Effects of Notch Misalignment and Tip Radius on Displacement Field in V-notch Rail Shear Test as Determined by Photogrammetry.

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EFFECTS OF NOTCH MISALIGNMENT AND TIP RADIUS ON DISPLACEMENT FIELD IN V-NOTCH RAIL SHEAR TEST AS DETERMINED BY PHOTOGRAMMETRY

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ABSTRACT

Evolution of the 3D strain field during ASTM-D-7078 v-notch rail shear tests on 8-ply quasi-isotropic carbon fiber/epoxy laminates was determined by optical photogrammetry using an ARAMIS system. Specimens having non-optimal geometry and minor discrepancies in dimensional tolerances were shown to display non-symmetry and/or stress concentration in the vicinity of the notch relative to a specimen meeting the requirements of the standard, but resulting shear strength and modulus values remained within acceptable bounds of standard deviation. Based on these results it is suggested that a parametric study combining analytical methods and experiment may provide rationale to increase the tolerances on some specimen dimensions. This could reduce machining costs, increase the proportion of acceptable results, and enable a wider adoption of the test method.

1. INTRODUCTION

The v-notch rail shear test has become a preferred method for the determination of in-plane shear properties of laminates and generally provides lower coefficients of variation relative to other test methods. The relatively small size and simple specimen geometry allows a reasonable machining cost and precise strain measurement using specially designed gages. Machining of the notch tip may be achieved precisely, but requires some degree of care or specialized tooling. Reports of difficulty in meeting the dimensional tolerances of the test standard were mentioned in a recent ASTM D30 committee meeting presentation[1] and questions were raised regarding the possibility of widening the values.

1.1 Existing Project Data

The present work was performed during the qualification tests for JSC flight hardware to verify material properties of AS4/3501-6 carbon fiber/epoxy composite laminate panels in 2008. An initial batch of specimens was received with dimensions that did not meet the requirements of the standard and the time required to deliver a corrected batch was unknown. In order to utilize the specimens, obtain property verification within a success oriented schedule, reduce risk in further assembly of sandwich panels, and utilize the ARAMIS system capability in our test laboratory, it was decided to proceed with testing and determine the strain field to evaluate if there was a significant effect on gage section properties due to any dimensional discrepancy.

1.2 Relevance to Community Needs

As described above, a desire to understand the effect of specimen dimensions in the subject test method was recently expressed and inspired the recovery and publication of data produced previously in order to provide available experimental data and contribute to the understanding of the response of non-standard specimens. Presentation of the strain field video clips is expected to be interesting and provide results that may be directly compared to FEA models predicting behavior in a suggested parametric study with systematic variation of dimensions.

1.3 Available Literature

The effect of dimensions on displacement field for the similar iosipescu test configuration was reported by Budiman et al for V and U-notch specimens[2] and experimentally by Ho et al. using moiré intereferometry[3]. A detailed elasticity solution and explanation of St. Venant's Effect for the same test is provided by Whitney[4].

2. EXPERIMENTATION

2.1 Test Method

Specimens of AS4/3501-6 unidirectional tape 8-ply quasi-isotropic laminates having the ply orientations of [0/90/+45/-45]s with outer scrim plys of 108GL/3501-6 E-glass fabric/epoxy were fabricated according to manufacturer recommended cure cycle and bagging configuration. Machining of notches was achieved using a diamond abrasive saw. Specimen V-notches were reported to be slightly misaligned and tip radii non-optimal with some wider than immediately adjacent V edges. Appropriate bonded resistance strain gages were applied as recommended in the gage section and paint speckle patterns sprayed on the opposite surface. Shear test was performed to failure according to ASTM-D-7078 using an MTS Insight load frame. One specimens having dimensions meeting the requirements of the standard was tested as a control. Additional specimens meeting the required dimensional tolerance were tested using only strain gages.

2.1.1 Standard Specimen Dimensions

Figure 1 shows the standard dimensions for the V-notch specimen with tolerance on the notch location relative to the edge specified to be within +/- 0.3mm. Angles are specified to be within +/- 0.5 degrees and the tip radius should be 1.30mm +/-0.3mm.

