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: . . .

2010

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7.						134
8.						136
9.						137
10.						138

). μ μ (μ μ
, μ μ
μ μ

μ μ
μ μ

μ μ μ μ μ μ

(electrodeposition).

μ Ni-W, Ni-P, Co-Zn

μ μ

μ μ μ μ

μ μ 8 μ

(μ μ μ μ)

Ni-W μ

% μ μ μ

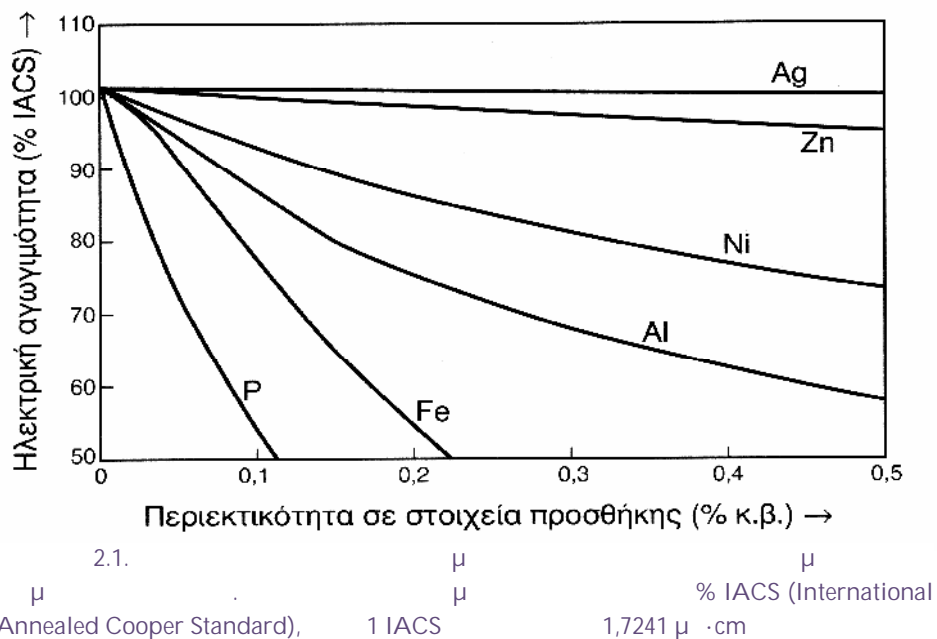
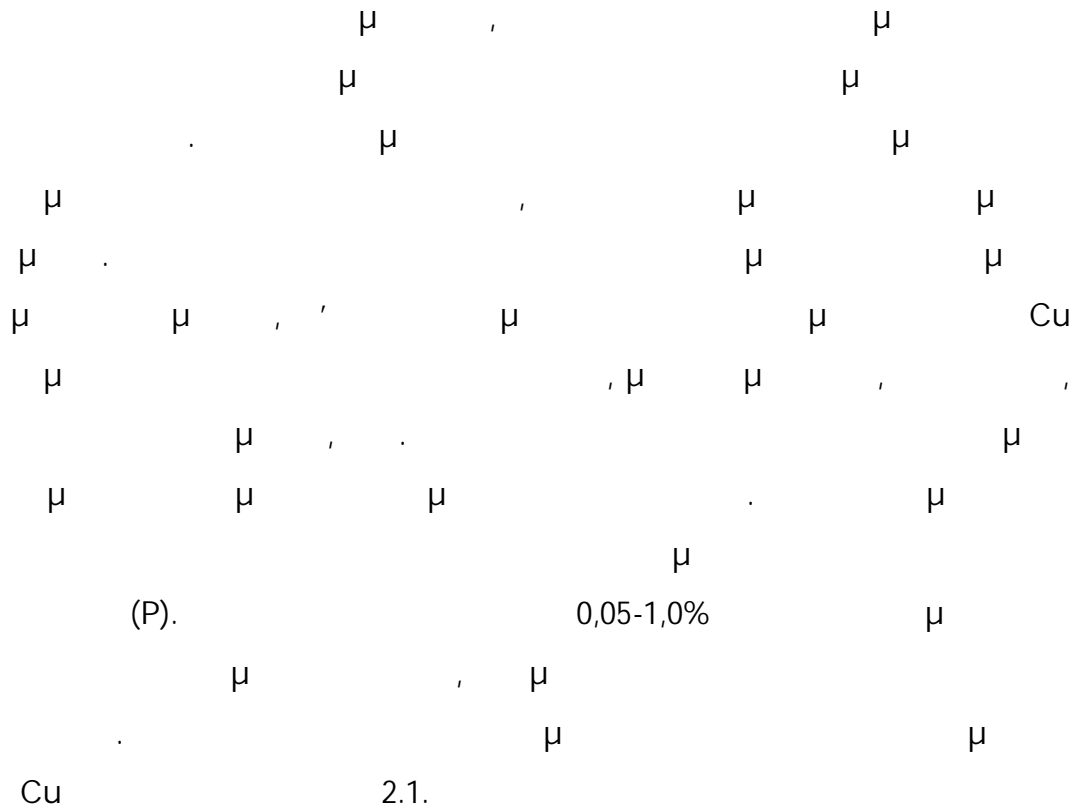
μ μ μ μ

μ μ μ

2.

2.1

2.1.1.



2.1.2. μ - μ

μ :

- μ Cu-Zn, μ
- μ Cu-Sn, μ μ
- μ Cu-Al, μ μ
- μ Cu-Ni, μ
- μ Cu-Zn-Ni, μ Maillechts
- μ Cu-Be, μ
- μ Cu-Si, μ

μ μ μ , μ :

μ μ μ .

μ μ μ μ μ

μ (2.1).

μ ()	0	0
μ 1/4	11	21
μ 1/2	21	37
μ 3/4	30	50
(4/4)	37	60
	50	75
(R)	60	84
	69	90

2.1. μ μ μ μ μ

μ CDA (Copper Development Association), μ
 μμ C, μ μ ,
 μ (μ
), μ (xx) μ (2.2.)

C1XX	(min 99.3% Cu)	μ
C2XX	μ 96-99,3%Cu	
C3XX	μ Cu-Zn ()	
C4XX	μ Cu-Zn-Pb (μ μ)	
C5XX	μ Cu-Zn-Sn (μ)	
C6XX	μ Cu-Al (μ)	μ Cu-Si
C7XX	(μ Cu-Ni ()	μ Cu-Ni-Zn (Maillechorts)
C8XX	, μ μ μ	
C9XX	μ Mn μ Cu-Zn-Si	
	μ Cu-Sn, Cu-Sn-Pb, Cu-Sn-Ni, Cu-Al-Fe	
	Cu-Ni-Zn	

2.2. μ μ , CDA.
 μ
 μ
 μ μ 39% . . (μ
 454°C), μ μ
 FCC μ - μ μ ,
 μ μ μ
 μ μ μ
 μ BCC .
 μ + μ μ .
 μ Muntz μ μ μ μ .

μ μ , μ , μ , μ
 μ μ .
 μ , μ , μ . μ
 μ . μ , μ ,
 μ μ . μ μ ,
 μ : μ μ 1400MPa (200.000psi),
 μ , μ .
 μ , μ μ . μ
 μ μ μ . μ
 μ μ 1,0 2,5 wt%. μ μ
 μ μ μ , μ ,

2.2

2.2.1

μ μ
 μ μ μ

2.2.2 μ

μ , μ μ μ
μ , μ μ
:

➤ _____ :
μ μ μ , μ
μ .
μ , μ

➤ _____ :
μ μ μ μ μ μ
μ μ
μ , μ
μ μ μ μ .
μ μ μ μ μ
μ μ .
μ , μ
μ
(μ), μ (μ), μ μ μ
μ .

➤ _____ :
μ μ μ μ
μ μ μ μ
μ , μ
μ μ .
μ .

2.2.3 μ μ

- μ μ μ :
 - μ , ,
 - μ ,
 - μ ,
 - μ ,
 - μ , , , ,
 - μ , , , , ,
 - laser, , , , ,
 - μ , , , , ,
 - μ : μ
 - μ , , , , ,
 - μ , , , , ,

μ , μ , μ

μ , μ

μ , μ

μ (μ) μ

μ , μ

μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ

μ
 μ 150
 μ μ
 μ μ μ μ
19
 μ μ
 μ μ
" " μ μ
 μ μ
 μ
R.Böttger (1843) μ
, R.Böttger μ
 μ $\mu\mu$
1878 E.Weston
pH μ
. 1900 R.Springer
 μ
 μ μ 1916
O.P.Watts, μ
 μ μ
 μ μ μ μ
 μ μ μ μ
 μ μ μ μ

μ . " Watts",
 μ μ
 μ μ
 μ μ .
 μ μ .
 μ μ '60, μ μ
 μ μ
 μ μ .
 μ μ ,
 μ μ .

[2.2.5](#) μ

 μ

- μ
- ' μ , μ ,
 - μ , μ :
 - μ , μ ,
 μ i_p , μ ,
 pH .
 - ,
 - μ ,
 μ (direct current),
 μ μ μ (pulse current) μ μ
 (pulse reverse current).
 - μ μ

•

μ

μ μ μ μ

2.2.6

μ μ

μ

μ , pH

μ μ μ μ

μ

μ

μ μ μ

μ μ μ μ

[hkl], μ μ

μ μ μ μ μ μ

μ μ μ μ μ

μ μ μ μ μ μ

μ μ μ μ μ μ

μ μ μ μ μ μ

μ μ μ μ μ μ

μ μ μ μ μ μ

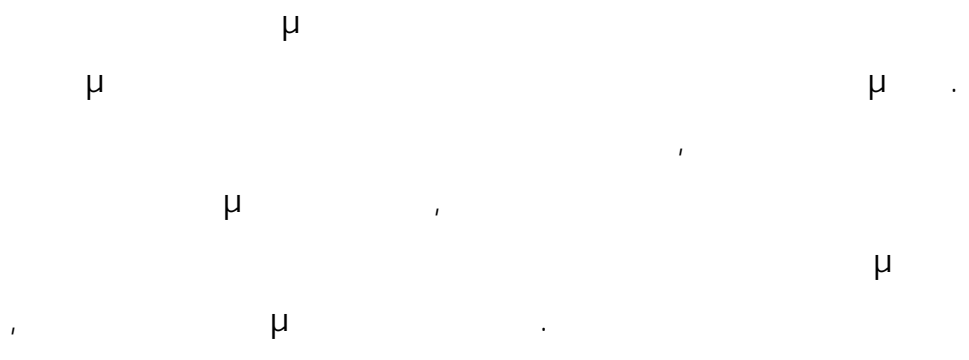
μ μ μ μ μ μ

μ μ μ μ μ μ

μ μ μ μ μ μ

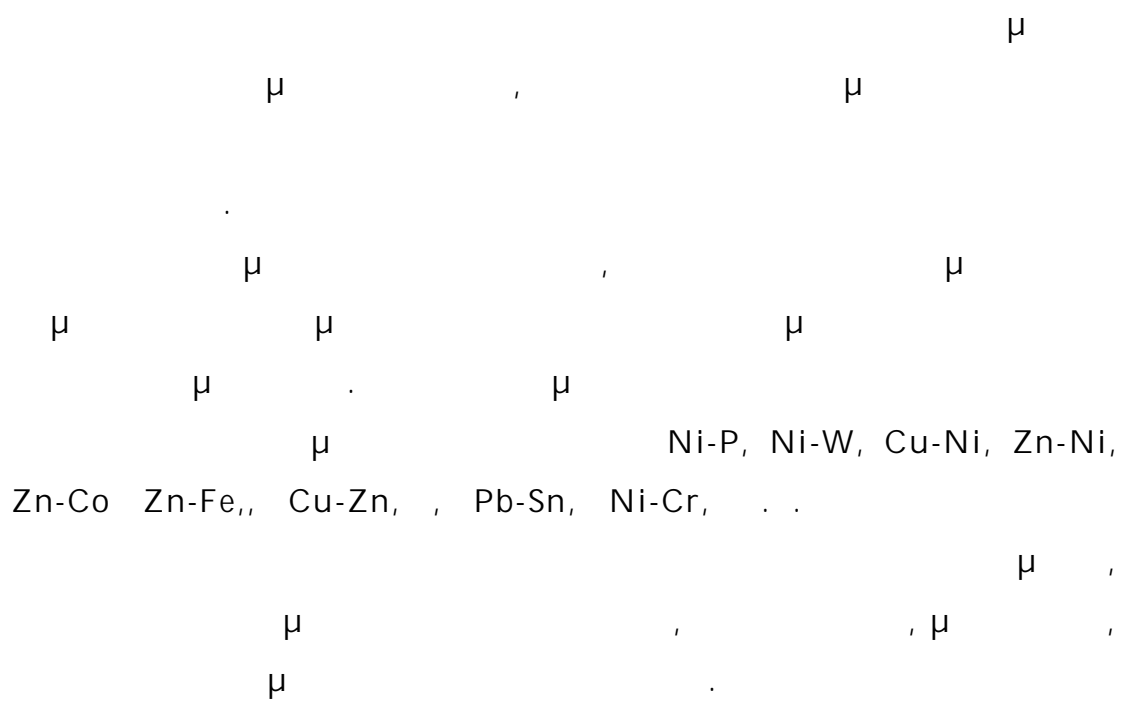
μ μ μ μ μ μ

μ μ μ μ μ μ



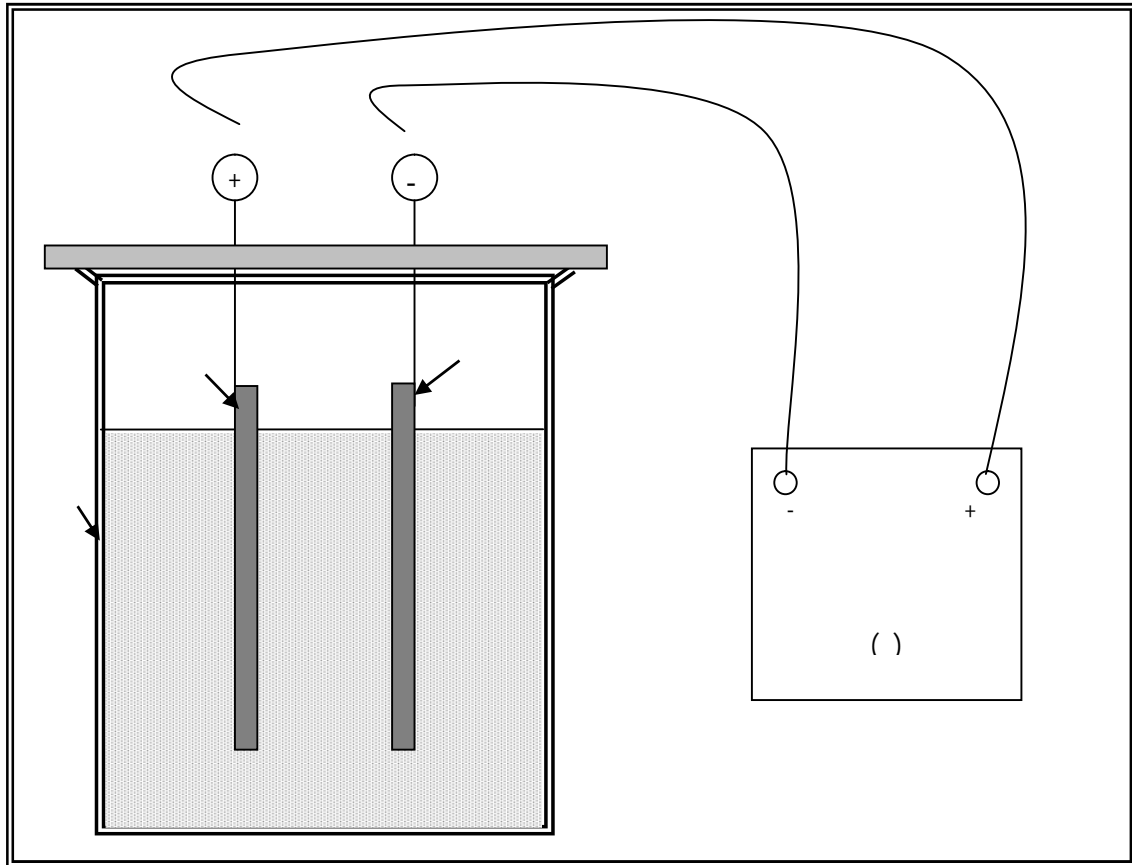
2.3

2.3.1



$\mu \mu$
 μ

2.2.



2.2.
(),

()

μ

μ ()

(),

(),

(),

(),

$\mu \mu$

μ ()

$\mu \mu$

$\mu \mu \mu$

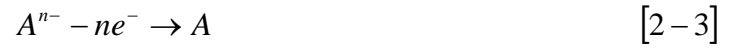
μ , μ .
(μ) μ
μ , μ (2-1), μ μ
μ μ
μ .



μ , μ μ , μ pH
μ , μ μ
μ μ μ
μ μ μ
μ μ μ
μ μ μ (Mⁿ⁺)
μ μ μ (2-2), μ μ
μ μ (Mⁿ⁺)
μ μ (M).



μ μ μ
μ μ μ
μ μ μ (Aⁿ⁻), μ μ
μ μ μ
μ (A) μ μ μ (2-3).



μ ,
 μ ,
 μ , μ (M) μ
 μ (M^{n+}) μ
 μ μ μ μ . μ
 μ
 :



Faraday. μ μ μ , μ μ ,
 μ I ,
 μ ,
 (2-5)

$$m = \frac{AIt}{nF} \cdot \beta \quad [2-5]$$

m μ μ μ , A μ
 μ , n , t
 μ , F Faraday (μ)
 Avogadro x) β
 μ . O μ
 μ ,
 μ ,



μ , μ μ μ
 μ μ μ μ μ μ
 μ μ μ μ μ
 μ μ μ μ μ μ
 μ μ μ μ μ μ

2.3.5 μ

μ μ μ μ μ μ
 μ μ μ μ μ μ
 μ μ μ μ μ μ
 μ μ μ μ μ μ
 μ μ μ μ μ μ

Nernst Helmonltz.
 adion.
 adion
 adions
 adions

adions. μ μ
 μ

,
.
 μ
 μ μ .
 μ μ
 μ μ μ μ ,
 μ μ μ μ μ .

2.4 μ _____

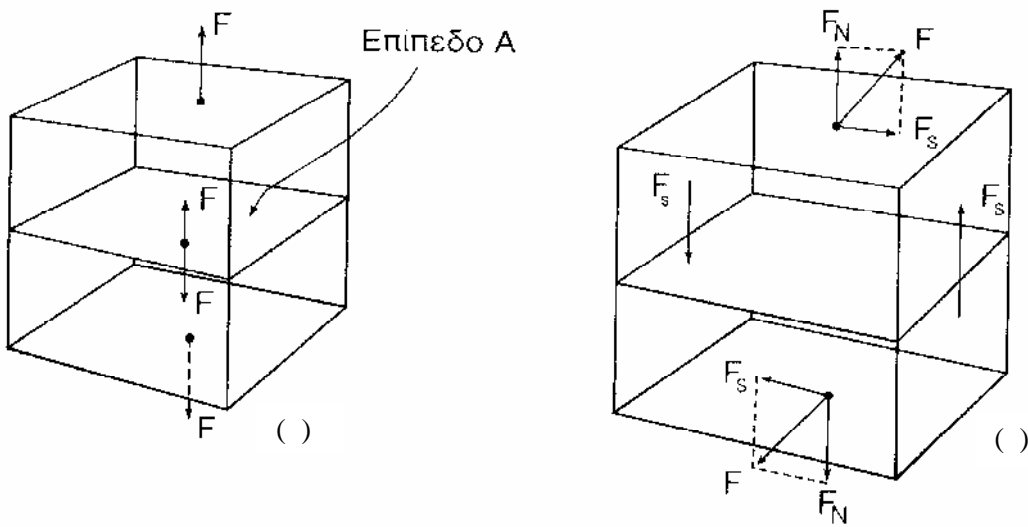
2.4.1 _____

μ
 μ , μ , μ
 μ ,
 μ μ μ ,
 μ μ μ μ μ ,
 μ μ , μ
 μ .
 μ μ μ , μ
 μ , μ ,
 μ . μ μ
 μ

(μ , μ pH
),
 μ μ μ .
 μ , μ 35 85 μ
 μ .
 , μ 14 μ
 . μ (Cr), μ (Mn), (Fe),
 (Ni), (Co), (Cu), μ (Cd), (u),
 (In), μ (Pb), (Rh), o (Ag), o
 (Sn) (Zn). μ μ
 μ μ μ . ,
 μ , μ
 μ μ () μ μ
 μ (2.4). μ
 , μ μ μ μ .
 μ - , - , - , -
 .
 μ μ μ ,
 μ μ
 μ μ μ
 μ .
 μ μ , μ
 μ .

μ (μ ,
),
 μ μ .
 μ - μ
 30°C μ $1/40$ μ μ
 (UNS 530400)
 μ μ μ .
 μ 650 800 HVN, μ
 μ 190 600°C 12 μ 24
 1200 μ 1400 HVN.
 μ μ μ
 μ μ μ μ
 (barrier coating) μ μ
 (capping layer) μ
 μ μ μ (MEMS). μ
 μ (Microelectromechanical Systems – MEMS) μ
 μ μ (μ μm) μ
 μ μ μ MEMS μ
 μ μ μ μ MEMS
 μ .
 μ , μ μ ,
 μ μ .
 μ μ μ
 μ Na_2WO_4
 μ ,
 (codeposition) μ (NiSO_4), μ
 μ μ Ni-W.

μ , μ μ (F_N) : μ (F_s). μ μ μ μ = $F_N /$.



2.6.: μ μ .

μ μ μ μ μ :

$$\tau = \frac{F_s}{A} \quad [2-7]$$

μ (μ) μ SI $N\ m^{-2}$, Pascal(Pa). μ

μ μ μ μ

μ μ μ $10^6 Pa$, Megapascal (MPa).

