POLISH ACADEMY OF SCIENCES

INSTITUTE OF FUNDAMENTAL
TECHNOLOGICAL RESEARCH
AND
COMMITTEE ON MECHANICS

40th SOLID MECHANICS CONFERENCE
29.08 - 2.09 2016, WARSAW

URL: http://solmech2016.ippt.pan.pl/table/abstracts.html

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Paper no. P232

EVALUATION OF DYNAMIC HARDNESS AND ADHESION OF THIN LAYER USING NANOSECOND LASER PULSE

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1. Introduction

Properties of materials under conditions of dynamic deformation significantly differ from those in static conditions. Sensitivity to the strain rate of most metals and alloys significantly increases at strain rates above 10 s^{-1}. The study of processes occurring in materials at very high speed of deformation is possible using nanosecond laser pulses. A shock wave is generated for this purpose. Nanosecond high power pulses and carefully selected absorption layer as well as inertial layers, allow obtaining a wave pressure from a few to several GPa [1]. The strain rate during the process is from 10^7 to 10^9 s^{-1} [2]. The plastic deformation of the material generated by the single nanosecond laser pulse can be basis for evaluation of the hardness of the material under the ultra-high strain rate. Tensile stresses at the interface of the material/layer, which caused separation of the layer from the substrate can be used for estimation adhesive strength for thin layer [3].

2. Experimental method

Nd:YAG laser with a wavelength of 1.064 μm and pulse time of 10 ns was applied in the test. The diagram of the measurement system is shown in Fig.1. Laser beam falls through the transparent inert layer (1) on the absorption layer (2), where it is absorbed and creates high pressure plasma, which in turn induces a shock wave. Propagation of the shock wave causes plastic deformations of samples (3) and delamination of layer (4). Piezoelectric PVDF sensor (5) creates a charge which is proportional to the transient value of pressure in the piezoelectric sensor. Measurements of shock wave pressures have been performed using piezoelectric, polymer PVDF sensors [4]. Typical pressure profile on back side of sample shows Fig. 1b. The study of plastic deformation induced by a nanosecond laser pulse was carried out for typical commercial metals and alloys: aluminium, copper, stainless steel.

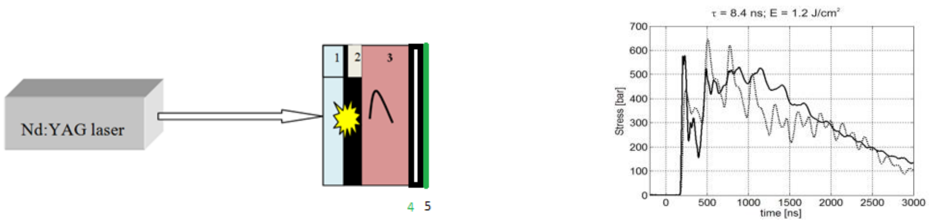

Fig. 1. A- Experimental scheme for testing dynamic hardness and adhesion of thin films. B- Comparison of calculated (- -) and experimental (--) profile of pressure of shock wave.

3. Results

The study showed that single laser pulses with energy of 0.35 - 1.22 J allow to get required

$$\dot{\varepsilon}^v = \frac{\boldsymbol{\sigma}'}{2\eta_s} + \frac{\mathrm{tr}(\boldsymbol{\sigma}) - 3\sigma_s}{9\eta_b}\mathbf{I} \qquad (1)$$

where $\boldsymbol{\sigma}'$ is the deviatoric stress, $\mathrm{tr}(\boldsymbol{\sigma})$ – the trace of the stress tensor, σ_s – the sintering stress, η_s – the shear viscosity modulus η_s – the bulk viscosity modulus.

In the multiscale approach, macroscopic constitutive properties, including the elastic moduli, bulk and shear viscosity, as well as the sintering driving stress are determined from micromechanical simulations of sintering. The micromechanical model of sintering has been developed within a framework of the discrete element method [2]. The DEM considers large assemblies of particles which interact with one another through contact forces. The rheological scheme of the contact model for sintering is shown in Fig. 1b. It includes elasticity, thermal expansion, viscosity (creep) and the sintering driving force, which is consistent with the macroscopic model.

The constitutive parameters of the DEM model of sintering depend on the parameters which can be determined using atomistic models. The methods of molecular statics and dynamics will be used to determine the elastic constants, surface energy and diffusion coefficients used as input data in microscopic sintering models.

4. Case study

Sintering of NiAl powder has been analysed as a case study using the multscale approach. Figure 2 shows selected mechanisms of diffusion considered in the molecular statics analysis. Average shear viscous modulus determined from the DEM simulations is plotted in Fig. 3 as functions of sintering time and relative density.

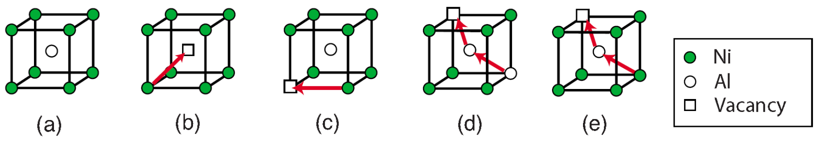

Figure 2. Schematic representation of NiAl crystal structure and selected hop mechanisms [3]

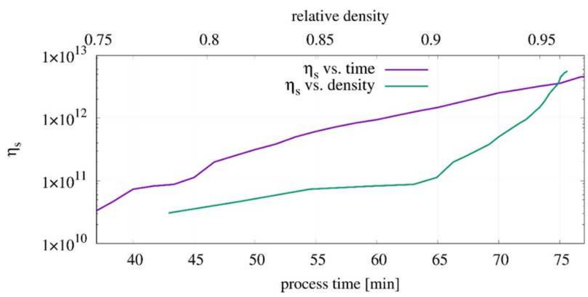

Figure 3. Average shear viscous modulus determined from the DEM simulations

Acknowledgement: This work has been financed from the funds of Polish National Science Centre (NCN) awarded by decision numbers DEC-2013/11/B/ST8/03287

5. References

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