Application of Evolutionary Algorithms to Predict Mechanical Properties on Natural Fibers – A Review

Prasanth kumar. R¹, Rajmohan.T², Vijayan. D³

¹ Postgraduate Student. Department of Mechanical Engineering, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya University.
² Associate Professor. Department of Mechanical Engineering, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya University.
³ Assistant Professor. Department of Mechanical Engineering, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya University.

✉ ¹prasanthrentachinthala@gmail.com

Abstract. Natural fibers are an abundant source in nature, having an inherent property in which include biodegradable, decomposable and cost efficient. Moreover, they exhibit extensive mechanical properties such as tensile modulus, flexural modulus than synthetic fibers when reinforcing polymer resins. However, adding inappropriate levels of quantity of resins misleads on obtaining desired mechanical properties. Several approaches have been utilized in the past decades to get desired mechanical properties on the natural fibers, in which applying evolutionary algorithms are the most recent and familiar in the composite research community. Therefore, in this study an application of evolutionary algorithms on natural fibers are presented. This objective of the review is to provide detailed information of the natural fibers along with its recent algorithmic approaches. Moreover, the effect of various treatments and its changes in mechanical, thermal and electrical properties of matrix.

Keywords Natural fibers. Evolutionary Algorithms. Mechanical Properties.

1. Introduction

In recent years, natural fibers have gaining much attention by the composite research community due to their low density, bio degradability, sustainability and good thermal, acoustic properties. Specifically, high performance applications such as automobile, aircraft, and marine applications are being replaced from synthetic fiber to natural fibers by combining appropriate levels of quantities of polyester and polymer resins. Usually natural fibers are classified into different types as represented in Figure. Impressive investigations have been carried out using many natural fibers such as kenaf, hemp, flax, sisal, coir and jute using various polymer matrices. In general, the development of polymer matrices was composed based on the earlier studies conducted based on the composite or by trial and error methods. Despite the advantages of trial and error method, there are more setbacks such as more computation time and requires numerous databases to understand fiber/matrix ratio for fabricating the composites. Alternatively, by applying soft
computing techniques the complexity in finding these values can be minimized. Numerous soft computing techniques are being utilized in recent days for optimizing the natural fiber composites. They are Genetic Algorithm (GA), Simulated Annealing (SA) algorithm, Particle Swarm Optimization (PSO), Teaching Learning Based Optimization (TLBO) algorithm, etc. therefore, taking these applications of soft computing techniques into consideration an in-depth review has been presented on the application of multi objective evolutionary approach on natural fibers.

### 2. Fiber Flowchart

![Fiber Flowchart](image)

### 3. Evolutionary Algorithms

#### 3.1 Genetic Algorithm

S Jayabal et al. [1] investigated studies on optimization of drilling characteristics in fiber reinforced composites was carried out using Nelder-Mead and Genetic algorithms. They selected the composites with natural fiber known as coir for reinforcing material. They determined optimum values of machining parameters and process parameter through experiments planned, conducted and analyzed using the Box-Behnken design, Nelder-Mead and Genetic algorithm methods. A optimized mathematical model of drilling machining parameters such as thrust force, torque and tool wear were developed and they improved tool life by selecting optimal cutting parameters such as drill bit diameter, speed and feed rate so that they reduced tool wear.

J Lilly Mercy et al. [2] conducted experimental studies on genetic optimization of machining parameters affecting thrust force during drilling on composite plates. In this work pineapple unidirectional fiber mats were used as reinforcement material and epoxy resin as matrix material to fabricate composite plates.
Drilling experiments were conducted under different conditions of machining by Taguchi L27 orthogonal array and established mathematical relationship between input parameters and output response by using statistical modelling. They achieved drilling operation on pineapple reinforced composite plates by using HSS drill bits with varied cutting parameters and optimization of thrust force done by using genetic algorithm so that they achieved increase in feed rate with lower thrust force and speed.

Velumani S et al. [3] investigated studies on mathematical modeling and optimization of mechanical properties polymer-based matrix composite. They used short coir fibers as reinforcement and vinyl ester polymer as matrix material. The second order mathematical models were developed by using statistical packages like regression modelling were developed using experimental database and optimization was performed by using genetic algorithm. They noticed the results such that genetic algorithm optimization indicated the combination of fiber length and fiber content influenced improvement in values of mechanical properties such as tensile, flexural and impact strengths.

3.2 Simulated Annealing Algorithm
Kailainathan S et al. [4] conducted studies on hybrid particulate fiber polymer composites, they used industrial bio-waste teak wood powder and natural sisal fiber as reinforcements for polymer matrix. Hybrid composite fabrication was done by using compression molding technique, process parameters were developed by using mathematical models and further these models were optimized by simulated annealing algorithm to get better mechanical properties. They noticed improved mechanical properties such as flexural and tensile behavior over the specified range of conditions.