μ

()

∴

1. μ

μ

2. μ

μ

3. μ

μ

4. μ

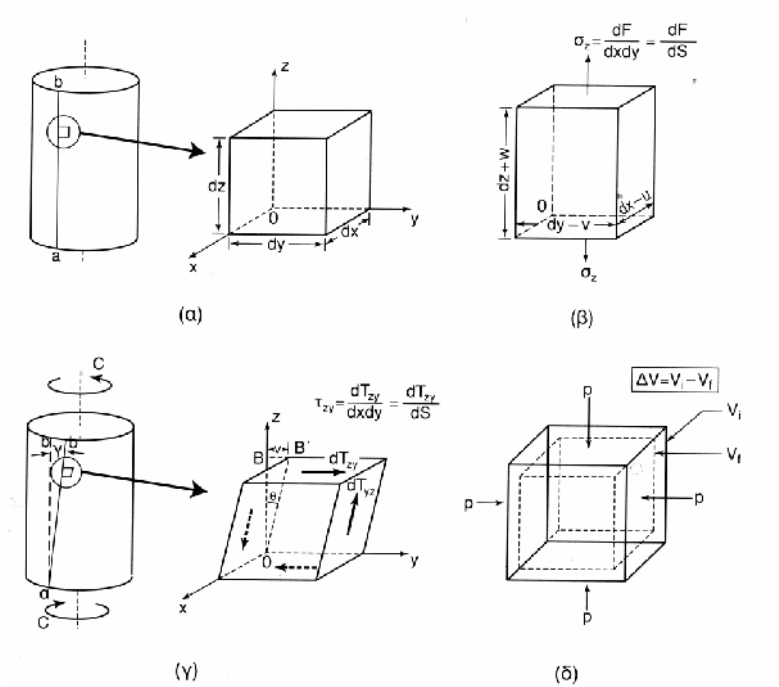
2.5.2.2 μ

()

μ

μ

μ



2.7.: μ
dx dy dz. ()

μ

μ

()

μ

()

μ

()

μ

(dx, dy, dz) , 2.7, μ
 (u, v, w) . μ
 μ :

$$\epsilon_x = \frac{u}{dx}, \quad \epsilon_y = \frac{v}{dy}, \quad \epsilon_z = \frac{w}{dz} \quad [2 - 8]$$

μ , μ

μ μ

μ :

$$\nu = - \frac{\text{πλευρική παραμόρφωση}}{\text{αξονική παραμόρφωση}} \Rightarrow \nu = - \frac{\epsilon_y}{\epsilon_z} = - \frac{\epsilon_x}{\epsilon_z} \quad [2 - 9]$$

μ Poisson, μ 0,25
 0,40. μ , =0,33.

μ μ μ

μ 100.

2.5.2.3 μ Hooke

$\mu\mu$ μ μ μ ,
 μ Hooke.

μ , x :

$$\sigma_x = E \cdot \epsilon_x \quad [2 - 10]$$

μ μ μ Young.

μ :

$$\tau = G \cdot \gamma \quad [2 - 11]$$

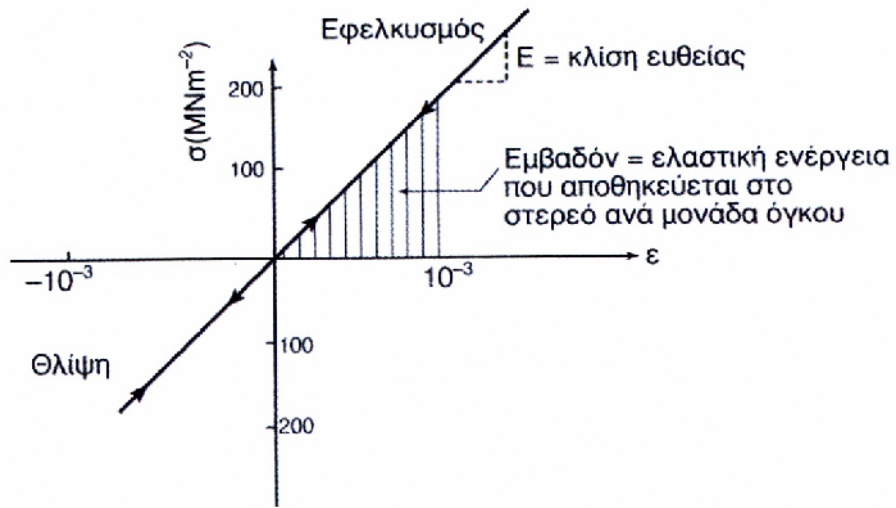
G , μ μ .

1 Gigapascal = 10^9 Pa).
 GPa (1GPa=

Hooke) (μ)
 . μ ,
 μ μ μ (=0,001 0,1%).
 μ μ μ μ μ .
 μ () μ
 (400 500%), , μ
 μ (0,01 1%) μ $\mu\mu$ μ
 μ .
 μ μ μ μ $\mu\mu$ -
 μ (-).

2.5.2.4

μ , μ μ
 . μ , μ
 μ . 2.8 μ -
 $\mu\mu$,
 μ Hooke (= •). μ $\mu\mu$
 μ . ,
 μ .



2.8.: μμ - μμ

μ

μ

μ

(

μ

μ

) μ

μμ

μ

,

μ

μ

2.9.

2.9

μ

μμ μ

μ

100%

2.9

μ

μ

μ

μ

Hooke.

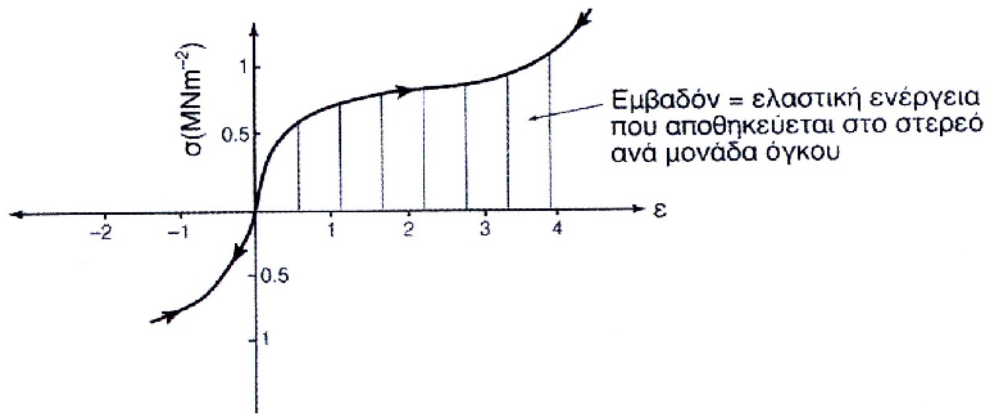
μ

μ

μ

μμ

μ



2.9.: μm - μm .

μ 2.10

μ μ

μ μ

μ , μ " μ "

μ μ μ -

μ μ μ μ

μ μ μ μ

μ μ μ μ

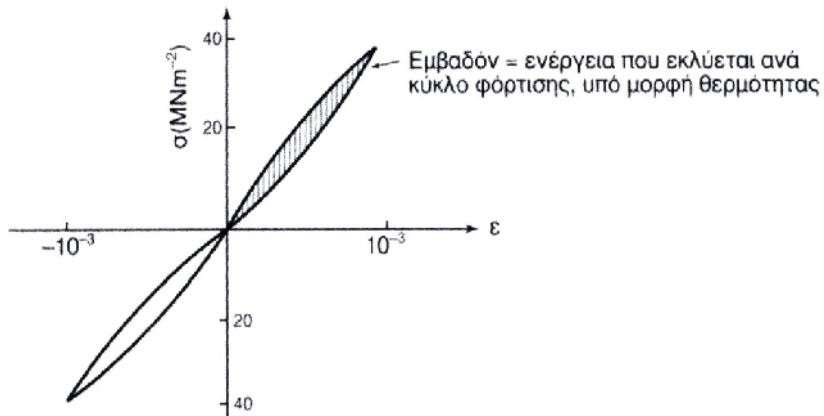
μ μ (μ) μ

(μ) μ μ

μ μ , μ μ

μ μ μ μ

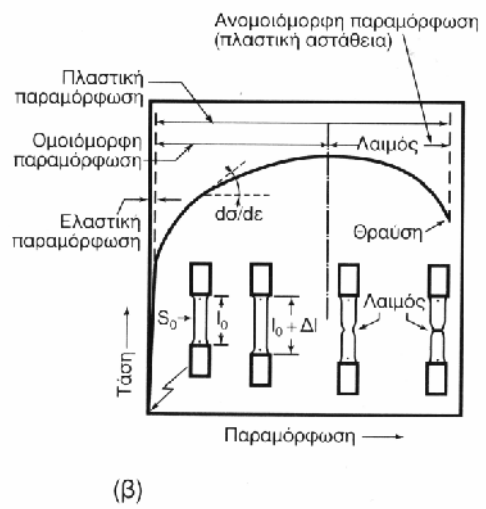
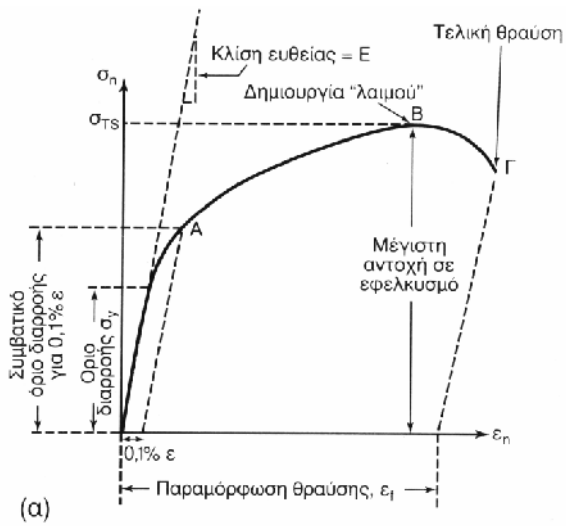
(μ , μ) .



2.10.: μm - μm .

2.5.2.5

μ ,
 μ .
 μ
 μ , μ μ
 μ , μ
 μ , μ
0,1% μ , μ
 μ μ μ ,
 μ (F) μ
 μ () , μ , μ $\mu\mu$
 μ μ 2.11. μ μ
 μ , μ μ
 μ , μ μ
 μ μ , μ μ
 μ μ μ μ μ .
 μ μ μ
 μ μ .
2.11. μ
:
y: . μ
 μ .
TS: μ μ (UTS). μ
 $\mu\mu$ - , μ μ ,
 μ μ .
f: μ . μ
 μ .
E: μ .



2.11.:) $\mu\mu$ - μ μ μ .) μ

μ μ

, μ

μ μ

μ

μ

μ

μ

μ

μ

(2.11).

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

(μ μ)

)

μ

(2.11),

μ

($\mu \mu$). $\mu \mu \mu$
 μ μ μ ,
 $\mu = l_0$) μ : ($\mu = 0$

$$\sigma_n = \frac{F}{A_0} \text{ και } \epsilon_n = \frac{\Delta l}{l_0} \quad [2 - 12]$$

"n" μ μ ,
 μ μ $\mu\mu$ - μ
 (2.11), μ μ ,
 μ μ μ μ . " μ "
 (μ) μ μ μ .
 μ μ μ μ .
 :

$$\sigma = \frac{F}{A} \quad [2 - 13]$$

(μ) μ μ .
 $\mu\mu$ μ - μ μ
 μ μ (μ)
 2.12). $\mu\mu$ 2.12 μ μ μ μ
 μ , μ μ

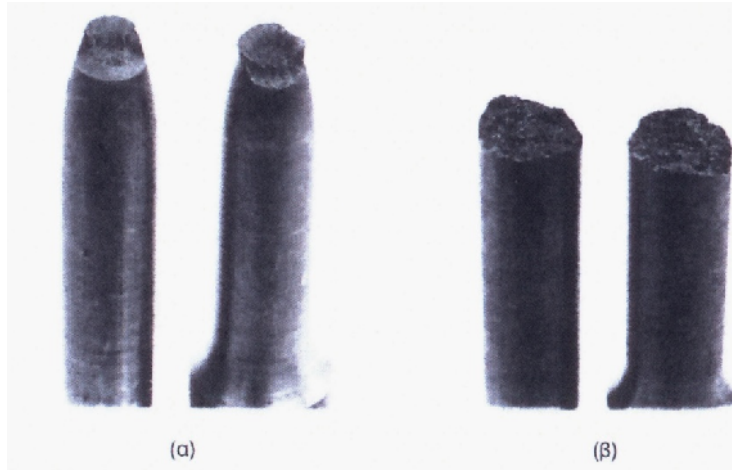
, μ μ μ μ ,
 μ μ n μ ,
 μ μ μ

$$\sigma = K \cdot \epsilon^n \quad [2-15]$$

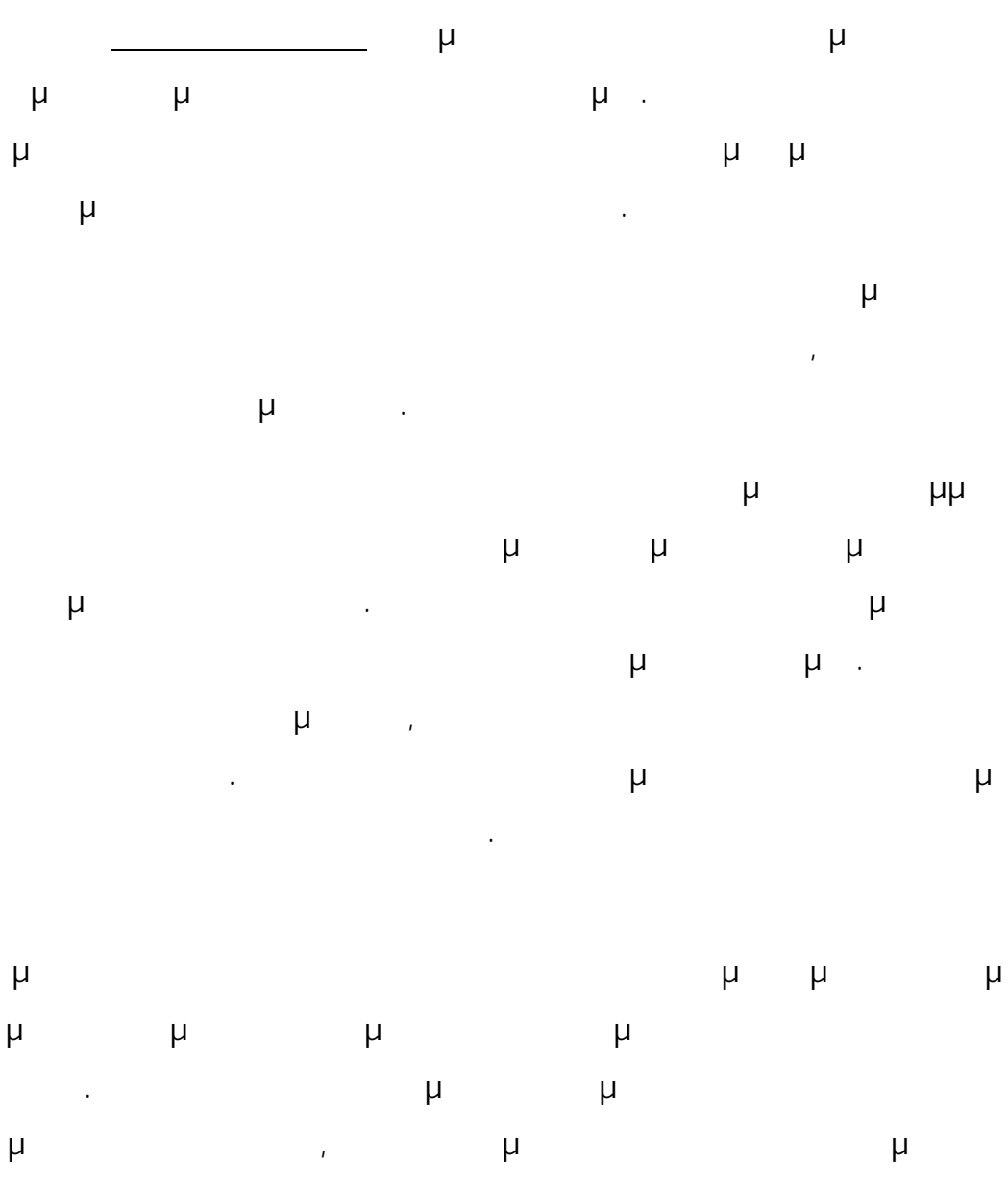
n , μ μ
 .
 μ μ , μ (2.11). μ ,
 μ μ μ μ μ μ
 μ μ ,
 μ μ μ , μ
 μ " " ,
 μ μ μ μ ,
 μ μ μ μ .

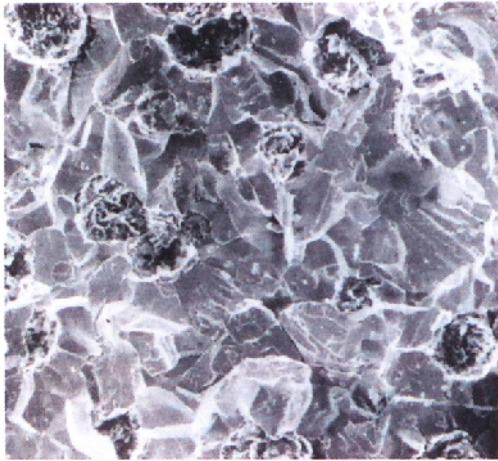
2.5.2.6

μ μ μ μ
 μ μ ()
 μ μ .
 μ (μ)
 μ μ μ ,
 μ μ μ μ ,
 μ μ μ (2.13).

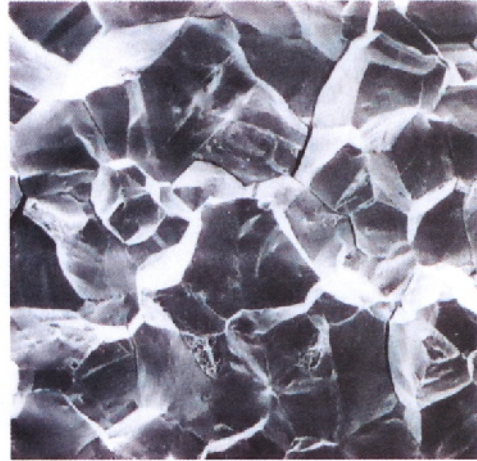


2.13.: μ AISI 1020. () μ





(a)



(b)

2.14.: ()

μ

μ

μ

()

μ

μ

μ

μ

μ

μ 2.14

μ

μ

μ

μ

μ

μ

μ

μ

μ 2.15

μ

μ

μ

μ

μ

μ

μ

μ

2.6

μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ μ μ μ

μ : μ μ μ

$$P_{\sigma} = P_{iv} + P_{\mu} \qquad [2 - 16]$$

$$, P = \mu$$

$$P = \mu$$

$$P_{\mu} = \mu \mu \mu \mu$$

$$\mu \mu S \mu \mu$$

$$S S_{\mu} \mu \mu$$

μ , , μ

, μ ,

μ μ (2-16) μ :

$$\sigma_{\sigma} \cdot S_{\sigma} = \sigma_{iV} \cdot S_{iV} + \sigma_{\mu} \cdot S_{\mu} \quad [2 - 17]$$

$$\Rightarrow \sigma_{\sigma} = \sigma_{iV} \cdot \frac{S_{iV}}{S_{\sigma}} + \sigma_{\mu} \cdot \frac{S_{\mu}}{S_{\sigma}} \quad [2 - 18]$$

$$\Rightarrow \sigma_{\sigma} = \sigma_{iV} \cdot C_{iV} + \sigma_{\mu} \cdot C_{\mu} \quad [2 - 19]$$

, C = μ .

C_{μ} = μ μ .

μ μ

, , μ μ :
= = μ (2-19) :

$$\frac{\sigma_{\sigma}}{s_{\sigma}} = \frac{\sigma_{iV}}{s_{iV}} \cdot C_{iV} + \frac{\sigma_{\mu}}{s_{\mu}} \cdot C_{\mu} \quad [2 - 20]$$

$$\Rightarrow E_{\sigma} = E_{iV} \cdot C_{iV} + E_{\mu} \cdot C_{\mu} \quad [2 - 21]$$

, , , μ μ ,
 μ .

2-21 μ μ μ μ

μ " ' " μ

μ μ .

μ μ μ μ μ

μ μ μ

$$\frac{P_{iV}}{P_{\mu}} = \frac{\sigma_{iV} \cdot S_{iV}}{\sigma_{\mu} \cdot S_{\mu}} \quad [2 - 22]$$

$$\Rightarrow \frac{P_{iV}}{P_{\mu}} = \frac{E_{iV} \cdot \varepsilon_{iV} \cdot S_{iV}}{E_{\mu} \cdot \varepsilon_{\mu} \cdot S_{\mu}} \quad [2 - 23]$$

$$\mu = \mu \frac{S_{IV}}{S_{\mu}} = \frac{C_{IV}}{C_{\mu}}$$

(2-23) :

$$\frac{P_{IV}}{P_{\mu}} = \frac{E_{IV}}{E_{\mu}} \cdot \frac{C_{IV}}{C_{\mu}} \quad [2 - 24]$$

(2-24) μ μ μ

μ , μ / μ , μ

μ

μ

μ

μ

"

μ

"

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

2.7

μ

μ

μ

μ

μ

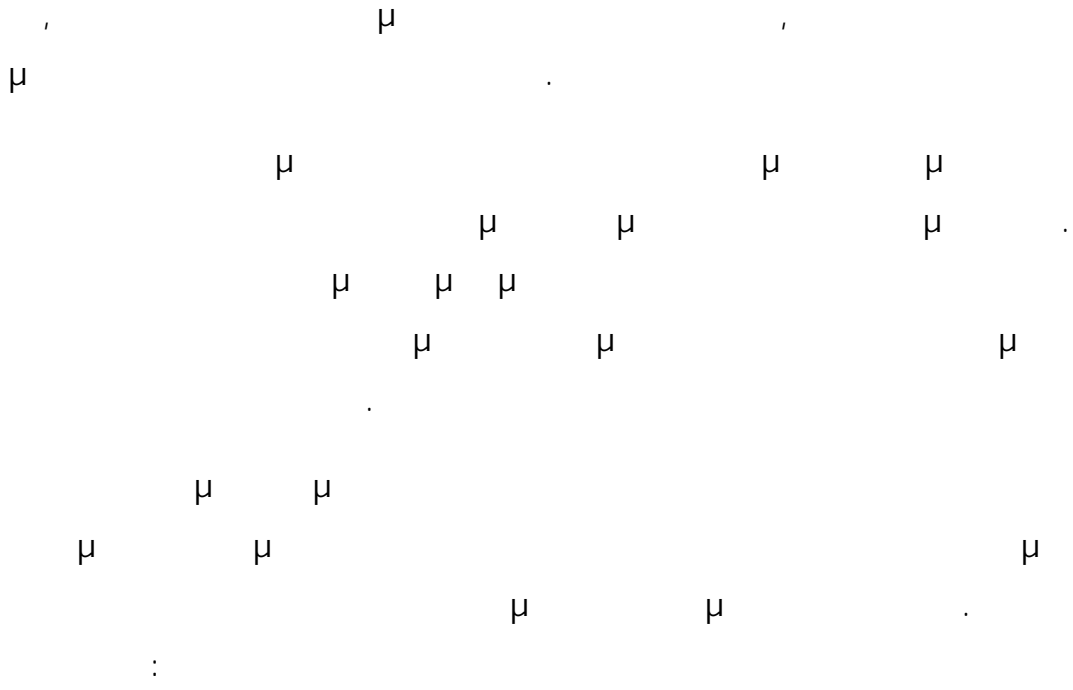
μ

μ

μ

μ

μ



i.



ii.

