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IDEA FUSION

spe AUTOMOTIVE COMPOSITES

MACHINE LEARNING APPROACH FOR PREDICTION OF FIBER ORIENTATION DISTRIBUTION IN MOLDED COMPOSITES

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COMPOSITES MODELING AND MANUFACTURING GROUP

21st Annual Automotive Composites Conference & Exhibition

Novi, MI, Sept. 8-10 2021

Digital Twins to Advance High-Rate Manufacturing Methods

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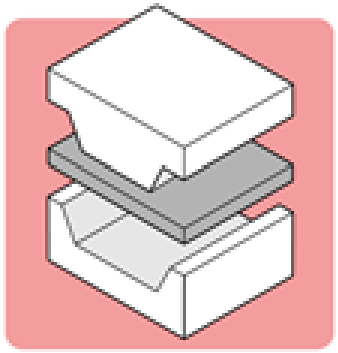
Loose Chopped Prepreg Platelets

CYTEC SOLVAY GROUP

TENCATE ADVANCED COMPOSITES Toray Group

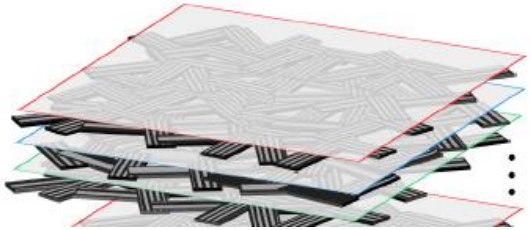


Mat / Organosheet:

Chopped prepregs;

Infused fiber bundles/tows (in-situ polymerized)

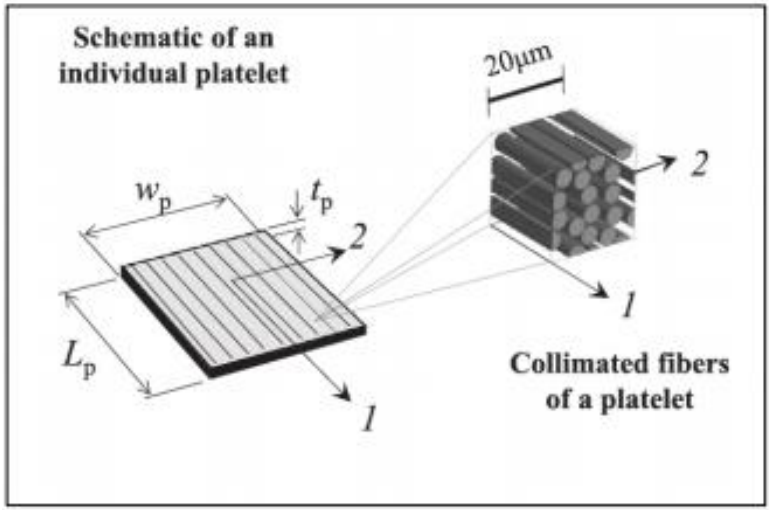
DOW HEXCEL JM Johns Manville

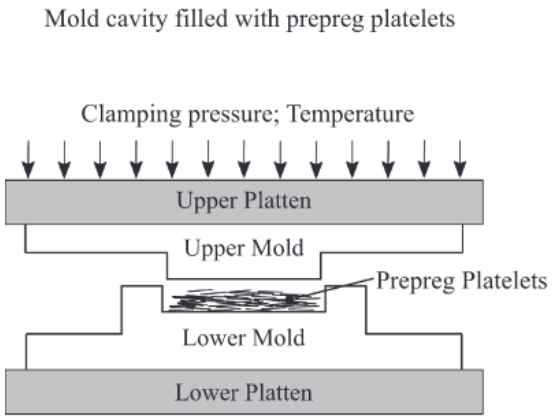


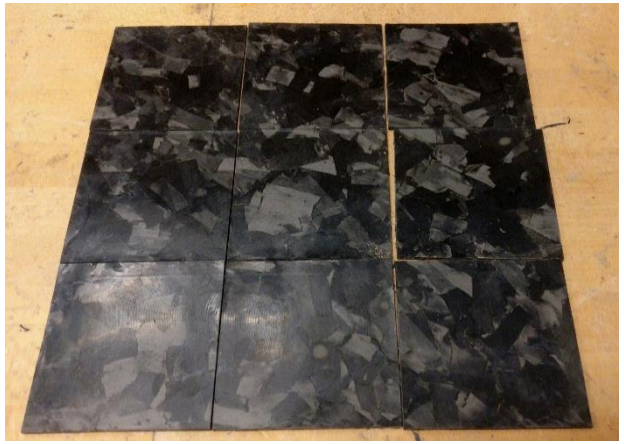
- Compression molding of discontinuous fiber forms, such as “chopped prepregs” is a cost efficient manufacturing method of complex shaped geometries
- Development of material & process technologies aimed at enabling high-volume production of thermoplastic composites requires:
  - Fundamental understanding of process-structure-property-performance relationships:
    - Origin of mechanical properties
    - Mechanisms of progressive damage accumulation
  - Integrated design solutions for manufacturing & performance:
    - Variability in the manufacturing process & performance characteristics
    - Anticipation of failure modes

PPMC Material System

- Prepreg platelets contain carbon fiber reinforced with polymer
- Prepreg is a transversely isotropic material
- PPMC fills a niche – it allows greater fiber volume fraction and fiber length, yet is formable into geometrically complex parts
- PPMC parts require time intensive inspection due to their stochastic local orientation states
- PPMC are beneficial as they are strong, stiff and light, and can be produced via high-throughput manufacturing processes such as compression molding







