ÓBUDA UNIVERSITY

DOCTORAL SCHOOL ON MATERIAL SCIENCES AND TECHNOLOGY

COMPLEX EXAM / RESEARCH REPORT

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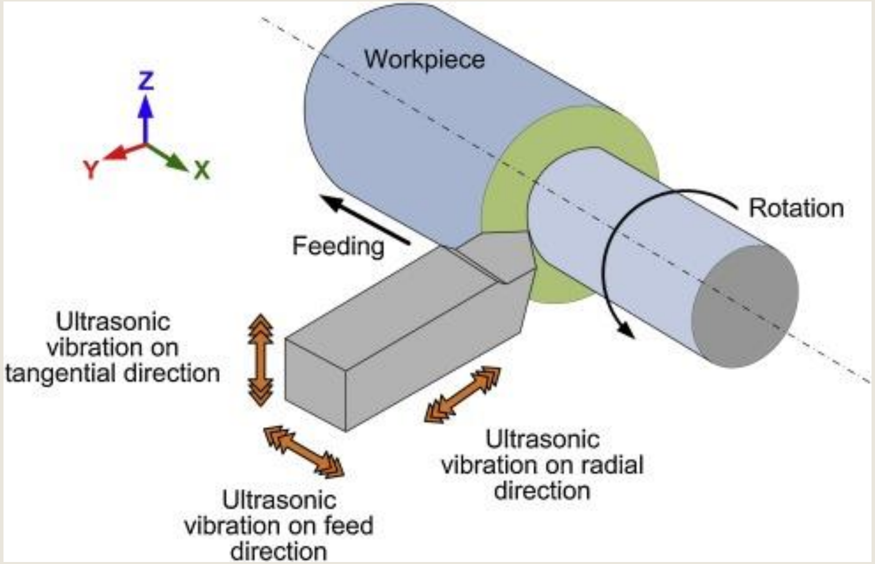
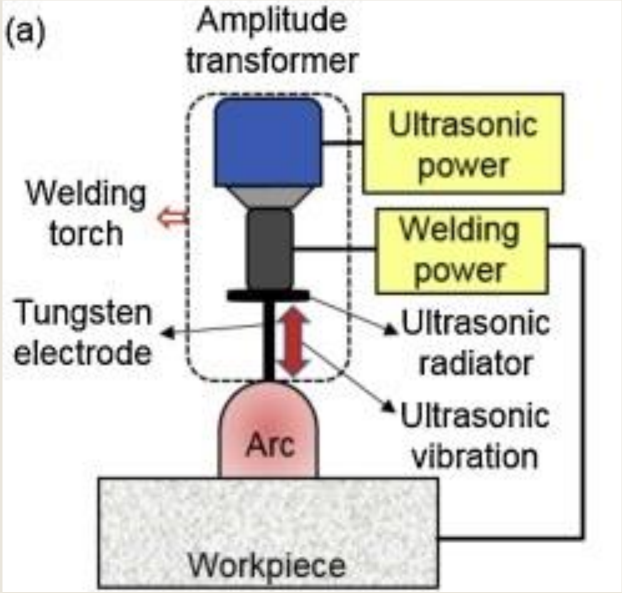
prof. Dr. Rusinko Andrew

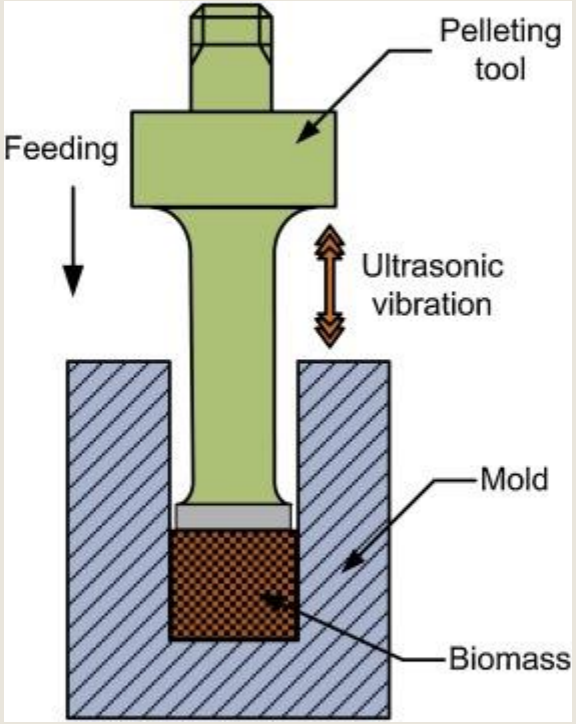
Research title:
The Effect of Ultrasound on the Irrecoverable Deformation of Metals