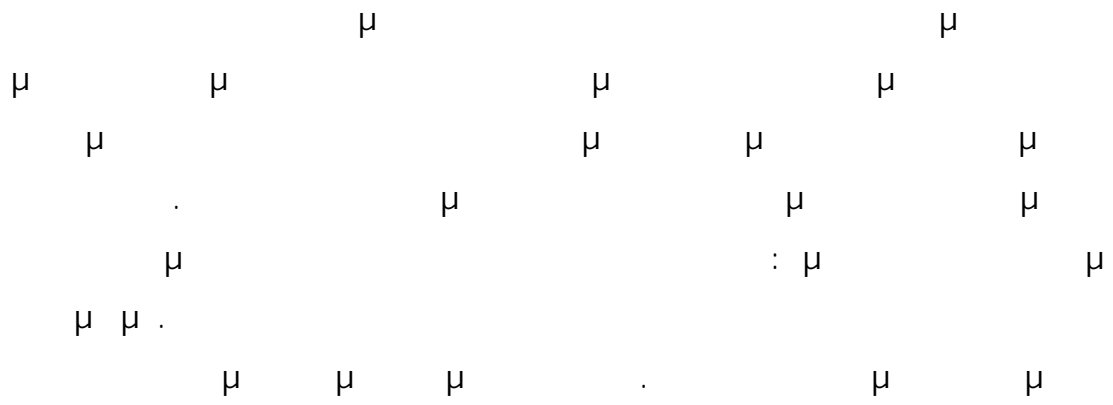


iii.

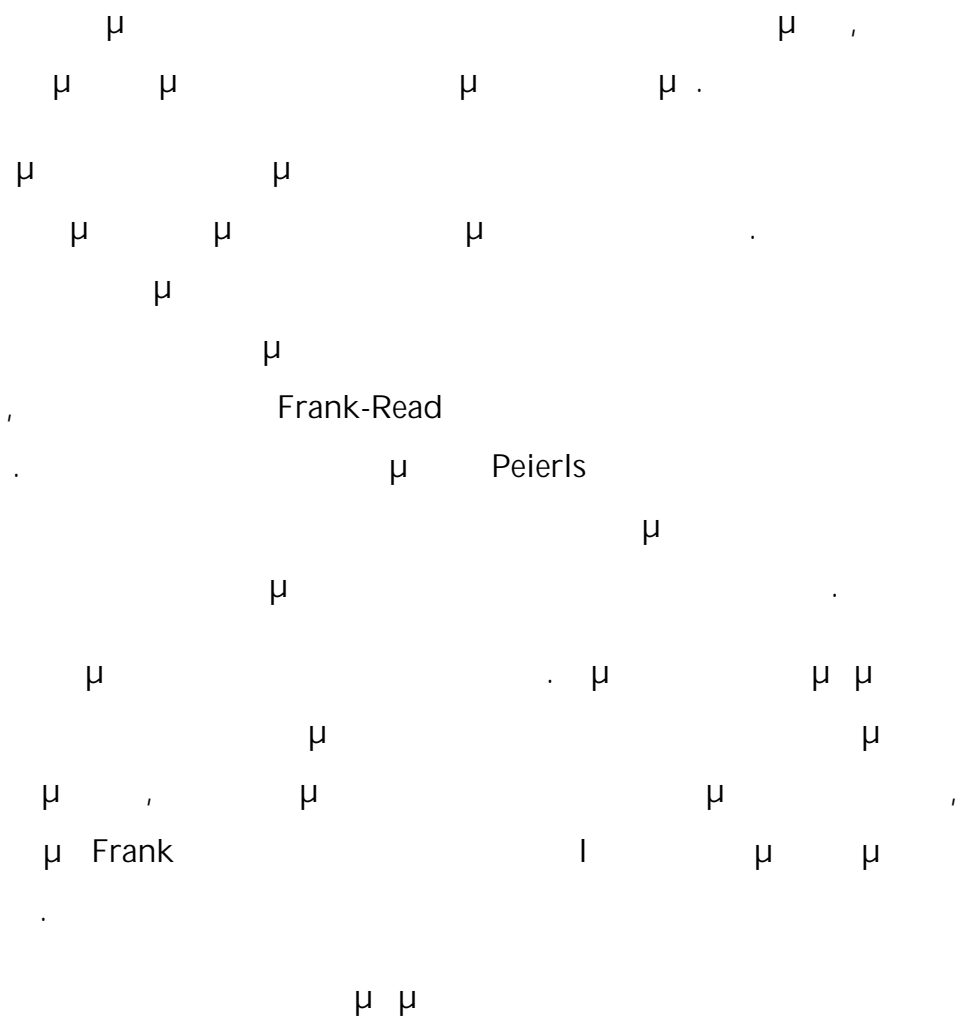
iv.



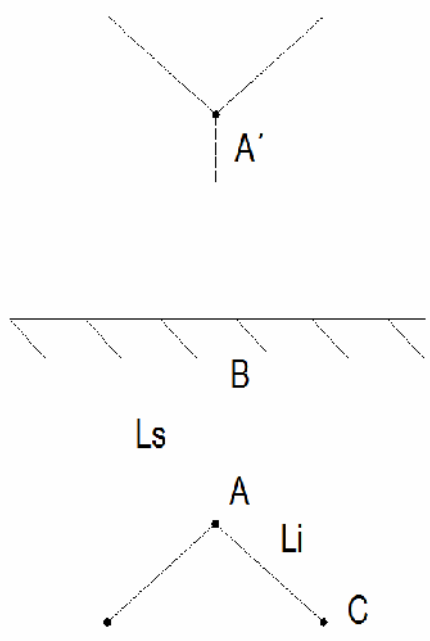
v.



Frank.



Fisher.



2.18.: "Fisher"

[10] μ Ni-50%
 Ni-W μ , μ
 .W. μ μ
 μ
 μ NiW. , μ
 Ni-W μ
 μ μ

Sriraman [11] μ
 μ $\mu\mu$
 μ μ Ni-W. μ \sim
 10nm μ Ni-W μ Hall-Petch
 μ μ μ μ
 μ μ μ Hall-Petch.
 $\mu\mu$ μ μ
 μ μ , μ

R.Jason [12] μ μ
 , μ μ (nanoindentation)
 μ , Ni-W μ μ
 μ μ μ
 8 80nm. μ μ
 μ μ μ μ
 μ μ μ μ

Kung-Hsu Hou

[13] μ

μ μ
 $\mu\mu$ μ μ Ni-W. μ
 μ μ μ μ
 μ μ μ Ni₄W
NiW. μ μ μ μ
 $\mu\mu$ μ μ Ni-W -

5 μ

μ μ

-

μ

μ

μ

μ

μ

μ

μ

μ

5.1

μ

μ

μ

μ

μ

5.1.1

μ

μ

μ

μ

μ

μ

μ

μ

10mm x 40mm x 1,5mm.

μ

μ

μ

μ

μ

μ

μ

(μ

)

μ

μ

μ

Ni-W,

μ

μ

μ

μ

μ 20mm x 40mm x 1,5mm.

8 -04, μ

5.1.2

μ Waterproof abrasive papers – Smirdex.



5.1.:



5.1.5 μ μ

μ μ μ μ
 μ μ μ μ
 μ μ μ μ μ
 μ 5min μ μ μ
 μ μ μ
 μ μ μ

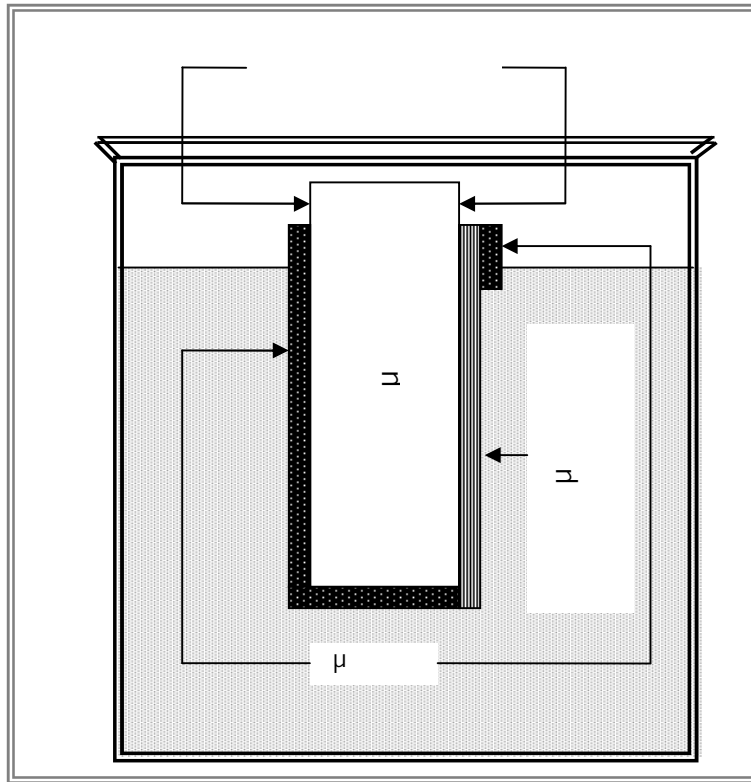
METASON 120.

5.1.6 μ

μ μ μ μ
 μ μ μ μ μ
 μ μ μ μ μ
 μ μ μ μ
 μ μ μ μ
 μ μ 30ml HNO₃, 10ml FeCl₃ 120 ml H₂O μ
 μ μ μ μ
 μ μ μ μ
 μ μ μ μ

5.1.7 μ

μ μ μ μ μ μ
 μ μ (5.3). μ
 μ μ 10mm x 30 mm μ
 μ μ μ 20mm x 30 mm
 μ μ μ
 μ μ



5.3.: μ μ

μ μ ,

5.2 μ Ni-W

μ

5.2.1 μ Ni-W

μ Ni-W

μ , μ

5.4 5.5

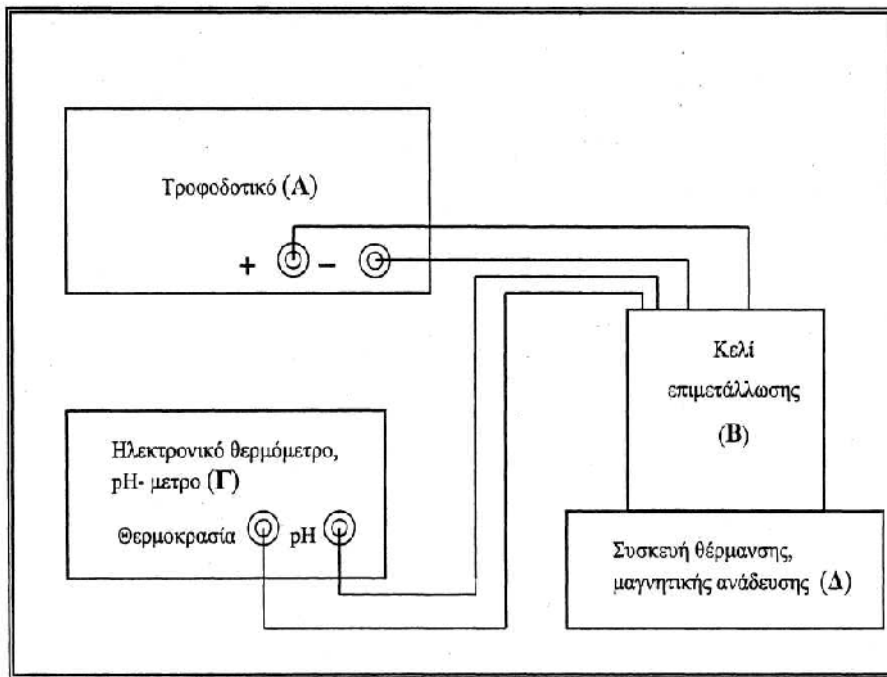
μ :

1. μ ()

2. μ μ ()

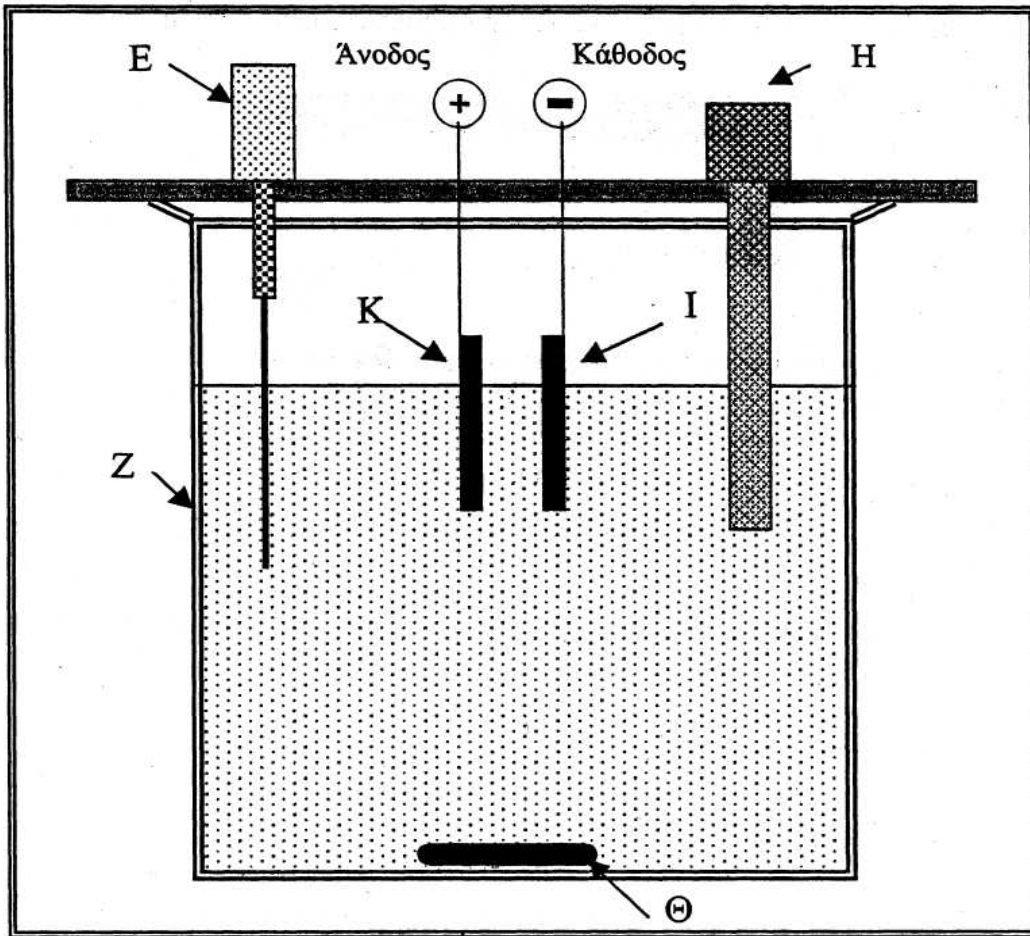
3. μ μ pH-μ ()

4. μ (5.4)



5.4.:

- μ () 250ml μ
- μ μ μ
- μ μ μ
- μ 500ml,
- μ
- (), 10mm x 40 mm.
- μ μ
- μ 10mm x 30mm (
- μ μ μ μ
- μ)
- (), μ
- μ μ
- μ 2 cm , μ



5.5.:

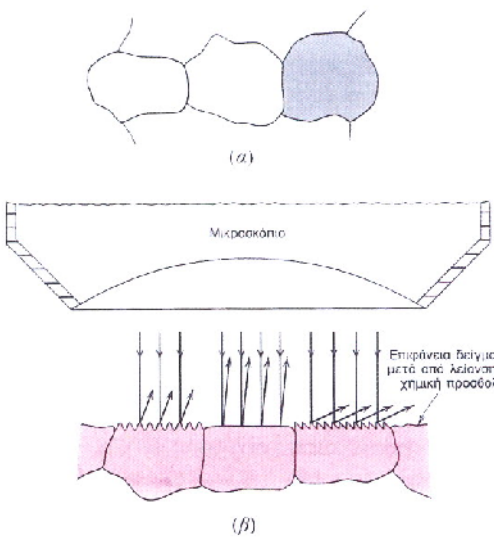
5.2.2 μ μ

Ni-W

μ μ Ni-W
 μ
(5.1) [9,14,15].

5.3

(reflecting mode).



5.6.:

(etching).

$\mu \quad \mu \quad \mu \quad \mu \quad \mu$

5.6

$\mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu$

$\mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu$

5.6 .

$\mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu$

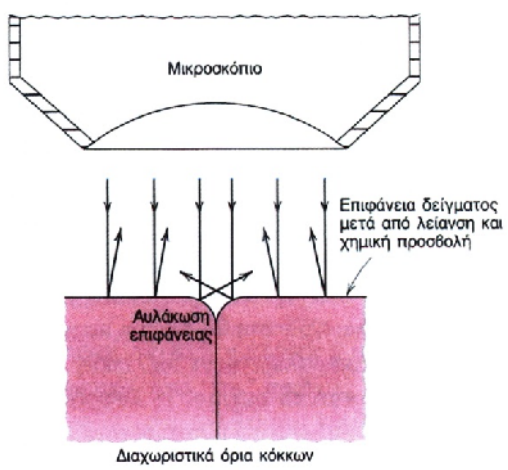
$\mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu$

$\mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu \quad \mu$

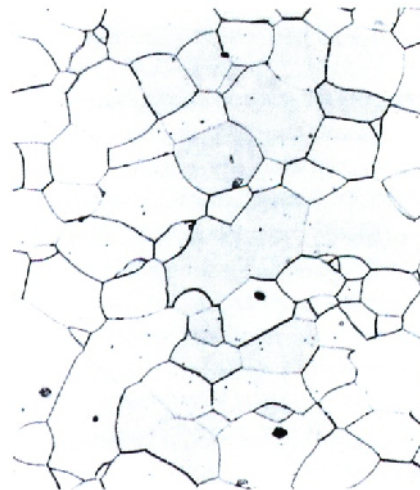
5.7 .

5.7

$\mu\mu$



(α)



(β)

5.7.: $\mu \mu$

μ

5.4

(Scanning Electron Microscopy, SEM)

H μ

Ni-W μ (S.E.M.).

(Scanning Electron

Microscopy, SEM)

0.2 μm. 1000x '30 (, μ)

10,000 x.

(TEM, Transmission

Electron Microscope)

μ (SEM,

Scanning Electron Microscope).

μ

μ , μ μ

μ μ ,

μ μ .

μ μ μ (. . .). μ
 μ μ μ μ μ
 μ μ μ (secondary)
 μ (backscattered)
 μ μ
. SEM

μ μ μ
 μ μ μ
 μ , μ μ

μ SEM μ μ μ
 μ μ μ

μ μ μ μ μ μ
 μ μ μ μ μ

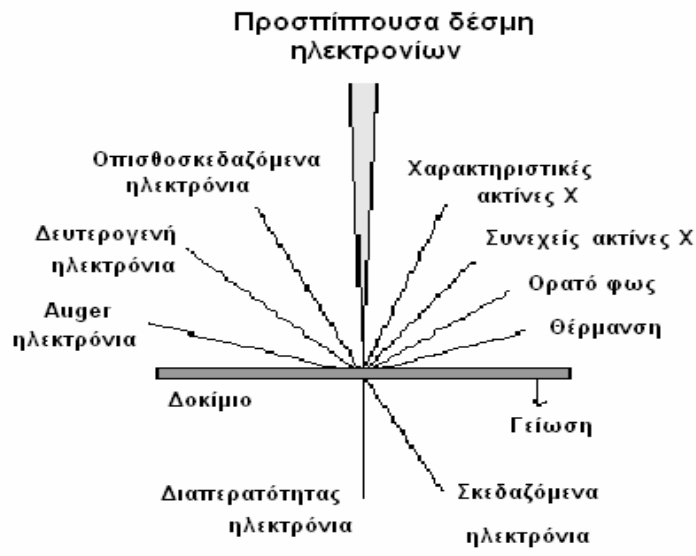
5.8 μ :

i. (Charging) μ
(μ μ μ μ μ μ)

ii. (, μ)

iii. (, μ)

iv. μ μ



5.8.:

(Backscattered Electrons).

30 KeV

(50 μ 80%)

180

(Backscattered electrons, BSE).

~6%

~50%

S

Auger

μ μ

μ

μ .

_____ :

SEM

μ

μ

μ

μ

μ ,

μ

μ

:

i.

μ

μ

μ

μ

ii.

μ

μ

μ ,

μ

μ

μ

μ

μ

μ

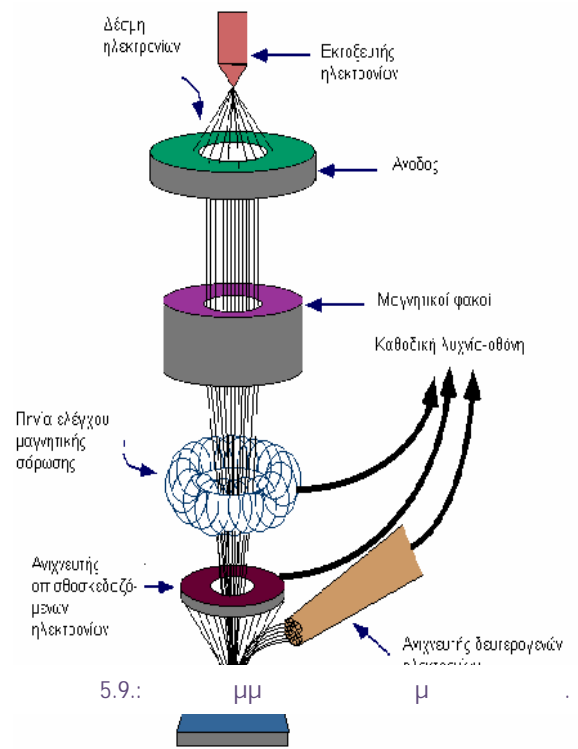
μ

iii.

μ

μ

μ

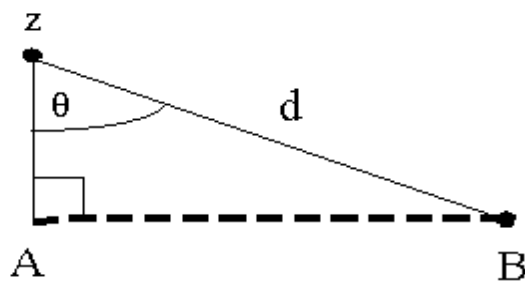
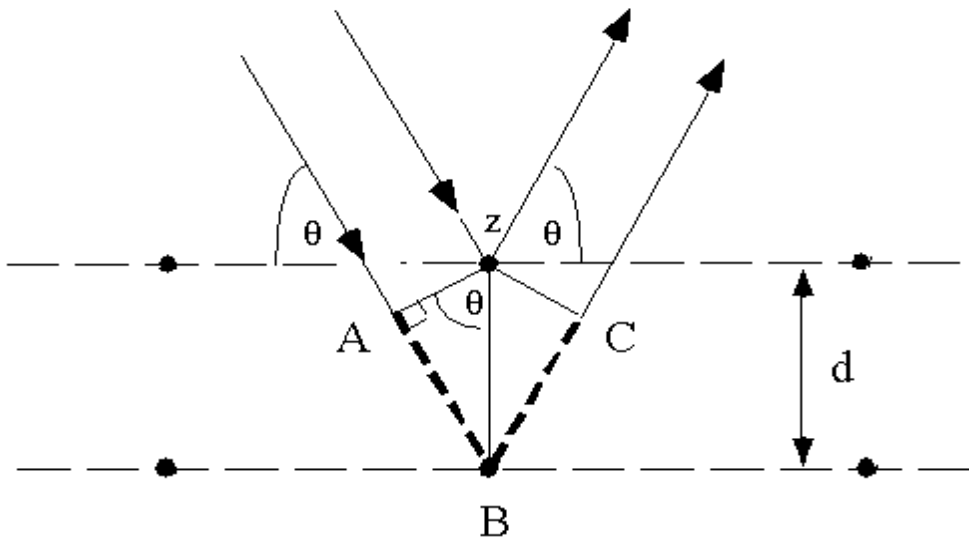


5.9.:

μμ

μ

μ μ



5.10.:

μ

μ μ

, μ

$d \mu$

Bragg.

