# Electrical conductivity of polymer composites: multi-level modification and simulation-based prediction

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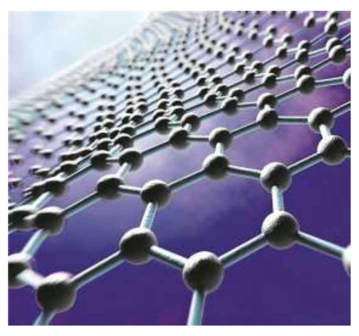
## Introduction

Polymer composites provides outstanding mechanical characteristics & manufacturability to create high-performance and light-weight structures for aerospace, automotive, energy and other high-tech industries. Increasing of inherently low electrical conductivity of polymer composites will open a door to new applications.

In the frame of AERO-UA pilot project, a possibility to develop smart composite structures with a combination of highly conductive and totally non-conductive areas is analyzed for the purposes of aircraft protection against lightning strike and ice accumulation as well as overall structural health monitoring.

## Ways to increase electrical conductivity of composites

- Introduction of graphene nanoparticles and its derivatives into polymer resin to form 3D conductive networks at lower volume content as a consequence of high aspect ratio;
- Cold spraying of conductive particles on reinforcing material to achieve required electrical resistivity throughout the material volume;
- Manufacturing of weft-knitted carbon fabrics with embedded conductive yarns.



## Simulation approaches

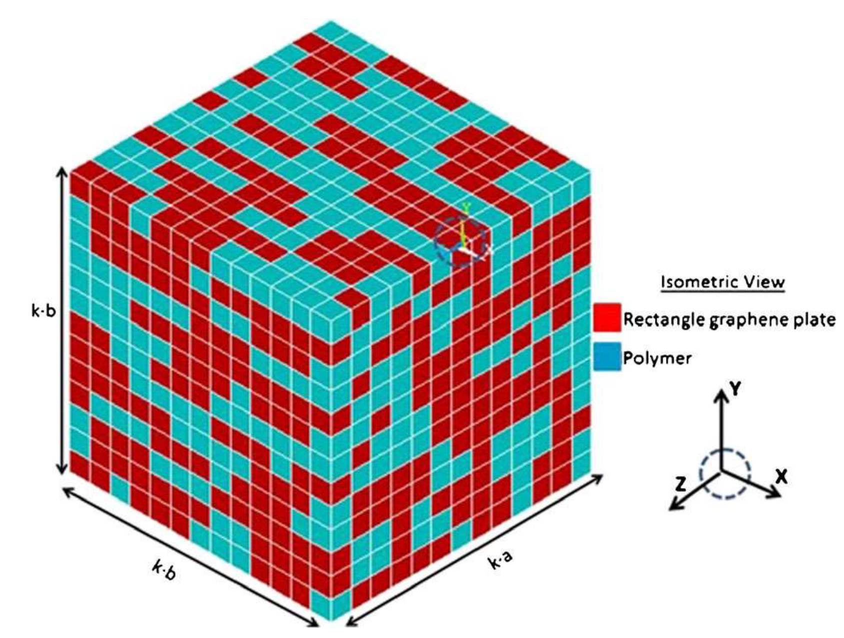
The dual aim of composites electrical properties simulation is to:

- Reduce an amount of experimental studies to determine the properties of materials;
- Choose a necessary architecture of 3d-fabric to obtain a multifunctional materials with specified properties

### Micro-scale approach

Effects that shall be take into account:

