THE EFFECT OF ULTRASOUND ON THE IRRECOVERABLE DEFORMATION OF METALS

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INTRODUCTION

In recent years, the advantages of using **ultrasonic vibration during plastic deformation** processes have been mostly studied experimentally. Also there have been a few attempts on computational studies of ultrasonic-assisted metal forming processes to consider are variations in mechanical behavior, microstructure evolution, and deformation regime of metals during and after propagation of ultrasonic vibrations.

THE PROBLEM

Many researches have attempted to explore a realistic mechanism caused to change mechanical behavior (**acoustic softening** or **residual softening / hardening**) whenever the ultrasonic vibration is imposed on metal, but its accurate underlying mechanism was **still not so clear.** The residual effect caused by ultrasonic vibration is quite contrary between some metals.

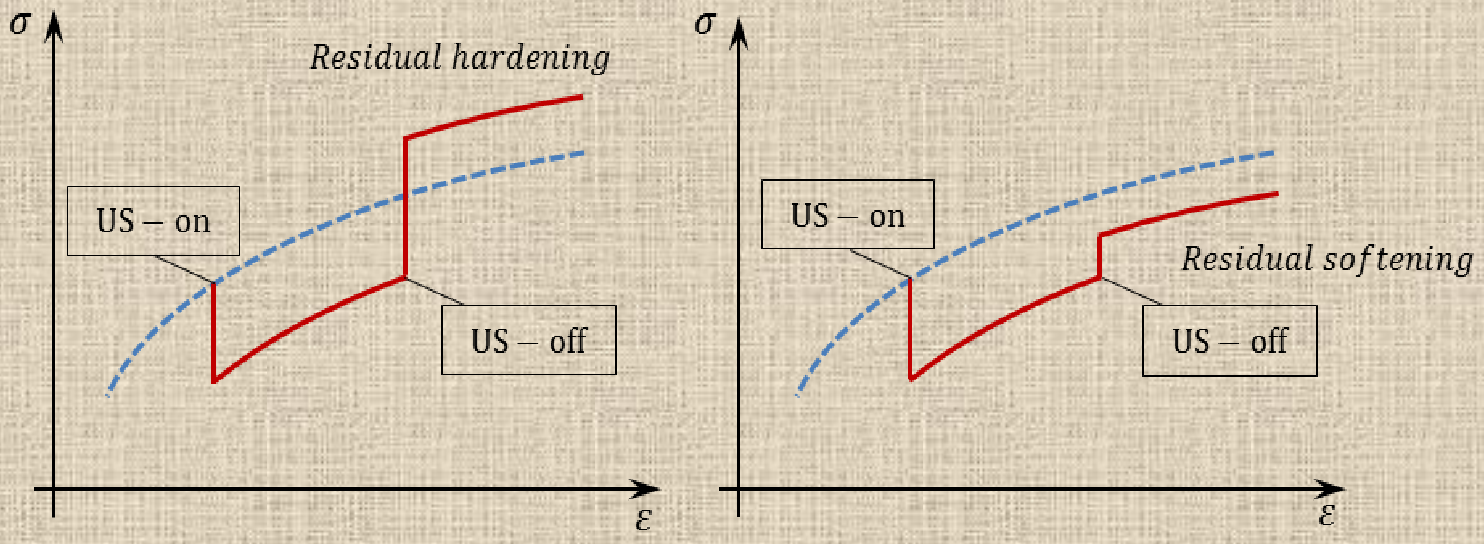

Fig. 1

AND WHAT

Rusinko* developed an analytical model which introduced a new term, ultrasonic defect intensity, into the **synthetic theory** of plastic deformation. This model described the ultrasonic temporary softening and the ultrasonic hardening **when ultrasound acts alone and did not** consider the residual softening / hardening **after** ultrasonic-assisted plastic deformation.

The plan was to develop a model accounting for the phenomenon of acoustic plasticity such as residual hardening in terms of the synthetic theory, **and that what we did in the this semester**.

*Rusinko, A. (2011). Analytical description of ultrasonic hardening and softening. Ultrasonic, 51(6), 709-714.

