World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:16, No:05, 2022

A Methodology Based on Image Processing and Deep Learning for Automatic Characterization of Graphene Oxide

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Abstract : Originated from graphite, graphene is a two-dimensional (2D) material that promises to revolutionize technology in many different areas, such as energy, telecommunications, civil construction, aviation, textile, and medicine. This is possible because its structure, formed by carbon bonds, provides desirable optical, thermal, and mechanical characteristics that are interesting to multiple areas of the market. Thus, several research and development centers are studying different manufacturing methods and material applications of graphene, which are often compromised by the scarcity of more agile and accurate methodologies to characterize the material – that is to determine its composition, shape, size, and the number of layers and crystals. To engage in this search, this study proposes a computational methodology that applies deep learning to identify graphene oxide crystals in order to characterize samples by crystal sizes. To achieve this, a fully convolutional neural network called U-net has been trained to segment SEM graphene oxide images. The segmentation generated by the U-net is fine-tuned with a standard deviation technique by classes, which allows crystals to be distinguished with different labels through an object delimitation algorithm. As a next step, the characteristics of the position, area, perimeter, and lateral measures of each detected crystal are extracted from the images. This information generates a database with the dimensions of the crystals that compose the samples. Finally, graphs are automatically created showing the frequency distributions by area size and perimeter of the crystals. This methodological process resulted in a high capacity of segmentation of graphene oxide crystals, presenting accuracy and F-score equal to 95% and 94%, respectively, over the test set. Such performance demonstrates a high generalization capacity of the method in crystal segmentation, since its performance considers significant changes in image extraction quality. The measurement of non-overlapping crystals presented an average error of 6% for the different measurement metrics, thus suggesting that the model provides a high-performance measurement for non-overlapping segmentations. For overlapping crystals, however, a limitation of the model was identified. To overcome this limitation, it is important to ensure that the samples to be analyzed are properly prepared. This will minimize crystal overlap in the SEM image acquisition and guarantee a lower error in the measurements without greater efforts for data handling. All in all, the method developed is a time optimizer with a high measurement value, considering that it is capable of measuring hundreds of graphene oxide crystals in seconds, saving weeks of manual work.

Keywords : characterization, graphene oxide, nanomaterials, U-net, deep learning
Conference Title : ICNAIIT 2022 : International Conference on Nanotechnology, Artificial Intelligence and Internet of Things
Conference Location : Berlin, Germany
Conference Dates : May 23-24, 2022