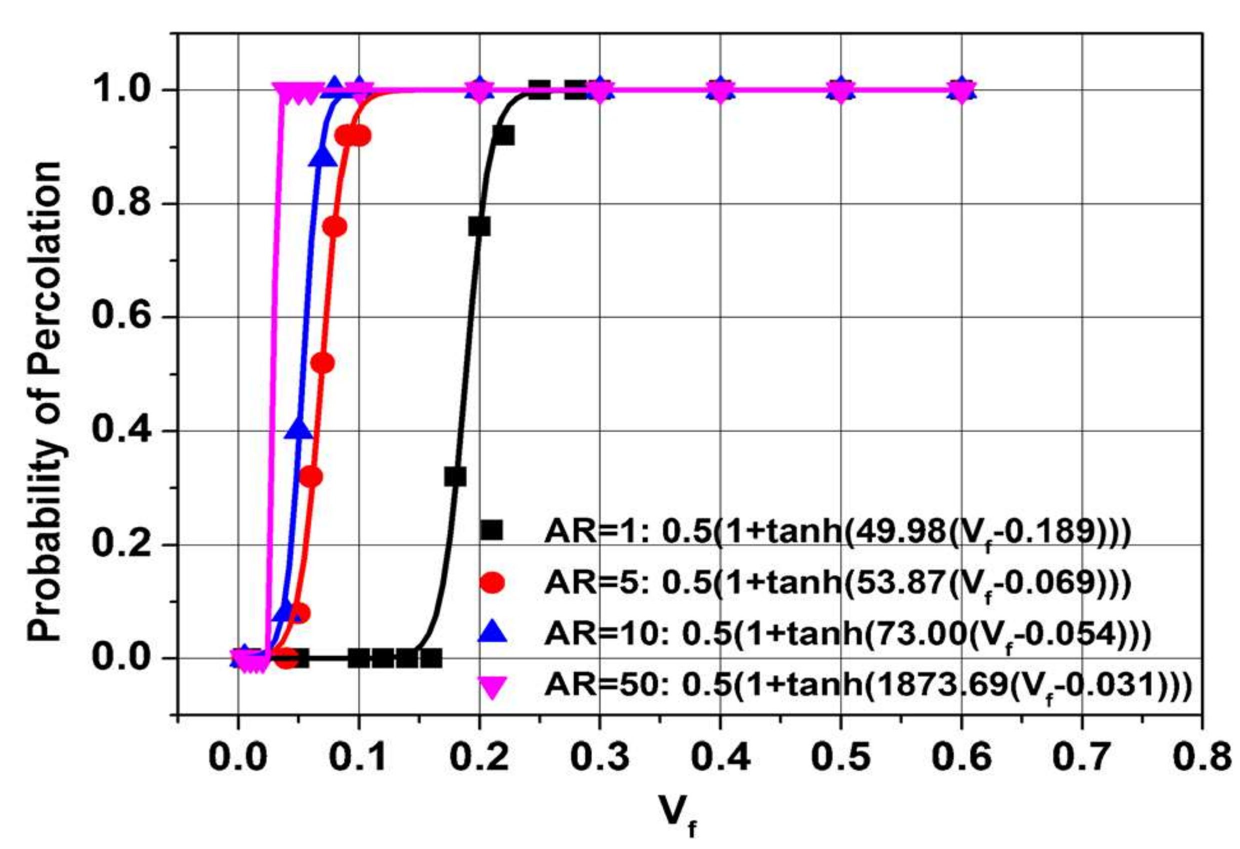
- Particles distribution over the composite material volume (percolation).
- Particles interaction with each other (tunnel effect).




Representative volume element (RVE) finite element

Proposed fitting function for percolation probability

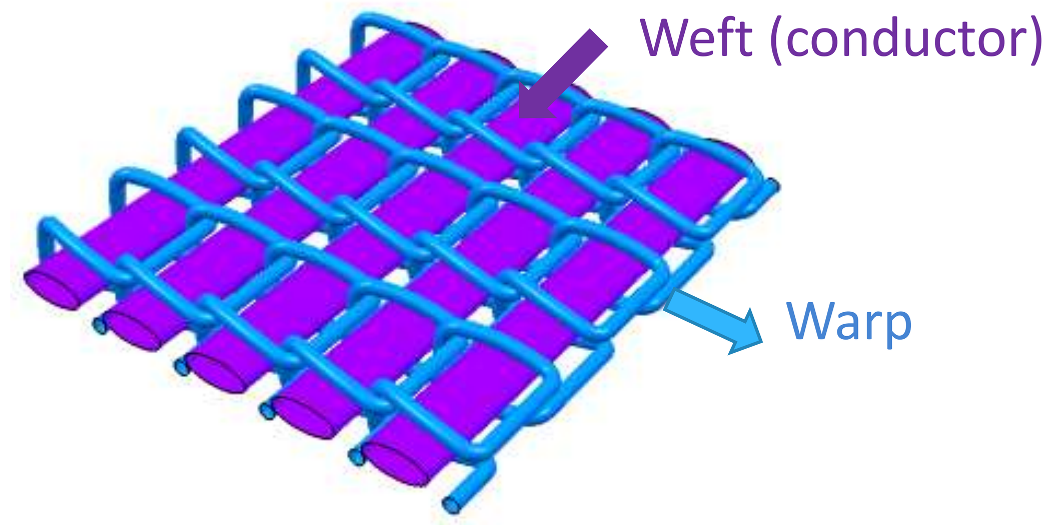
$$P(V_f) = \frac{1}{2}\left(1 + \tanh\left(A\left(V_f - B\right)\right)\right)$$




