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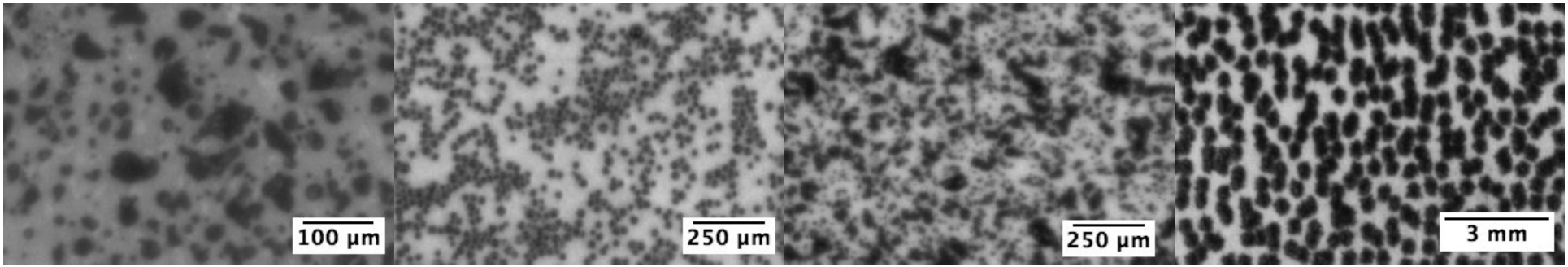

A Speckle Patterning Study For Laboratory-Scale DIC Experiments

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iDICs Conference 2016

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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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Motivation: "Good" Speckle Patterns

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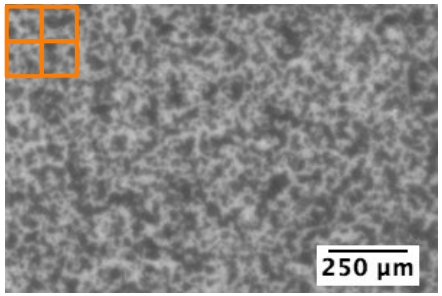
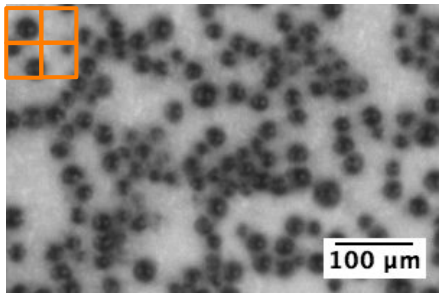
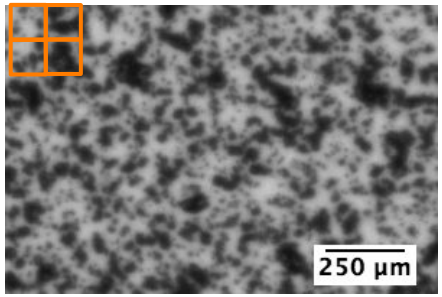
How can we quantify the appropriateness of speckle patterns to reduce the time required to generate and select a pattern for a given application?



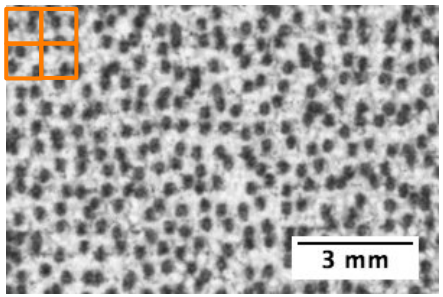
Airbrush



Carbon Powder



Toner Powder



UV-Printed Computer-Generated Pattern

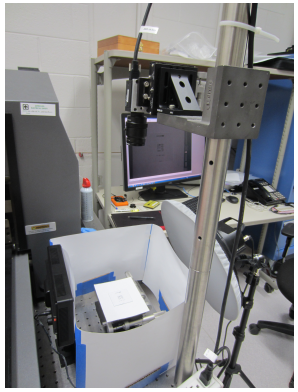
Orange Boxes Represent Four 35-pixel Subsets

Metrics for a "Good" Speckle Pattern

- Random speckles with even coverage over pattern
- Speckle Size:
  - Minimum 3-5-pixels to prevent aliasing
  - Maximum: Not "too large" - as to require large subset sizes (Goal here: less than 15-pixels)
- Speckle contrast
  - Desired: 150-180 counts for an 8-bit camera
  - Minimum of 100 counts for an 8-bit camera
- Pattern Coverage of ~50%
- Low error in sub-pixel displacement / strain measurement: pattern has the measurement resolution required for the application

Methodology

Camera Setup and Resolution



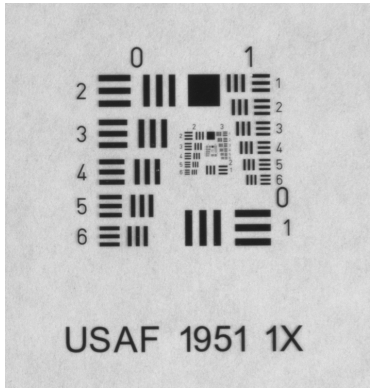
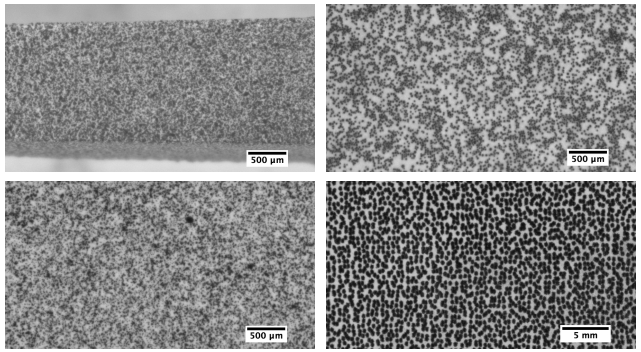


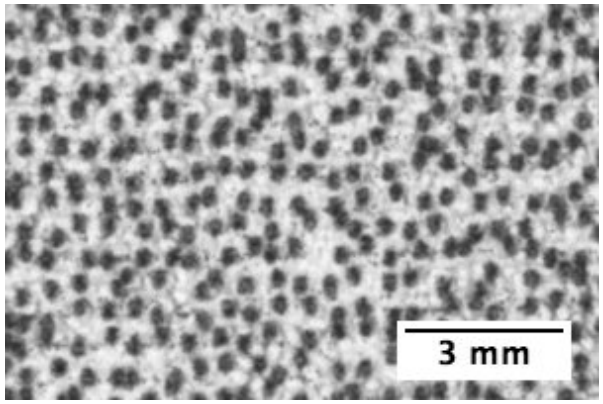
Image USAF Resolution Target to Measure Image Resolution for Each Setup