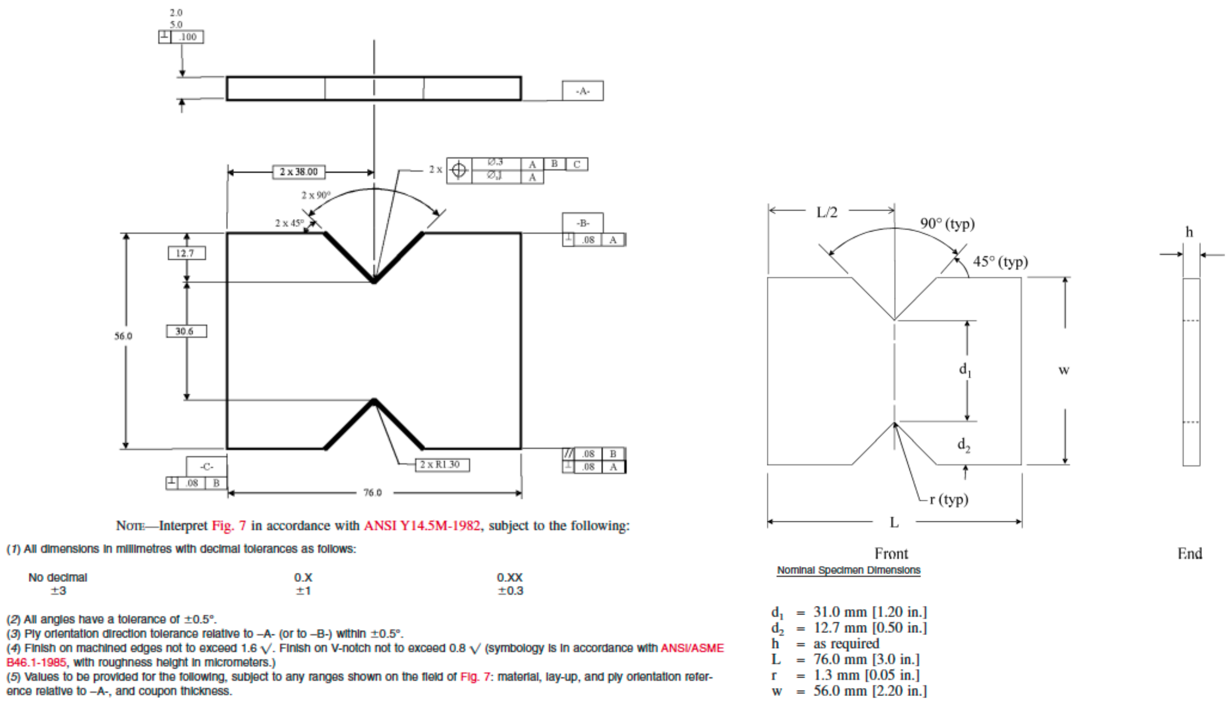


Figure 1 ASTM-D-7078 V-Notch Rail Shear Specimen Dimensions and Nomenclature.

2.1.2 Test Specimen Dimensions

Actual Pre-test specimen dimensions are illustrated in Figure 2. Visible notch misalignment >1mm and tip radius variations from sharp (<0.5mm) to large (>3mm) are evident. Accurate original dimensions were unavailable due to the loss of specimens and test records during the two years after the tests were performed and the flight project completed. Attempts to obtain measurements from the ARAMIS image files resulted in large errors (>1mm).

