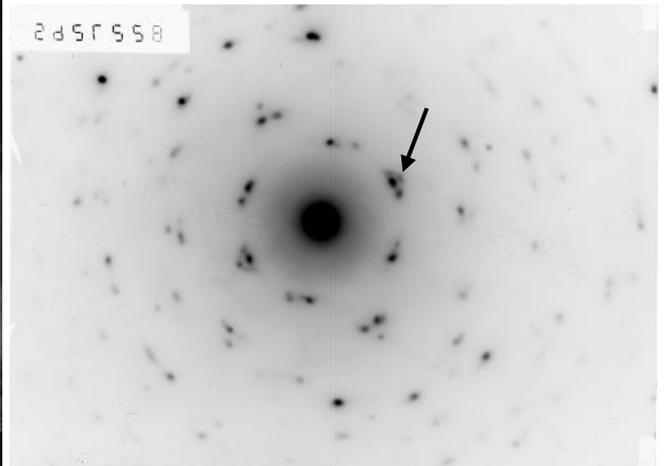
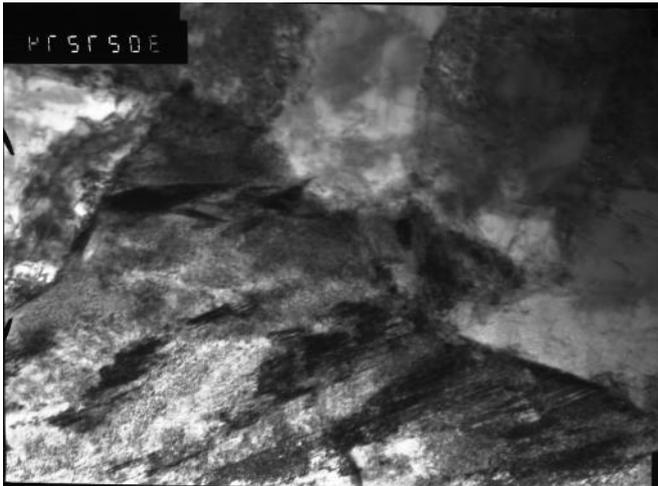
, , - , 20000;
 - . 5.7.3.3.4.4 , 20000
 . 5.7.3.3.4.4 - 13 900° , 0,5 . ,
 760° , 0,5 . , 20° /



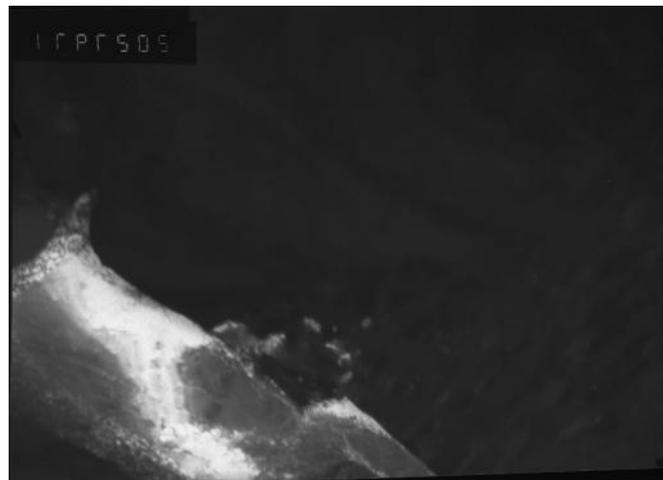
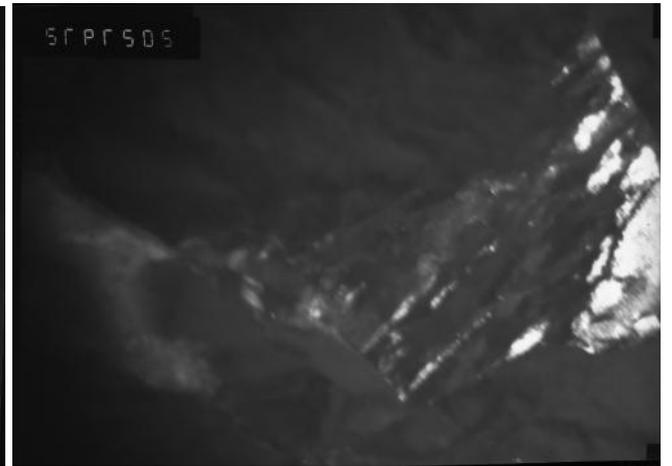
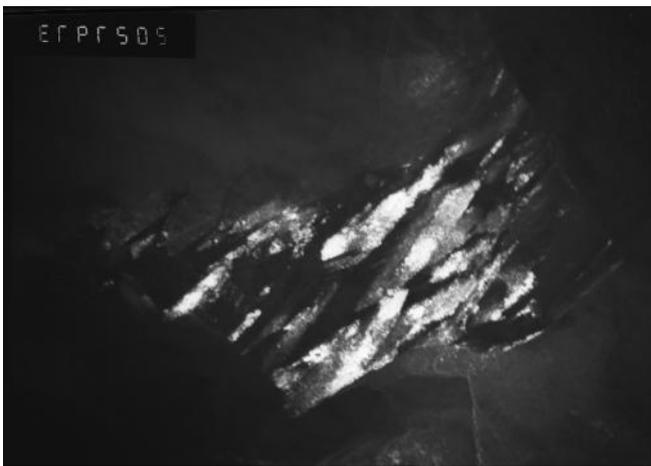
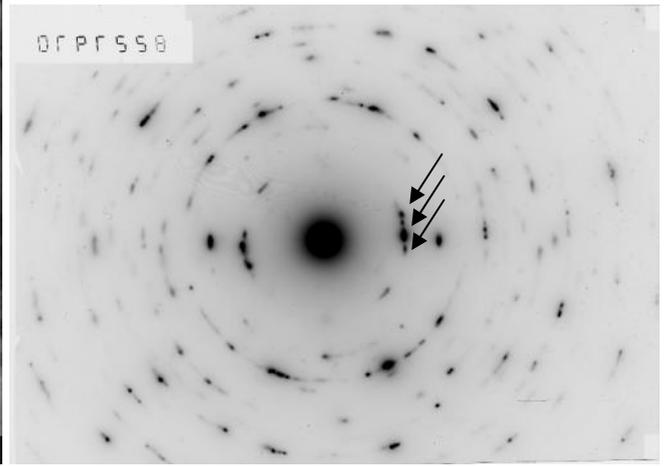
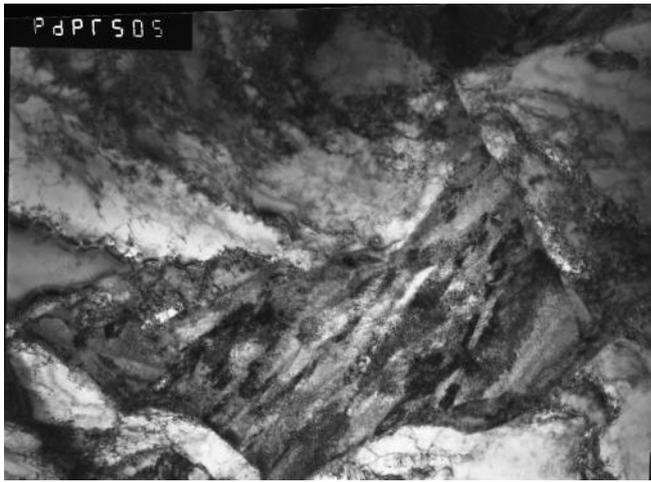
— , 20000;
 — , 30000;
 — , 30000;
 — . 5.7.3.3.4.5 $\bar{1}2\bar{1}$, 37000;
 — ;
 . 5.7.3.3.4.5 — 13 900° , 0,5 .. ,
 760° , 0,5 .. 40° /



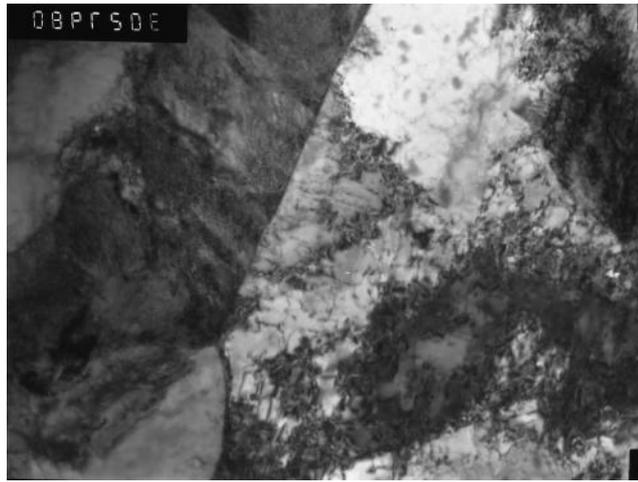
- , 20000;
 - ;
 - , 30000;
 , - . 5.7.3.3.4.6 $\bar{4}22$, 002, 30000;
 . 5.7.3.3.4.6 - 13 900° , 0,5 .. ,
 760° , 0,5 .. 40° /



- , 30000;
 - ;
 - .5.7.3.3.4.7 , 30000;
 .5.7.3.3.4.7 - 13 900° , 0,5 .. ,
 760° , 0,5 .. 40° /



— , 20000;
 - ;
 , , - . 5.7.3.3.4.8 , 20000;
 . 5.7.3.3.4.8 - 13 900° , 0,5 . ,
 760° , 0,5 . 70° /

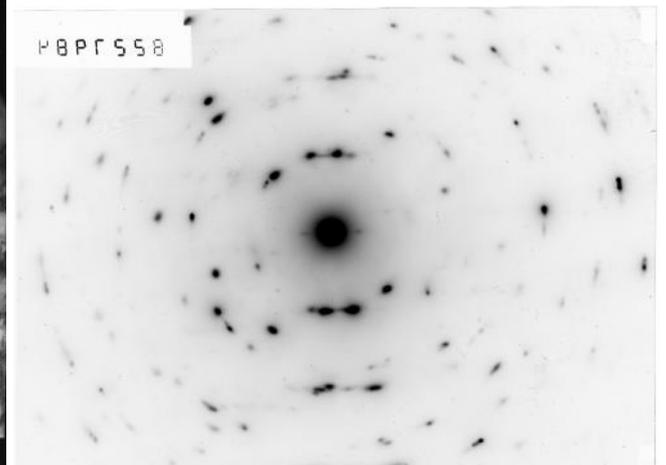
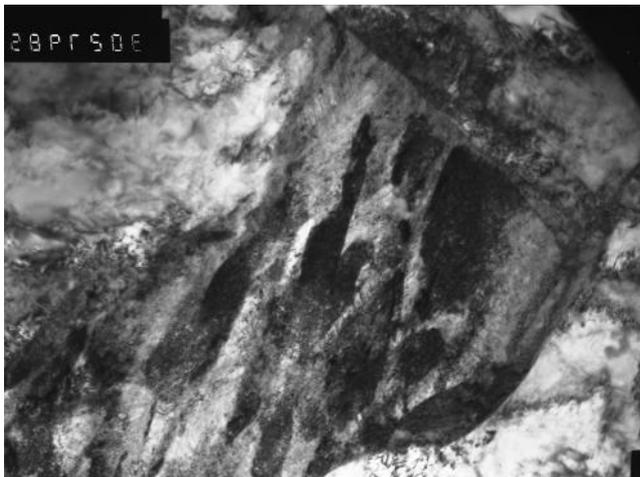
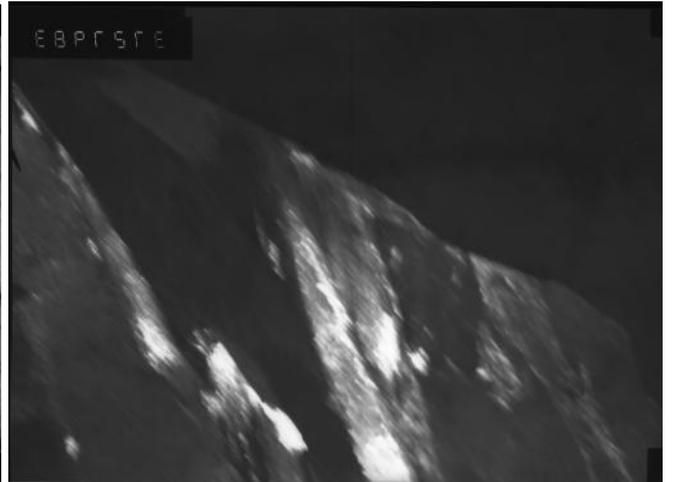
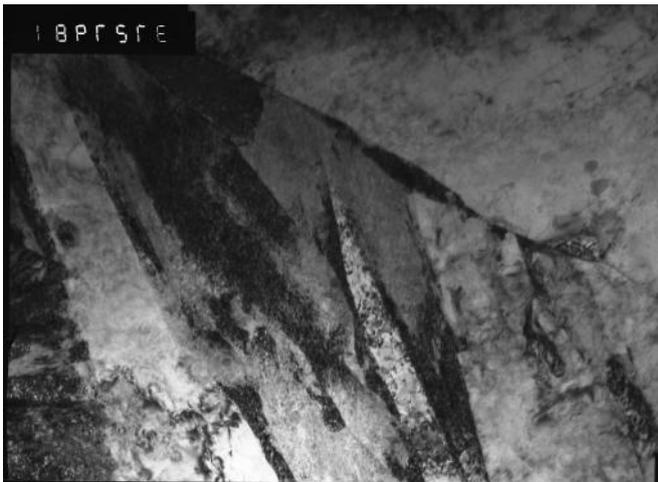


.5.7.3.3.4.9 –
760° ,0,5 ..

13
70° /

900° ,0,5 ..

,



- , 37000;
 - .5.7.3.3.4.10 , 37000;
 - , 30000;
 - ;
 .5.7.3.3.4.10 – 13 900° , 0,5 .,
 760° , 0,5 ., 70° / ,

5.7.4

1. ,
13 . 900 °
13 -

2. 13
0,1 ° / , $\alpha \rightarrow \gamma$

3. ,
13

4.

830 ° , 800 ° 760 (755) °
5, 10, 20, 40 70 ° / . , 13
830 ° 760 °
(5-10 ° /) Γ_3 .
(40-70 ° /), ,

5. 13

5, 10, 20, 40 70 ° / . ,

800 ° 5 30

(40-70 ° /);

70 ° /

γ→α

α→γ

800 °

6.

13

20 ° /

800 ° 760 °

(40 %

760 °),

.

.

13 .

6.1.

6.1 – 13

, %										
C	Si	Mn	S	P	Cr	Ni	Cu	Al	N	V
0.16	0.3	0.53	0.012	0.007	0.60	0.05	0.06	0.04	0.007	0.06

1. 600 ° ,
 520 ° KCV⁻⁸⁰ ,
 755 – 860 °
 () ;
 2. (580 – 700 °)
 KCV⁻⁶⁰ ,
 800 ° 520 ° .
 1050,
 900 ° , 30 .
 755 , 770 , 800 , 830
 860 ° , 40
 600 ° 70
 520 ° ,

520 °

1,1 .

520 °

±1,5°

±0,5°

2

900 ° ,

800 ° () ,

40

6

580 ° 700 °

70 ,

520 ° 2-

HB₃₀₀₀

KCV⁻⁸⁰

6.1

4 (. 4.3.1)

13

740, 755 ° . .

() ,

V⁻⁸⁰

:

)

;

) ()

, V⁻⁸⁰.

, 600° .

... [56],

, 500 – 550° . , 35

() ,

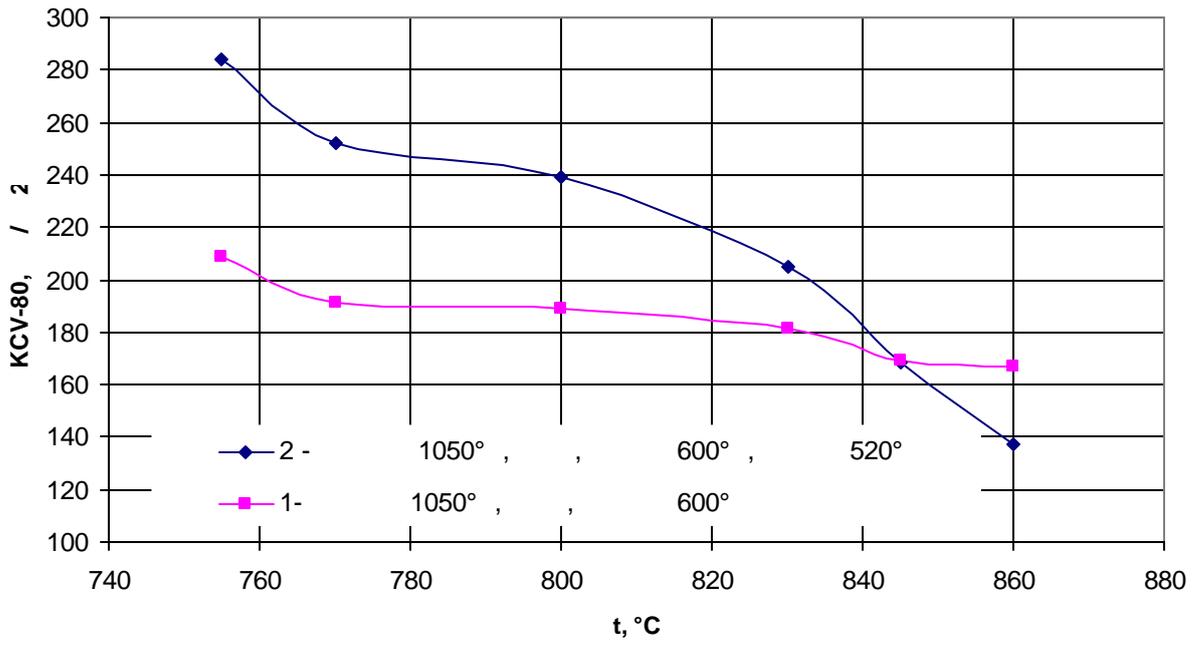
13 600° – ,

520° .

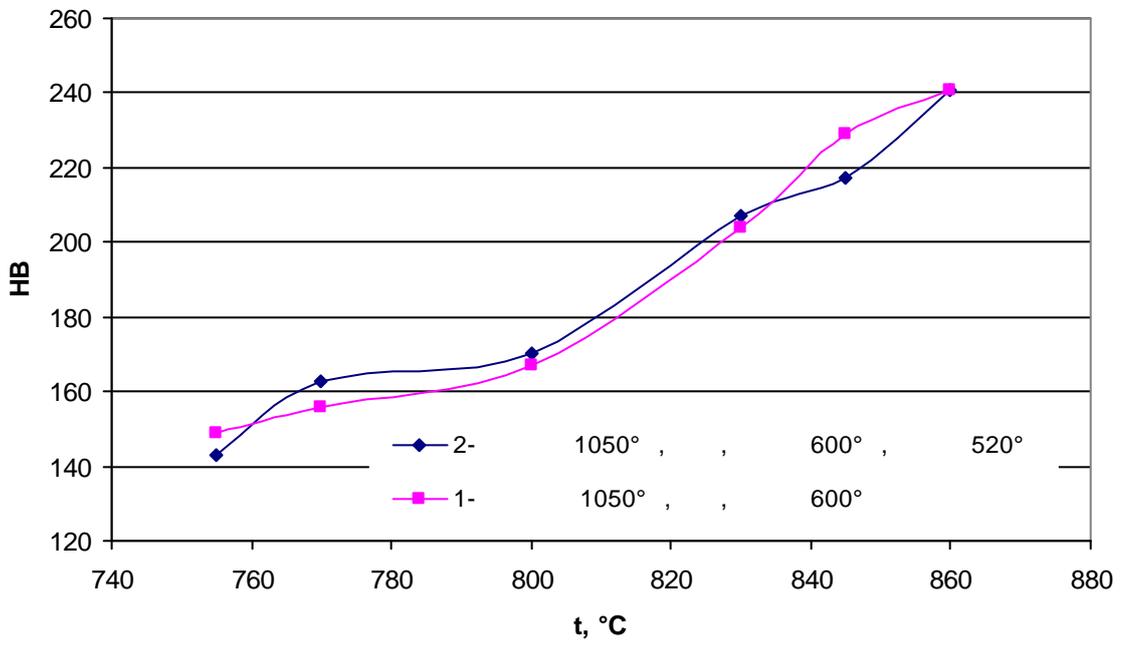
600° 600 + 520

° . 6.1.1, . 6.1.2

, , , .



6.1.1 – 600° (1) 600+520° (2)
1050°



6.1.2 – 600° (1) 600+520° (2)
1050°

[94].

« » -

« ».

600 °

600 ° ,

520 °

() 600 °

[95, 96]

0,005 – 0,08%

0,003 – 0,008 % .

600 – 620° [94].

520 ° ,

520 °

(

),

600 ° .

T

t,°

[97]: $L=T \cdot (20+\lg t)$.

620° =893

70 (1.17 .),

L= 17920.

520° =793

400 ., . . 200

. 70-

560 °

12-

520

° . . .

,

250

60°

Fe₃C.

[98],

900 °

: 800 830 ° .

600 ,

600+520 ,

600+520+600 ° ,

620 520 °

600 °C

6.1.1.

6.1.1 –

13 ,

900 ° ,

3 .

, °	I- 600° .		II- 520°		III- 600°	
	HB ₃₀₀₀	KCV ⁻⁸⁰ / 2	HB ₃₀₀₀	KCV ⁻⁸⁰ / 2	HB ₃₀₀₀	KCV ⁻⁸⁰ / 2
800	175	231	160	247	179	229
830	197	216	179	243	197	220

, 1050 ° :

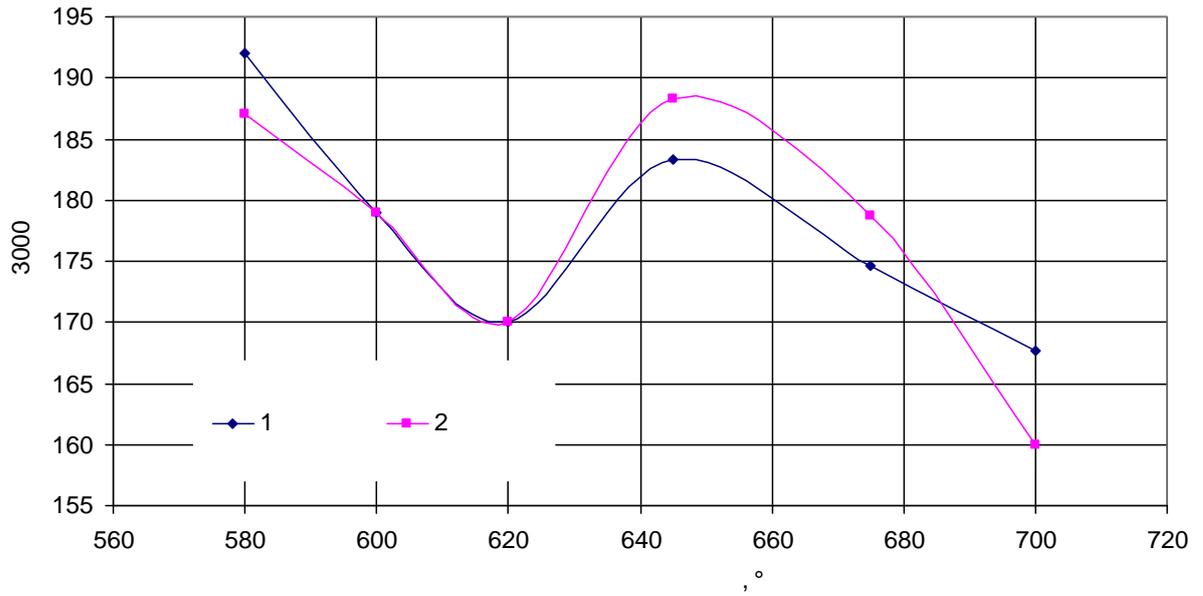
600 ° ,

600 520 ° ,

(800 °)

(520 °).

. 6.1.3.



. 6.1.3 –

, 800° (), 900°
 (1) 520° (2);

580 620°

620°

645° ,

[99],

[98],

0,8%.

[99, 100]

1%.

0,6 %.

VC

[101, 102] 0,02%, VC

0,06% V. ,

620°

640° (. 6.1.3).

520 °

580 °

600 620 ° ,

645

680 ° .

Fe-C, PQ

520°

VC , 580° ,

Fe₃C

VC,

520 ° ,

645

675° . ,

600 620°

:

700 °

VC

(.6.1.3). ,

700 °

. 6.1.4.

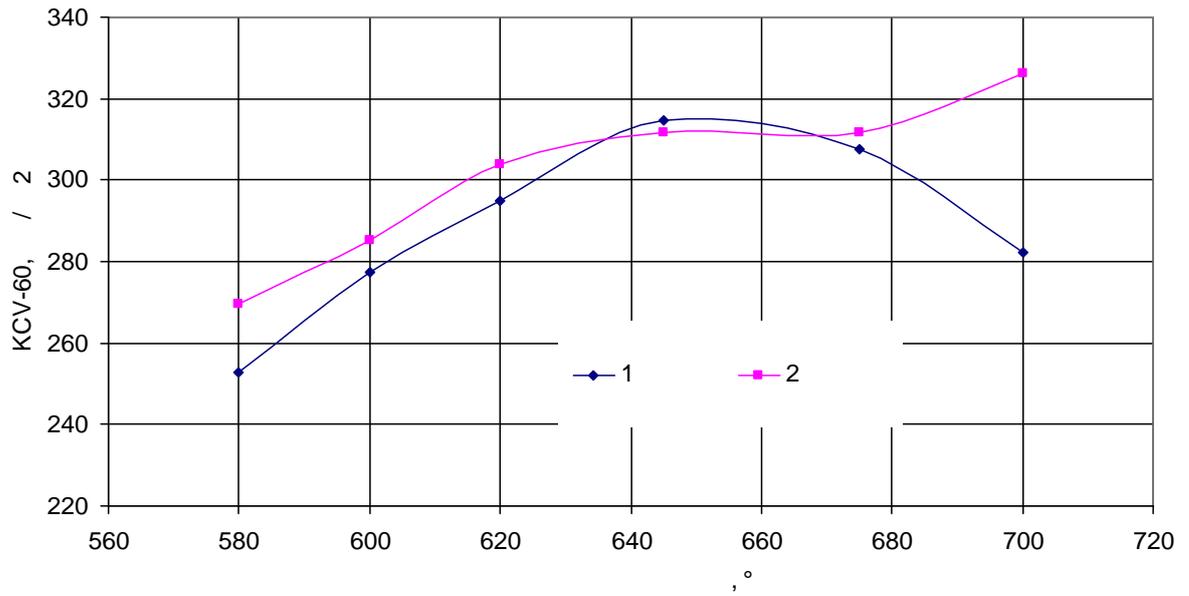
580 645 °
600°

645 ° ;

VC.

645 °

[105].



. 6.1.4 -

, (1) 800° , 520° (2); 900°

520°

, 580, 600 620° .

VC

520°

645 – 675° ,

VC,

V.

700° ,

6.2

1. 900° , 13 1050 600° , 1
2. 520° , ,
3. , ,
4. 580 – 700° 620° 645° , VC.
5. 520° 580 700° , . . VC Fe₃C

257

, ,
,

VC,

645 675° .

6.

.

580 – 620°

675 –

700°

.

700° , , - ,

VC ,

.

7

20 2

20 2 ,

20 2

1050 ° ,

30

900 ° ,

. 7.1.

;

. 7.2 , 7.2 .

[103],

60-70° .

. 7.2 .

. 7.3

70-80°

. 7.2

[103].

(. 7.2),

(.

7.3),

.