Speckle Pattern Generation



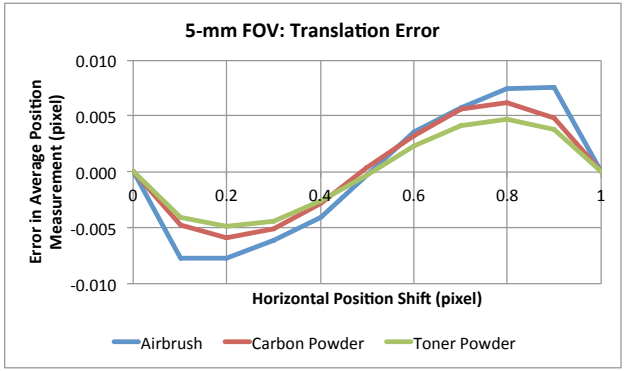
(upper left) Airbrush; (upper right) Carbon Powder; (lower left) Toner Powder; and (lower right) UV-printed Pattern for a Large FOV

Speckle Pattern Evaluation



Quantify Speckle Size, Coverage, and Contrast

Speckle Pattern Translation



Numerically Shift Images and Calculate Error in Determining Image Shift using DIC

Speckling Techniques Under Consideration

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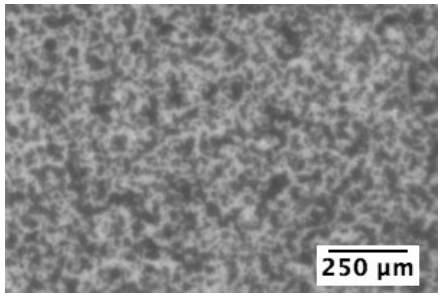
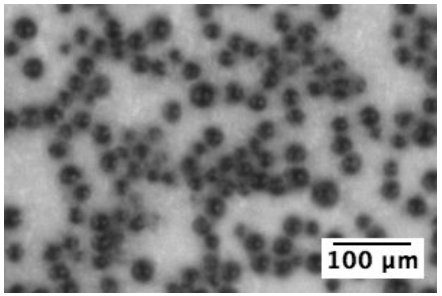
Airbrush



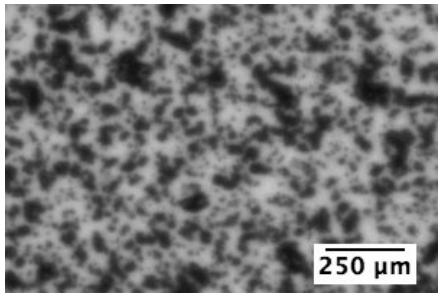
Golden Artist High Flow Paint (Phthalo Blue), Diluted with Water 3:1 ratio, Applied with a Harder & Steenbeck Infinity CR Plus Airbrush with 0.15-mm Nozzle onto White SEM Primer Spray Paint

Carbon Powder



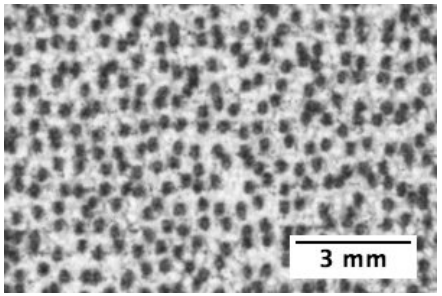
20-50 µm Carbon Powder, Deposited via Canned Air into a Bottle of Carbon Powder with MERV7 HVAC Filter Paper over the Opening, onto White SEM Primer Spray Paint

Toner Powder



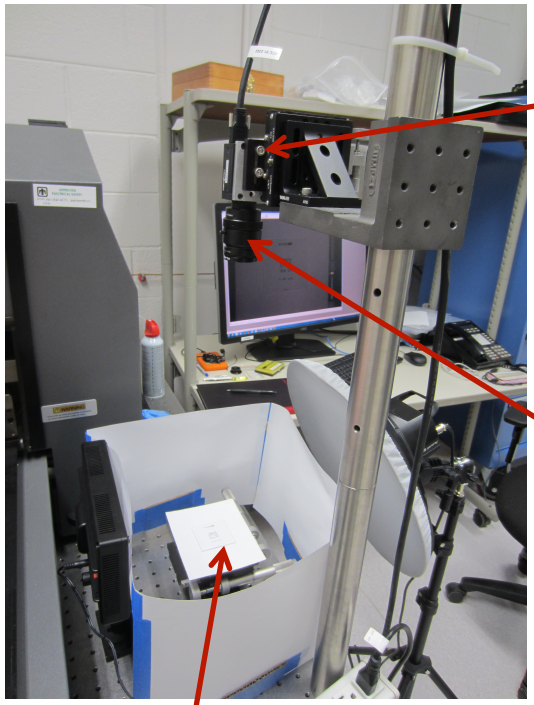
HP Laser Jet 12A Black Toner Powder, Deposited via Canned Air into a Bottle of Carbon Powder with MERV7 HVAC Filter Paper over the Opening, onto White SEM Primer Spray Paint

UV-Printed Pattern



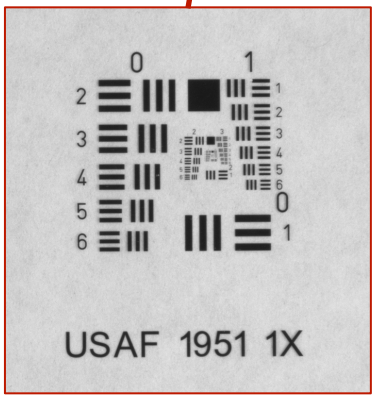
Computer-Generated Pattern (Correlated Solutions Speckle Generator Program with Radius 0.006”, Density 44%, Variation 75%) Printed Using a Direct Color Systems UV LED Inkjet Printer