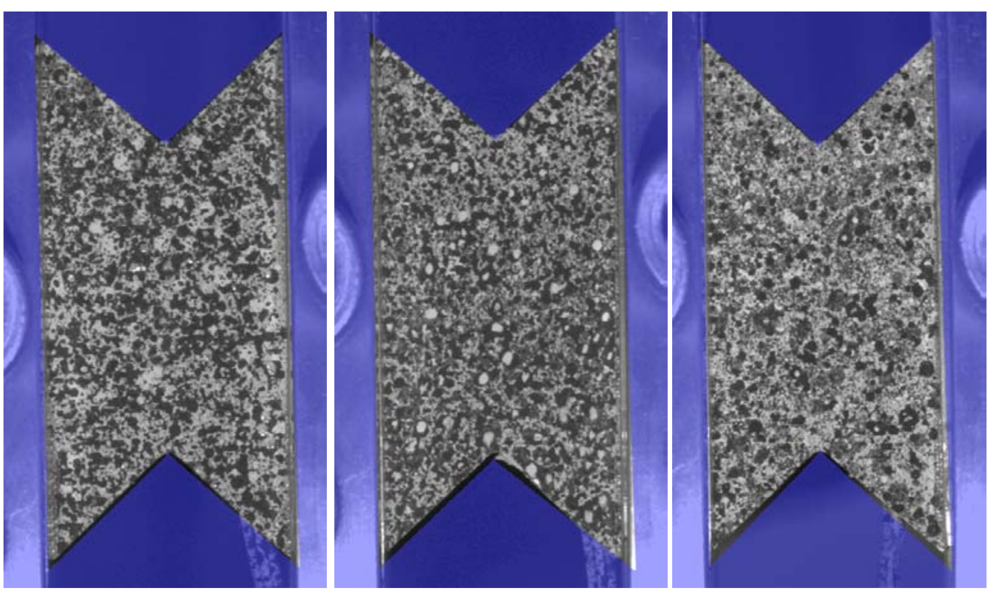
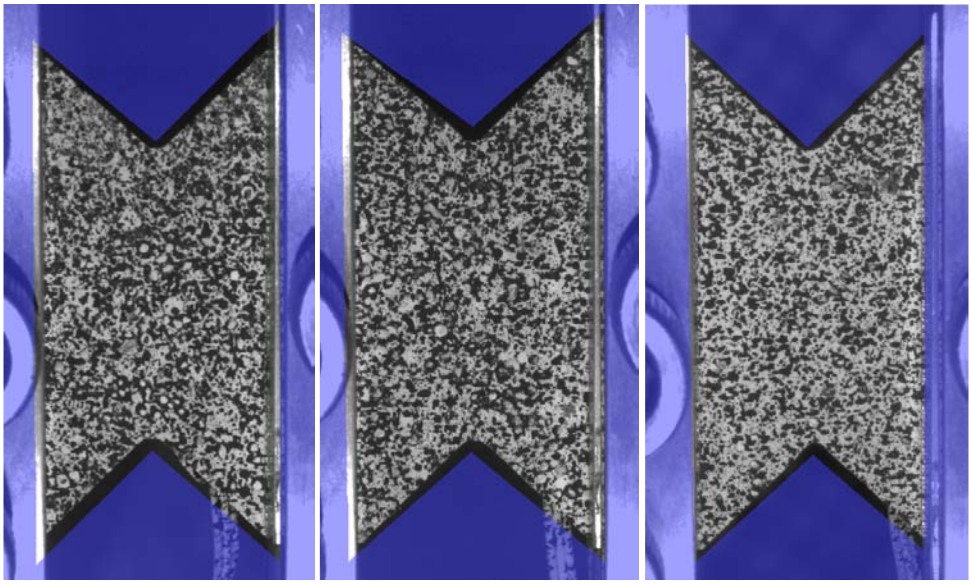


Figure 2a) ABB-01 2b) ABB-02 2c) ABB-04



2d) ABB-05 2e) ABB-07 2f) ABB-10

Figure 2a)-2f) Pre-Test Specimen Images Showing Notch Alignment and Tip Radii.

2.1.3 Mechanical Test Fixture

The rail test fixture with strain gage on the front side is shown in Figure 3 while the speckle pattern is present on the back (Figure 4). This provides simultaneous measurement and correlation of strain using both methods.

