RESEARCH ARTICLE

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Locating Cracks in 1050 Aluminium Alloy by Digital Image Correlation

Kavita Tewari[*1], R.K.Kulkarni[2]

[1,*] Department of Electronics Engineering, VESIT, (Mumbai University), Mumbai, India-400071; e-mail: kavita.tewari@ves.ac.in.
[2] Department of Electronics Engineering, VESIT, (Mumbai University), Mumbai, India-400071.

ABSTRACT

In this paper deformation of commercial 1050 grade aluminum alloy is studied by digital image correlation (DIC) technique using open-source software, Ncorr. For this purpose, samples of aluminum alloy were subjected to uniaxial deformation under a scanning electron microscope (SEM) till the initiation of crack. Intermittently images were captured during deformation and by using DIC technique, variations in the microstructure of the deformed samples were identified in terms of displacement. Using these displacements, normal strains E_{xx}, E_{yy}, and E_{xy} shear strain were estimated to subpixel accuracy. By superimposing the region of crack and distribution of strains in the microstructures, it was possible to show that near the crack, strains not only attain high values but also show large fluctuations. Various aspects relating to the nature of strain distribution are discussed in the paper.

Keywords*:* Digital Image Correlation, Ncorr, Strain Measurement, 1050 Al.

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INTRODUCTION

Commercially pure 1050 aluminum alloy is being widely used in various industries, because of its high electrical conductivity and corrosion resistance [1]. This alloy is also used as a heat sink, as it has a higher thermal conductivity in comparison to other alloys [2]. It has relatively lower mechanical strength as compared to other aluminum-based alloys, but the alloys can be strengthened by cold working [3]. During application, 1050 Al based structural components undergo various stresses which occasionally induce deformation leading to the failure of the component. In many applications, which include electrical current-carrying components, chemical carrying pipelines, to name a few, failure of a component can be more svere than the general failure observed in components.

With the advances made in microscopic and image processing capabilities, it is possible to study the distribution of stresses and identify the regions of stress concentration prior to the crack formation.

Corresponding Author : Kavita Tewari, Department of Electronics Engineering, VESIT, (Mumbai University), Mumbai, India-400071; e-mail: kavita.tewari@ves.ac.in

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Ghadbeigi et al. [4] have studied local deformation in dual-phase steel by using digital image correlation (DIC) techniques to show that severe deformation remained localized within the ferrite grains and the formation of micro-cracks initiates at the interface between martensitic and ferrite phases. Lunt et al. [5], through DIC, could successfully quantify stress distribution in both the phases; equiaxed á and fine precipitate $\alpha 2$ phases in the Ti-6V-4Al alloy.

DIC-based techniques, therefore, have tremendous scope in metallurgical systems where these techniques can be utilized in identifying regions of stress concentrations in a sample undergoing deformation. Typically, by analyzing microscopic images before and after deformation DIC can provide semi-quantitative to quantitative information in terms of displacement and strain fields [6]. DIC technique, without any presumption, can provide an accurate estimation of strain locally as well as globally and that too of a real system.

With advances made in the scanning electron microscope (SEM), it is possible to estimate deformation at submicro-scale which can be digitally recorded during the process of deformation. Such in-situ deformation studies under a scanning electron microscope can further be enhanced by combining the 2D-DIC techniques with high spatial resolution microscopy, which finds several applications in broader areas [6,7].

In the present paper, a 2-D DIC system that makes use of open-source MATLAB based 2D DIC software Ncorr has been used to measure the distribution of full-field displacement and strain [8]. The aim of the present study is to utilize the DIC technique to identify the possible regions of stress concentration in the material. For this purpose, commercial Al (1050 Al) has been subjected to in-situ deformation under SEM at a specific strain rate till the crack within the sample was visible. Intermittently SEM images were obtained during experiments which were used for image correlation after the experiment to find out if the DIC is able to identify the region of stress concentration.

METHODOLOGY

For image correlation, a reference image is subdivided into smaller regions which are called as subsets. Within these subsets, deformation is assumed to be uniform, and the deformed subsets are then tracked in the deformed image. Initially, subsets are considered as a contiguous group of points in the reference image which have integer pixel value in the reference image. The transformation of original points into a deformed set is assumed to be related to a linear, first-order transformation. For further detail can be obtained in reference [6]. Deformation is estimated in terms of u displacements, v displacements and strains. To find out the deformation of a subset, the DIC algorithm finds the extremum of a correlation function. In order to have an initial guess, computation at integer location was carried out and a correlation criterion is defined to find out similarity between the reference and deformed subset. To find out the deformation in a subset, the extremum of a correlation cost function was estimated using DIC algorithms. The normalized cross-correlation (NCC) defined in references [6, 8] has been used in the present study. Details of computing Lagrangian strains can be obtained reference [7,8].

