STRAIN LOCALIZATION AND FRACTURE STRAIN PATH IN A HIGH-STRENGTH 7075 ALUMINUM ALLOY

BIẾN DẠNG CỤC BỘ VÀ QUÁ TRÌNH BIẾN DẠNG PHÁ HỦY TRÊN HỢP KIM NHÔM 7075 ĐỘ BỀN CAO

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ABSTRACT

The significantly increased demand of lower CO_2 emission, fuel-efficient, and lightweight has driven the advancement of lightweight materials. Aluminum alloys 7075 owing to its excellent mechanical properties and high strength-to-weight ratio, were widely used in many industry applications. In this study, a series of upsetting tests was carried out on high strength aluminum alloy 7075 at room temperature to evaluate the strain localization and the evolution of fracture strain path evolution during plastic deformation process. Many different types of specimens were tested to characterize fracture behavior in in-plane shear, uniaxial tension, and plane strain tension. Fracture strains under various loading conditions were measured using a 3D-Digital Image Correlation (DIC) system.

Keywords: *Digital Image Correlation; Mechanical properties; Measurement.*

TÓM TẮT

Nhu cầu gia tăng một cách đáng kể về giảm lượng khí thải CO_2, tiết kiệm nhiên liệu và trọng lượng nhẹ đã thúc đẩy sự phát triển của các vật liệu nhẹ. Hợp kim nhôm 7075 do có các đặc tính cơ học xuất sắc cùng với tỷ lệ độ bền trên trọng lượng rất cao, được sử dụng rộng rãi trong nhiều ứng dụng công nghiệp. Trong nghiên cứu này, một loạt các thí nghiệm phức tạp đã được thực hiện trên hợp kim nhôm độ bền cao 7075 ở nhiệt độ phòng để đánh giá vị trí biến dạng và sự phát triển của đường biến dạng dẫn tới phá hủy trong quá trình biến dạng dẻo. Nhiều kiểu mẫu thí nghiệm khác nhau đã được thực hiện để mô tả hành vi biến dạng dẫn đến phá hủy trong trạng thái xé đơn, kéo đơn trục và kéo biến dạng phẳng. Giá trị biến dạng dẫn đến phá hủy trong các điều kiện tải khác nhau được đo bằng hệ thống tương quan hình ảnh kỹ thuật số 3D (DIC). Biến dạng phá hủy trên bề mặt của các mẫu được sử dụng để xây dựng quỹ tích phá hủy dẻo trên bề mặt vật liệu cho AA7075.

Từ khóa: *Đo lường không tiếp xúc; Ứng suất; Biến dạng phá hủy.*

1. INTRODUCTION

In recent years, weight reduction has long been indicated as a key priority for improving fuel economy. One of the leading trends in weight reduction in the automotive and aerospace industries is change from steel to aluminum alloys. Aluminum alloys show various advantages compare to steel such as weight reduction, corrosion resistance, high strength-to-weight ratio, and manufacturing flexibility… Aluminum alloy AA7075 has large applications in aircrafts, missiles and automobiles for many components. In the present study, the fracture behavior and evaluation of 7075 aluminum alloy was studied under different stress-states in order to explore the characteristics of the material under extreme situations. A series types of tests was carried out covering a wide range of stress states on specimens: uniaxial tensile test, shear test, plane strain test at room temperature. Additionally, the non-contact measurement method, 3D Digital Image Correlation (DIC), also was applied to obtain the deformation during experiment process.

Figure 1 shows a DIC system using to monitor the tensile specimen surface [1]. DIC measurement device generally uses an optical system to measure displacement, strain and deformation fields of an in-plane surface or out of plane surface of specimens [2]. Series of digital images on the surface of object at different loadings states are captured during the test, then matching algorithms and numerical differentiation are applied to quantitatively extract full-field displacement and strain responses of the object.

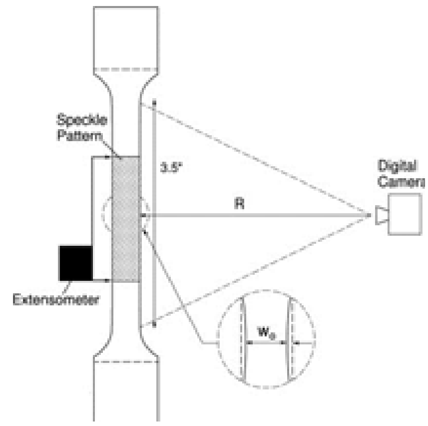

Figure 1. 2D Digital image correlation techniques in tensile test [1]

2. EXPERIMENTS

2.1. Material and specimens

The material studied in this paper was aluminum alloy 7075-T761. It is a representative of the class of advanced high-strength aluminum which are increasingly important in lightweight materials. All specimens are extracted from 1.5mm thick sheets with the longitudinal axis along the rolling direction. The chemical composition of AA7075 is given in Table 1.

Table 1. Chemical composition (% wt) of the investigated alloy

Zn	Mg	Cu	Mn	Fe	Si	Cr	Ti	Al
5.8	2.5	1.6	0.28	0.40	0.35	0.21	0.19	Balance

Three different types of specimens were extracted from the original aluminum sheets, as follows: (a) (a) Central hole (CH) specimens, which feature a 20-mm wide gauge section with an 8-mm diameter hole in the center; (b) Plane strain (PS) specimens, which have a 10-mm width at the narrowest section and a 20-mm width at the widest section; (c) The in-plane shear tension specimen geometry was employed in this study for quasi-static shear testing. These shear specimens can be used for both constitutive modeling and fracture characterization.