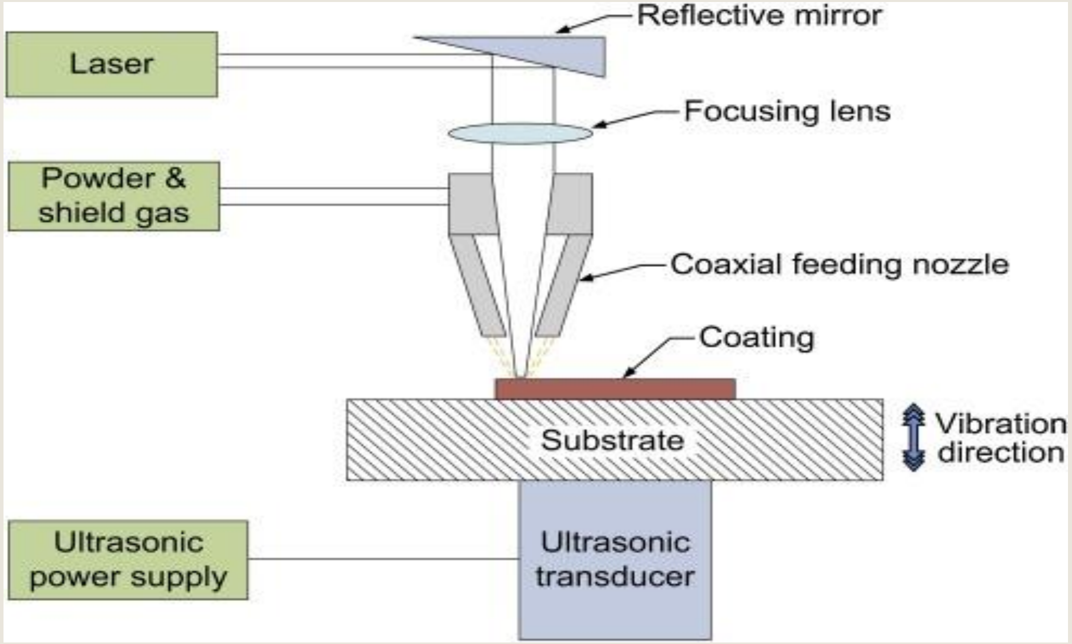
Neptun code:
F19Gox

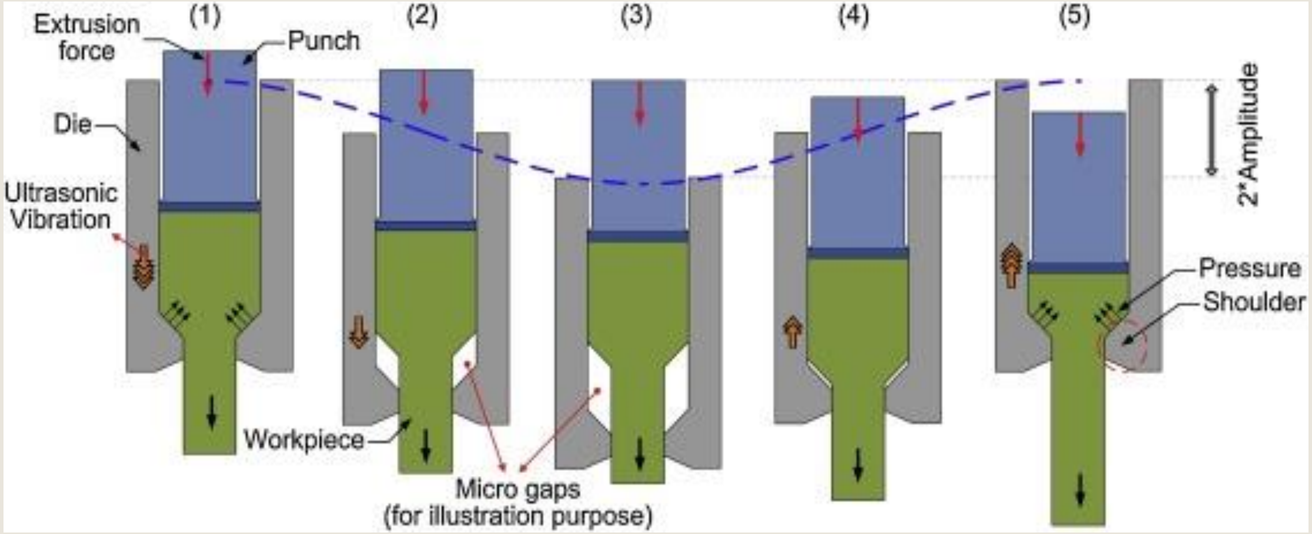
1. INTRODUCTION - The phenomena we consider











2. THE AIM OF THE WORK

My research is aimed to model the following phenomena:

- *Temporary ultrasonic softening*
- *Residual ultrasonic effects*
- *Ultrasonic recovery of strain hardened materials*
- *Ultrasound-assisted creep for continuous and periodic sonication*

For mathematic apparatus I utilize the Synthetic theory of irrecoverable deformation .

3. BASES OF SYNTHETIC THEORY

$$\vec{\boldsymbol{e}} = \iiint_V \varphi_N \vec{\boldsymbol{N}} dV \,, \tag{1}$$

$$d\psi_N = r d\varphi_N - K\psi_N dt, \tag{2}$$

$$\psi_N = H_N^2 - I_N^2 - S_P^2 = \begin{cases} \left(\vec{\boldsymbol{S}} \cdot \vec{\boldsymbol{N}}\right)^2 - I_N^2 - S_P^2 & \text{for planes reached by } \vec{\boldsymbol{S}}\text{: } H_N = \vec{\boldsymbol{S}} \cdot \vec{\boldsymbol{N}} \\ 0 & \text{for planes not reached by } \vec{\boldsymbol{S}}\text{: } H_N > \vec{\boldsymbol{S}} \cdot \vec{\boldsymbol{N}} \end{cases} \tag{3}$$

Plastic deformation in uniaxial stress state

$$\varphi_N = \frac{2}{3r}\left[(\sigma \sin\beta \cos\lambda)^2 - \sigma_S^2\right], \quad (4)$$

$$e = \frac{4\pi}{3r}\int_{\beta_1}^{\pi/2}\int_0^{\lambda_1}\left[(\sigma \sin\beta \cos\lambda)^2 - \sigma_S^2\right]\sin\beta \cos\lambda \cos\beta \, d\lambda d\beta = a_0\Phi(b), \quad (5)$$

$$a_0 = \frac{\pi\sigma_S^2}{9r_0}, \qquad \Phi(b) = \frac{1}{b^2}\left[2\sqrt{1-b^2} - 5b^2\sqrt{1-b^2} + 3b^4 \ln\frac{1+\sqrt{1-b^2}}{b}\right]. \quad (6)$$

$$\sin\beta_1 = \frac{\sigma_S}{\sigma} \equiv b, \qquad \cos\lambda_1 = \frac{\sigma_S}{\sigma \sin\beta}. \quad (7)$$

4. EXTENTION OF SYNTHETIC THEORY

4.1 For the purpose of **modeling the effects of ultrasound on the plastic strain** of metals, we extend Eq. (2) by two terms, U_t and U_r:

$$r\varphi_{NU} = H_N^2 + U_t^2 + f(\gamma)U_r^2 - S_S^2. \qquad (8)$$

$$U_t = A_1 {\sigma_m}^{A_2}(2 - e^{-pt})\left(\vec{u} \cdot \vec{N}\right), \qquad t \in [0, \tau] \qquad (9)$$

$$U_r = h(\varepsilon - \sigma_m) \times A_3 \int_0^{\tau} {\sigma_m}^{A_4} dt\,, \qquad (10)$$