FOV and Characterization of Patterns

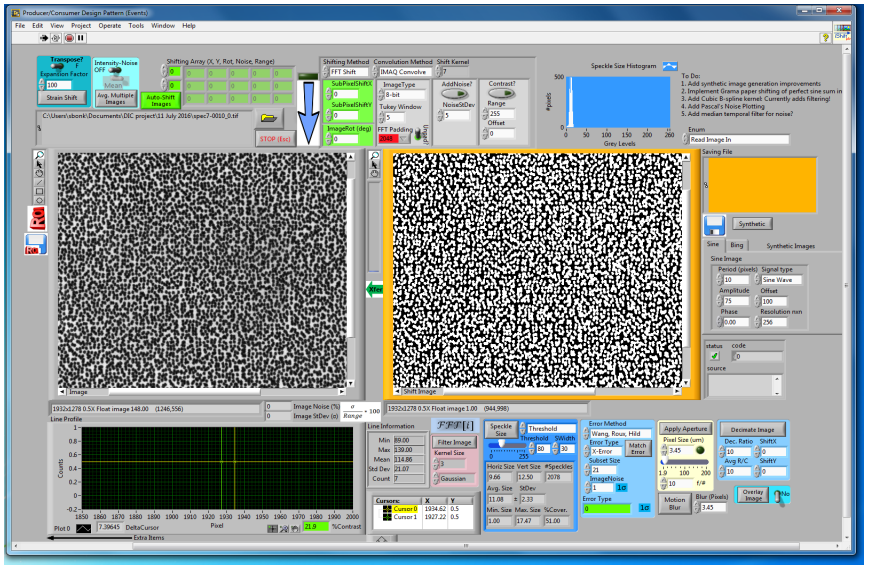


12-MP PGR Grasshopper CCD

35-mm Compound Lens (Shown Here) or Navitar 6000X Zoom Lens



USAF 1951 Resolution Target Used to Quantify with Smallest Resolvable Object (Element with >20% Contrast Between Line and Space)



Custom LabVIEW Program for Characterizing the Pattern, Measuring Speckle Size, Speckle Coverage, and Contrast Over the Pattern or User-Defined Line

Note: The results can be scaled to other size CCD cameras to get a general sense of how a speckle pattern would be in a different camera (e.g. the original 12-MP is more dense than a 5-MP camera, so sizes in pixels on the 5-MP will smaller), allowing for down-selection of patterns to directly study with other cameras.

Sub-Pixel Translation Study

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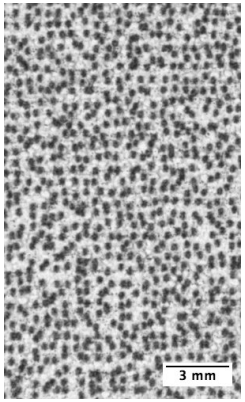
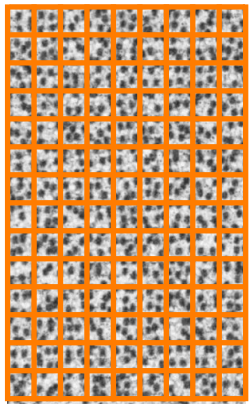
Sub-pixel Translation of Patterns



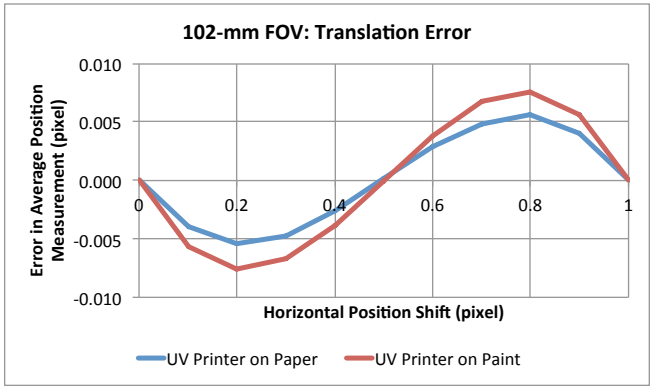
Performed translation in 0.1-pixel increments between 0 and 1 pixels in the x-direction for a region of 300 X 500 pixels using MATLAB

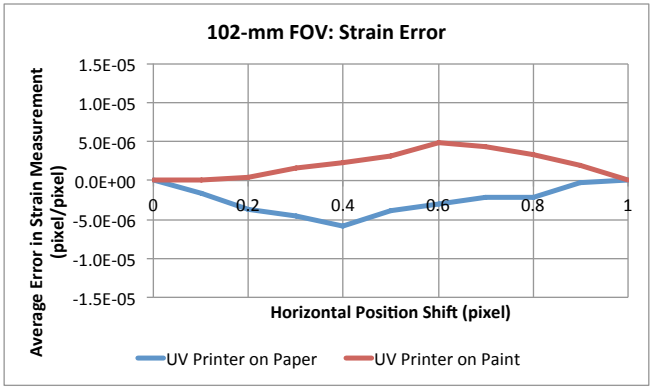
DIC Analysis of Numerically Shifted Images



Performed DIC analysis of each shifted image using Sandia's DICe program [Subset 35 pixels, Step 15 pixels, Strain Window 45 pixels]

Error in Position and Strain Measurement





Calculate position error by subtracting the numerical shift from the average x-displacement measurement and strain error by the average strain measurement (which should be zero)