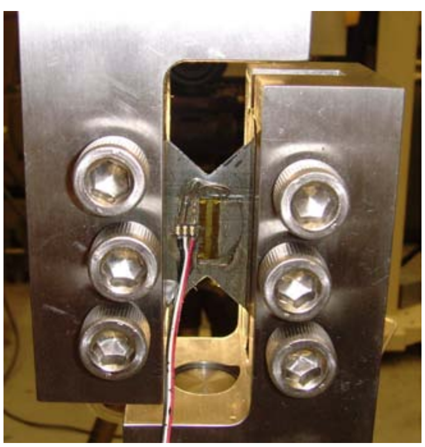


Figure 3. Specimen Strain Gage Side

Figure 4. Speckle Pattern Side

2.2 Photogrammetry

During all stages of specimen loading optical images were recorded at appropriate rates from dual cameras focused on the entire surface area of the specimen exposed between the test fixture grips. Camera position relative to the specimen is shown in Figure 5. Global displacements were obtained using the ARAMIS system software that calculates the values utilizing relative changes in position of the random speckle pattern and accepted algorithms. A contour pattern with color coded displacement values and overlaid vector fields illustrating direction were produced as a function of time during the test using both an auto-scaling feature and a fixed scale. Shear strain values were determined at several fixed points along the centerline between the notch tips as a function of time and compared with strain gage readings. Maximum displacements and corresponding locations were determined immediately prior to specimen failure and contour plots from those final frames are presented below.

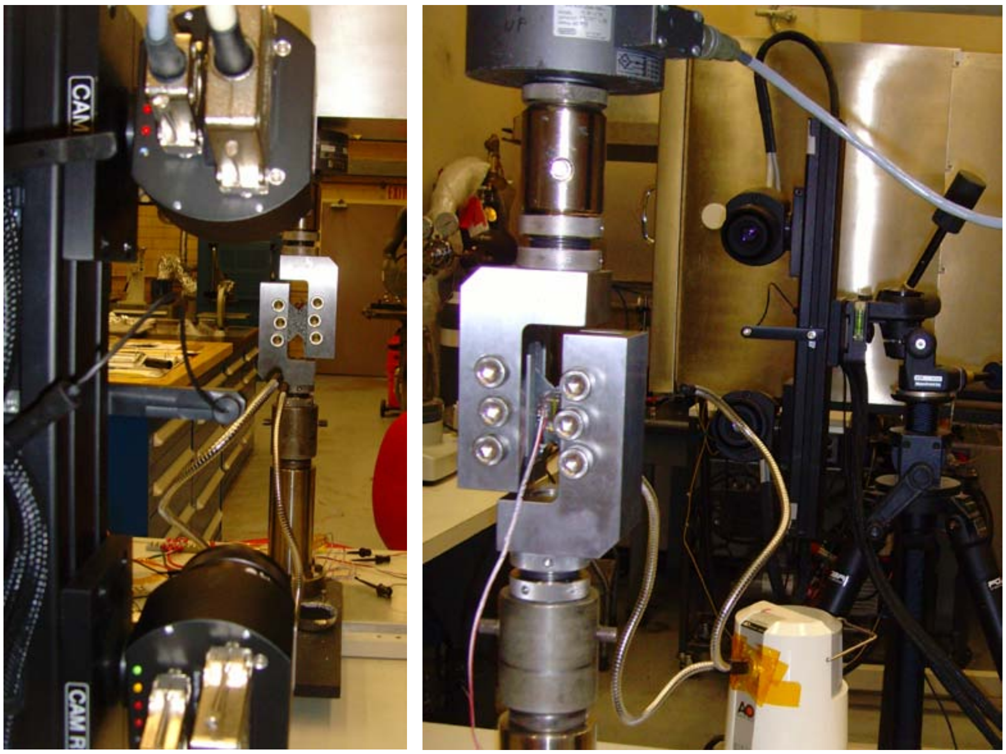


Figure 5. Dual Camera Position Showing Vertical Alignment (front and back views)

3. RESULTS

3.1 Photogrammetry

The measured surface strain fields just prior to break and stage points are illustrated in Figures 6 through 11. The strain scales vary for each specimen as shown in the color spectrum on the right of each image. The percent strain for each stage point along the gage section, as a function of time, is shown in the plots on the right of each figure. The timing of the strain data may be correlated with the load/stress data at a later date.

3.2 Mechanical Properties

The mechanical properties are shown in Figure 12 with the strain gage response and stress response for specimens ABB-01, 02, 04, 05, 10. Additional data from specimens having dimensions that are acceptable per the standard are shown in Table X.