WHAT WE HAVE DONE

The goal was (**i**) to construct model $\sigma \sim \varepsilon$ curves in the compression tests for pure aluminum according to the sonication regimes shown in Fig.2, (**ii**) to compare the analytic results with those obtained by *Yao et. al. Since we consider only the case of residual ultrasonic hardening, Further throughout we work with the formula: $r\varphi_{NU} = H_N^2 + U_t^2 - U_r^2 - S_S^2.$

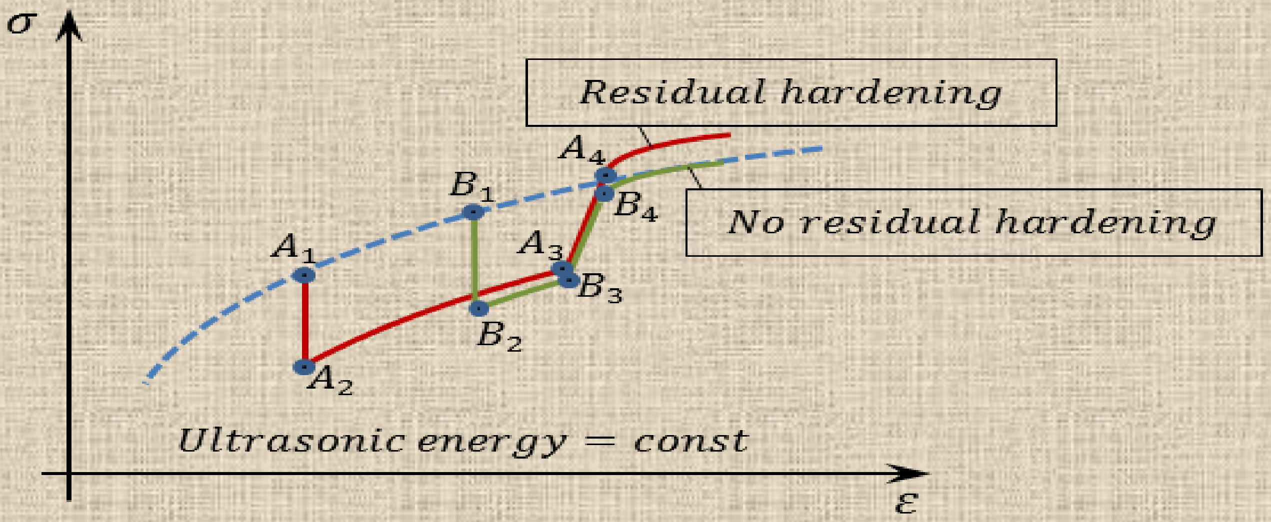

Fig. 2

*Yao, Z., Kim, G. Y., Wang, Z., Faidley, L., Zou, Q., Mei, D., & Chen, Z. (2012). Acoustic softening and residual hardening in aluminum: modeling and experiments. International Journal of Plasticity, 39, 75-87.

- The analytic σ~ε curve from Fig.3 which is plotted via Eqs. (1-3), shows good agreement with experimental data.

$$e = \frac{4\pi}{3r}\int_{\beta_1}^{\pi/2}\int_0^{\lambda_1}[(\sigma\sin\beta\cos\lambda)^2-\sigma_S^2]\sin\beta\cos\lambda\cos\beta\, d\lambda d\beta = a_0\Phi(b), ...1$$

$$\Phi(b) = \frac{1}{b^2}\left[2\sqrt{1-b^2}-5b^2\sqrt{1-b^2}+3b^4\ln\frac{1+\sqrt{1-b^2}}{b}\right] ....2$$

$$\sin\beta_1 = \frac{\sigma_S}{\sigma} \equiv b, \quad \cos\lambda_1 = \frac{\sigma_S}{\sigma\sin\beta}. ....3$$