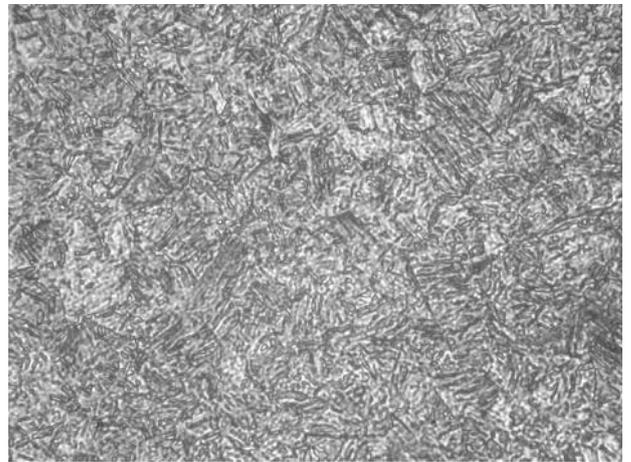
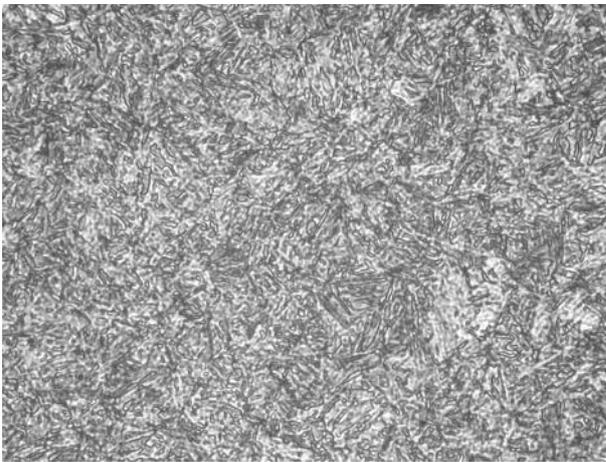
;

5-

10 . . 7.4

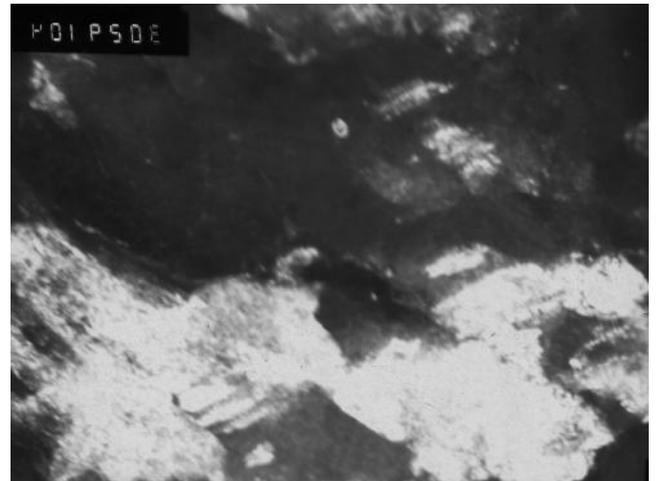
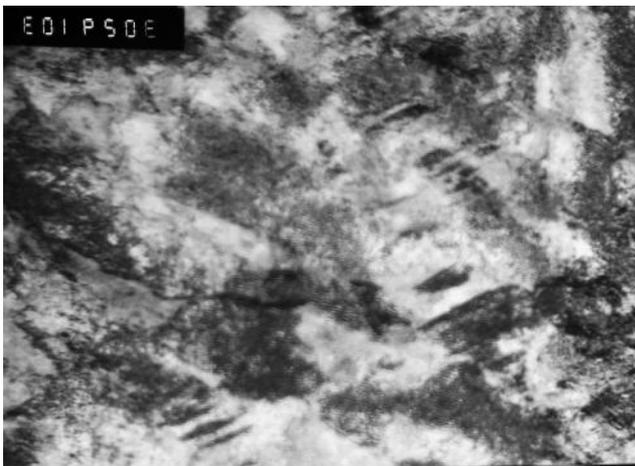
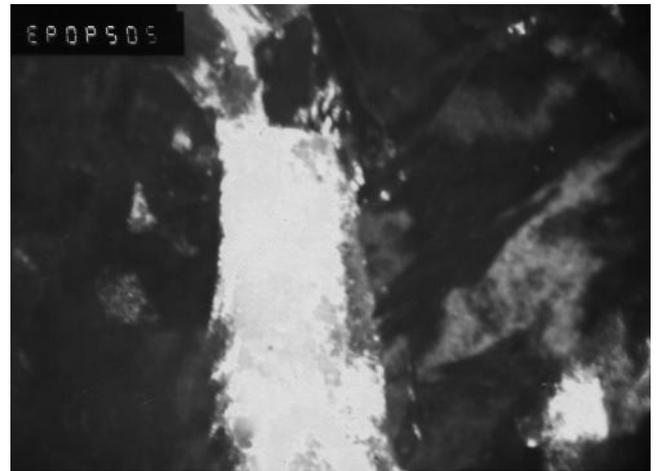
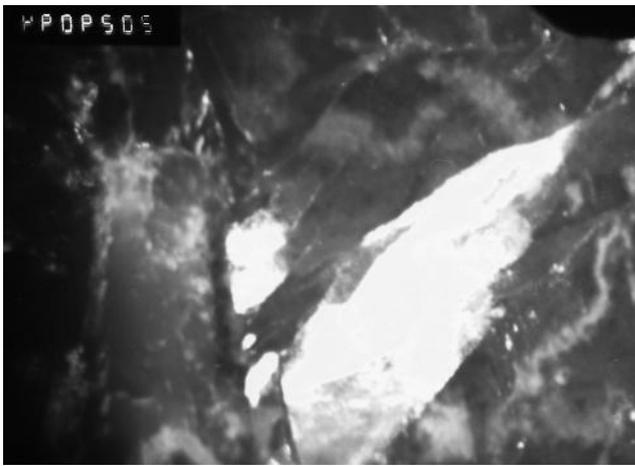
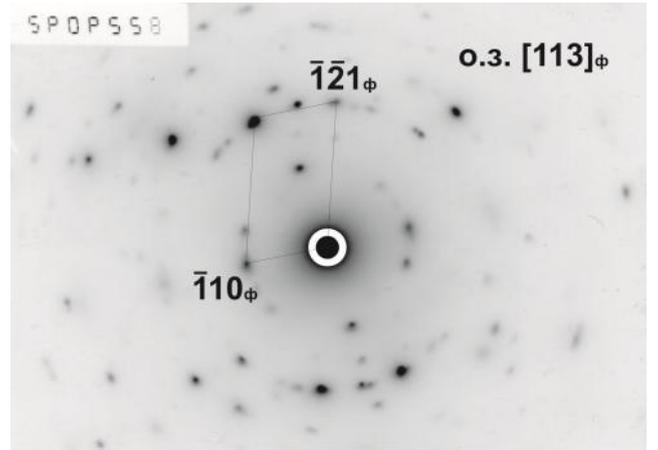
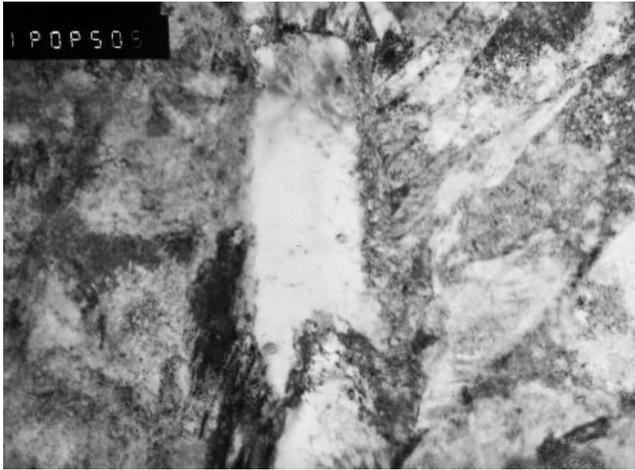
,

.

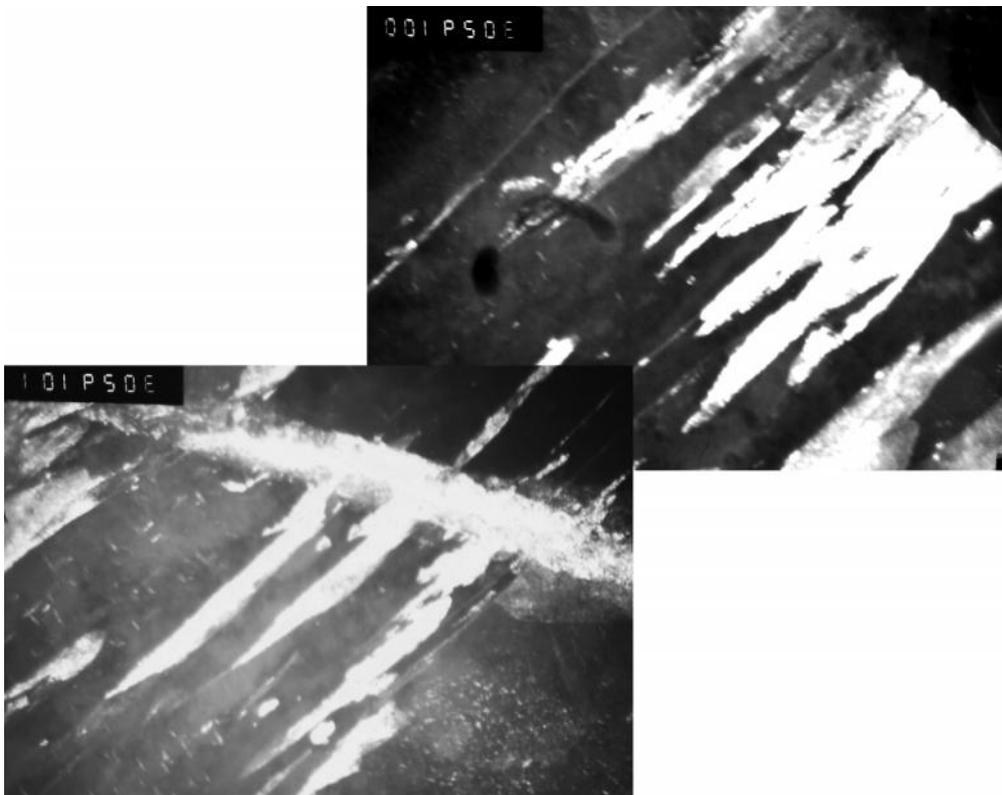
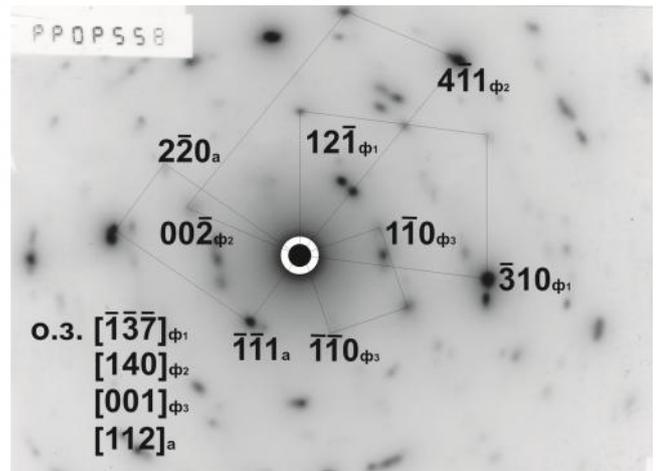
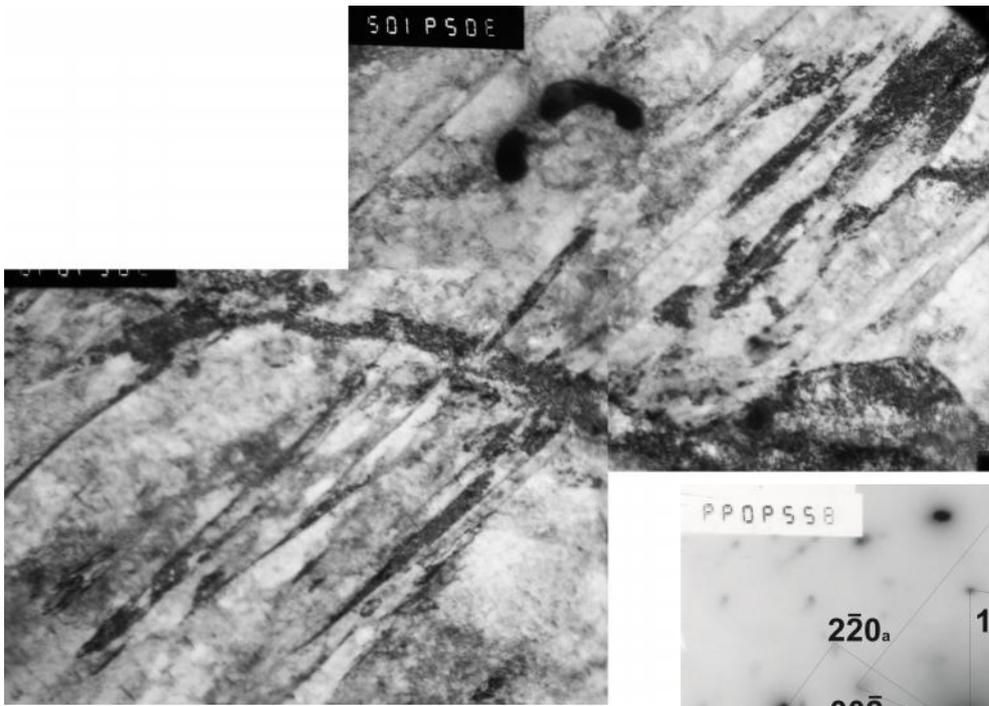


. 7.1 -
900°

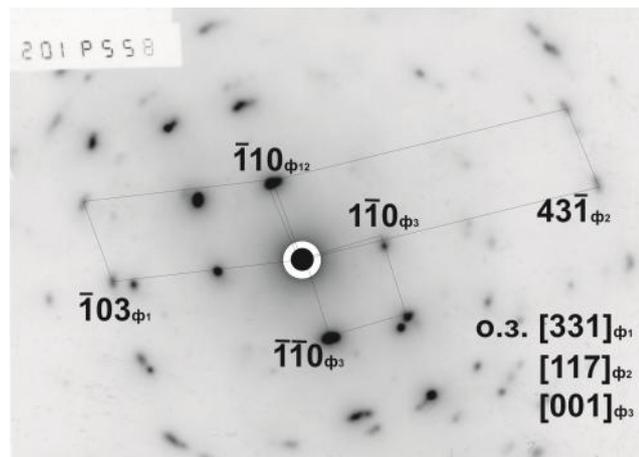
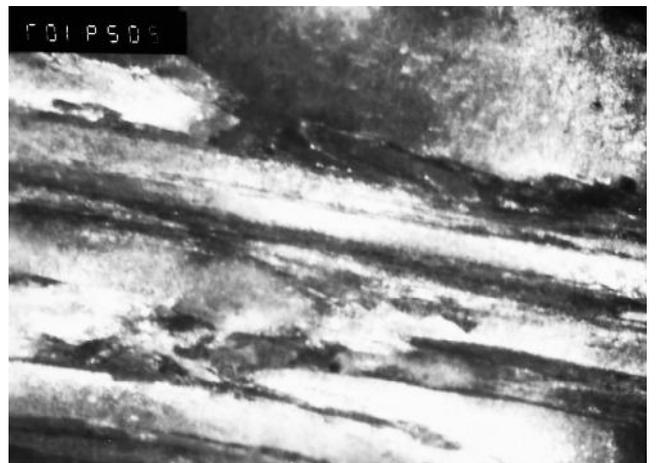
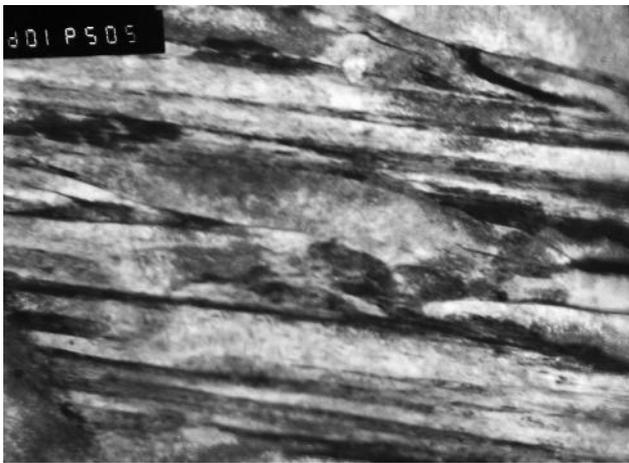
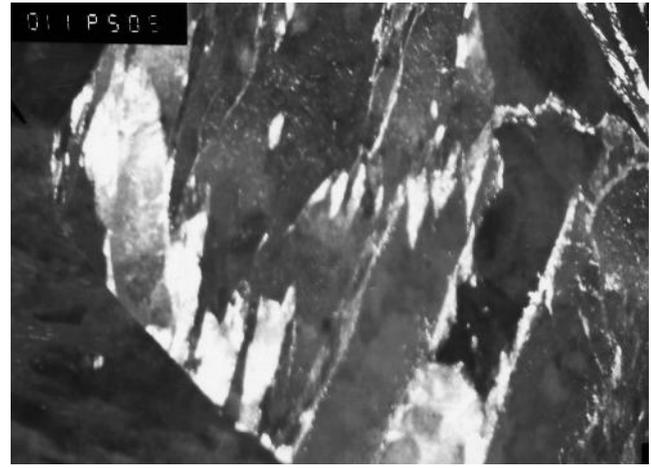
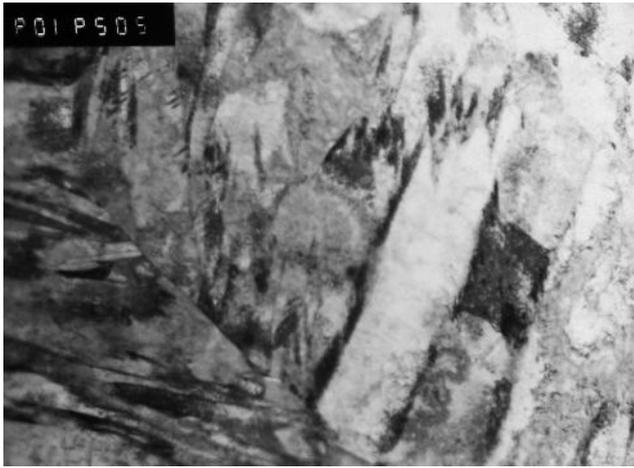
20 2
, 500.



— , 20000;
 — , ;
 — , 20000;
 — , 30000;
 — , 30000;
 — , 30000;
 . 7.2 - 20 2 (-110) 30000;
 90° :



- , 30000; - ;
 - (12-1) , 30000;
 .7.3 - 20 2 900°



, , - , 20000;
 - (-110), 20000;
 .7.4 - 20 2 90°

7.1

20 2 .

7.1.1
20 2

1 (717-728) ° ,

723 ° (. 7.1.1.1).

α→γ

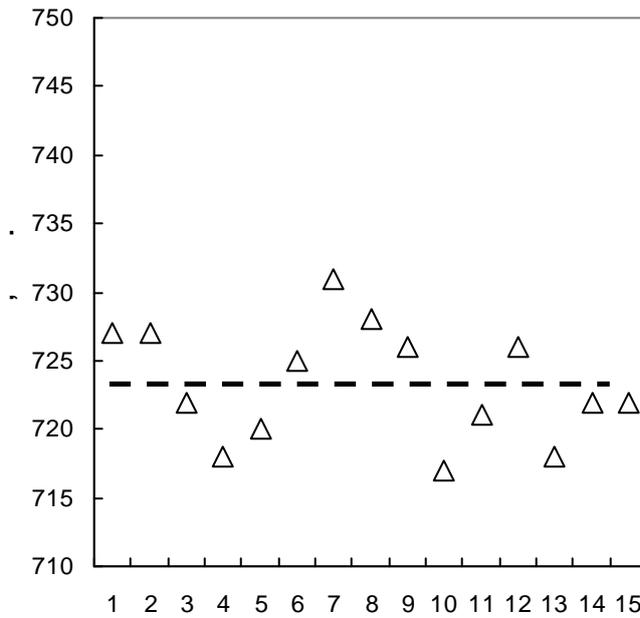
814 ... 823 ° ,

3

819 ° .

96° ,

1%/° .



. 7.1.1.1 -

1

20 2 .

20 2

3-

: 755, 800 830 ° .

1- 3

1 32

77° ,

3.

α→γ

. 7.1.1.2.

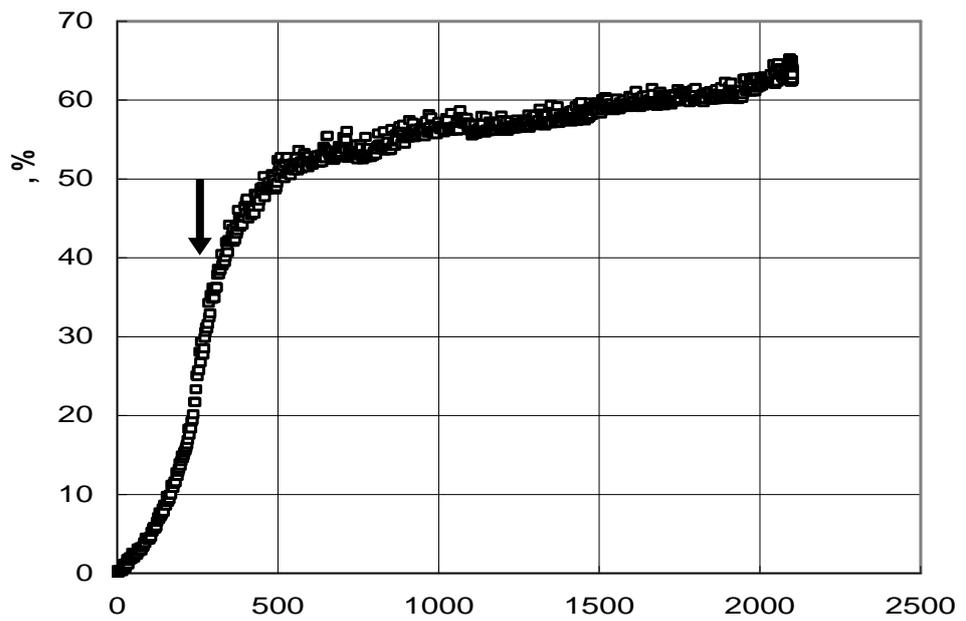
1 755 °

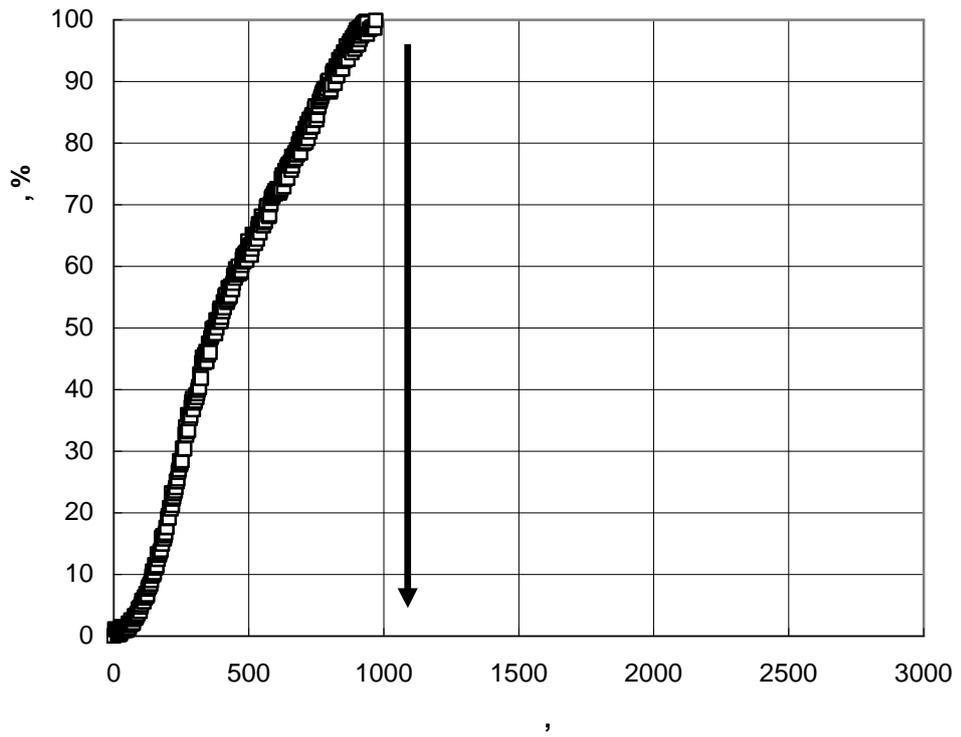
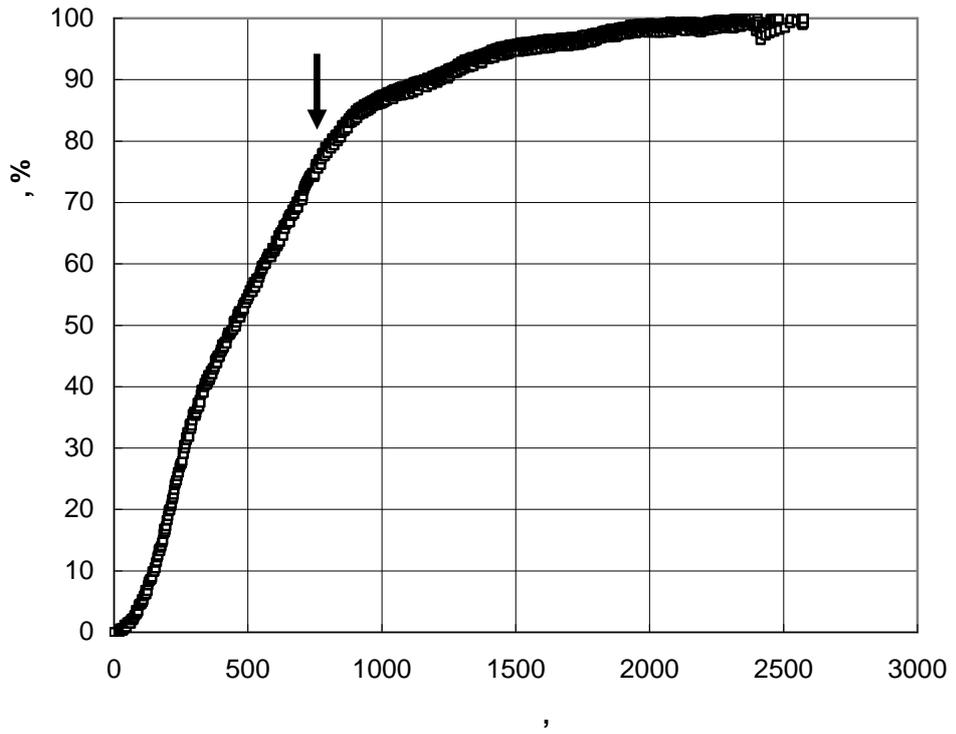
185 ;

(. 7.1.1.2). 800°
 77 % ; $\alpha \rightarrow \gamma$ 20
 10

(. 7.1.1.2). $1 \quad 830^{\circ}$ $0,1^{\circ} /$
 1000 (16) ; $\alpha \rightarrow \gamma$
 (. 7.1.1.2),

. 7.1.1.3
 $\alpha \rightarrow \gamma$ 20 2



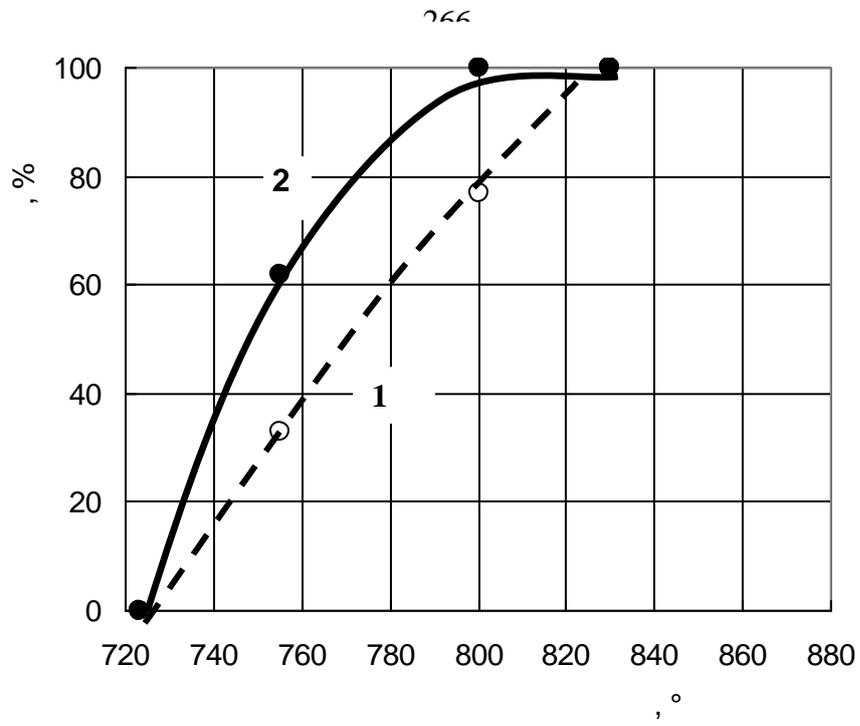


- $=755^{\circ}$; (1290 ; 33 %);
 - $=800^{\circ}$; (767 ; 77 %);
 - $=830^{\circ}$; 977 , 1047
 . 7.1.1.2 - 20 2

1,

1

,



. 7.1.1.3 -

1 -
2 -

30

7.1.2

1

30

. 7.1.2.1-

7.1.2.14 .

