Synthetic Microstructure Data Generation For Machine Learning Composite Architecture Prediction

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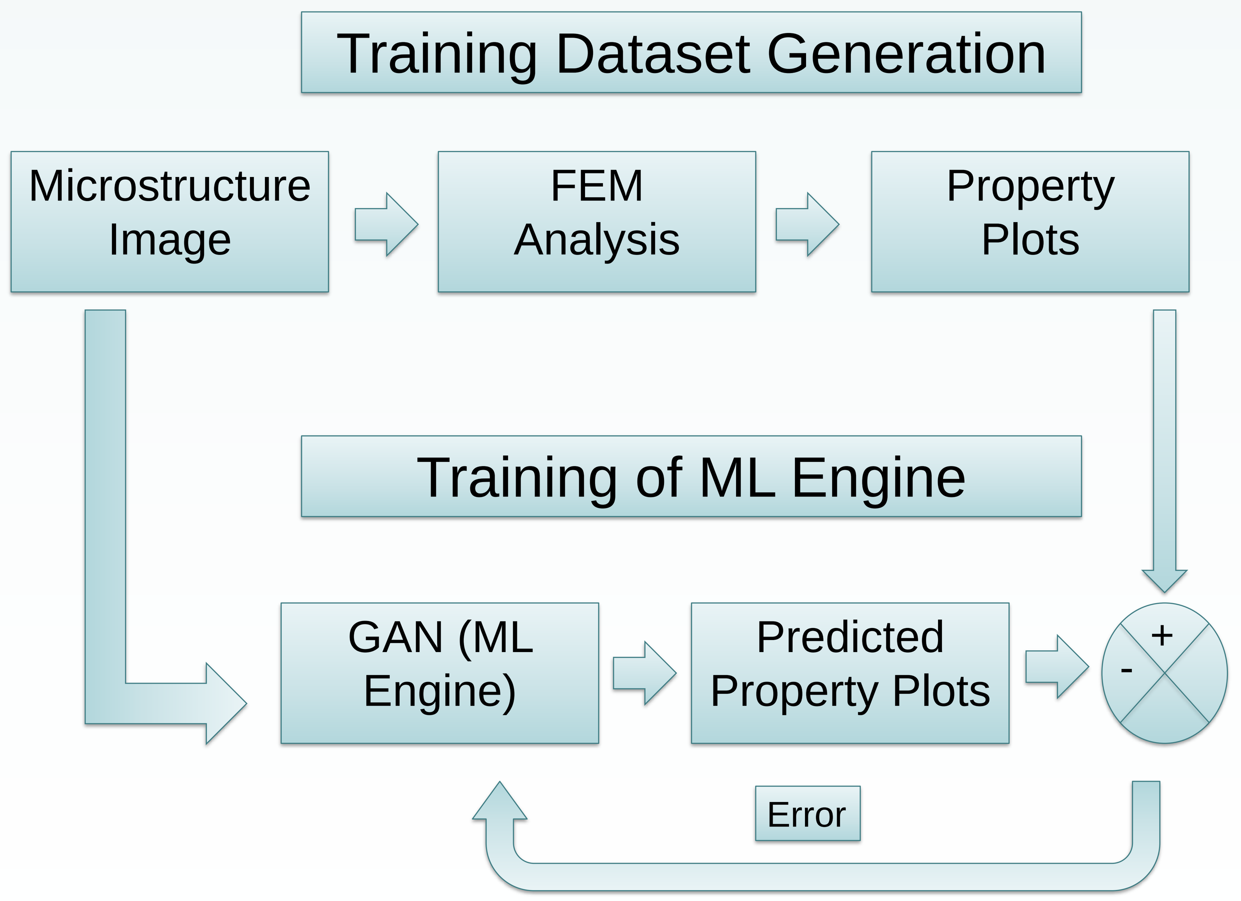
Abstract