Varying Scales of molded platelet Applications

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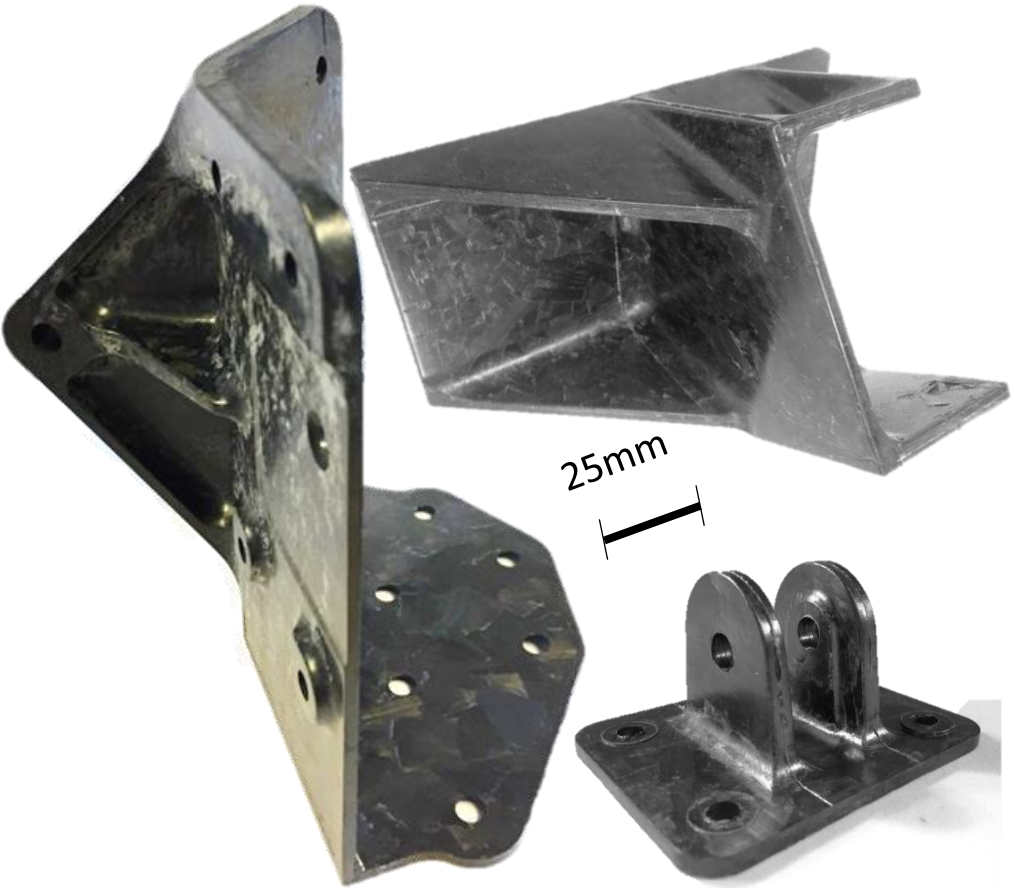
Example (Aerospace)

Compression Molded Parts



Liftgate Inner (Ford):

Dow's Vorafuse™

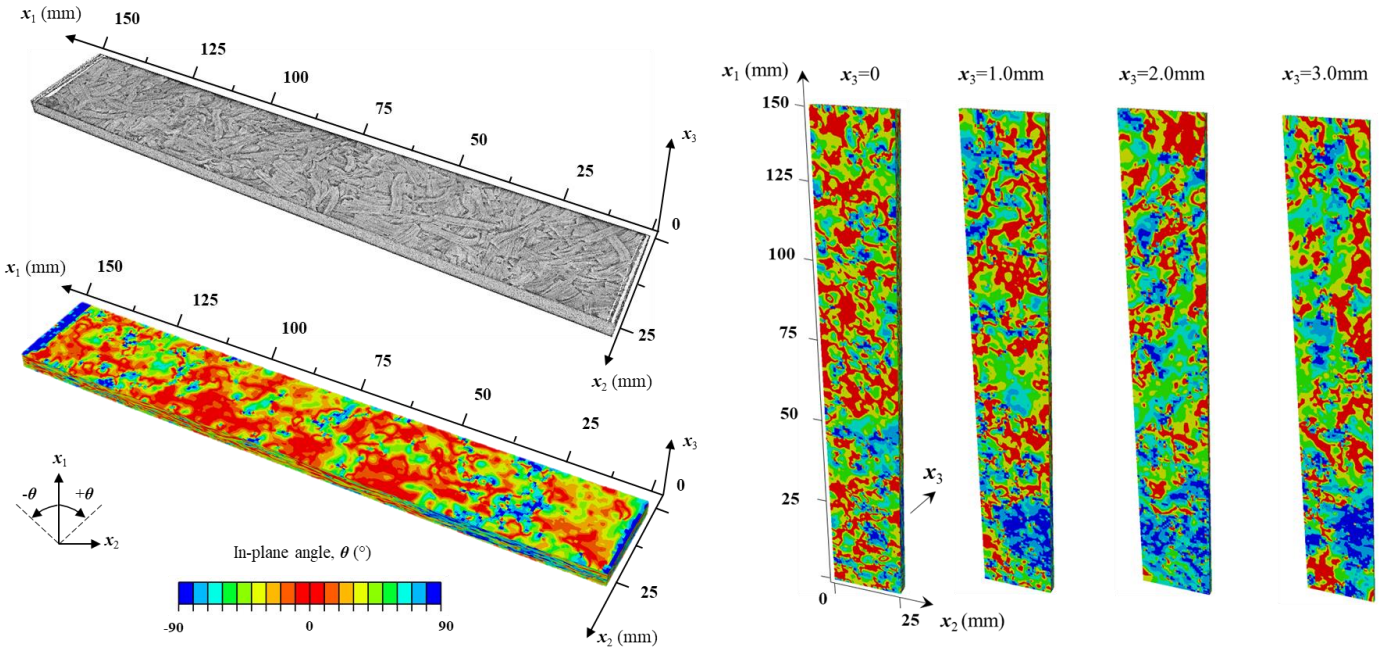
Thermoplastic Blocker Door

Motivation

- Establishing rapid non-destructive evaluation of the fiber orientation distribution (FOD):
  - Identification of the faulty components, areas of concern, inconsistencies in the resulting FOD
  - Development of the digital thread process by identifying the unique manufacturing signature embedded into the components meso-structure
  - Inspection techniques that readily allow structural analysis