4.2 for modelling the **Ultrasonic Recovery** we established the formula**:**

$$H_{NU} = \sqrt{\sigma_S^2 + \frac{3}{2}\psi_{N0}\exp(-A_1(\sigma_m H_{\max})^{A_2} t)}. \quad (11)$$

Where H_N is the plane distances :

$$HV = R \cdot \sqrt{\sigma_S^2 + \frac{3}{2}\psi_{N0}\exp(-A_1(\sigma_m H_{\max})^{A_2} t)}. \quad (12)$$

4.3 To extend the Synthetic theory for the case of **ultrasound-assisted creep**,

$$\psi_N = H_N^2 - I_N^2 - S_P^2 + U_C^2. \quad (13)$$

We define U_C as

$$U_C = \vec{U} \cdot \vec{N}, \qquad \vec{U} = \psi_{NU}\vec{u} \quad (14)$$

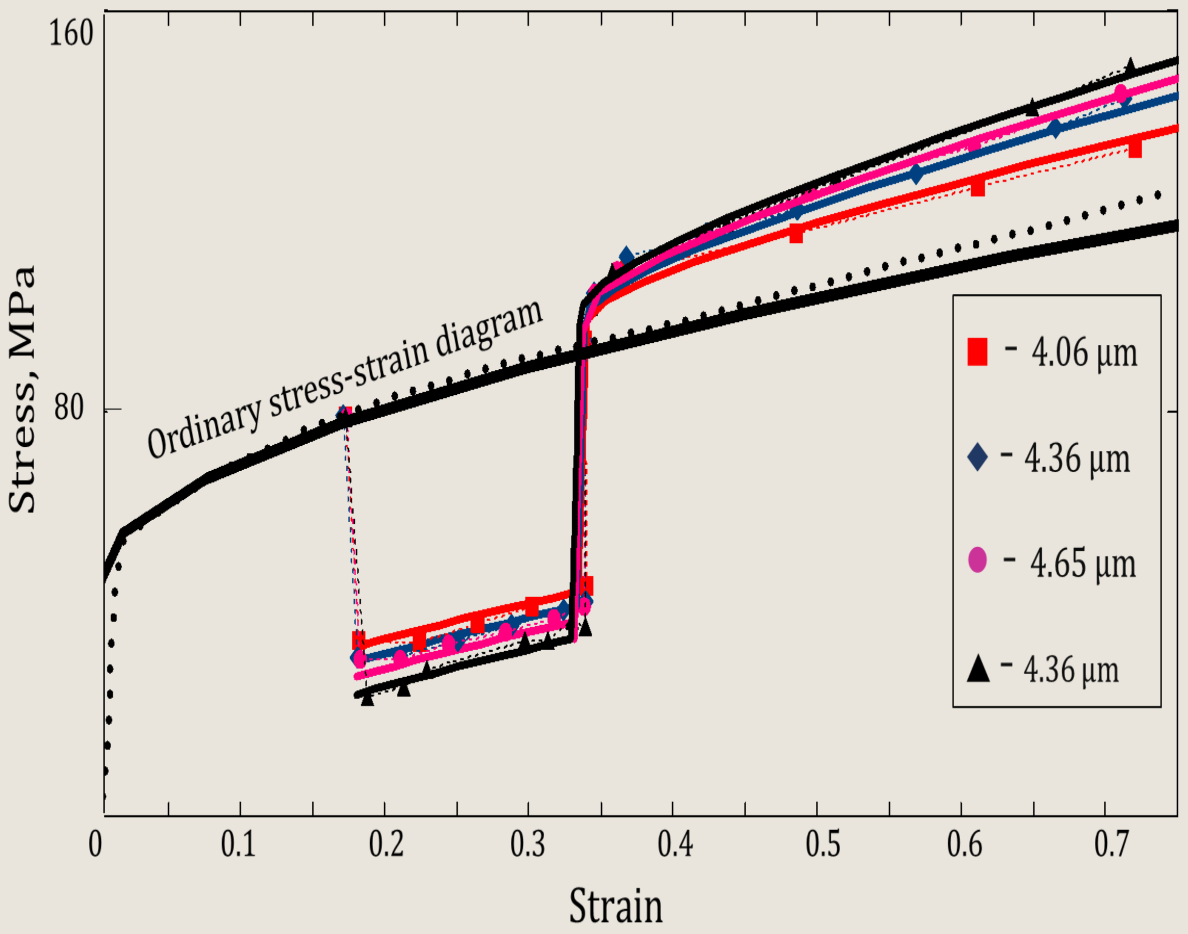
where ψ_{NU} is ultrasound-induced defect intensity:

$$\psi_{NU} = A_1 {S_m}^{A_2}(1 - e^{-wt}) \quad (15)$$

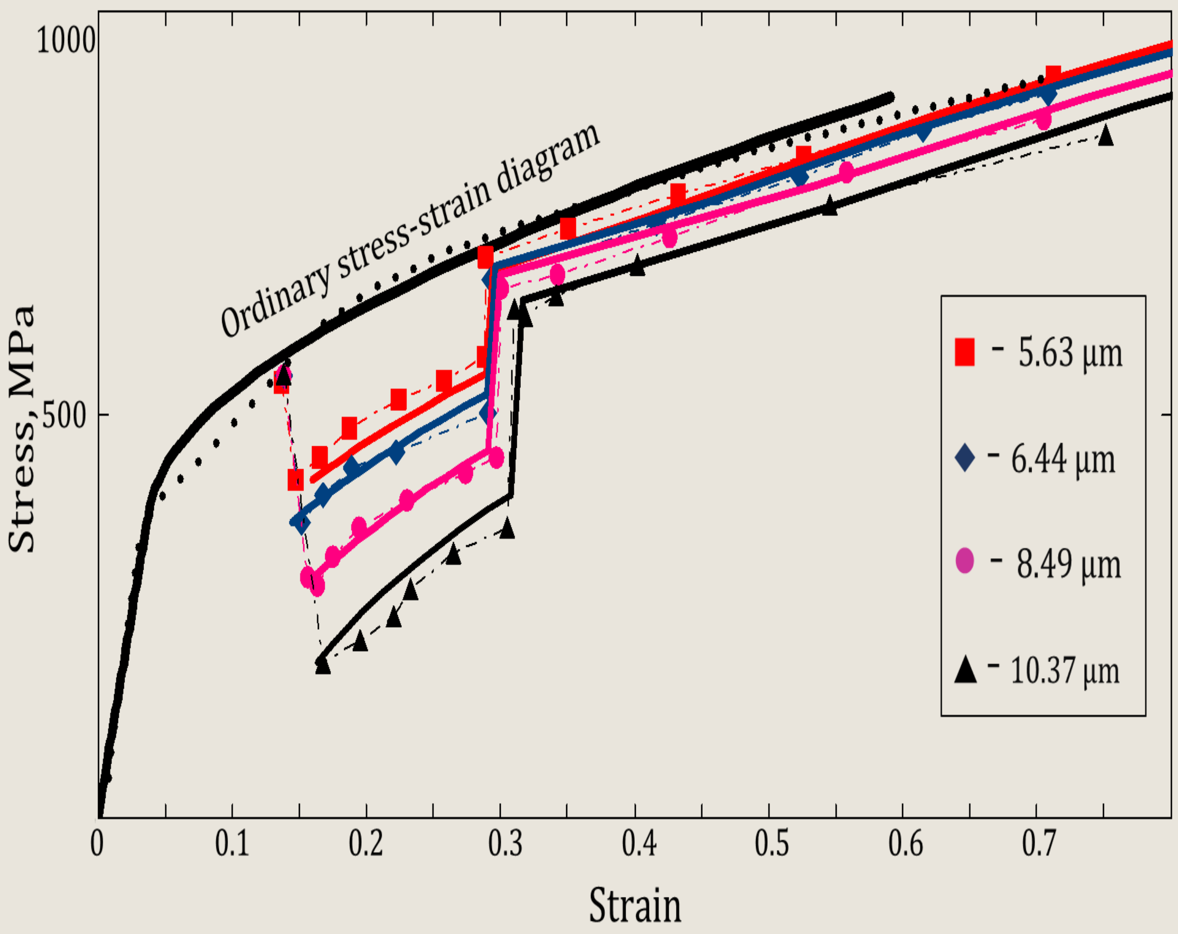
Where S_m is an oscillating stress amplitude.

$$K_U = K + A_3 S_m \quad (16)$$

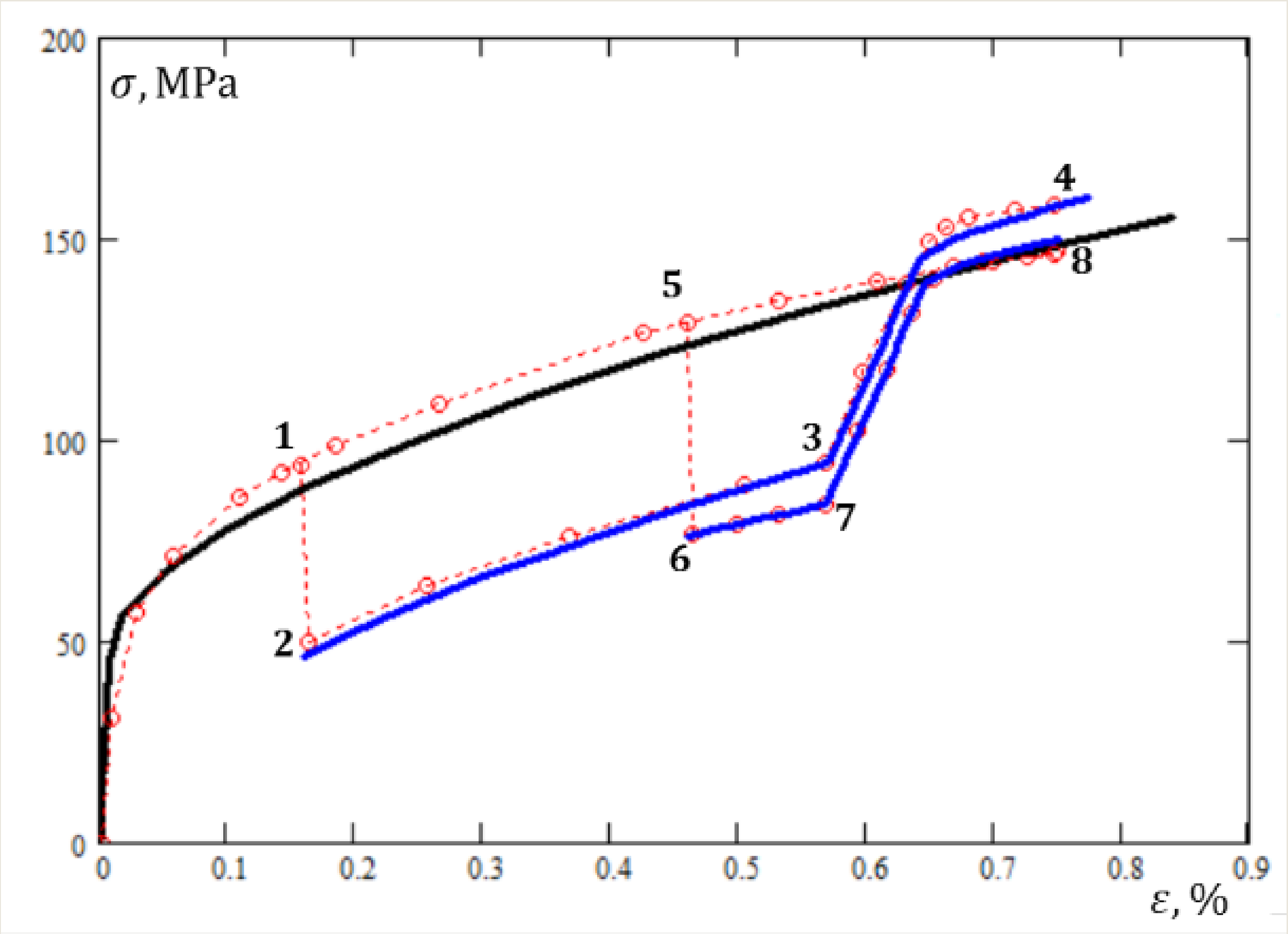
5. RESULTS



Stress~strain compression diagrams of aluminum in the ultrasonic field (symbols – experimental data; solid lines – model).



