Int J Mater Form (2008) Suppl 1:81–84
DOI 10.1007/s12289-008-0041-0

The Activation Energy for Plastic Flow in Spatially Extended Polycrystalline Systems during Tension Test

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ABSTRACT: The target of this work is to obtain the activation energy for plastic flow in spatially extended polycrystalline systems during tension test with constant crosshead velocity. For the reason that, during a tension test at constant crosshead velocity in spatially extended polycrystalline systems, the strain rate is reduced period-by-period and these thermo mechanical conditions could change the amplitude of vibration of the atoms and their frequency due to the amount of vibration energy absorbed and related with the variety of disorders occurring during such irreversible deformation process. In this framework, the activation energy for plastic flow in spatially extended polycrystalline systems is obtained by applying the theoretical mathematical model of quantum mechanics and relativistic cosmic micromechanics connection proposed by Muñoz-Andrade.

Key words: Plastic Flow, Activation Energy, Dislocation Dynamics, Quantum Mechanics and Relativistic Cosmic Micromechanics Connection.

1 INTRODUCTION

On the relativistic point of view, Albert Einstein proposed that the physical objects are spatially extended. With this argument he presented a new way to understand the physics of the universe, where the concept of empty space loses its significance [1]. In this way single crystals are considered spatially extended crystalline systems (SECS) and polycrystalline metals and alloys are considered as spatially extended polycrystalline systems (SEPCS). During deformation the microstructure of a SECS or SEPCS changes in several ways and evidently, at the same time, the SECS or SEPCS are in a nature cosmic micromechanics connection [2-5]. This is a conceptual principle to describe the dynamics of infinite number of spatially extended physical systems and their interactions with respect to each other inside and outside our universe.

Recently, based on the constancy of the speed of light as essential postulated of the special theory of relativity proposed by Albert Einstein, was possible showed that theoretically the Max Planck scale and the Edwin Hubble scale are directly associated by the next relationship recently proposed [5-6]:

$$c = \lambda_P \xi_U \exp\left(\frac{Q_P}{kT_P}\right) = \lambda_H \xi_P \exp\left(-\frac{Q_P}{kT_P}\right). \quad (1)$$

Where, c is the speed of light (c = 299 792 458 m/s), λ_P = Planck length = $1.62\text{x}10^{-35}$m, this value represents the Burgers vector of the universe at the Planck scale [5], ξ_U = the Hubble parameter or expansion rate of the universe (ξ_U =70 (km/sec)/Mpc = 2.26854593 $\text{x}10^{-18}\text{s}^{-1}$), the expansion rate of the universe was obtained using the definition of the rate reaction theory [7], Q_P = the Planck activation energy of the system at the Planck scale (Q_P = $1.221\text{x}10^{28}$eV), wherever the quantum effects and gravitational effects are of equal importance, k = the Boltzmann constant (k = $8.617\text{x}10^{-5}$eV/K = $1.38\text{x}10^{-23}$J/K), T_P = the Planck Temperature (T_P = $1.010285625\text{x}10^{30}$K) after the Big Bang [7], λ_H =

Hubble length = $1.32x10^{26}$m and $\xi_P = c/\lambda_P = 1.850570728x10^{43}s^{-1}$, this frequency factor represents the expansion rate of the cosmic structure at Planck scale.

The most significant of Eq. (1) is that this model could be used to expresses that the constancy of the speed of light is related with the cosmic micromechanics connection during irreversible deformation processes in SEPCS as follow [5-6]:

$$c = \lambda_{\perp}\xi_{\perp} \exp\left(\frac{Q_{\perp}}{kT}\right). \quad (2)$$

Where, $\xi_{\perp}$ is the strain rate for plastic deformation associated with the Orowan equation for plastic flow [8]: $\xi_{\perp} = \rho_{\perp} v_{\perp} \lambda_{\perp}$. $\lambda_{\perp}$ = Burgers vector, $\rho_{\perp}$ = density of dislocations, $v_{\perp}$ = the average glide velocity of dislocations, T is the absolute temperature and $Q_{\perp}$ is the activation energy to induce the irreversible deformation process associated with dislocations dynamics and self accommodation processes during the tension test at room temperature of SEPCS.