This project explores the generation and analysis of synthetic microstructures to predict property plots of composite materials using ML Algorithms. Nowadays, data-driven methods are used to predict the properties of materials. The FEniCS framework was employed to perform FEM Simulations to generate the property plots of composite materials. These plots served as labelled data for training a Generative Adversarial Network (GAN) model. The GAN model was developed to predict stress intensity and displacement plots for unseen microstructures. The results demonstrated the potential of the GAN model to accurately predict stress intensity and displacement patterns based on synthetic microstructures. This approach has significant implications for materials engineering, as it provides a means to efficiently generate and analyze microstructures as an alternative to physical experiments. Combining FEniCS and GANs opens new avenues for understanding and designing composite materials with tailored mechanical properties.

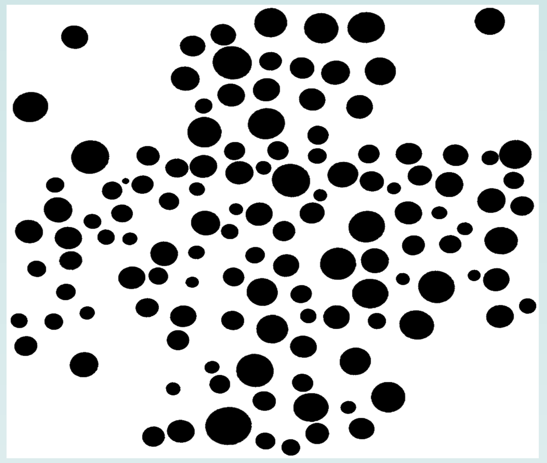
Introduction

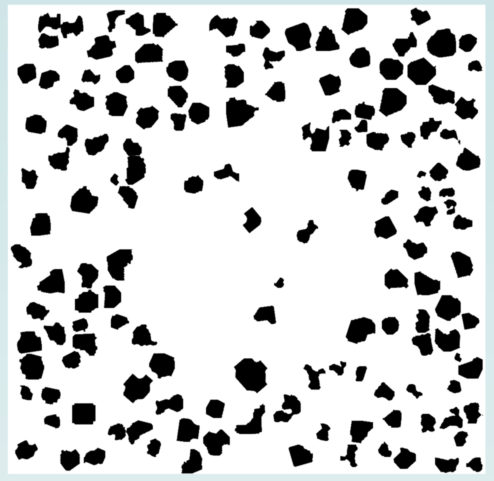
Synthetic microstructure generation plays a crucial role in materials research and development as it can produce the properties of materials under given conditions. This information is valuable for designing new materials with desired properties or optimizing existing ones. Synthetic microstructures also help to generate a large enough dataset for training ML Models. The research aims to accelerate materials engineering by combining image processing, computational modelling and machine learning techniques. The following diagram shows the overall flow of the project.