μ Bragg μ

d

Siemens

D5000

μ

Cu,

μ μ

μ μ 30 mA.

μ

X

i.

μ μ μ

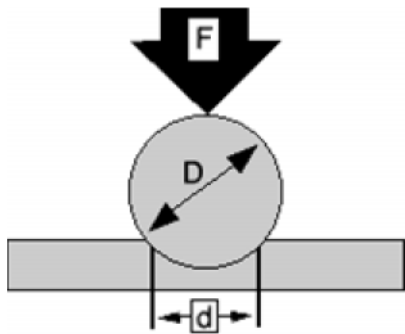
ii.

iii.

μ

Brinell

F (kN), D (mm), d (mm)



$$HB = \frac{2F}{\pi D (D - \sqrt{D^2 - d^2})}$$

5.12.: Brinell.

Brinell.

$F = 29\text{kN}$

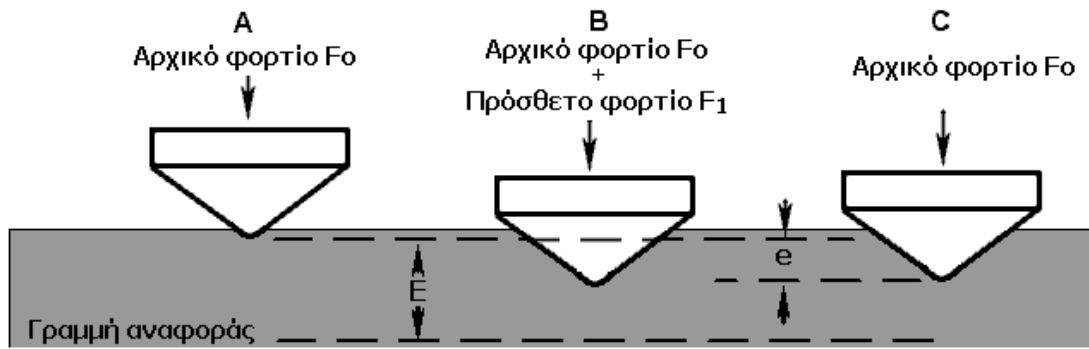
$D = 10\text{mm}$

Vickers

F (N), d (mm)

$$HV = 1,854 \frac{F}{d^2}$$

F (N), d (mm)



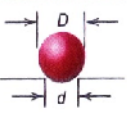



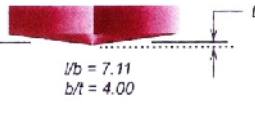
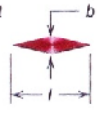
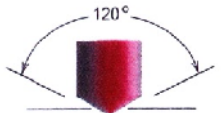



5.14.: μ μ Rockwell

5.6.1

Vickers. , μ μ
 μ μ , μ μ
 μ μ μ
 μ 136 . μ μ μ
 μ Rockwell Brinell μ μ 1 1000g. μ
 μ μ μ μ μ .
 μ μ μ μ (5.2).
 μ () μ μ
 μ μ μ μ μ
 Knoop Vickers μ HK HV μ μ Knoop
 μ μ μ μ μ μ
 μ μ μ μ μ μ
 μ μ μ Knoop μ
 μ μ μ
 μ μ μ Ni-W
 μ 50gr 10 sec.

2000.

Shimadzu HMV-

Δοκιμή	Διευσδυτής	Σχήμα αποτύπωσης		Φορτίο	Μαθηματικοί τύποι για τον αριθμό σκληρότητας ^a
		Πλάγια όψη	Κάτοψη		
Brinell	Σφαίρα 10 mm από χάλυβα ή καρβίδιο βολφραμίου			P	$HB = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$
Vickers μικροσκληρότητα	Διαμαντένια πυραμίδα			P	$HV = 1.854 P/d_1^2$
Κμοορ μικροσκληρότητα	Διαμαντένια πυραμίδα			P	$HK = 14.2 P/l^2$
Rockwell και επιφανειακή Rockwell	Διαμαντένιος κώνος			60 kg 100 kg 150 kg	Rockwell
	χαλύβδινες σφαίρες διαμέτρου 1/16, 1/8, 1/4, 1/2 in.				

5.2.:

μ

5.7

(A.F.M., Atomic Force Microscopy)

μ
μ

μ

μ
μ

μ

μ

μ

μ
μ

μ

μ

[16].

(AFM).

STM. STM (Scanning Tunneling Microscope). Gerd Binnig 1981

IBM

Binnig & Rohrer 1986. STM

STM, Binnig

AFM (Atomic Force Microscopy)

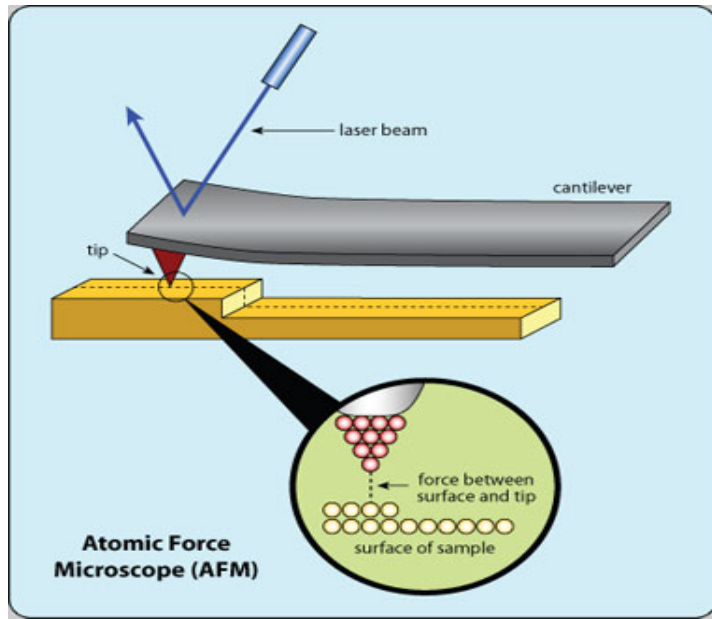
AFM (1μ)

AFM

AFM

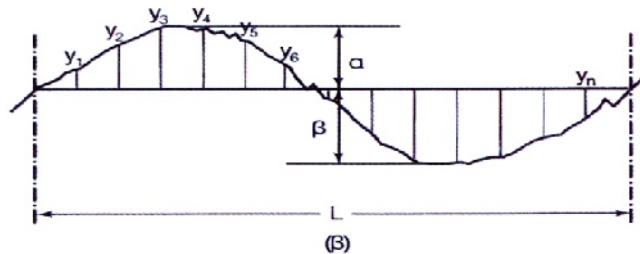
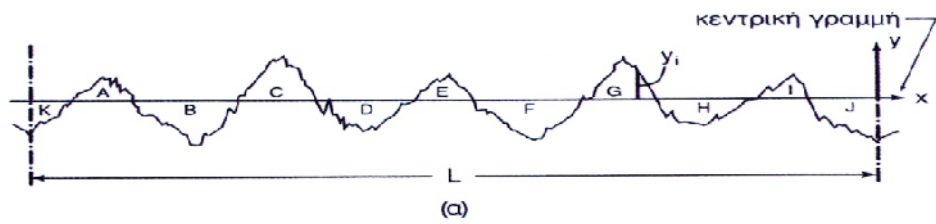
AFM ($< 1\text{nN}$)

AFM, μ
 AFM μ
 μ
 μ μ μ μ
 AFM μ
 μ μ (contact mode), μ
 μ μ



5.15.: μ μ μ

μ μ μ μ
 μ μ μ
 μ μ μ
 μ μ μ μ
 μ μ μ μ



5.16.: . () μ μ μ μ μ μ μ μ μ μ

5.8 (scratch test)

μ μ μ μ μ [16,17,18]

μ - μ μ μ

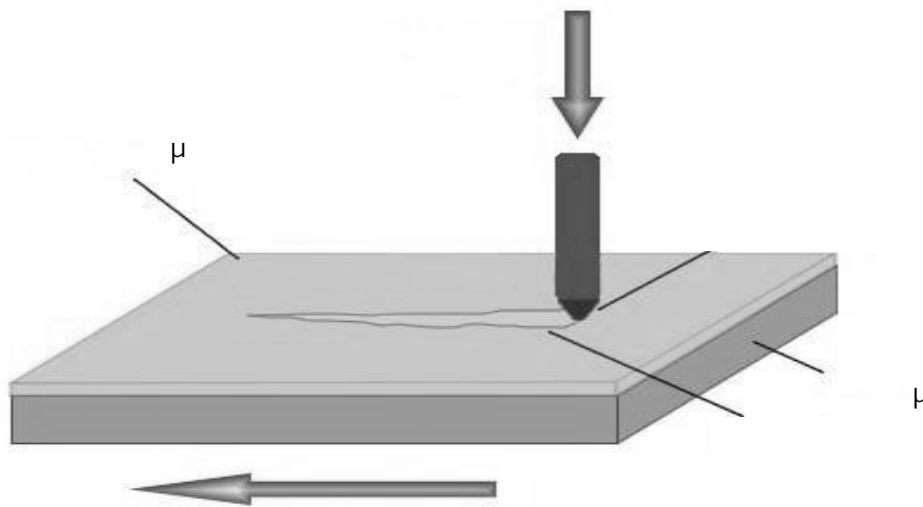
μ μ μ μ μ μ μ

μ μ μ μ μ μ μ

μ μ μ μ μ μ μ « μ »

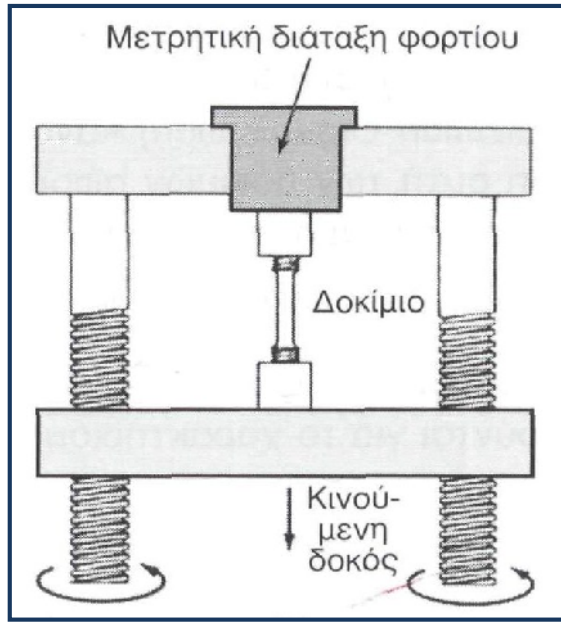
(mechanical interlocking) μ

μ ,
 μ , μ
 μ , μ
 μ
 μ μ . [19,20]
 μ μ μ μ μ μ Ni-W
 μ μ μ (scratch test).
 μ μ , μ μ μ
 μ , μ μ .
 μ μ μ μ
 (5.17) REVETEST CSEM,
 μ μ μ . [21,22].



5.17.:

μ ,
 μ , μ
 μ μ 0 μ 120 . μ
 μ 10 /mm
 10mm/min.



5.19.: μ μ

μ μ μ μ μ
 Instron 4482. μ μ
 μ μ μ μ μ
 μ μ μ μ μ μ μ
 μ μ μ μ μ μ μ %
 μ μ μ μ μ μ μ

100%.

$$\epsilon = \frac{\Delta L}{L_0} \times 100\%$$

- = μ μ
- L = μ
- L₀ = μ μ

μ μ μ μ μ μ μ

$$\sigma = \frac{F}{S}$$

- =
- $F = \mu \mu \mu$
- $S = \mu \mu , \mu$

, $\mu\mu - \mu \mu \mu$
 $\mu \mu \mu \mu$

, $\mu \mu \mu \mu$

() $7\mu\text{m}$ () $15\mu\text{m}$ () $22\mu\text{m}$ () $25\mu\text{m}$.

$\mu \mu$
 $\mu 10^{-4} \text{ s}^{-1}$

, $\mu \mu\mu$
 μ , μ
 μ

$7\mu\text{m} \quad 22\mu\text{m}, \mu$
 $\mu \mu \mu \mu$
 $25\mu\text{m} \mu \mu \mu$
 $5 \cdot 10^{-5} \text{ s}^{-1} \quad 10^{-3} \text{ s}^{-1}$

, $\mu \mu \mu \mu$
 $22\mu\text{m} \mu \mu \mu \mu$
 $\text{s}^{-1} \mu \mu 10^{-4}$
 $\mu \mu$

μ μ μ μ
μ μ μ μ
μ .

6 μ μ

μ μ μ μ μ

6.1 _____ μ _____ Ni-W

_____ μ _____

6.1.1 _____ μ _____

μ

μ μ :

i. μ μ μ μ

ii. μ μ Ni-W

(30,60,90,120min).

6.1.1.1 _____ μ _____ Ni-W

μ μ μ

(SEM).

5,

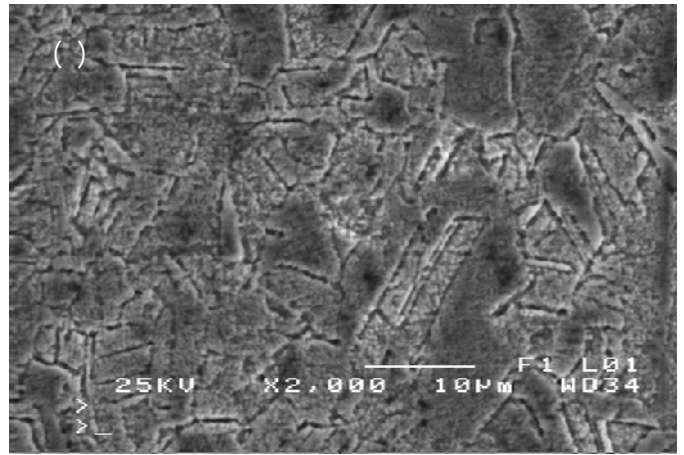
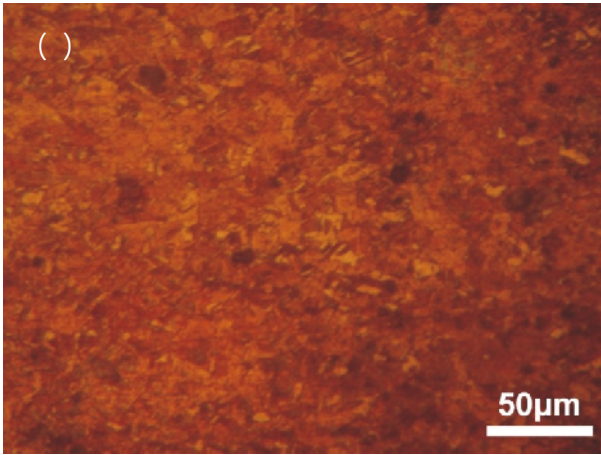
μ μ μ

6.1 μ

μ 6.1

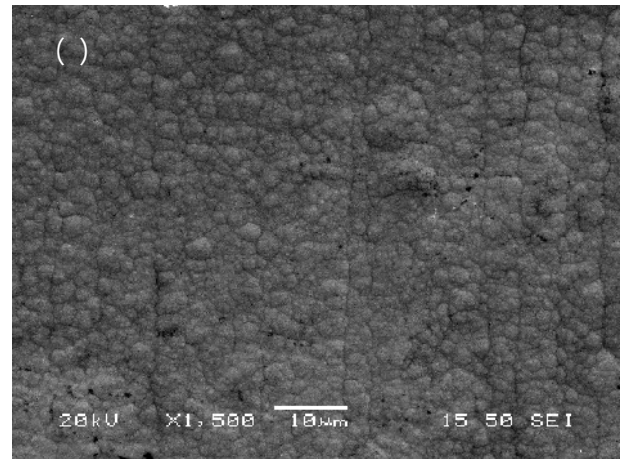
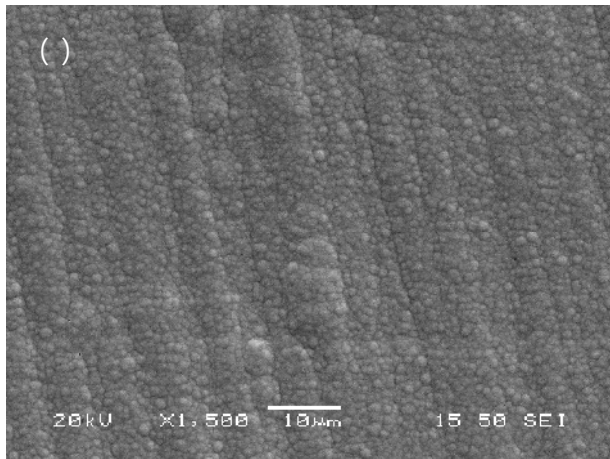
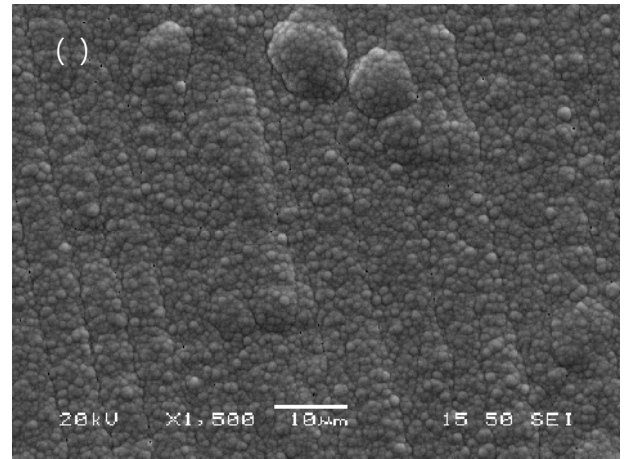
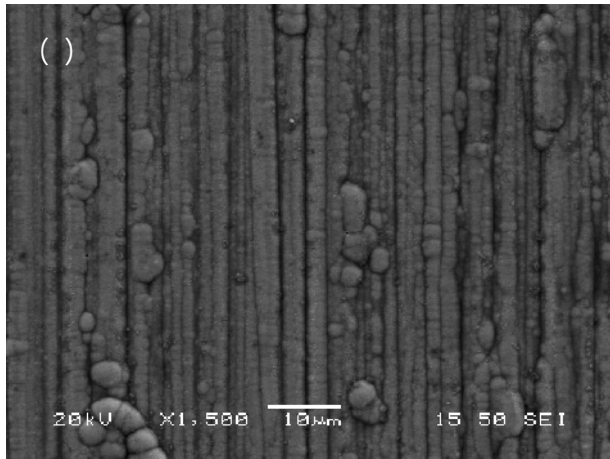
μ .

μ μ μ ,
 μ
 μ
 μ μ μ 30ml HNO₃, 10ml FeCl₃ 120 ml
 H₂O μ [23].



6.1.: μ Cu.() μ () μ .

, μ μ
 μ (EDAX)
 μ μ
 (100% Cu).
 μ μ
 Ni-W μ μ μ
 (6.2)
 μ (SEM) μ
 μ μ
 (nodular structure) μ μ μ .



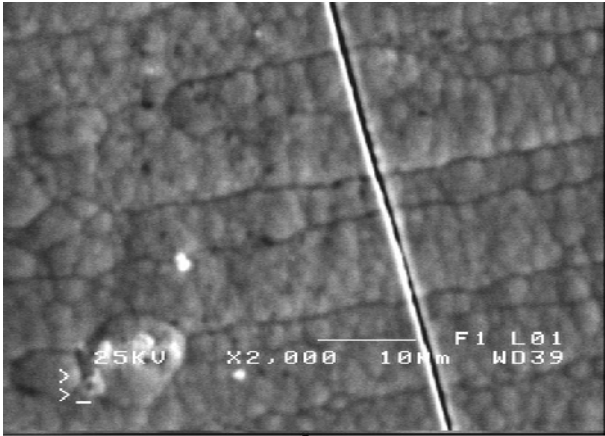
6.2: Ni-W (a) 30min. (b) 60min. (c) 90min. (d) 120min.

µ
µ µ

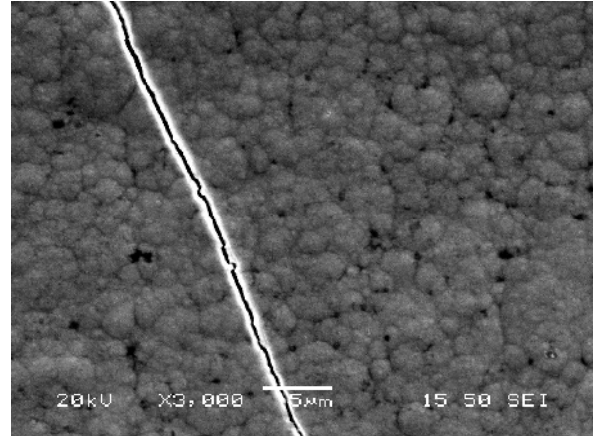
µ
Ni-W µ
µ

µ
µ
120min.

(6.3).



6.3.: Ni-W μ 120min.



μ μ

(6.3),

(120min) μ μ μ .

μ μ , [24,25],

μ

μ μ .

, μ μ μ

μ (EDAX)

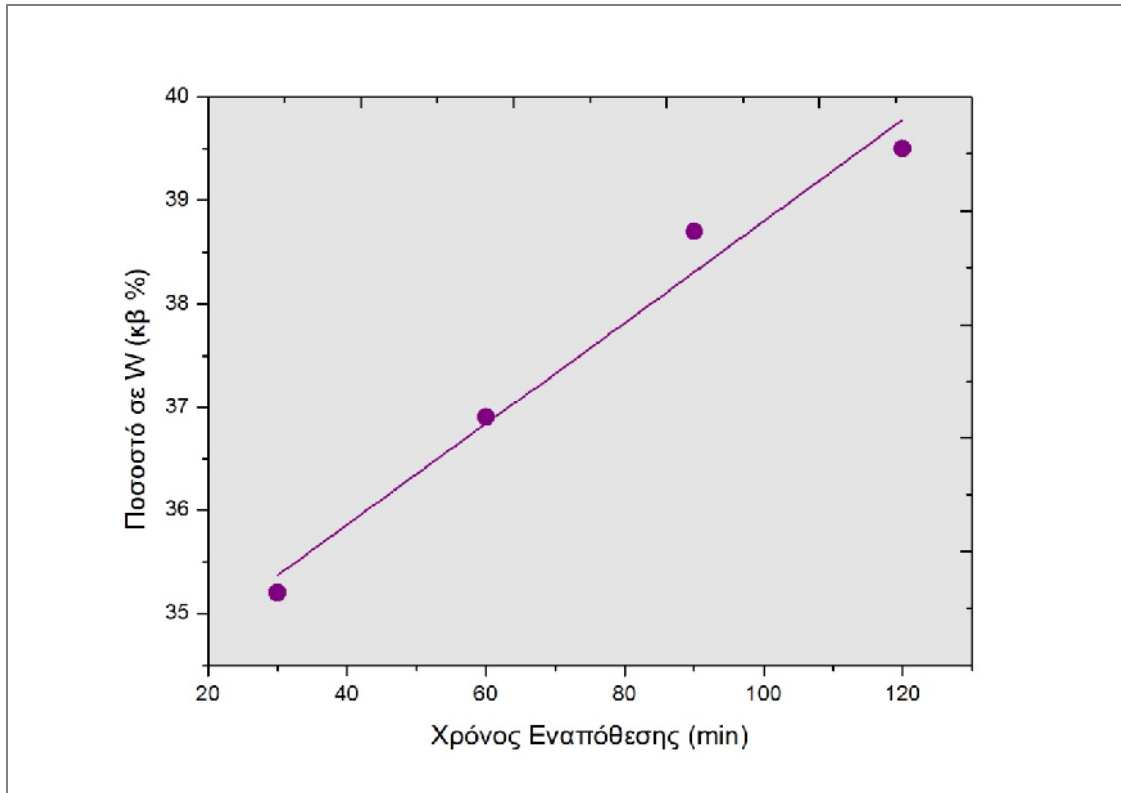
. μ μ

(6.1).

