

Measurement of Fracture Strains for Advanced High Strength Steels (AHSS) Using Digital Image Correlation

Gang Huang, Benda Yan and Hong Zhu

ArcelorMittal

Copyright © 2009 SAE International

ABSTRACT

Predicting fracture behavior of Advanced High Strength Steels (AHSS) on both manufacturing and crash simulations is becoming more and more important with the wide use of AHSS in automotive industry. The accurate measurement of fracture strains is a critical input for predicting failure in FEA simulations. It is well known that fracture is a highly localized behavior and fracture strain is gauge or size dependent. In this paper, a full field measurement technique, Digital Image Correlation (DIC), is employed to measure gauge-dependent fracture strains for several Advanced High Strength Steels (AHSS) under tensile test conditions and Limit Dome Height (LDH) tests. Applications of the fracture strains for FEA simulation are discussed.

INTRODUCTION

Ductile fracture has been extensively studied for different metals in recent years [1-3]. Numerous fracture criteria have been documented in literature for prediction of ductile failure, some of which have been implemented in commercial FEA codes [4-7]. For strain-based criteria used in fracture prediction, the fracture strain data are very critical for material input and criterion calibration. It was pointed out that there was difficulty in measuring fracture strain when using conventional methods, especially for sheet metals [1].

Conventionally, extensometer, strain gauge and Linear Variable Differential Transducer (LVDT) are used to measure strains from quasi-static or high strain rate tests. In stamping process of AHSS with bending, the fracture strain could reach as high as 60%. Due to the issues of

measurement limit (for strain gauge or extensometer) or accuracy (for LVDT), conventional methods cannot be readily used to measure high fracture strains for AHSS. Other than above conventional methods that are frequently used, electrochemically etched grids could be possibly applied to measure fracture strains; however, because of issues of mesh size and the nature of non-continuous measurement, it is difficult to measure fracture strain conveniently and accurately. The digital image correlation technology, developed two decades ago, is a non-contact tool for full-field deformation measurement, and has been widely applied for material characterizations [8-10]. It is able to continuously measure large strain at any deformation stages.

In this study, DIC was utilized to measure fracture strains for several AHSS in uniaxial tensile tests and LDH tests. For uniaxial tensile tests, effective fracture strain data were obtained as function of gage length. For LDH tests, Fracture Forming Limit Curves were determined based on the measured major and minor fracture strains.

EXPERIMENT

UNIAXIAL TENSILE TESTS- Instron 4485 (I5) system was used to conduct uniaxial tensile tests on several AHSS; the specimen dimensions and testing parameters were based on ASTM E8-01; a Dolphin F-145B camera was used to acquire images continuously at speed of 20 frames/second so as to capture the moment of fracture, as shown in Figure 1 for the test setup. Before tests, the blanks were painted with speckles on the surface. Then a 2-D DIC software was used to determine displacements and strains.

LIMIT DOME HEIGHT TESTS- In LDH tests, an MTS LDH forming machine was used and Nakazima testing procedures were applied; the blanks were of 7" long with the width varied from 1 inch to 7 inches to represent different strain conditions. Steel grades of 1.4mm DP590 bare and 1.2mm GATRIP780 were tested; two cameras oriented with a fixed angle between each other were positioned above the forming equipment, as shown in Figure 2. The LDH tests were performed on 4 blanks for each steel grade in tensile tests and for each width of each steel grade in LDH tests. During the forming process, the length or the depth of specimens the tests increases and speckle pattern also changes showing the deformation of the steel. Images of the specimen and the speckle pattern were recorded simultaneously at speed of 15 frames/second during forming until fracture occurred. Thereafter the specialized 3-D DIC software, which is capable of analyzing the random speckle pattern, was used to analyze the acquired images to calculate the major and minor strains of every point of the deformed specimens at different deformation stages.