20 2

[104],

5 ° / , . 7.1.2.1,

(678-588 °)

(562 °);

15-20 %.

10 20 /

r1

638 521 °

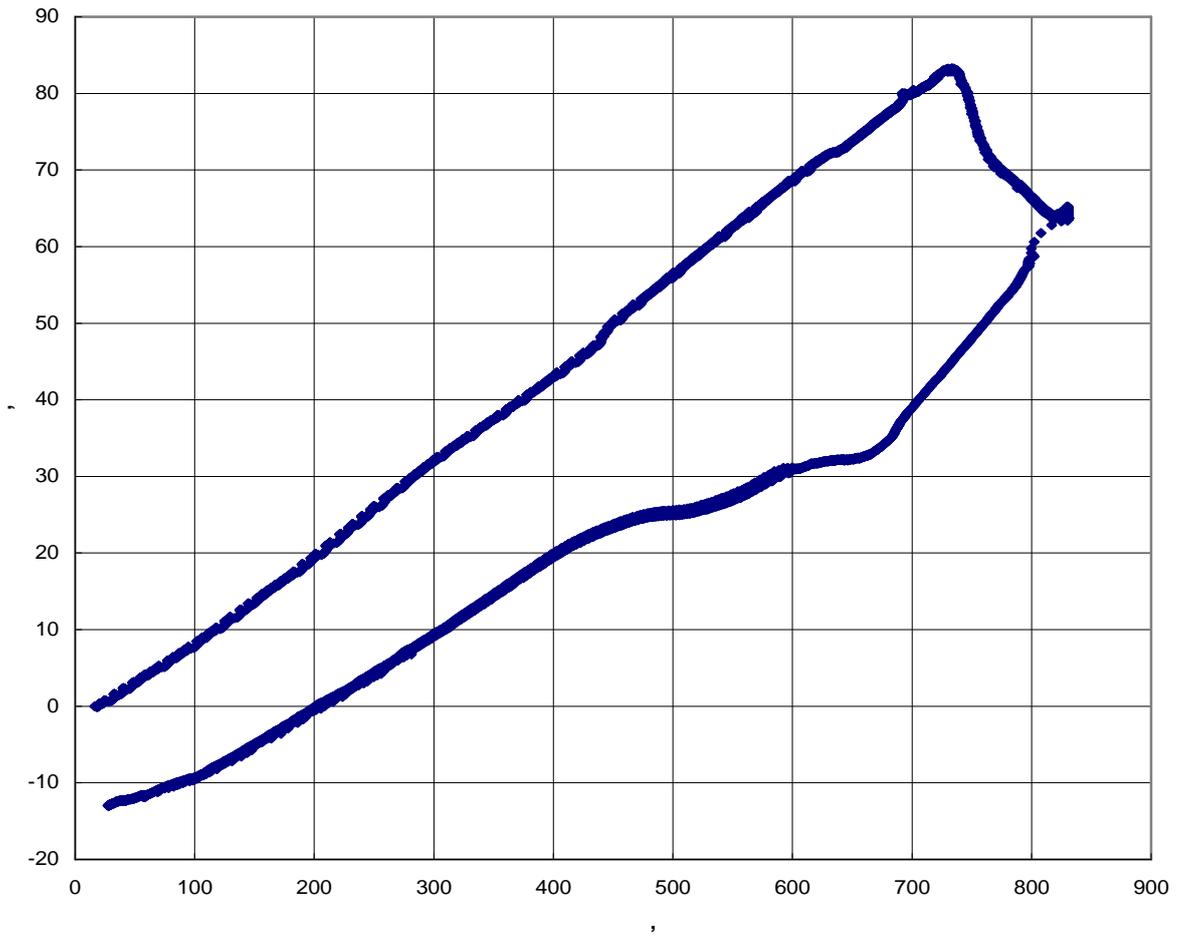
,

, . 7.1.2.2-7.1.2.4.

20 2

. 7.1.2.15.

20 2 900 830 5



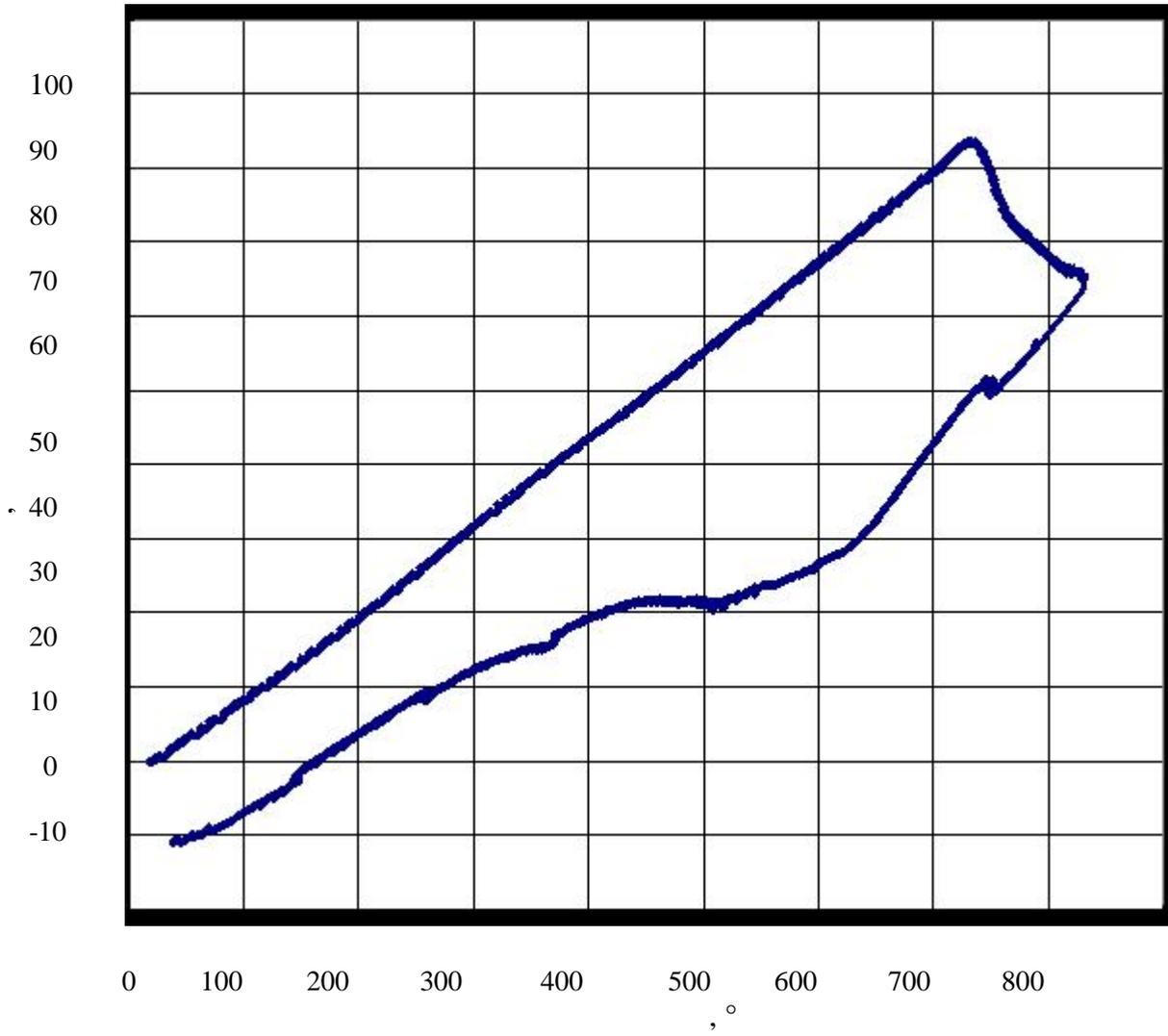
. 7.1.2.1 -

20 2 .

900 °

830° ,

5 ° /

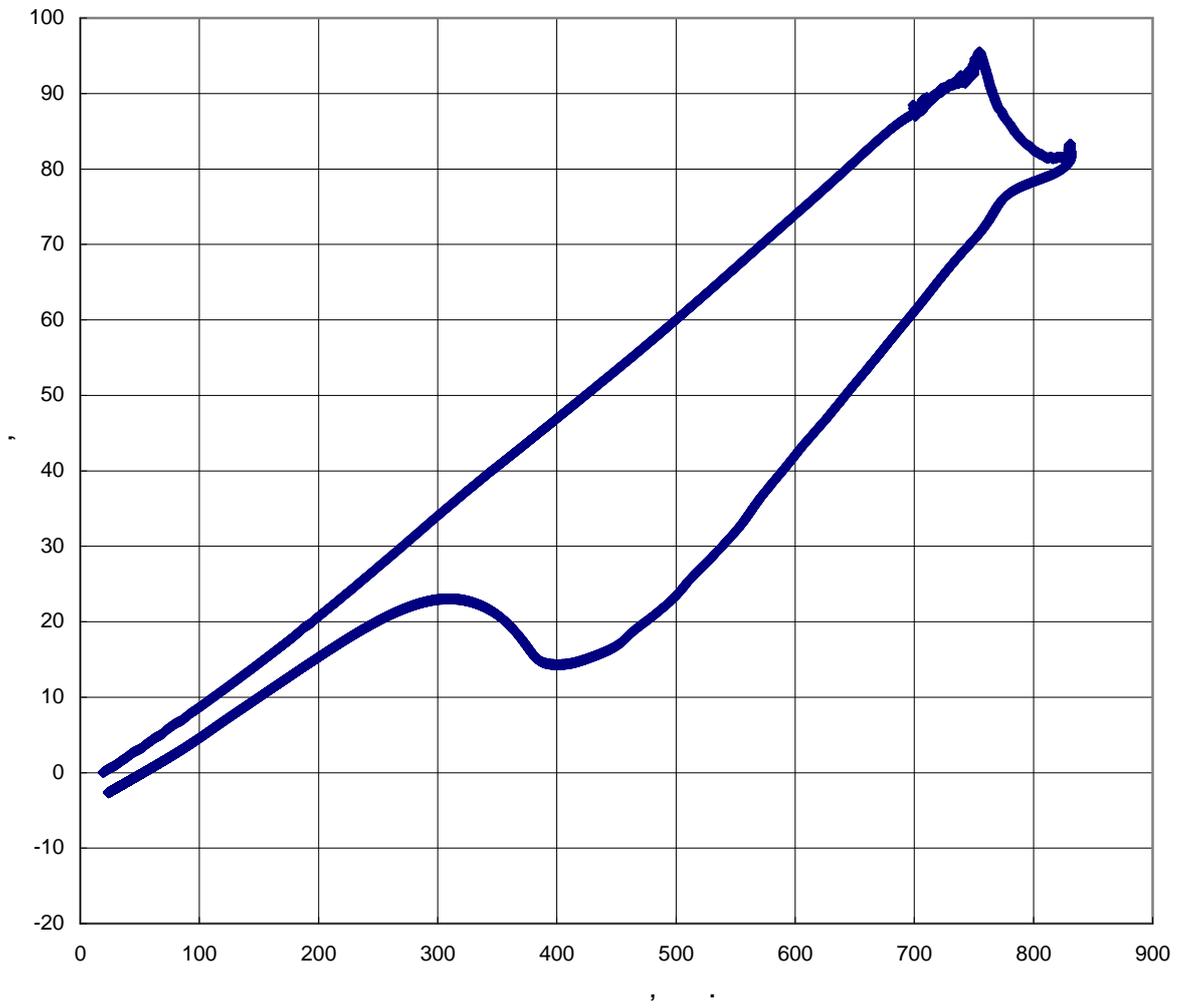


.7.1.2.2 -

830° , 20 2 .

900°
10° /

20 2 830 40

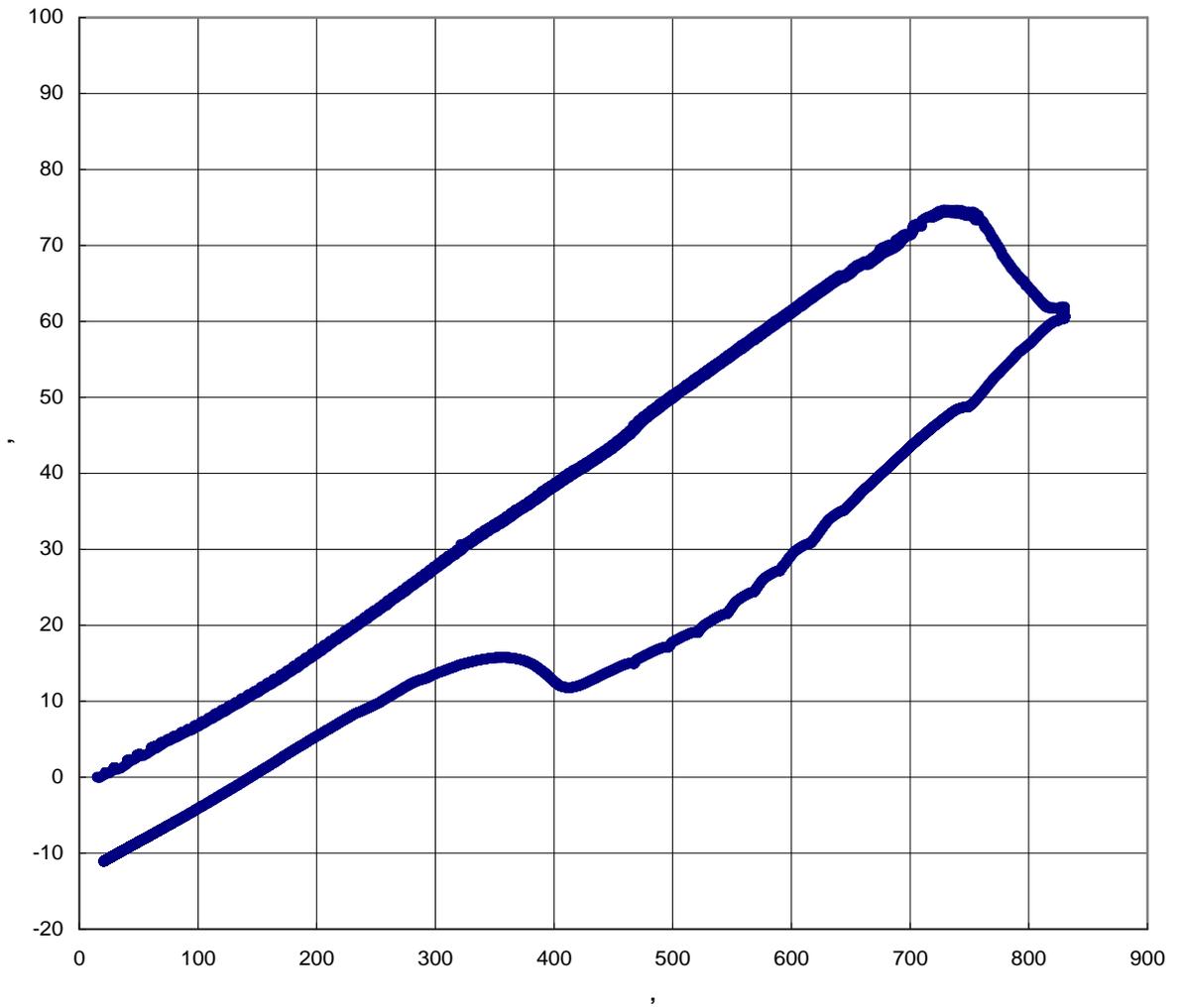


.7.1.2.3 -

830° , 20 2 .

900°
40° /

20 2 830 70

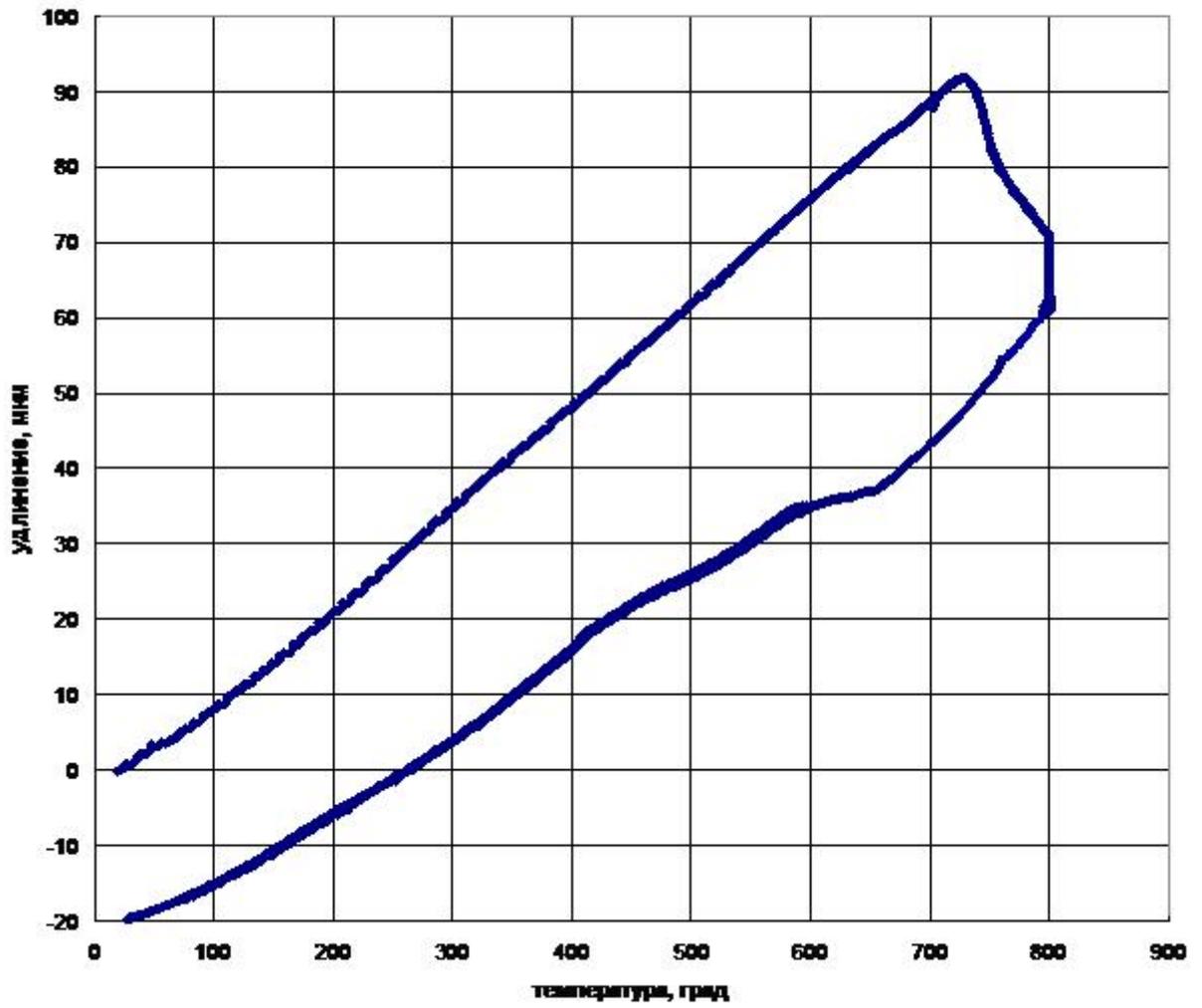


. 7.1.2.4 -

830° , 20 2 .

900° / 70° /

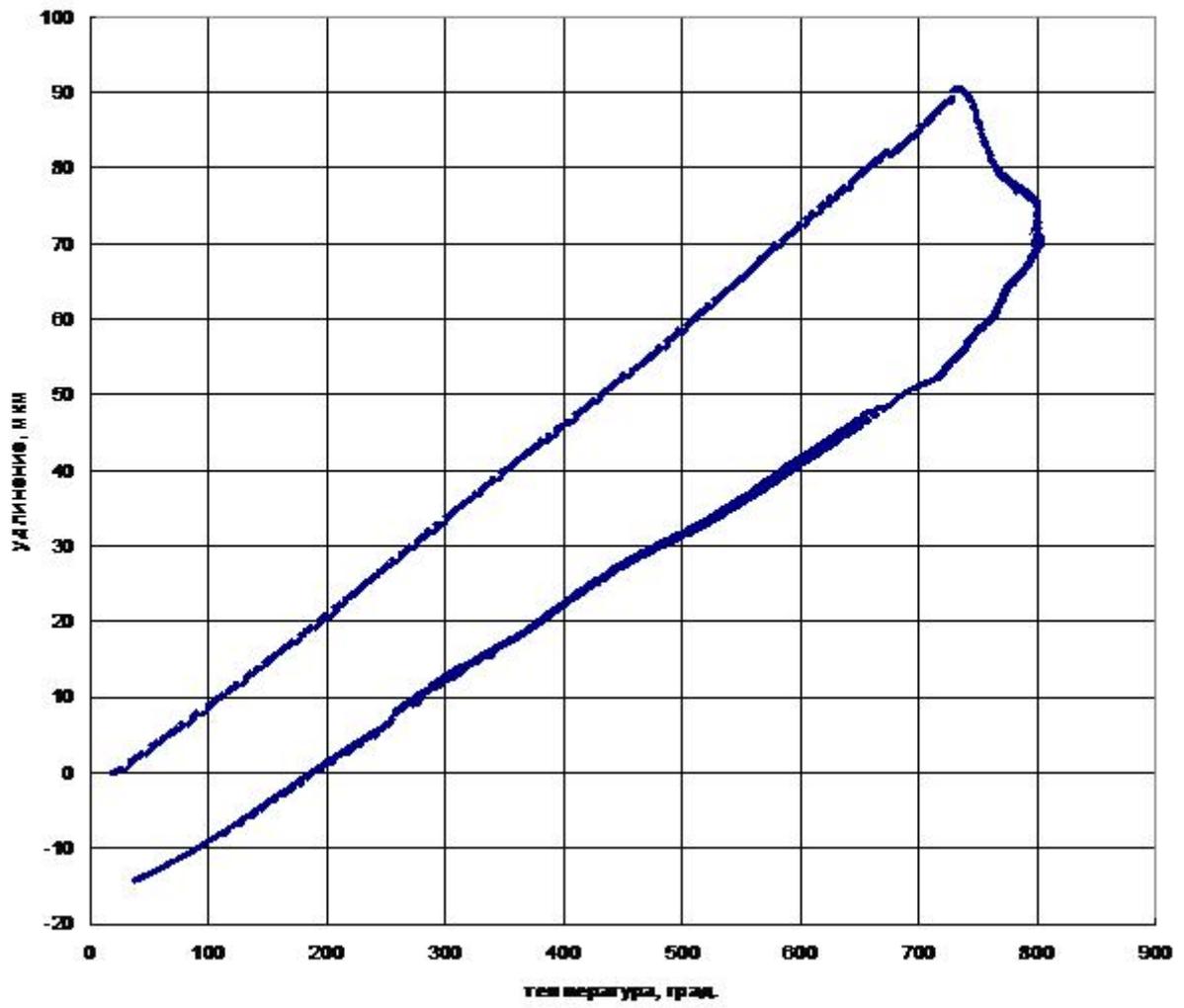
200725 800 5



. 7.1.2.5 -

20 2 .
800° ,900°
5° /

200726 800 10



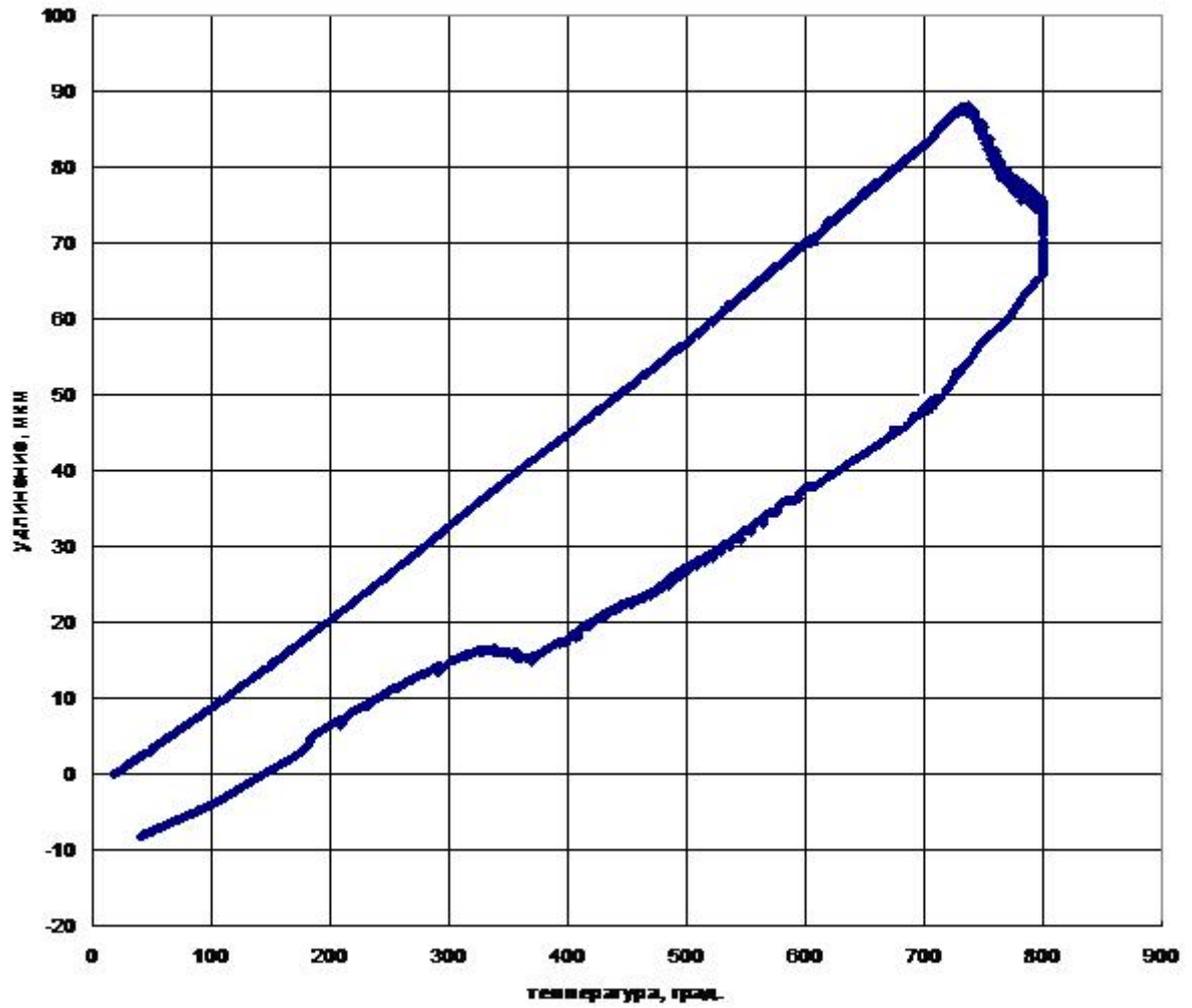
.7.1.2.6 -

800° ,

20 2 .