102-mm FOV Results

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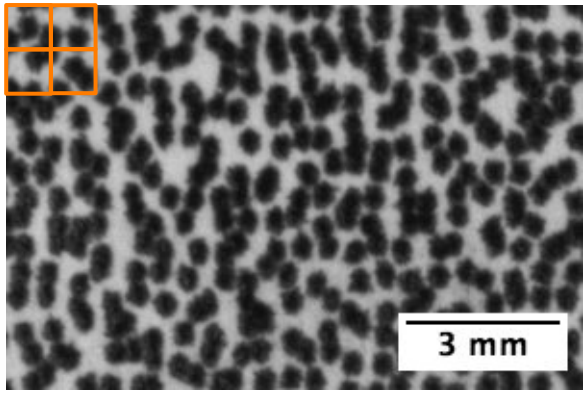
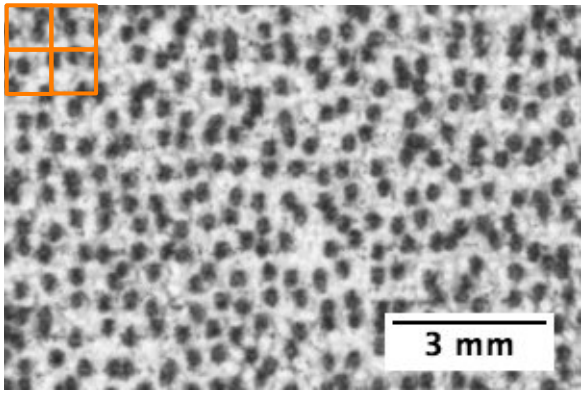
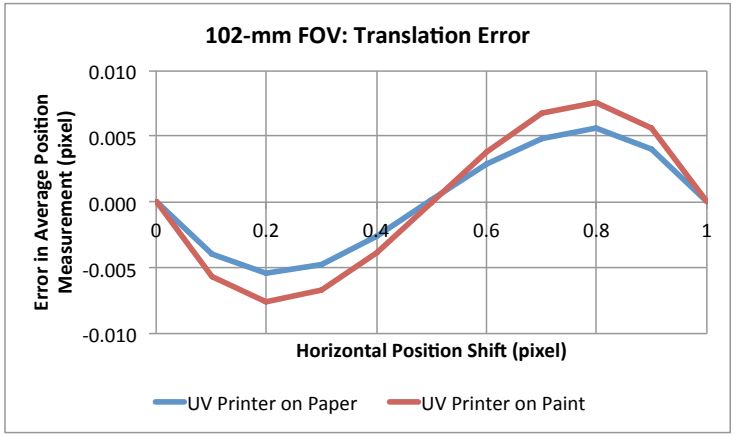
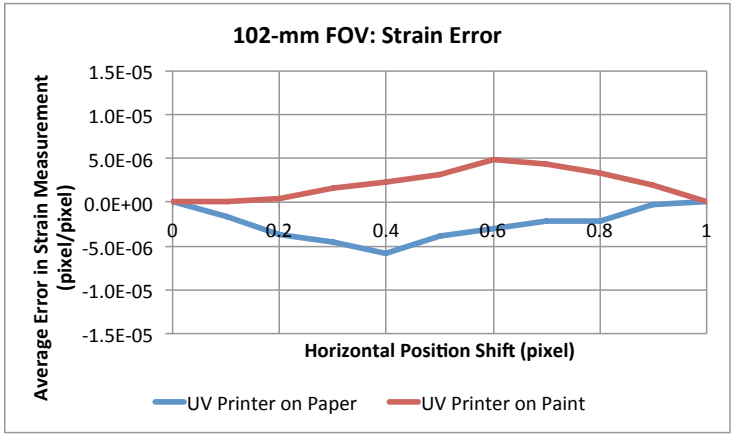
Both patterns were the same from Correlated Solutions Speckle Generator software (Radius 0.006”, Density 44%, Variety 75%), **but printed on white paper (left) and on metal with a white spray paint base coat (right)**





Speckling Technique	Average Speckle Size (pixel)	Standard Devation Speckle Size (pixel)	Maximum Speckle (pixel)	Percent Coverage	Line Scan Minimum Value (0-255 counts)	Line Scan Maximum Value (0-255 counts)	Percent Contrast (Max-Min) / (Max+Min)
UV-printed Pattern on White Paper	11.28	2.22	17.44	51%	19	220	84%
UV-printed Pattern on Spray Paint	5.95	3.15	13.54	38%	45	225	67%

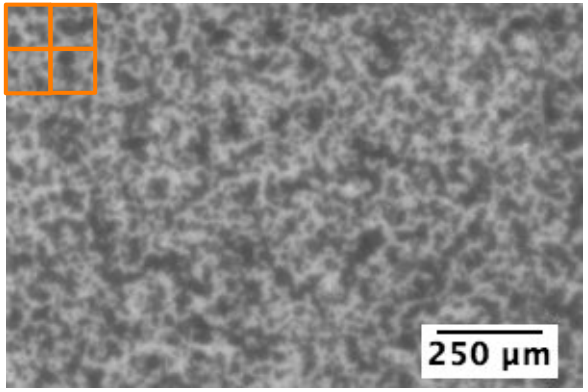




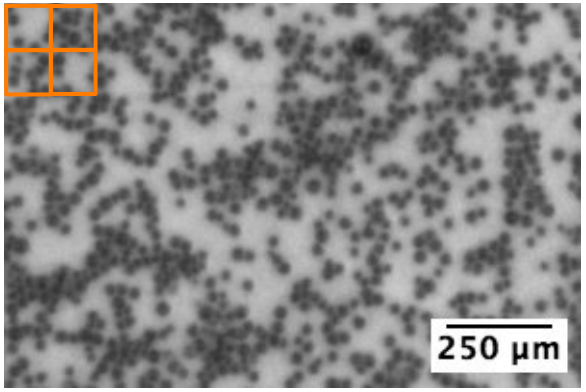
Observation:
The base layer of the speckle pattern can affect the results, so perform such studies with representative conditions of the application.