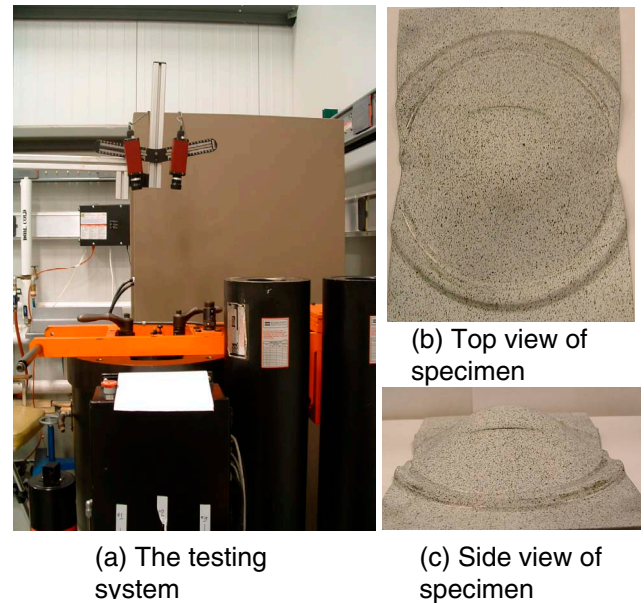


Figure 2. Setup of LDH test using DIC system and LDH specimen

RESULTS AND DISCUSSIONS

In order to determine the gage length dependency of fracture strain from uniaxial tensile tests, different gage length sizes were applied on the acquired images in both tensile direction and width direction and 2-D DIC analyses were applied. Because of the geometry of ASTM specimens, the gage length is limited up to 12.7 mm, while the gage length in tensile direction can reach much higher. Nevertheless, the gage length dependency of minor strain (true strain) was not noticeable, as shown in Figure 3. Therefore, the effective strains based on the strains in two directions can still be obtained for larger gage lengths by assuming constant minor strain with respect to gage length. Figure 4 shows the effective true fracture strains determined from the measured strain components. From Figures 3 and 4, it is clear that, compared to the minor strains, the effective fracture strains for all tested steels are highly dependent on the gauge length, especially when gauge length is less than 20 mm. This indicates that strain localization was mostly concentrated in tensile directions between necking and fracture.

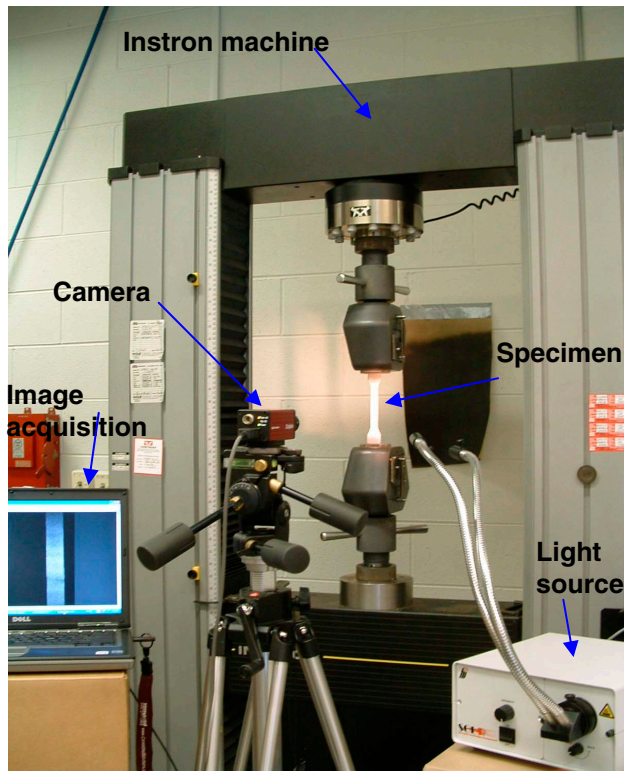


Figure 1. Setup for measurement of full stress-strain curve from tensile tests