μ		Weight% (. .)
30min	Ni	64,74
	W	35,26
Total		100
60min	Ni	63,10
	W	36,90
Total		100
90min	Ni	61,26
	W	38,74
Total		100
120min	Ni	60,48
	W	39,52
Total		100

6.1.: μ μ Ni-W

$\mu\mu$ μ
 μ μ
 ($\mu\mu$ 6.1),
 $\mu\mu$.

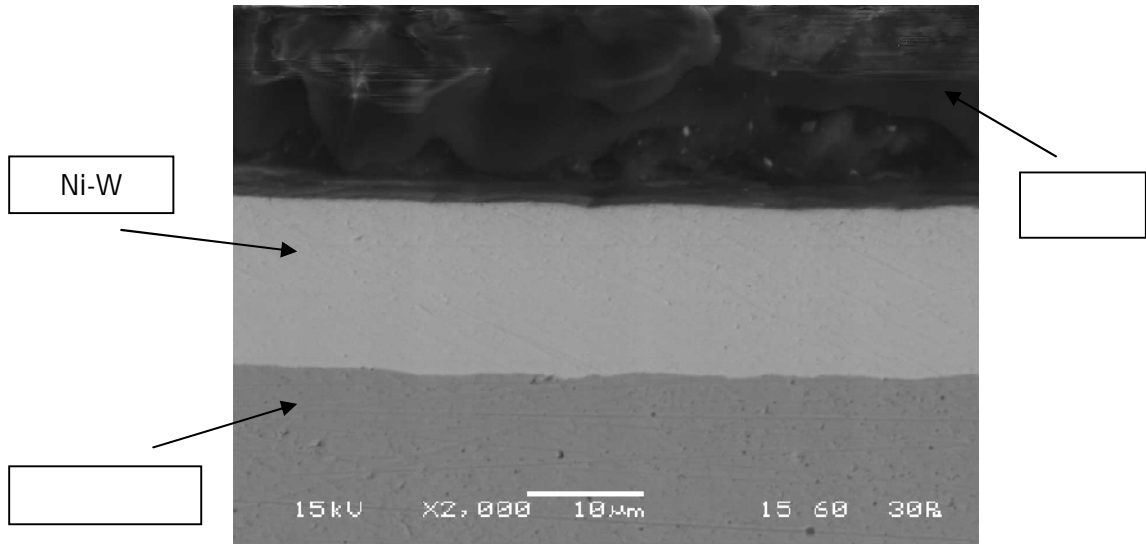


6.1.: Ni-W
 μ μ μ μ
 , μ μ
 μ μ
 μ

(min)	(μm)
30	6,6
60	14,8
90	21,9
120	25,0

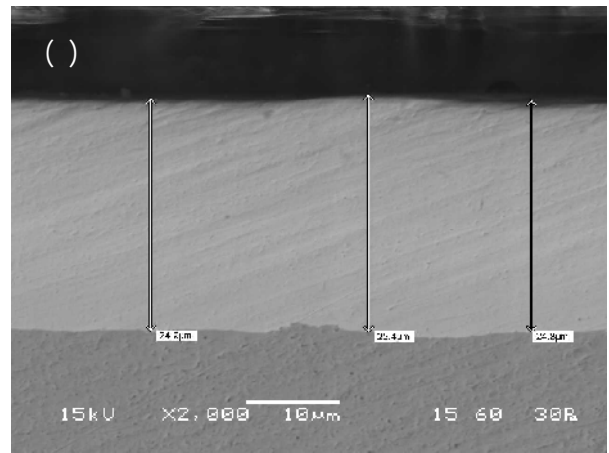
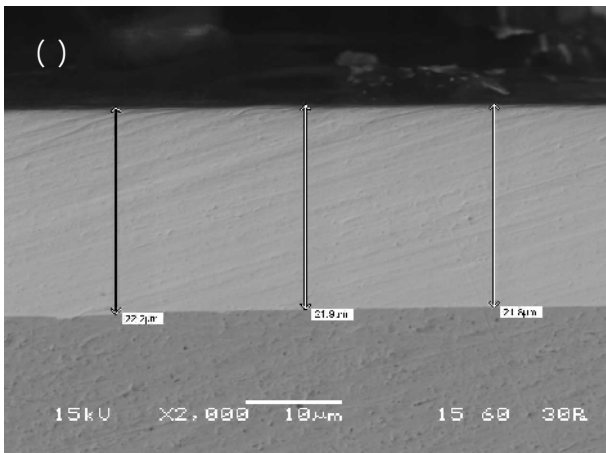
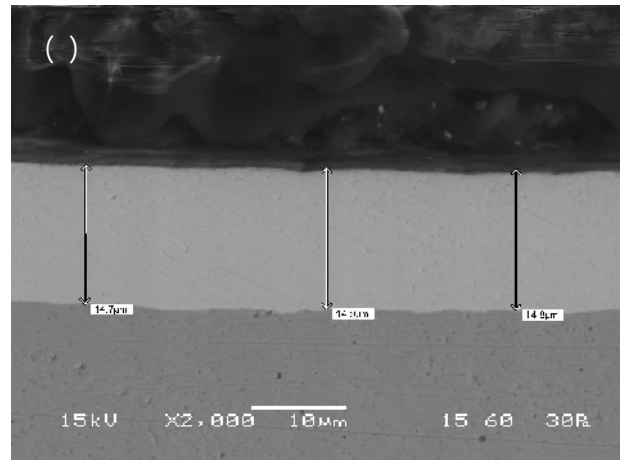
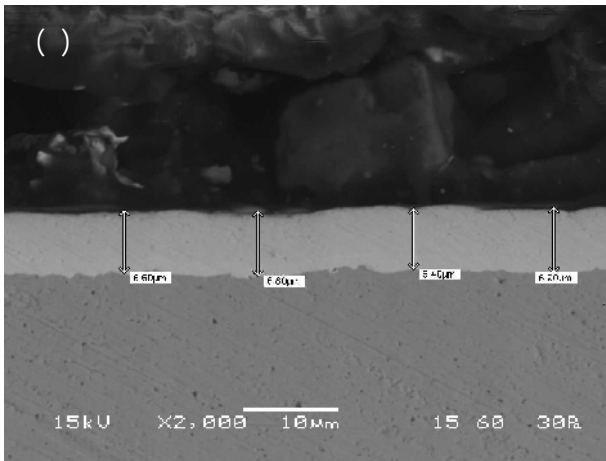
6.2.: μ Ni-W

6.4 μ μ Ni-W, μ μ μ μ μ



6.4.: Ni-W 15 μ m μ μ μ

(6.5) μ μ μ Ni-W



6.5.:
Ni-W

μ

() 30min. () 60min. () 90min. () 120min.

μ

μ

μμ

μ

μ

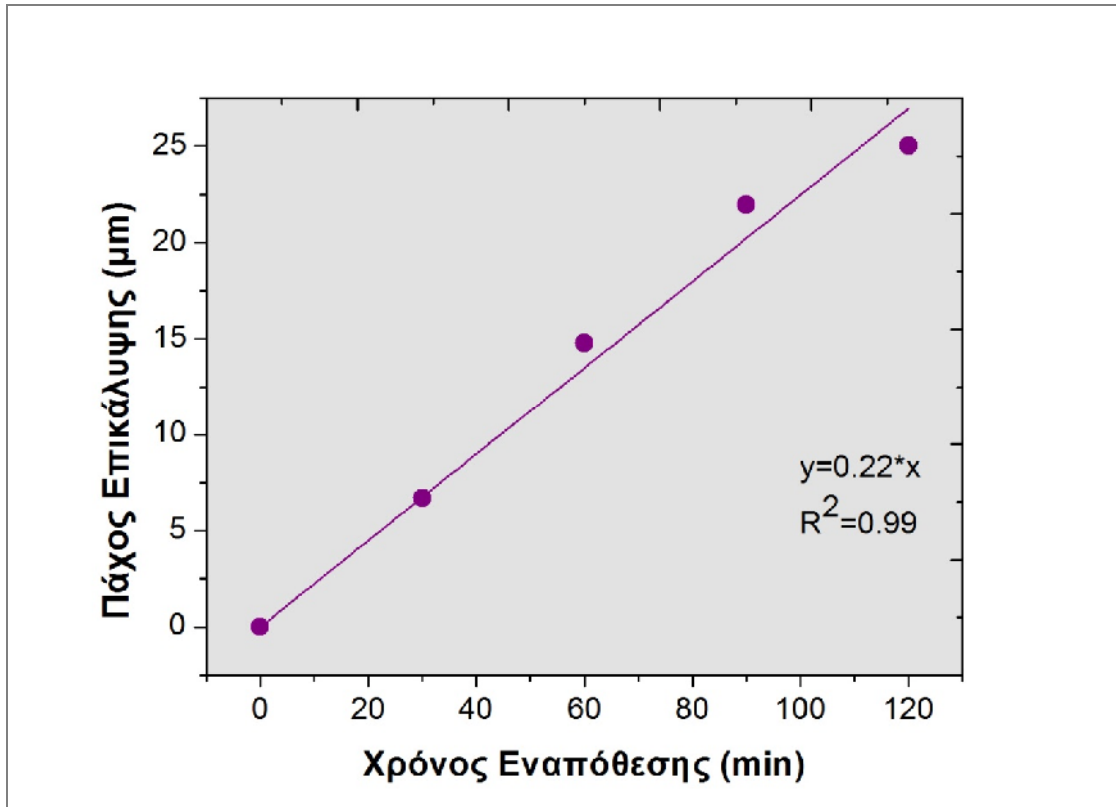
(μμ 6.2),

μμ

μ

μ μ

μ μ



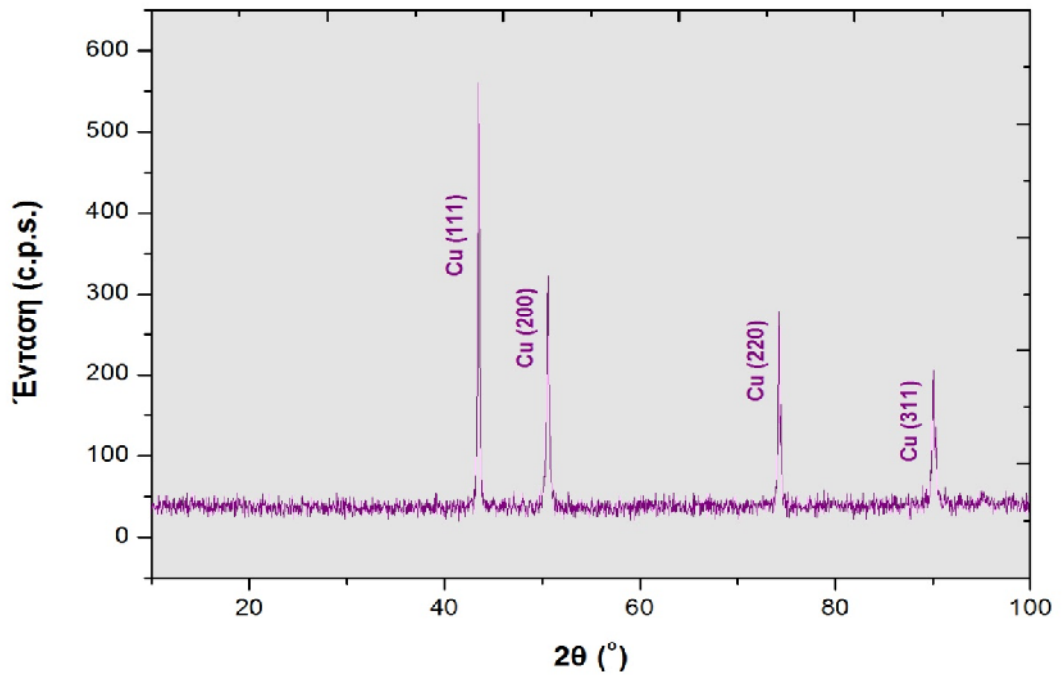
μm 6.2.: μm μ

6.1.2 μ μ X (XRD)

μ () μ
 Ni-W

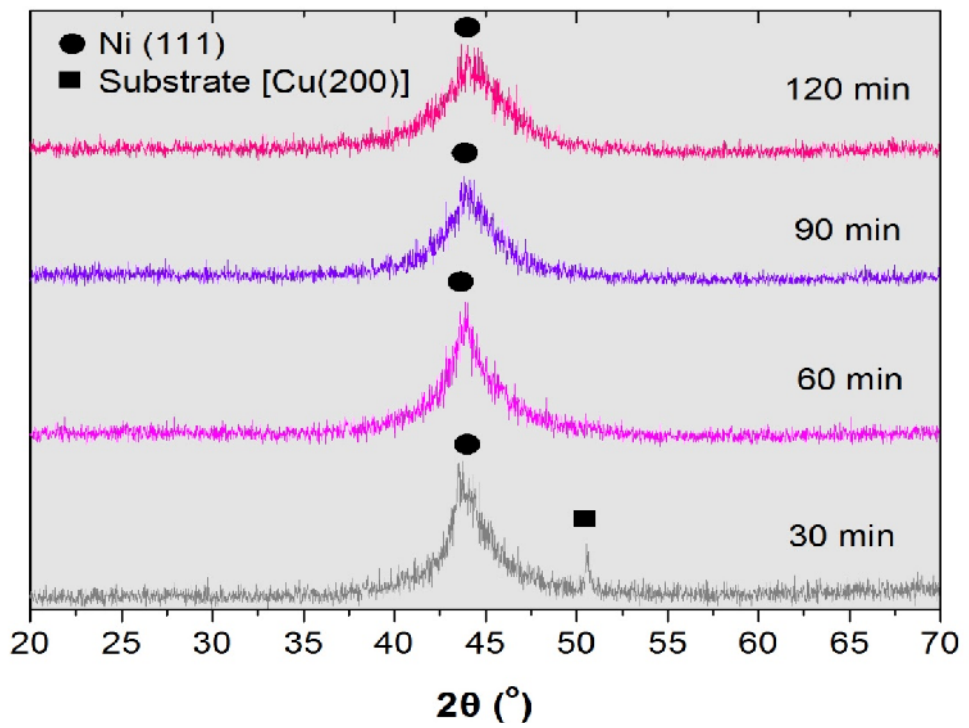
μ 6.1 μ μ
 μ μ

(111), (200) (220).



μ 6.1.: μμ - μ (Cu).

μ 6.2 μμ
μ



μ 6.2.: μμ - μ Ni-W

μ (6.2),
 μ , μ (FCC).
 μ 6.2 μ μ μ
 30min μ
 Ni-W μ μ
 μ 7 μ m.
 μ μ ,
 μ [Ni(111)]
 μ μ Debye-Scherrer
 $\mu\mu$ μ μ
 μ Debye-Scherrer :

$$D = \frac{0,94 \times \lambda}{\beta \times \cos\theta} \quad [6 - 1]$$

: D, μ μ

, μ μ

, μ (FWHM)

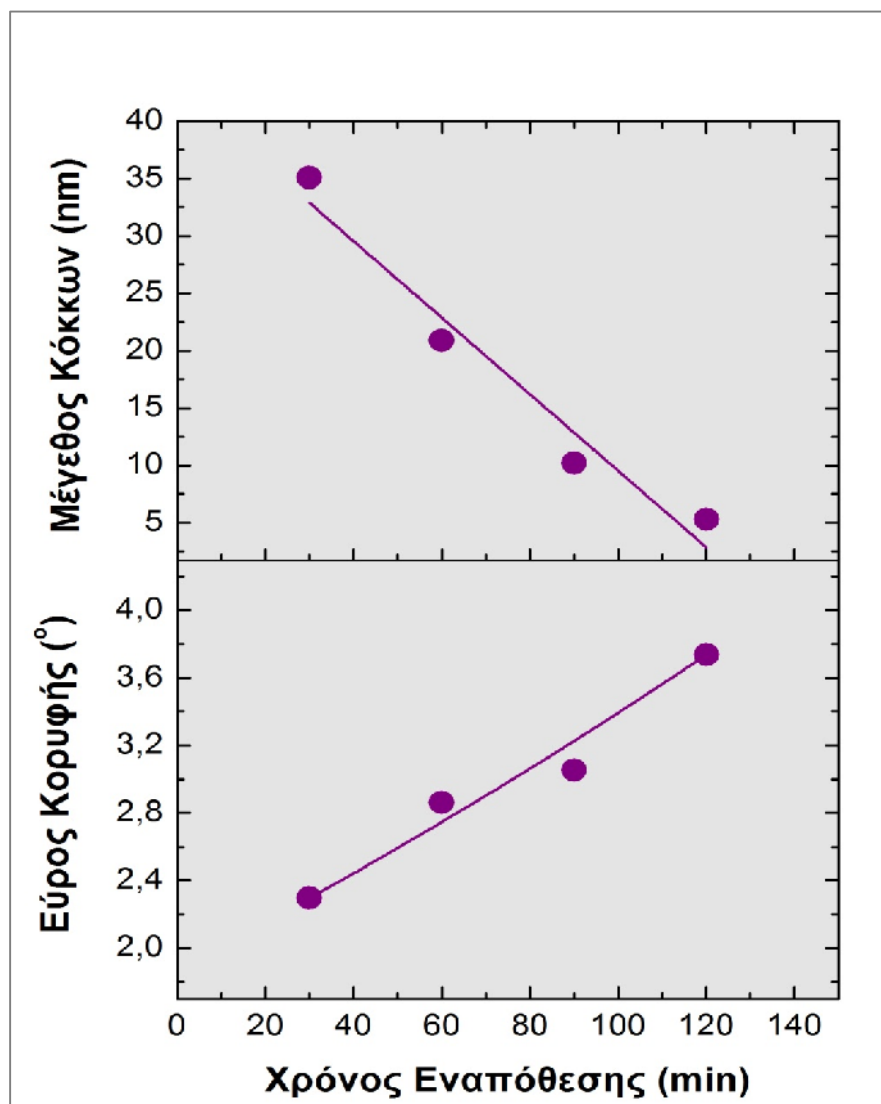
, Bragg

μ

(6.3) μm (μm 6.3)

(min)	(nm)
30	35,1
60	21,0
90	10,2
120	5,3

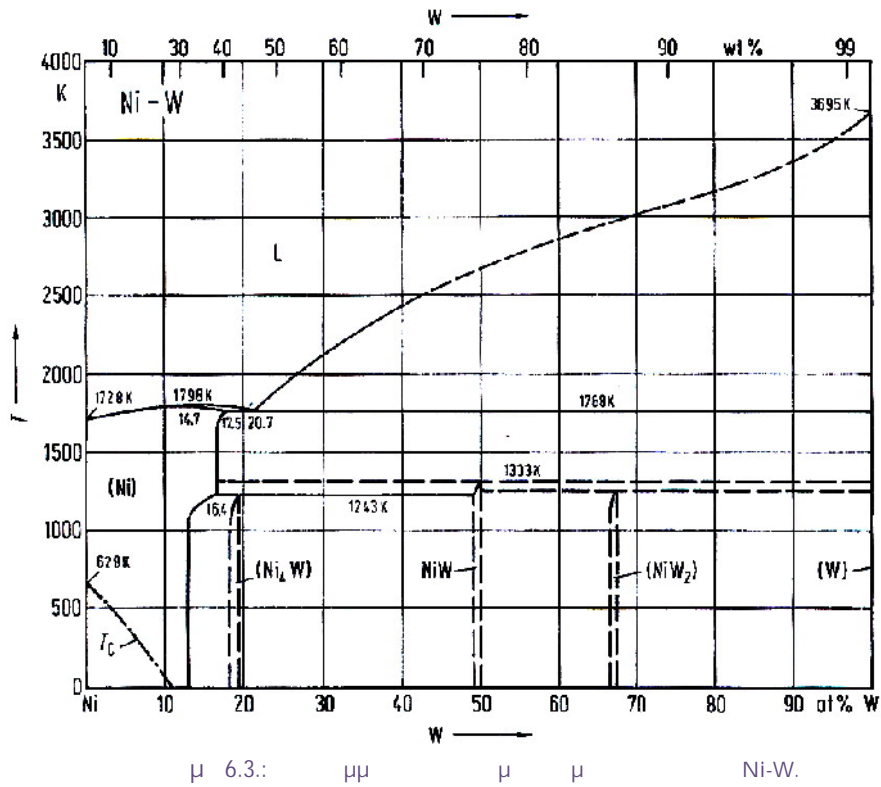
6.3.: μm μ μ



μm 6.3.: μm μ μ μ

Ni,

(Ni-W [26]).



μ 6.3: μ μ Ni₄W μ

μ μ

μ

(broadening)

μμ

μ

(overlapping)

μ

μ

μ

μ

Ni₄W.

μ

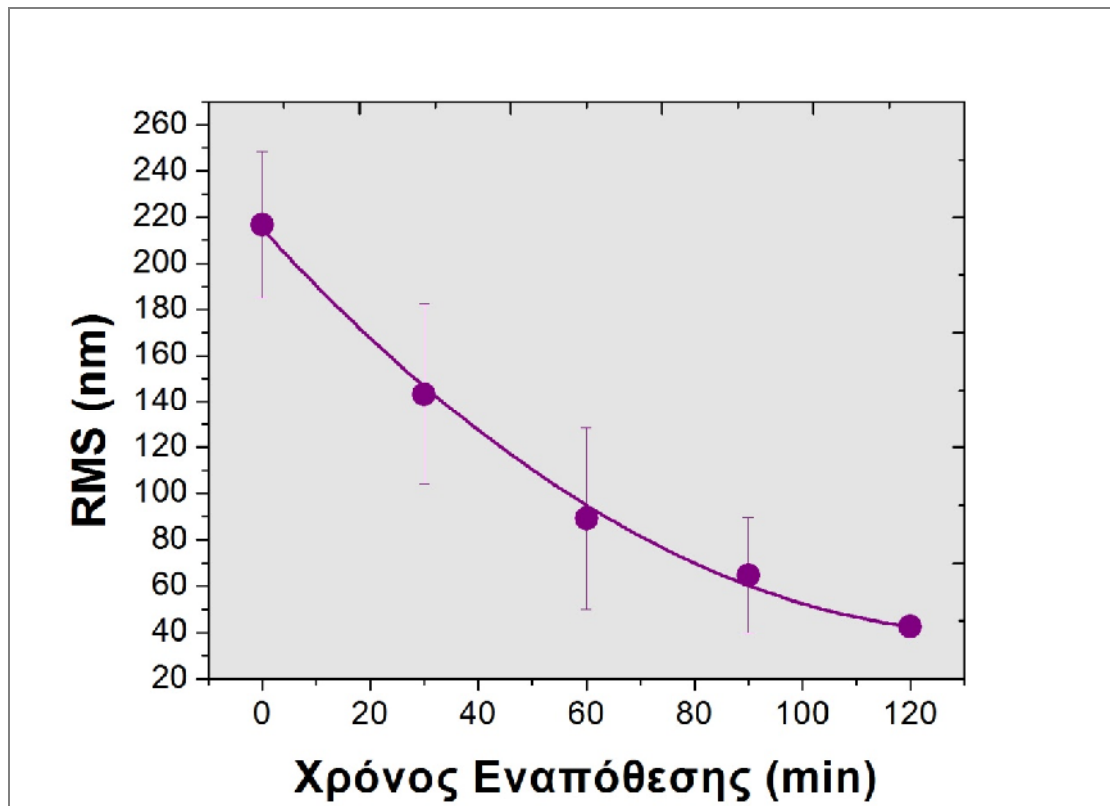


6.4

μμ 6.4.