10° /

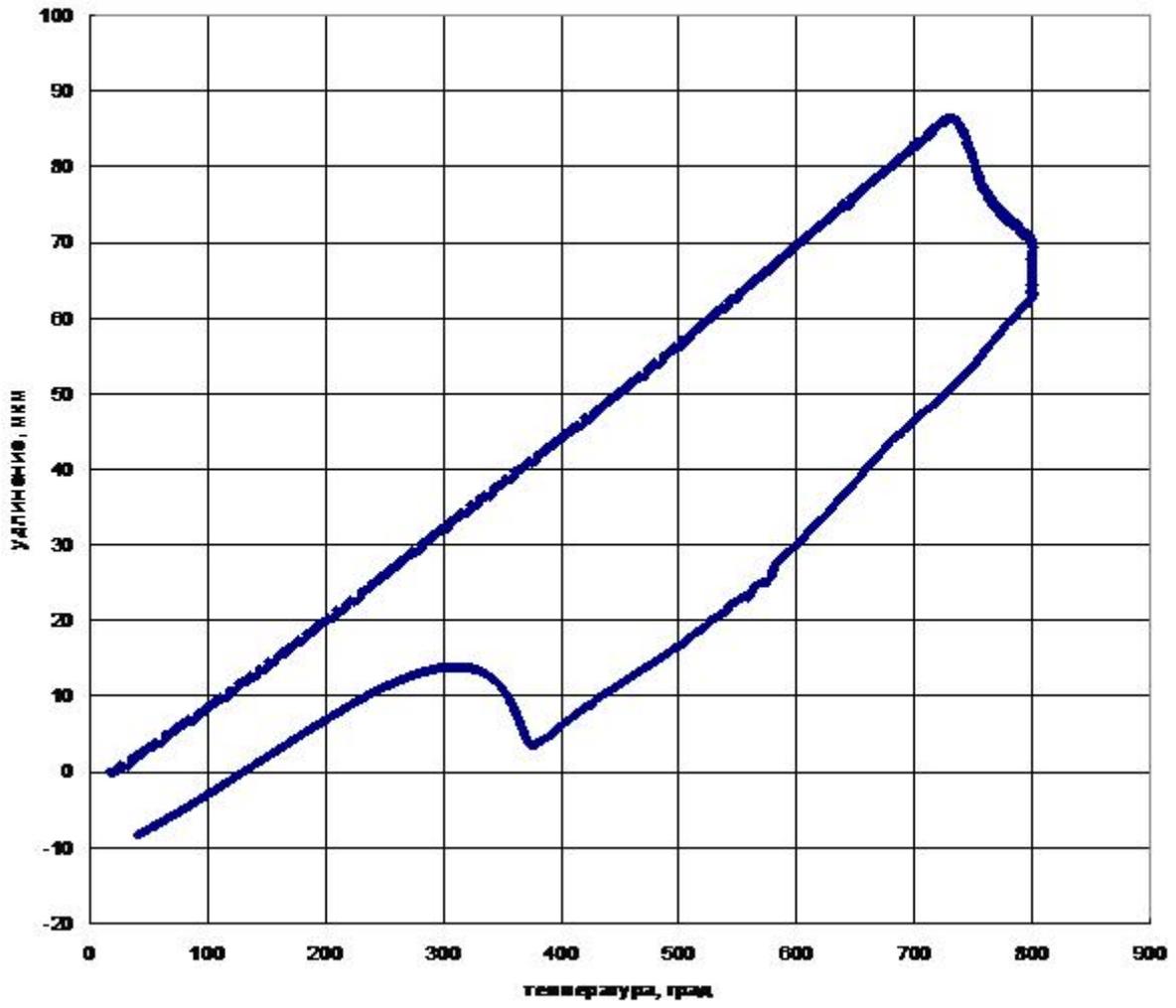
900° .



.7.1.2.7 -

800° , 20 2 .

900°
20° /



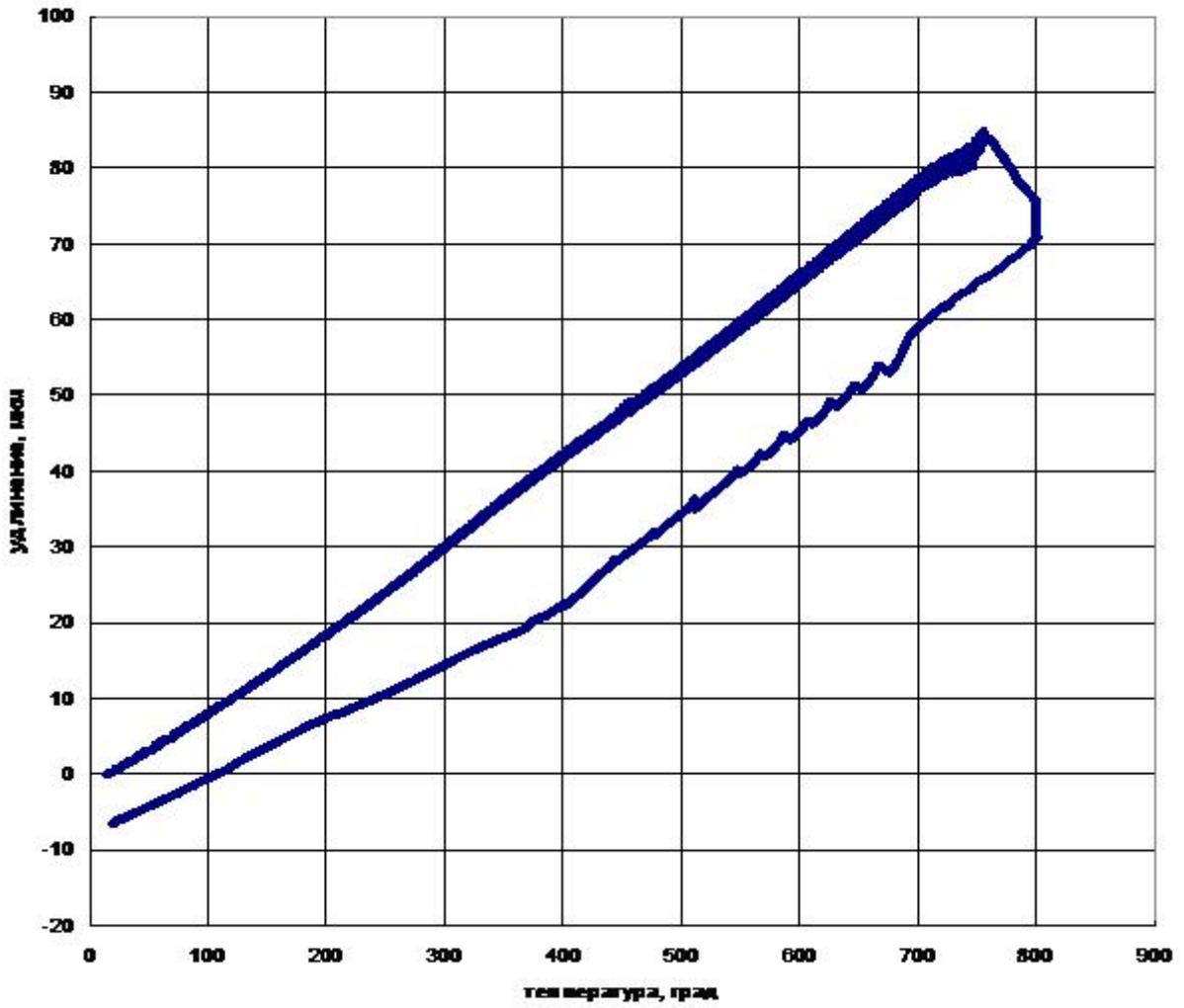
. 7.1.2.8 -

20 2 .

800° ,

900°
40° /

20X12G 800 70

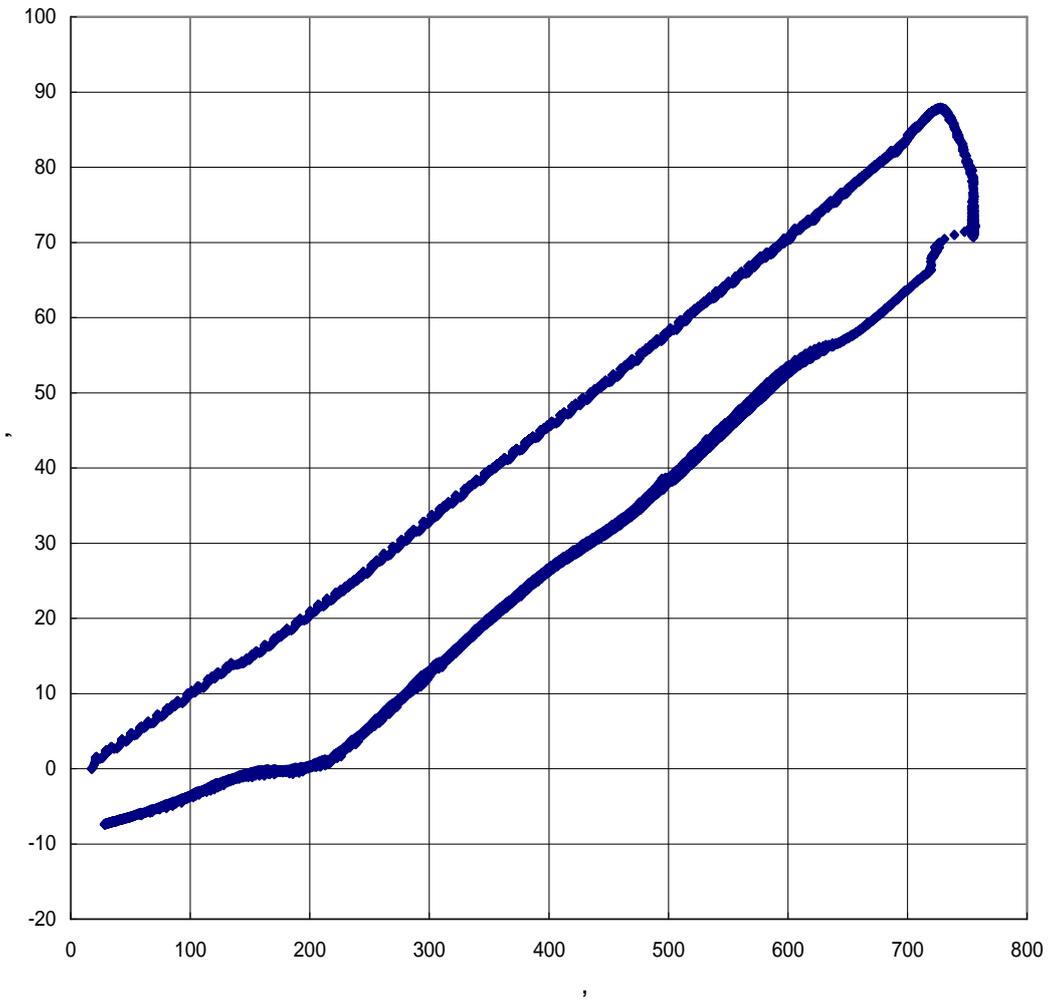


.7.1.2.9 -

800° , 20 2 .

900°
70° /

20 2 755 5

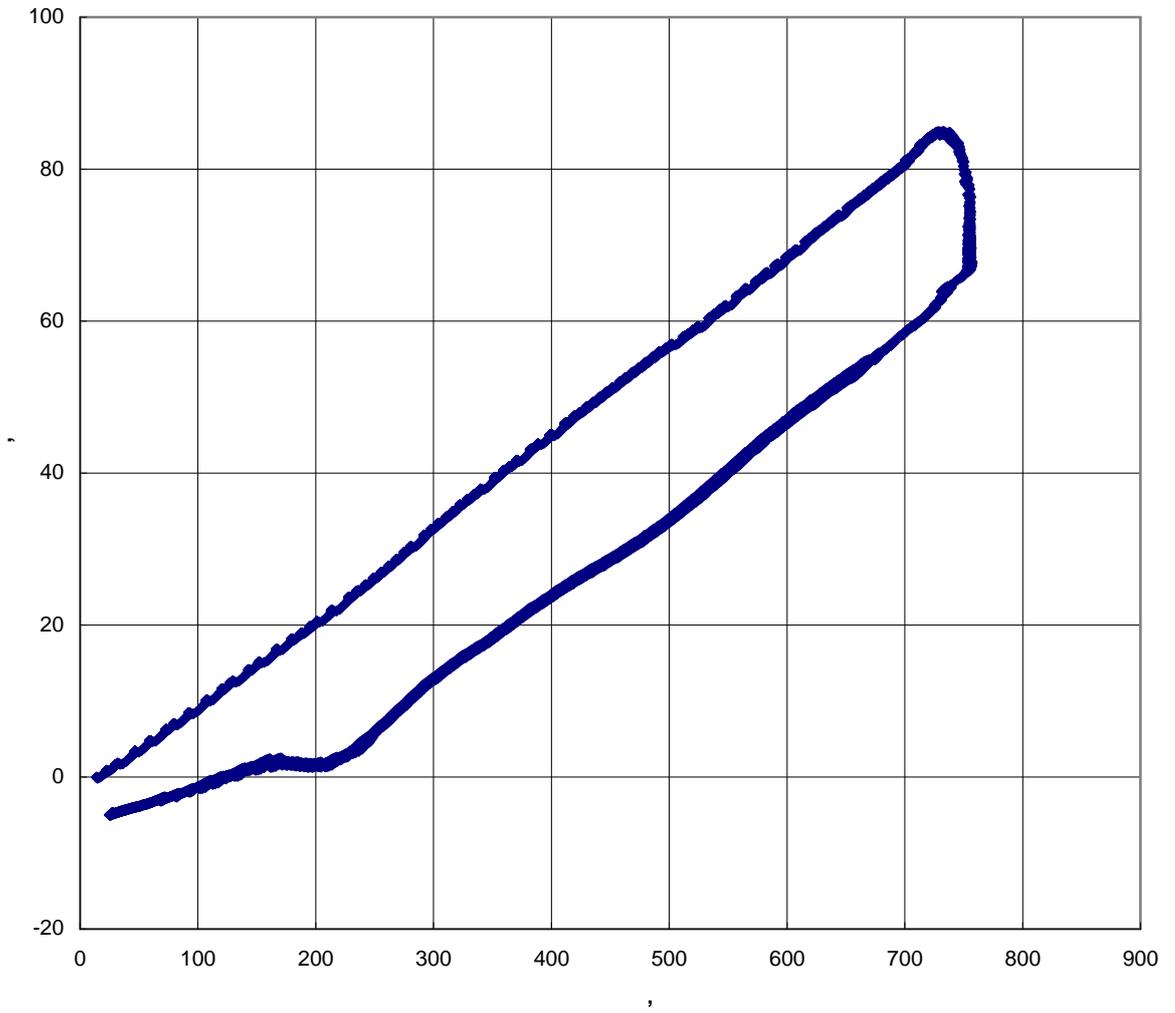


. 7.1.2.10 -

755° , 20 2 .

900°
5° /

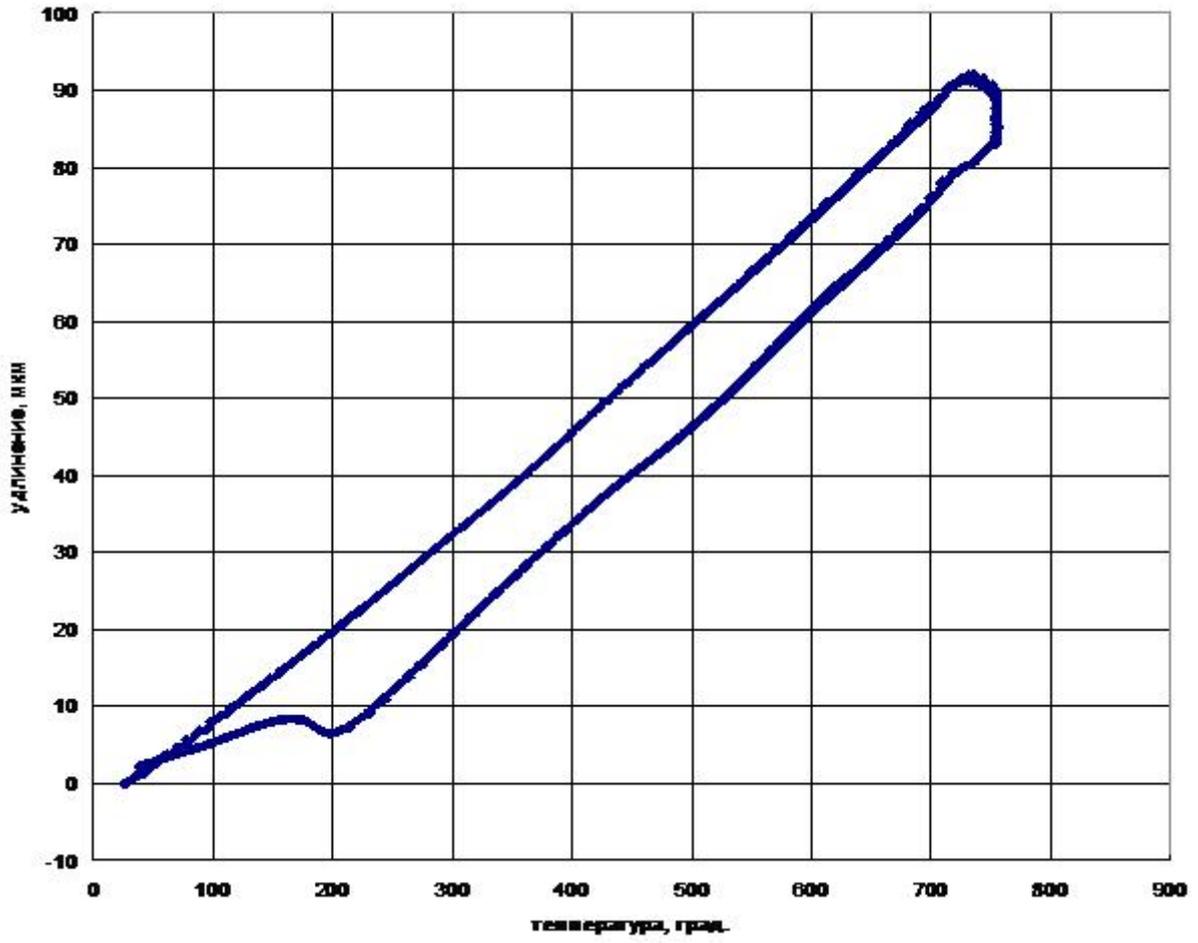
20 2 755 10



. 7.1.2.11 -

20 2 . 900 °
755° , 10 ° /

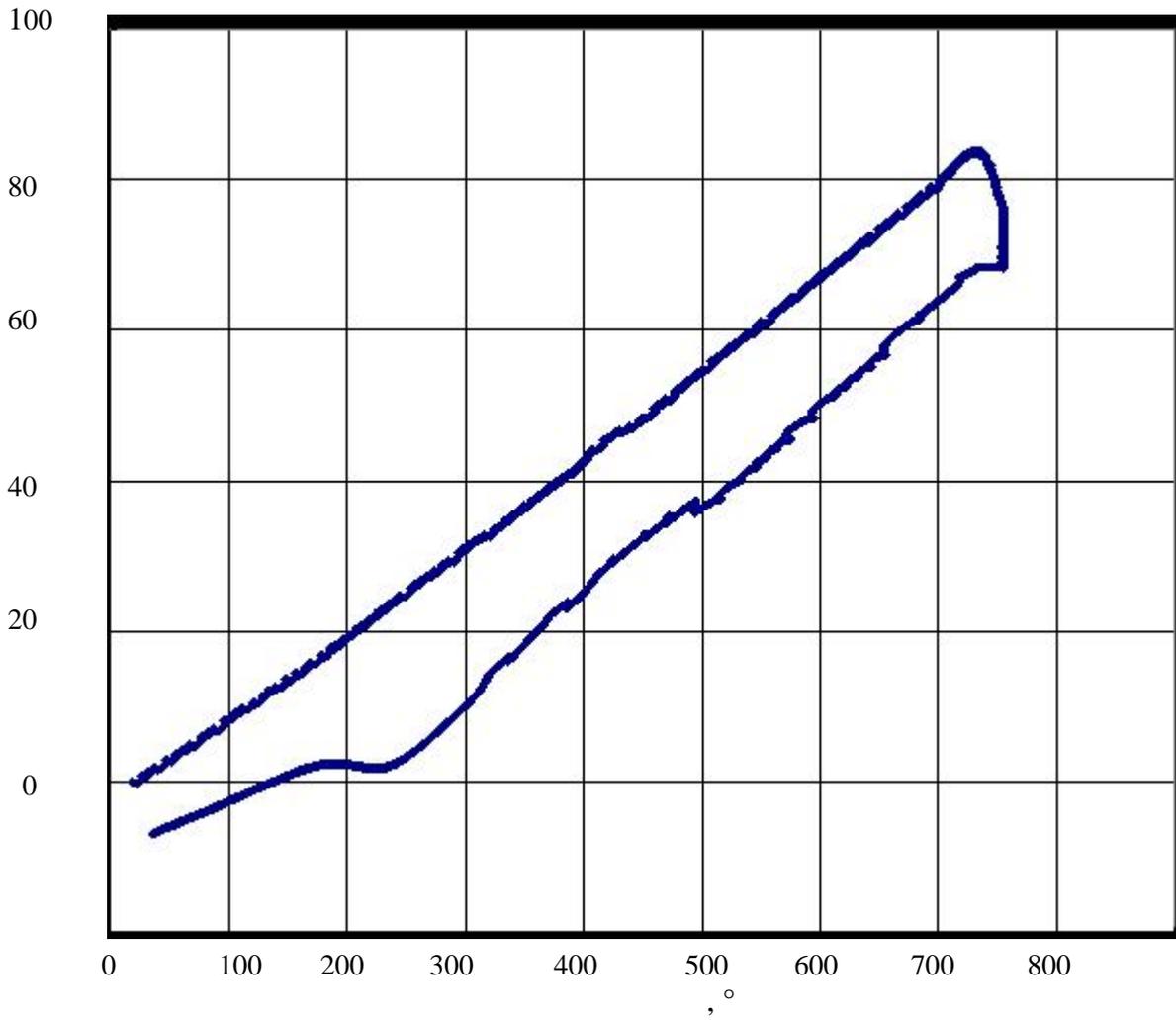
20X126 755 20



. 7.1.2.12 -

755° , 20 2 .

900°
20 ° /

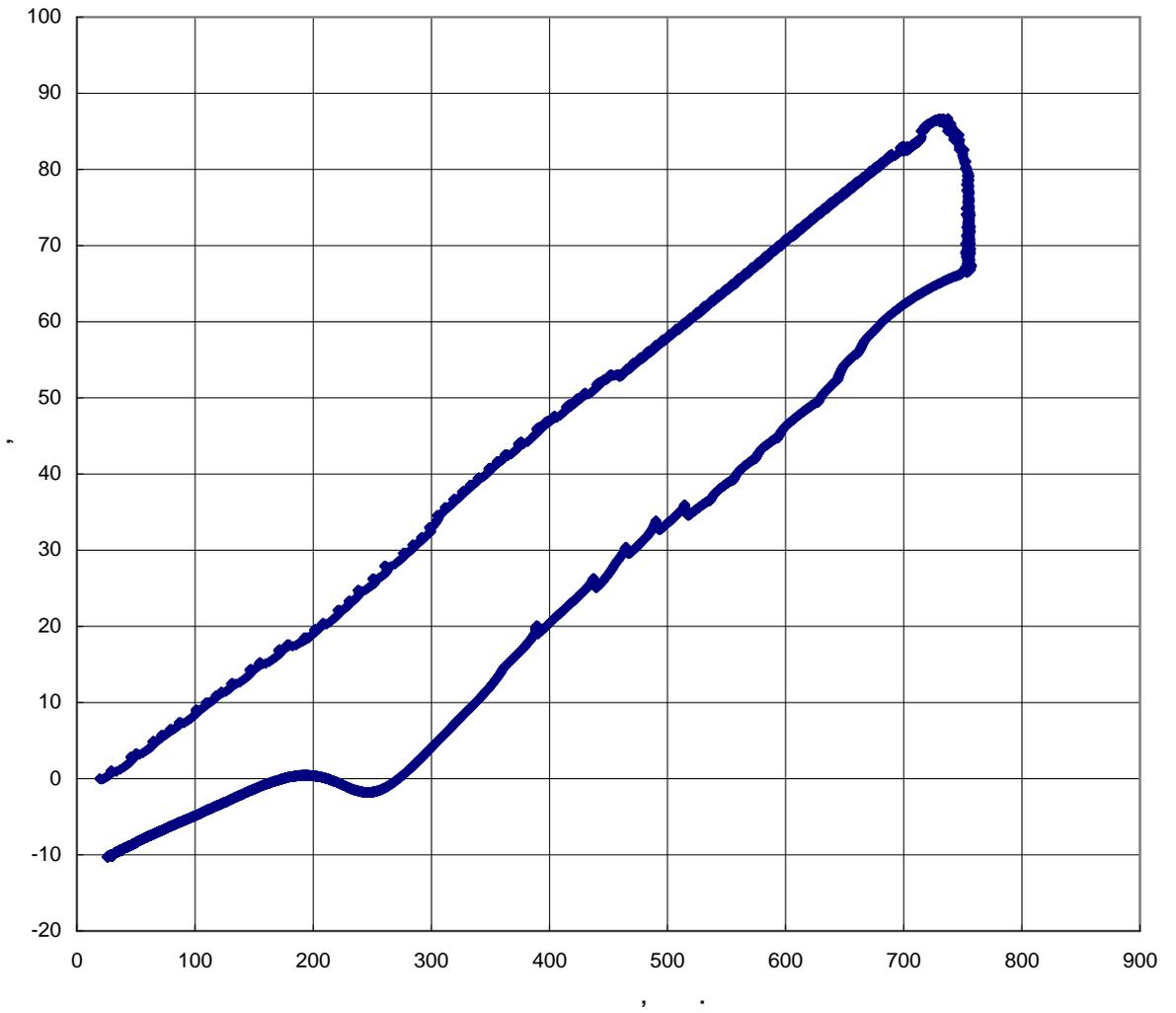


. 7.1.2.13 -

755° , 20 2 .

900°
40 ° /

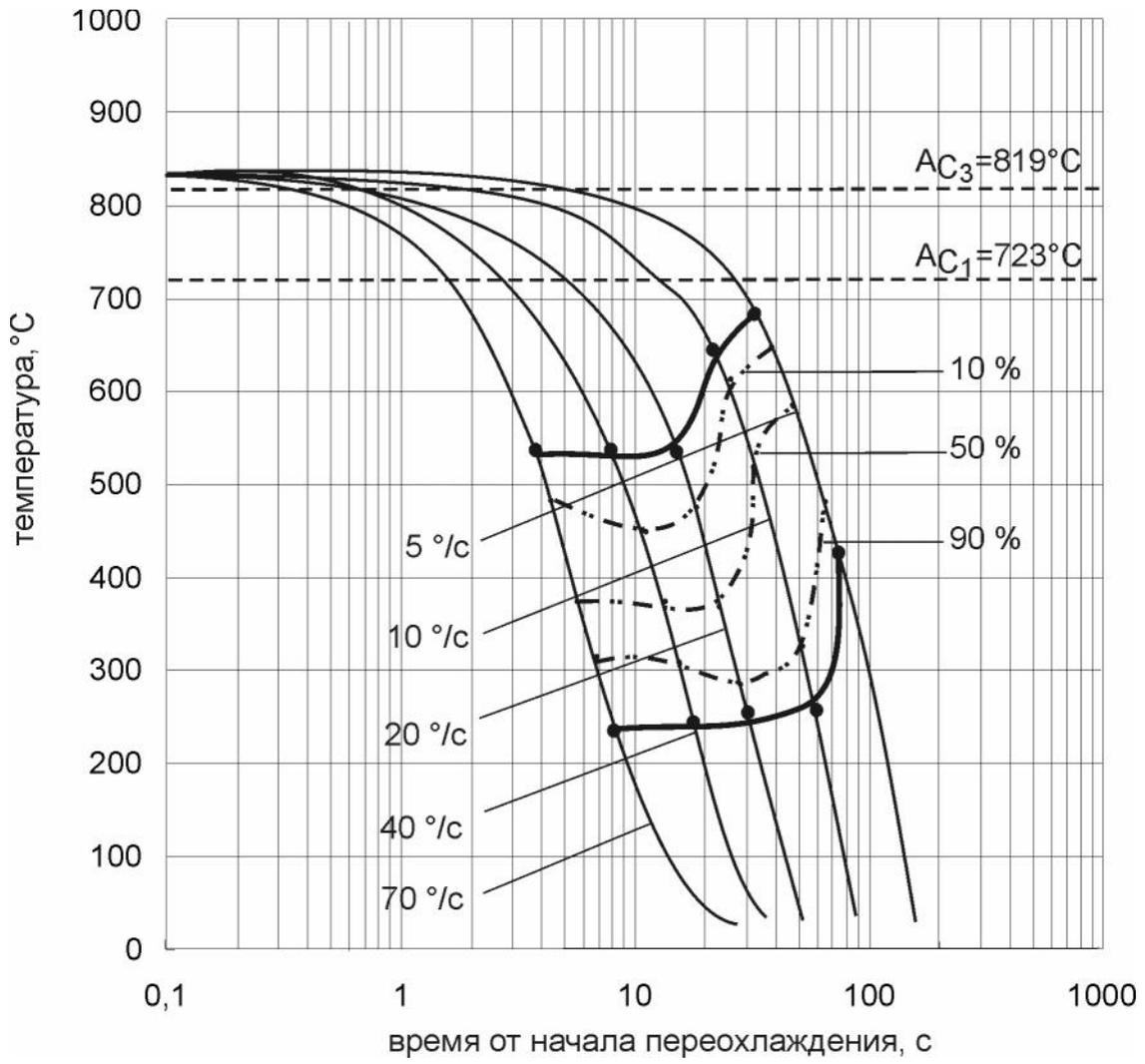
20 2 755 70



. 7.1.2.14 -

755° , 20 2 .