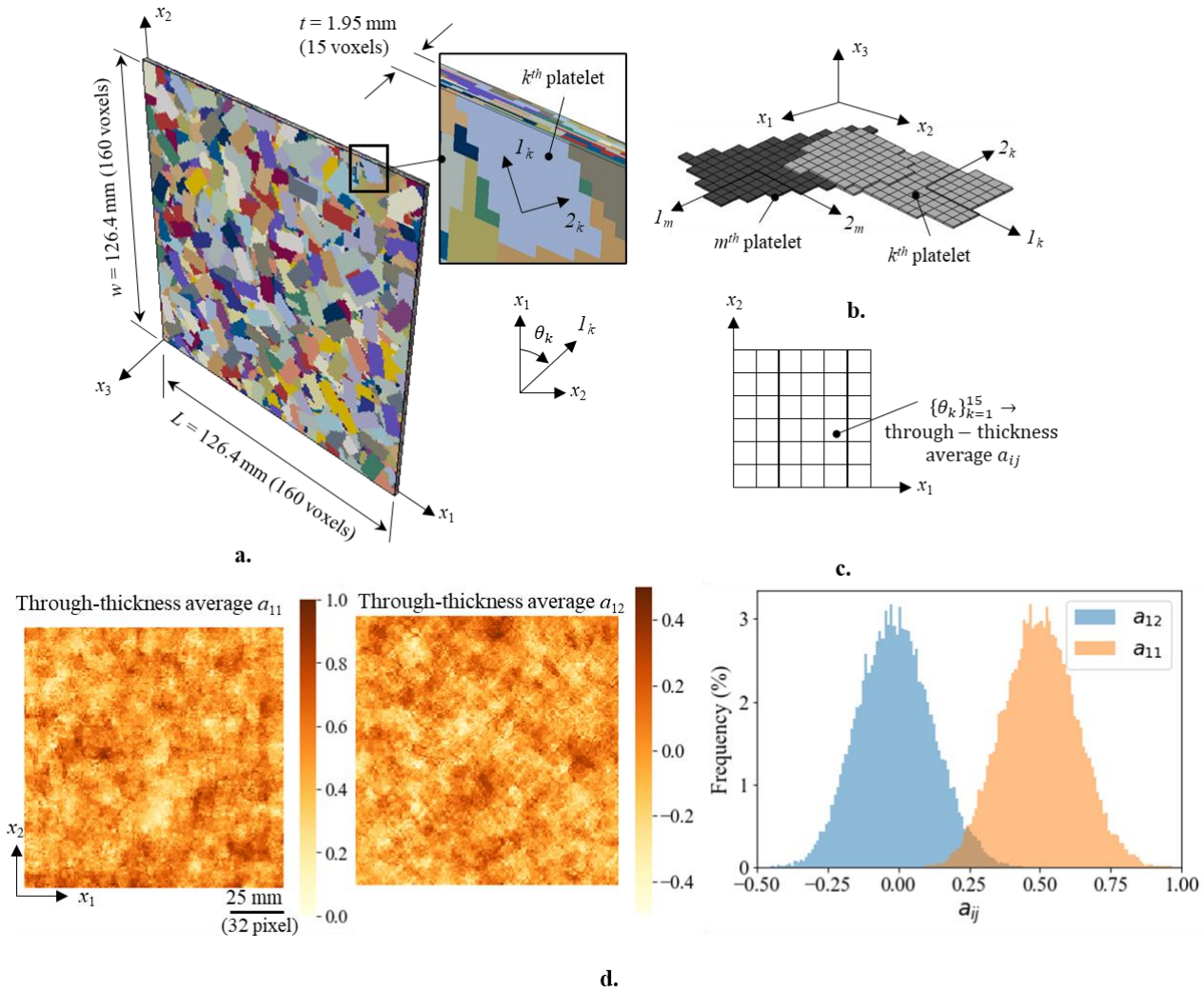
Fiber Distribution

- Individual platelet boundaries visible in grey image
- Surface fiber orientation is not representative of the fiber orientation throughout the thickness



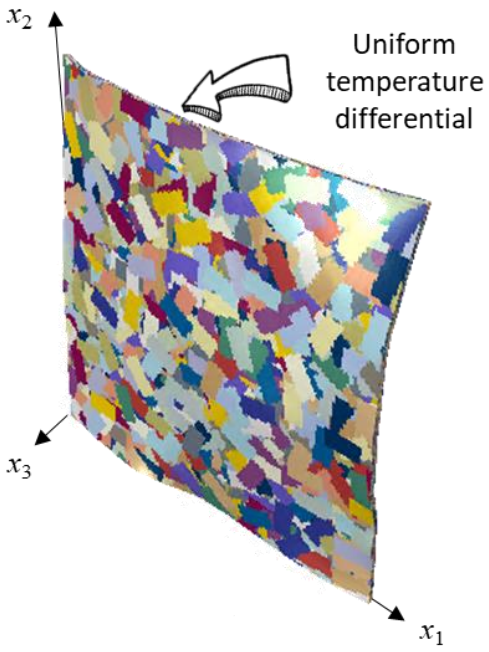
PPMC Plate Simulation

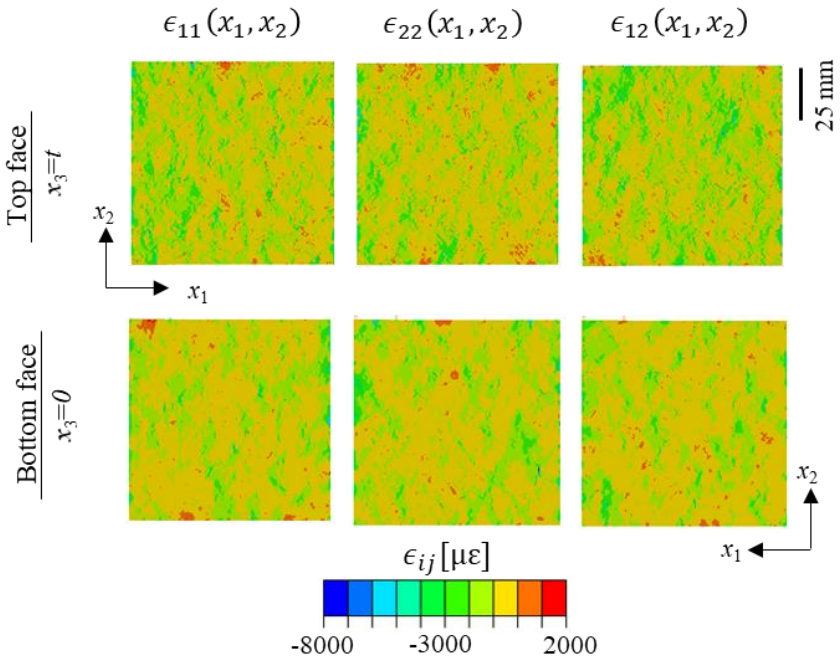
- PPMC virtual plate, subdomains shown in different colors (a)
- Fiber orientation distribution tensor (FOD) described by Advani and Tucker is plotted over the plate (c)
  - Only the a_{11} and a_{12} terms are required to describe a PPMC with a 2D random material orientation state
- The probability density of a_{11} and a_{12} are shown (d)