Orange Boxes Represent Four 35-pixel Subsets

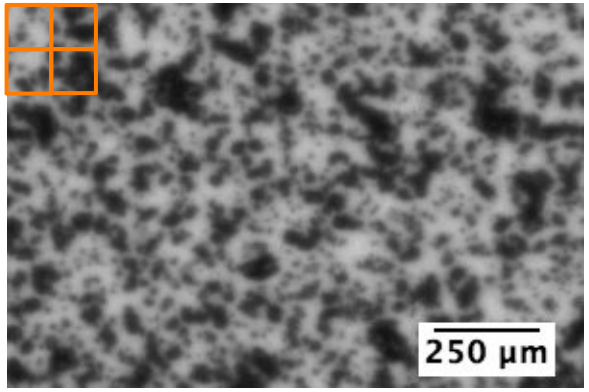
13-mm FOV Results



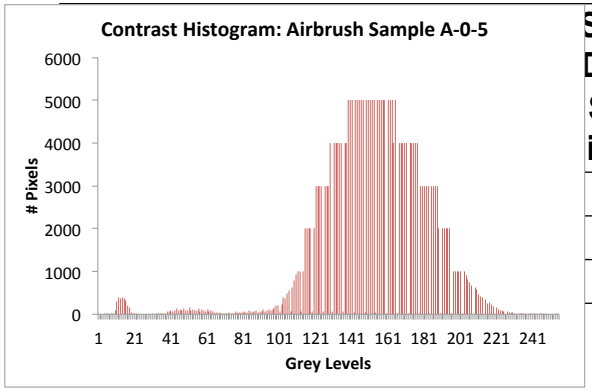
Airbrush

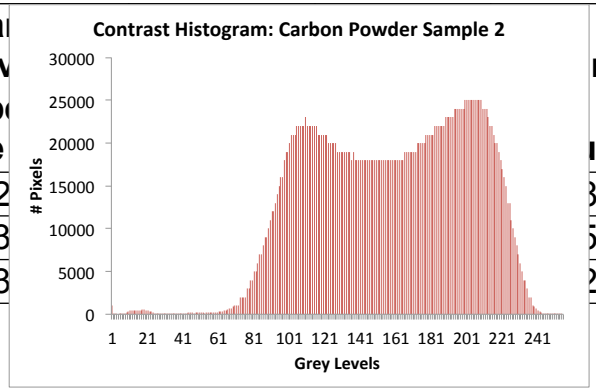


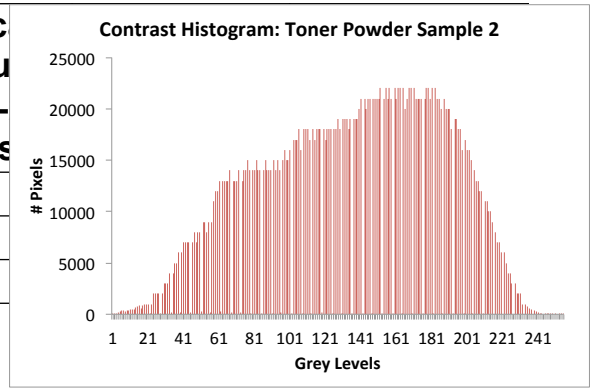
Carbon Powder



Toner Powder





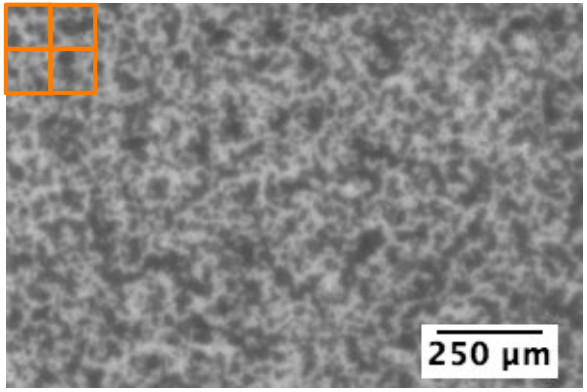


Observations:

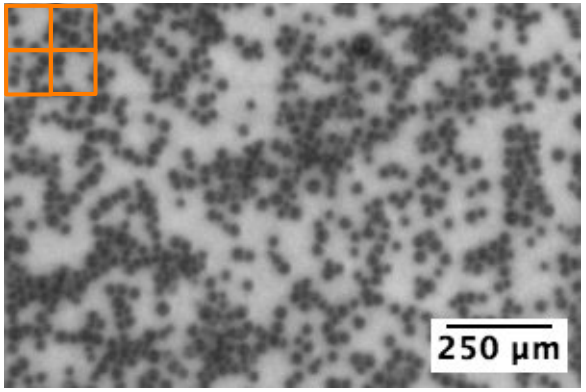
- The carbon powder has an ideal size, while the others may have aliased speckles.
- All patterns have similar coverage.
- All patterns have similar percent contrast, but different distribution over the range.

Orange Boxes Represent Four 35-pixel Subsets

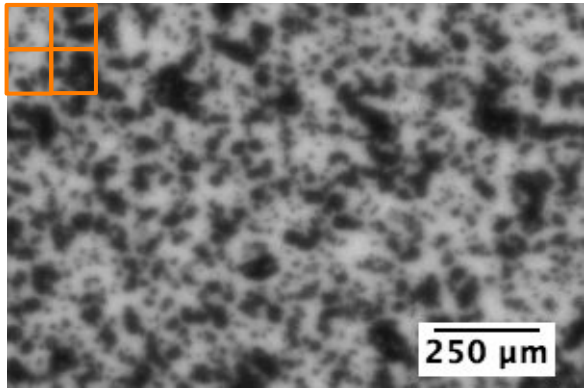
13-mm FOV Results



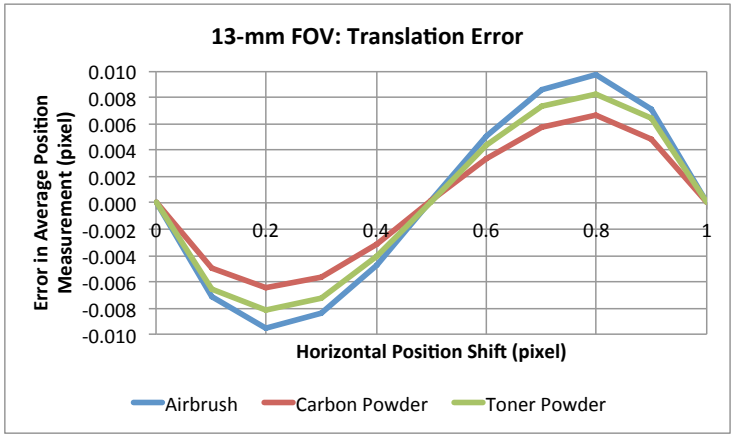
Airbrush

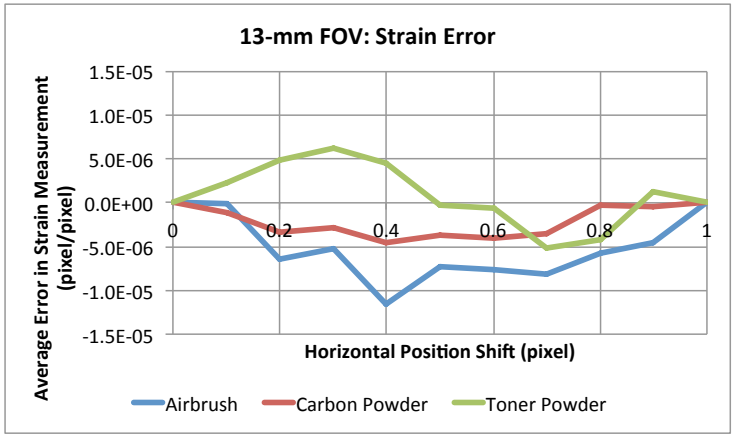


Carbon Powder



Toner Powder



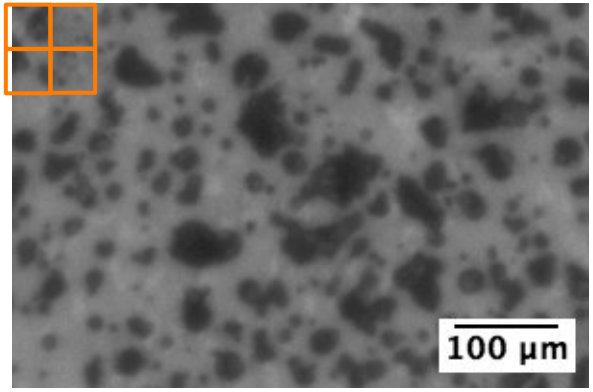


Observations:

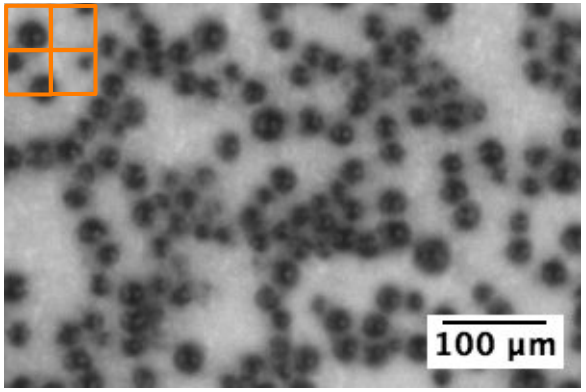
- The carbon powder had the lowest errors, while the airbrush had the highest.
- The airbrush and toner powder produced acceptable DIC results. Perhaps some technique modification could increase the speckle size and reduce the error.
- Speckle size appears to be the main contributor to larger error in the airbrush.