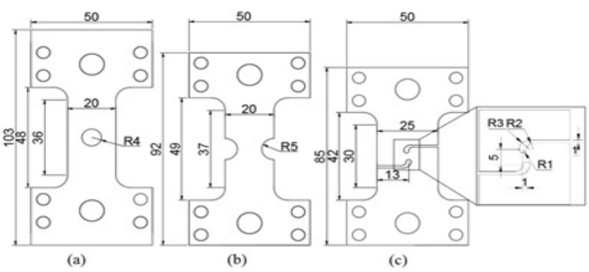

Figure 2. Type of specimens: (a) Central hole, (b) Plane strain, (c) in-plane shear [3]

2.2. Experiment setup

In this study, a 3D-DIC measurement system was employed to conduct all the upsetting test. There are two 5Mp camera were adopted for recording the surface of specimens at the time of experiments. The tension test was performed under displacement control in a universal testing machine run at a rate of 0.5 mm/min, the deformation resulted in a strain rate of $10^{-4}s^{-1}$. To allow the DIC captures the specimens surface, a fine speckle pattern was painted onto one side surface of the specimen. The deformation of the specimen was monitored with two digital cameras equipped with a timer that recorded 5 frames every single second.

Figure 3. Two typical DIC techniques and their imaging models and system.

In these experiments, some points need to clarified here for the measurement of fracture strain surface. Firstly, the von Mises equivalent strain is the output data for the study of ductile fracture for all loading conditions and no additional input is required in advance of measurement. Secondly, the fracture strain measured by DIC is supposed as pure plastic fracture strain. Ductile fracture takes place after large plastic deformation and the elastic deformation is negligible compared to the large plastic components. Besides, ductile fracture is assumed to initiate on specimen surfaces and can be measured directly with the DIC method. This is valid for sheet metals with poor ductility such as advanced high strength steel, aluminum alloys, titanium alloys, magnesium alloys, etc. Aluminum alloy 7075-T76 show a poor ductility with short elongation with very high strength. The failure happens from the inside and suddenly spread outward to the surface of material. Because this failure process is extremely fast and suddenly, ductile fracture is assumed to exit on the surface of material.

3. CONSTRUCTION OF THE FRACTURE STRAIN PATH

To construct the fracture locus of Al7075 using ductile fracture criterion proposed in the space of stress triaxiality (η) and equivalent plastic strain to fracture ($\bar{\varepsilon}$). The equivalent plastic strain to fracture was measured using 3D DIC for all specimens, including central hole tension specimens, pure shear tension specimens, and plane strain tension specimens. The strain distributions are carried out at fracture strokes for each specimen.

Stress triaxiality is defined as the ratio of mean stress (σ_m) to the equivalent stress (σ_e). Based on the J_2 theory, this ratio can be calculated as follows [4]:

$$\eta = \frac{\sigma_m}{\sigma_e} = \frac{(\sigma_1 + \sigma_2 + \sigma_3)/3}{\frac{1}{\sqrt{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}} \quad (1)$$

Here σ_i are the principal stresses.

In the plane-stress condition, stress triaxiality can be calculated as:

$$\eta = \frac{(\sigma_1 + \sigma_2)/3}{\sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1\sigma_2}} \quad (2)$$

By using the flow rule, we derive the following relationship to carry out the stress triaxiality from the DIC results.

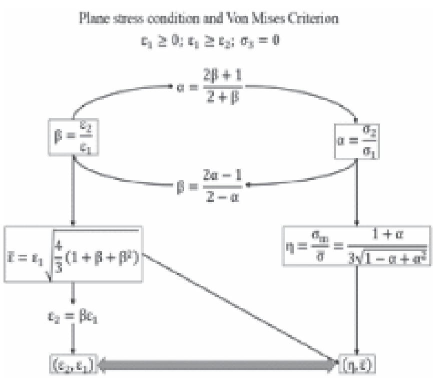

Figure 4. Transformation between two different spaces: principal strain and mixed space of equivalent strain and stress triaxiality

Figure 5 shows the strain path to fracture on the surface of three types of specimens in the space of stress triaxiality and equivalent plastic strain to fracture. A wide range of stress triaxiality was observed from near zero (in-plane shear tension) to uniaxial tension (central hole tension) and plane strain. Strain localization varies for each type of specimen. In in-plane shear tension and plane strain tension, local deformation occurs at the center of the deformed area, whereas in central hole tension, local deformation is concentrated along the edge of the circular hole.

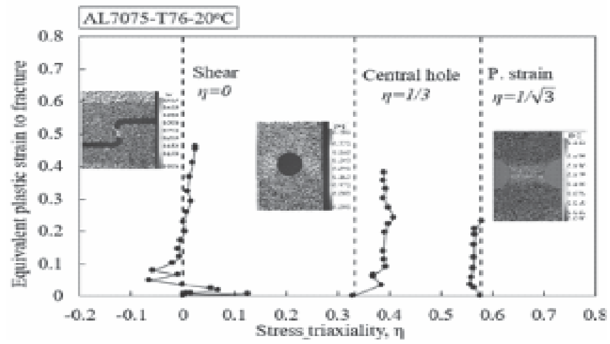

Figure 5. Strain path to fracture for AA7075 calculated by using 3D-DIC

4. CONCLUSIONS

In this research, a wide range of upsetting tests were carried out on high-strength aluminum alloy 7075-T761 at room temperature to obtain the surface strain evolution and surface strain path to fracture during plastic deformation. The details of the algorithm method and the setup of the optical system were explained. Different specimen types were tested to characterize fracture behavior in in-plane shear, central hole, and plane strain tension. Local strain and the evolution of strain paths under various loading conditions were measured by 3D Digital image correlation (DIC) to construct fracture strain path for AA7075.

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