900°
70 ° /



. 7.1.2.15 –

830°

20 2

0,5 .

r₁

r₃,

250-300 ° .

r₃

230 ° .

,

830 °

20 2

800 °

, . 7.1.2.5-7.1.2.9

. 7.1.2.16.

800 °

 γ - ,

.

,

,

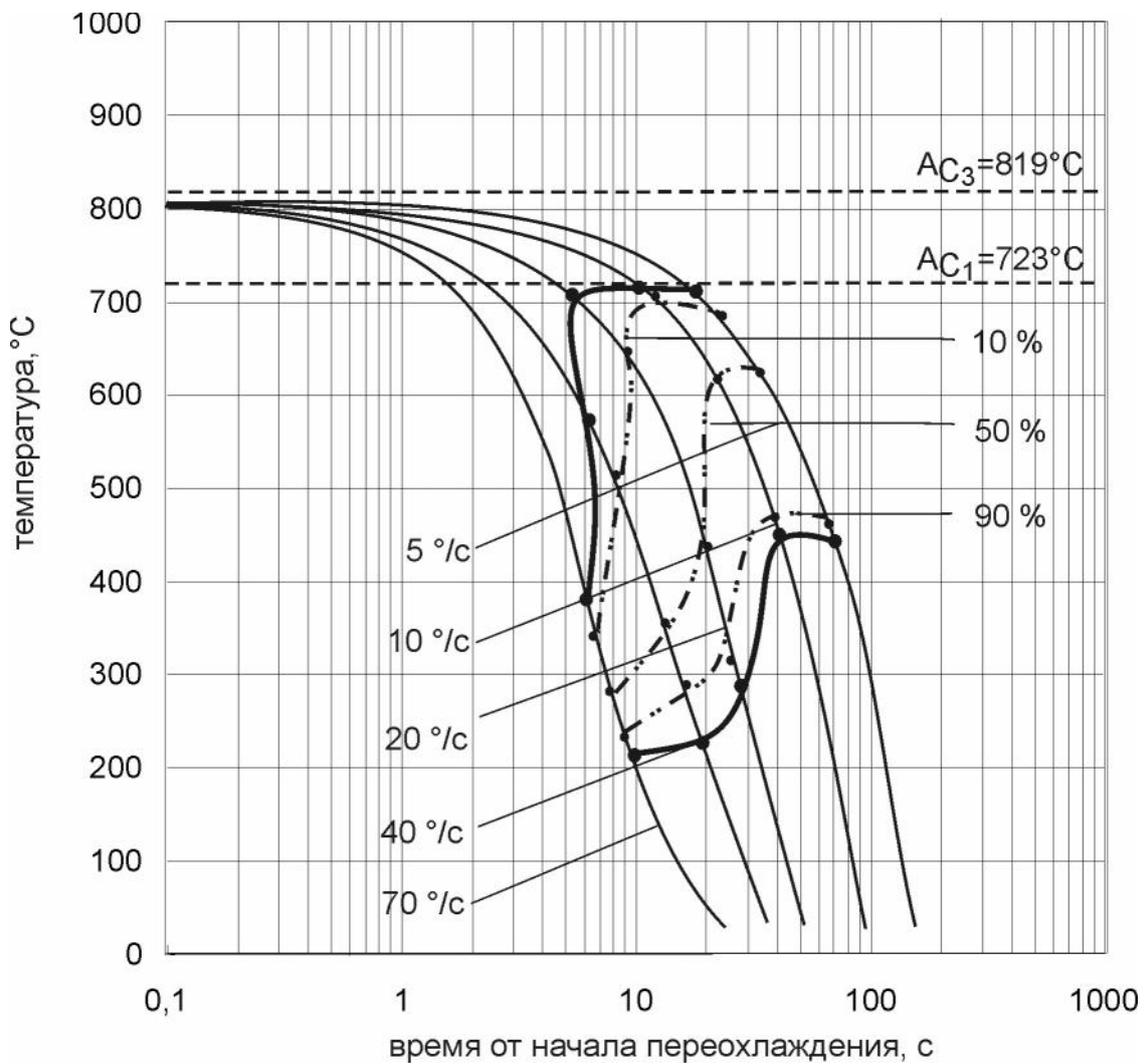
 r_1 .

5 70 ° /

300 (720 391 °).

 r_1

.



. 7.1.2.16 –
20 2

800°

0,5 .

20 2

755 °

. 7.1.2.17.

755 °

30

60 %;

5-10 ° /

675-600 °

, ,
,

5 70 ° /

525-401 ° .

,
.

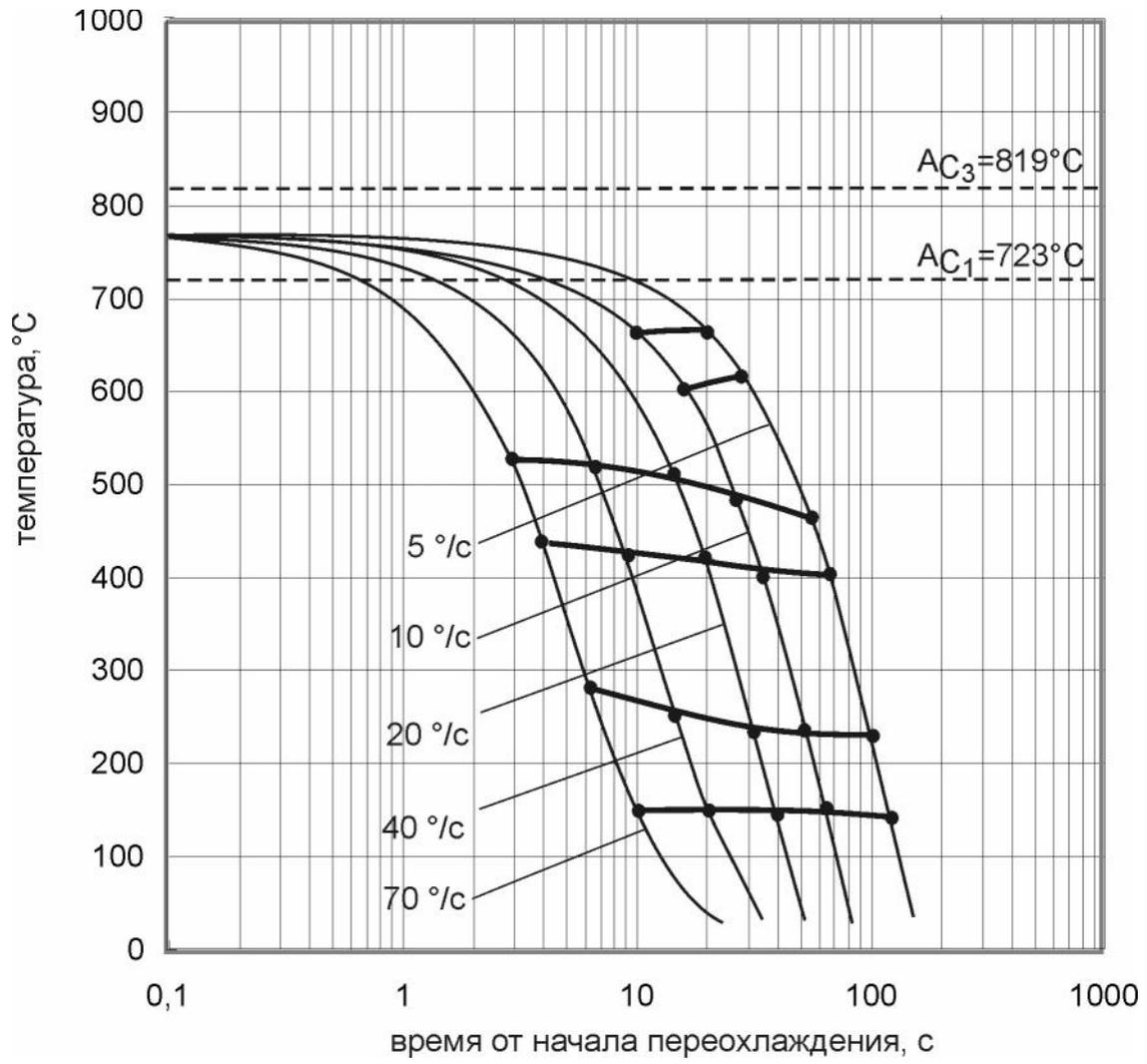
() . - ,

755 °

,
. 5 ° / .

221-143 ° .

. (70 ° /)
283 ° .



. 7.1.2.17 –
20 2

755°

0,5 .

7.2

20 2

7.2.1

20 2

:

900°

0,5 ,

7.2.1

830 °

(5-20 ° /)

, . (7.2.1.1 ,).

,

,

10-15 %,

,

40 /

;

,

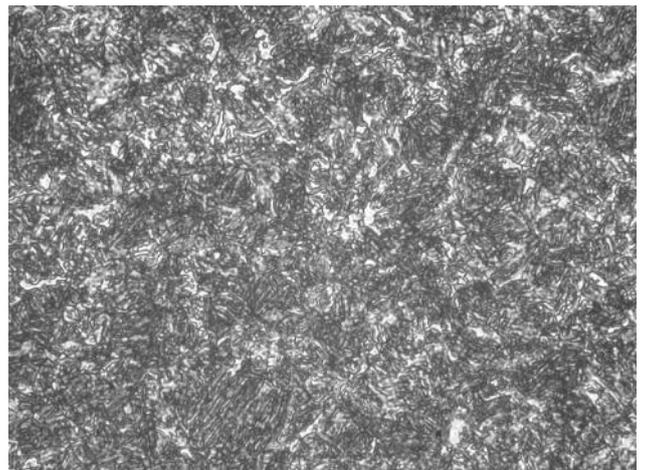
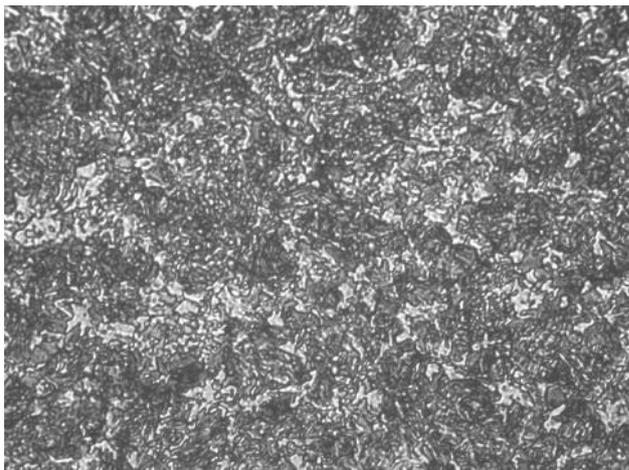
,

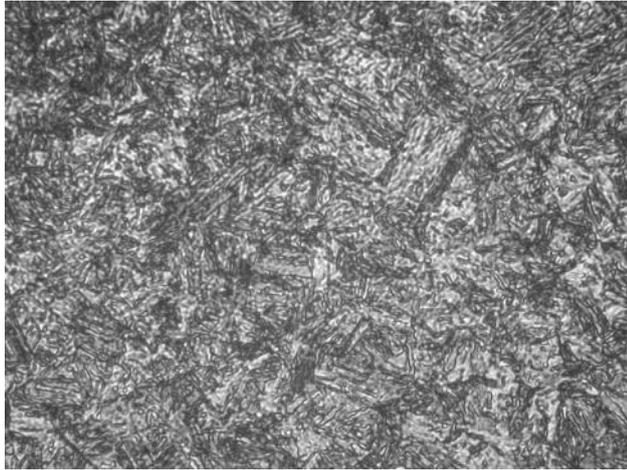
(. 7.2.1.1).

,

830 °

.





.7.2.1.1 -
900° 0,5 ,

20 2 :
; 830° ,0,5 ,
, 500: -5° / , -20° / , -40° /

800°

5 10 ° /

1-2

(.7.2.1.2 ,).

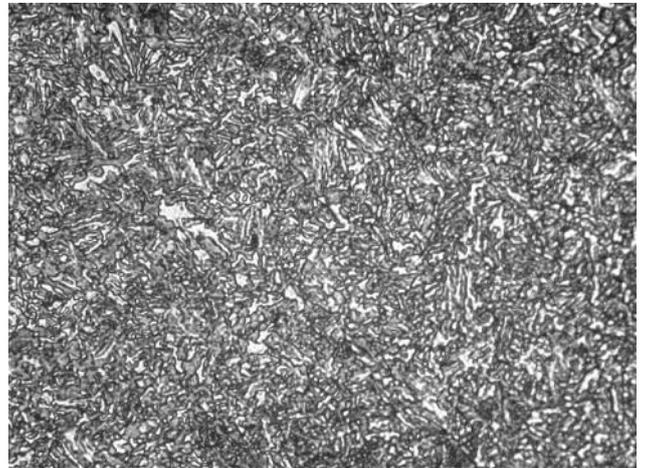
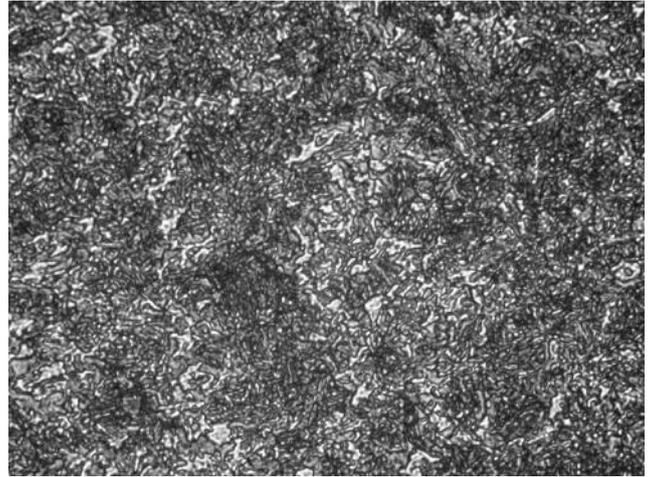
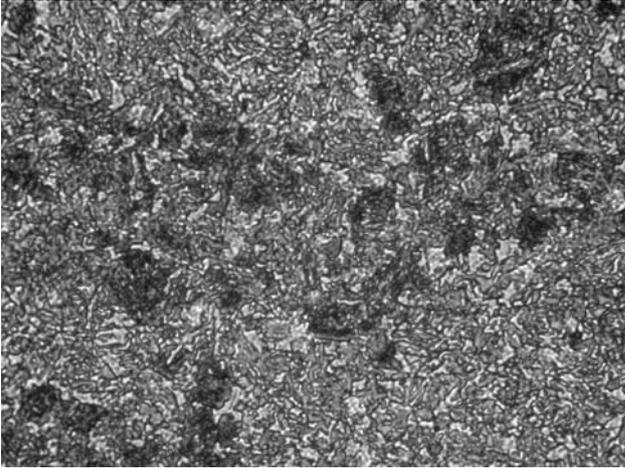
5 ° / (.7.2.1.2)

, - , ,

, - ,

,

-

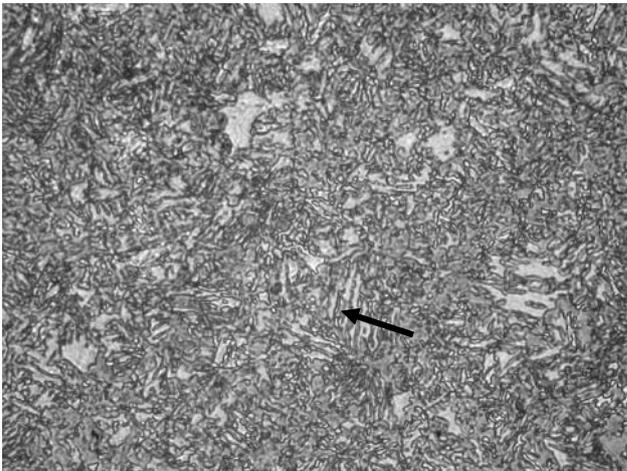
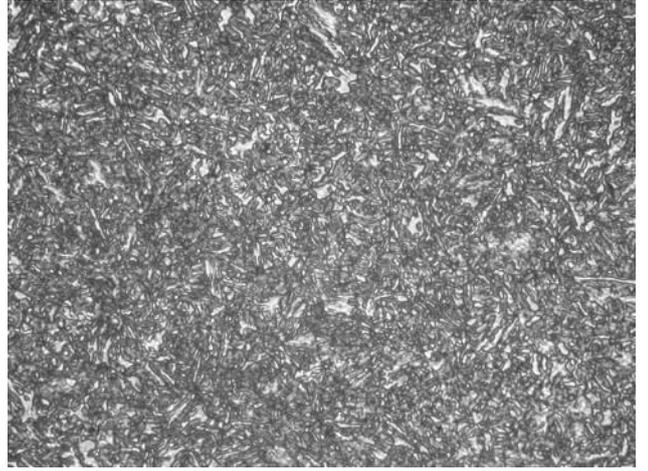
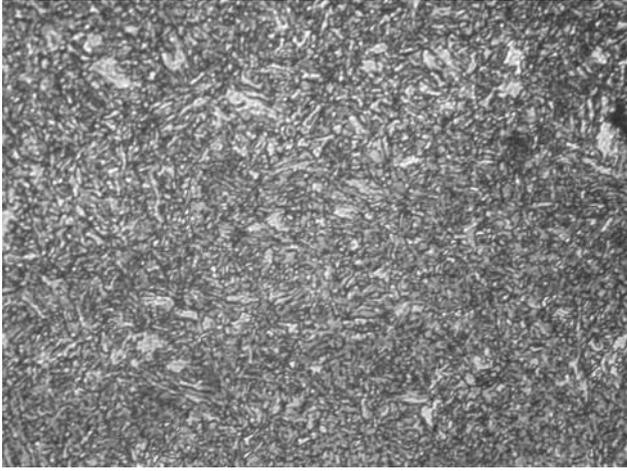


.7.2.1.2 - 20 2 :
 900° 0,5 , ; 800° ,0,5
 , 500: -5° / , -10° / , -20° / , -40° /

7.2.1.3

755 °

830° ,



. 7.2.1.3 - 20 2 :
 900° 0,5 , ; 755° , 0,5
 , 500: -5° / , -20° / , -40° /

. 7.2.1.3 , , ,
 5, 20 40° / , -
 2-5 . , -

()

(. 7.2.1.3)

« », .

- - ,

(,

), - .

« » (-)

, 40 ° / . ,

. , (5

20 ° /) ,

.

7.2.2 **20 2** : **1050°**
0,5 , ; **900 ± 0,5** ,

$\alpha \rightarrow \gamma$

830 ° (. 7.1.1.2),

30

, - .
(5-10 ° /) (. 7.1.2.1, 7.1.2.2),

,

.

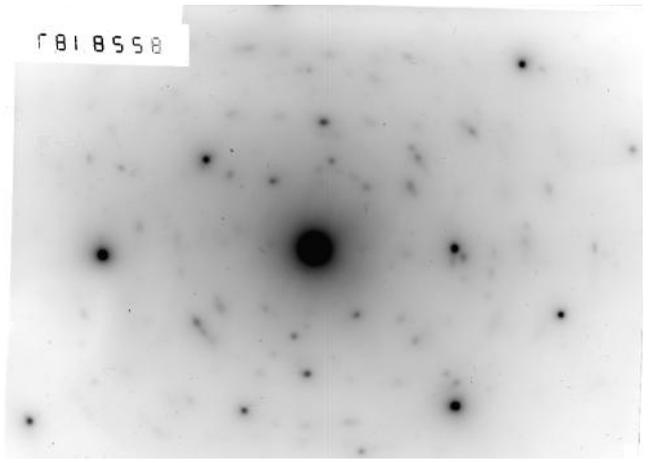
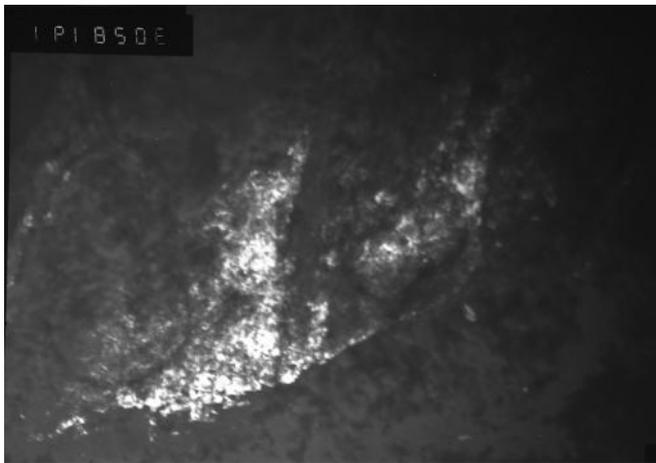
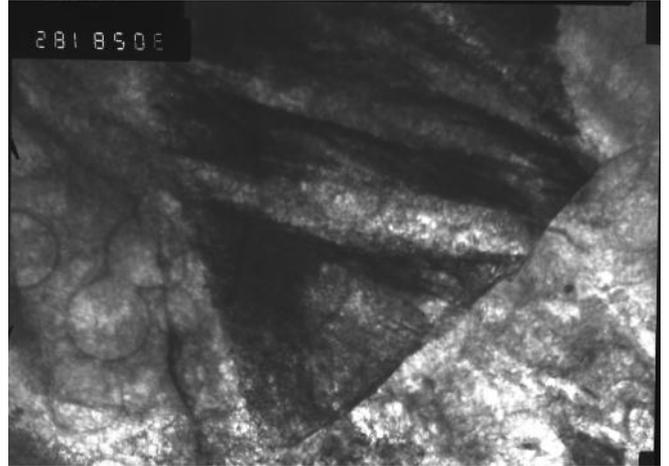
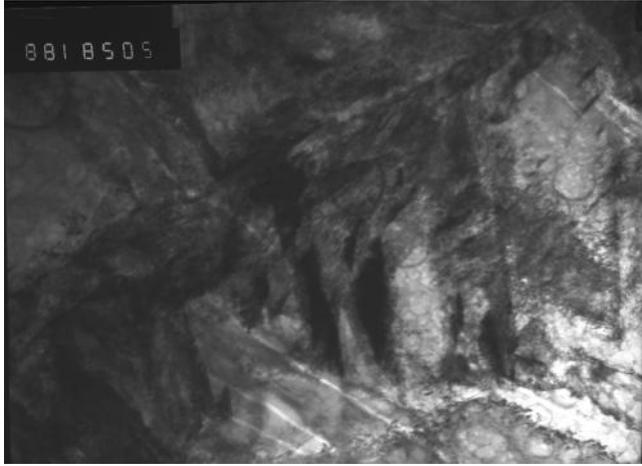
10

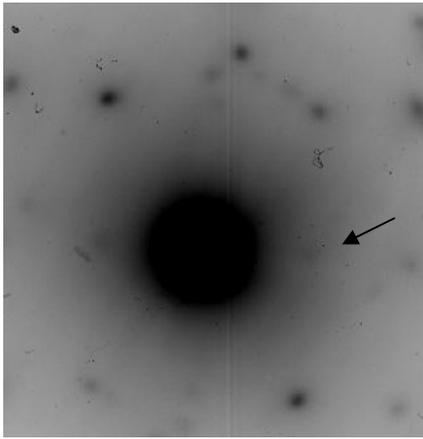
°C/ . 7.2.2.1

.

4-6 , ,

Fe_3C (.3.35).





- , 20000;
 - , 30000;
 - , 30000;
 - ; - ;
 . 7.2.2.1 - 20 2 : 900° ,
 0,5 . ; 830° , 0,5 . ,
 10° /

(100)
(. 7.2.2.1).

.
 70 /
 540 ° ,
 420 350 ° , 232 °
 (. 7.1.2.4, 7.1.2.15).

. 7.2.2.2, 7.2.2.3

0,1-0,3 (. 7.2.2.2 ,

, 7.2.2.3 ,),
(7.2.2.3 ,).

-

-

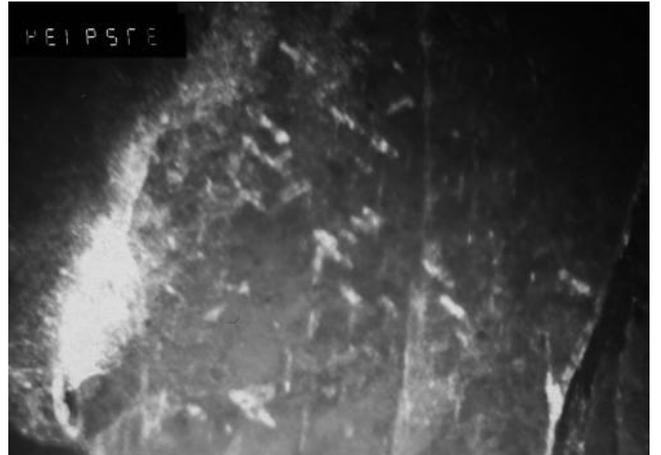
,
(.7.2.2.2 -).

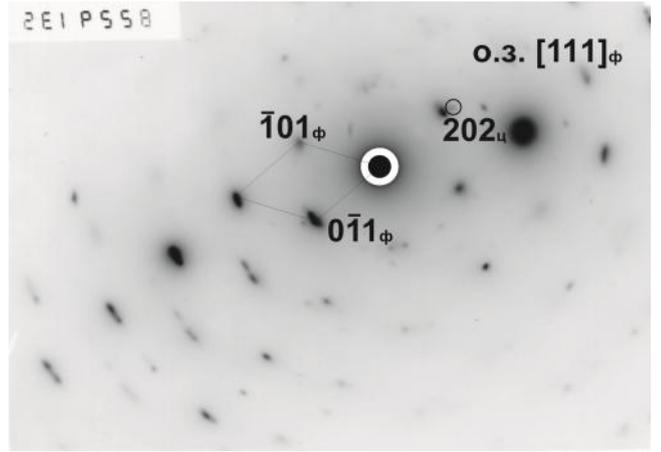
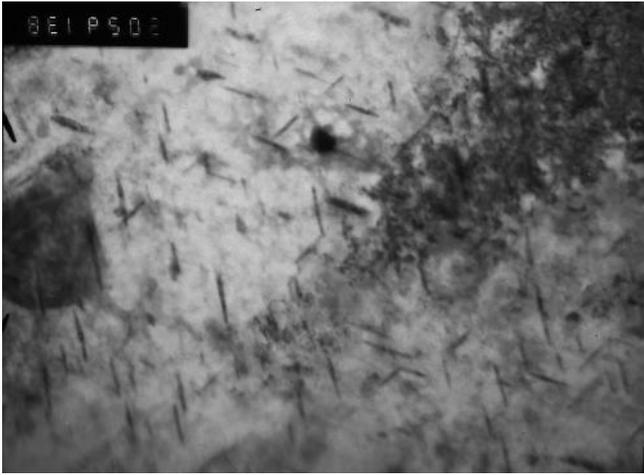
,

Fe_3C , (.7.2.2.2).

