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ENHANCING CONCRETE QUALITY ASSESSMENT WITH MACHINE LEARNING MODELS

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ABSTRACT

Machine learning, a subset of artificial intelligence, enables computers to learn from data and make predictions based on identified patterns within large datasets. This study explores the potential of machine learning models in classifying the compressive strength of concrete specimens with diverse ingredient compositions. While existing literature has investigated estimating concrete density, there is a notable absence of studies focused on categorizing compressive strength. To address this gap, three machine learning classification algorithms—Decision Tree, Naive Bayes Classifier, and K-Nearest Neighbors—are employed to classify concrete samples. The study evaluates and compares the performance of each algorithm.

The findings reveal that the Decision Tree classifier outperforms the other algorithms, achieving an average precision and recall of 99%, an f1-score of 0.99, and an accuracy of 99%. This study not only establishes the effectiveness of machine learning in concrete strength classification but also provides valuable insights into the practical application of machine learning algorithms using a real-world dataset. The results underscore the potential of machine learning as a powerful tool to enhance the accuracy of concrete strength classification.

Keywords: Classification · Concrete · Decision Tree Algorithm · Machine Learning · Naïve Bayes Algorithm.

1. INTRODUCTION

As the global economy surges forward, and urban landscapes continue to expand, the imperative to design structures capable of safely sustaining various loads becomes paramount. This multifaceted challenge involves the intricate processes of designing, constructing, and maintaining buildings that can withstand seismic activity and diverse environmental conditions without compromising structural integrity. Engineers play a pivotal role in ensuring the robustness of these structures, necessitating a profound understanding of how designs will perform in real-world scenarios.

In the realm of civil engineering, one crucial aspect of this understanding is compressive strength analysis. This analytical approach allows engineers to determine the structural capabilities of buildings, roads, and bridges. Compressive strength analysis is chosen for its direct correlation between structural performance and material properties, facilitating straightforward comparisons between different materials.

Concrete, as a fundamental composite material comprising aggregate, cement, and water, holds a central role in construction. The compressive strength of concrete, defined as the force a concrete sample can withstand before breaking, serves as a critical parameter. It is a key metric used to assess the suitability of concrete for various projects and is integral to ensuring the longevity and integrity of structures.

In this dynamic landscape of construction and engineering, where resilience is paramount, this study explores the significance of compressive strength analysis in the context of real-world scenarios.

The interplay of material properties, structural performance, and the challenges posed by a growing global economy form the backdrop against which engineers navigate the complexities of building design and construction. This research aims to contribute valuable insights into the role of compressive strength analysis, providing a foundation for creating structures that not only meet safety standards but also stand the test of time in an ever-evolving world.

2. DATABASE DESCRIPTION

The dataset for this research comprises 1030 concrete sample test results, sourced from literature These samples serve as the basis for classifying compressive strength in this study. The input variables include Cement (C), Blast Furnace Slag (BFS), Fly Ash (F.Ash), Water (W), Superplasticizer (S), Coarse Aggregate (C.Agg), Fine Aggregate (F.Agg), Age (A), and Compression Strength (CS). The output variable is the class number (CS), representing the compressive strength classification.

Compressive strength classes are categorized as follows: Class 1 for low-strength concrete (compressive strength < 25 MPa), Class 2 for normal-strength concrete (compressive strength between 25 and 50 MPa), and Class 3 for high-strength concrete (compressive strength > 50 MPa). Descriptive statistics for the variables are summarized in Table 1, providing insights into the characteristics of the dataset.

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2.1 Correlation Analysis:

A visual representation of the colormap correlation matrix is presented in Fig. 1. This matrix elucidates the relationships among different variables in the dataset. Dark blue indicates a strong positive correlation, while yellow signifies a strong negative correlation. Notably, the correlation matrix highlights strong associations between Cement, Superplasticizer, Age, and Compressive Strength.

Understanding these correlations is crucial for the subsequent application of machine learning classification algorithms. This dataset analysis lays the foundation for comprehending the interplay of variables and their impact on concrete compressive strength classification.

	C	BFS	F.Ash	W	S	C.Agg	F.Agg	A	CS
Minimum	102.00	0.00	0.00	121.75	0.00	801.00	594.00	1.00	2.33
Maximum	540.00	359.40	200.10	247.00	32.20	1145.00	992.60	365.00	82.60
Average	281.17	73.90	54.19	181.57	6.20	972.92	773.58	45.66	35.82
Std	104.46	86.24	63.97	21.35	5.97	77.72	80.14	63.14	16.70

Table 1: Statistics of the dataset.