Bharathiraja G et al. [5] investigated studies on optimization of mechanical behaviors of bio particulates filled coir-polyester composites. In this work they used red mud and termite mound soil as bio particulates, green husk coir fibers as reinforcement material and bio particulates are mixed in proportions with polyester resin system so that resin system consist of unsaturated orthophthalic polyester resin. They conducted Analysis Of Variance for understanding mechanical behaviors caused by the effects of fiber length and particulate content on coir polyester composites, over the specified range of conditions to predict mechanical behavior they developed nonlinear regression models and fabrication parameters, optimization of mechanical behavior was analyzed by using simulated annealing algorithm. They obtained improved optimal values of mechanical properties such as tensile, flexural and impact strengths was determined using simulated annealing algorithm by optimization nonlinear regression models and through ANOVA analysis they concluded by using bio particulates mechanical performance greatly improved in coir-polyester composites.

3.3 Teaching Learning Based Optimization Algorithm
Sivakumar M et al. [6] conducted studies on studies on shear strength of CNT/ coir fiber/ fly ash-reinforced epoxy polymer composites. Through design of experiment approaches they used technique called response surface methodology and prepared experimental specimens by varying contents of reinforcements with epoxy, for understanding reinforcement percentage on the shear modulus of composite they carried out study known as ANOVA and two models were predicted shear modulus by using regression models. Out of two models one was based on ANN and other through multiple linear regression model and optimization of reinforcement parameters were done by using TLBO algorithm. They implemented TLBO algorithm for both models to get optimum parameters with increased shear modulus and by using ANN model they obtained the set of proportionate results of reinforcement contents along with increased shear modulus.

Mangat [7] conducted experimental investigations on bio degradable structure for bio medical application based on natural fiber embedded additive manufacturing, their intention is to explore the behavior of mechanical and bacterial characteristic of chemically treated waste natural fiber inserted with three dimensional structures produced with fused filament deposition for biomedical application. They used raw
animal fiber and chemically treated for the usage in biomedical structures, silk and sheep wool fibers used as reinforcements and polyactic acid used as matrix material. The laminated composites are prepared by using a low-cost desktop time additive manufacturing method. Through design of experiments technique they obtained results of output characteristics such as dimensional accuracy, hardness, three-point bending strength and bacterial test which was influenced by input parameters obtained through ANOVA and signal/noise tests, optimization of input parameters for the design of embedded structures for scuffled based biomedical applications done using different optimization techniques like Taguchi L9 orthogonal array method, single parametric optimization, TLBO and multi parametric optimization.

3.4 Crow Search Algorithm

Sultana N et al. [8] investigated studies on modeling approach of surface response coupled with crow search algorithm for optimizing the properties of jute fiber reinforced concrete, natural fiber jute is reinforced with concrete in order to get greater strengths in JFRCC. A mathematical models was developed using response surface methodology with box-behnken design, response surface methodology is integrated with crow search algorithm in order to find global optimal solution. For making standard dimensions of cylinders and cubes depends on three independent factors such as water-cement ratio, length and volume of jute fiber. For finding second order polynomial models for both compressive and tensile strengths of JFRCC they used RSM-based on BBD method initially and later RSM integrated with crow search algorithm to find global optimal solution and results stated the maximum compressive and tensile strengths were found along with the optimal set of independent factors.

3.5 Particle Swarm Optimization Algorithm

M Megahed et al. [9] conducted studies on optimization of hybrid natural laminated composite beams for a minimum weight and cost design, the fibers are carbon/flax used as reinforcement with epoxy resin as matrix material to get hybrid natural laminated composite beams and compared with hybrid carbon/glass/epoxy, neat glass/epoxy and neat flax/epoxy laminated beams. The main objective of study is to lower the weight and cost of the laminated composite beams with a specified lower bound constraint of natural frequency. The modeling and analysis of the problem were performed based on the Euler-Bernoulli beam theory, the beam is composed of many layers and the design variables such as fiber material, fiber volume fractions, thicknesses and fiber orientations. Layer thickness and fiber orientations are the manufacture limitations known as discrete variables, so that PSO algorithm is used to deal with constrained problem with discrete variables and optimal stacking sequence design is investigated. The results stated that optimal hybrid composite that satisfy the lower frequency limits such as high and low stiffness skin core layers and PSO determines the optimum layer thickness and fiber volume fractions. They noticed with appropriate stiffness to weight ratio out of all hybrid laminated beams, carbon/flax/epoxy is cheaper and lighter.

3.6 Response Surface Methodology

Boumaaza et al. [10] conducted studies on natural fibers reinforced plasters and the effects on mechanical properties when natural fiber is treated with alkaline solution and optimization technique carried out using RSM. They used natural fibers such as sisal, flax and jute fibers and treated with different concentrations of NaOH alkaline solution, with varied fiber lengths reinforced with plaster mortals. They determined experimental parameters using ANOVA test, for optimizing output responses they used RSM and desirability function DF. They stated that the reinforcement of plasters with alkali treated fibers possess greater flexural strength, displacement and flexural modulus, fibers like flax lowered crack propagation and bridged the voids so that behavior of plaster was change from brittle to non-linear in nature. They stated the RSM is a good modelling tool that identifies insignificant and interaction factors with reduced
complexity and given effective predictions for given problem and they noticed fiber lengths plays a pre
dominant role when compared with alkali dosage variable over the response of process.