-

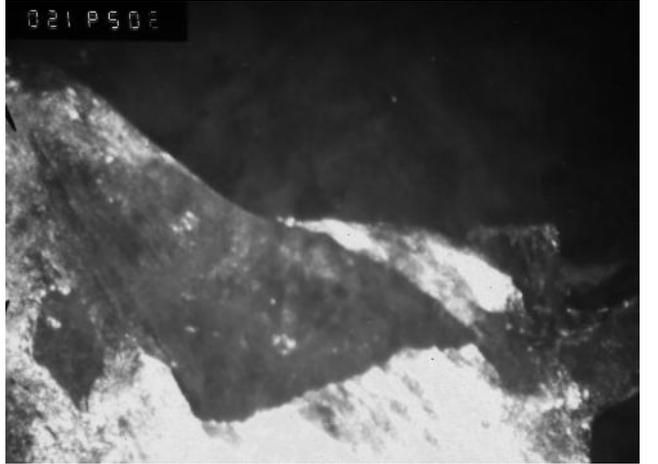
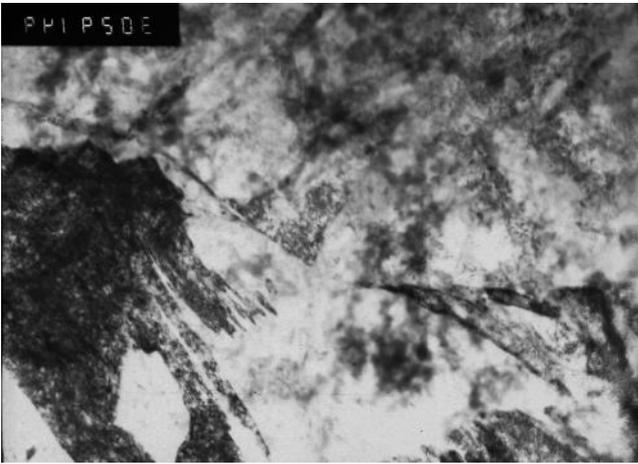
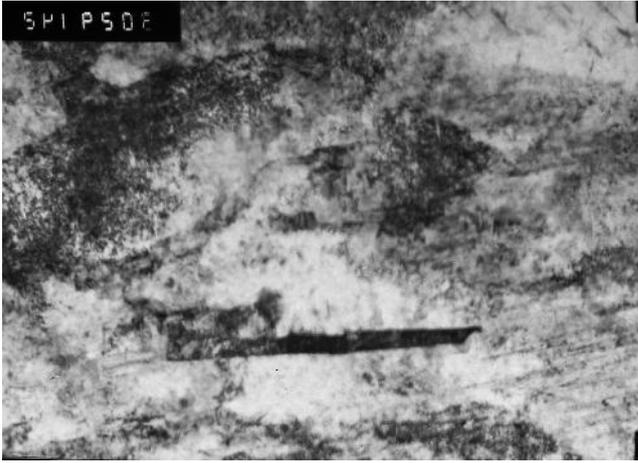
,

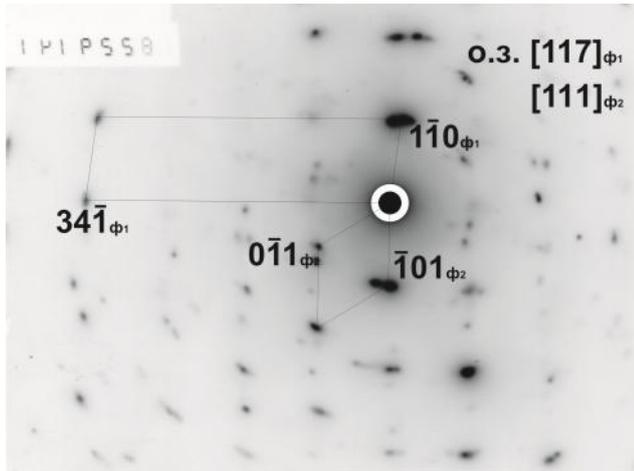




, - , 20000;
 - , 37000;
 , - , 37000, 50000;
 -

. 7.2.2.2 - ; 20 2 : 900° ,
 0,5 , ; 830° , 0,5 , 70
 ° /





, - , 30000;
 , - , 30000;
 -

.7.2.2.3 - ; 20 2 : 900° , 0,5
 , ; 830° , 0,5 ,
 70° /

800 ° 80 %

, $\alpha \rightarrow \gamma$

800 °

, 830 ° .

10 ° /

(. 7.2.2.4 ,) .

2-5

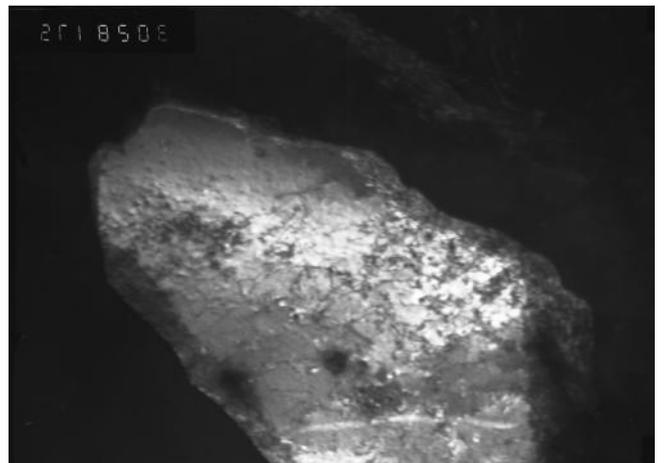
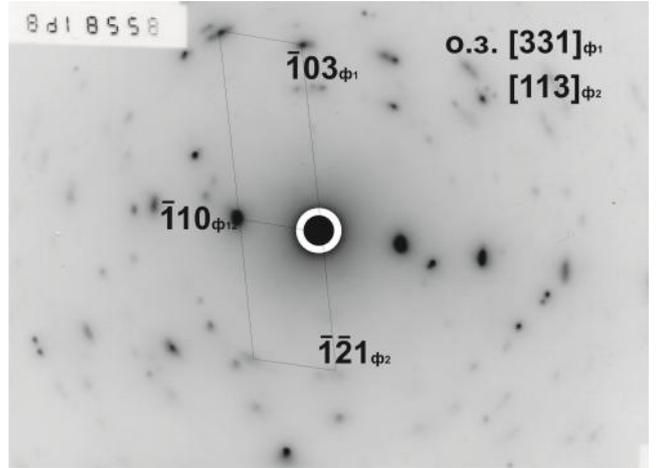
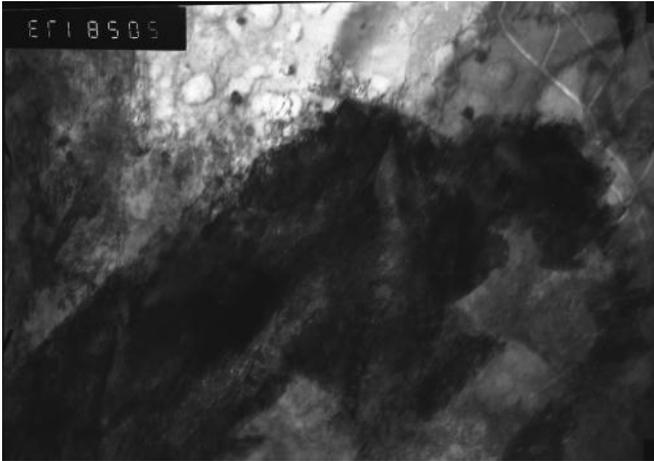
(. 7.2.2.4, 7.2.2.5) .

7.2.2.5.

(7.2.2.5 , 7.2.2.5) .

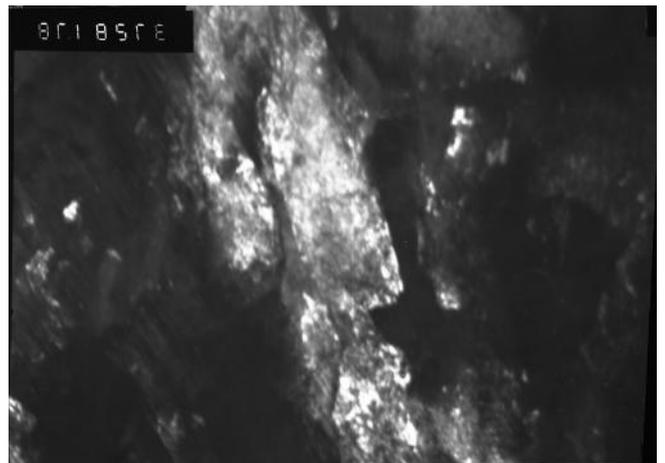
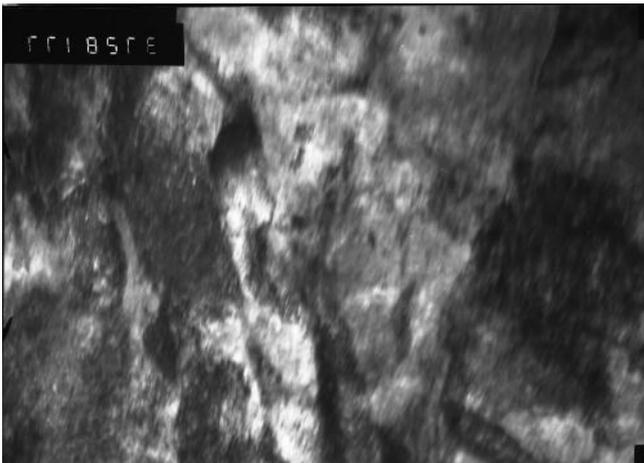
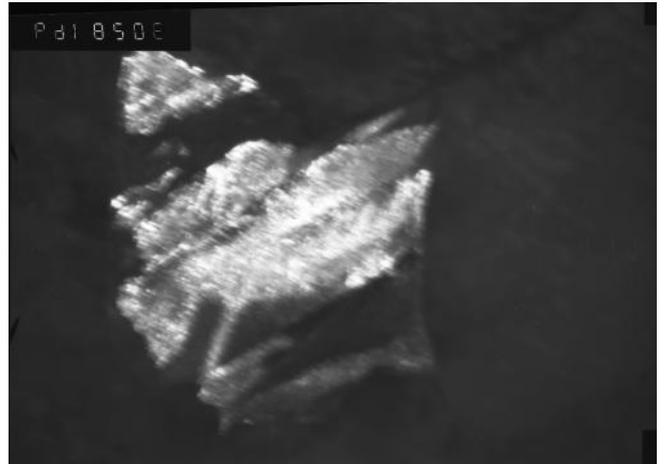
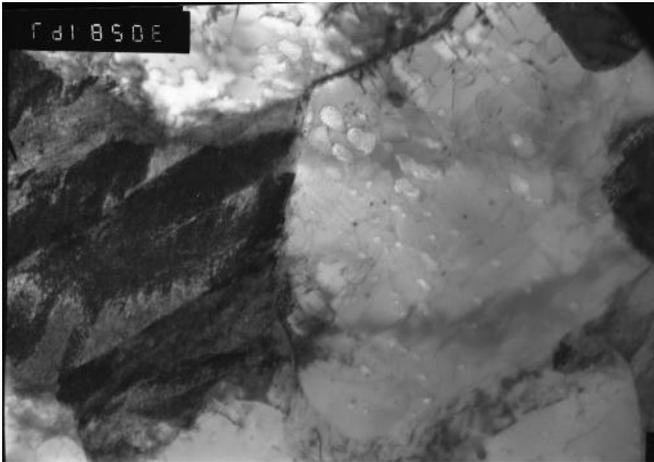
(. 7.2.2.5)

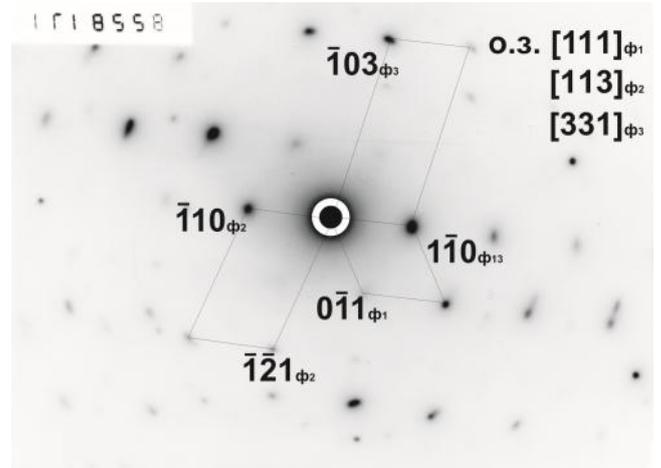
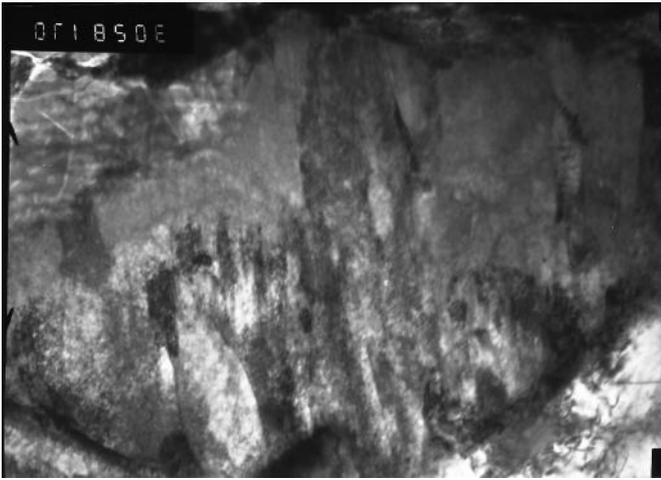
7.2.2.5 .



- , 20000;
 - ;
 - , 30000;
 -
 . 7.2.2.4 - 20 2
 900° , 0,5 , ;
 10° /

$\bar{1}10$, 30000;
 :
 800° , 0,5 ,





, - , 30000;
 - 3.39 $\bar{1}10$, 30000;
 - , 37000;
 - 3.39 $\bar{1}03$, 37000;
 -

.7.2.2.5 - 20 2 : 900° , 0,5
 , ; 800° , 0,5 ,
 10 ° /

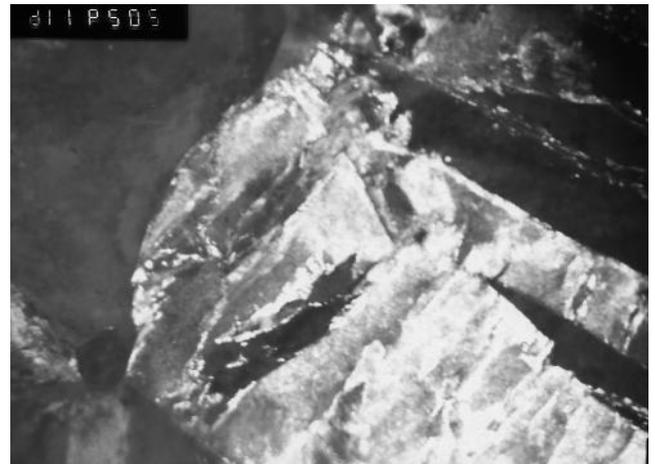
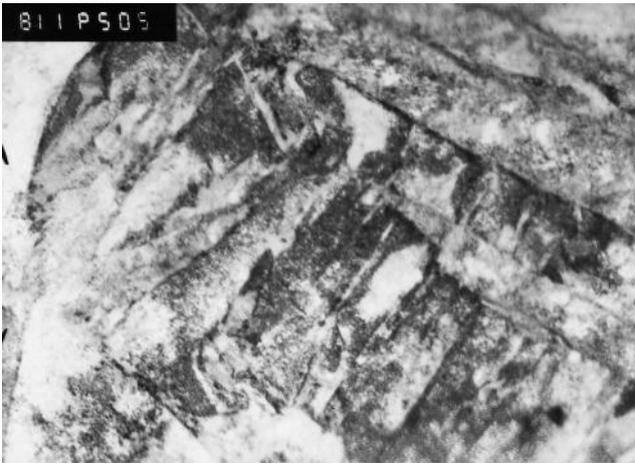
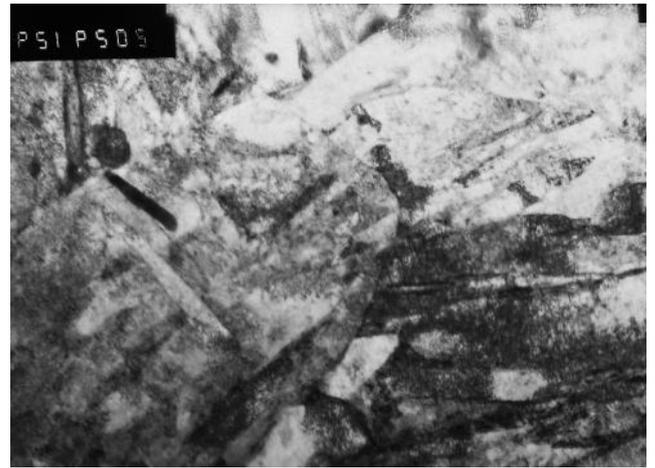
70 ° /
390 ° ,

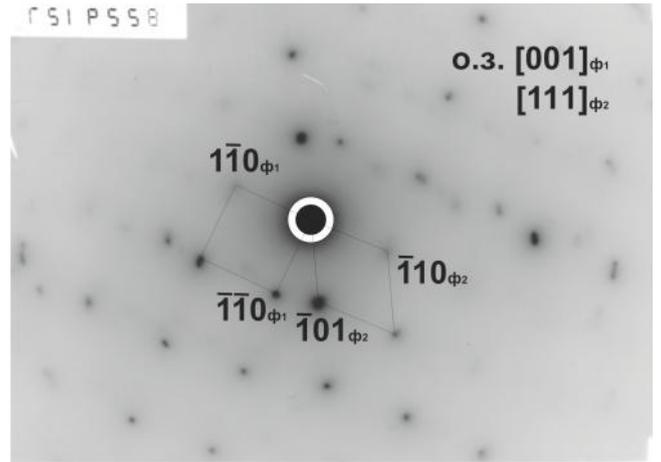
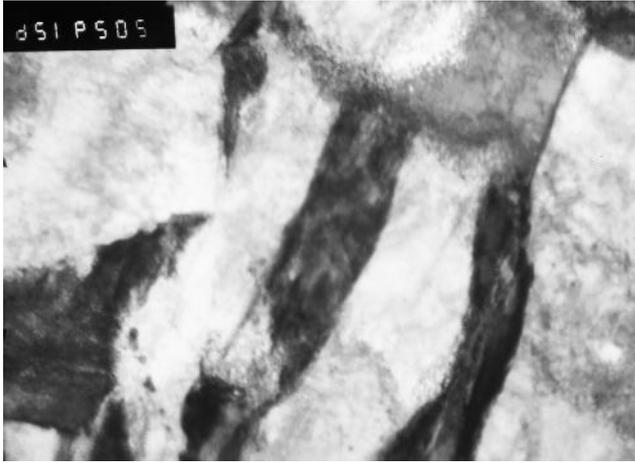
100

γ-

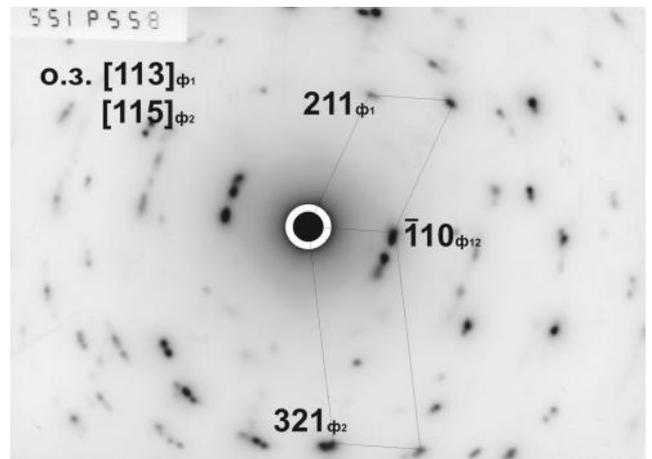
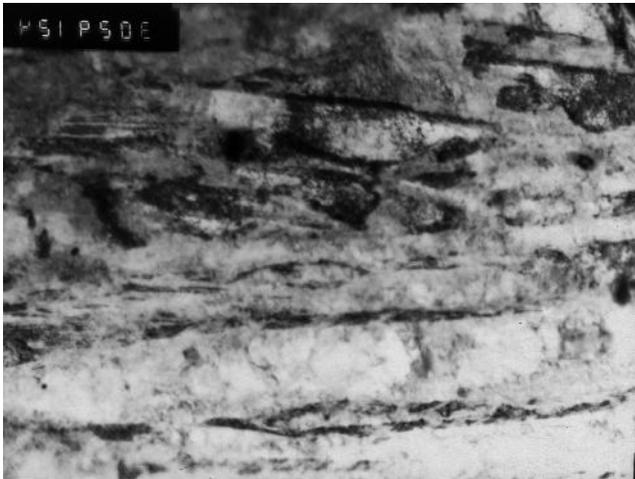
(. 7.1.2.16).

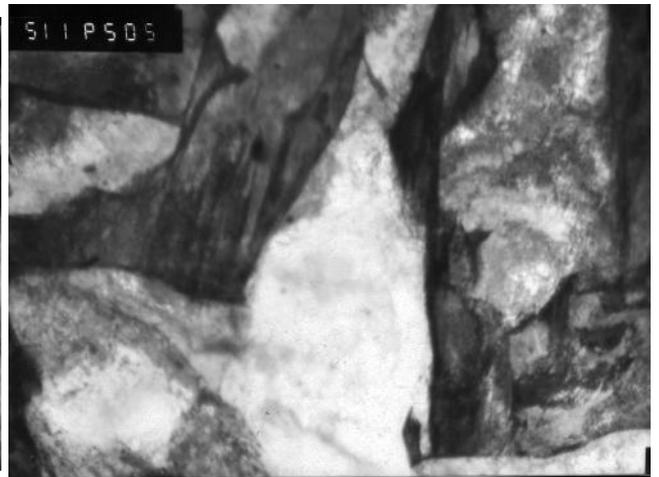
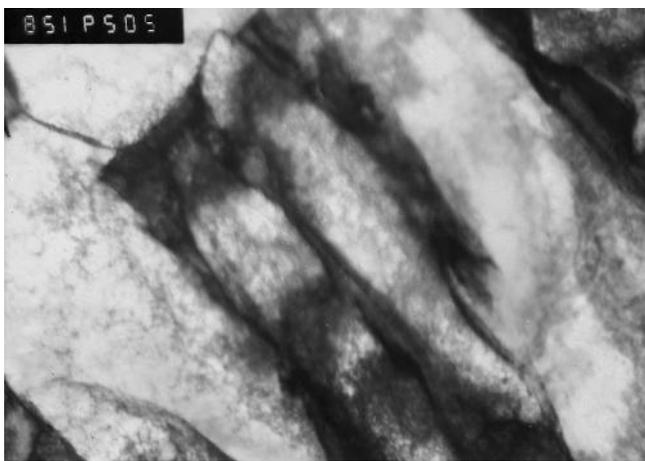
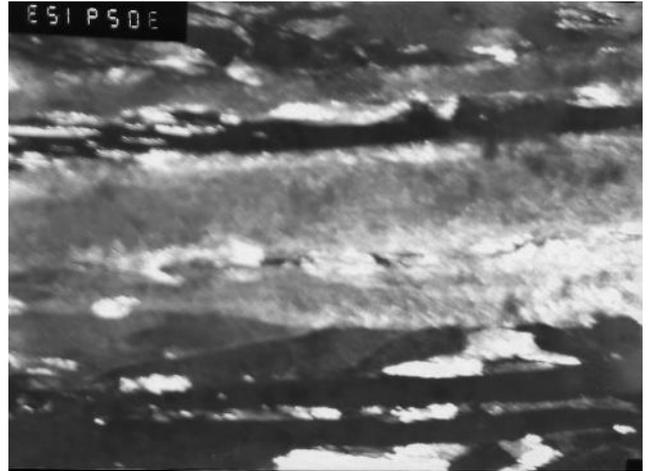
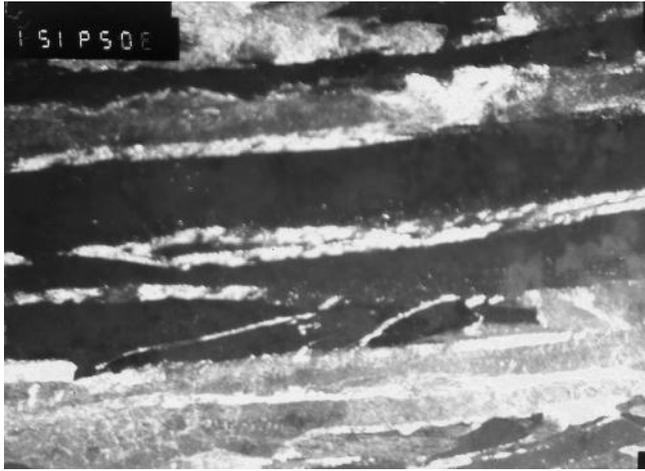
(. 7.2.2.6, 7.2.2.7).





- , 15000;
 , , - , 20000;
 - (-110), 20000;
 - .7.2.2.6 - 20 2 : 900° , 0,5
 , ; 800° , 0,5 ,
 70° /





- , 30000;
 - ;
 , - (110) , 30000;
 , - , 20000;
 .7.2.2.7 - 20 2 : 900° , 0,5
 , ; 800° , 0,5 ,
 70° /

,
830 ° ,
,

. 7.2.2.6 α- 0,1

(.7.2.2.7 ,).

« » (. 7.2.2.6 , 7.2.2.7).

830 °
755° 0,5
(60 %)

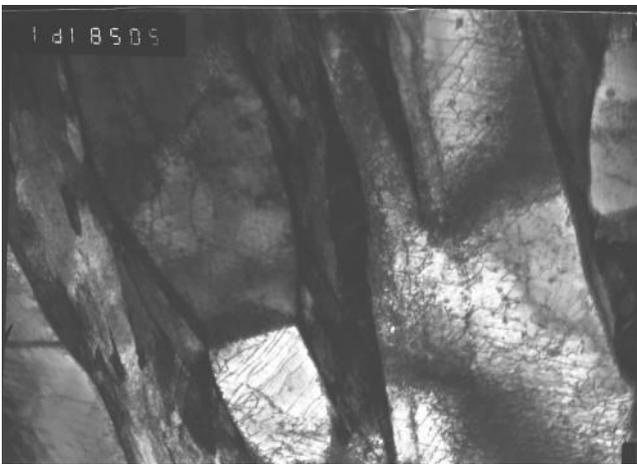
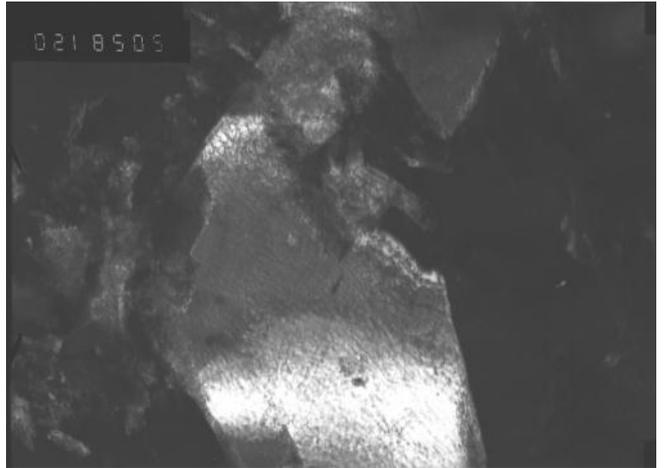
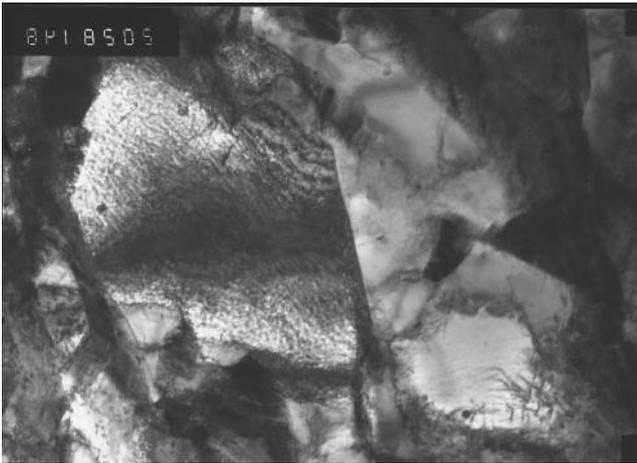
. 755 ° ,
830 ° 800 ° .
20 2 5-10 ° /

α-

α-

()

7.2.2.8

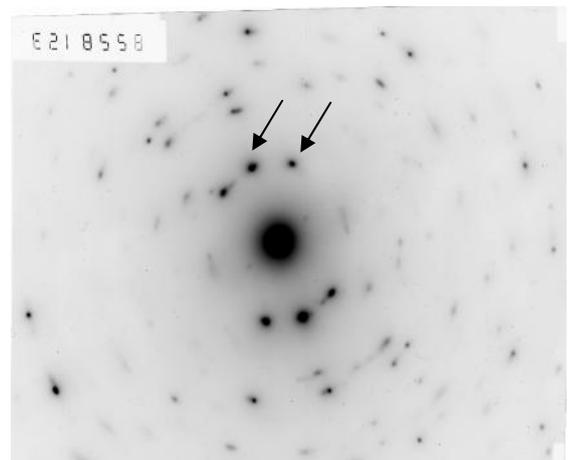
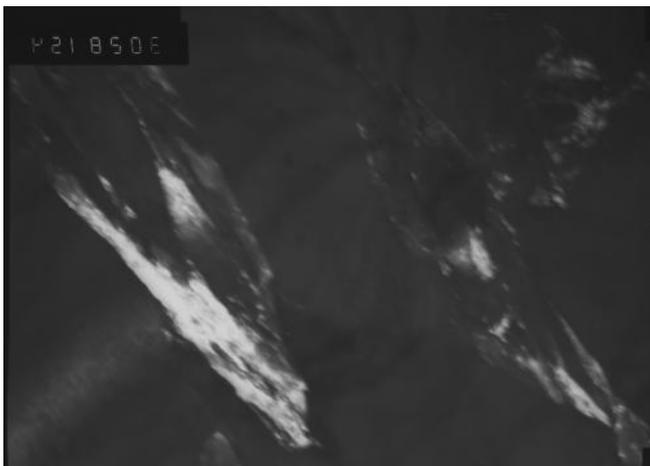
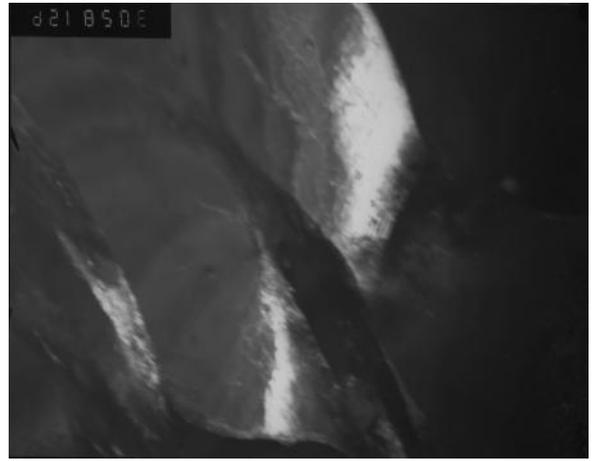
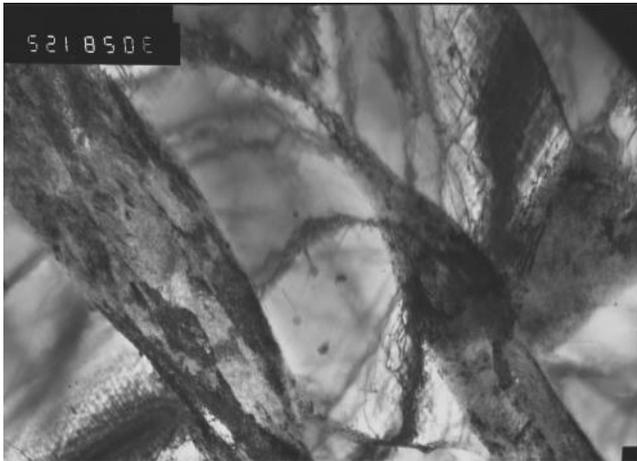


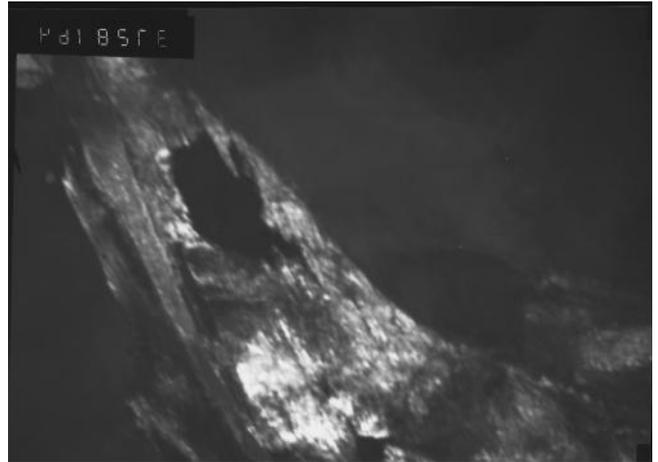
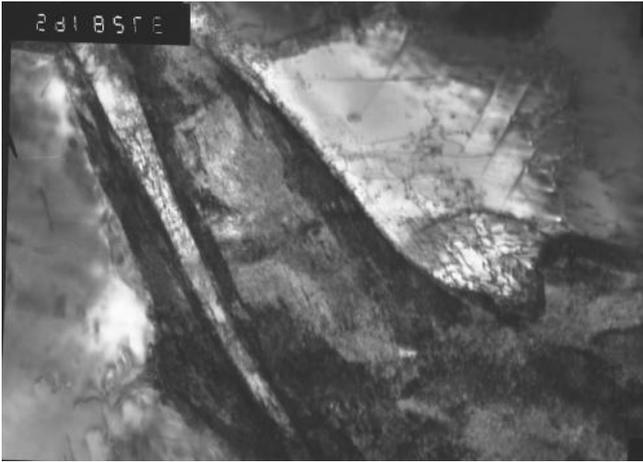
, , - , 20000;
 - , 30000;

. 7.2.2.8 - 20 2 :
 900° , 0,5 , ; 755° , 0,5 ,
 10° /

. 7.2.2.9 ,

- - « »
, « » ,
.
, . 7.2.2.9 ,
.
,
,
« ».
,
(. 7.2.2.9 ,).