It's interesting to observe that water shows a negative correlation with compressive strength in the dataset. This aligns with common knowledge in the field of concrete engineering, where the water-to-cement ratio is a critical factor influencing compressive strength. The negative correlation suggests that as the amount of water in the concrete mix increases, there tends to be a decrease in compressive strength. This phenomenon is attributed to the dilution effect – higher water content can lead to increased porosity and reduced binding capacity of the cement, resulting in weaker concrete.

Conversely, as mentioned, increasing cement, superplasticizer, and age are associated with improved compressive strength. Cement provides the binding material, superplasticizer enhances workability and reduces water requirements, and age allows for proper curing and strengthening of the concrete over time.

Understanding these correlations reinforces the fundamental principles of concrete mix design. It emphasizes the importance of carefully balancing the proportions of ingredients to achieve the desired compressive strength and overall performance of the concrete. This knowledge is crucial for engineers and practitioners involved in concrete construction, as it informs the decision-making process in designing durable and resilient structures.

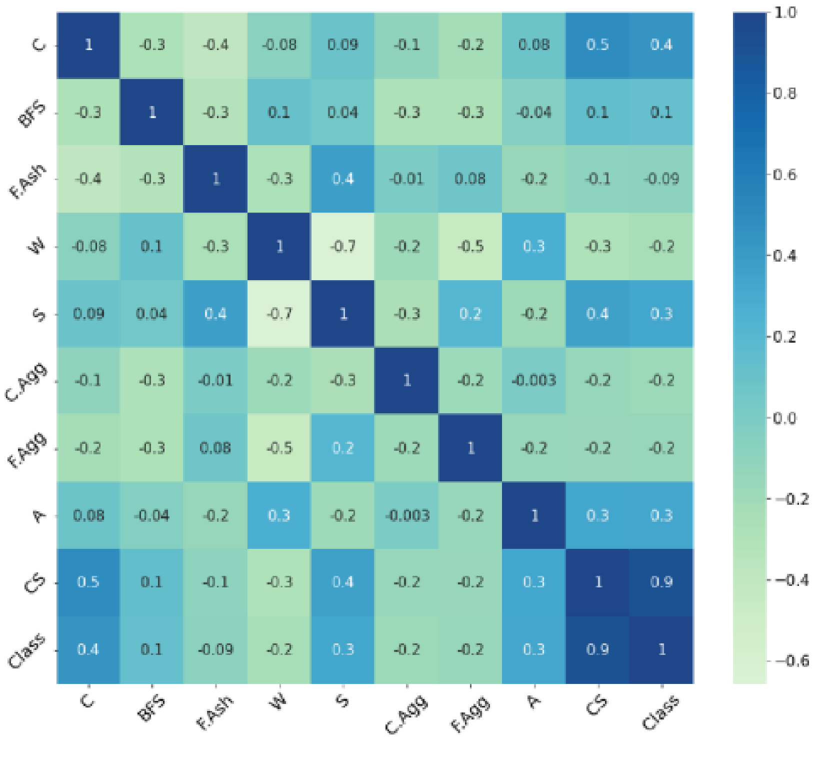

Figure 1: Correlation matrix of variables in the dataset

It appears that Figure 2 serves as a visual representation of a concrete compressive strength test. Compressive strength, a critical property of concrete, represents the maximum force the material can withstand before breaking or yielding. The test involves subjecting a concrete specimen to a load and measuring the resulting deformation. The procedure typically includes applying a gradually increasing load to the concrete specimen until failure occurs. The load is applied vertically to the specimen, and the corresponding deformation or strain is measured. The compressive strength is then calculated by dividing the maximum force applied by the cross-sectional area of the specimen.

Figure 2 likely illustrates key elements of this test, providing a visual insight into the experimental setup, the apparatus used for applying the load, and possibly the deformation measurements. Such visual representations are valuable for researchers, engineers, and practitioners in the field of concrete technology as they aid in understanding the practical aspects of the testing process and the behavior of concrete under load. If available, a detailed description of Figure 2 or any accompanying captions could provide further context and insights into the specific aspects of the concrete compressive strength test being depicted.

Figure 2: Representation of concrete compressive strength test

3. METHODOLOGY

In this study, the methodology involves the application of three widely used machine learning algorithms: Decision Tree, Naive Bayes, and K-Nearest Neighbors (KNN). Each algorithm has unique characteristics that make it suitable for classification tasks, and their selection is based on their versatility and relevance to the specific use cases being investigated.