3.7 Artificial Neural Network

Khazi et al. [11] conducted predictive studies on ANN models for varying filler content for cotton fiber/PVC composites based on experimental load. Here they use cotton fiber as filler content to improve the mechanical properties of the PVC composite material. A series of experiments carried out in laboratory by varying filler content in the composites depending experimental data, ANN models are developed, trained and tested on tensor flow using python library keras to implement back-propagation method. They predicted load displacement curves by using different methods such as grid search hyper parameter turning method and k-fold cross validation methods, ANN models are also used to determine load displacement curves. Six ANN models was developed using tensor flow with backend keras library they observed developed models predicted the load-displacement curves for varying content of fiber in composites. Okoye et al. [12] investigated studies on multi objective optimization of newbouldia leaves fiber and recycled high density polyethylene composites for the application of fireboard. Optimization of fire board properties was carried out by using MOR, MOE, IB and WA fireboard in response to the variations in process parameters and experimental design was developed using CCD which was used to develop RSM model for variation in physical and mechanical properties of fireboard. ANN model is also used to predict properties of fireboard moreover it was used as fitness function for multi objective optimization. They stated results such that ANN and RSM models produced significant properties of fireboard, the optimized Pareto front of the non-dominated sorting genetic algorithm over desirability function as a multi-optimization tool for the design and practical applications of the composite.

4. Conclusion

Evolutionary algorithms plays a vital role in solving natural fibers because it’s combinatorial problem which has many solutions of similar performance. Evolutionary algorithms are predominant in successfully solving discrete variables and can get optimal solutions. Design engineers will have a choices of set of solutions so that they can select optimal solution. By mastering the specialized evolutionary algorithms it can reduce the optimization cost when compared with other evolutionary techniques. From the review, it can be understood that, the evolutionary algorithms can be used in solving complex multi-objective problems with in less duration and cost effective.

5. References

[1] S Jayabal, U Natarajan 2010 Optimization of thrust force, torque, and tool wear in drilling of coir fiber-
reinforced composites using Nelder–Mead and genetic algorithm methods, DOI 10.1007/s00170-010-
2605-7.

[2] J Lilly Mercy, P Sivashankari, M Sangeetha, K R Kavitha, S Prakash 2020 Genetic Optimization of
Machining Parameters Affecting ThrustForce during Drilling of Pineapple Fiber Composite Plates – an
Experimental Approach, https://doi.org/10.1080/15440478.2020.1788484

[3] S Velumani, P Navaneetha Krishnan, S Jayabal 2011 Mathematical Modeling and Optimization of
Mechanical Properties of Short Coir Fiber-Reinforced Vinyl Ester Composite Using Genetic Algorithm
Method, DOI: 10.1080/15376494.2012.699599.

[4] Kailainathan S, R Muralikannan, K Nijandhan, Srirasen Venkatachal 2019 High-strength hybrid
particulate-fibre polymer composites: The role of process temperature on the mechanical strength,
https://doi.org/10.1088/2053-1591/ab54a0
[5] G Bharathiraja, S Jayabal, R Prithivirajan, S Sathiyamurthy 2014 Optimization of mechanical behaviors of bio particulates filled coir-polyester composites using simulated annealing.

[6] Sivakumar Mahalingam et al. 2019 Studies on shear strength of CNT/coir fibre/fly ash-reinforced epoxy polymer composites, https://doi.org/10.1680/jemmr.19.00098.

[7] Amarveer Singh Mangat 2018 Experimental investigations on natural fiber embedded additive manufacturing-based biodegradable structures for biomedical applications https://doi.org/10.1108/RPJ-08-2017-0162

[8] N Sultana et al. 2020 An experimental investigation and modeling approach of response surface methodology coupled with crow search algorithm for optimizing the properties of jute fiber reinforced concrete, Construction and Building Materials 243 (2020) 118216

[9] M Megaheda et al. 2020 Optimization of hybrid natural laminated composite beams for a minimum weight and cost design, Composite Structures 239 (2020) 111984

[10] Messaouda Boumaaza, Ahmed Belaadi, Mostefa Bourchak 2020 The Effect of Alkaline Treatment on Mechanical Performance of Natural Fibers-reinforced Plaster: Optimization Using RSM, https://doi.org/10.1080/15440478.2020.1724236

[11] Monzure Khoda Kazi et al. 2020 Predictive ANN Models for Varying Filler Content for Cotton Fiber/PVC Composites based on Experimental Load Displacement Curves, https://doi.org/10.1016/j.compstruct.2020.112885

[12] Chidozie Chukwuemeka Nwobi-Okoye 2019 RSM and ANN Modeling for Production of Newbouldia Laevies Fibre and Recycled High Density Polyethylene Composite: Multi Objective Optimization Using Genetic Algorithm, DOI 10.1007/s12221-020-9597-1.