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Investigation of Damage Growth by Measuring the Chord Modulus, Micro Hardness and Macro Hardness Variation in ST37 Steel

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ABSTRACT: In this paper, by using the theory of continuum damage mechanic and experimental methods, damage evolution is investigated. There are various experimental and theoretical methods for measuring the damage in materials. the experimental methods can be categorized in two type, i) destructive methods like analysis of chord modulus variation, and the ii) non-destructive methods like micro hardness or macro hardness evaluation. In this paper at the first, true stress - true strain diagram of material using the simple tension test and chord modulus variation using repetitive loading - unloading test is obtained. For measuring plastic strain, grids are etched on the tension sample by using electroetch device. And then by measuring major ellipsoid diameter on the broken sample and comparing with the preceding circle, plastic strain at different points is specified. At specified points of the sample, the micro hardness and the macro hardness are measured. Using the data of these three experimental methods, the corresponding damage is evaluated and the corresponding charts are plotted. Finally the evaluated damage by these three methods is compared. It is observed micro hardness and loading-unloading-tension test have relatively similar progress, but macro hardness progress had a significant difference with these two methods. It's also observed, average of three methods is close to micro hardness method rather than two other.

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1- Introduction

Continuum damage mechanic is known as a tool for identification process of damage growth. Using continuum damage mechanic and having damage growth parameter, estimation of damage process during geometrical deformation is possible. Lemaitre and Dufailly introduced micro hardness process evaluation as a sufficient way for investigation damage growth [1]. During plastic deformation pores grow in the material. With pores growth toughness of material will decrease therefore we can use variation of elastic zone for extracting damage evolution path [2, 3]. Ganjiani used micro hardness for investigation damage in aluminum 2024, experimental and numerical results were consistent. Bellenger et al. introduced an elastic-viscoplastic-damage model for metal forming, the model involved large deformation. They expressed although in some case such as extrusion and forging damage growth can be neglected but in other cases such as punch and machining it's unavoidable [4]. In this paper in order to extracting damage, tension test and stress-strain behavior is required. in order to extracting true stress-true strain relation, Zhang et al. studied flat samples under tension test [5], The method used with them is used to extracting true stress-true strain behavior. Choung and

Cho studied tension test on circular cross section samples [6]. The purpose of this article is to investigate damage growth procedure in st37 using three methods of micro hardness, macro hardness and repetitive loading-unloading and also experimental comparison results of these methods. For this purpose results of three methods are used to extracting damage procedure.

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2- Methodology

We categorize theoretical concepts in two case of variation of surface hardness and variation of elastic zone. For method of surface hardness variation we can compare variation of hardness with stress. Formulation of this method is represented below briefly [7, 6]. Yield stress at any stage is according to Eq. (1).

$$\sigma_a = (1-D)(R+\sigma_y) \tag{1}$$

In the Eq. (1), D, R and σ_y are damage parameter, isotropic hardening parameter and yield stress. also we have from experimental and numerical studies:

$$H = k(1-D)(R+\sigma_y) \tag{2}$$

Combination of Eqs. (1), (2) and some procedure that are described in related references give Eq. (3).

$$D = 1-\frac{\tilde{H}}{H^*} \tag{3}$$

in the Eq. (3), $\tilde{H}$ and H^* are hardness at the specified strain and reference hardness specified by true stress-true strain diagram.

Other methods for extracting damage procedure experimentally are evaluation of elastic zone variation. In this method variation of chord modulus is compared to primary chord modulus. Formulation of this method is represented below briefly.

$$E = \frac{E_0}{1-D} \tag{4}$$

in Eq. (4), E_0 and E are primary and variable chord modulus during deformation. The damage growth procedure in metals have a mechanism that for this mechanism many relations have been presented. Here two of them is used, the Bonora model and the Lemaitre model, in the Eq. (5) and (6) they are presented [8, 9].

$$D = D_0 + \left(D_c - D_0\right)\left\{1-\left[1-\ln\left(\varepsilon/\varepsilon_D\right)/\ln(\varepsilon_R/\varepsilon_D\right]^{\alpha}\right\} \tag{5}$$

$$\dot{D} = \frac{D_R}{\varepsilon_R - \varepsilon_D}\left[\frac{2}{3}(1+\upsilon)+3(1-2\upsilon)\left(\frac{\sigma_m}{\sigma_{eq}}\right)^2\right]\dot{\varepsilon} \tag{6}$$

3- Results and Discussion

In order to extracting damage procedure, at the first the stress-strain diagram is required. For this purpose tension test is done. The purpose of this article is comparing results of damage procedure extracted by repetitive loading-unloading, micro hardness and macro hardness so using instron 8502 and using extensometer from beginning of plastic deformation to rupture condition, 9 stage of loading-unloading is done in accordance with Fig. 1.

