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Combining GPU-based full-field and strain-controlled 2D-DIC for simplified crack growth experiments

A. Blug[a], F. Conrad[b], D. J. Regina[a], A. Bertz[a], C. Kontermann[b], D. Carl[a], M. Oechsner[b]

[a]Fraunhofer Institute for Physical Measurement Techniques IPM, Georges-Koehler-Allee 301,
79110 Freiburg, Germany; contact: andreas.blug@ipm.fraunhofer.de
[b]Technical University of Darmstadt, Chair and Institute for Materials Technology IfW,
Grafenstrasse 2, 64283 Darmstadt, Germany; contact: fabian.conrad@tu-darmstadt.de

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Abstract —The combination of a 2D digital image correlation (DIC) system based on a graphics processing unit (GPU) with a CoaXPress 2.0 camera acquiring up to 3 GB/s of image data enables a real-time evaluation of both, integral strain for strain-control and full-field DIC on images selected automatically in real-time. This combination enables the use of one single sensor for strain-controlled crack growth and crack characterization. The full-field displacement is compared to a finite-element model (FEM) using the crack contour measured by the DIC system.

Keywords — high-speed DIC, in-situ measurement, strain-control, finite-element model

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Introduction In crack growth experiments, mechanical extensometers are commonly used to secure strain-controlled conditions, alternating-current-potential drop (ACPD) monitors to measure the crack growth rate according to Paris equation and full-field DIC systems for measuring crack contour as well as Mode I and Mode II crack-flank displacements. In principle, all of these quantities are measurable by the DIC method, but the measurement rate is too slow for strain-control according to ASTM E 606 [1]. In addition, the huge amount of image data of more than 100.000 cycles in high cycle fatigue experiments (HCF) is difficult to handle without real-time evaluation. This article presents first results of a GPU-accelerated DIC system [2] which circumvents all these problems.

Methods Figure 1 (left) shows the DIC sensor head in front of the biaxal testing machine with a cruciform specimen with axes A and B for biaxial crack growth. In 'strain-control' mode for crack growth, integral strain along both axes is calculated from four regions of interest (ROI) and passed as

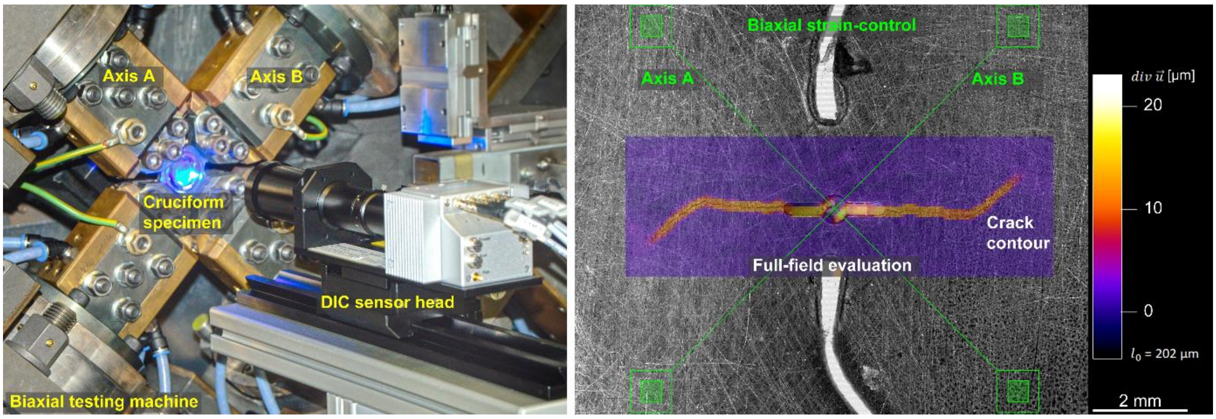

Figure 1: Left: DIC sensor head in front of the biaxial testing machine equipped with a cruciform specimen. Right: camera image of specimen surface superimposed by the four ROIs for biaxial strain-control and full-field evaluation.