Furthermore, with this framework, it has been shown that by the application of the quantum mechanics and relativistic cosmic micromechanics connection model, it is feasible to obtain the activation energy ($Q_{\perp}$) for plastic flow in SEPCS as follow [3-6]:

$$Q_{\perp} = -kT \ln\left[\frac{\rho_{\perp}\upsilon_{\perp}\lambda_{\perp}^{2}}{c}\right] = -kT \ln\left[\frac{\xi_{\perp}\lambda_{\perp}}{c}\right]. \quad (3)$$

On quantum mechanics perspective, Max Planck proposed that matter absorb or emit energy in discrete amounts that he called quanta [9-10]. As a result of this theory, the nature of plastic flow in SECS or SEPCS could be associated with the emission or absorption of discrete amount of quanta given by $E_{\perp} = h\xi_{\perp}$, where, h is the Planck constant (h = $6.6260755 \times 10^{-34}$Jsec), $E_{\perp}$ is the quanta of energy associated of a given frequency, $\xi_{\perp}$, or strain rate during the deformation process of the elastic field for SECS or SEPCS. In this framework, the main purpose of this work is to obtain the activation energy for plastic flow during tension test at constant crosshead velocity of a SEPCS associated with the fulfilled curve of the true stress versus true strain obtained during the tension test, where the frequency $\xi_{\perp}$, or strain rate during the deformation process is reduced period-by-period.

2 EXPERIMENTAL PROCEDURE

The material used for this investigation was the SEPCS AISI type 304, austenitic stainless steel. A set of five unidirectional tensile tests of this material at room temperature were carried out in an Instron 100kN Universal Testing Machine at different crosshead velocities. The average initial dimensions of tensile test samples were gage length of 20.12 mm and diameter of 4 mm. The set of tensile test has been conducted covering a range of constant cross head velocities: V_1 = 2.0 mm/min, V_2 = 4.0 mm/min, V_3 = 6.0 mm/min, V_4 = 8.0 mm/min and V_5 = 10.0 mm/min.

3 ANALYSIS OF THE EXPERIMENTAL RESULTS

The typical graphics of true stress versus true strain for the five tensile test described above of the SEPCS AISI type 304, austenitic stainless steel, are shown in figure 1. Here, it is interesting to observe that the true strain tends to reduce as the constant crosshead velocity of the testing is increased; nevertheless this effect depends on the maximum stress reached for the sample during the tensile deformation. In this context, the variation of true stress with strain rate is exposed in figure 2. Where, the range of the strain rate is increased as the constant crosshead velocity is increased. In the same way the variation of true strain with strain rate, can be seen in figure 3. By means of the Eq. (3), where the Burgers vector, $\lambda_{\perp}$ = 0.2525nm, for AISI type 304 austenitic stainless steel, ($\lambda_{\perp}$ was calculated by applying the procedure presented by J. C. Li et al. [11]), the variation of activation energy for plastic flow with true stress for the five tensile test is shown in figure 4. At this point, it is remarkable to observe that the range of activation energy for plastic flow is reduced as the constant crosshead velocity is increased. Also, the variation of activation energy for plastic flow with true strain during tension test is shown in figure 5. Finally, the variation of activation energy for plastic flow with strain rate during tension test at room temperature with a constant crosshead velocity is shown in figure 6. It is interesting to examine that the mechanical properties experimentally obtained and the activation energy for plastic flow calculated in this work are in a closed agreement with the values reported recently by modeling the material behavior of metastable stainless steels [12].

