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A critical review on machine learning applications in fiber composites and nanocomposites: Towards a control loop in the chain of processes in industries

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ABSTRACT

Fiber composites must be evaluated to achieve correct use in various fields. Their properties, performance, condition, and integrity can be quickly predicted and optimized by machine learning (ML), after extensive training, compared with experiments and conventional computational simulations. In this document, papers on ML applications in fiber composites were collected and critically reviewed. It was revealed that kind learning environments have been primarily used. Supervised ML has been more frequently used than unsupervised ML, whereas some specific semi–supervised ML (*e.g.*, reinforcement learning) or deep predictive control have been overlooked. Most ML applications have been successful on the laboratory scale and in the short term. Furthermore, the deployment of ML applications has been overlooked. In addition, retroactive feedback from the manufacturing of fiber and polymers to the manufacturing of composite laminates and structures was neglected. Accordingly, a control loop in the chain of manufacturing processes was discussed. Additionally, language processing tools and statistics were used to summarize and analyze the papers. Finally, it was proposed that multiscale modeling using ML and physics is a potential approach to advance predictions for future applications. Therefore, physicochemical interactions (van der Waals or electrostatic) from nanoscale can be included.

1. Introduction

In general, fiber–reinforced composite (FRC) materials are made of a hard (stiff) elongated material (*i.e.*, the reinforcement material) embedded in a softer (more flexible) material (*i.e.*, the matrix material) [1–3]. An example of a FRC material is wood, which is made of cellulose fibers in a lignin matrix. The matrix can be polymeric, metallic, or ceramic, but most commercial FRCs use a polymeric (thermoset or thermoplastic) matrix [1–3], which is known as fiber–reinforced polymer composite (FRPC). The fiber material can be short or long fibers (*e.g.*, carbon or glass fibers) used for matrix reinforcement. The direction of the reinforcement fibers embedded in the matrix affects the tensile strength (σ [Pa]) of the FRPC [1,2]. Some of the properties of FRPCs that are of great interest include the fracture energy (G [J/m^2]), σ, thermal conductivity (K [W/(m·K)], thermal expansivity (α [1/K]), Young's modulus (E [Pa]), and density [kg/m^3]. FRPCs are used in automotive, marine, aviation, and aerospace industries, such as in airplanes and spaceships, because of their improved stiffness (E), strength (σ), corrosion resistance, fatigue life, wear resistance, enhanced thermal properties (K and α_{Th}), and reduced weight [1–3].

FRPC structures (*e.g.*, boards, car doors, or airplane parts) are manufactured using thin layers of FRPC stacked over one another. A layer is also called ply or lamina, which contains fibers aligned in one direction. In increasing suitable properties (*e.g.*, σ and damage and failure) in various directions, plies are stacked in sequences, creating a laminate. Although long continuous fibers are typically used to make plies, short fibers can also be used, allowing for versatile extrusion, drawing, and

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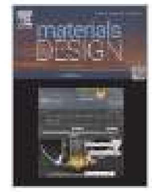

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Highlights

- Statistics and language processing tools were used to analysis papers.
- Fiber polymer composites were largely used in machine learning applications.
- Nanoparticles as reinforcement and nonpolymeric matrices were less frequent.
- Neural and deep neural networks were frequently used.

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