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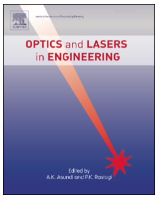

Measurement of true stress–strain curves and evolution of plastic zone of low carbon steel under uniaxial tension using digital image correlation

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ABSTRACT

Three-dimensional digital image correlation has been utilized widely in many fields due to its advantages of non-contact, full-field measurement and simplicity. Based on 3D-DIC measurement system and electronic universal testing machine, two uniaxial tension tests for low carbon steel specimen were performed to acquire the true stress–strain curves. An assumption was made that specimen's cross section keeps as a circle in tension test whose diameter could be determined by calculation of the curvature of surface shape. Therefore, true stress of specific cross section was acquired and hence the true stress–strain curves were obtained. In addition, the evolution of plastic zone of specimen under uniaxial tension was studied as well. And experimental results indicate that at certain time instant of expanding process of plastic zone, region that has already entered the plastic zone and that has not entered such zone yet is keeping in a constant deformed state, while region that is entering the plastic zone provides axial plastic deformation, which is almost equal to crosshead movement of testing machine.

1. Introduction

Nowadays, digital image correlation (DIC) is a well-established method for deformation measurement and has been utilized extensively in many fields [1–9] due to its advantages of non-contact, full-field measurement and simplicity. It should be noted that two-dimensional DIC (2D-DIC) is only suitable for in-plane displacement/strain field on planar objects and its measuring accuracy of strain is easily affected by lens distortions [10,11], especially by out-of-plane motion [12,13], which will lead to a noticeable strain error. Therefore, 2D-DIC is not an excellent choice in situations which requires accurate strain measurement. However, strain is of great importance in determining mechanical properties of material, particularly for brittle material such as concrete. Three-dimensional DIC (3D-DIC) using two cameras is capable of obtaining 3D displacement and surface strain by considering the change of surface shape owing to object deformation, therefore it can provide accurate results of surface strain fields. In recent years, applications of 3D-DIC have significantly increased [14–19], from forming limit diagram [20] to measurements in extreme environments [21].

Ductile material is used widely in engineering for its merits of easy machining and large deformation before failure. For ductile material, its mechanical properties such as yield stress and ultimate stress are playing an important role in engineering design. Therefore, we should know its stress–strain curves in tension test in advance. The stress is generally estimated through dividing load by the specimen's initial

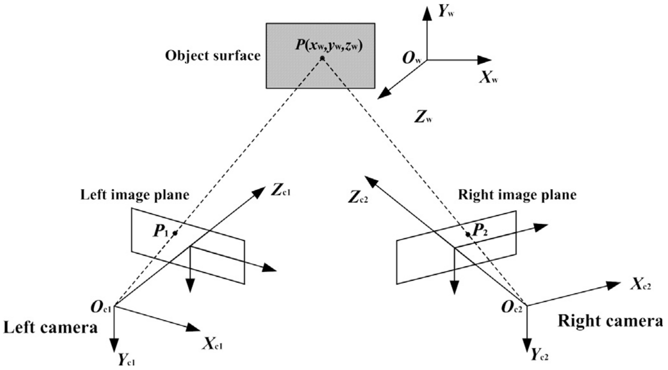

Fig. 1. Schematic diagram of 3D-DIC.

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cross-sectional area, which is called engineering stress. However, the specimen's cross-sectional area is decreasing throughout the tension process, which indicates that engineering stress cannot reflect the specimen's true stress. The electrical resistance strain gauge is the most common type for accurate strain measurement. But its limited measuring range (generally up to 20,000 $\mu\varepsilon$, i.e. 2.0%) restricts its applications in fields of large strain measurement. In addition, extensometer is utilized widely in strain measurement and its strain is usually obtained through dividing elongation by gauge length, which is called engineering strain. As a result, the acquired strain with extensometer is an average of strain within gauge length, which cannot represent local strain when inhomogeneous deformation such as strain localization occurs. Therefore, the engineering stress–strain curves obtained using the aforementioned method deviate from true stress–strain curves for ductile material such as low carbon steel, which leads to a value of ultimate stress less than its true counterpart. Accordingly, some approaches were proposed by researchers to obtain the true stress–strain curves. Hochstetter et al. [22] determined the true stress–strain curves of amorphous polymers by nanoindentation experiments. Joun et al. [23] proposed a method to acquire the true stress–strain curves over large range of strains using engineering stress–strain curves with a finite element analysis. Based on the constant volume assumption and 2D-DIC, Wang et al. [24] obtained the true stress–strain curves of sheet-metal tensile test. The stress–strain curve including post-necking strain was determined by Kamaya and Kawakubo [25] using digital image correlation and finite element analysis. In addition, full-field deformation distribution for ductile material is also researched using DIC technique [26,27], which can supply evidence for theoretical knowledge. In summary, none of the existing methods for true stress–strain curves is capable of measurement of true stress.