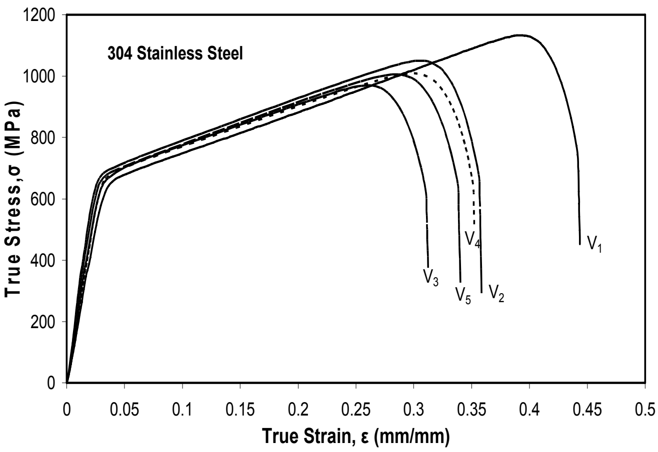

Fig. 1. Unidirectional tensile flow stress development with true strain at room temperature with constant crosshead velocity of SEPCS 304, austenitic stainless steel.

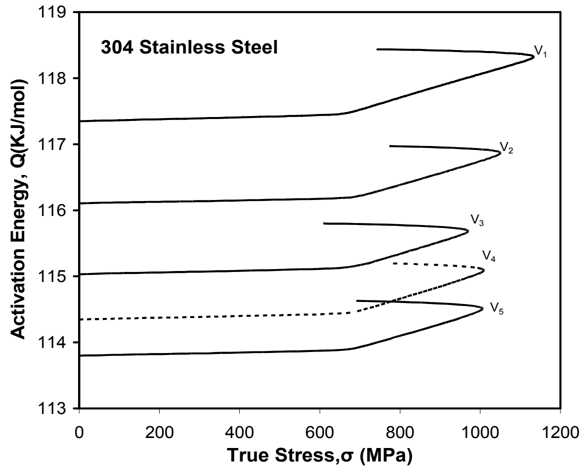

Fig. 4. Variation of activation energy for plastic flow with true stress during tension test at room temperature with a constant crosshead velocity of SEPCS 304, austenitic stainless steel.

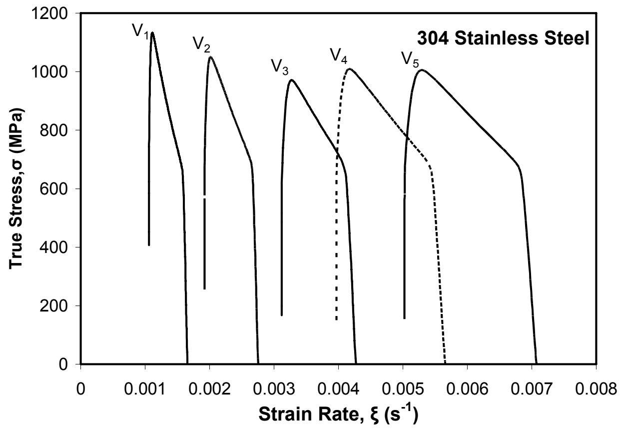

Fig. 2. The variation of true stress with strain rate, during tension test at room temperature with a constant crosshead velocity of SEPCS 304 austenitic stainless.

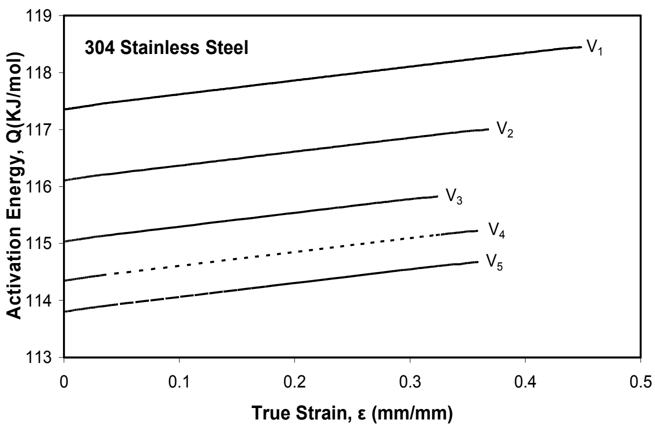

Fig. 5. Variation of activation energy for plastic flow with the true strain during tension test at room temperature by constant crosshead velocity of SEPCS 304 austenitic stainless steel.

