Analysis of electro-conductive network formation in multilayer graphene sheet/epoxy resin nanocomposites

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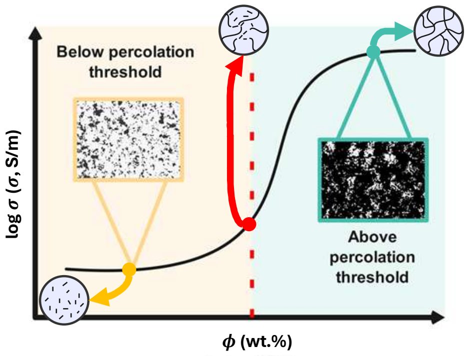
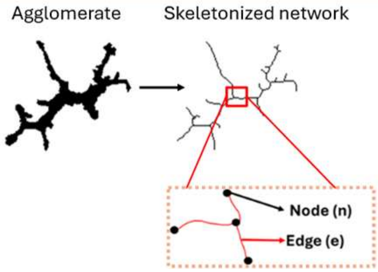
Electrical percolation networks and graph theory

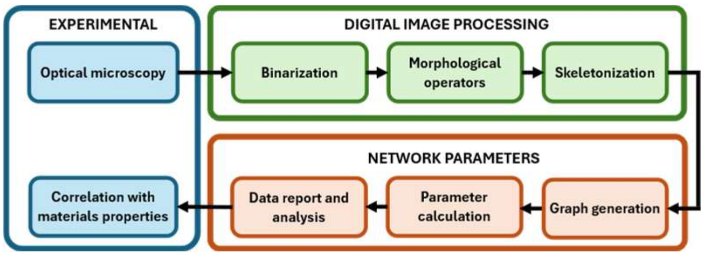


Electrical percolation in polymer nanocomposites describes the transition from an insulating to a conductive state as the filler content (ϕ) increases [1]. Although extensively studied, the morphological mechanisms governing this transition are still not fully elucidated. Below the percolation threshold, isolated domains limit the electrical conductivity (σ), whereas above it, a continuous conductive network emerges [2].



Building on a graph-theory framework [3], this work presents a novel image-based methodology in which conductive networks are abstracted into node–edge graphs derived from skeletonized morphologies to quantitatively characterize conductive paths.

General workflow



Novel methodology transforming optical microscopy images into graph representations through digital image processing, enabling the calculation of network connectivity parameters to quantify structural interconnectivity.

Digital image processing

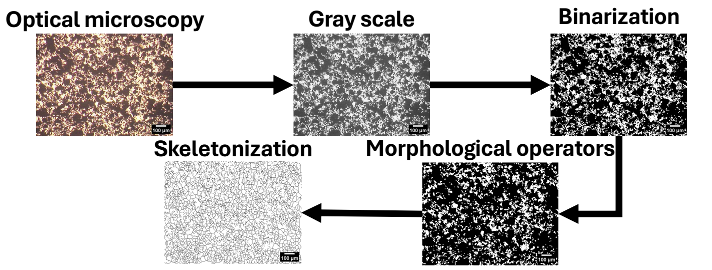
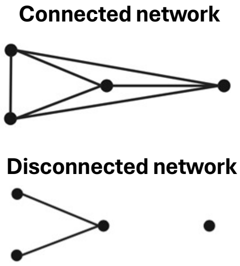


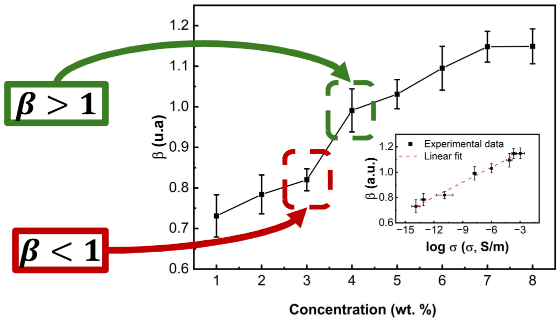
Image processing workflow illustrating the transformation of an optical micrograph into a graph representation: grayscale conversion, binarization, application of morphological operators, and skeletonization for network extraction and analysis.

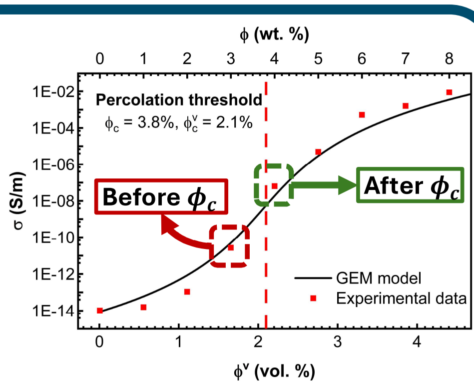
Interconnection parameters correlations

Beta index (β)

$$\beta = \frac{e}{n}$$







Network descriptors extracted from the processed images were evaluated against filler concentration and compared with the electrical percolation behavior obtained experimentally, assisted by the general effective media (GEM) model [4]. The beta index, shown as example, takes values below unity for disconnected or fragmented networks, whereas values above one reflect the emergence of multiple interconnected pathways. Other global parameters exhibited similar trends, confirming that network interconnection metrics sensitively capture the onset of effective conductive pathways and correlate with the observed electrical conductivity response.

Conclusions and perspectives

Graph theory was applied to quantify interconnectivity in multilayer graphene/epoxy nanocomposites. Combining conductivity data with image graph analysis revealed a clear link between microstructure and transport response. The beta index was a good indicator of percolation, reflecting the transition from isolated to connected domains. This methodology offers a reproducible tool for studying conductive network formation and can be extended to other material system and property domains governed by connectivity.

Acknowledgements

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References

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