Percolation probability in respect of volume fraction for studied graphene aspect ratios (AR)

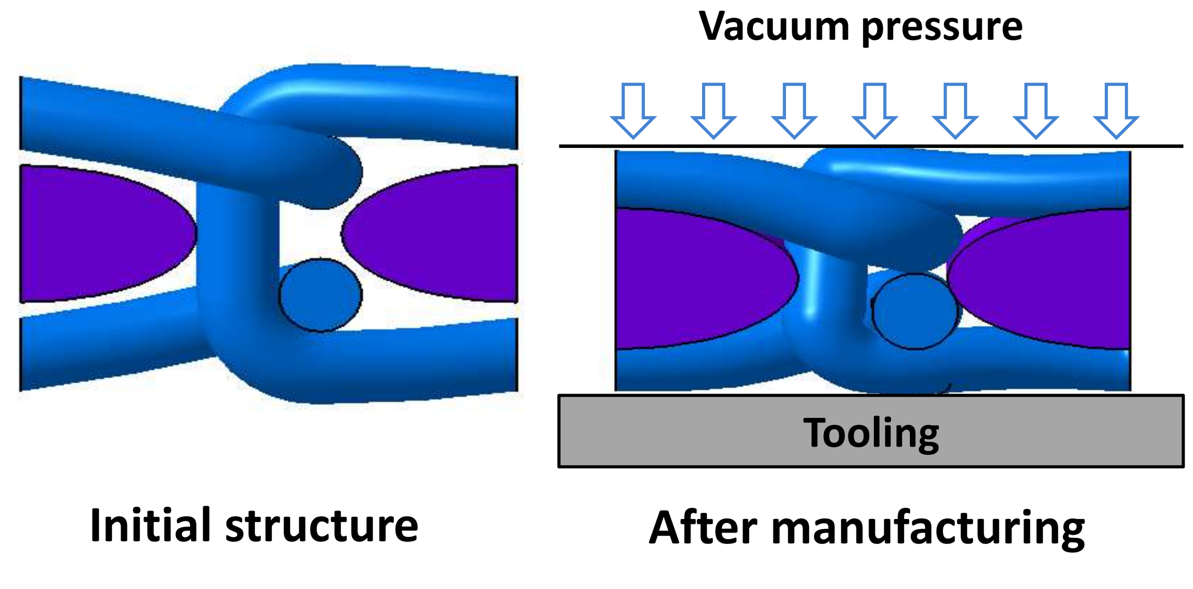
### Meso-scale simulation approach

Research focus is CFRP based weft-knitted fabrics with 3d architecture

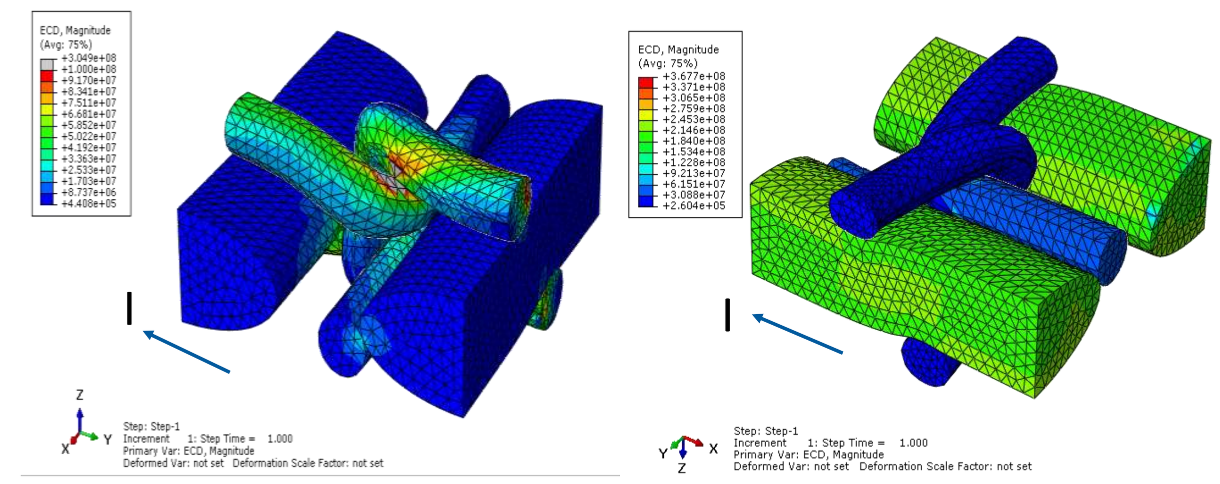



3d-model of weft-knitted fabric

Electrical properties of composite based on 3d-fabrics will depend on manufacturing process, which cause the deformation of the fabric.