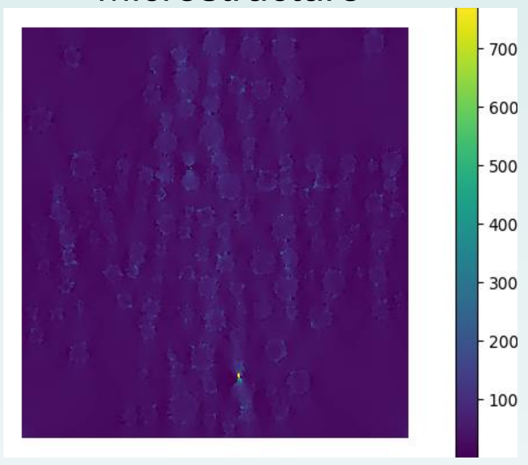


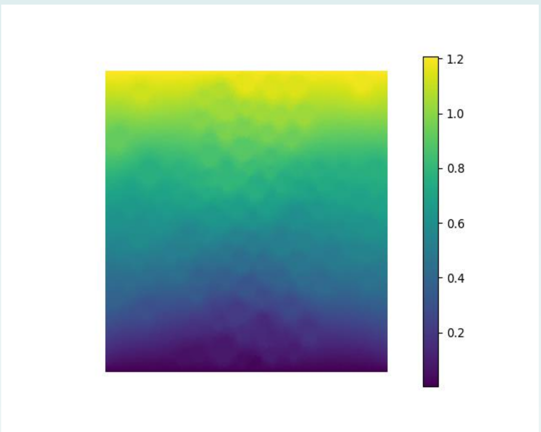
Methodology

This research first generated two datasets of composite microstructure images, one with circular grains and another with irregularly shaped grains. The Stress Intensity and Displacement Plots were obtained from the FEniCS framework. The next step was training the dataset using a pix2pix GAN architecture. It was prepared for 50, 100, 150,200, and 250 iterations, after which the RMS error became low.