EXPERIMENTAL

An in-situ straining experiment was carried out using Scanning Electron Microscope (Model Sigma) equipped with Kammrath and Weiss tensile stage. Flat tensile samples of commercially pure aluminum (1050 grade) (nominal composition given in Table I) of gauge length 25 mm were in-situ strained (strain rate 10^{-4} /sec). During experiments, microstructural features of the sample undergoing deformation were intermittently recorded using secondary electron detector. Determined mechanical properties are shown in Table II.

Table-I: Typical Composition of 1050 Grade AL

	Al	Cu	Fe	Mn	Mg	Si	Ti
Wt%	99.5	0.025	0.09	0.05	0.05	0.25	0.035

Table-II : Mechanical Properties of AL

Tensile Strength	Proof Stress	Elongation before crack
102 MPa	88MPa	10%

A reliability-guided DIC (RG-DIC) method was used for the selection and propagation of seed. For this purpos the Gauss-Newton method was used. The u- and v- displacements were calculated for the subset of the size of radius 10. With the help of seed tracker the seeds were correctly tracked on the deformed images.

RESULTS AND DISCUSSION

Figures. 1(a) and (b) show the reference and deformed secondary electron images of the sample of 1050 Al. Directions of the applied load are marked by the arrows in Figure 1(a). Due to applied tensile load, the samples started deforming, and due to deformation crack initiated on the surface of the sample (marked by an arrow in Figure 1(b)).

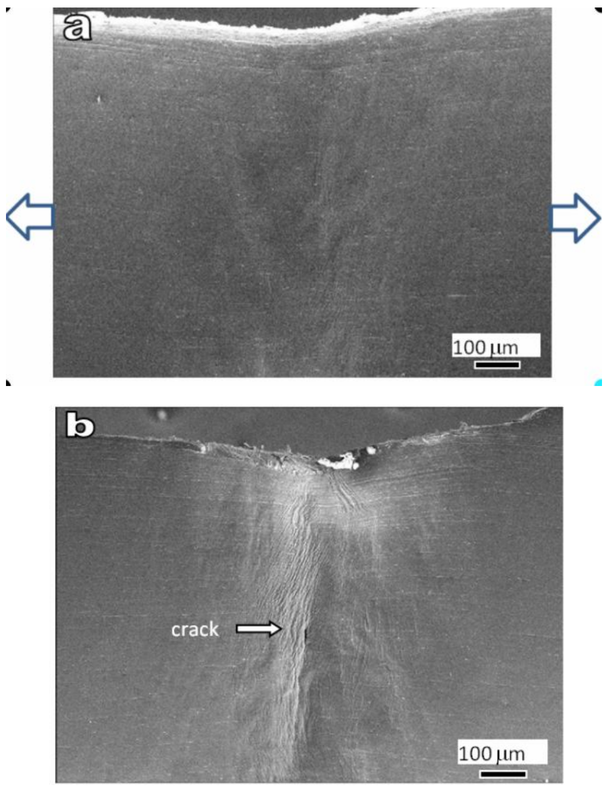
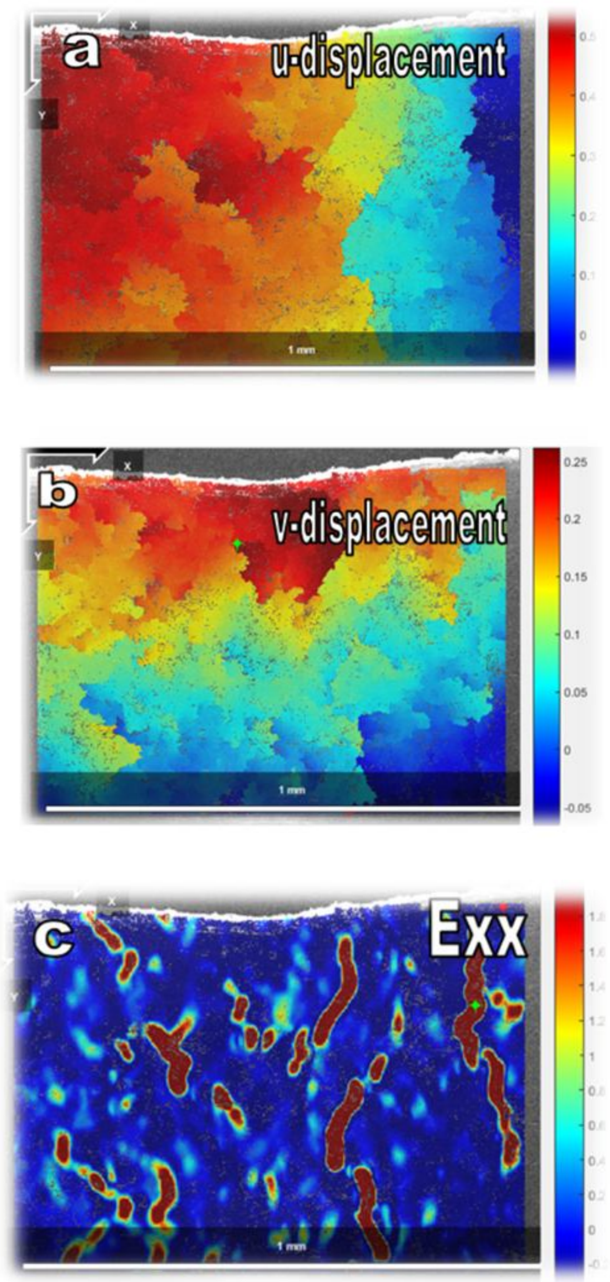