PPMC Non-Uniform Deformation Fields

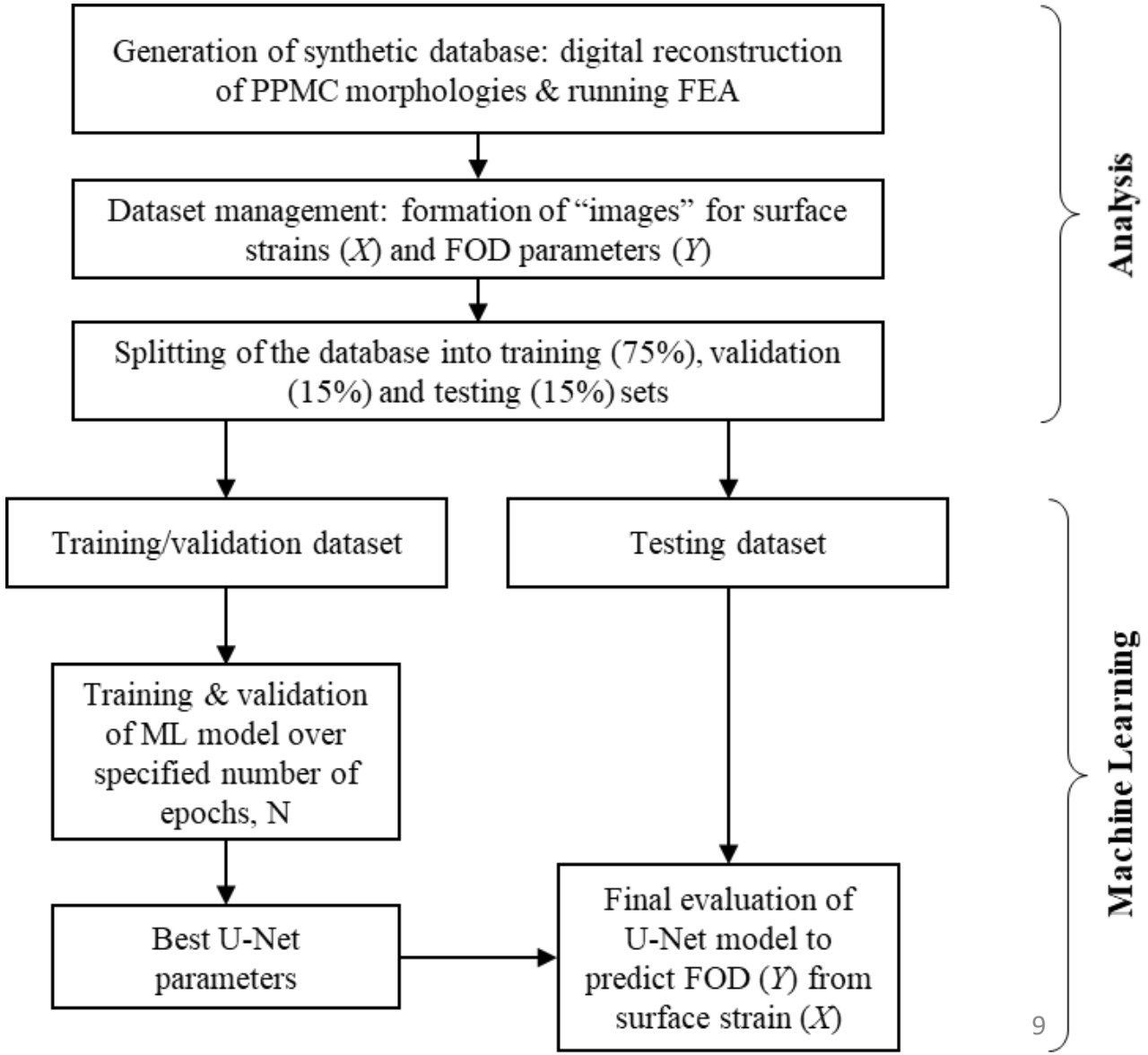
- Due to stochastically varying nature intrinsic to PPMC, non-uniform deformation fields will develop as a result of temperature change
- Local strain fields of the plate are also non-uniform