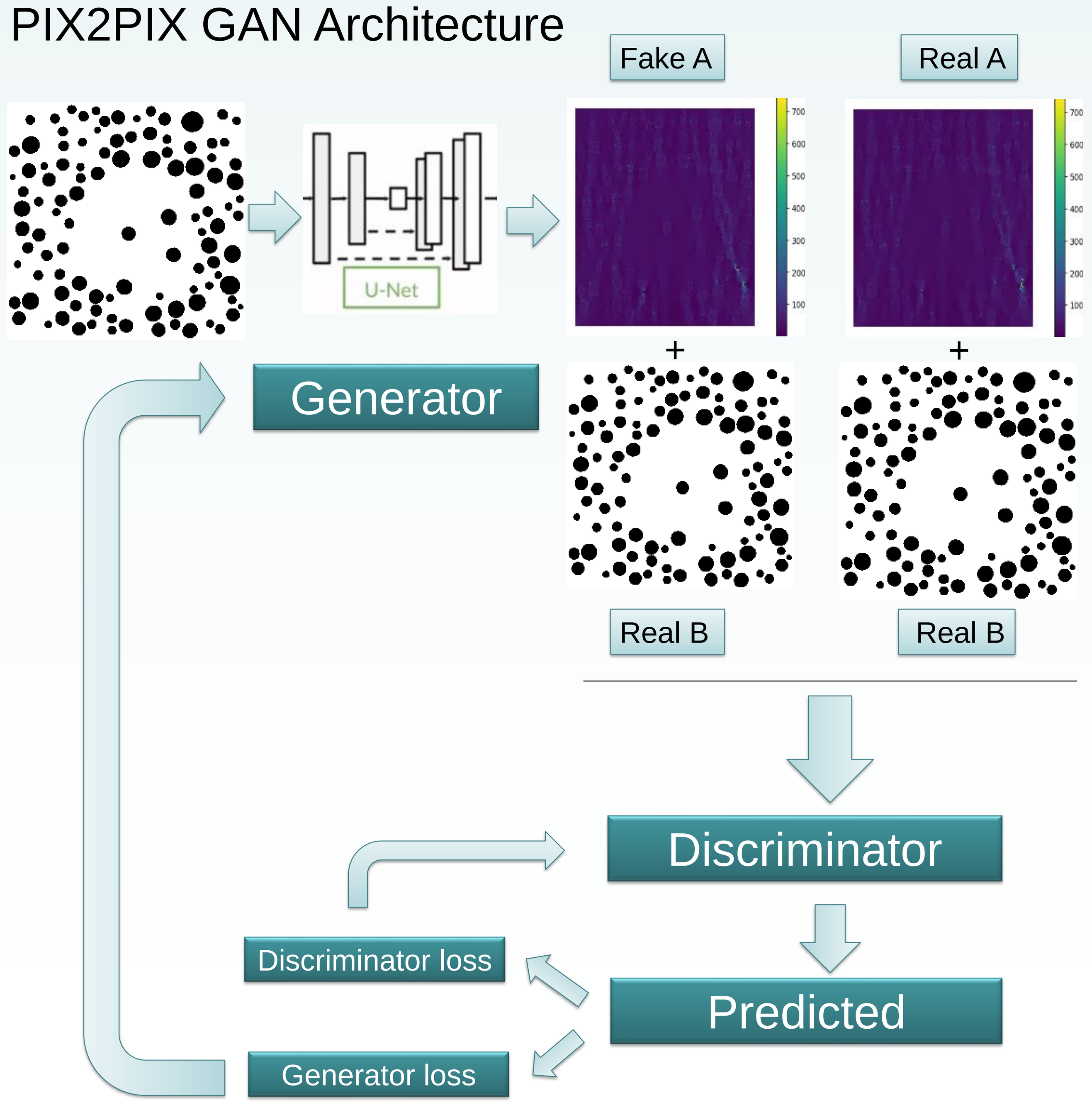

Circular Shaped Microstructure


Irregular Shaped Microstructure


FEniCS Generated Stress Intensity Plot

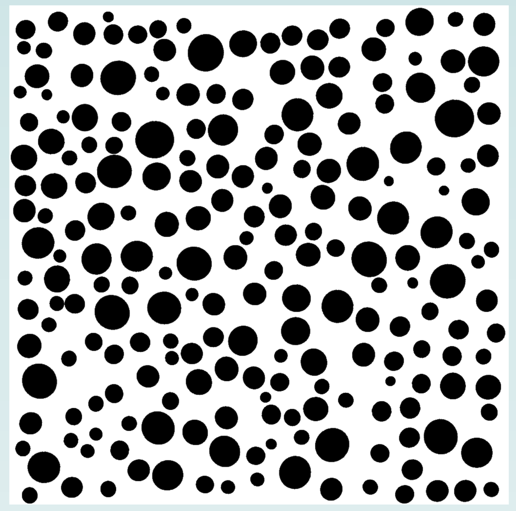

FEniCS Generated Displacement Plot

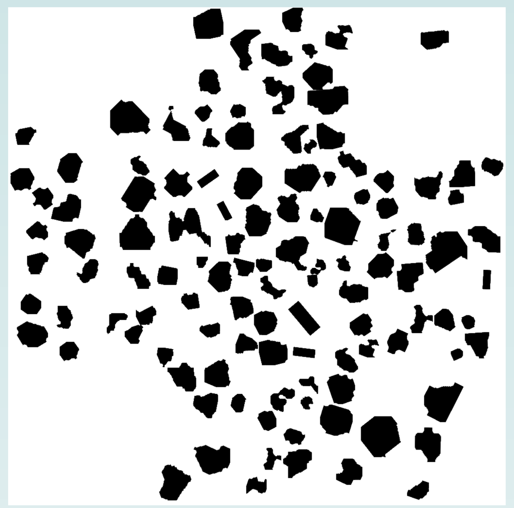
PIX2PIX GAN Architecture

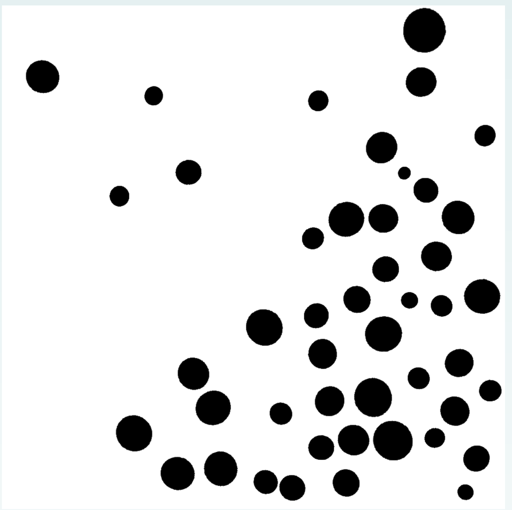


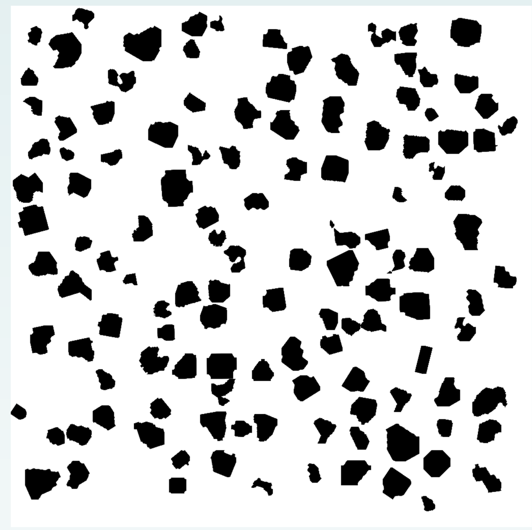
Results

Two distinct datasets were created, each focusing on different types of microstructures. For the first dataset, circular grains were used as the primary shape. Various parameters, including size, distribution, orientation, and area fractions, were systematically varied to offer diversity. The second consisted of irregular grains showing a deviation from the uniformity of circular grains.