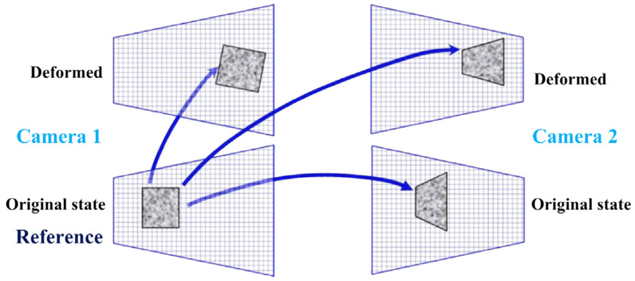

Fig. 2. Subimage matching for 3D displacement calculation in 3D-DIC.

Fig. 3. Standard specimens with random speckle pattern.

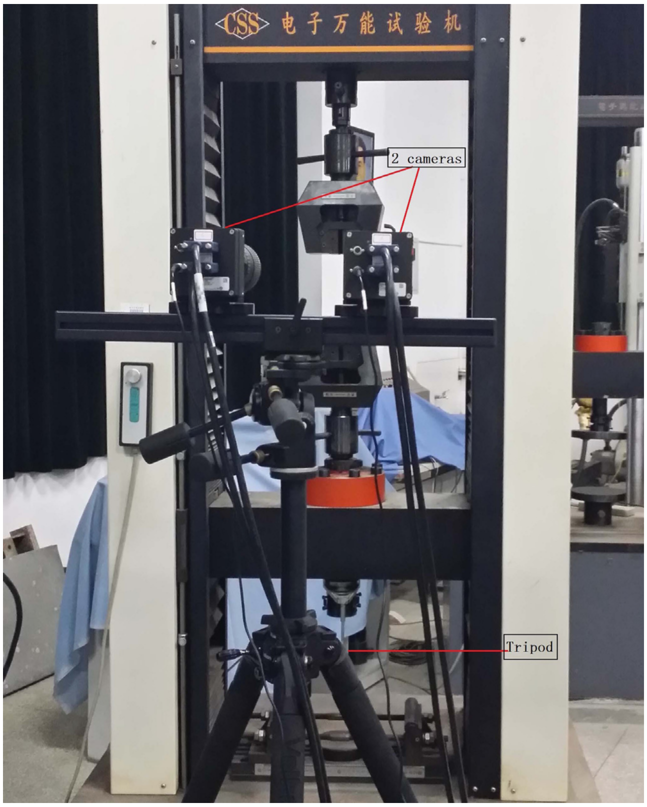

Fig. 4. Experimental system of measurement based on 3D-DIC.

In order to obtain true stress, we will present a method to estimate the real-time cross-sectional area of specimen under tension, which could be achieved by 3D-DIC due to its excellence in surface shape and

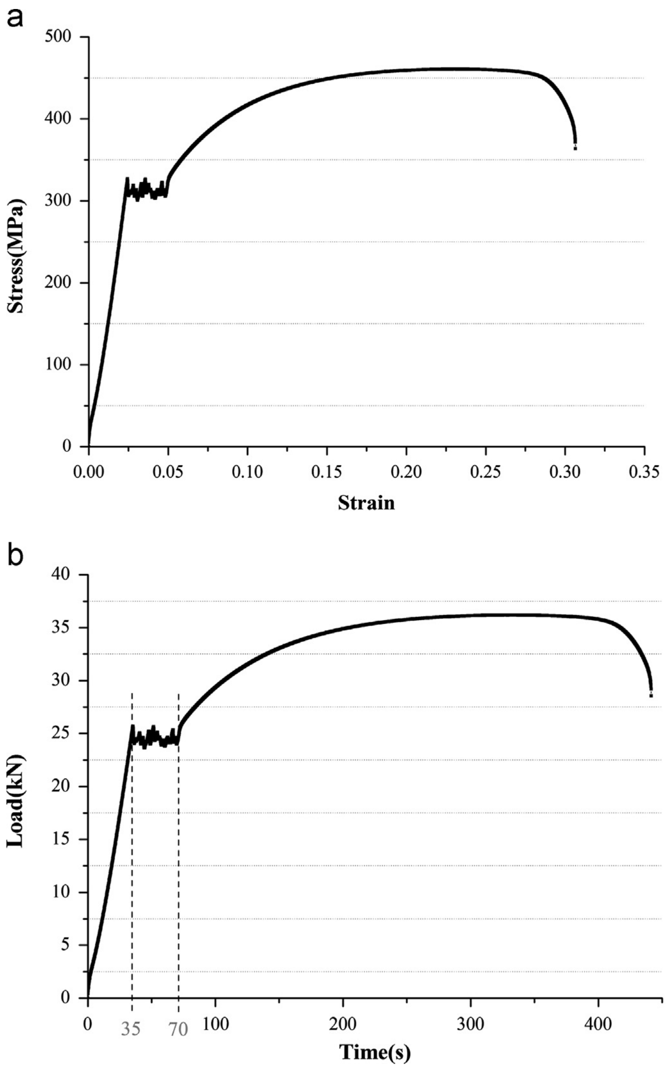

Fig. 5. (a) Engineering stress–strain curves and (b) load–time curves of specimen 1.