Non-Contact 3D Deformation and Strain Measurements using Digital Image Correlation for Biomedical Applications

T. RUSIN[1], **C. WEISSMAN**[2]

Key words: *DIC, Strain, Deformation, Multicamera-DIC, Micro-DIC*

In recent years, many material testing laboratories have employed non-contact optical imaging techniques instead of standard strain gauges. In some applications, standard strain gauges can not be used for various reasons such as fragile or thin materials or the need to obtain a full field measurement of the object without the need to mount numerous gauges. The most popular optical method is 3D Digital Image Correlation (DIC) which uses stereoscopic imaging and analysis to obtain strain measurements results over the test sample. The 3D DIC technique uses two cameras which are aligned to the object surface at appropriate angles for the field of view required. A calibration target is then used to enable the calculation and reconstruction of the 3D space from each of the 2D views of the two cameras. In order to make DIC measurements it is necessary to have a stochastic pattern (random dots) on the sample so that a correlation algorithm can track the displacement or motion of the surface as it is deformed. Using this information allows for the calculation the 3D deformation and resultant strain field from sequential images of the object.

The Digital Image Correlation technique was used for the first time in 1980s in a single camera setup for measuring surface displacement providing in-plane 2D measurements of strain [1, 2]. The method was successfully used for measurements of the mechanical properties of biological tissues [3]. Biomaterial research has several unique challenges for the measurement of deformation and strain. In particular, specimens are typically small and delicate which makes them difficult or impossible to measure using standard strain gauges. Furthermore, most organs and tissues are non-uniform in shape which makes data analysis of stress/strain relationship problematic. Thus, the DIC technique is ideally suited for biomechanical measurements thanks to the ability of the method to obtain true full-field, non-contact and three-dimensional information of displacements and strains on biomedical materials and components in both the macro and microscale. In addition, DIC can be used for other measurements including; tension, compression, torsion, bending and combined loading, peel, creep, relaxation and more on a wide range of biomaterials. The recent introduction of Stereo microscopic DIC opens new avenues of research for micromechanical measurements of ultra-small and sensitive materials [4]. The advantage of both high measurement sensitivity and accuracy [5] enables the measurement of deformation induced not only by direct mechanical loading but also by thermal loading, changes of humidity, and physiological factors.

The DIC technique not only yields measurement results quickly, but it also provides the researcher with these results as a comprehensive data set. Such data is necessary to fully understand complex materials and structures including those with anisotropic characteristics, as well as the ability to compare the experimental results with computational (i.e. FEA) models. Biomaterial deformation and strain measurements often face unique challenges such as; components with complex geometries, interactions of materials with dissimilar compositions (i.e. bone with implants, skin with sutures, etc.), and structures that have multivariable dependencies. Furthermore, modern DIC systems provide the user with numerous tools to assist with the analysis and presentation of the results such as; report generation of measurements independent of the application and system configuration, correlation of measurement results with numerical simulations via standardized data exchange formats, validation of material behaviour with complex structures, and compatibility with 3D printing. One of the latest and most useful developments for the DIC technique is the ability to

[1]Tomasz Rusin, Dantec Dynamics GmbH, Ulm, Germany, e-mail: trn@dantecdynamics.com

[2]Cliff Weissman, Dantec Dynamics Inc. Holtsville, NY, e-mail: cwn@dantecdynamics.com

use more then 2 cameras in the measurement system. The multi-camera DIC solution provides the unique ability to acquire deformation and strain information all around a 3D object as well as very large objects and those with multifaceted and complex geometries in one single measurement step. Multi-camera DIC configurations achieves a single coordinate system by arranging the individual cameras in a strategic array such that their fields of view overlaps in pairs. The multi-camera setup enables measurement of objects with high radii of curvature, around corners, cylindrical, cubic, and spherical geometries can be evaluated. The advantages of the multi-camera DIC solution over standard 3D DIC systems includes; no need to stitch measurement results from non-simultaneously acquired data sets, increased accuracy on large or obscured areas observed simultaneously by several cameras, no coordinate transformations required, easy calibration of all cameras simultaneously, flexible setup capable of accommodating various test object geometry.

Multi-camera systems provide significant advantages to biomechanical research applications thanks to the ability to determine the real stress results during mechanical test of specimens with arbitrary shapes, sizes, and compositions. Such objects like bones, spine and skull can be measured at 360 degrees using an 8 camera system. An example of a compression test of a cylinder is shown below in Fig. 1. A flat specimen example is shown on the right which used a 4 camera setup. This type of setup can be very useful for real stress measurements of flat specimens such as skin.

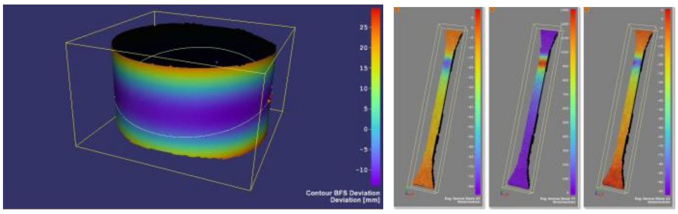

Fig. 1. Full-field evaluation of a cylindrical object with an 8 camera DIC System (left image). On the right - tensile test of flat specimen with use of 4 camera system in bi-plane configuration. Strain distribution in X, Y and Z (thickness) direction (right 3 images).

Stereo Microscope 3D Digital Image Correlation opens new possibilities for very small and delicate specimens. Standard DIC systems are not able to measure specimens smaller than about 10mm because both objectives in stereoscopic setup have limited depth of field. This limitation can be overcome using stereo microscope. Micro DIC enables measurements of small objects such as; dental implants, trabecular bone structure, and rings of a stent (Fig.2).

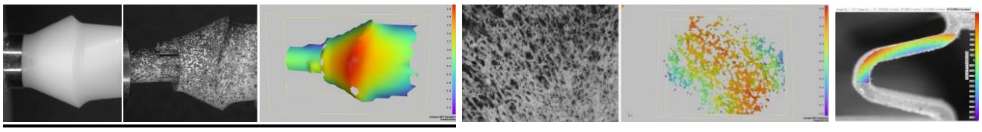

Fig. 2. Micro DIC results on 3 different small scale objects. First three images: dental implant, implant with stochastic (speckle) pattern, correlated result (best fit plane). Image 4 and 5 from the left show trabecular bone structure (native structure image and correlated). It is possible to correlate image on single trabeculae. Last image on the right presents sinusoidal ring of a stent (best fit plane).

References

[1] PETERS W. H., RANSON W. F., *OPT. ENG.* 1982, 21, 213.

[2] CHU T. C., RANSON W. F., SUTTON M. A., PETERS W. H., Exp. Mech. 1985, 25, 232.

[3] D. ZHANG, D. D. AROLA, J. Biomed. Opt. 2004, 9, 691.

[4] RUSIN T. and KOPERNIK M., *Characterization of Biocompatible Materials Using Stereo Microscope 3D Digital Image Correlation*, Advanced Engineering Materials 2016, 18, No. 9 © 2016

[5] SIEBERT T., BECKER T., SPILTTHOF V, NEUMANN I. and KRUPKA R.. *Error Estimations in Digital Image Correlation Technique*. Applied Mechanics and Materials Vols. 7-8 (2007) pp 265-270.