Orange Boxes Represent Four 35-pixel Subsets

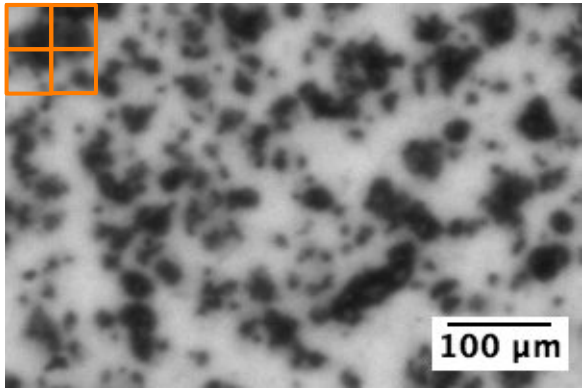
5-mm FOV Results



Airbrush



Carbon Powder



Toner Powder

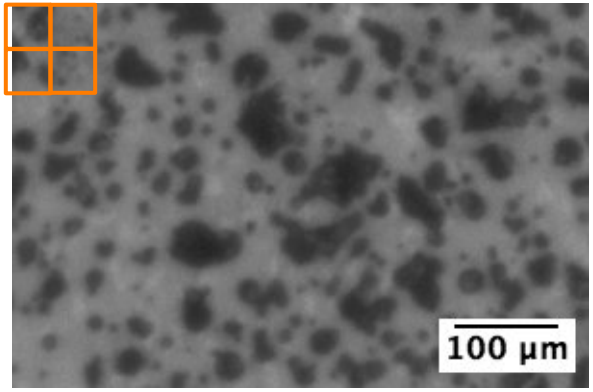
Speckling Technique	Average Speckle Size (pixel)	Standard Devation Speckle Size (pixel)	Maximum Speckle (pixel)	Percent Coverage	Line Scan Minimum Value (0-255 counts)	Line Scan Maximum Value (0-255 counts)	Percent Contrast (Max-Min) / (Max+Min)
Airbrush	7.02	4.62	20.08	37%	40	149	58%
Carbon Powder	7.34	6.14	22.33	35%	24	207	79%
Toner Powder	6.98	5.72	23.18	34%	14	216	88%

Observations:

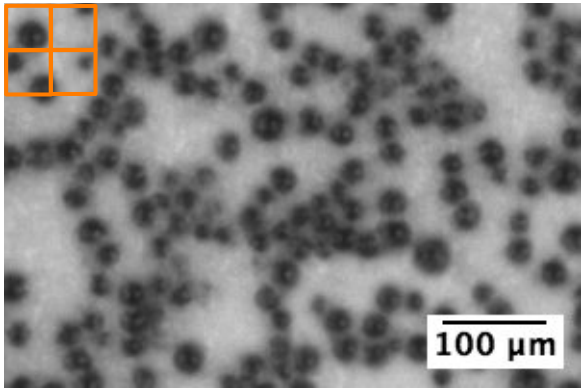
- **The average and maximum speckle size of each pattern and the percent coverage are similar.**
- **The contrast of the airbrush is lower than the carbon powder and toner powder, likely due to the blue color instead of black.**