3.1 Decision Tree:

Decision Tree is chosen for its simplicity and intuitive nature. It is known for its applicability in a wide range of scenarios. Decision Tree models are effective in capturing complex relationships within the data, making them suitable for classification tasks.

3.2 Naive Bayes:

Naive Bayes is selected for its versatility in handling both classification and regression problems. It is based on the probabilistic Bayes theorem and is particularly effective when dealing with large datasets. Naive Bayes is known for its simplicity and efficiency, making it a popular choice for various applications.

3.3 K-Nearest Neighbors (KNN):

KNN is chosen for its approach of predicting the class of an input value based on the similarity to its K nearest neighbors. It is particularly effective in scenarios where the data has local patterns or clusters. KNN is known for its simplicity and can be adapted to different types of datasets. The selection of these three algorithms is based on their general effectiveness and suitability for the classification task at hand. The study will involve implementing and fine-tuning these algorithms to classify the compressive strength of concrete samples. Evaluation metrics such as accuracy, precision, recall, and F1-score will be used to assess the performance of each algorithm, and a comparative analysis will be conducted to determine the most effective approach for the specific dataset and objectives of the study.

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3.4 Iterative Re-weighting with Random Splitting:

This common method involves iterative re-weighting of instances with the random splitting of existing data points. The iterative process generates multiple split clusters, contributing to the creation of a comprehensive decision tree.

3.5 Random Forest:

Another method involves creating a Random Forest, which leverages the considerable computational power available in modern computers. The Random Forest technique builds an ensemble of decision trees using various initializations, enhancing the robustness and accuracy of the classification model. The Decision Tree classification model is selected for its interpretability and ease of use. It allows for the exploration of complex relationships within the dataset and provides a transparent decision-making process. The study will involve implementing the Decision Tree algorithm on the concrete compressive strength dataset and evaluating its performance against other chosen machine learning algorithms.

4. RESULTS AND DISCUSSION

This study explores the application of machine learning in classifying the compressive strength of concrete specimens with varying ingredient compositions. Three machine learning classification models—Decision Tree Classifier (DTC), Naive Bayes Classifier (NBC), and K-Nearest Neighbors (KNN)—are employed for this classification task. To ensure uniformity in variable scales, the standard scaler is applied across all machine learning models. The dataset is divided into a training set comprising 75% (780 samples) and a validation set consisting of the remaining 25% (260 samples). The classifiers are trained on the training set, and their performance is assessed on the validation set using key evaluation metrics, including accuracy, precision, recall, and F1-score.

The evaluation metrics are defined as follows:

Accuracy: The ratio of accurately detected occurrences to all instances is provided, and it is referred to as

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN} \times 100 \quad (1)$$

Recall: Recall shows a dataset's capacity to contain every relevant instance. The result is expressed as: Classification models identify all relevant events in a recollection

$$Recall = \frac{TP}{TP+FN} \times 100 \quad (2)$$

Specificity: It is written as and defined as the ratio of actual negative cases to true negative occurrences (FP + TN)

$$Specificity = \frac{TN}{TN+FP} \times 100 \quad (3)$$

F1-Score = 2 * Precision * Recall (4)
Precision + Recall

Table 2 shows the classification reports for each ML model. From the table, DTC has the highest accuracy at 99% followed by NBC at 90%. KNN has the lowest accuracy at 84%. Also from the table, the DTC and NBC models have similar performance when compared to each other and both are better than KNN. Moreover, DTC provided the best performance with average precision and recall of 99%, and an f1-score of 0.99. The findings of this study demonstrated that the compressive strength of concrete samples can be predicted with high accuracy—nearly 100%—using machine learning.

Table 2: Classification reports for ML classification models

		DTC				NBC				KNN	
	1	2	3		1	2	3		1	2	3
precision	1.00	0.99	1.00		0.87	0.93	0.88		0.86	0.86	0.78
recall	0.98	1.00	1.00		0.94	0.90	0.88		0.79	0.86	0.86
f1-score	0.99	1.00	1.00		0.90	0.91	0.88		0.82	0.86	0.82
accuracy		0.99				0.90				0.84	

5. CONCLUSION

The DTC model is found to be the most accurate, with an accuracy of 99%. The NBC and KNN models are also found to be accurate, with accuracies of 90% and 84%, respectively. This study demonstrates that ML is a powerful tool that can be used to improve the accuracy of concrete compressive strength classification. ML can be also applied to estimate the compressive strength of other concrete structures such as beams, columns, piers, and walls.

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