Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 54(8) (2022) 383-386
DOI: 10.22060/mej.2022.21081.7376

A New Method for Calculating the Fracture Strain of Shear and Notched Specimens at Various Temperature and Stress Triaxialities

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ABSTRACT: Determining stable characteristics of material behavior under the effects of stress and temperature on the material is significantly important for optimal design. The aim of this study is to present a new method for measuring the fracture strain of shear and tensile parts in different stress triaxialities with the effect of temperature, using a Video Measuring Machine measuring device. Aluminum 5083-H321 is used in this study. For this purpose, twenty-four different samples including shear and tensile samples for four types of triaxialities 0.2, 0.33, 0.38, and 0.55 were prepared for testing in the temperature ranges (25, 200, and 400°C). The samples are tested under monotonic (static) loading conditions. The fracture strains are measured. The stress triaxialities are calculated in the finite element simulation. The obtained results are compared with the other experimental results and also with the numerical results of the Rice and Tracy model. A good agreement is found between these results which validates the new proposed technic for measuring the shear fracture stain. Based on the results, the curve of fracture strain versus stress triaxiality has a decreasing trend at 25°C, while this curve is almost constant at 200°C and has an increasing trend at 400°C.

Review History:

Received: Feb. 07, 2022
Revised: Jul. 14. 2022
Accepted: Aug. 21, 2022
Available Online: Sep. 02, 2022

Keywords:

Stress triaxiality
Temperature
Fracture strain
Finite element simulation
Video measuring method

1- Introduction

Extensive studies have been carried out to predict the ductile fracture of metals and its dependencies on stress triaxiality and Lode angle parameters. Driemeier et al. [1], found the dependence of the behavior of aluminum alloy on different stress triaxiality and strain rates through experiments. Gatea et al. [2] used the digital image correlation measurement method to analyze the notch elongation and deformation along with the tensile specimen. Su et al. [3] investigated the experimental and numerical analysis of the effect of temperature on fracture strain at different stress triaxialities on pure iron. Zistl et al [4] presented a comparison between the experimental and numerical analysis of damage and fracture behavior of ductile metals under non-proportional loading with compression and shear preloading. Bharti et al [5] predicted experimentally and numerically the failure of AA1050 aluminum sheet using some uncoupled phenomenological damage models. They found a good agreement can be found between the experimental observations and numerical predictions for fracture location. Cortis et al [6] carried out multiaxial tests to investigate the effects of dynamic action and temperature on the mechanical and fracture behavior of an API X65 steel. They used a Split Hopkinson Bar (SHB) facility for dynamic tests, and a uniaxial testing machine equipped with a high-temperature furnace. Numerical simulations of the experiments were also implemented for calibration and validation purposes. Wu et al [7] identified the temperature- and stress state-dependent yield and fracture behaviors for the Mg-Gd-Y alloy. The mechanical experiments at 25~300 ℃ were carried out by various designed specimens, including tension, compression and shear. Gao et al [8] by their experimental and numerical work found that the stress state has strong effects on both the plastic response and the ductile fracture behavior of an aluminum 5083 alloy. Furthermore, Chen et al. [9] explained how annealing temperature affects the mechanical properties and sensitivity of the AL5083-H116 aluminum alloy.

In this study, a new method for measuring fracture strain via Video Measuring Machine (VMM) under different stress triaxiality and temperature conditions has been introduced. For this purpose, the notched, shear, and dog-bone specimens for aluminum 5083 alloy are analyzed numerically and experimentally.

2- Simulations and Experiments

In this research, tests with notched bed samples for tensile mode and grooved bed samples for shear mode have been used. Notched and shear samples are prepared and manufactured following ASTM-E8M and ASTM-B831-05 standards, respectively. The stress triaxiality parameter (η)