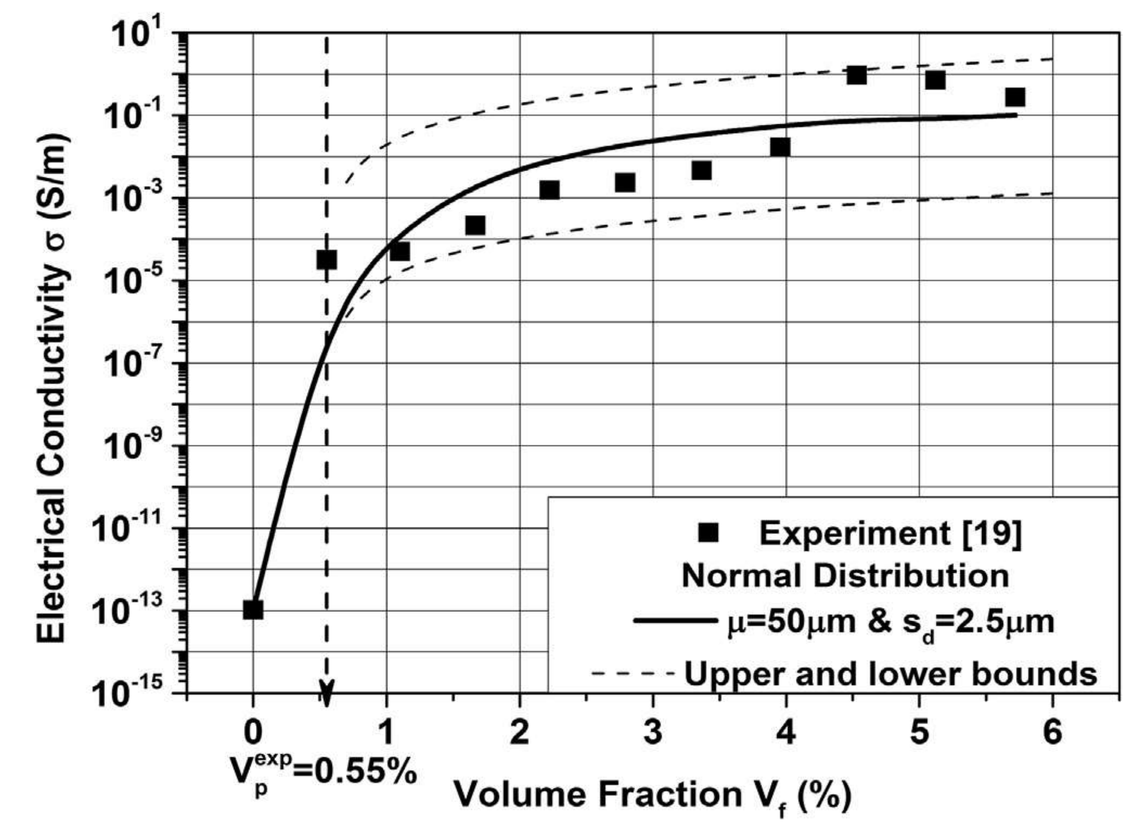

Simulation of fabric deformation under vacuum pressure



Distribution of electrical current density in VRE of weft-knitted fabric

## Experimental validation

Results of electrical properties prediction for grephen-filled composites




Electrical conductivity vs Volume Fraction (experimental data and numerical predictions)

Results of comparison of predicted and calculated electrical resistivity of CFRP-based weft-knitted fabrics

| Direction | Electrical resistivity, $10^{-6}$ Ohm·m | | Variance coefficient of experimental value, % | Difference between calculated and experimental values, % |
|---|---|---|---|---|
| | Predicted | Average measured | | |
| Warp | 1,681 | 2,476 | 3.8 | 32 |
| Weft | 78.5 | 88.5 | 7.4 | 11 |

## Conclusion

An improved multi-scale finite element model for prediction of electrical resistivity with graphene-filled polymer matrix proposed. The approach takes into consideration influence of manufacturing process in the form of the reinforcing material deformation during the molding. Results obtained with use of proposed model are in good agreement with the experimental results. Therefore, the proposed approach can be used for selection of the fabric weaving scheme if actual material structure is unknown.

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*This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 724034*