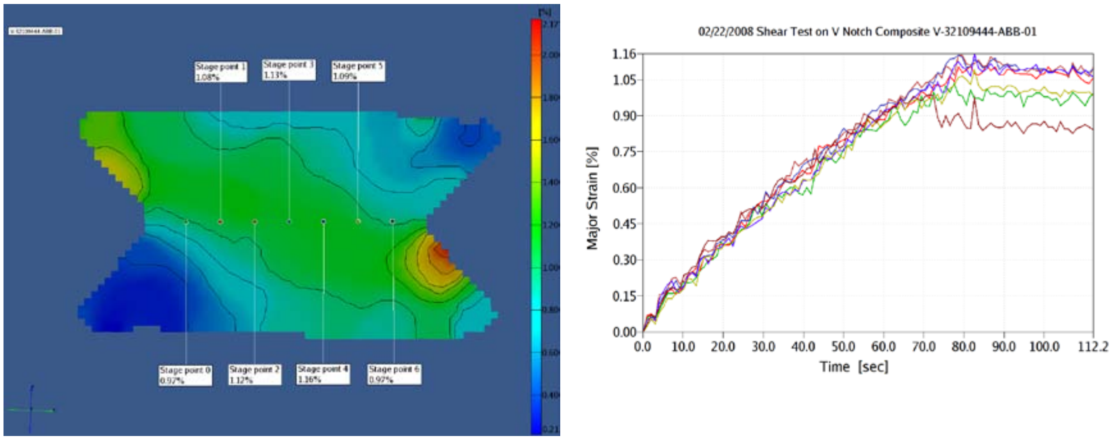


Figure 6. Sample ABB-01: 3D Major Strain Field at Break and Major Strain vs Time at Stage Points 0-6.

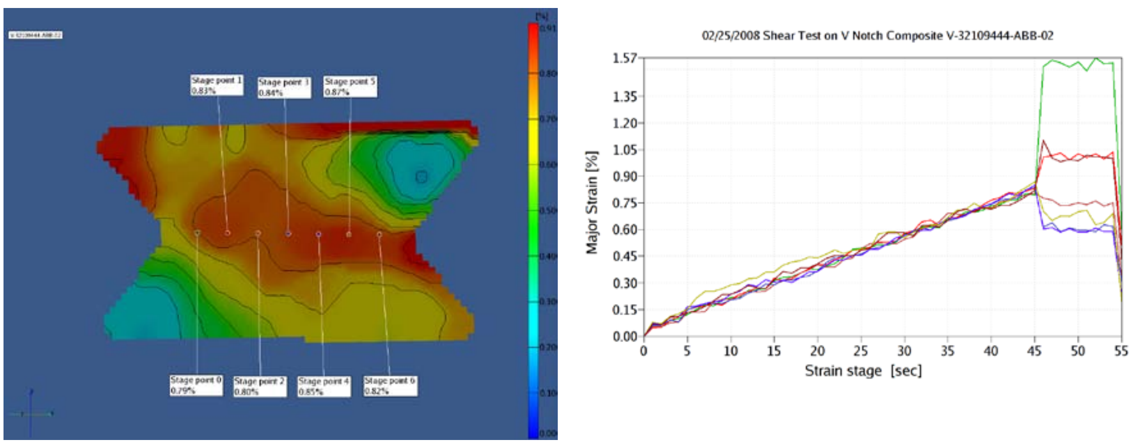


Figure 7. Sample ABB-02: 3D Major Strain Field at Break and Major Strain vs Time at Stage Points 0-6.