Orange Boxes Represent Four 35-pixel Subsets

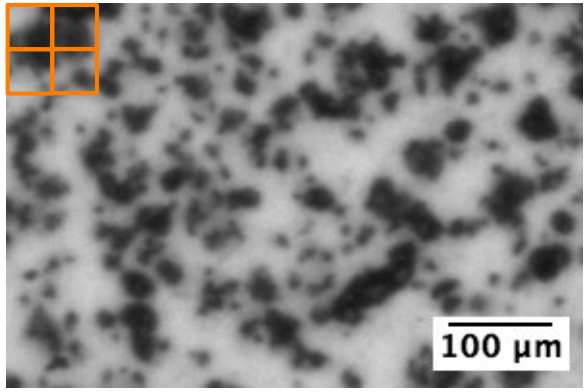
5-mm FOV Results



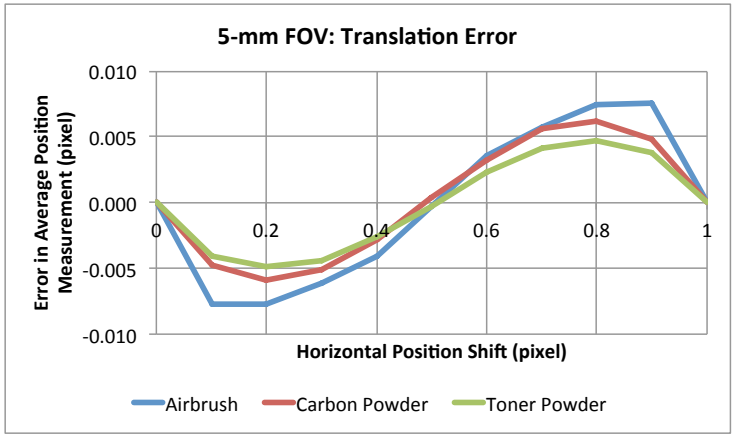
Airbrush

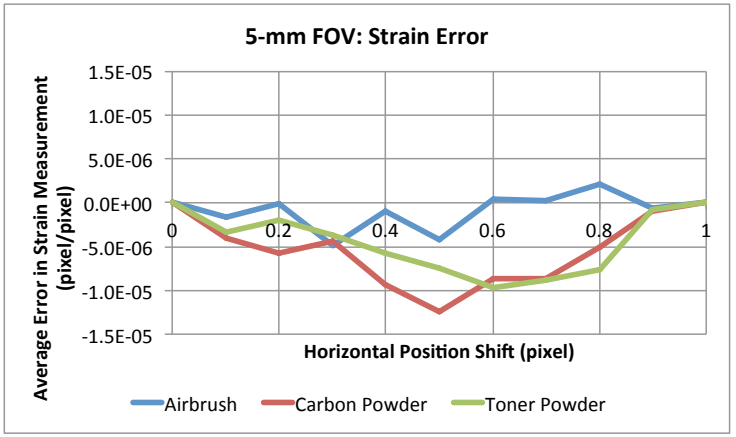


Carbon Powder



Toner Powder



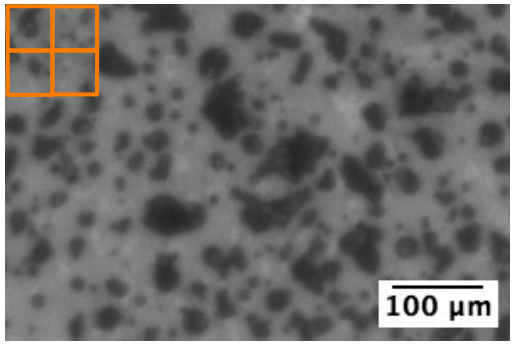


Observations:

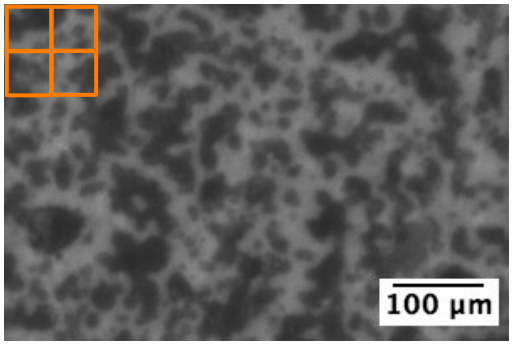
- **Position error is lower for the toner and carbon powders, but the strain error is lower for this particular sample of airbrush.**
- **These errors for all the techniques are generally acceptable. The user would need to check for repeatability between multiple samples to distinguish between methods.**