Using Eq. (4) and data of loading-unloading test, damage growth procedure is extracted. At Fig. 2 this is represented. In the following micro hardness and macro hardness is done and using output data of these two test and true stress-true strain diagram, damage growth procedure is obtained. Results of three methods are shown in Fig. 3.

Finally comparison of interpolated results using Bonora and Lemaitre model was done. Table 1 and 2 show the interpolated results. In the Table 1 this is obvious that Lemaitre model can't predict behavior of st37 properly because of scatter of result and low amount of R-square but according

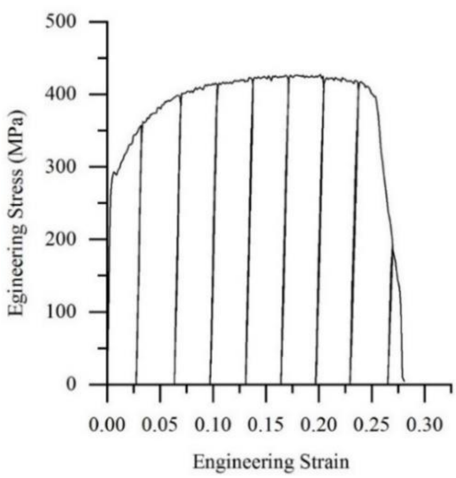

Fig. 1. Diagram of engineering stress-strain by repetitive loading-unloading test on st37

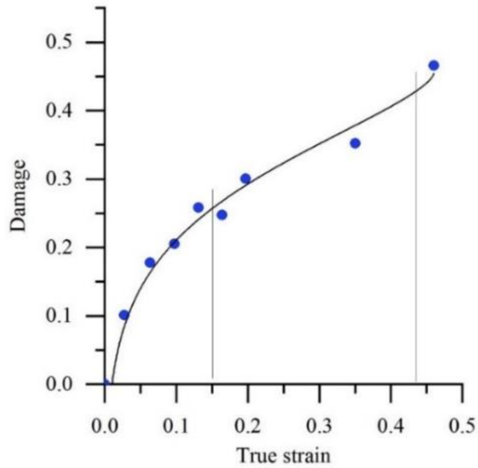

Fig. 2. Damage development process in tension sample according to repetitive loading-unloading

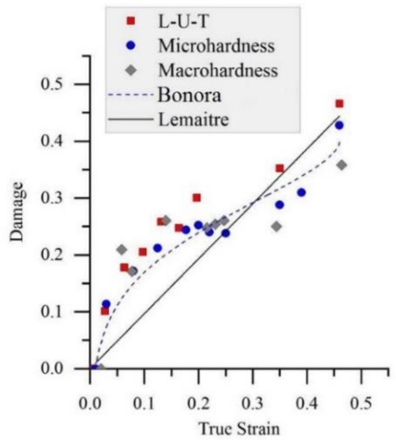

Fig. 3. Comparison and interpolation of evaluated damages by micro hardness, macro hardness and chord modulus variation methods

Table 1. Parameters related to interpolated three test results via Bonora relation

Parameter / Test Type	ε_D	ε_R	D_c	α	R^2
Loading unloading tension	0.01	·0.46	0.45	0.65	**0.99**
Micro hardness	0.01	0.46	0.42	0.55	**0.94**
Macro hardness	0.02	0.46	0.26	2.99	**0.72**
Average	0.01	0.46	0.4	0.6	**0.95**

to Table 2, Bonora model has a high amount of R-square and specially for micro hardness method this model can predict behavior greatly. Also from Fig. 3 Bonora model can predict 3 phase of st37 behavior and Lemaitre model can't predict this three phase goodly.

4- Conclusion

Damage behavior of materials is a critical characteristic for simulation and prediction of material behavior. The aim

Table 2. Parameters related to interpolated three test results via Lemaitre relation

Parameter / Test Type	ε_D	ε_R	D_R	R^2
Loading-unloading-tension	0.01	0.46	0.52	**0.66**
Micro hardness	0.01	0.46	0.43	**0.66**
Macro hardness	0.01	0.46	0.42	**0.13**
Average	0.01	0.46	0.43	**0.65**

of this paper was investigating damage growth in st37 using 3 method of repetitive loading-unloading, micro hardness and macro hardness. For this purpose the related test done and output data specified. Damage procedure included three phase and Lemaitre couldn't show this three phase. Also damage procedure obtained by micro hardness have less scatter data and it is logical to use this method in order to extracting damage growth procedure.

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