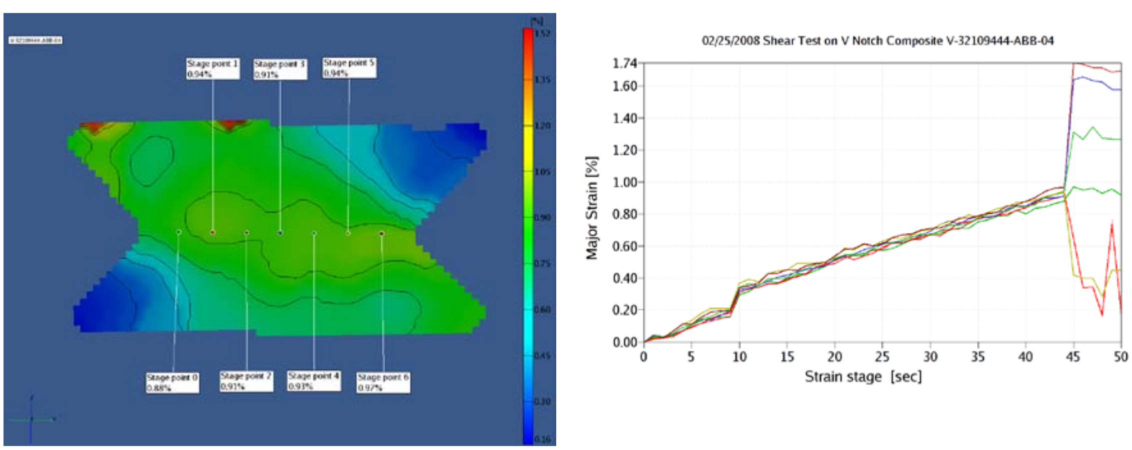


Figure 8. Sample ABB-04: 3D Major Strain Field at Break and Major Strain vs Time at Stage Points 0-6.

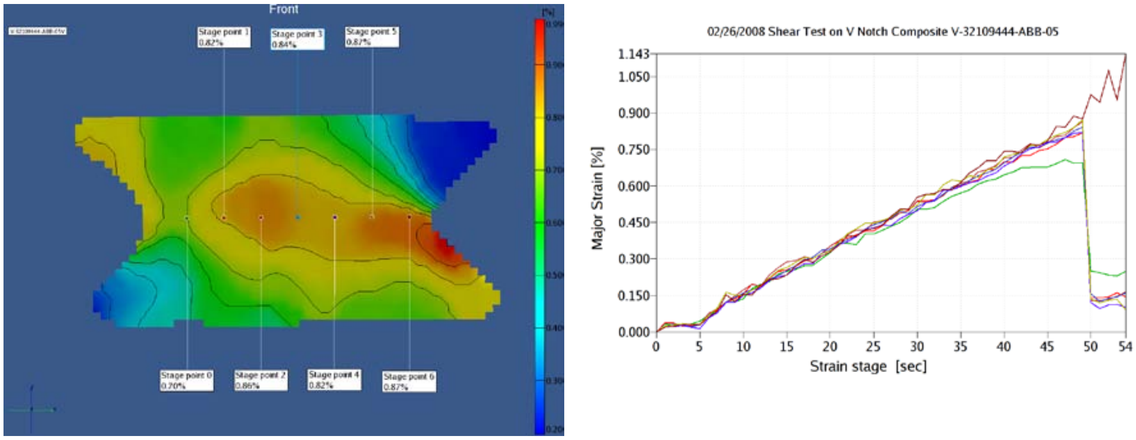


Figure 9. Sample ABB-05: 3D Major Strain Field at Break and Major Strain vs Time at Stage Points 0-6.

