Chapter 16

Optimizing Composite Material Selection Using the Artificial Bee Colony Algorithm: A Comprehensive Approach

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ABSTRACT

The selection of optimal materials for composite structures is an important step in engineering design, balancing performance, cost, and weight. In this chapter, the Artificial Bee Colony (ABC) algorithm, a nature-inspired optimization technique, is applied to efficiently identify the best composite material configurations. The ABC algorithm is inspired by the foraging behavior of honeybees, offering robust search capabilities and convergence properties. We discuss the principles underlying the ABC algorithm, its application to material selection, and performance evaluation criteria for composites. We compare

DOI: 10.4018/979-8-3693-7974-5.ch016

it with traditional optimization techniques and make it clear that it outperforms them in solving complicated multidimensional problems. Case studies give an example of how it can be used for obtaining the optimal solution in several engineering applications. This chapter provides a comprehensive guide for researchers and engineers to improve design efficiency and performance by utilizing bio-inspired algorithms in material selection.

INTRODUCTION

Composite materials are built from at least two constituent materials having significantly different physical or chemical properties. These materials maintain their identities within the final structure, and each type of material adds a synergistic blend toward maximizing desirable properties of each component. Often a composite includes a matrix, like polymer, metal, or ceramic, and reinforcement, like fibers or particles. The elements are bonded through the matrix, which reinforces and transfers the load between the elements, thus improving the strength, stiffness, and fatigue characteristics of the composite. Some examples include fiberglass, carbon fiber-reinforced polymers, and ceramic matrix composites (Wang et al., 2023). Such materials can exhibit outstanding performance benefits such as high strength-to-weight ratios, resistance to corrosion, and the possibility of tailorability for specific applications. Applications include aerospace and automotive systems, civil engineering, and manufacturing of sporting goods.

Material selection for composite structures would be important to have ideal performance, cost-effectiveness, and sustainability. Material selection is a multidimensional problem that considers factors like weight, mechanical properties, strength, durability, cost, and environmental impact. For example, in aerospace engineering, material selection impacts the efficiency with which fuel can be carried, the payload, and its overall performance. The automobile industry is not far either, as material selection there affects vehicle safety, amount of fuel consumed, and emissions. Effective selection of material can lead to great gains in the performance of a product and significantly reduce lifecycle cost. Thus, selection processes should be carried out systematically and based on informed knowledge (Banharnsakun, 2020). So often engineers are forced to deal with difficult trade-offs of the properties of material, invoking such powerful computational tools and optimization techniques to choose the optimal combination (Gusev et al., 2020).

Optimization algorithms play an important role in material selection through systematic methods to define optimal constraints on the best solutions. Conventional techniques applied for optimization include linear programming, gradient descent, and genetic algorithms in solving complex problems in engineering. These methods rely on the mathematical formulation and iterative processes traversing the solution space and continuing toward the vicinity of optimum solutions. However, the selection of composite material itself is extremely complex and multi-dimensional in nature and thus requires even more advanced approaches. In this context, bio-inspired algorithms such as the ABC algorithm come into relevance to finding solutions for optimization problems. A principle behind the algorithm is based on the principle of swarm intelligence that functions through collective intelligence and adaptive behaviors of biological systems (Yue et al., 2019).

This inspiration from the foraging behavior of honeybees has provoked research to develop the Artificial Bee Colony algorithm for optimization purposes, especially complex tasks such as material selection. Honeybees, in their natural environment, work in a decentralized and self-organized manner to find and exploit food sources efficiently. This is translated into a computational model in the ABC algorithm