Figure 1: (a) Reference (b) Deformed images of the sample of 1050 Al

The crack was more or less perpendicular to the direction of loading. Typical values of the mechanical properties measured in the present study matched well with those reported in the literature (compare values listed in Table II with those given in reference [9]). The direction during the DIC was so selected that the direction of stress was assigned as X-axis and a major portion of the crack which was perpendicular to the direction of the crack was assigned as the Y-axis.

The computed u-displacement, representing displacement along the X-axis, and the v-displacement, representing the displacement along the Y-axis, are shown in Figures 2(a) & (b) respectively. From Figures 2(a) & (b) it could be noticed that the distribution of the displacement is neither uniform nor symmetrical across any direction. Estimated E_{xx}, E_{xy}, and E_{yy} strains are shown in Figure 2(c)-(e) respectively. Strain localization is clearly visible in these figures. Distribution of E_{xx} (Figure 2(c)) showed alignment of the localized maxima along the Y-axis which is also the line of the crack. It may be noted that the direction of the alignment of the maximum values of E_{xx} is perpendicular to the vector direction of E_{xx}. In contrast, E_{yy} and Exy plots do not show such alignment (Figure 2 (d)-(e)). E_{xy} shows the presence of alternate compressive and tensile stresses in the nearly same regions where maxima of E_{xx} were located (compare Figure 2(c) with 2(d)). In other regions values of E_{xy} are nearly close to zero. By superimposing images (Figure 1 (b) and Figures 2(c)-(e)), it is possible to locate the possible position of the crack [10].



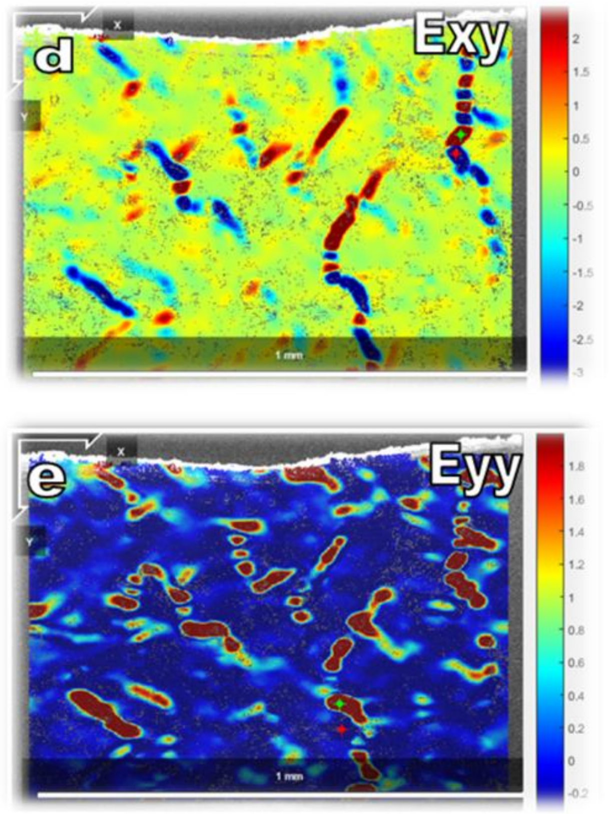


Figure 2: (a) u-displacement, (b) v-displacement, (c) E_{xx}, (d) E_{xy}, and (e) E_{yy}

The parameter of strains are summarized in Table III.

Table-III : Parameters of Strains

	Minimum	Maximum	Mean	Standard deviation
E_{xx}	-0.264	2.144	0.892	0.667
E_{xy}	-0.809	1.740	0.957	0.550
E_{yy}	-0.276	1.679	0.943	0.487

In addition, strain distribution curves at different locations of x and y coordinates can be plotted and if the location of cracks and maxima of strains coincide, information about the strain around the crack can be inferred. For this purpose, linear distribution of E_{xx}, E_{xy} and E_{yy} are plotted in Figure 3 Figure 3(a) shows the distribution of E_{xx} at ~160 mm from the origin along the Y-axis. Sharp peaks at 450, 600, and 900 mm were noticed. When the distribution of E_{yy}, E_{xy} strains were plotted at these values of x of 450, 600, and 900 mm, maximum fluctuations in the value were obtained at the position of 600 mm (Figure 3(b)-(d)).