Stress~strain compression diagrams of titanium in the ultrasonic field (symbols – experimental data; solid lines – model).



Vibration-assisted σ~ε diagrams; lines – model, ○ – experiment.

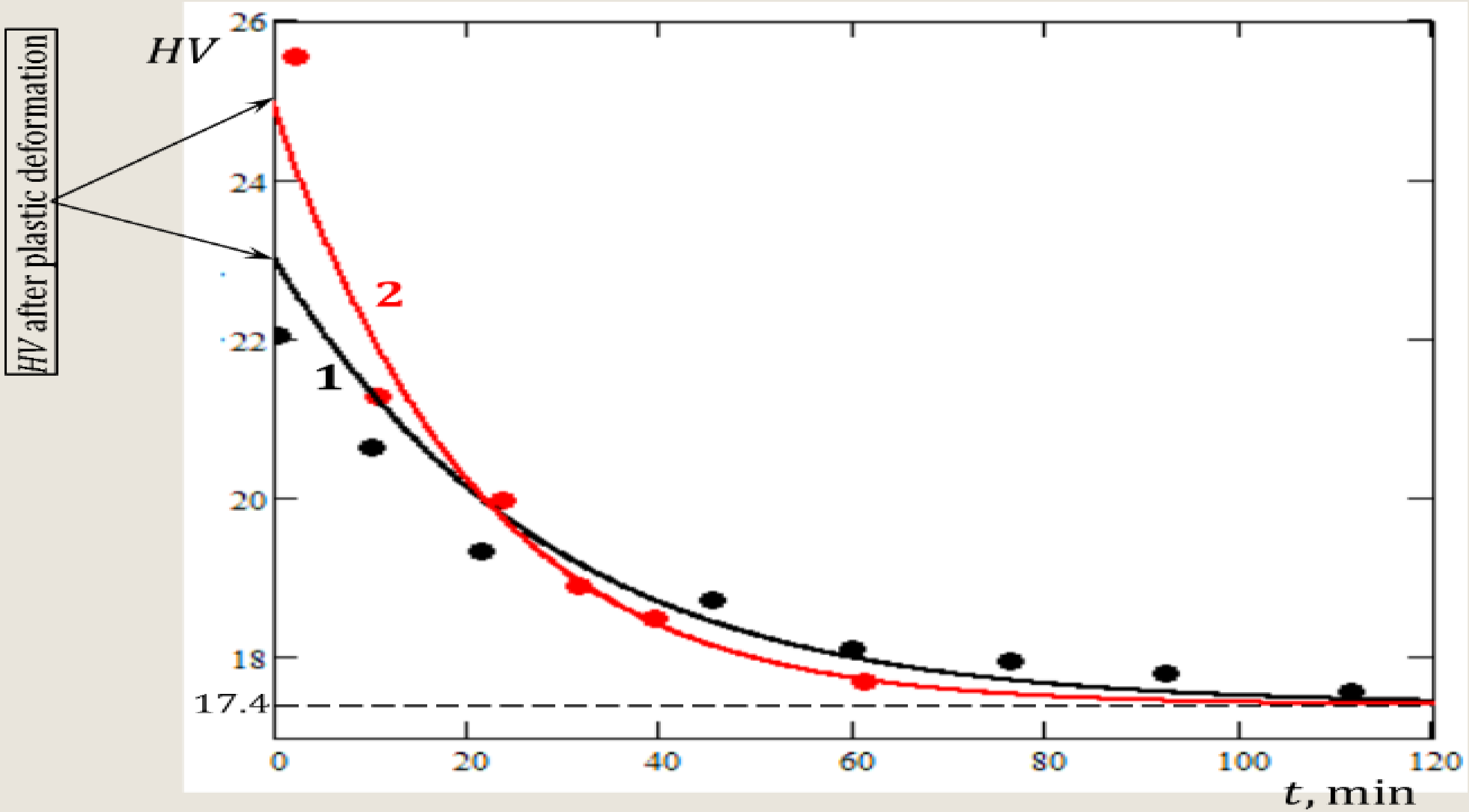
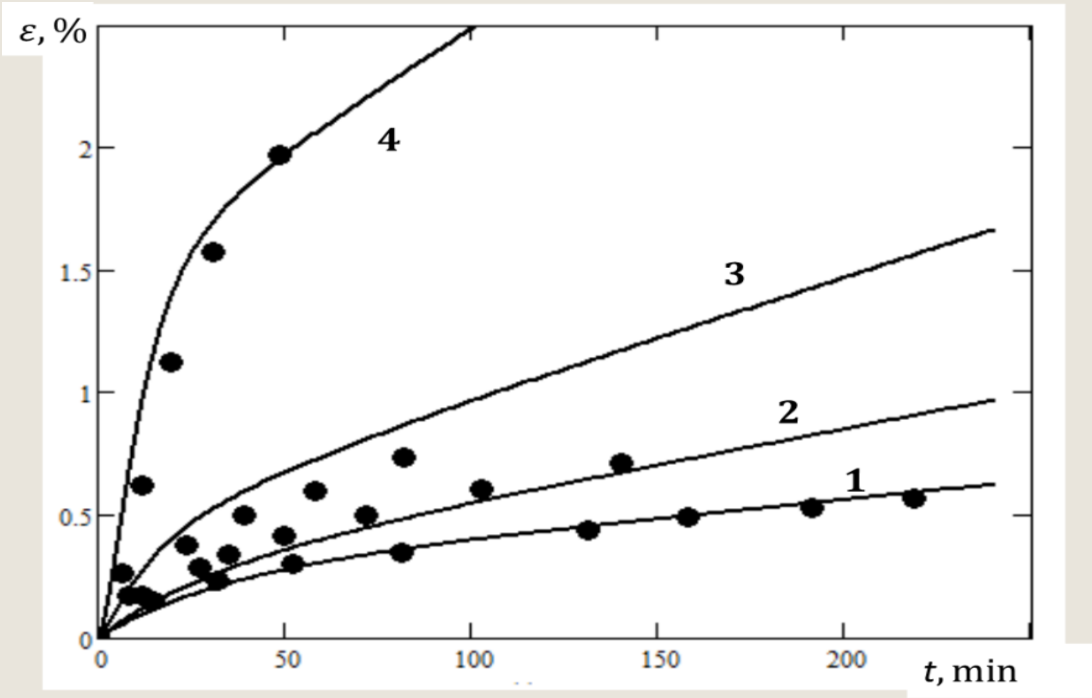
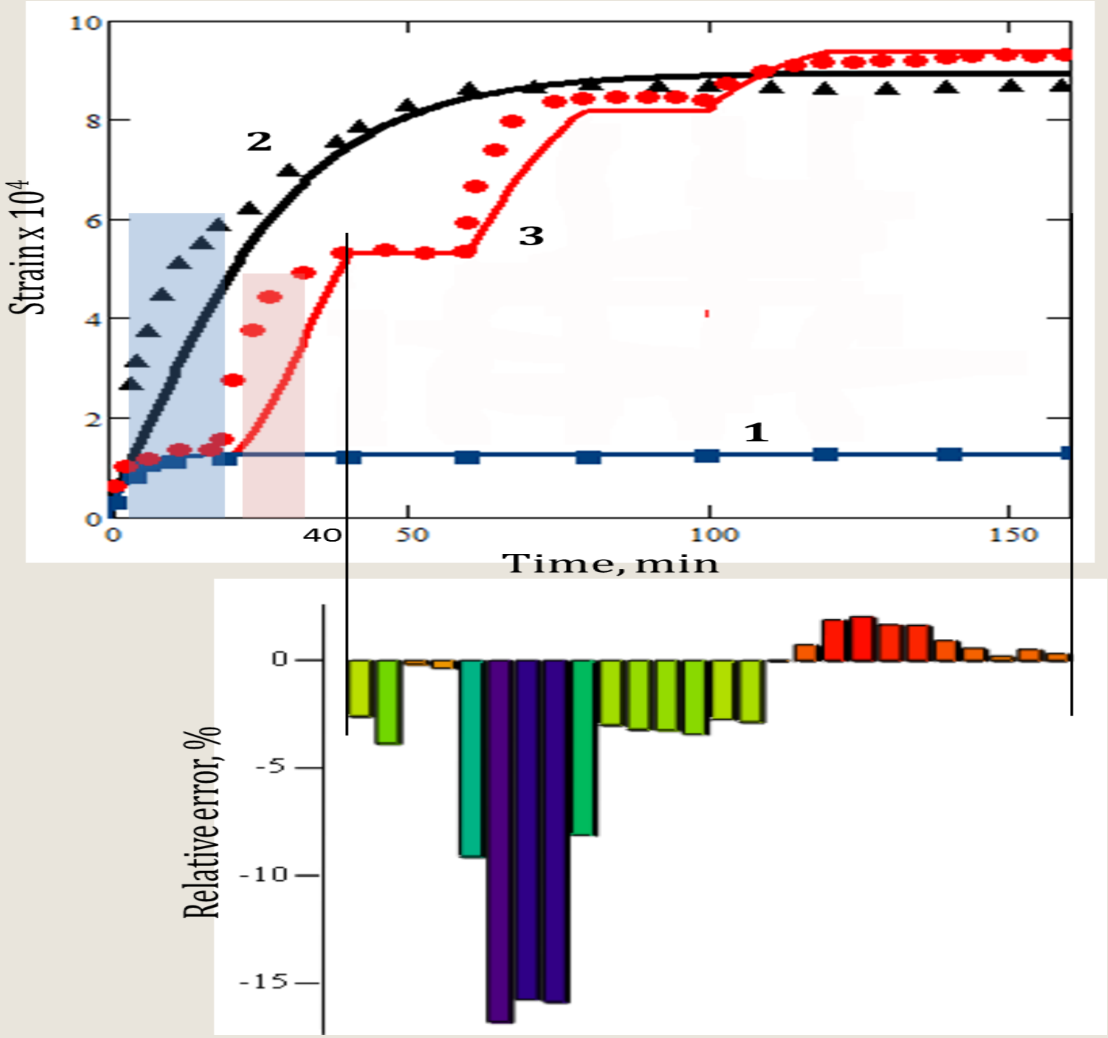