- , 30000;
 , - 3.43 , 30000;
 -- 3.43 ;
 - , 37000;
 - 3.43 , 37000;

.7.2.2.9 – 20 2 : 900° , 0,5
 , ; 10° / 755° , 0,5 ,

(40 70 ° /)

(. .7.1.2.17).

(15000)

: α- (-) ,

(.7.2.2.10). α-

(.7.2.2.10).

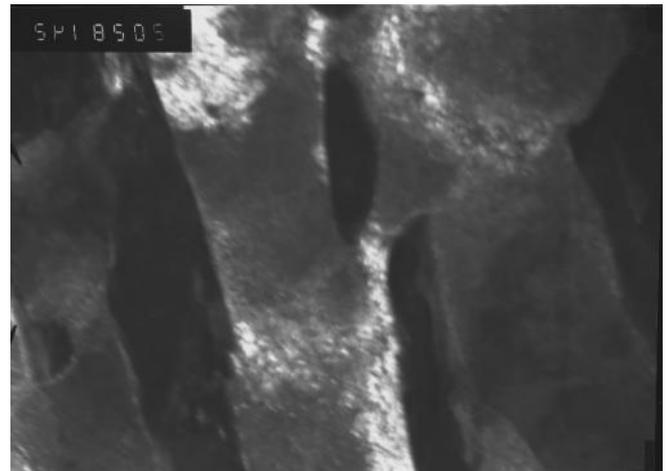
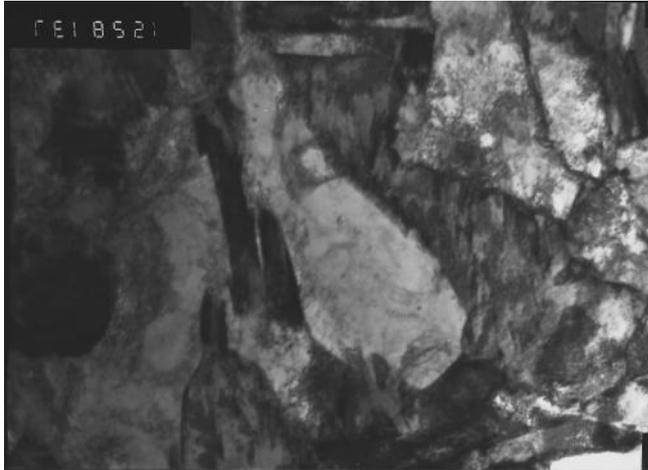
(.7.2.2.10 ,).

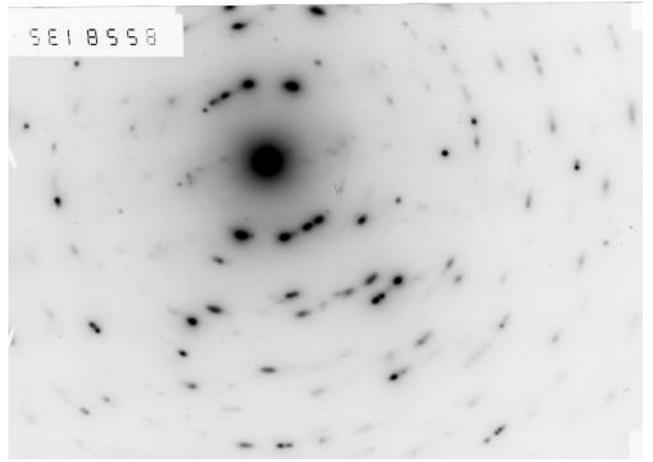
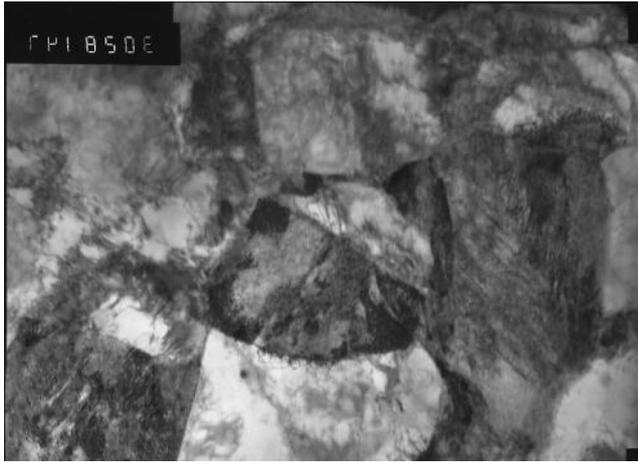
(. 7.2.2.10 , 7.2.2.11).

,

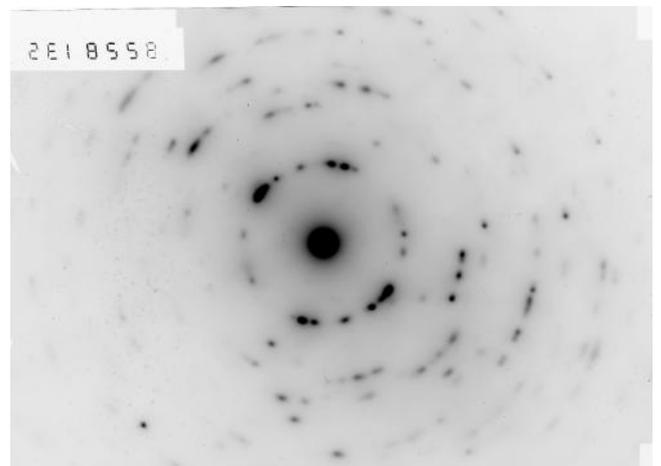
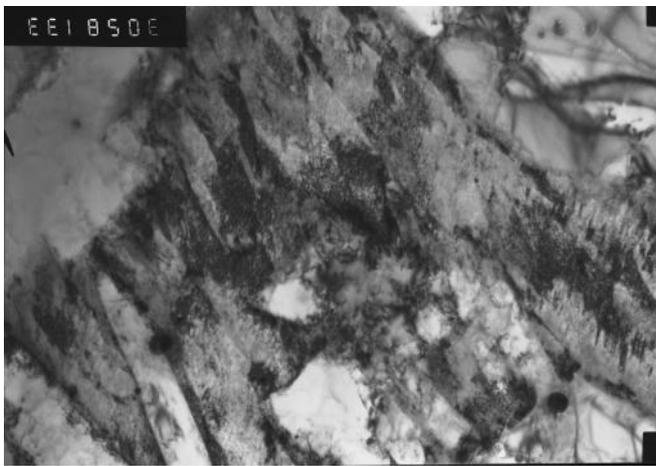
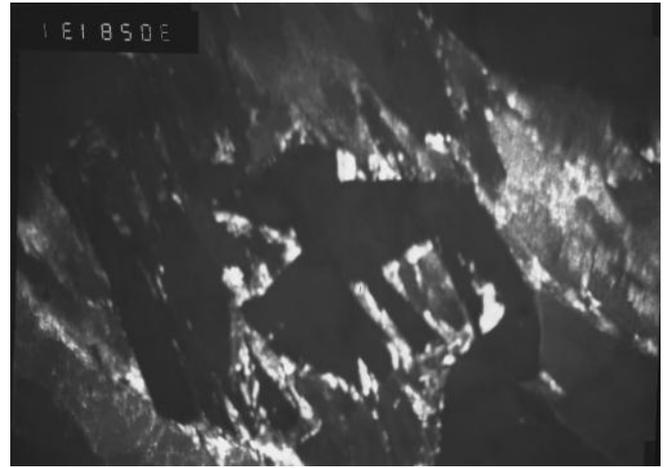
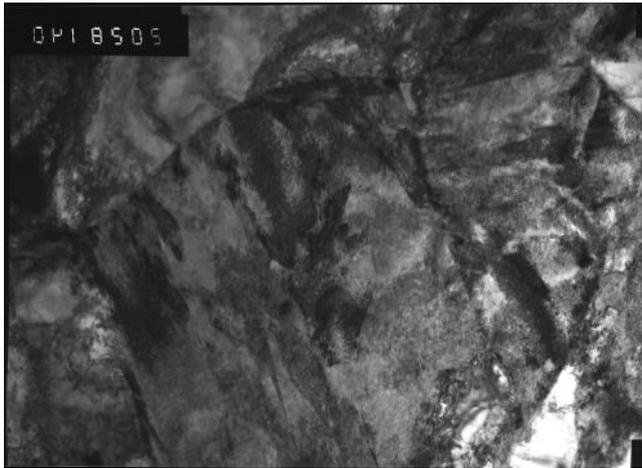
Fe_3C (. 3.44),

,





- , 15000;
 , - , 20000
 - . 7.2.2.10 , 20000;
 - , 30000;
 - . 7.2.2.10 ;
 . 7.2.2.10 - 20 2 : 900° ,
 0,5 , ; 755° , 0,5 ,
 70° /



- , 20000;
 , - .7.2.2.11 ;
 - , 30000;
 - .7.2.2.11 , 20000

 .7.2.2.11 - 20 2 : 900° ,
 0,5 , ; 755° , 0,5 ,
 70° /

,
 ,
 « ».
 755 °
 .
 ,
 α- (. 7.2.2.11)
 ,
 α- (. 7.2.2.11).

7.3

1. , 20 2 . 900 °

2. 20 2 0,1 ° / , α→γ

3. , 817-823° . 20 2

4. 830 ° , 800 ° 755° 5, 10, 20, 40 70 ° / .

5. 20 2

800-755°

6.

,

—

,

.

7.

,

20 2

.

755°

.

8

-

8.1

13

16

12

[106, 107, 92, 5, 3]

13

16-18

13

1317-006.1-

593377520-02

:

8.1.1

	σ , %	σ , %	δ_5 , %	KCV-50, / ²	%
1317-006.1- 593377520-02 (52)	372,4 491	509,6	23	98	50

8.1.2

	σ_{th} , %	CLR, %	CTR, %	, /
1317-006.1- 593377520-02 (52)	75% σ (279,3)	3	1	0,5

1317-006.1-593377520-02 (52)

9

5639,

2

5640.

5

« ».

Ø273 16

13

:

920° ,

;

840°

,

710° .

0,4-0,6 / .

.

.

«

»

« »

16

,

4,

13

830 °

760 °

r₃.

3

« »

(20-30%).

[84]

,

-

3,

[107, 108]

,

1

.

,

.

16

840° .

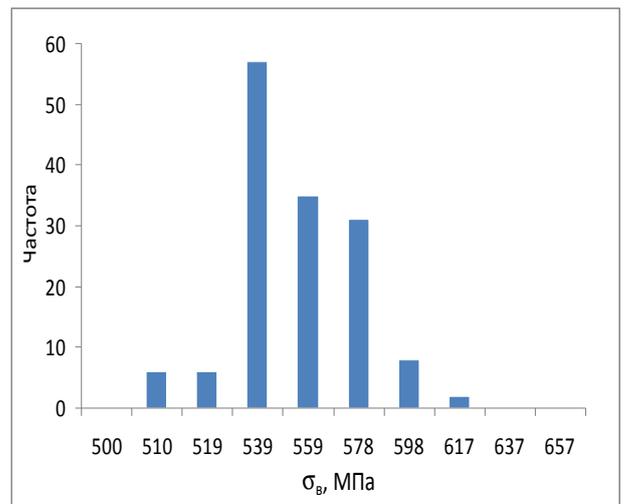
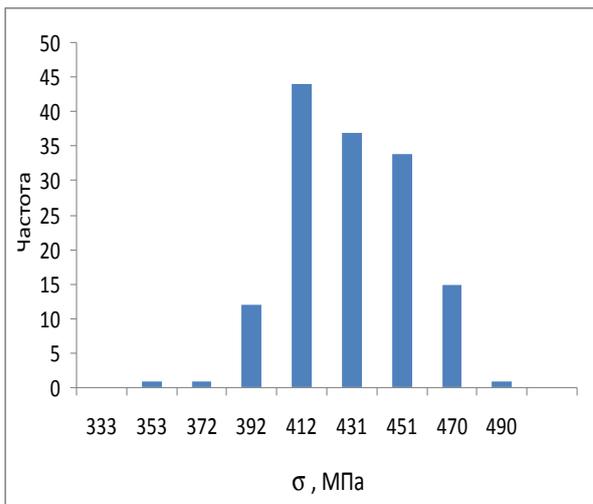
72

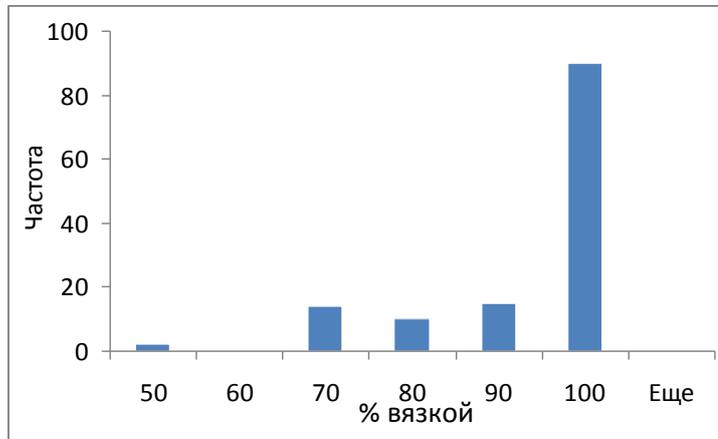
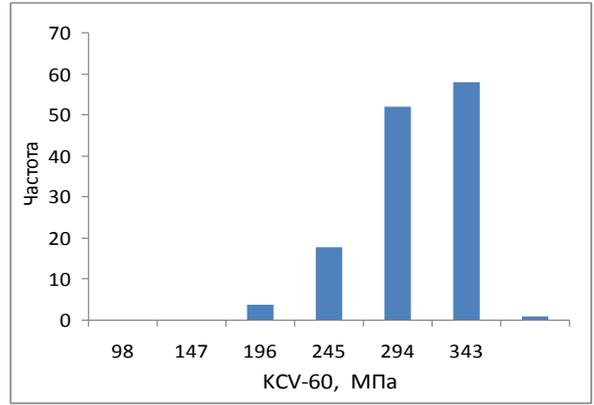
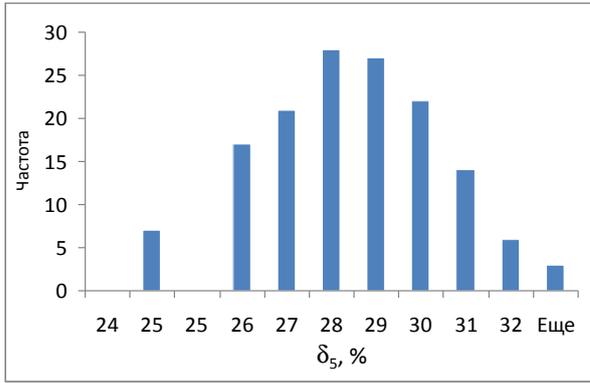
.

8.1.3

σ , МПа	343	475,3	422,8	23,1
σ , МПа	509,6	607,6	548,8	21,5
δ_5 , %	25	34	28,5	1,9
KCV-60 / σ^2 %	166,6	347,9	280,3	35,8
%	45	100	91,9	13,4

8.1.1 , ,





. 8.1.1

.
 1-2
 CTR 1%, σ_{th} 75%
 5640.
 1317-006.1-593377520-02: CLR 3%,
 0,5 / .
 NACE TM
 0284-2003,
 — NACE TM 0177-2005,
 — « »
 « »

,

1317-006.1-593377520-02 (52).

15

2015 .

8.2

20

13 20 , 4.5 « 20»

20 « »

20 , 273-426 8...14 , « »
14-158-114-99

8.2.1.

8.2.1

14-158-114-99	,	,	, %	/	KCV+20, / ²	KCV-50, / ²	, %
426 8...14	338,1-470,4	501,8-627,2	25	0,80	147	39,2	50

8

5639,

-

2

5640.

[9, 10].

0,02-0,05%

8.2.1.1.

1300° ,

950-1050° .

450-550°

500 (

. 2.6.1).

. «

»

« »

(7-8) , -

426 9...14

25-30%

(700-750°

850-950°).

$$D = \frac{4}{3} \cdot \frac{d}{f} \quad (8.2.1)$$

D - d f ,
 d_i $\frac{d}{f}$
 $\frac{1}{\sum_i \frac{f_i}{d_i}}$, ,
 V, Nb - . Al, Ti,

$$d^2 = sD \quad (8.2.2) \quad [102]$$

$$d^2 = s \int \frac{D}{V} dT \quad (8.2.3)$$

s - ,
 D - ,
 Al, Ti, V, Nb -
 1000° [102]

$$D_V = 6,81 \cdot 10^{-16} ; D_{Nb} = 0,11 \cdot 10^{-16} ; D_{Ti} = 7,53 \cdot 10^{-16} ; D_{Al} = 6,26 \cdot 10^{-16} \text{ }^2/ .$$

8.2.1

8

16 20 .

8.2.1.1

8.2.1.1

14-158- 114-99	, %								
		Mn	Si	S	P	V	Al	Nb	N
	0,17- 0,22	0,50- 0,64	0,17- 0,37	0,020	0,015	0,02- 0,05	0,03- 0,05	-	-
. 51110	0,20	0,64	0,26	0,019	0,012	0,04	0,05	0,02	0,008

8-9

0,01-0,03%.

40 .

0,02%.

: 1280-1300° ,

(1050-

950°),

700-750°

840-860° ,

780°

690° .

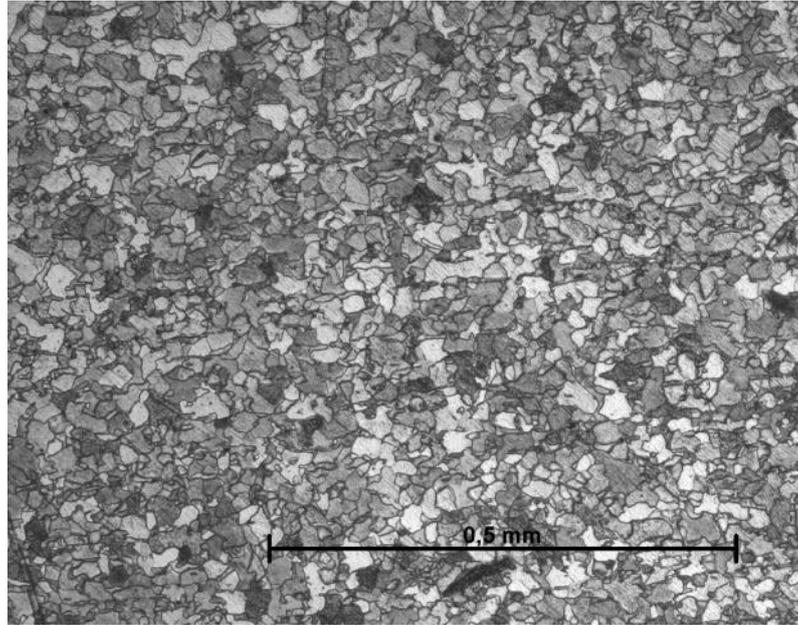
8.2.2

7-8-6 .

- 9-10 .

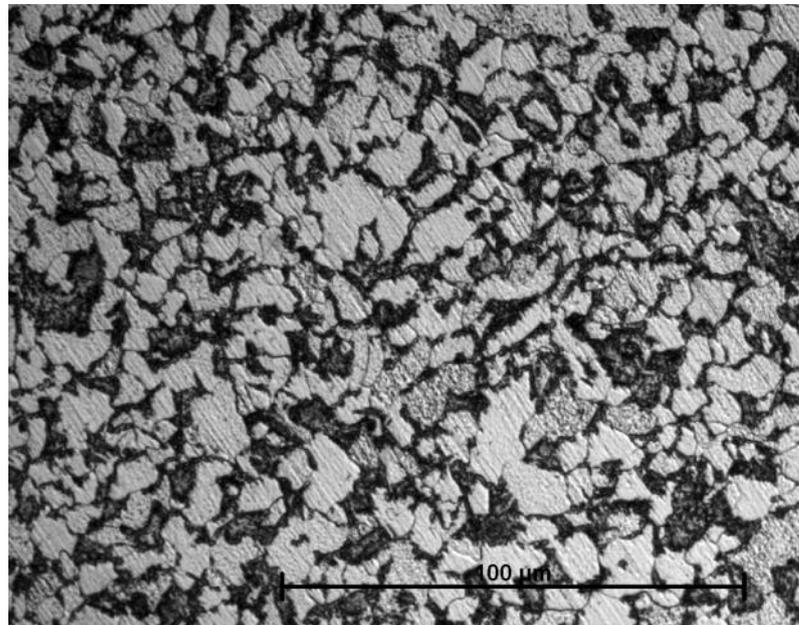
8.2.2.1,

8.2.2.2.



. 8.2.2.1

, 100

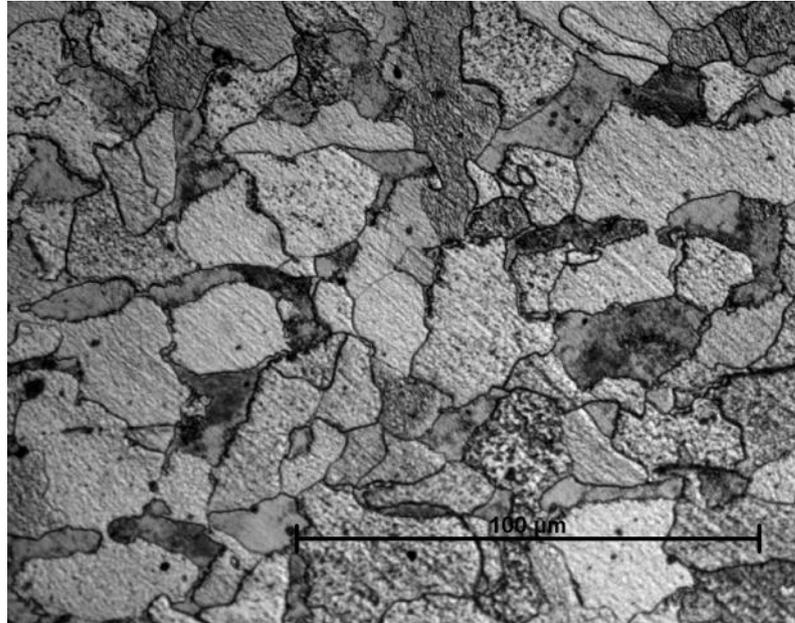


. 8.2.2.2

, 0,02% Nb, 500

, 20 , 8-9 (. . 8.2.2.3), . .

5639.



. 8.2.2.3

,
 , 500
 20 0,01-
 0,03% (0,02%Nb)

426 16 :

9-10

8.2.2.1.

8.2.2.1

14-158-114-99	,	,	, %	/ /	KCV+20,	KCV-	, %				
					/ ²	50, / ²					
	338,1-470,4	501,8-627,2	25	0,80	147	39,2	50				
,	,	,	,	,	238,14	228,34	100				
					217,56	255,78	100				
					396,9	539	31	0,74	226,38	243,04	100
					362,6	519,4	32	0,70	254,8	184,24	65
					250,88	247,94	78				
					250,88	171,5	65				
,	,	,	,	,	227,36	186,2	72				
					216,58	190,12	79				
					406,7	539	28	0,75	225,4	184,24	77
					367,5	539	26	0,68	238,14	174,44	78
					218,54	196	91				
					230,3	171,5	82				

$$\lg(\%Nb)(\%C + \frac{12}{14}\%N) = 2.26 - \frac{6770}{T} \tag{8.2.4}$$

[110]. (% Nb), (% C), (% N) –

20 (- 0,2% 0,008%)

().

3,

: 12 - 22 ° / .
 , 20,

12 . [111]

8.2.3

20 .

1)

(1-2)

3

2)

20

8.3

[56-61]

[84, 107, 108]

[90, 107],

13 20 ,

1000° (

),

13

[112]

r₃

r₁

C₃

, ... ,

()

8.3.1

16

426 32

13

8.3.1.1.

8.3.1.1

13

, %										
C	Si	Mn	S	P	Cr	Ni	Cu	Al	N	V
0,17	0,26	0,56	0,005	0,009	0,59	0,13	0,20	0,03	0,008	0,06

5,5

1: 920° ,

1,5 , ; 830° , 1,5

650° , 3 ,

2:

: 920° , 1,5 , 2,5-

3,5 (3);

830° , 1,5 ,

690° , 3 .

±10° .

-60°

V-

HRB,
(KCV-60),

8.3.2

1

8.3.2.1.