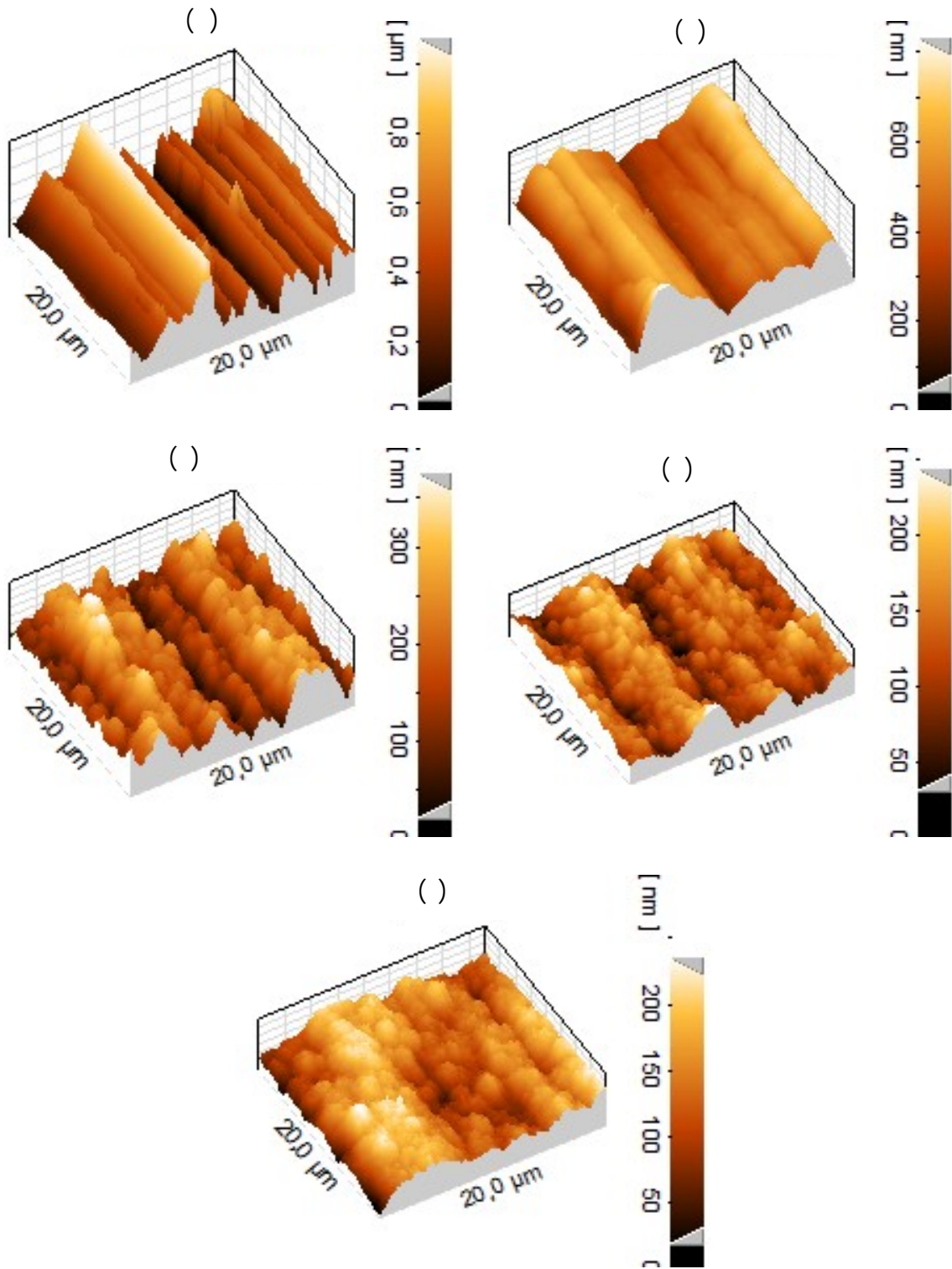
μ			RMS (nm)
μ			216,7
μ	μ Ni-W	7μm	143,1
μ	μ Ni-W	15μm	89,3
μ	μ Ni-W	22μm	64,7
μ	μ Ni-W	25μm	42,5

6.4.: μ



μμ 6.4.: μμ μ μ

μ μ μ (A.F.M., Atomic Force Microscopy).



6.6.:
(A.F.M.) () μ

μ μ μ
() 7μm. () 15μm. () 22μm. () 25μm.

6.6
 Ni-W, μ $\mu\mu$ μ μ
 6.4 μ μ $\mu\mu$ μ μ μ
 μ μ .

6.1.4 Ni-W

μ
 μ μ
 :
 i. μ
 ii. μ μ Ni-W
 (30, 60, 90, 120min).

6.1.4.1 μ
 μ μ μ
 e KARL FRANK μ 5Kg μ 10sec.
 μ μ μ 10
 μ μ .
 μ :

	(HVN)
1	67,9
2	67,1
3	67,4
4	67,4
5	68,4
6	67,1
7	67,2
8	67,9
9	67,7
10	68,1
67,6HVN	

6.5.: μ

6.1.4.2

μμ μ

μ μ Ni-W
 μ μ Vickers.
 μ μ HMV200 Shimatzu.
 μ μ μ μ
 μ μ μ μ
 μ μ 50gr 10sec.

μ

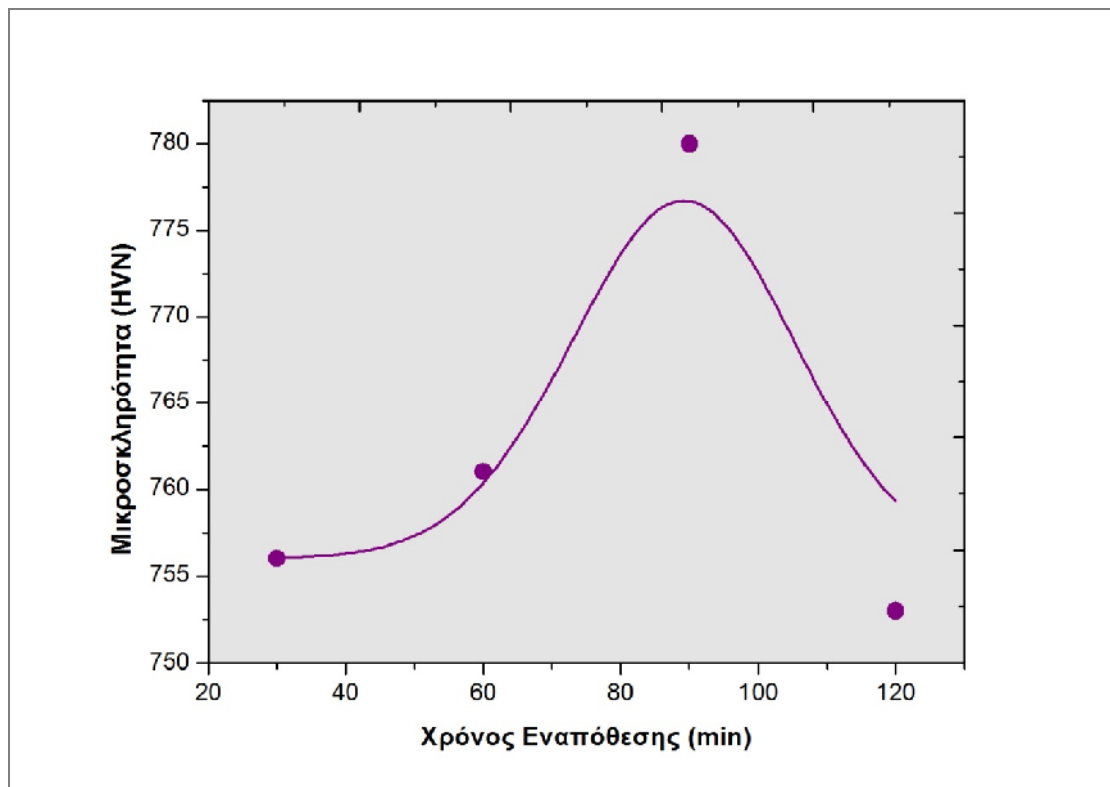
:

- i. μ μ μ μ
- ii. μ μ μ μ

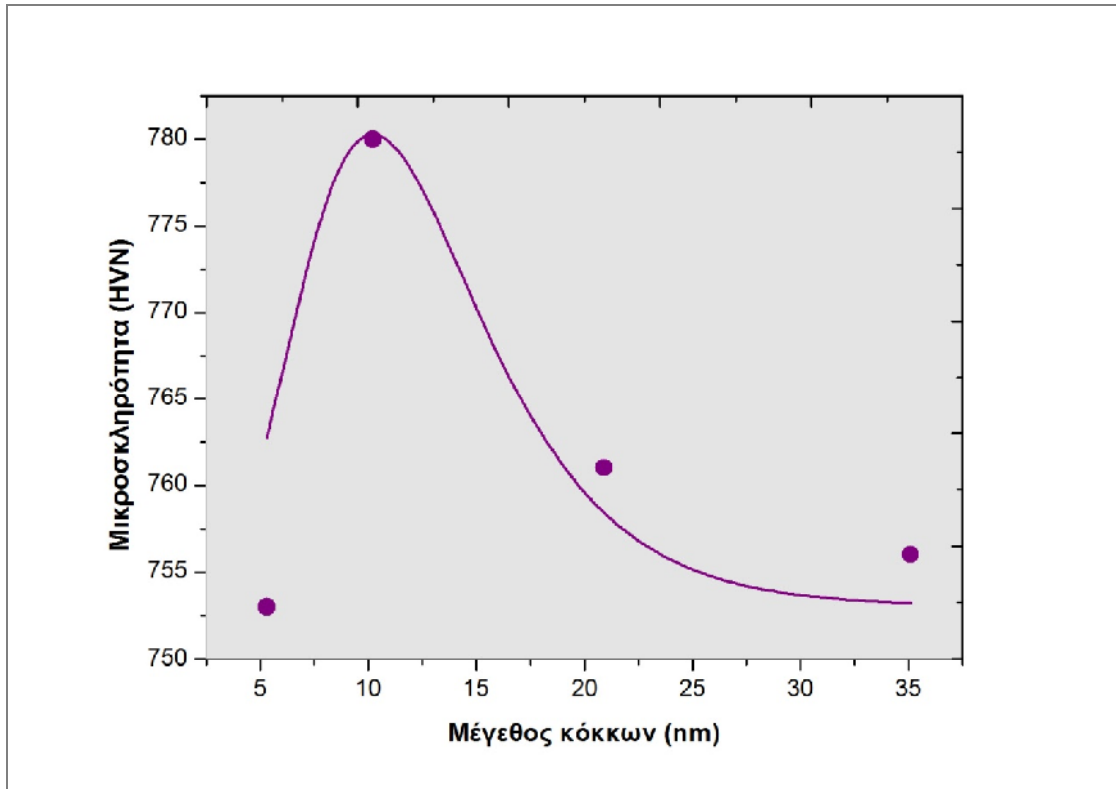
μ , μ 10
 μ μ .
 μ μ μ
 6.6 $\mu\mu$ 6.5 6.6.

μ (min)	(HVN)
30	756
60	761
90	780
120	753

6.6.: μ μ .



$\mu\mu$ 6.5.: $\mu\mu$ μ μ μ

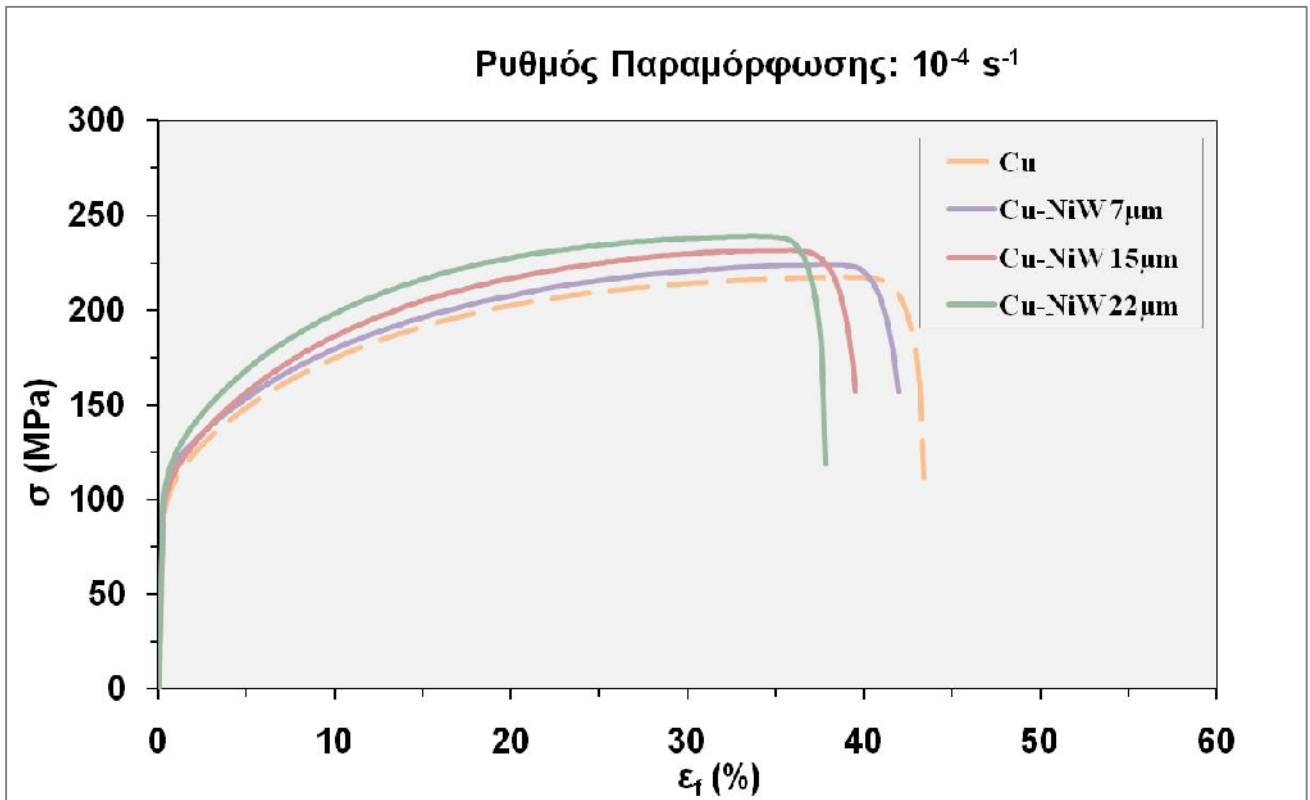


μμ 6.6: μμ μ μ μ μ
 μ 6.6 μμ
 (μμ 6.5 6.6) μμ
 μ μ μ μ μ
 μ μ μ μ [11,27].
 μ μ μ μ Hall-
 Petch [3], μ μ μ μ μ μ
 μ μ μ μ [9,28,29]
 Hall-Petch μ μ μ
 μ 8-10nm.
 μ μ μμ 6.6., μ
 μ μ

μ μ μ
 μ μ μ μ μ
 μ μ .
 μ μ μ
 μ :

- τ_s : μ μ (UTS). μ
 $\mu\mu$ - , μ μ ,
 μ μ .
- f : μ . μ
 μ .
 μ μ μ μ
 $\mu\mu$ - μ ,
 μ μ .

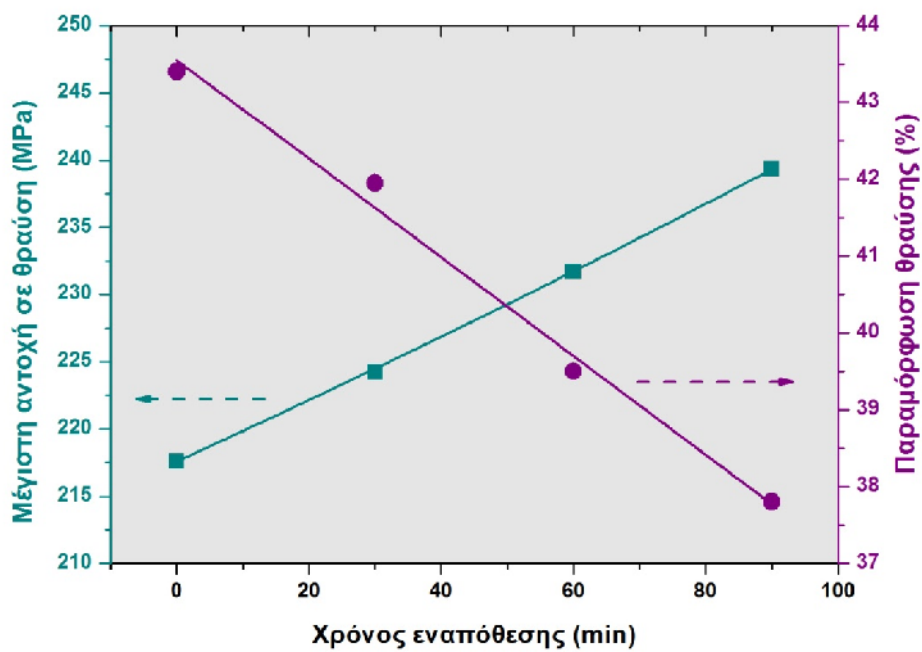
μ μ μ
 μ μ μ μ
 μ μ
 μ μ
 10^{-4} s^{-1} μ
 $\mu\mu$ ($\mu\mu$ 6.7).



μμ 6.7.: μμ - μ μ Ni-W.

μ μ μ μ

μ (μμ 6.8), μμ .



μμ 6.8.: μμ μ μ μ

Ni-W.

μ
 μ μ μ μ () $7\mu\text{m}$ () $15\mu\text{m}$
 () $22\mu\text{m}$, $\mu\mu$ - μ
 ($\mu\mu$ 6.7), :

		μ μ μ Ni-W		
		$7\mu\text{m}$ μ	$15\mu\text{m}$ μ	$22\mu\text{m}$ μ
UTS (MPa)	217,6	224,2	231,7	239,32
f (%)	43,4	41,95	39,5	37,8

6.7.: μ μ μ μ Ni-W

$\mu\mu$ μ μ
 μ μ μ
 μ μ μ
 μ μ μ
 μ μ μ

[31]:

$$\sigma_{comp} = \sigma_m \cdot C_m + \sigma_c \cdot C_c \quad [6 \square]$$

, comp

m

μ

c

Ni-W,

C_m

C_c

$\mu\mu$

μ

μ

μ μ

μ . μ μ

μ μ μ

μ Cu - Ni-W. μ μ

μ μ [30]. μ μ

μ μ μ μ

Ni-W, μ μ (G_{Cu}) 44GPa,

(G_{Ni}) 76GPa μ (G_W) 161GPa.

μ

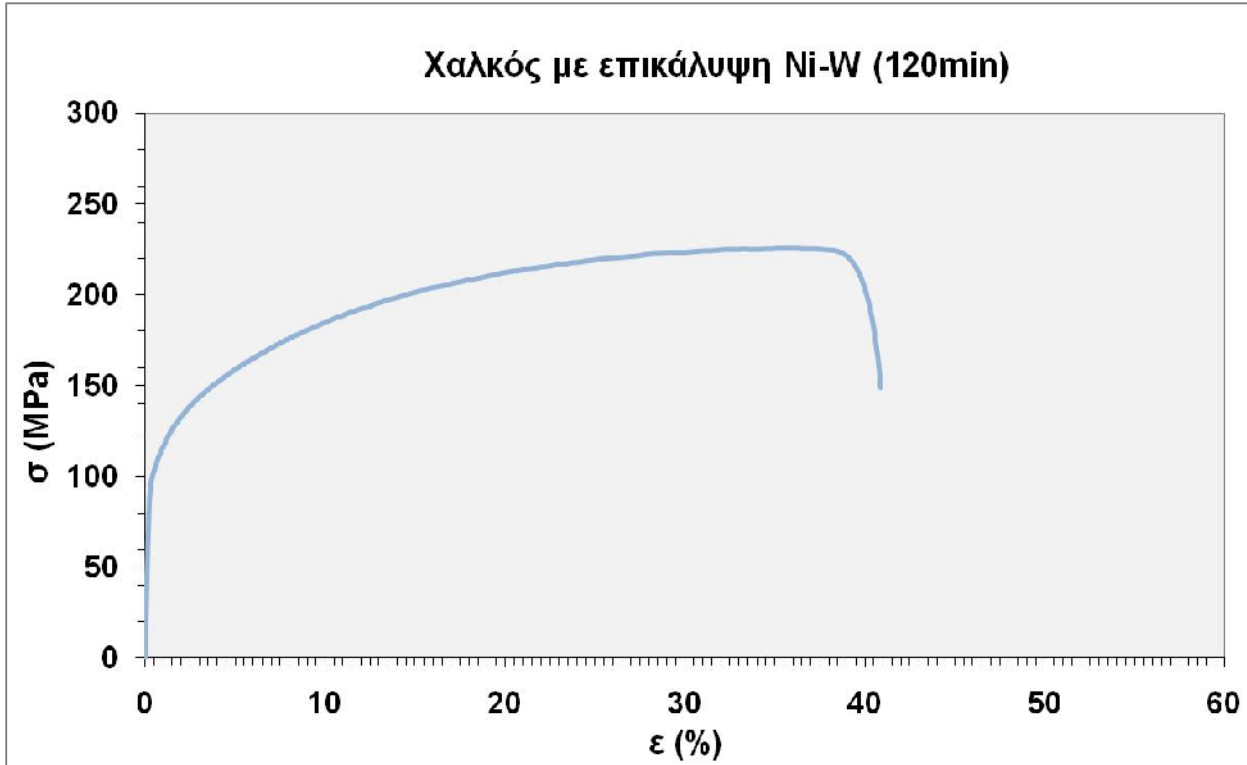
μ 22μm 25μm (120 min)

μ , , μ μ .