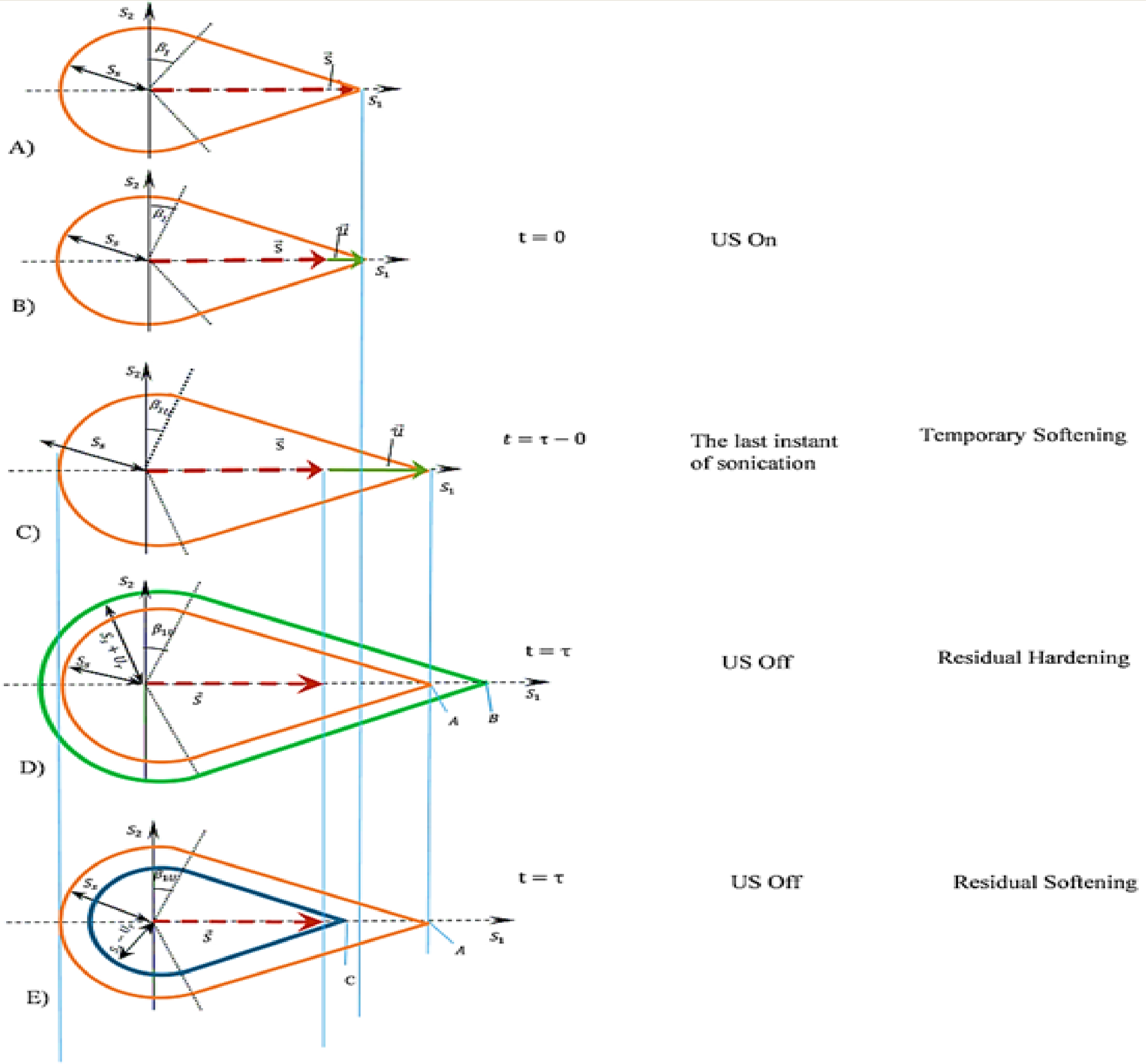
Fig. 8 HV vs. sonication time plots for the plastically deformed aluminum specimen: and. • - experiment [Kulemin, 1978], lines – model



