Development of innovative intelligent model to estimate the strength properties of hemp bio composite mixture using the combination of water cycle algorithm and MARS method

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ABSTRACT

Considering the characteristic of ordinary concrete, which is a composite material with characteristics such as resistance and low tensile strain range. Basically, the two main weaknesses of concrete, which include the brittle behavior of concrete and the weakness in its elasticity, have made the use of concrete structures made of ordinary concrete face major problems. In general, by adding fibers to the concrete mixture, it is possible to improve the mechanical properties of concrete. In this research, an innovative approach using the water cycle algorithm was used to combine with the adaptive multivariate regression spline method (MARS) to model and predict the compressive strength and tensile strength of concrete containing hemp bio composites. For the development of each of the proposed models, 153 mixing designs along with their compressive strength results were collected from authoritative articles. After analyzing and evaluating the influencing parameters by Mallow coefficient, the input parameters to the smart models include the ratio of water to cement base materials, the ratio of hemp seeds to cement base materials, the weight percentage of hemp seeds, cement base materials, seeds hemp, density of cement base material, density of dry material and strength of cement base material were selected. The results showed that the correlation coefficient for the compressive strength model for MARS optimized with the algorithm and Mars is 0.991 and 0.971, respectively, and the tensile strength is 0.928 and 0.911, respectively, in the training and testing phase. Investigations show that the proposed MARS model optimized with meta-heuristic algorithm has good performance and high accuracy in estimating the compressive strength and tensile strength of concrete containing hemp bio composite. The external validation results also show that the proposed approach can be introduced as predictive models and the correlation between predicted values and experimental values cannot be random.

KEYWORDS

Hemp bio composite, natural fibers, artificial intelligence, MARS method, water cycle algorithm.

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1. Introduction

The planet is currently undergoing rapid climate change, resulting in a significant increase in overall atmospheric warming within a relatively short period of time. Currently, 30% of global power production is dedicated to meeting the energy needs of civil sectors. Specifically, approximately 60% of the world's electric power is consumed by commercial and residential buildings [1]. In addition to consuming a substantial amount of energy throughout their life cycle, buildings are also responsible for nearly 30% of global greenhouse gas (GHG) emissions [2]. Another significant contributor to carbon emissions is the concrete industry. Research has shown that the cement industry alone consumes approximately 12-15% of total industrial energy and releases 5-7% of the world's carbon emissions into the atmosphere [3]. According to a report by the International Energy Agency (IEA), the cement industry produced 4.1 Gt of cement in 2018, resulting in the emission of 4.1 Gt of carbon. Consequently, it can be deduced that a substantial amount of energy, both in terms of production and usage, is expended in the manufacturing of traditional construction materials and the operation of buildings. This process also results in the emission of CO_2 into the atmosphere, leading to heightened environmental concerns among scientists and engineers. The reduction of CO_2 emissions and energy consumption in buildings, as well as the availability of environmentally-friendly alternative construction materials, have become essential and central concerns in contemporary civilization [4].

The use of bio-aggregate-based building materials has been growing in popularity in the creation of cost-effective and environmentally friendly construction engineering materials [5]. In the creation of cost-effective and environmentally friendly construction engineering materials [6]. Multiple research has found different raw materials utilized in the manufacturing of bio concrete. Among these resources, plant barks like hemp have proven to yield consistent outcomes owing to their (a) hygrothermal properties, (b) capacity to decompose naturally, (c) sustainability, and (d) renewable nature of plants. In this regard, this study proposed model according to artificial intelligence (AI) method coupled with evolutionary algorithm for modeling the strength estimation of the hem-based bio composites. To do so, multivariate adaptive regression splines (MARS) method integrated with water cycle algorithm to present auto-estimated and evolutionary predictive model.

2. Material and Methods

A comprehensive database consisting of 153 data points for bio-composites was developed using data from earlier studies conducted by other researchers to implement the AI model.

2.1. Multivariate adaptive regression splines

Multivariate adaptive regression splines (MARS) is a statistical technique developed by Jerome H. Friedman in 1991 for regression analysis. The user's text is a reference to a source or citation. Non-parametric regression is a technique that extends linear models by automatically modeling nonlinearities and interactions between variables. MARS constructs a model using two distinct stages: the forward pass and the reverse pass. The two-stage strategy is identical to the one employed by recursive partitioning trees. The forward pass often leads to overfitting of the model. In order to enhance the model's generalization capabilities, the backward pass systematically removes the least effective term at each stage until it identifies the optimal sub model. The Generalized cross validation criteria is used to compare model subsets. The backward pass has an advantage over the forward pass in that it has the ability to pick any word to delete at any given step, whereas the forward pass can only observe the next pair of terms at each step [7].