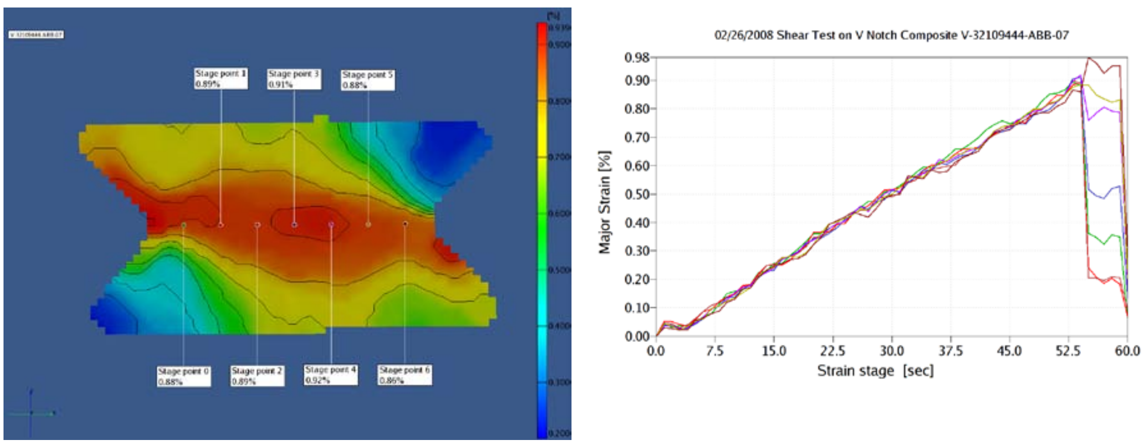


Figure 10. Sample ABB-7: 3D Major Strain Field at Break and Major Strain vs Time at Stage Points 0-6.

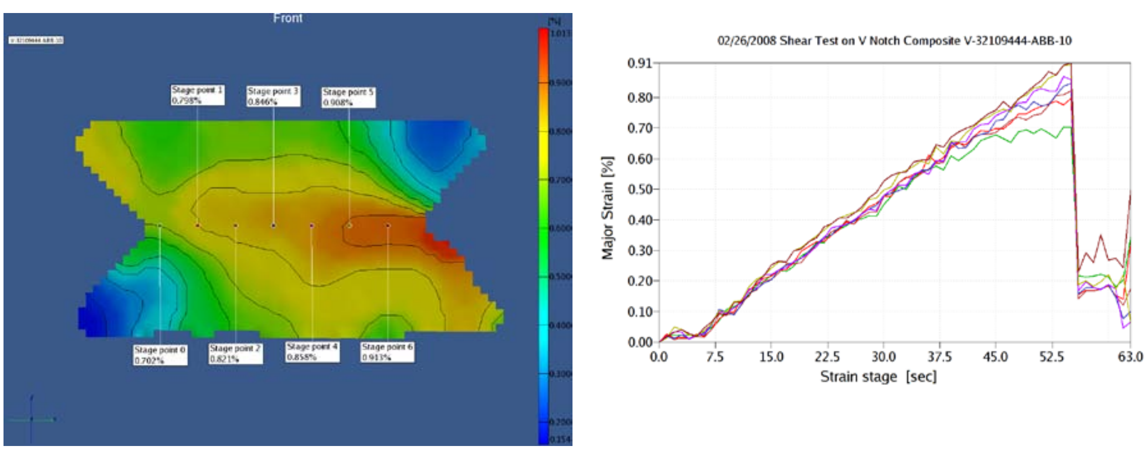


Figure 11. Sample ABB-10: 3D Major Strain Field at Break and Major Strain vs Time at Stage Points 0-6.