Orange Boxes Represent Four 35-pixel Subsets

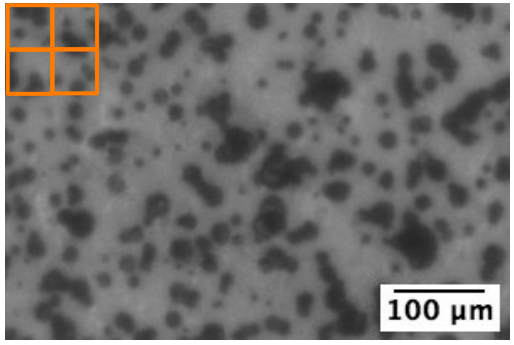
Comparison of Repeated Techniques



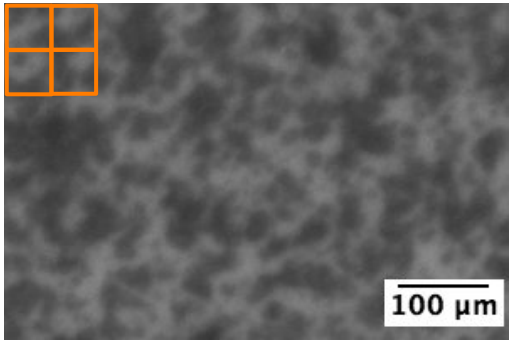
Airbrush – D15E



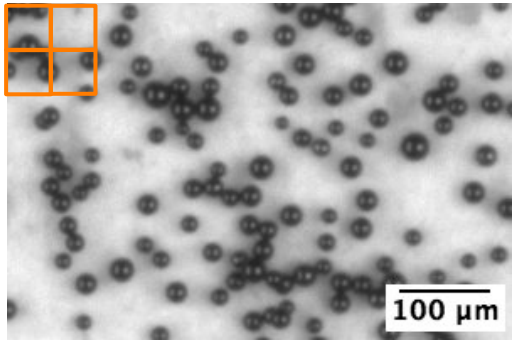
Airbrush – D14A



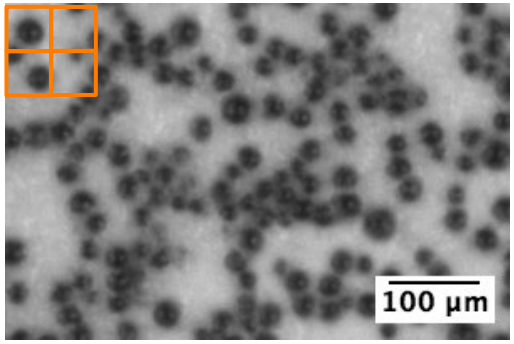
Airbrush – D15C



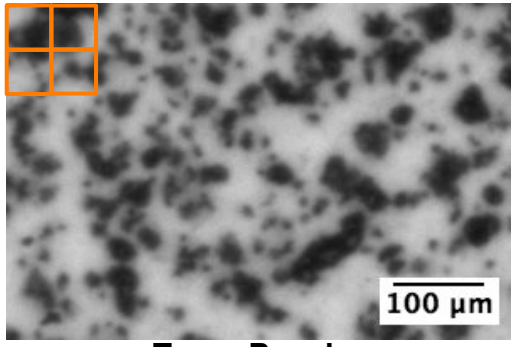
Airbrush – A14



Carbon Powder - S



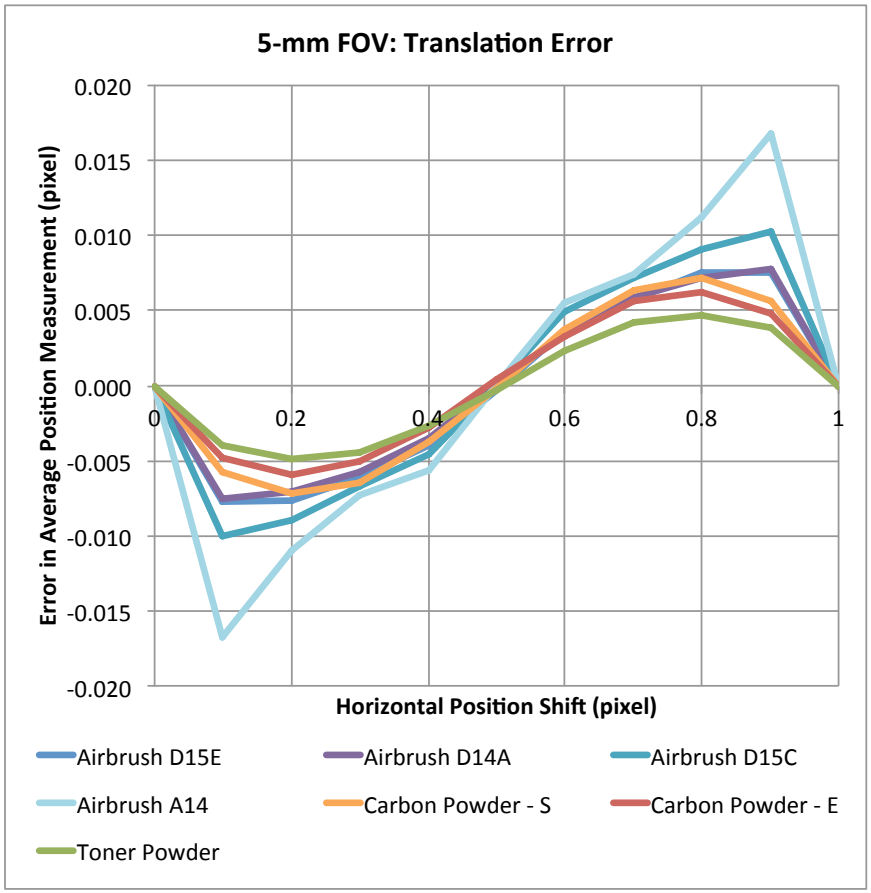
Carbon Powder - E

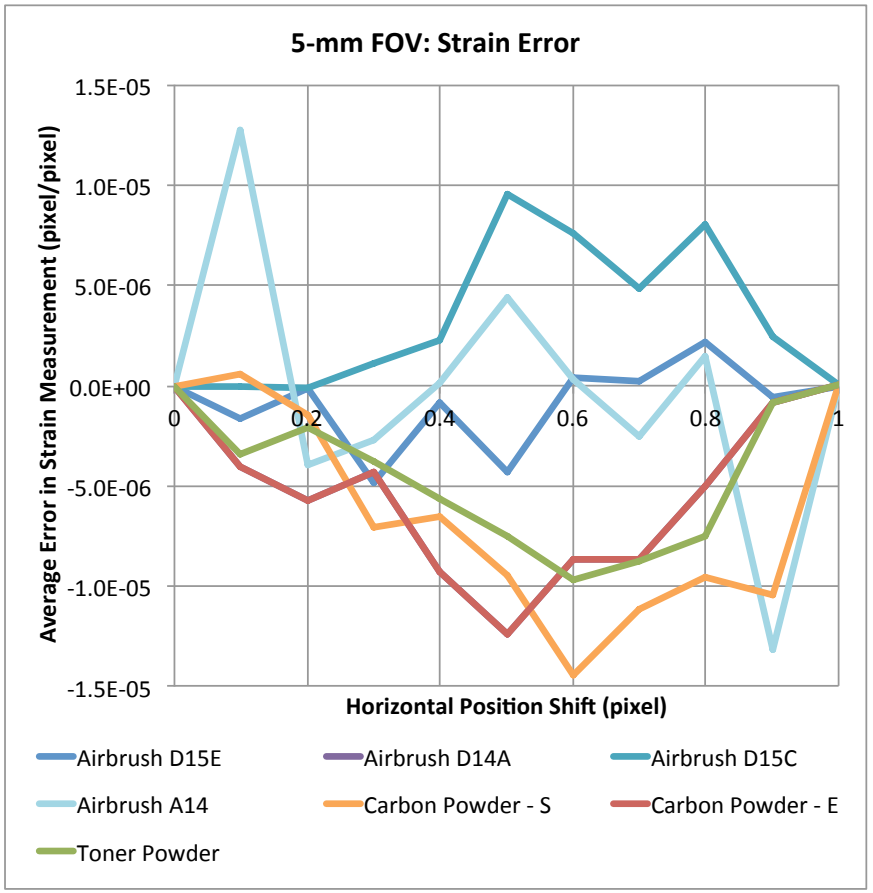


Toner Powder

Orange Boxes Represent Four 35-pixel Subsets

Comparison of Repeated Techniques

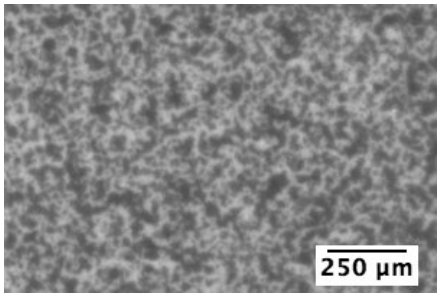




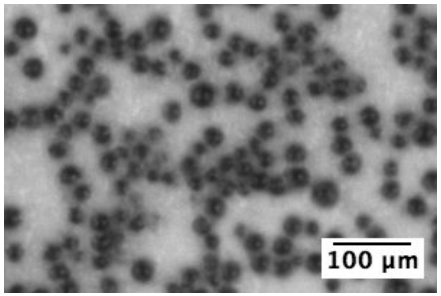
The variability in the sub-pixel translation error data shows that repeatability of pattern generation should be a consideration. If all techniques are close, then selecting the more repeatable one would be advised to reduce the variability during a test series when the user would not be checking each specimen as rigorously done in this study.

Summary

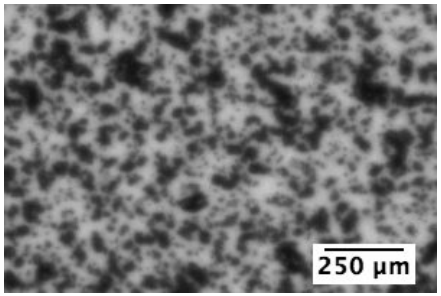
- Quantitative characterization of speckle patterns provides the user with evidence upon which to make a speckling technique selection.
- This study of speckle patterns outlined a general approach for quantifying desired pattern characteristics through imaging several candidate patterns; measuring speckle size, coverage, and contrast; and determining errors in the DIC measurements of translation and strain.
- In this study for FOVs from 5-102 mm, we observed
  - The base coat of the pattern affect the results.
  - For small FOVs, particle deposition technique generally have lower error than painting techniques.
  - Repeatability of a technique is a factor in selecting the optimal speckling technique.



Airbrush



Carbon Powder



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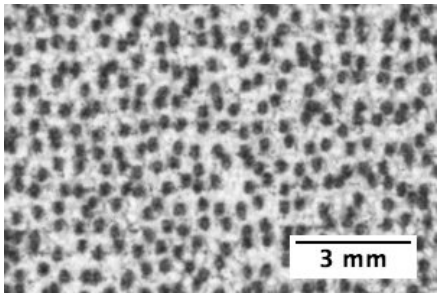

UV-Printed Computer-Generated Pattern