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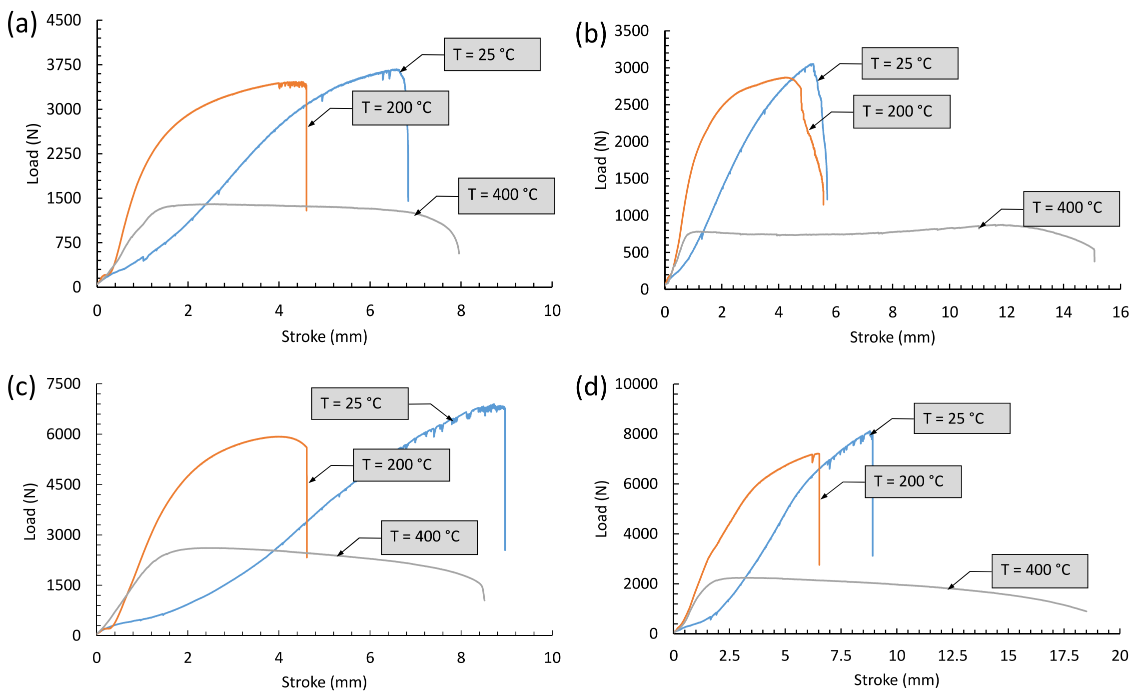

Fig. 1. Force-displacement diagram of samples at different temperatures for different triaxialities: a) 0.2, b) 0.33, c) 0.38 and d) 0.55.

is calculated as the following Eq. (1).

$$\eta = \frac{\sigma_m}{\sigma_{eq}} \tag{1}$$

In the above relation, η is the ratio of mean stress σ_m to equivalent Von-Mises stress σ_{eq} which will be defined as:

$$\sigma_m = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3} \tag{2}$$

$$\sigma_{eq} = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2\right]} \tag{3}$$

After several studies, the geometric dimensions of the notched and shear samples were designed and modeled according to the output drawings. By simulating in Abaqus software, four specimens for different stress triaxiality were obtained. Then, in experiments, 24 specimens were fabricated for testing in 4 types of stress triaxialities and three different temperature conditions of 25, 200, and 400°C. According to the above explanations, 24 force-displacement diagrams are obtained for four stress triaxiality models under three temperature conditions. By averaging the results of every two similar tests, 12 diagrams for each type of stress triaxiality, we can finally reach the final four diagrams in Fig. 1. We have a sensitization at 200°C.

3- Fracture Strain Measurement

To measure the effective fracture strain of shear parts, the broken shear parts visualize in the VMM machine. The measurement is made on a damaged part and the point where it is stretched and broken is determined. Shear strain (γ) in

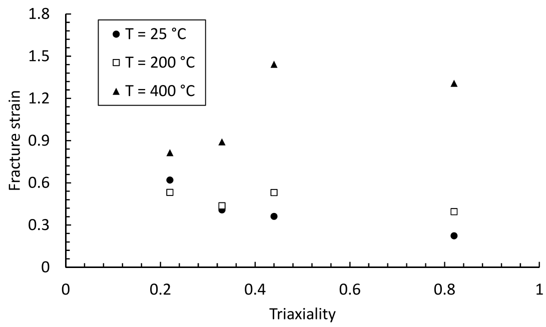

Fig. 2. Effect of temperature on fracture strain in different stress triaxialities for5083 aluminum

terms of Radian, which is the angle of the transient lines from the specified points (breaking point and the image of the same point before failure) is obtained from the following Eq. (4).

$$\varepsilon_{eff} = \frac{\gamma}{\sqrt{3}} \tag{4}$$

The following thickness change method is used to measure the effective fracture strain of tensile notched parts. Notched parts after testing at different temperatures failed in the notched zone. Using the VMM device, the thickness of the fracture zone is measured, and the average of these measurements is used in Eq. (5).

$$\varepsilon_{eff} = 2\ln\left(\frac{t_1}{t_2}\right) \tag{5}$$

In this equation, t_2 is the final thickness after failure and t_1 is the initial thickness of the notch, which is 1.8 mm for all of the notched specimens.

4- Conclusions

According to the above results, the fracture strain changes in terms of the stress triaxialities at different temperatures are shown in Fig. 2. Examining the following diagram, it can be seen that in the 0.2 triaxiality, the fracture strain changes are not very dependent on temperature and in the 0.38 and 0.55 triaxialities there is the highest dependence. At 25°C, the fracture strain rate in terms of the stress triaxiality is descending and at the initial and final strains of 200°C, it has the least changes and remains almost constant. But at 400°C, it rises between the initial and final strains. The experimental results show that the effect of temperature is not uniform.

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HOW TO CITE THIS ARTICLE

A. Ostadi, M. Ganjiani, A New Method for Calculating the Fracture Strain of Shear and Notched Specimens at Various Temperature and Stress Triaxialities, Amirkabir J. Mech Eng., 54(8) (2022) 383-386.

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