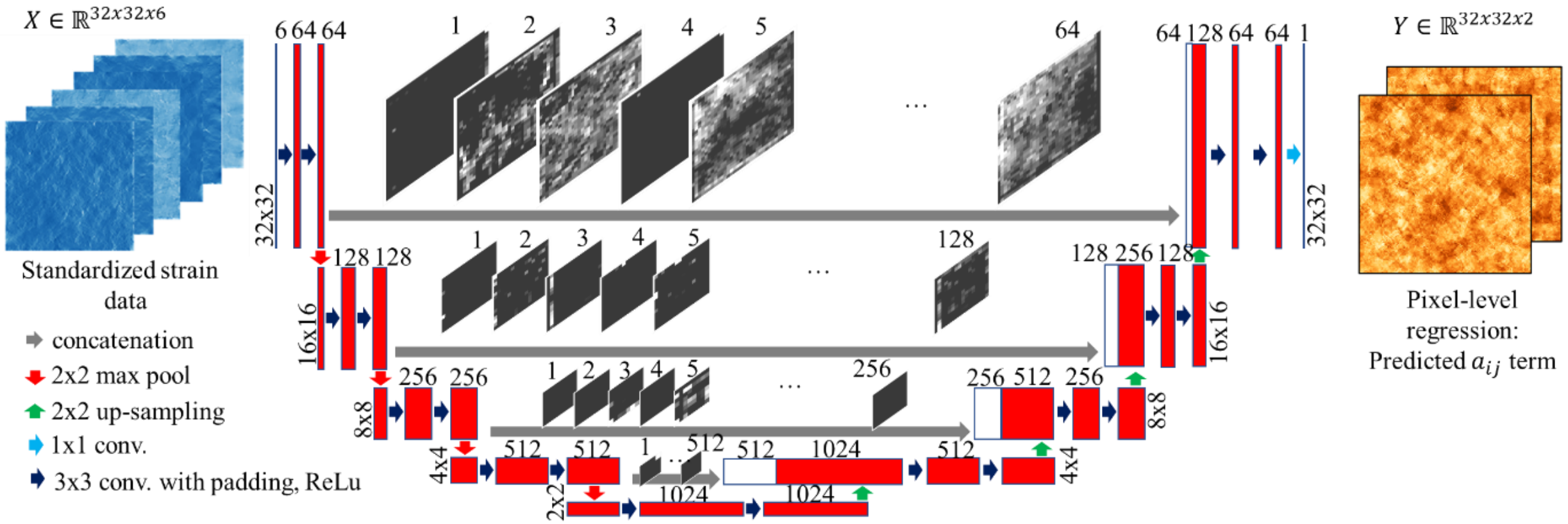


Problem Solution

- Digimat software is used to construct 2D random PPMC morphologies in a 5” x 5” plate
- ABAQUS software is used to perform finite element analysis (FEA) uniform temperature differential simulation
- Entire process is automated via python scripting
- 2000 simulations were performed to generate the dataset for the study
- Each simulation had 25 smaller 32x32 pixel patches extracted so as to increase the size of the dataset (Figure 3)



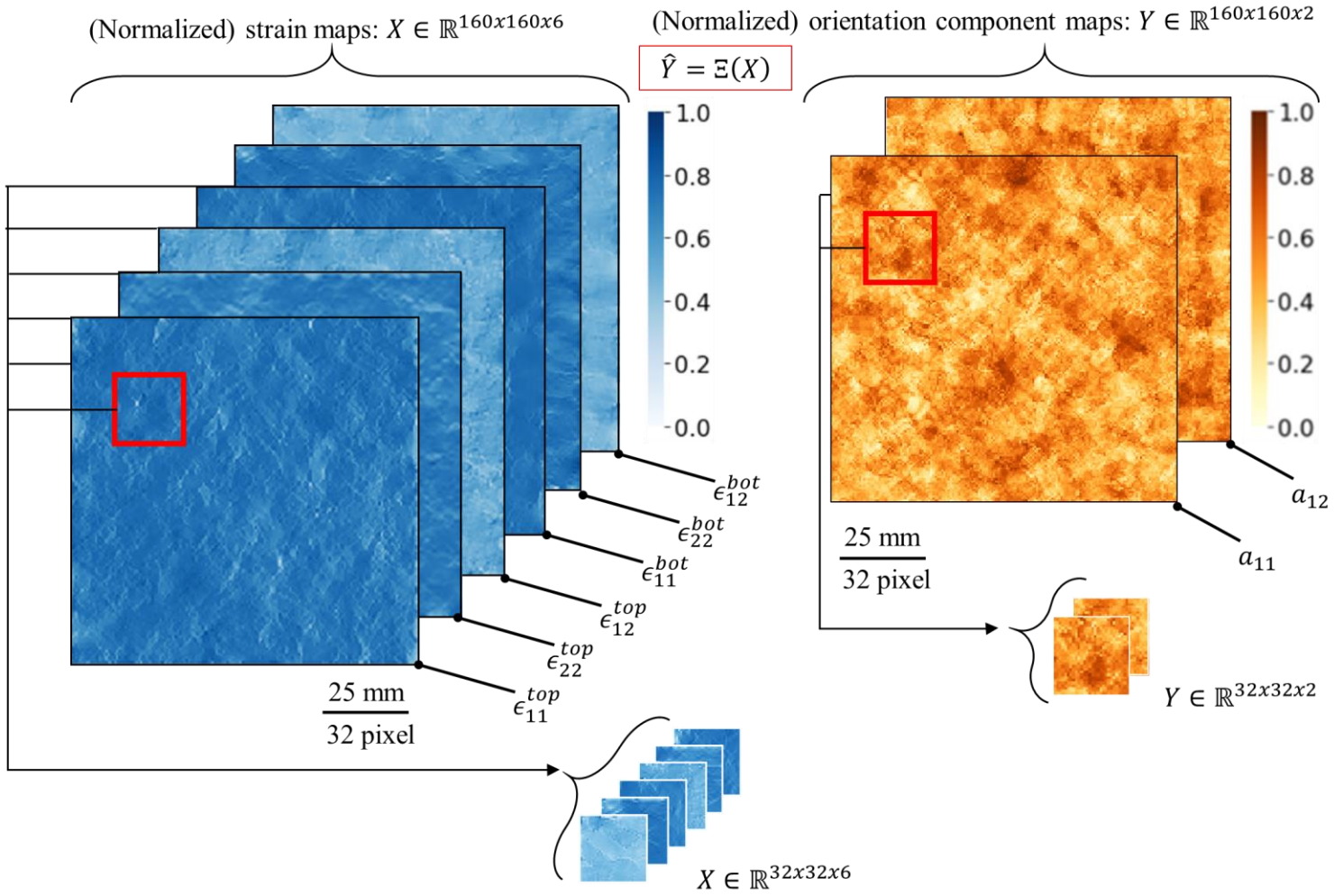
U-Net Deep Learning Architecture



- U-Nets in this study were evaluated with root mean squared error (RMSE) and mean absolute error (MAE) loss functions