2.2. Water cycle algorithm

The water cycle algorithm encompasses the concept, rationale, and structure. The WCA emulates the trajectory of rivers and streams as they go towards the ocean and was developed from the observation of the water cycle phenomenon. Let us suppose the presence of rain or precipitation phenomena. WCA is recommended based on the careful examination of natural phenomena, such as the movement of rivers and streams as they make their way towards the oceans. Rivers and streams often originate from elevated mountainous regions where the melting of snow and glaciers occurs. They then flow downwards, accumulating precipitation and merging with other streams along the way, until they ultimately reach the seas. During the hydrologic cycle, the water from lakes and rivers undergoes evaporation and transpiration by plants and trees during photosynthesis. This water is then transported to the sky, where clouds are formed. As the temperature of the atmosphere decreases, the clouds undergo condensation and the water falls to the earth as precipitation [35]. Underground water supplies and aquifers are replenished by the melting of snow and the occurrence of rainfall. The subterranean water flows under the terrestrial surface in a manner akin to the flow of water on the earth. The water from rivers and streams undergoes evaporation and the cycle repeats [8].

3. Result and Discussion

This research conducted a comparison study to evaluate the strength behavior of SLSC (Self-Compacting Lightweight Concrete) that includes agro-waste material. The study aimed to propose formula-based interpretable models for this purpose. Once the crucial critical characteristics for strength prediction were determined, the data was divided into a 75/25% ratio for analysis using data intelligence techniques. In this study, statistical measures such as R, RMSE, NSE, and MAE are used to assess the efficacy of the constructed models in predicting outcomes. Table 1 assessed the predictability of the model for strength prediction using MARS and MARS-WCA methodologies, based on the performance metrics. The accuracy of the MARS and MARS-WCA created models exceeds 90%, which is noteworthy. According to the information shown in Table 1, the proposed interpretable MARS-WCA model performs better than the standalone MARS model in predicting the strength of eco-friendly hemp-based concrete for both the train and test subsets. The MARS-WCA model significantly enhances the accuracy of the global prediction model, as seen by the reduction in RMSE values for compressive and tensile strength in the testing subset to 1.36 MPa and 0.91 MPa, respectively.

Table 1. Performance metrics of proposed models

			R	NSE	RMSE	MAE
Compressive strength	Train	MARS	0.974	0.93	0.82	0.49
		MARS-WCA	0.993	0.97	0.51	0.32
	Test	MARS	0.971	0.88	2.10	1.14
		MARS-WCA	0.991	0.95	1.36	0.75
Tensile strength	Train	MARS	0.917	0.911	1.14	0.31
		MARS-WCA	0.928	0.95	0.95	0.18
	Test	MARS	0.904	0.895	1.10	0.3
		MARS-WCA	0.911	0.91	0.79	0.11

To compare the modeling procedure of CS and TS, the regression plots are depicted in Fig 1. Because of the closeness of the red fitted curve line and predicted data point. As can be seen, the MARS-WCA model data points are around the red line. The developed MARS-WCA provides better agreement between the experimental data and the most accurate of CS and TS prediction in both the training and testing subsets provided by than standalone MARS.

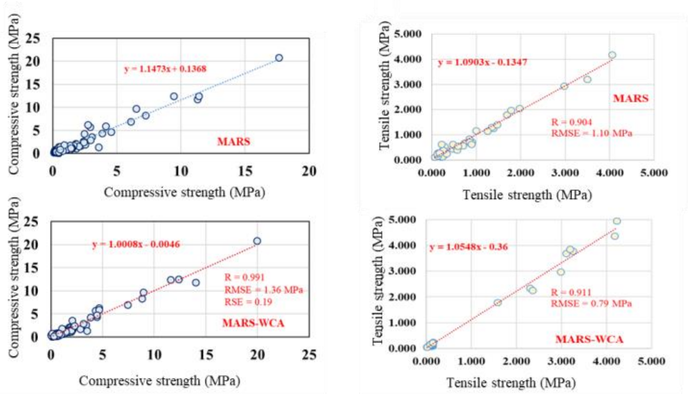

Fig. 1. Regression plots of developed models

4. References

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