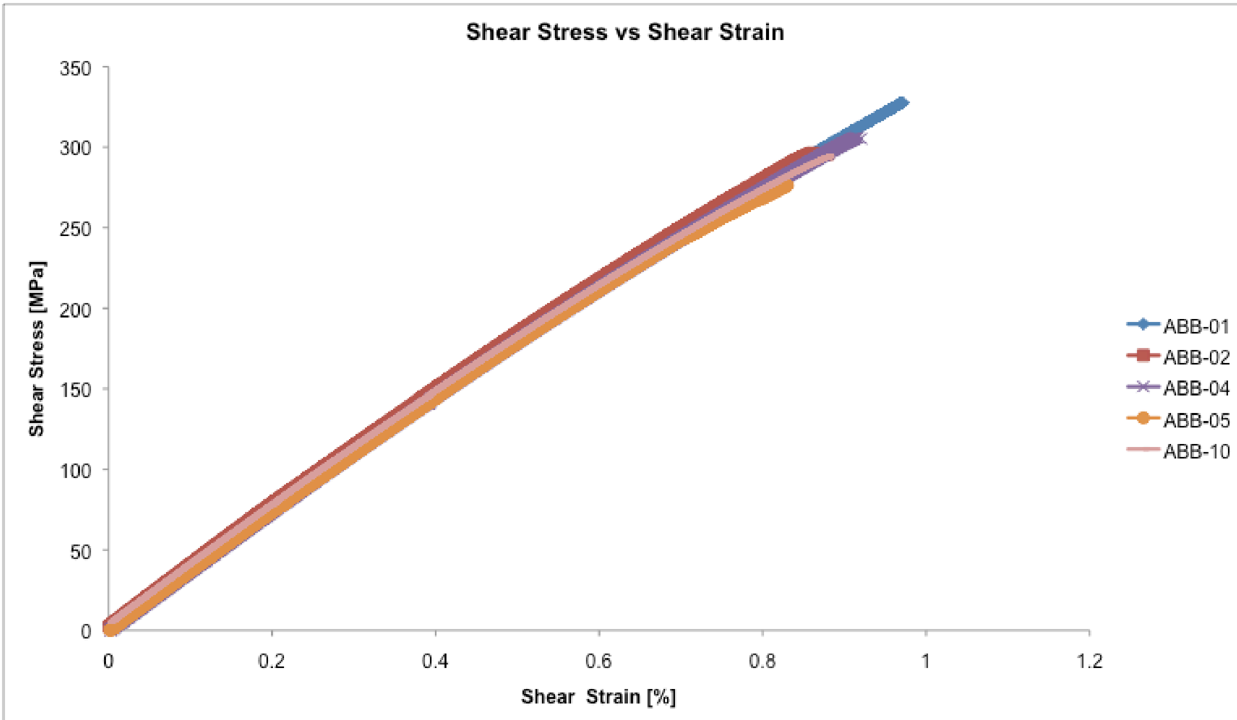


Figure 12 Shear Stress vs Shear Strain for Specimens

Table 2 Dimensions and Resultant Properties of Specimens

Specimen #	ABB-01	ABB-02	ABB-04	ABB-05	ABB-07	ABB-10	SD	%CoV
Width (mm)	33.02	33.02	33.02	33.02	33.02	33.02	0.00	0
Thickness (mm)	1.17	1.17	1.17	1.17	1.17	1.17	0.00	0
Peak Load (N)	13298.62	11428.02	11799.82	10655.46	11908.46	11356.99	881.08	7.50
Peak Stress (MPa)	344.48	296.02	305.65	276.01	308.47	294.18	22.82	7.50
Strain At Break (%)	0.97	0.86	0.92	0.83	0.93	0.88	0.05	5.56
Modulus (GPa)	547.20	555.14	543.12	540.42	541.87	541.49	5.55	1.02

4. CONCLUSIONS

The gross dimensional deviations from the standard evident in misaligned notch centers and tip radii resulted in some non-symmetry in the overall surface strain field of the specimens, however the gage section directly between the notches retained a relatively uniform shear strain. The ultimate shear strength and modulus values were found to be consistent with coefficient of variation of 7.5% and 1.02% respectively. Likewise, the strain to break values were within a 5.56% CoV and the strain gage values agree well with the maximum strains measured by the photogrammetry (ARAMIS) technique.

4.1 Further Work

This initial study was performed with the intention to provide rationale for accepting test values for specimens that did not meet the dimensional requirements of the standard and to determine if significant stress concentrations or lower strength and modulus values result from dimensional discrepancies. It is suggested that a simple stress analysis with a systematic parametric variation of dimensions could be combined with additional experimental verification of a fraction of conditions to provide sufficient rational to widen the acceptable tolerance limit of the ASTM-D-7078 specimen.

5. REFERENCES

1. Adams, D., presentation to ASTM D30 committee, Kansas City, MO, Winter 2010.
2. Budiman, H. T. et al, "Effect of Specimen Length and Notch Geometries on the Performance of Notched Shear Specimens", AIAA-92-2297.
3. Ho, H. et al. "Effect of Specimen Length on the Performance of Iosipescu Composite Shear Specimens" *Science and Engineering of Composite Materials* 3 (1994) pp 1-10.
4. Whitney, J. M. "St. Venant Effect in the Iosipescu Shear Specimen" *Proceedings of the American Society of Composites*, 1 1995 pp 845-852.