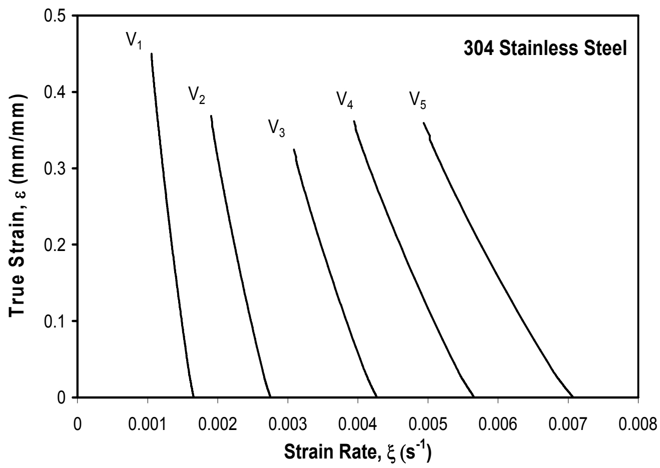

Fig. 3. The variation of true strain with strain rate, during tension test at room temperature with a constant crosshead velocity of SEPCS 304, austenitic stainless steel

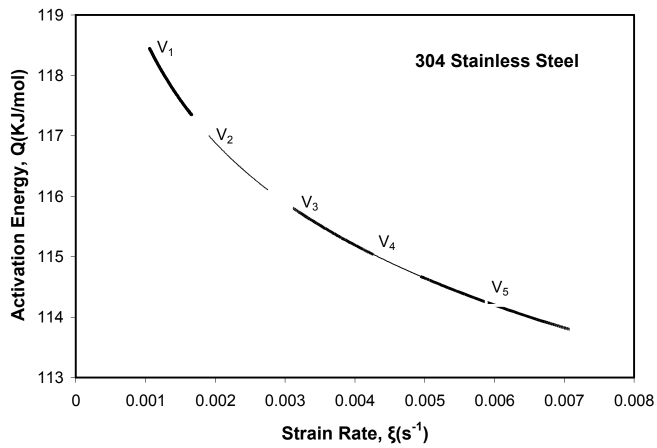

Fig. 6. Variation of activation energy for plastic flow with strain rate during tension test at room temperature at constant crosshead velocity of SEPCS 304, austenitic stainless steel.

4 DISCUSSION

During the tension test of SEPCS with a constant crosshead velocity at room temperature, the strain rate is reduced period-by-period. These thermomechanical conditions are change the amplitude of vibration of the atoms and their frequency due to the amount of vibration energy absorbed and related with the variety of disorders occurring during such irreversible deformation process.

The quantum mechanics and relativistic cosmic micromechanics connection model used in this study provides a quantitative description to these phenomena and mechanics, where the activation energy for plastic flow, in such SEPCS is increased as the true stress and the true strain are increased. Although, their values depend on the constant crosshead velocity used during tension test. These results, suggest us that the frequency of deformation or strain rate associated to the dynamics of mobile dislocations plays an essential role because the activation energy for plastic flow increased as deformation is happening.

The findings in the present contribution are interesting for the reason that the activation energy for plastic flow obtained by the Eq. (3) are in a closed agreement with the range of values obtained for the micromechanical changes that occur during dynamic softening and hardening of metastable stainless steel for large strain finite element calculations of forming processes that has been recently reported [10].

5 CONCLUSIONS

The quantum mechanics and relativistic cosmic micromechanics connection model for cosmology and plasticity used in this contribution allows obtaining the activation energy associated to the mechanics of plastic flow in a SEPCS AISI type 304, austenitic stainless steel, during the tension test with a constant crosshead velocity at room temperature. In this SEPCS, during deformation the activation energy for plastic flow decreased as the crosshead velocity is increased. Also, the activation energy for plastic flow increased as the strain rate decreased during the tension test at constant crosshead velocity. As well, the activation energy for plastic flow increased as the deformation process is development and the strain hardening takes place in the SEPCS AISI type 304, austenitic stainless steel.

ACKNOWLEDGEMENTS

The author thanks to V. J. Cortés-Suárez for the facilities to perform the tensile tests in the Universal Testing Machine, and to M. R. Aguilar-López, for her technical assistance. As well, special thanks to J. L. Muñoz-Andrade and A. M. Habraken for their comments and advice to improve this work.

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