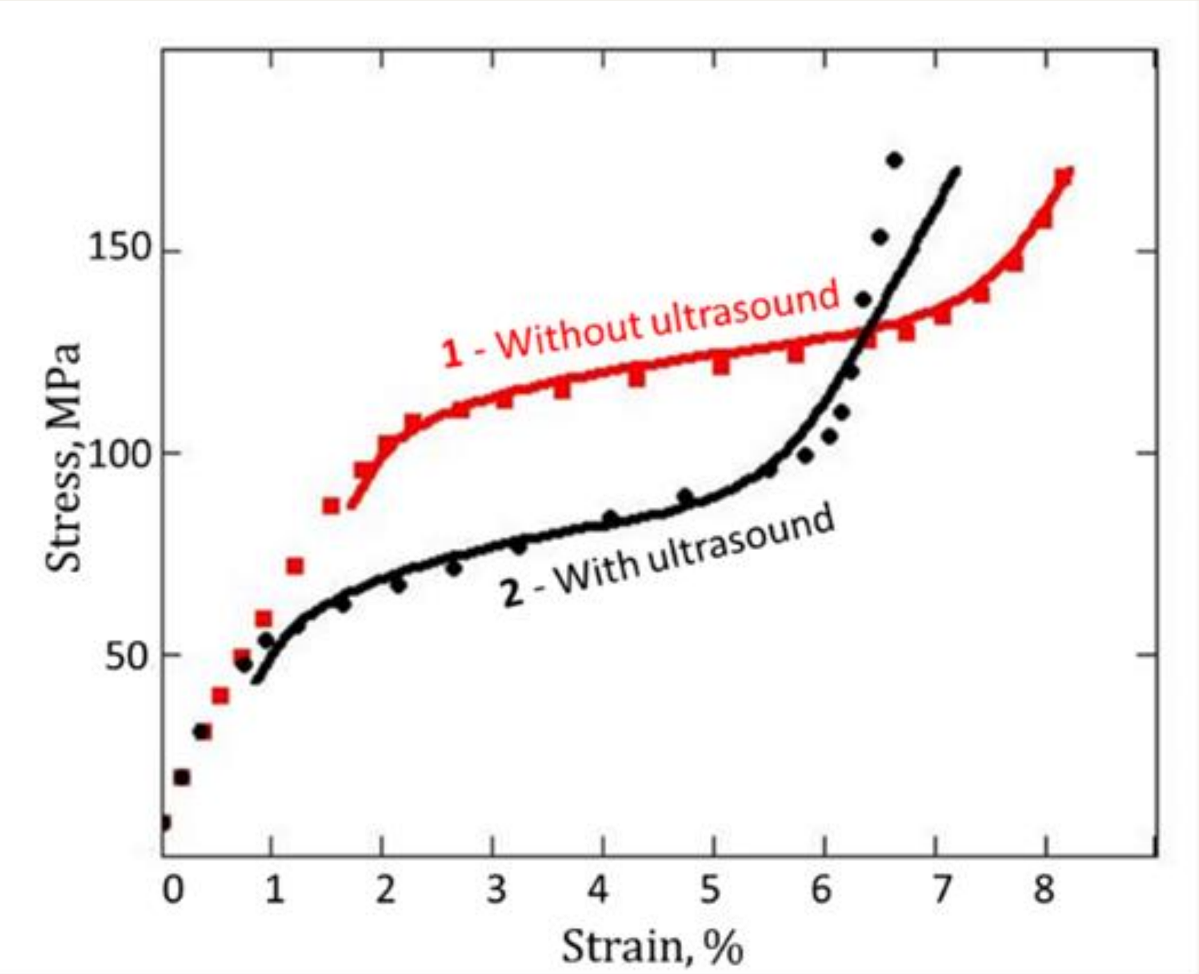
Creep diagrams of aluminum in uniaxial tension (σ=10 MPa, T=40℃), 1 – ordinary creep, 2-4 ultrasound-assisted creep with oscillating stress amplitudes of 0.6 MPa (2), 1.3 MPa (3), and 2.0 MPa (4); ● – experiment, lines – model.