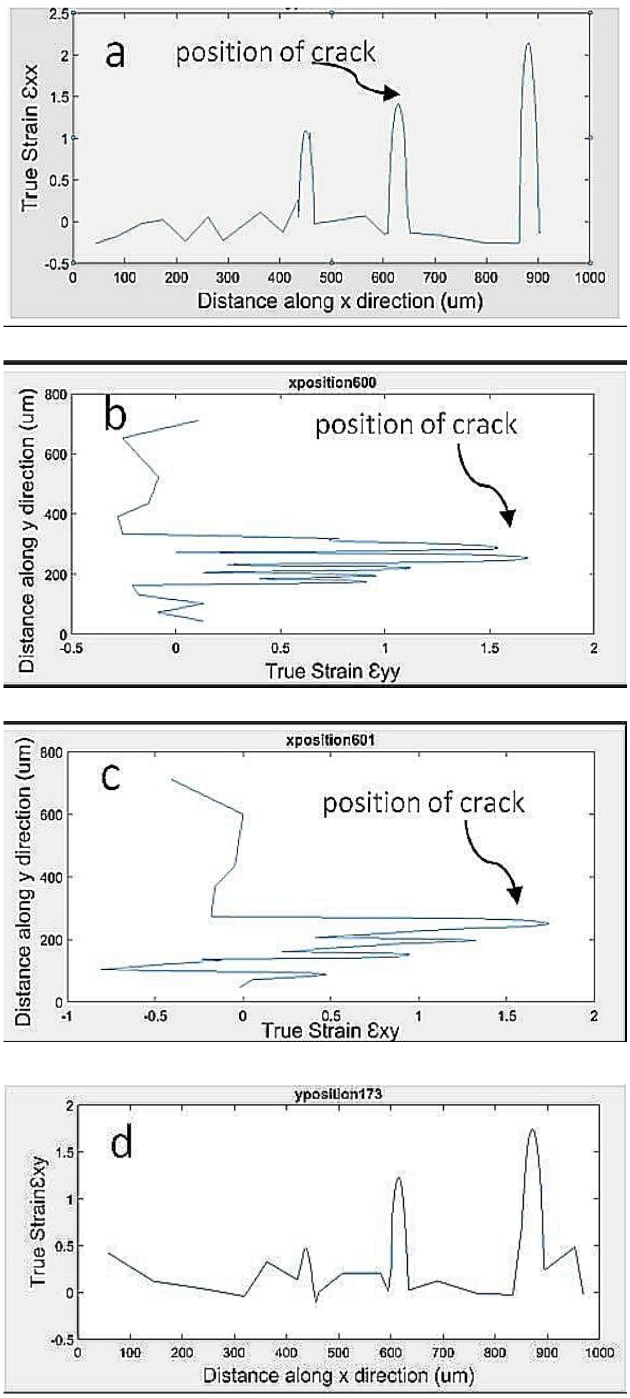


Figure 3: (a) True strain E_{xx} along the x-direction, (b)True shear strain E_{yy} along the y-direction, and (c) True shear E_{xy} along the y-direction. (d) True shear E_{xy} along the x-direction.

The location, therefore, represents the region where not only large strains are located but large fluctuations in the strain are also located. Such a large magnitude of strains, on one hand, suggests that the sample has undergone large plastic deformation and, on the other hand, fluctuations in the values show that the region of instability. Such regions, therefore, should represent the region of crack initiation [10]. This location when superimposed on Figure 2 (b), it nearly matched with the location of the crack. Based on the image correlation analysis it can be inferred that the strain concentration regions can be successfully identified. Many of these regions could be a potential source of crack initiation. It may be noted that in the present case samples were not prepared to the mirror finish condition and still DIC could successfully locate the possible location of the very initial stages of cracking. It can be stated that DIC can be successfully utilized in identifying the regions of strain concentration by taking high-resolution images of the same regions over the various degree of deformation. In order to have a high spatial resolution, SEM images were used in the present study, however, authors believe that DIC can be extended to those images captured by high-resolution optical cameras.

Conclusion

In the present work, commercial Al (1050) was in-situ deformed under SEM. Various microstructures were taken during deformation which were analyzed by digital image correlation using Ncorr open-source software. The u and v displacements, normal strains E_{xx}, E_{yy}, and shear strain E_{xy} were estimated. Localization and alignment of strains were observed in the case of E_{xx} whereas E_{xy} and E_{yy} did not show any such alignment. Upon plotting the linear distribution, these values have shown large fluctuations representing instabilities near the crack.

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