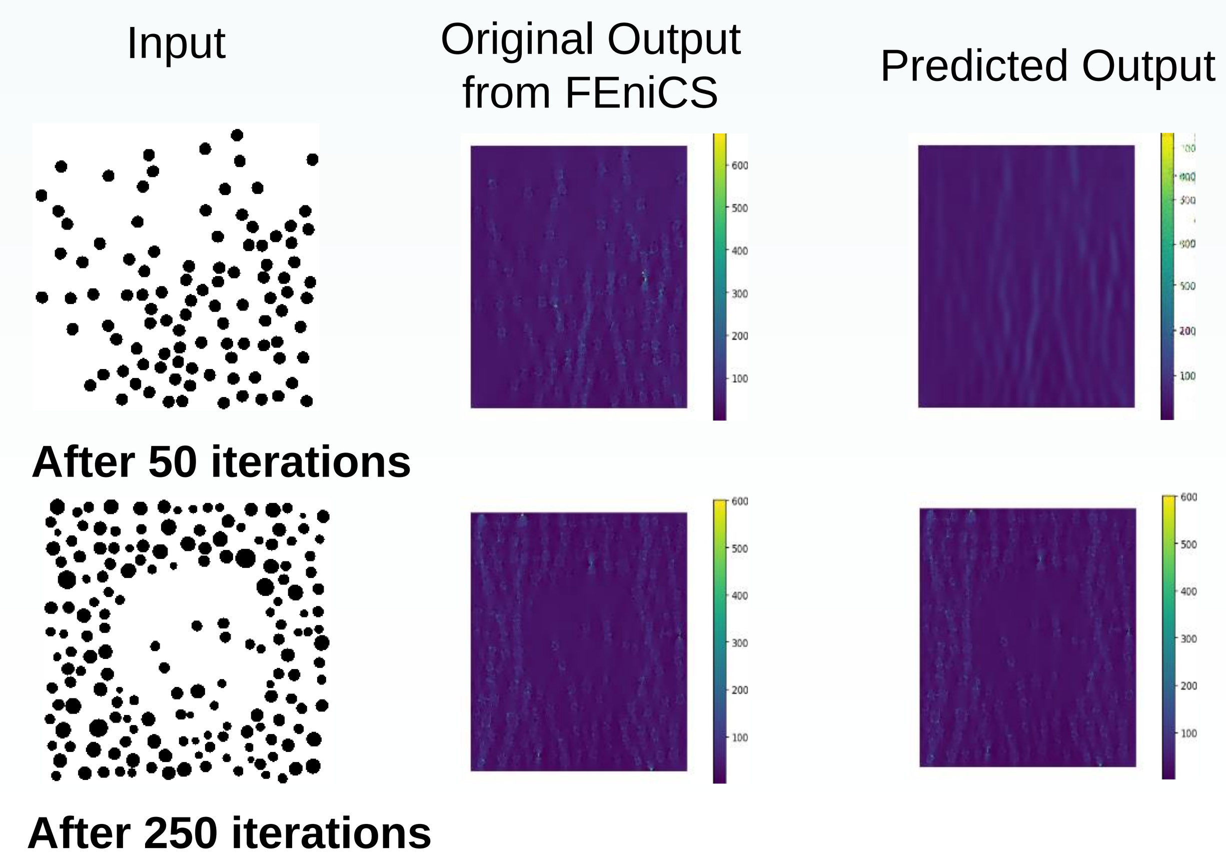

Circular Shaped with homogenous distribution Microstructure

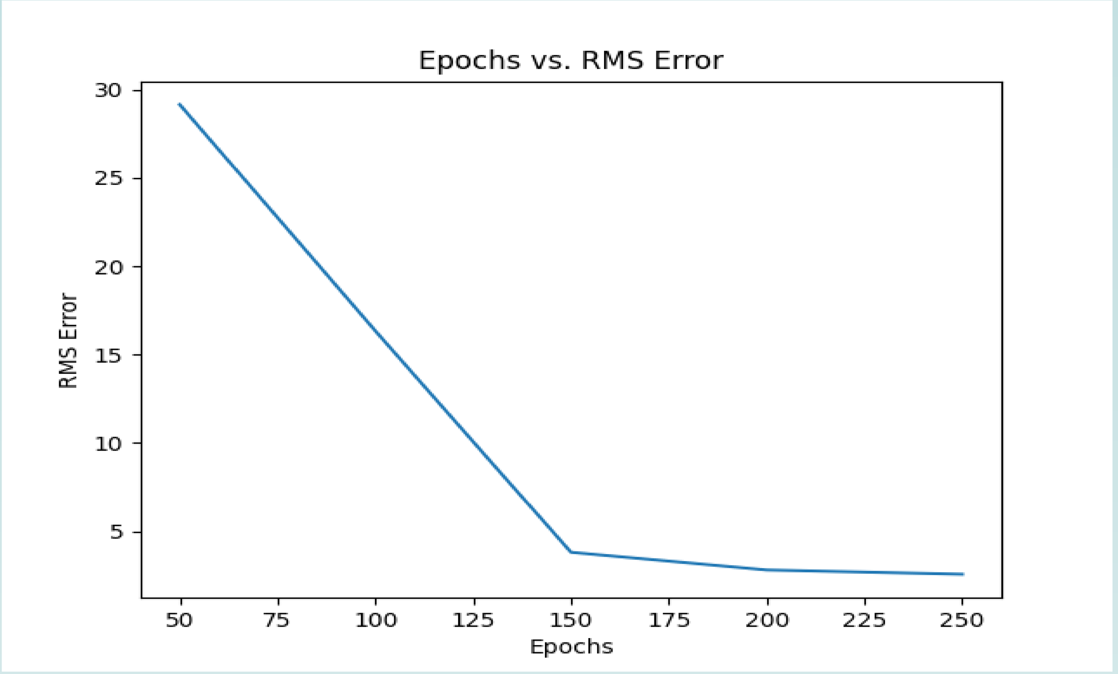

Irregular Shaped with plus distribution Microstructure


Circular Shaped with hyperbolic distribution Microstructure


Irregular Shaped with homogeneous distribution Microstructure

The GAN model was trained on various iterations, and the results are shown below.





The graph visually depicts the relationship between the number of iterations and the corresponding RMS error, showcasing the reduction in error with increased iterations.

Conclusion

The successful generation of synthetic microstructures helped create a dataset containing microstructure images and stress intensity images. The application of Machine Learning enabled us to generate the stress intensity of a two-phase composite microstructure image. Hence the developed framework contributes to the understanding and design of composite materials. These results depict the capabilities of GAN models to predict microstructure properties. Therefore this method provides an alternative to physical experimentation for obtaining properties.

Future Work

The project's next step is to train the model to generate the Displacement Plot for circular-shaped microstructures. Further, we will develop a similar dataset for the microstructure containing irregularly shaped grains in future.

References

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