8.3.2.1

13 ,

/	, / ²	, / ²	5, %	KCV-60, / ²	%
1	40,5±3	54,6±3,5	30±4	5,1±3,2	32±27,5
2	41,5±4	53,5±3,35	30,8±4	26,5±10	80±20

KCV-60.

1,

426 32

« » (1030-1050°)

[112]

1

2.

3 [92],

426 32

13

900-500°

6-14° / (

2000

700

$\frac{\quad}{2}$).

13 (5, [106]),

3

8.3.2.2.

13

(σ , σ , δ_5)

20...-70° .

KCV

8.3.2.2

/	KCV- 20, / ²	%	KCV- 40, / ²	%	KCV- 50, / ²	%	KCV- 60, / ²	%	KCV- 70, / ²	%
2	31,6±0,5	100±0	26,2±0,5	83,3±15	25,6±1,4	81,5±8,3	27,7±5,7	86±14	22,6±2,6	75±5

2

13

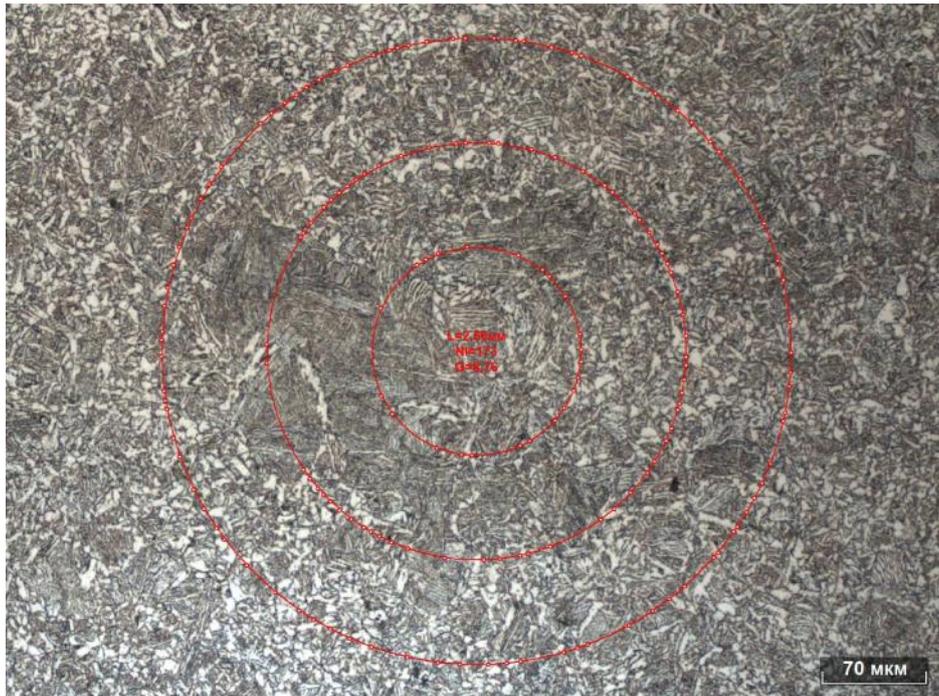
50%;

. 8.3.2.1

426 32

13

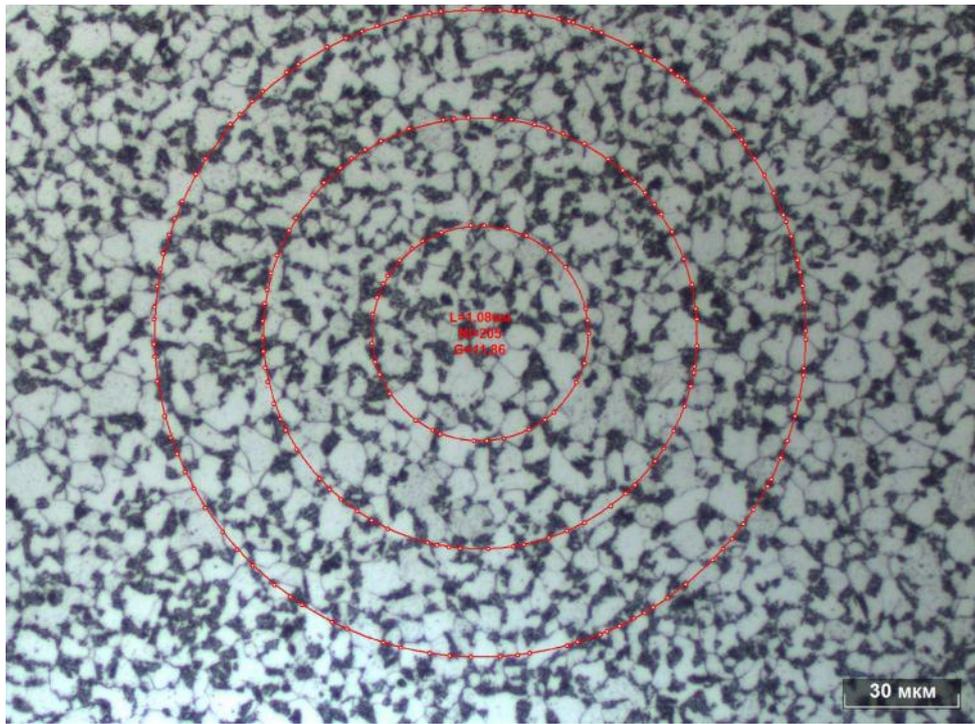
1.



. 8.3.2.1

. 8.3.2.2

2.



. 8.3.2.2

. 8.3.2.1, 8.3.2.2

:

1

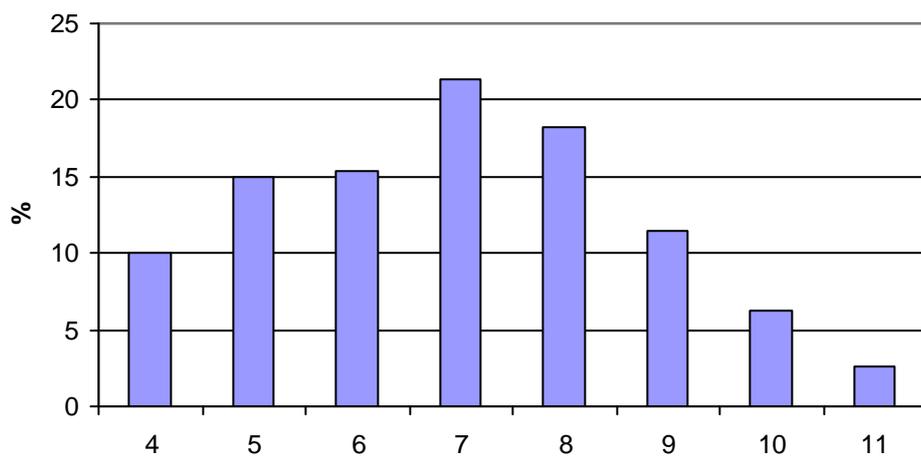
8-9

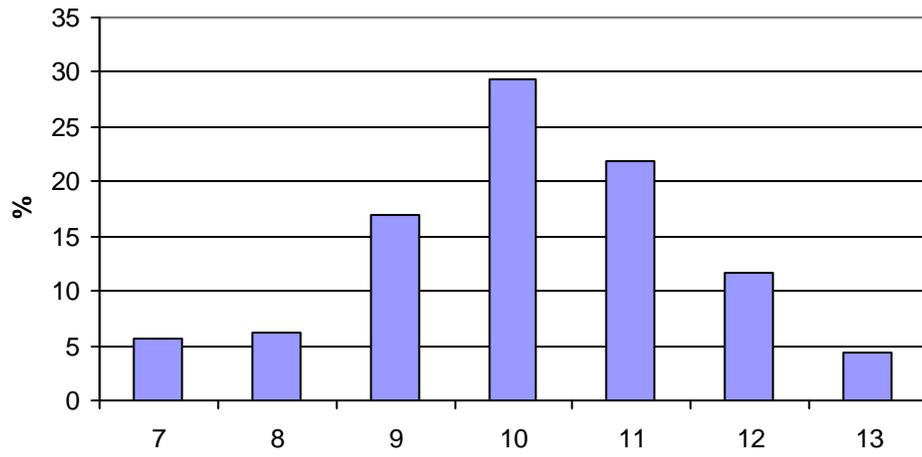
5-6,

2

10.

, Thixomet





. 8.3.2.3

1 , ,

,

,

2 - - .

,

-

-

[48, 104].

,

,

.

.

8.4

-

20 2

« »
20 2 .

:
8.4.1

	σ ,	σ ,	δ_5 , %	KCV-60,		%
				/	²	
14-158- 121-2005	379	655	14	50	35	50

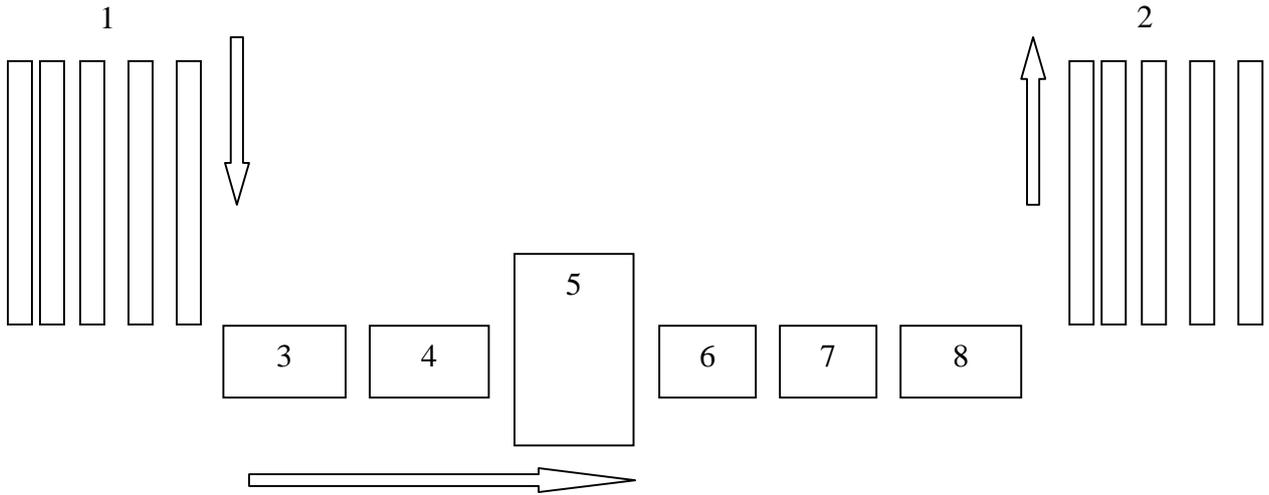
KCV-

60.

, , 20 2 ;

.
.
3 :

. 8.4.1 .



. 8.4.1

1, 2 – , 3,6- - ; 4, 7, 8 –
 - ; 5 – .

« »

1050°),

8.4.1

454 24

20 2

24 150 150 .

920±10° ,

(740, 750, 760, 780, 800, 820, 840, 860°) ±10° ,

600±10°

V-
9454 (3

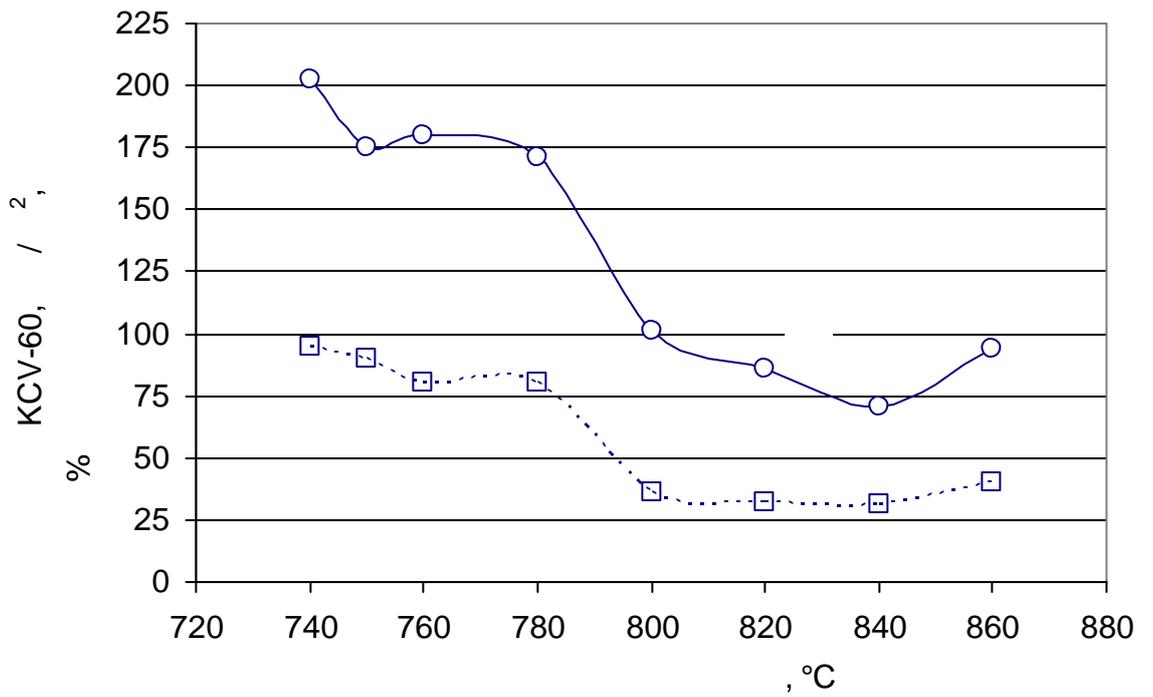
KCV-60
).
8.4.1.1.

8.4.1.1

		, %										
		C	Si	Mn	S	P	Cr	Ni	Cu	Al	N	Nb
20	2	0,18	0,30	1,40	0,005	0,008	0,80	0,10	0,10	0,04	0,008	0,05

8.4.2

. 8.4.2.1



. 8.4.2.1 —

20 2

—
20 2

;

1

,

.

3

-

-

-

,

,

..

30

[56].

,

820°

KCV-60

20 2 :

820±30°

780±30° .

670...700° ,

,

,

,

.

179

.

8.4.2.1.

,

15 3,3%.

3

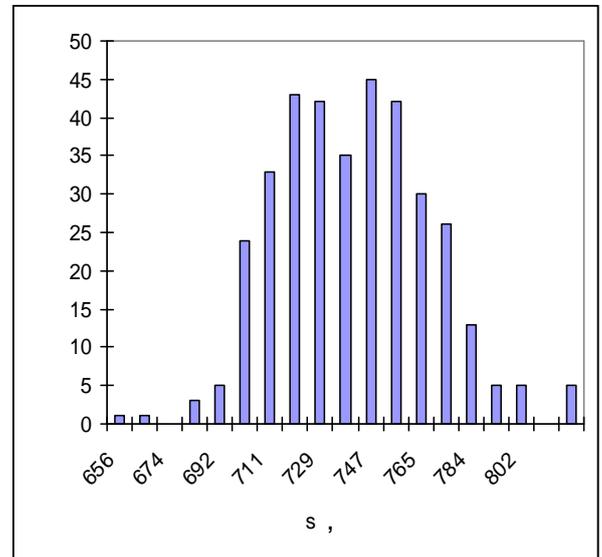
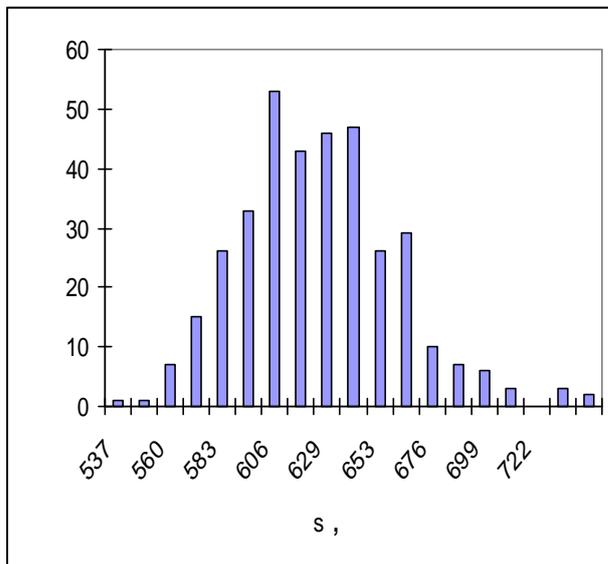
2

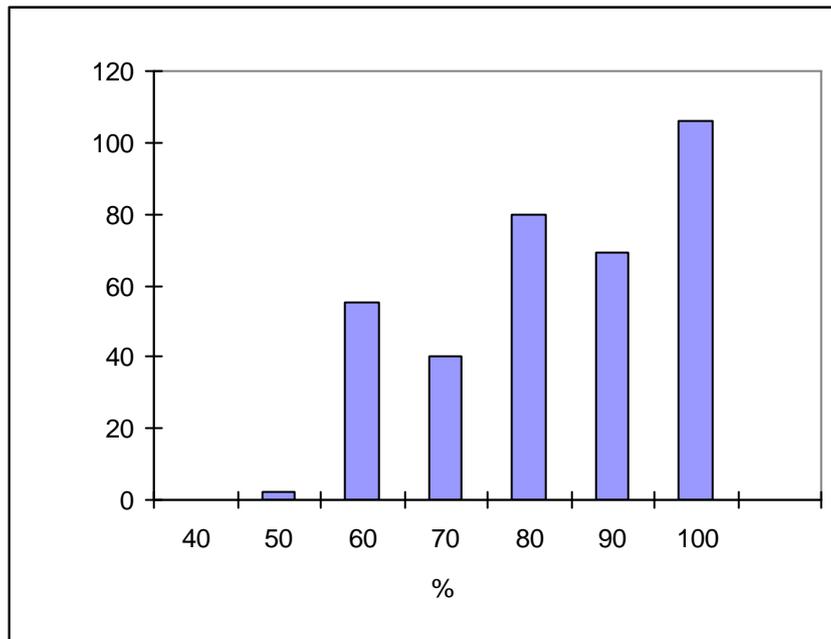
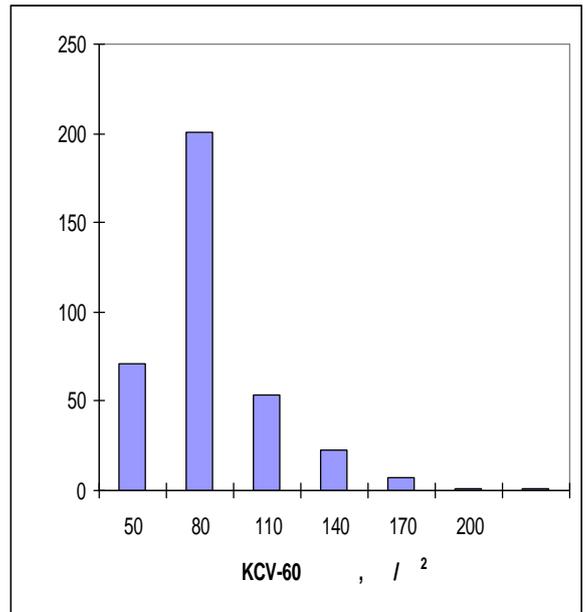
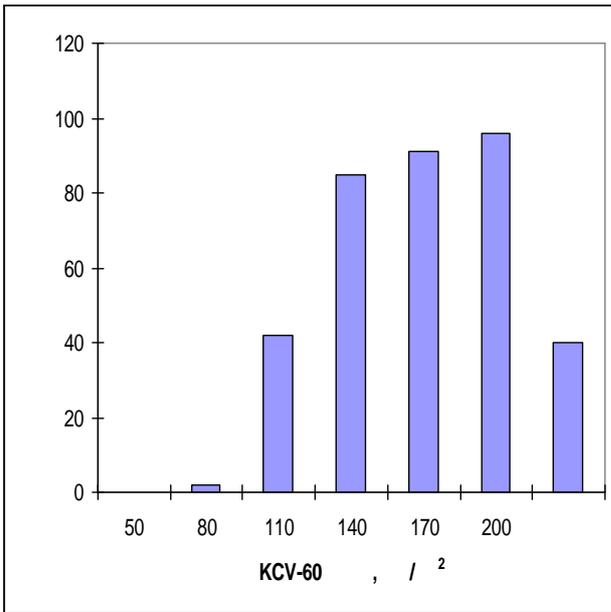
30 %.

8.4.2.1

σ ,	537	745	619,9	34,9
σ ,	656	820	736,5	27,7
$\delta_5, \%$	15,5	31	22,2	2,23
KCV-60 / ²	77	260	157	37,3
KCV-60 / ²	35	202	70,9	26,3
%	50	100	80,3	16,1

8.4.2.2 , ,





. 8.4.2.2

,

5 . / .

750-770° .

[107].

1.

,

2.

20 , 13 , 20 2

3

3.

.

4.

-

,

,

5.

.

,

,

.

13

1050°

900° - 770° .

,

-

.

,

.

800 ° 760 °

13

10, 20, 40 70 ° / .

800 ° 5 30

5,

(40-70

° /);

70 ° /

6.

13

KCV-80

1...800° ,

20 2

KCV-60

7.

3

20 (

) 13 :

)

20 .

(1-2)

3

20

, ,

)

13

16-18 ,

,

;

)

20 2 ,

;

)

13 .

1. API 5L 44
2.
7. 2005 . . 67
3.
. //
. - 1977. - 7. - . 53-56
4.
. 2002. 624 .
5. 1983. 1. . 63.
6.
. 4. . 13-18.
7.
. 2006. 240 .
8.
. 1984
9.
. 1998.
10.
11.
1998.

- - . 2008.
12.
- 13 .// - 2001, 7, . 48-50.
13.
- , 2007. .7. 2(33).
- 14.E. Anelli, D. Calleluori, J. C. Gonsales, J. Cumino. Sour service X65 linepipe for offshore special application. Proceedings of the eleventh (2001) international offshore and polar engineering conference.
- 15.X65 steel for seamless linepipe and risers for on- and offshore projects. www.vmtubes.com
16.
 , 1970. 368 .
17.
 , 1989. 288 .
18. 1982. 3. . 70.
19. 1981. 3. . 146.
20. /
 , 1982. 116-121.
21. 1979. 3. . 217.
22.
- 2003.
23.
 , 2005.

24. . . , . . .
//
. , 1964. 11.
25. . . . : ,
, 1990.
26. . . . : , 1957.
27.
- . 1970, . 22,
. 50, . 99-106.
28. Mitsutsuka M. // Tetsu-to-Hagane. 1983. 69 (2), p.268-274.
29. Sasaki K., Sugitani Y. // Tetsu-to-Hagane. 1977. vol. 63, p.184.
30. Ishiguro M. // Tetsu-to-Hagane. 1974. vol.60, p.464.
31. Nozaki T., Matsuno J., Murata K. // Trans. Iron Steel Inst. Jpn. 1978. Vol. 18, p. 330.
32. Bolle E., Moreau J.C. // Proc. Int. Conf. On Heat and Mass Transfer in Metallurgical Processes, Dubrovnik Yugoslavia. 1979, p.304.
33. Shimada M., Mitsutsuka M. // Tetsu-to-Hagane. 1966. vol.52, p.1643.
34. Bolle E., Moreau J.C. // Proc. Of Two Phase Flows and Heat Transfer. III. NATO Advanced Studies Inst.. London. 1976. p.1327.
35. Mizikar E.A. Iron Steel Ing., 1970. vol.47, p. 53.
36. Hodgson P.D, Browne K.M. Quenching and carburizing. 3rd International Seminar // Melbourne. Sept 1991. IFHT. p. 146-159.
37. Viscorova R., Sholz R., Spitzer K.-H. Advanced Computational Methods in Heat Transfer // IX Vol. 53 of WIT Transactions on Engineering Sciences. Southampton. S040 7AA. UK. p. 163-172.
38. . .
// . 12. 1964.
39. . .
// . 1976. 12.

40. //
 « ».
 1969.
41. Shimada M., Mitsutsuka M. // Tetsu-to-Hagane. 52 (1966). 1643.
42. //
 « ».
 , 1969.
43. , 8, 1966. . 46-50.
44. , 7, 1960. . 655-657.
45. : ,
 1980, 5. . 11.
46.
 , 1, 1983, . 23-24.
47.
 . . 3. . :
 , 1983.
48. : 1999.
49. : , 1986. 207 .
50.
 Al, Si, P, As Ni
 , 26, 1968.

51. . . ,
. 8, 1962. . 108-110.
52. . . ,
. , 2, 1968.
53. . . , . . ,
30 , 10, 1993.
54. Li Hong-ying, Li Yang-hua, Wang Xiao-feng, Liu Jiao-jiao, Xiao Pei-lu.
Effect of quenching process on mechanical properties and ductile-brittle
transition behavior of 28CrMnMoV steel. J. Cent. South Univ. 20:
1456–1461. 2013.
55. . . , ,
. -
.
. 1950.
56. . . , . . . « . . . »
. , 1, 1970. . 5-8.
57.
. 4, 1957. . 31-34.
58. . . , . . ,
. , 5, 1981.
59. . . , . . ,
. , 11, 2011.

60. Ovri Henry, Kamma Celestine Monde. Evaluation of the transformation mechanisms and mechanical properties of ferrite-martensite microalloyed steels. *Materials Research*, vol. 11, 1, 2008.

61. . . , (+) , 10 7. , 110, 2, 2010.

62. . 2148660. : . . .

63. 2112049. : . . .

64. . . , . . , . . 09 2

. , 8, 1994. . 15-17.

65. . . . 8, 1989, . 21-24.

66. . . . : , 1982. 127 .

67. . . , . . - . , 4, 2008. . 64-68.

68. . . , . . , . . , . . .

. , 87, 1, 1999.

69. . . , , 2, 1986. . 20-22.

70. . . ,

- « -2010». , 2010 .
71.
- . 2012.
72.
- . // , 2, 2011. .82-86.
73. Talip Y. Alp, Faisal I. Iskanderani. Development of HSLA steel for hydrogen service in oil and gas industries. Proceedings of the 6th Saudi Engineering Conference, KFUPM, vol. 5. December, 2002.
74.
- 42
- . // , 1, 2006. . 31-35.
75. : , 1989.
76.
- . // , 1, 1960. . 152-156.
77. 2. : , 1966.
78. Mathcad e. , 2000.
79. : , 1954.
80.
- . // , 12, 1977. . 1130-1132.
81. : , 1953.
82. : , 1975. 488 .

83.
05 2 2.// , 11,
1986. .31-34.
84.
.// , 4, .110,
2010. .417-423.
85.
. , 1994. 288 .
86.
.// , 4, 1999. .10-15.
87. //
, 7, .67, 1981. .852-866.
88.
, 1973. 205 .
89.
.1992.
90.
.// , 7, 2012.
.744-755.
91.
.//
2. , 1983. .83-92.
92.
.// , 8, 2010. .37-41.
93.
. , 1963. 311 .

- . 1035-1044.
107. // , 10. 2012. . 113.
- . 1035-1044.
107. //
- . 39. 2012. . 71-78.
108. //
- . 6. 2014. . 115. . 656-663.
109.
- . . : , 1985. . 83-84.
110. Irvine K.J. et al. Grain refined C-Mn steels. Journal of the Iron and Steel Institute. 1967, 25:2, Feb., p. 161-182.
111.
- 14 . . :
- . -
- , 1(1285). 2007. . 36-38.
112.
- « . » . , 1973, . 208.

УТВЕРЖДАЮ

Начальник отдела производственных технологий-главный технолог ОАО



В.П. Пашнин

2016 г.

Акт

о внедрении новой технологии термической обработки нефтегазопроводных труб из стали 13ХФА и хладостойких обсадных труб из стали 20ХГ2Б

На индукционных установках цеха №5 внедрена новая технология термической обработки труб из стали марки 13ХФА по ТУ 1317-233-00147016, ТУ1317-006.1-593377520 групп прочности К48-К52. Новая технология включает следующие особенности:

1. Для нефтегазопроводных труб с толщиной стенки 11 мм и более из стали 13ХФА проводится двойная закалка, причем первая закалка с температуры выше A_{c3} , а вторая от температуры $840\pm 30^{\circ}C$, после закалки из межкритического интервала проводится высокий отпуск;
2. Для хладостойких обсадных труб из стали 20ХГ2Б проводится двойная закалка, причем первая закалка с температуры выше A_{c3} , а вторая от температуры $780\pm 30^{\circ}C$, после закалки из межкритического интервала проводится высокий отпуск.

Внесены изменения в технологическую инструкцию. При использовании новой технологии стабильно обеспечивается выполнение норм технических условий по механическим свойствам, микроструктуре и коррозионной стойкости.

Экономический эффект от выполнения заказов составил 20 млн руб за 2015 год.

Главный специалист по производству
бесшовных труб

К.Э. Бубинов