Dataset

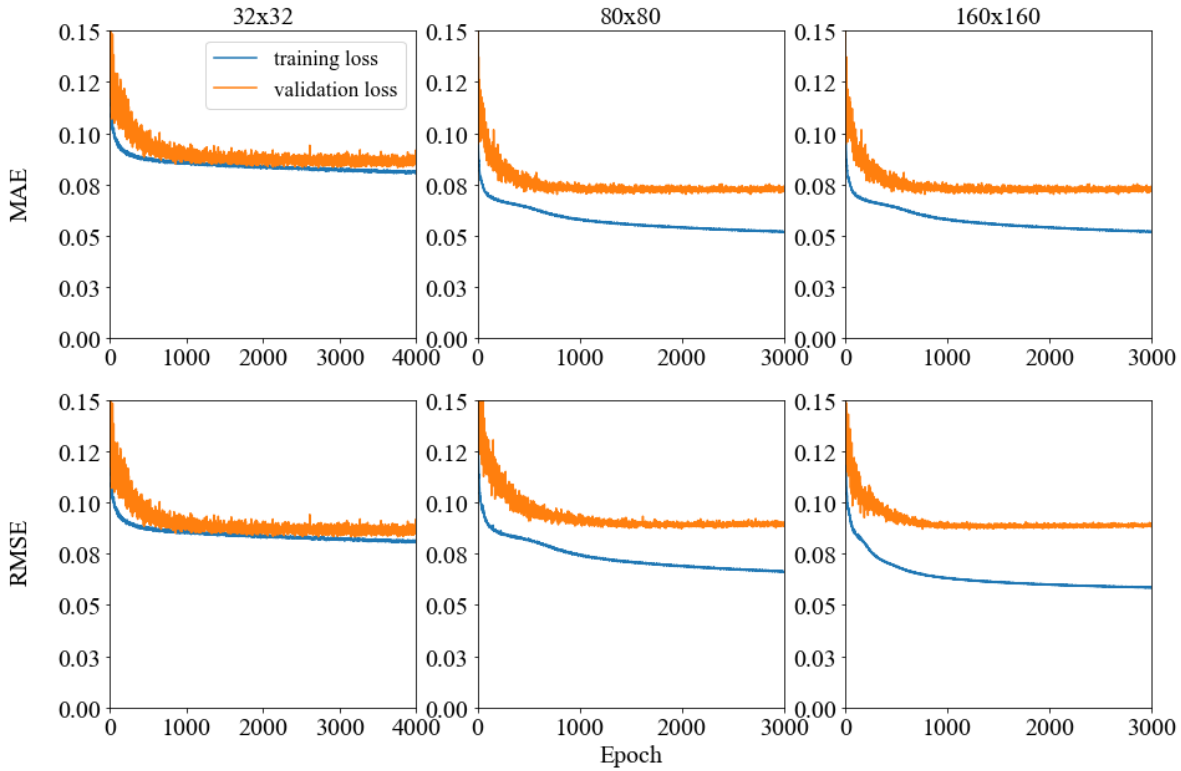
- Smaller patches were extracted from each plate and used for U-Net training
- Different patch sizes were used during training, and corresponding U-Net performance was evaluated

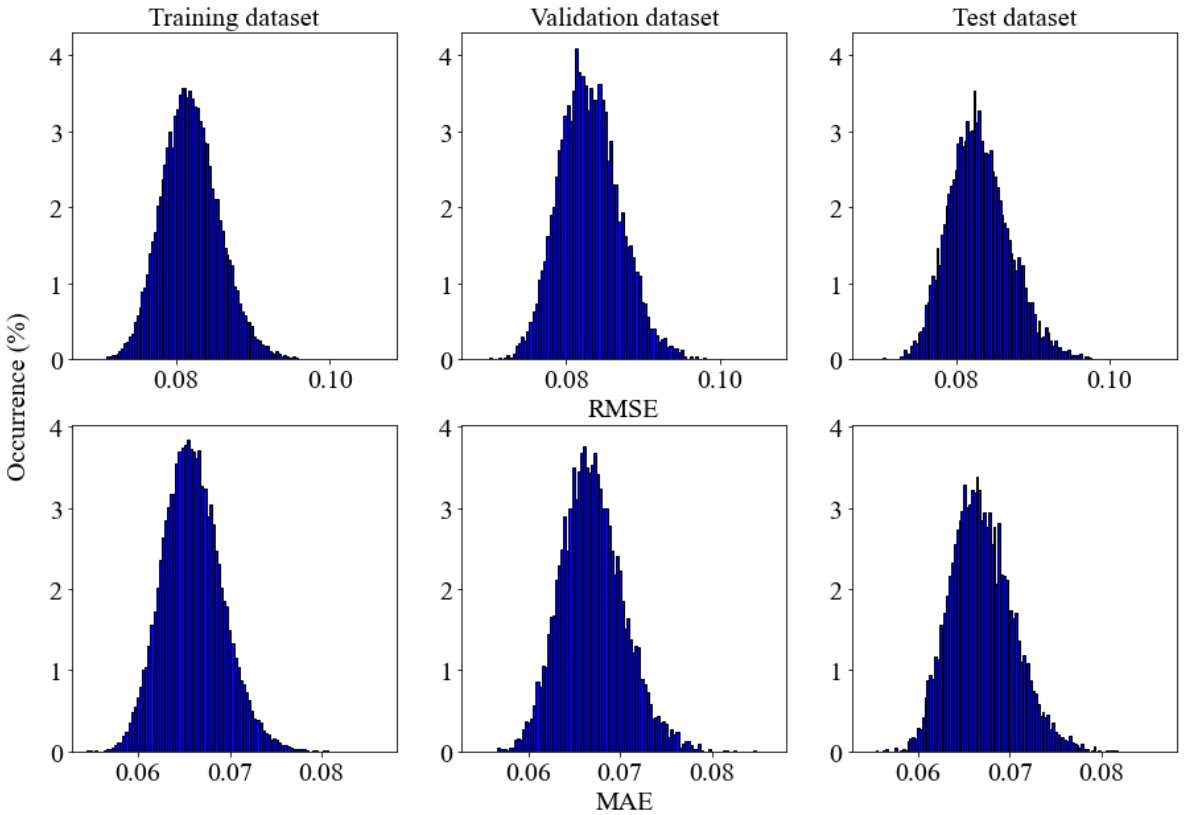


Datasets Used in Study

Patch Size (pixels)	32^2	80^2	160^2
Train X dataset shape (pixels)	(35000,32,32,6)	(5600,80,80,6)	(1400,160,160,6)
Train Y dataset shape (pixels)	(35000,32,32,2)	(5600,80,80,2)	(1400,160,160,2)
Validation X dataset shape (pixels)	(7500,32,32,6)	(1200,80,80,6)	(300,160,160,6)
Validation Y dataset shape (pixels)	(7500,32,2)	(1200,80,80,2)	(300,160,160,2)
Test X dataset shape (pixels)	(7500,32,32,6)	(1200,80,80,6)	(300,160,160,6)
Test Y dataset shape (pixels)	(7500,32,32,2)	(1200,80,80,2)	(300,160,160,2)