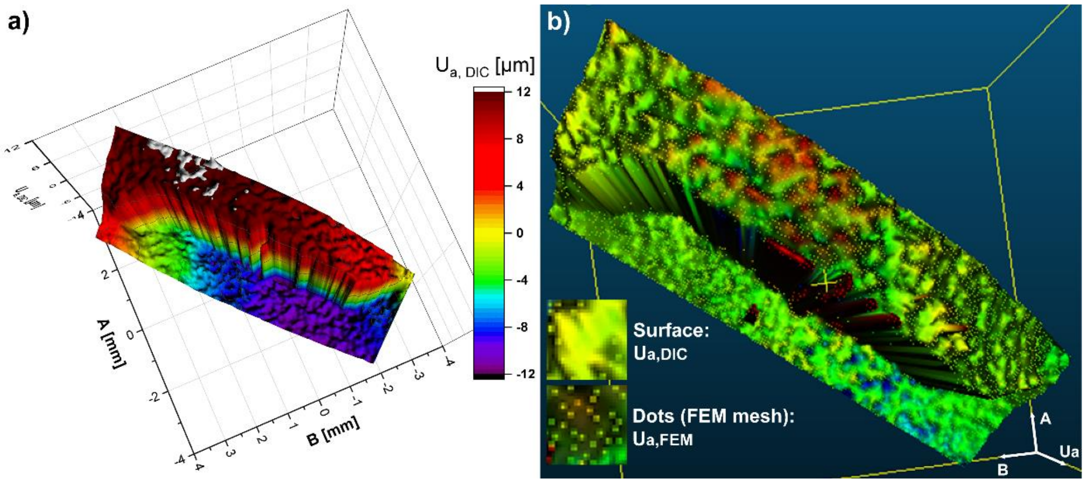

Figure 2: Comparison between biaxial full-field DIC measurement and fracture mechanical FEM model of the cruciform specimen. a) 3D view of displacement Ua,DIC (A,B) in A-direction over axes A, B. b) Displacements Ua,DIC from a) and Ua,FEM calculated using the DIC crack contour. The color shows the difference $\Delta U_a = U_{a,DIC} - U_{a,FEM}$.

analogue signal to standard PID controllers as described in [2]. In ‘full-field’ mode, up to 40,000 ROIs are evaluated to measure crack contour and crack-flank displacement. Both cases are shown on the right side of Figure 1: A camera image is superimposed by the four ROIs for biaxial strain-control with a base length of 10 mm and by a full-field evaluation of a biaxially grown crack. The crack contour is visualized by the divergence $div\,\vec{u}$ of local displacement $\vec{u}$ (base length $l_0 = 0.2$ mm) as a direction-independent measure for local strain [3]. Both modes work on natural metal surfaces without markers such as speckle paint.

Results In full-field mode, a resolution of 5 µm/pixel was required for a good agreement between full-field crack evaluation, ACPD and FEM [3]. Therefore, a base length of $l_0 = 10$ mm under 45 degrees corresponds to a minimum of approximately 1500 lines per image. Using a camera based on the CoaXPress 2.0 standard, images with a resolution of 1600 x 1540 pixel are acquired with 850 Hz. As the GPU correlation rate is up to 74 kHz, the camera frame rate still limits the measurement rate in strain-control mode. However, this frame rate of 850 Hz allowed robust biaxial strain-control for cycle frequencies up to 5 Hz at cracks with a length of 7 mm acting as a strong perturbation. For smaller fields-of-views, e.g. for uniaxial control, strain-control is possible with measurement rates up to 2 kHz.

As shown in Figure 2, full-field DIC allows experimental validation of fracture mechanical FE models. Figure 2 a) shows a 3D view of the measured displacement component $U_{a,DIC}$ measured under a load of 35 kN on axis A and 17.5 kN on axis B of the testing machine. The discontinuity of about 20 µm is due to the opening of the crack. To verify the material model, the crack contour measured by the divergence $div\,\vec{u}$ (see Figure 1) was meshed for a 2D-planar-shell-model in Abaqus [3]. In Figure 2b, the values $U_{a,FEM}$ at the knots of the mesh are drawn as dots together with the $U_{a,DIC}$ surface from Figure 2a). The color of the DIC surface shows the difference $\Delta U_a = U_{a,DIC} - U_{a,FEM}$ between model and measurement. In red areas, ΔU_a is larger than 0.5 µm, blue areas range below -0.5 µm. The standard deviation of $\Delta U_a(A, B)$ is 0.4 µm, i.e. in the range of full-field DIC noise. The results show that DIC is able increase information from crack growth experiments although the setup is simplified.

References

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