Comparison of Finite Element Analysis and Instron's 2D Digital Image Correlation

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Introduction:

Finite element analysis (FEA) has become an increasingly important tool in the medical device industry to analyze stress profiles of components under various loading scenarios. FEA software is able to create stress profiles by meshing the component into simpler subcomponents, creating a set of elemental equations for each subcomponent, and then recombining the equations in order to produce a full solution. Despite its technical accuracy, there are certainly discrepancies between the FEA results and those found in actual testing. For example, inconsistencies in component machining, material variations, and environmental testing conditions can all affect results. For this reason, there has been a recent push for real-world comparison of data found through FEA.

As of now, an accepted method for making this comparison has been through the use of strain gauges. In fact, ASTM F04 released a new standard in March of 2016, ASTM F3161-16, which specifically discusses the testing of knee femoral components. The standard ran independent studies that found FEA and strain gauge analysis to correlate within 10%. However, strain gauges (Figure 1) can be difficult to setup, with significant time and experience required to properly apply the gauges to a component. In addition to this, strain gauges are limited in recording component deformation to the area that the strain gauge covers. In contrast, FEA produces a full-field strain map of a component's deformation.

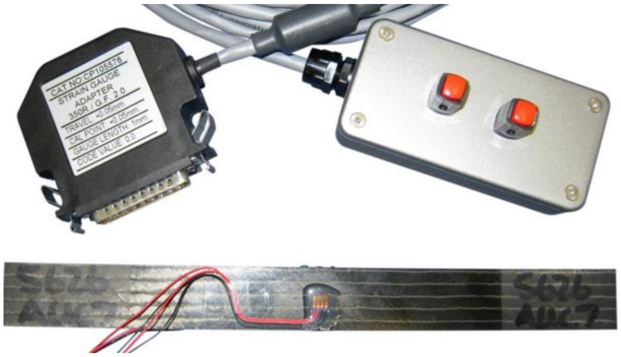

Figure 1: Example of a Strain Gauged Specimen

Given the limitations of strain gauges, many laboratories have shifted to utilizing Digital Image Correlation (DIC) software to produce a full-field strain map over the entire body of a component. In 2014, Instron developed the first fully-integrated materials testing DIC solution. Instron's 2D DIC software utilizes a video extensometer to map the strain fields on a randomly speckled specimen under loading. The image collection rate is synced with the system's load and displacement data so that every image is seamlessly correlated to force data. Within the software, virtual strain maps are created to visually compare with the results from FEA. Also, post-processing can be done to add virtual strain gauges and virtual extensometers to quantitatively measure deformation.

Experimental Design:

To run a comparative test between FEA and DIC, a custom component was designed and machined, with the purpose of representing a generic scaled spinal fracture fixation plate. The plates were made out of 6061 aluminum and CNC machined by Protolabs®. A total of 5 specimens were created.

The specimens were then spray painted white and speckled with black spray paint (Figure 2). Speckling a specimens with a random pattern is required to track strain on the specimen.

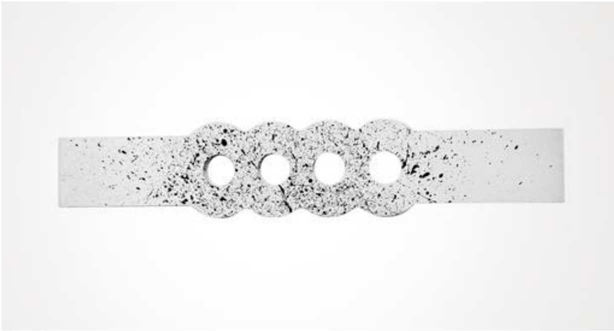

Figure 2: Speckled Specimen Pre-test

DIC software measures incremental movements in speckle locations in order to create a full-field strain map.

Testing was performed on all 5 components using mechanical wedge action grips with serrated faces. An Advanced Video Extensometer equipped with a 16mm lens was used for testing. Each component was tested in tension to failure, reaching a peak load of nearly 28,000 Newtons. Following testing, post-processing was completed in Instron's DIC software.

Using the physical modeling software embedded in SOLIDWORKS®, stress maps of the material were created, recreating the conditions experienced under typical axial loading, at the tested load.

Results:

Overall, the visual representation of full-field strain acquired from DIC analysis (Figure 3) directly correlated with the visual full-field stress map produced in SOLIDWORKS' FEA package (Figure 4).

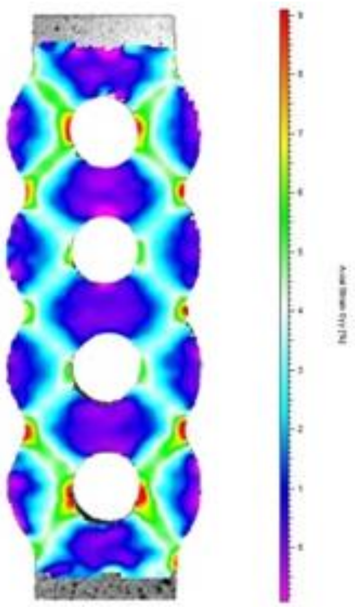

Figure 3: Strain Mapping from Instron's DIC Analysis

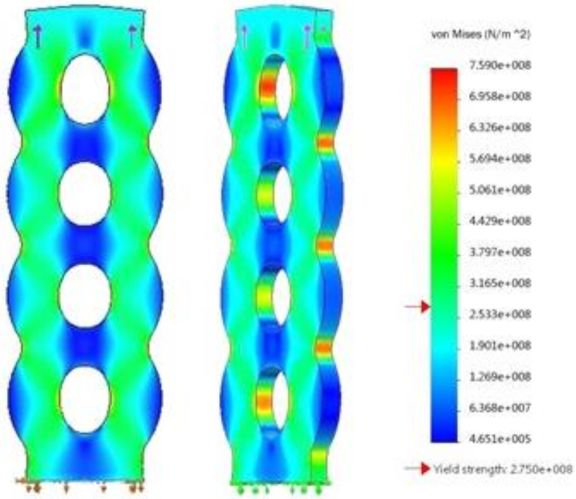

Figure 4: Stress Mapping from SolidWorks Analysis

Discussion:

SOLIDWORKS' FEA package has limitations compared to other FEA software packages and is only capable of producing stress mapping. In comparison, Instron's DIC software produces strain mapping. With this said, stress and strain maps are directly correlated and in most cases, will align considering straining is the direct cause of stress in specimens. In future testing of this concept, a more robust FEA solution would likely to be used. Both maps were found at a load of 25,000 Newtons, after specimen yielding, in order to provide the most conclusive results.

After post-processing, the resulting mappings were shown to have comparable stress/strain concentrations as in Figure 3 and Figure 4. Uniform patterns were found on both analyses, driven by the specimen geometry. It is interesting to note that the highest stress concentrations seen on the 2D mapping of DIC were only apparent when looking at the 3D mapping done in SOLIDWORKS. While 3D DIC solutions are commercially available, these solutions are not fully integrated with the materials testing system and create additional variables associated with set-up and calibration.

Conclusion:

The testing done was exploratory in nature, to identify the degree to which Instron's DIC could conform to computer modeling software. This initial testing has proven the concept, and future testing should be done to further investigate the capabilities of DIC with more advanced FEA software.