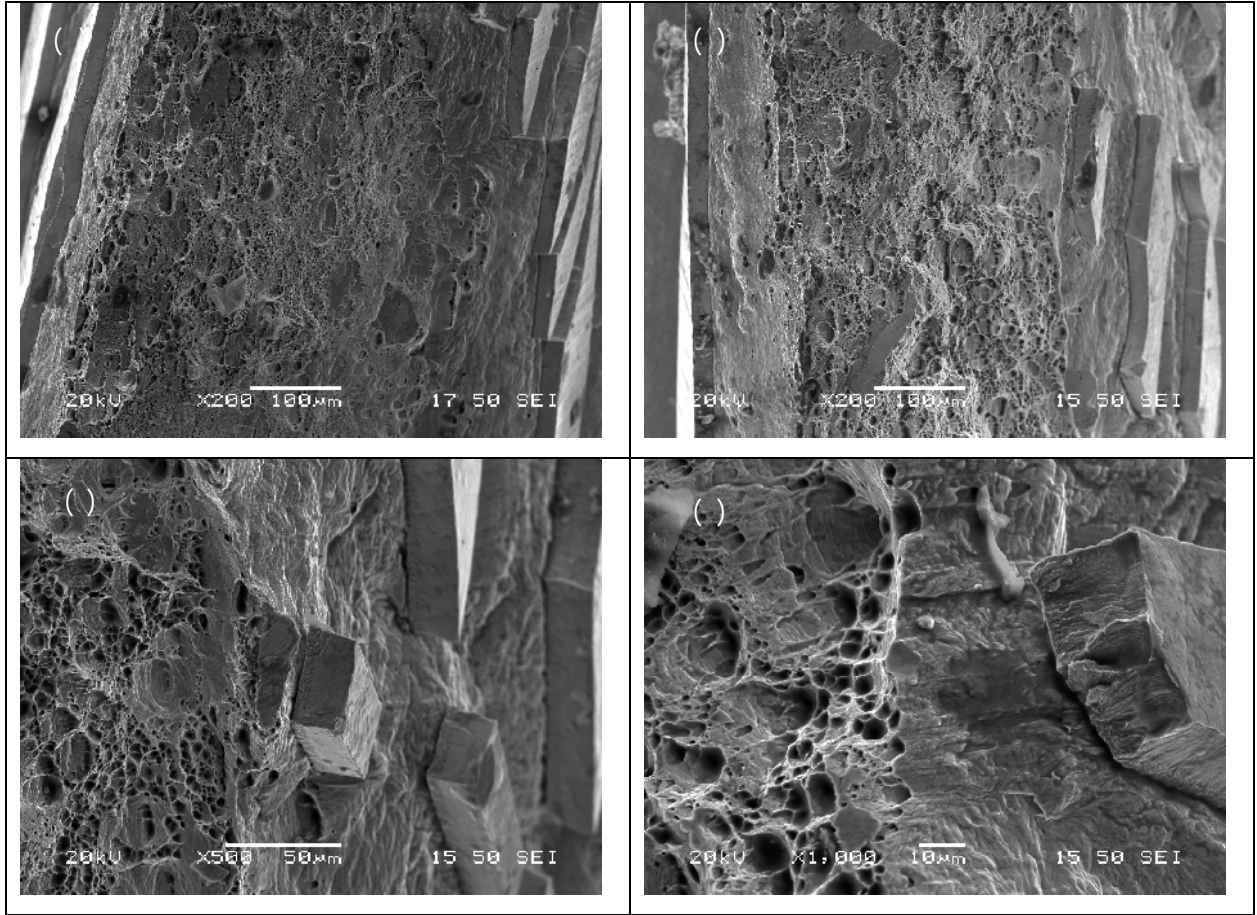
μ μ μ ,

μ ,

μ μ



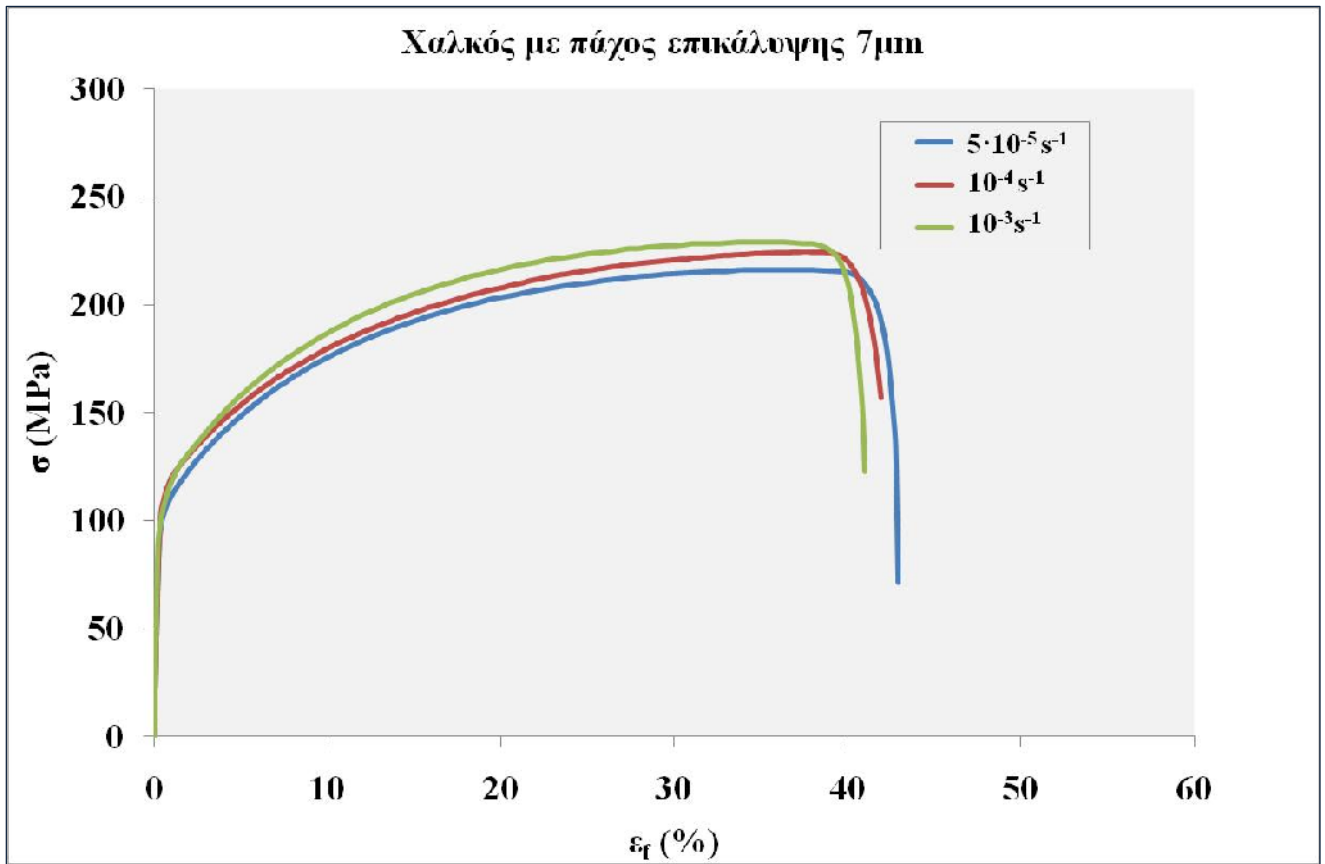
μμ 6.9.: μ μ μ Ni-W. μ



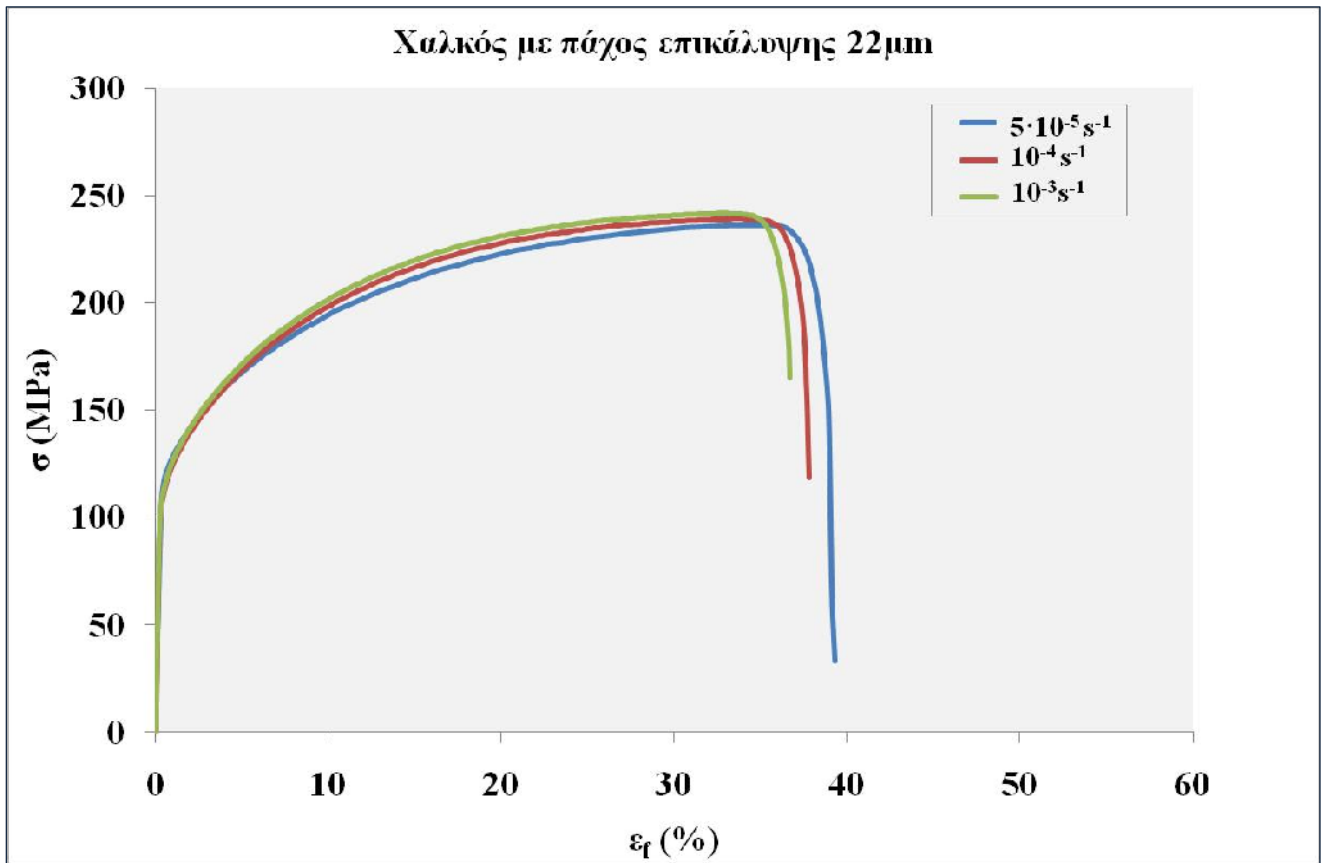
6.7.:
 () 7μm. () 15μm. () 22μm. () 25μm

μ μ Ni-W

μ
 (dimples), μ
 , μ
 Ni-W μ μ
 (cleavage), μ
 μ μ μ



μm 6.10.: μ μ - μ μ Ni-W 7μm



μm 6.11.: μ μ - μ μ Ni-W 22μm

[33]: $\sigma_{comp} = N \cdot \dot{\epsilon}^n$ [6]

7µm 22µm. T
 Ni-W µ

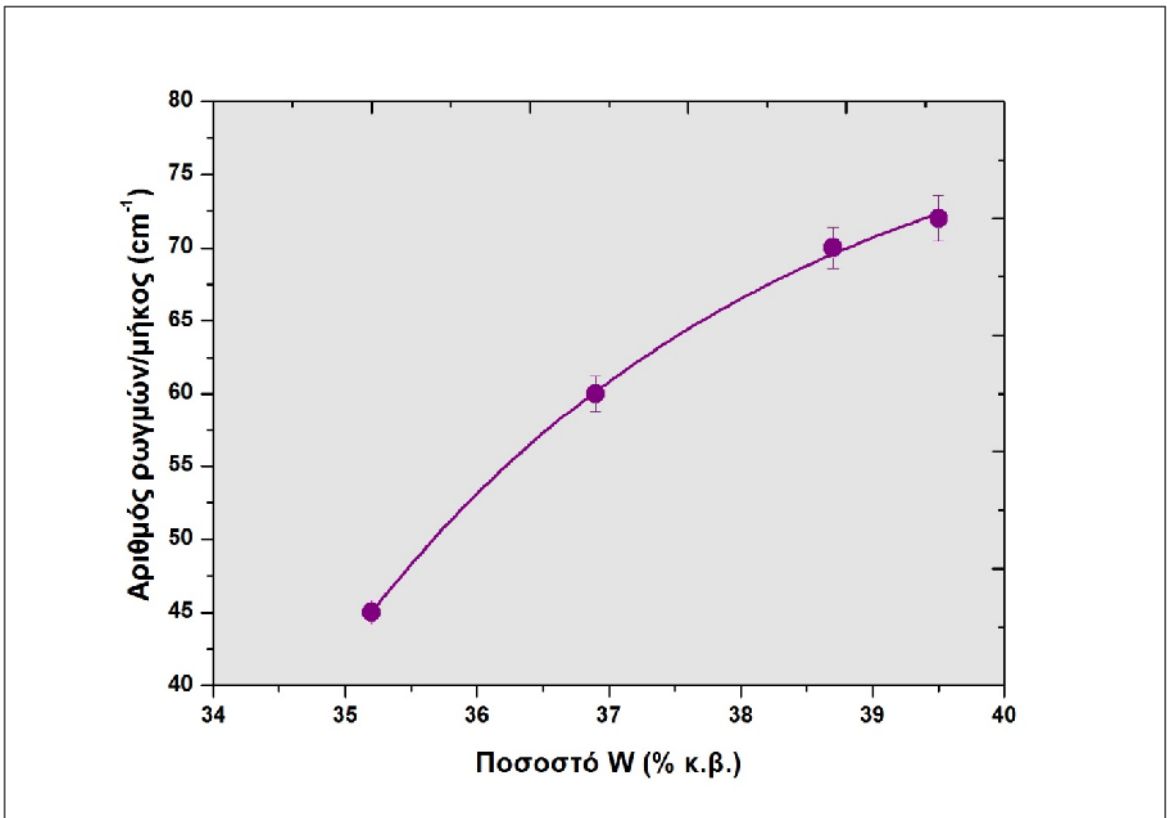
[33]:

$$\sigma_{comp} = N \cdot \dot{\epsilon}^n \quad [6]$$

, , ,
 $\dot{\epsilon}$, µ µ
 n, µ (strain-rate sensitivity).

6.2.3 µ

6.2.3.1 µ µ
 µ µ Ni-W, µ µ
 µµ µ µ µ µ
 µµ :



μμ 6.12.:
Ni-W

μμ

μ
μ .

μ

μμ (μμ 6.12)

μ

μ μ

μ .

μ

μ

μ

μ

, μ

μ

μ

μ

μ .

6.2.3.2

μ

μ

, μ

μ

μ

μ

, μ

μ

μ

μμ

μ

μ

μμ

μ

μ

μ

μ

μ

μ

μ

22μm

μ

μ

μ

10⁻⁴s⁻¹.

μ

μ

μ

μ

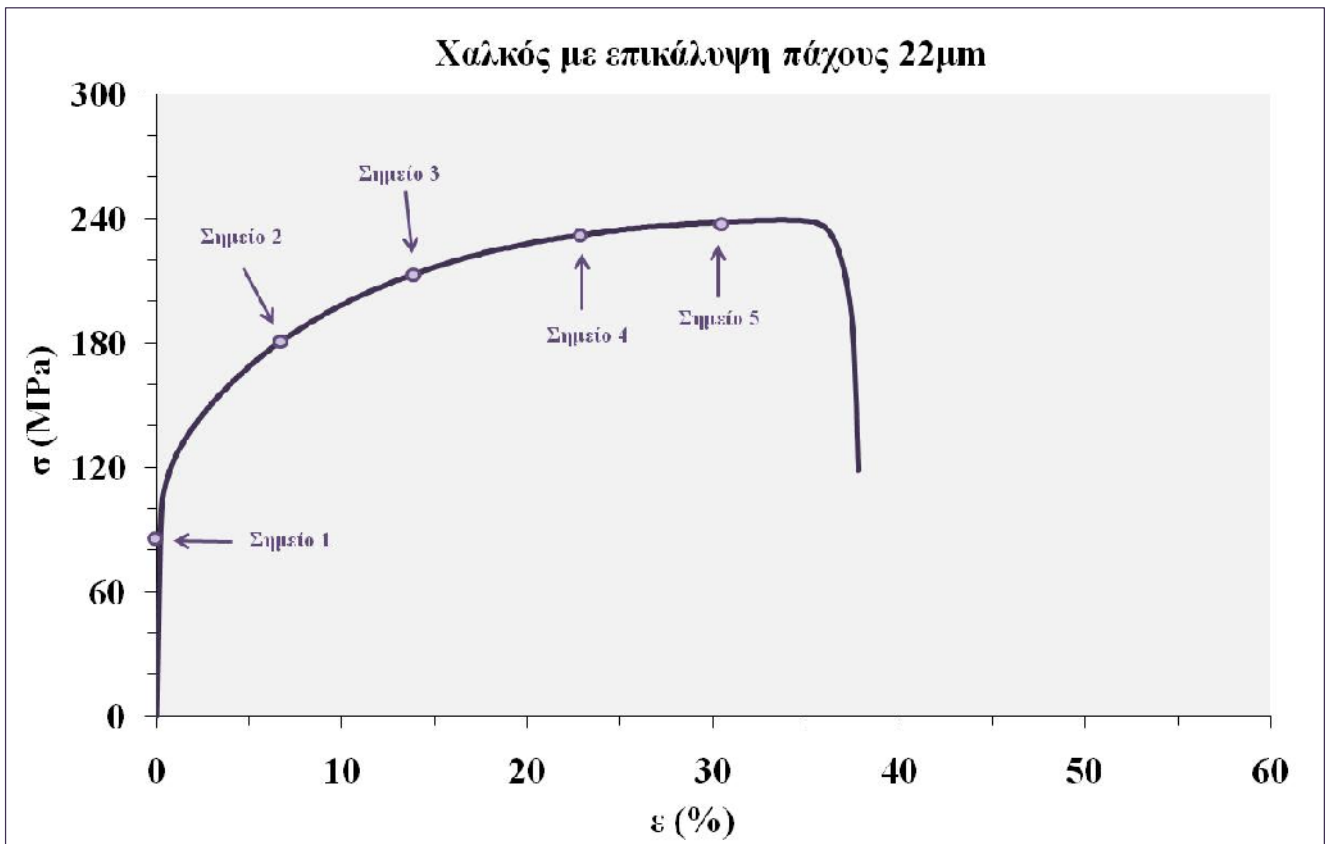
μm

-

(

μm

6.13).



μm 6.13:

μ "o"

μ

μ

Ni-W

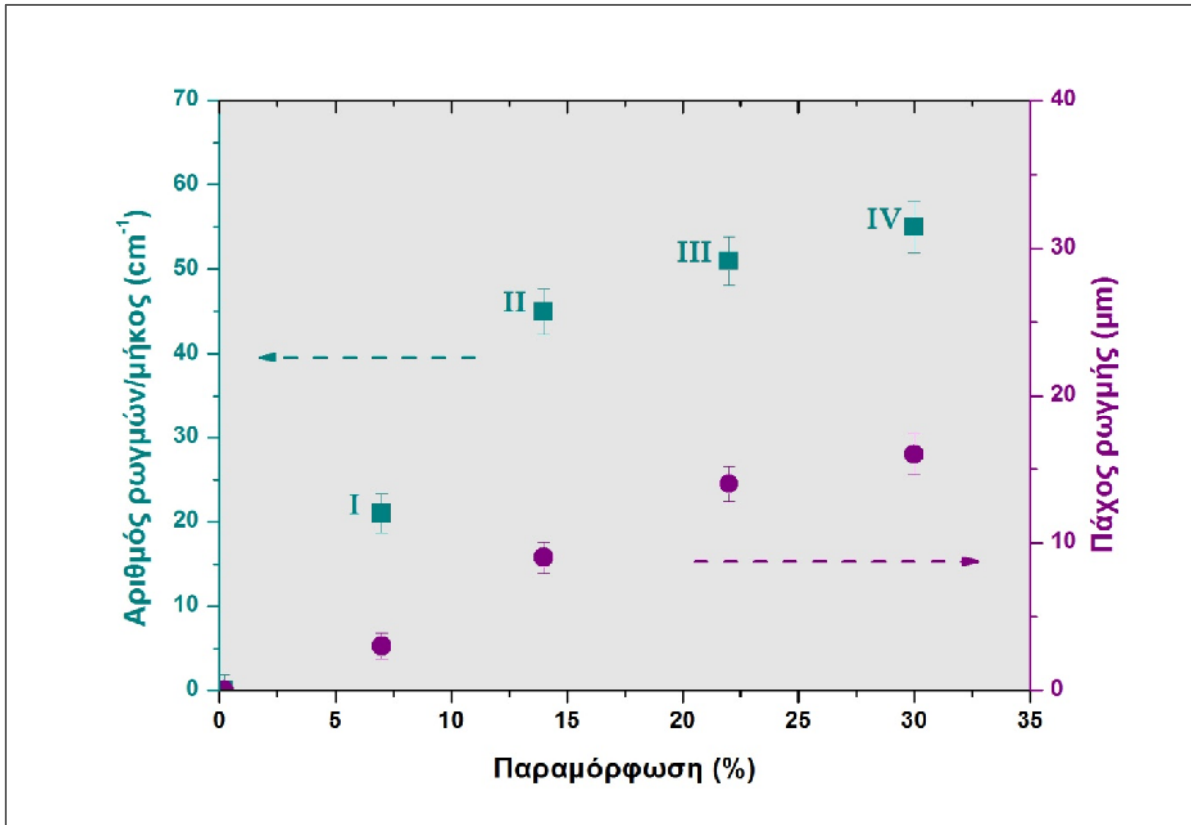
22μm

μ .

μm μ

μ

μ .



μμ 6.14.:

μ μ μ

μ

μ μ μ

μ

μ

μ

μ

μ

μ

μ

μ

μ

μ (Cu)

μ (Ni-W) [34].

μ

μ

μ

μμ

() (μμ 6.13. μ 2)

μ μ .

() (μμ 6.13. μ 3)

μ μ .

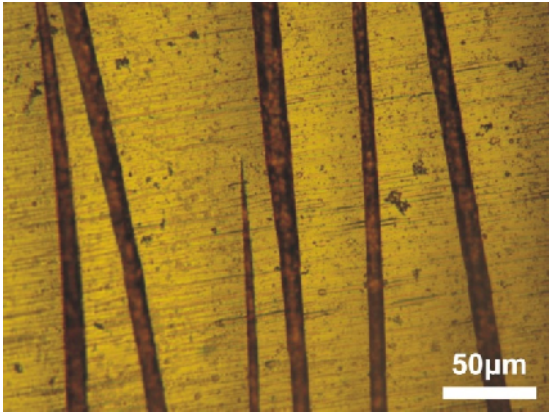
() (μμ 6.13. μ 4)

μ μ (IV) (μμ 6.13.