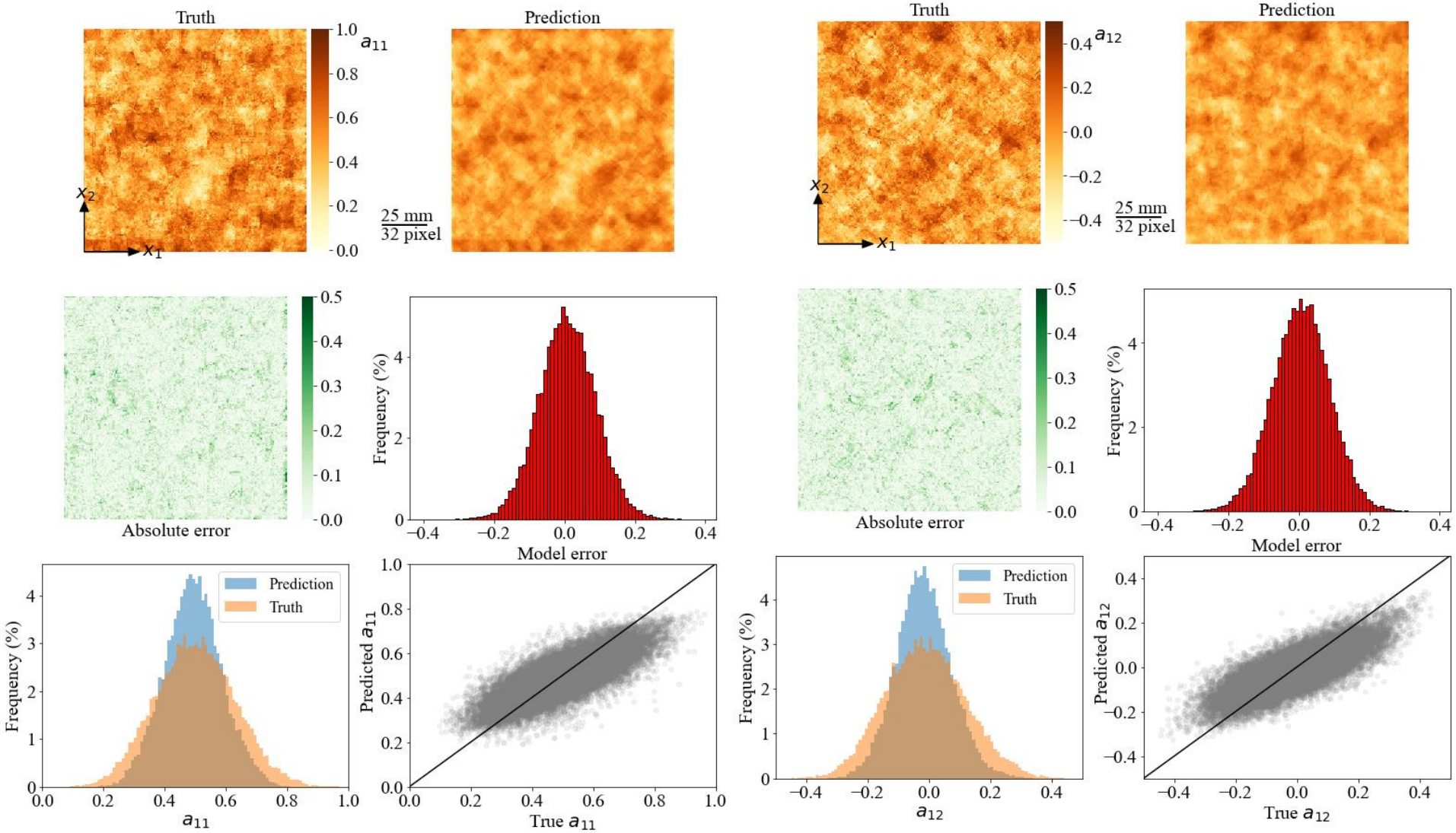
Results



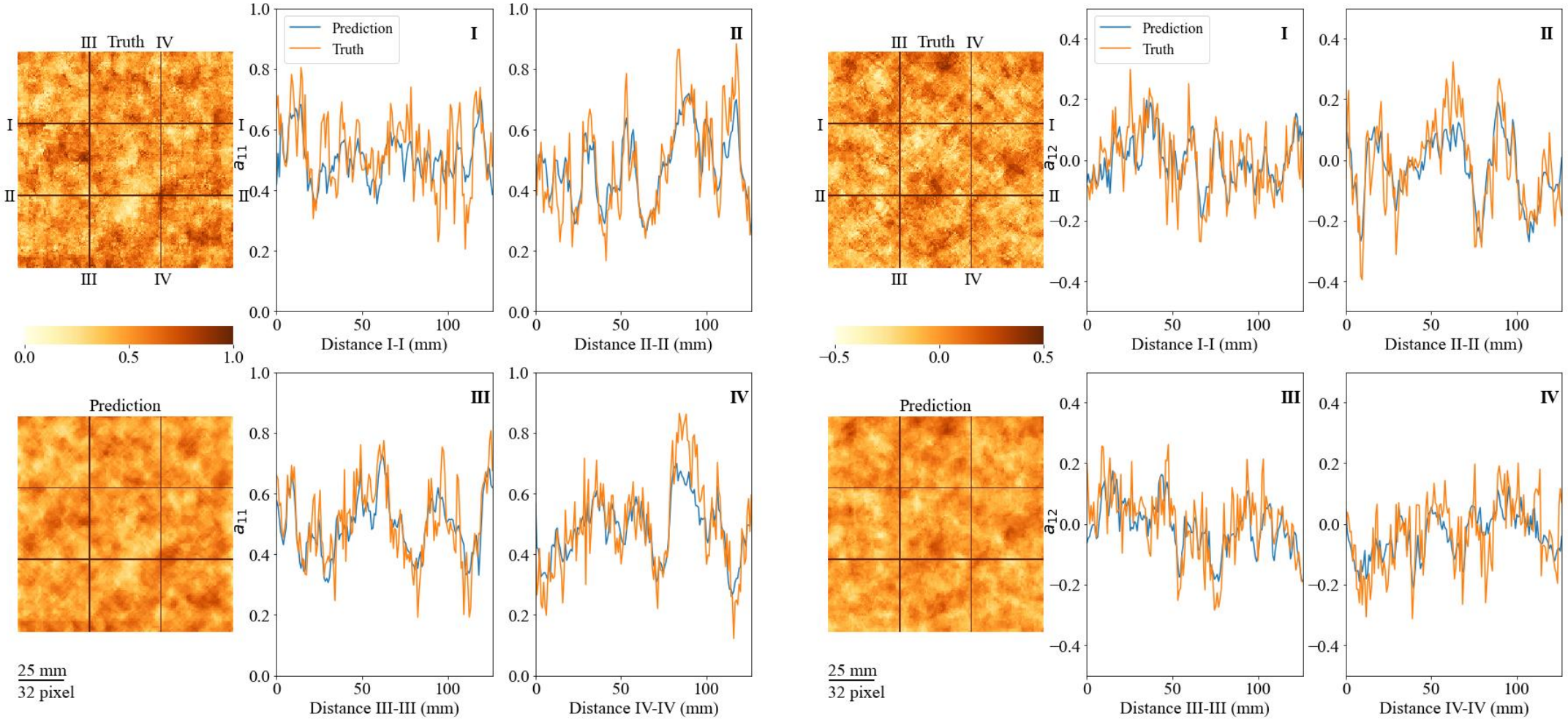


- Majority of model learning occurs within first 1000 epochs
- Model trained with 32x32 input patches and RMSE achieved lowest test dataset loss of 0.066

Results


Truth
Prediction
a_{11}
x_2
x_1
25 mm / 32 pixel
Absolute error
Frequency (%)
Model error
Prediction
Truth
a_{11}
Predicted a_{11}
True a_{11}
a_{12}
Predicted a_{12}
True a_{12}

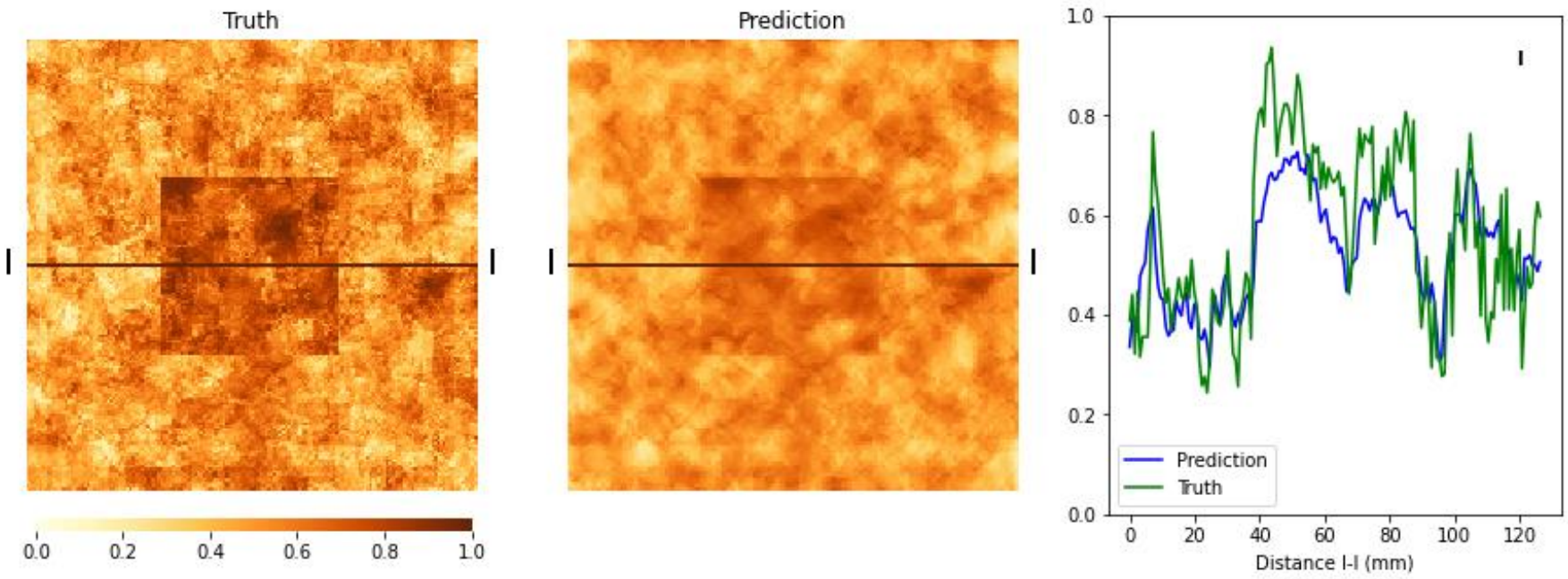
Results



- Model captures trend, yet still oversmoothed

Results

- Model can detect embedded region with global a_{11c}= 0.75
- The model detects this patch yet underpredicts the high a_{11} values observed
- This is expected as higher a_{11} values are less frequent in the training dataset



Conclusions

- The trained U-Net can accurately predict the local through-the-thickness FOD terms with 6.6% error
- This error is attributed to over-smoothing of the FOD term predictions
- The U-Net overpredicts values near the mean dataset value, but underpredicts less commonly occurring values
- The U-Net can accurately detect regions of fiber bias

Acknowledgements

- Richard Larson is acknowledging the support of the NSF Scholarship in STEM (Award # 1833896).
- The authors acknowledge the support of the Batten College of Engineering Technology Multidisciplinary Research Seed Grant

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Backup

Loss metric	Patch Size (pixels^2)	Patches extracted per plate	Epochs	Epoch of saved parameters	Training Time (hrs)	MAE (training)	RMSE (training)	MAE (test)	RMSE (test)
RMSE	32^2	25	4000	3226	16.18	0.065	0.082	0.066	0.083
	80^2	4	3000	1997	12.30	0.057	0.072	0.069	0.087
	160^2	1	3000	1214	20.04	0.065	0.065	0.069	0.086
MAE	32^2	25	4000	2723	16.43	0.066	0.083	0.067	0.084
	80^2	4	3000	779	12.29	0.064	0.080	0.070	0.088
	160^2	1	3000	1297	19.97	0.051	0.065	0.069	0.086