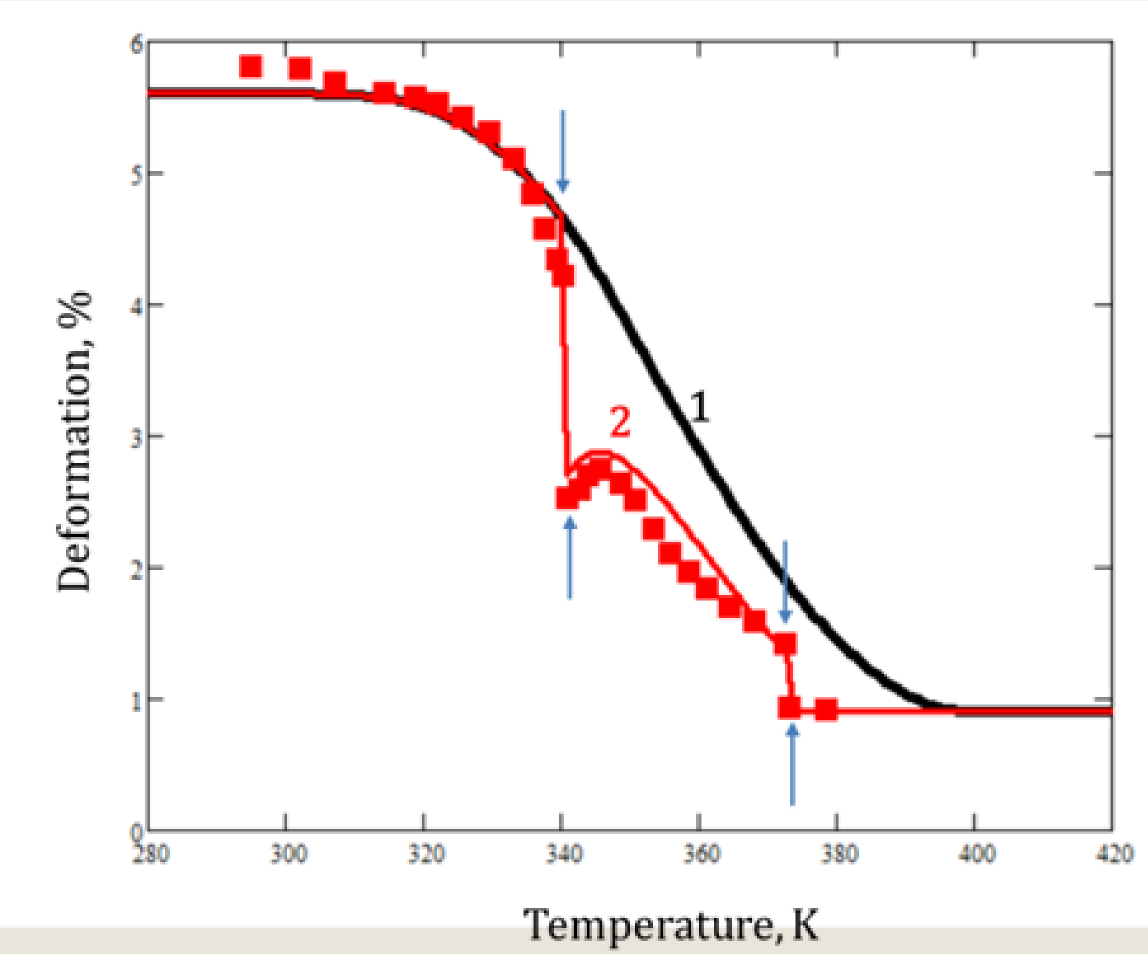
Strain vs. Time diagrams of copper: 1 – ordinary creep, 2 – ultrasound-assisted creep with continuous sonication, 3 – ultrasound-assisted creep with periodic sonication; symbols – experiment, lines – model. Error bars are constructed for the case of periodic sonication (t≥40 min).


A)
B)
t = 0
US On
C)
t = τ − 0
The last instant of sonication
Temporary Softening
D)
t = τ
US Off
Residual Hardening
A
B
E)
t = τ
US Off
Residual Softening
C
A

RECENT SEMESTER



Pseudoelastic σ~ε diagram of NiTiRe alloy at constant temperature (T_0=283 K) in uniaxial tension: 1 – static loading, 2 – simultaneous action of static and ultrasonic loading (f=18 kHz). Lines – model, symbols – experiment.



State diagram of NiTi alloy in deformation-temperature coordinate. The sample is subjected to uniaxial tension σ=30 MPa. The arrows show the moments of switching-on (↑) and switching-off (↓)of ultrasonic vibrations; ■ –experiment (Rubanik et al., 2008), lines – model.

7. LIST OF PUBLICATION

No	Published
1	Andrew Rusinko, Ali H. Alhilfi, Evolution of Loading Surface in the Ultrasonic Field, Proceedings of the Engineering Symposium at Bánki, ISBN 978-963-449-225-2, 2020, p 35-40.
2	An analytic description of the creep deformation of metals in the ultrasonic field, Mechanics of Time-Dependent Materials, DoI:10.1007/s11043-021-09505-0 (**1.72**)
3	The effect of ultrasound upon the strain hardened metals, Acta Polytechnica Hungarica (**1.806**)
4	Ultrasound-assisted creep deformation of metals, Acta periodica technologica (**0.18**)
	Under Reviwe
5	Ultrasonic temporary softening and residual hardening in terms of the synthetic theory (engineering review)
6	Modelling of ultrasonic temporary and residual effects (jtam, journal of theoretical and applied mechanics)
7	Ultrasonic temporary softening and residual softening in terms of the synthetic theory, Gradus.
8	Effect of ultrasound on the pseudoelasticity of shape memory alloys (Journal of Theoretical and Applied Mechanics)
9	Effect of ultrasound on the austenite transformation of shape memory alloys (Meccanica)

8. COURSES COMPLETED

Course	Lecturer
Finite Element Modeling Of Material Technologies	Dr. Gonda Viktor
Modeling Of Thermally Activated Transformation Processes In Alloys	Dr. Réti Tamás
Principles Of Plasticity	Dr. Endre Ruszinko
Material Testing II	Dr. Mihaly Reger Antal
Titanium And Titanium Alloys	Dr. Peter Pinke
Non-Classic Problems Of Plasticity And Creep	Dr. Endre Ruszinko
Hungarian As A Foreign Language I.	Sandor Sloboda
Finite Element Modelling Of Heat Transfer	Sándor Borza
Modelling In Crystal Plasticity	László Tóth

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