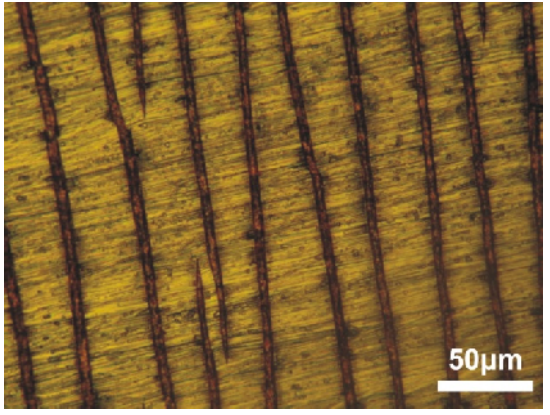
μ 5)

μ μ

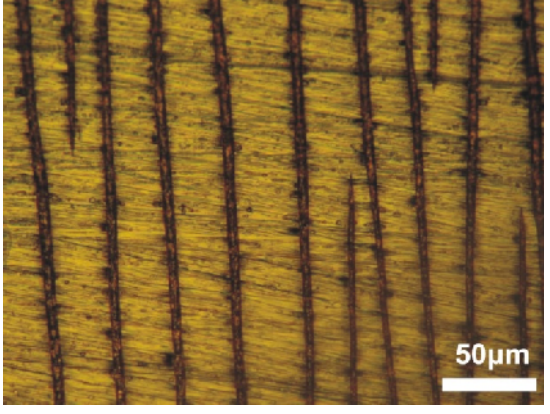
μ μ μ
 μ μ .
 μ $\mu\mu$ μ
 μ μ μ
 μ $\mu\mu$ 6.11 ,
 μ μ μ , μ μ



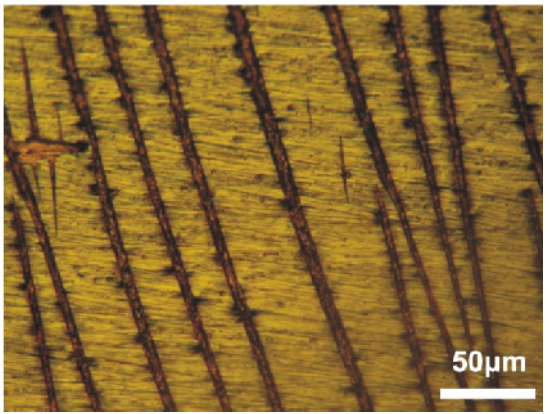
()



()

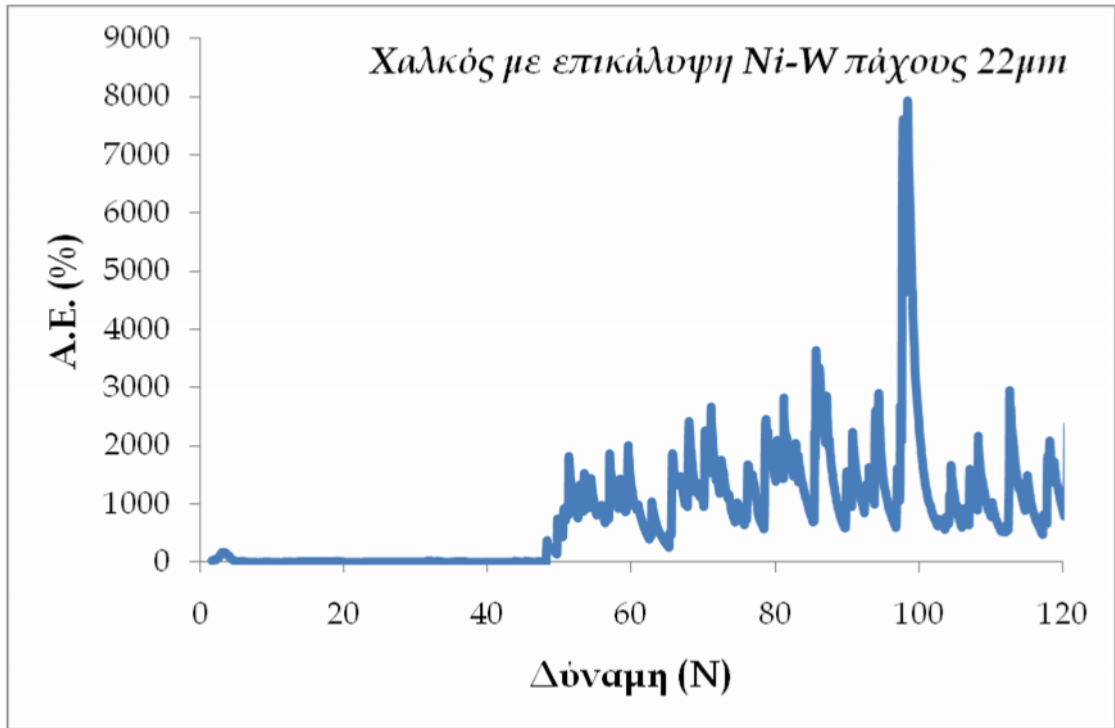


()

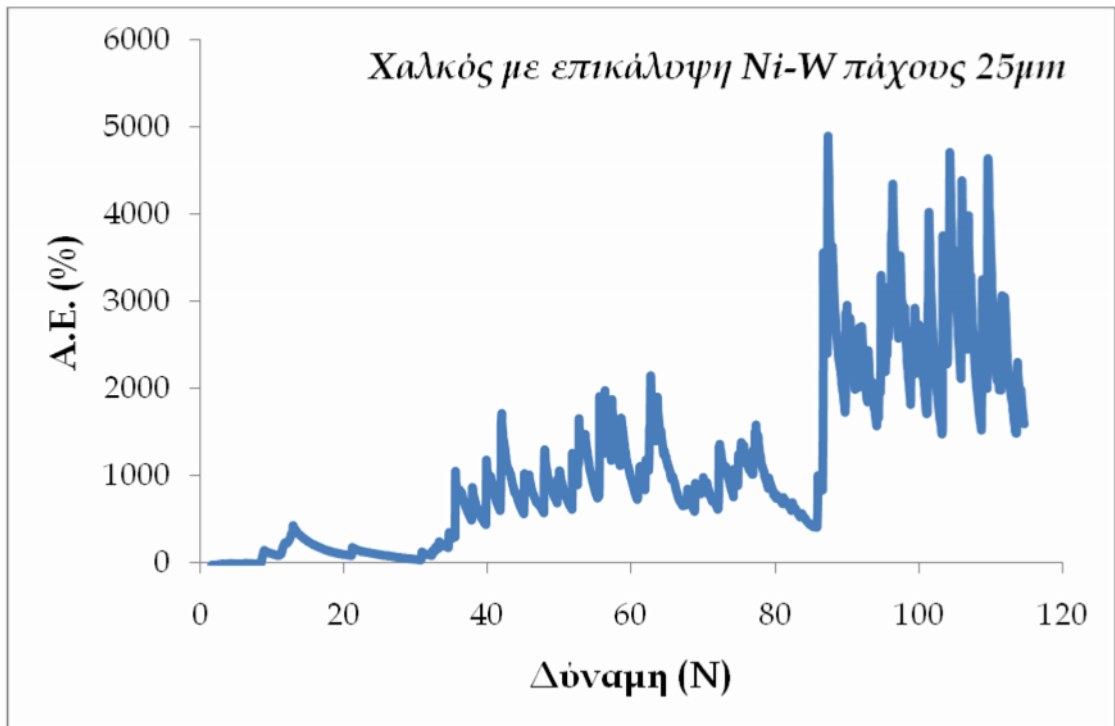


()

() 6.8.: μ μ () . () . ()
 v.



μμ 6.17.: μμ μ μ Ni-W 22μm (39 . .% W).



μμ 6.18.: μμ μ μ Ni-W 25μm (40 . .% W).

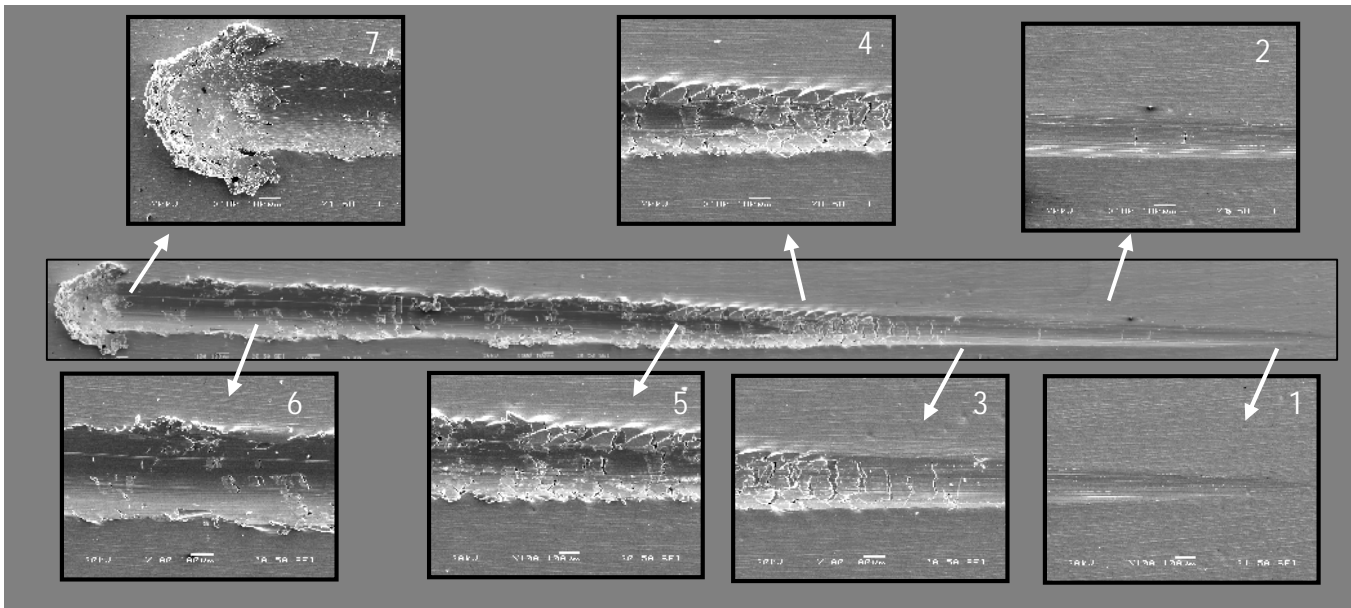
µµ µ , Ni-W
 µ µ
 . µ
 (6.9).

		L _C	L _A
30min	7µm	5	20
60min	15µm	30	40
90min	22µm	50	100
120min	25µm	40	85

6.9.:

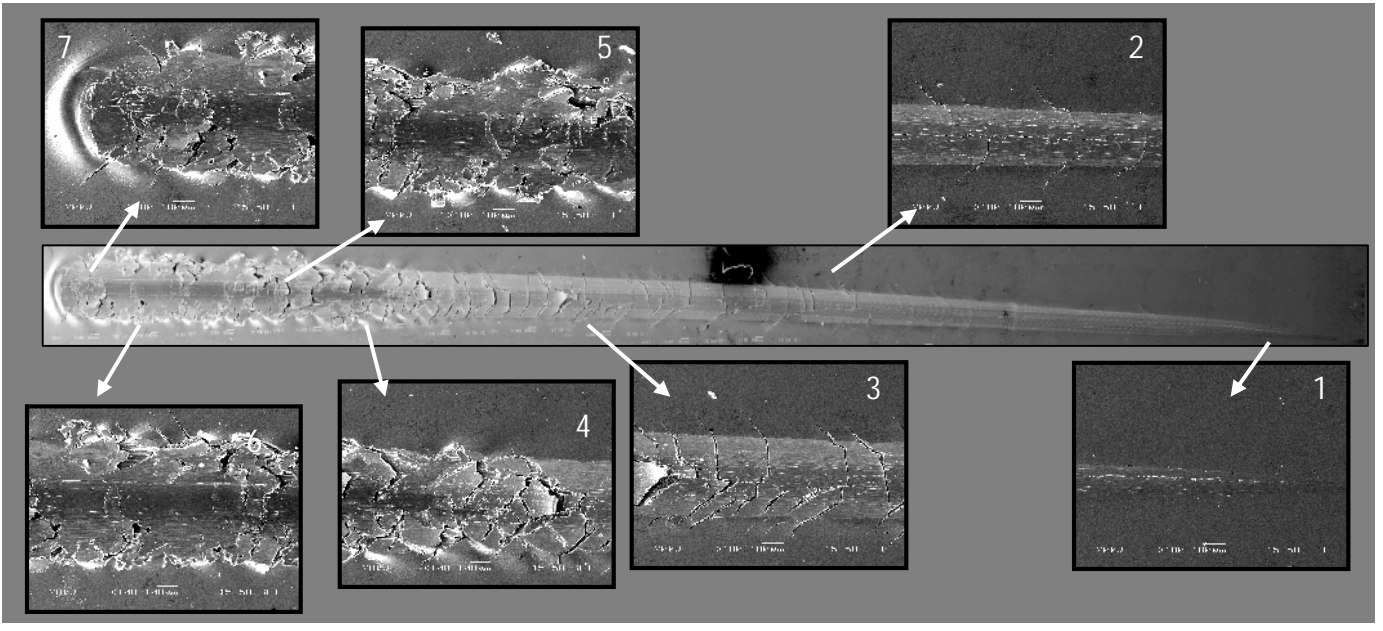
µ µ ,
 µ
 µ 22µm,
 µ µ µ
 µ µ
 µ 120min, µ
 25µm, µ
 µ µ µ µ
 µ
 µ µ µ µ µ
 µ µ µ µ µ
 Ni-W µ

μ 6.4.1, μ μ μ μ μ [35]. μ μ μ μ μ μ (μ 6.4.2), μ 6.4.3
 μ (20). μ 6.4.4
 μ (μ) μ μ 6.4.5 6.4.6 Ni-W
 μ μ μ μ μ 6.5
 μ 15 μ m, μ μ μ



μ 6.5.: Ni-W 15 μ m

μ 6.5.1, μ
 Ni-W,
 μ 7 μm , μ μ μ
 μ μ μ
 μ , μ 6.5.2. μ
 μ μ μ
 μ , μ 6.5.3. μ 6.5.4
 Ni-W.
 μ , μ 6.5.5.
 μ 6.5.6 6.5.7 μ Ni-W
 μ
 μ .



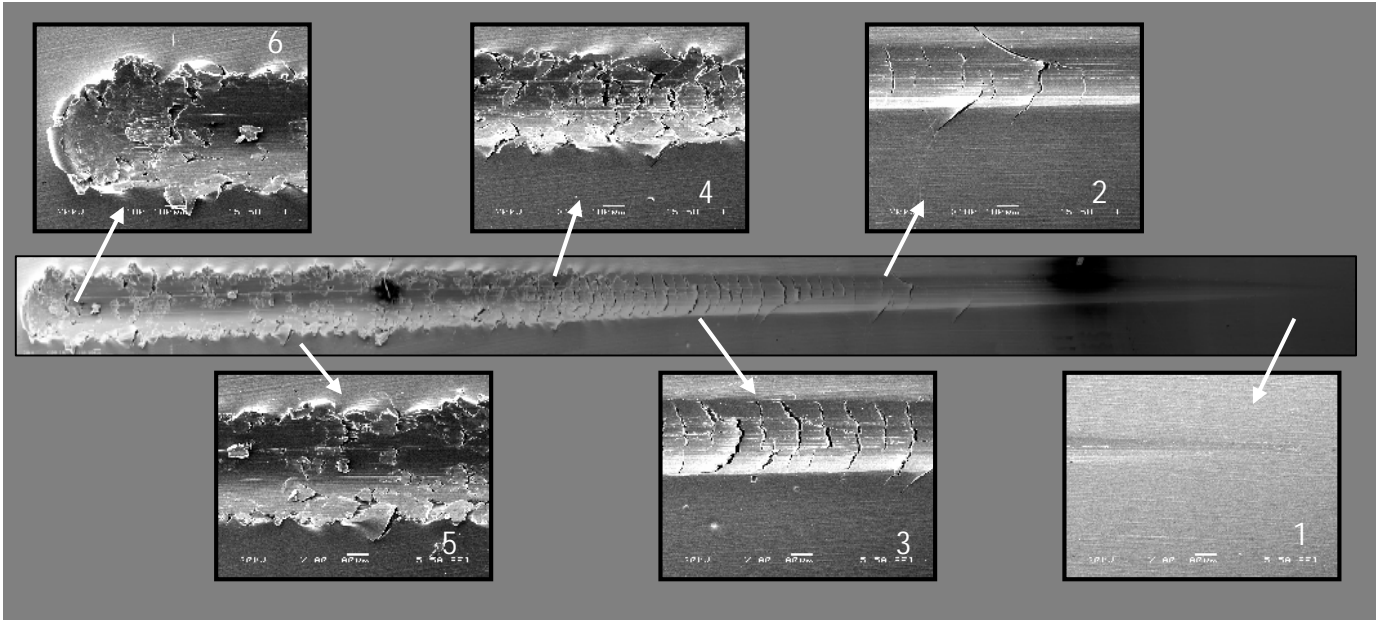
μ 6.6.
 22 μm . μ μ
 15 μm .
 μ
 μ μ .

μμ

μ

μ

μ



μ 6.7.:

Ni-W

25μm

μ 6.7

25μm.

μ

μ

22μm

μ

μ

μ

μ

μ

μ

μ

μ

μ

μμ

μ

22μm.

μ

μ

μ

μ

Ni-W

μ

μ

() 7μm () 15μm () 22μm

() 25μm, μ

μ

μ

μ

μ

μ

μ

: (1) μ μ μ
Ni-W , (2)
 μ (3) (μ)
 μ .

7. μ μ

μ μ μ ,
 μ :

- μ Ni-W

μ μ . μ
 μ 35,2 – 39,5 % . . .

- μ Ni-W

μ μ μ , 120
(25 μ m)

μ .

- % . . . μ

, μ μ . ,
 μ μ μ μ
 μ (8-10nm). μ

μ μ Ni-W
 μ 35,1 5,3 nm.

- μ Ni-W
 μ μ μ
7 μ m 25 μ m.

- Ni-W
 μ μ

• $\mu\mu$ μ
 μ μ Ni-W. μ μ
 μ μ μ μ μ μ
 • μ μ Ni-W, μ μ μ μ μ μ
 μ $\mu\mu$ $\mu\mu$ μ μ μ μ μ
 μ 22 μm 25 μm μ μ μ μ
 μ μ μ μ μ μ μ μ
 • μ μ μ μ μ μ $\mu\mu$
 μ μ Ni-W. μ μ μ μ
 • μ μ μ μ μ μ μ μ
 μ μ μ μ μ μ μ μ
 • Ni-W μ μ μ μ μ μ
 (scratch test). μ μ μ μ μ μ
 μ μ Ni-W 25 μm μ μ μ
 μ μ (22 μm). μ μ μ

8.

μ μ Ni-W μ , μ
 μ μ μ μ ,
 μ μ μ . μ ,
 μ . μ μ
 μ , μ μ μ .
 \triangleright , μ
Ni-W, μ
 μ , μ ...
 \triangleright μ μ μ μ
Ni-W μ μ .
 \triangleright μ μ μ Ni-W
 μ μ μ μ μ
 μ μ μ .
 \triangleright μ μ μ μ μ
Ni-W μ μ .
 \triangleright μ μ μ μ μ
Ni-W .

9.

μ
μ .

μ μ μ μ .

μ

, ,

μ μ μ
μ .

μ ,

μ .

. μ , μ μ .
μ .

μ μ :

μ

μ (. . . .)

μ μ .

. . . . ,

μ μ μ μ

. . . . μ μ μ (A.F.M.).

. . . . μ , μ .

, μ μ

μ μ μ μ

μ .

10.

1. " , . . . ,
2. " - ,
3. " , . . . μ ,
4. " - μ " , . . . μ ,
5. " μ " ,
6. " μ " , . . . μ ,
7. " μ " , William D.Callister.
8. " μ μ " , . . . μ ,
9. Tohru Yamasaki, *Scripta Mater.*, 44 (2001) 1497.
10. C.N.Panagopoulos, G.D.Plainakis, D.A.Lagaris, *Mater. Sci. Eng. B.*, in Press, (2010).
11. K.R.Sriraman, S.Ganesh Sundara Raman, S.K.Seshadri, *Mater. Let.*, 61 (2007) 715.
12. R.Jason, A.Schuh, *Scripta Mater.*, 61 (2009) 1056.
13. Kung-Hsu Hou, Yun-Feng Chang, Sha-Ming Chang, Chia-Hua Chang, *Thin Solid Films*, , in Press, (2010).
14. A.Giga, Y.Kimoto, Y.Takigawa, K.Higashi, *Scripta Mater.*, 55 (2006) 143.
15. C.A.Schuh, T.G.Nieh, H.Iwasaki, *Acta Mater.*, 51 (2003) 431.
16. J.W.Dini, "Electrodeposition", *The Material Science of Coating and Substrates*, Noyes Publication, ParkRidge, New Jersey (1993).
17. K.L.Chopra, "Thin Film Phenomena", Mc Graw-Hill, New York, (1970).

18. D.W. Butler, C.T.H.Stoddart, P.R.Stuard, J.Phys, D: Appl. Phys., 3 (1970).
19. B.N. Chapman, J.Vac.Sci.Technol., 11 (1974).
20. H.Weiss, Surf. Coat. Technol., 71 (1995) 201.
21. L.I.Tushinsky et al, "Coated Metal: Structure and Properties of Metal-Coating Composition", Springer, Berlin, (2002).
22. S.J.Bull, Tribology Internat., 30 (1997) 491.
23. A.S.M. Handbook, "Metallography and Microstructures", Vol.9, (1992).
24. N.Eliaz, T.M.Sridhar, E.Gileadi, Electrochim. Acta, 50 (2005) 2893.
25. M.Donten, H.Cesiulis, Z.Stojek, Electrochim. Acta, 45 (2000) 3389.
26. A.S.M. Handbook, "Alloy Phase Diagrams", Vol.3, (1992).
27. J K.R.Sriraman, S.Ganesh Sundara Raman, S.K.Seshadri, Mater. Sci. Eng. A, 418 (2006) 303.
28. D.Clark, D.Wood, U.Erd, Nanostructured Materials, 9 (1997) 755.
29. Y.Wu, D.Chang, D.Kim, S.C.Kwon, Surf. Coat. Technol., 173 (2003) 259
30. C.N.Panagopoulos, Mater. Let., 8 (1989) 216.
31. C.N.Panagopoulos, Ar.Panagiotakis, Mater. Let., 11 (1991) 70.
32. R.Flinn, P.Trojan, "Engineering materials and their applications", 4th ed. Boston Wiley- VCH, (1994), p.115
33. C.N.Panagopoulos, M.I. Kritikou, A.M.Michaelidis, S.Vlachos, Mater. Proc. Technol., 84 (1998) 225.

34. C.N.Panagopoulos, V.D.Papachristos, G.Sigalas, J. Matter. Sci., 34 (1999) 2587
35. V.D.Papachristos, C.N.Panagopoulos, L.W. Christoffersen, A.Markaki, Thin Solid Films, 396 (2001) 173