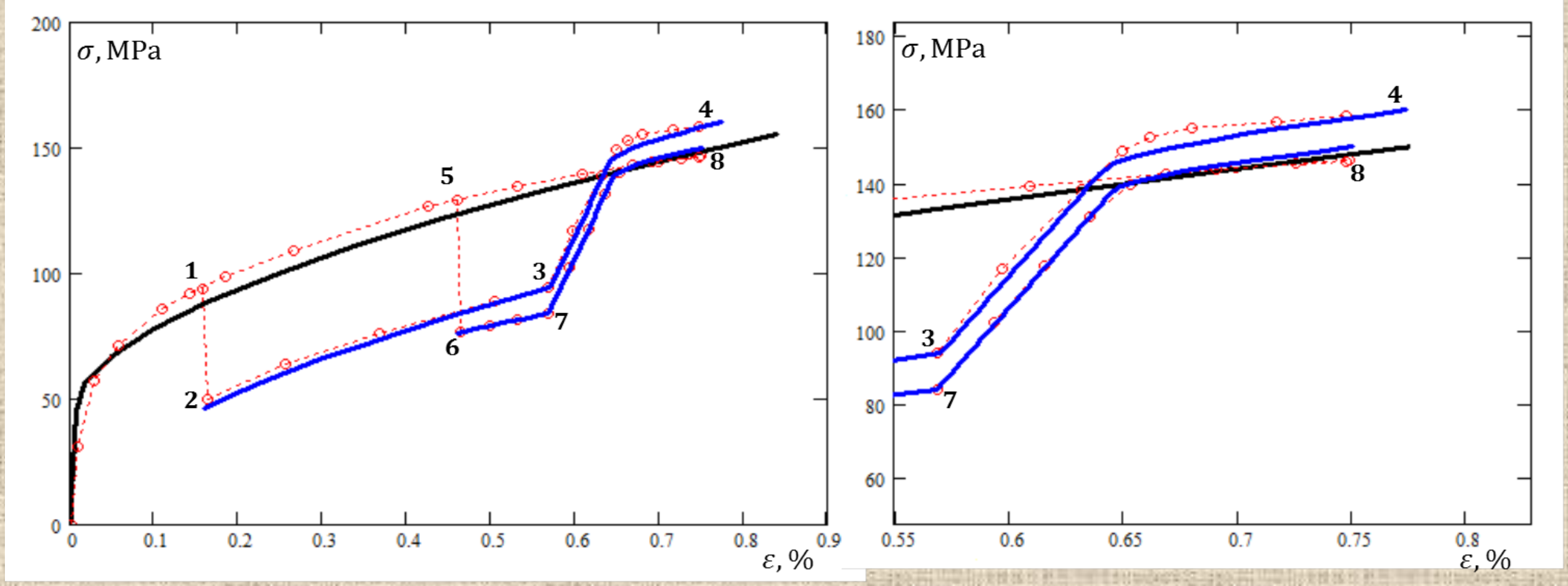

Fig. 3

Next step is the instant when the US is on. We utilize Eq. (4) to calculate the ultrasound induced stress drop for ultrasonic energy. Constants A1 and A2 in Eq. (4) lead to correct result (point 2 in Fig. 3). Further, Eq. (5) serves as an analytical tool to plot σ~ε diagram under the action of ultrasound.

$$\sigma_U = \sqrt{\sigma^2 - \frac{3}{2}\left(A_1 U^{A_2}\right)^2}. \qquad \text{............ .... .4}$$

$$e_U = a_0 \Phi(b_U), \qquad b_U = \frac{\sigma_S}{\sqrt{\sigma_U^2 + \frac{3}{2}\left(A_1 U^{A_2}\left(2 - e^{-pt}\right)\right)^2}} \qquad \text{... ... . 5}$$

Finally, the deformation of post-sonicated material, portion (3-4) in Fig. (3). This portion is plotted via Eqs. (6-8). As seen from Fig. 3, the model result shows good agreement with experimental data.

$$\Delta e = \frac{2\pi}{r} \int_{\beta_2}^{\pi/2} \int_{0}^{\lambda_2} \Delta\varphi_{NU} \sin\beta \cos\lambda \cos\beta \, d\lambda d\beta \qquad \ldots\ldots\ldots\ldots\ldots\ldots.6$$

$$\sin\beta_2 = \frac{\sqrt{\sigma_S^2 + \frac{3}{2}[A_3 U^{A_4}\tau]^2}}{\sigma}, \qquad \cos\lambda_2 = \frac{\sqrt{\sigma_S^2 + \frac{3}{2}[A_3 U^{A_4}\tau]^2}}{\sigma \sin\beta}. \quad \ldots.\ldots..7$$

$$e = e_U + \Delta e + \frac{\sigma}{E}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots8$$

- We inserted two terms into the plastic flow rule, which govern the deformation characteristic of material both during sonication and after it. The first term reflects two opposing processes occurring during acoustoplasticity –accumulation and dynamic annealing of defects –, with the later has a prevailing role in total deformation (temporary softening). The second one characterizes how the defect structure of post-sonicated material affects the further deforming of material (residual softening or hardening).

PUBLISHING

The paper’ Ultrasonic temporary softening and residual hardening in terms of the synthetic theory’ now with editor for the journal ’Mechanics Research Communications’.

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Mechanics Research Communications

Editor-in-Chief: A. Rosato

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› CiteScore: 2.25 ⓘ Impact Factor: 2.229 ⓘ

ISSN: 0093-6413

THE NEXT STEP

The next steps are (i) to develop a model accounting for residual softening, (ii) to model ultrasonic temporary softening with application of FEM. Both points are planned to be accomplished in terms of the synthetic theory of irrevocable deformation.

COURSES COMPLETED

Code	Course	Lecturer	Number of credits
OATATVEM1ND	Finite element modeling of material technologies	Dr. Gonda Viktor	6
OAIAFRT1ND	Modeling of thermally activated transformation processes in alloys	Dr. Réti Tamás	6
OATKEALIND	Principles of plasticity	Dr. Endre Ruszinko	6
OATVFAM2ND	Material testing II	Dr. Mihaly Reger Antal	6

Thank You

Any Question?