Impact of Petrological contents on the Engineering Properties of Carbonate Aggregates: A Machine Learning Approach (Postprint)

Authors: Javid Hussain, Jian Chen

Date: 2025-07-29T19:11:10+00:00

Abstract

Rock aggregates have been extensively exploited in construction, and the associated engineering features play a critical role in their application. The main aim of this research is to assess the impact of petrographic characteristics on the engineering properties of carbonate rocks. A total of 45 carbonate rock samples from different geological formations within the Salt Range (Western Himalayan Ranges, Pakistan) were subjected to comprehensive petrographic analyses and standard aggregate quality control tests. The engineering characteristics encompassed Los Angeles abrasion value, aggregate crushing value, aggregate impact value, specific gravity, water absorption, and unconfined compressive strength, whereas petrographic examination of thin sections quantified the mineralogical composition. Statistical methods and machine learning models have been applied to elucidate the relationships and establish potential predictive relationships between the petrographic and engineering features of the aggregates. The analysis identified clay, calcite, feldspar, and dolomite as the primary determinants influencing the engineering behavior of carbonate aggregates. Although multiple regression analyses produced R^2 values exceeding 0.84, the multiple regression equations did not provide substantial insights into the impact of all petrographic parameters on engineering properties. To enhance predictive accuracy, advanced machine learning models, including Random Forest, Gradient Boosting, Multi-Layer Perceptron, and Categorical Boosting, were applied. Among these, the Gradient Boosting model demonstrated superior predictive capability, overcoming both traditional regression methods and other machine learning algorithms validated through Taylor diagram and ranking system which included (correlation coefficient (r)=0.998, R^2=997, Root mean square error=0.075, Variance Accounted For (VAF)%=99.50, Mean Absolute Percentage Error (MAPE) %= 0.385, Alpha 20 Index ($ $20-index)= 100, and performance index (PI))= 0.975. These results highlight the ability of machine learning techniques in providing a more effective and reliable prediction of aggregate engineering properties based on petrographic data. This approach offers significant advantages in the preliminary assessment of aggregate suitability, contributing to more efficient resource allocation in construction projects.

Full Text

Preamble

Impact of Petrological Contents on the Engineering Properties of Carbonate Aggregates: A Machine Learning Approach

Javid Hussain[1234], Jian Chen[1234]*

[1]State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan 430071, China; (tehseenzafar@uaeu.ac.ae; chenjiaan@whrsm.ac.cn)
[2]University of Chinese Academy of Sciences, Beijing 100049, China
[3]China-Pakistan Joint Research Center on Earth Sciences, Islamabad 45320, Pakistan
[4]Hubei Key Laboratory of Geo-Environmental Engineering, Wuhan 430071, China

Abstract

Rock aggregates are widely utilized in construction, where their engineering properties critically govern their suitability for various applications. This study investigates the influence of petrographic characteristics on the engineering properties of carbonate rock aggregates. Forty-five carbonate rock samples from diverse geological formations within the Salt Range (Western Himalayan Ranges, Pakistan) were subjected to comprehensive petrographic analysis and standard aggregate quality control tests. The evaluated engineering properties included Los Angeles abrasion value, aggregate crushing value, aggregate impact value, specific gravity, water absorption, and unconfined compressive strength. Mineralogical composition was quantified through petrographic examination of thin sections. Statistical methods and machine learning models were employed to elucidate relationships and establish predictive frameworks linking petrographic and engineering parameters.

The analysis identified clay, calcite, feldspar, and dolomite as the primary constituents influencing the engineering behavior of carbonate aggregates. While multiple regression analysis yielded R^2 values exceeding 0.84, these models failed to provide comprehensive insights into the effects of all petrographic parameters on engineering properties.

To improve predictive accuracy, advanced machine learning algorithms were implemented, including Random Forest, Gradient Boosting, Multi-Layer Perceptron, and Categorical Boosting. The Gradient Boosting model exhibited superior predictive performance, surpassing both traditional regression methods and other machine learning algorithms. Validation via Taylor diagram and ranking system demonstrated exceptional accuracy, with performance metrics including correlation coefficient (r) = 0.998, R^2 = 0.997, root mean square error = 0.075, variance accounted for (VAF) = 99.50%, mean absolute percentage error (MAPE) = 0.385%, alpha-20 index ($ $20-index) = 100, and performance index (PI) = 0.975. These results demonstrate that machine learning techniques can provide more effective and reliable predictions of aggregate engineering properties from petrographic data. This approach offers significant advantages for preliminary assessment of aggregate suitability, contributing to more efficient resource allocation in construction projects.

Keywords: Construction projects, engineering properties, Gradient Boosting, petrographic characteristics, statistical analyses, Salt Range

Note: Figure translations are in progress. See original paper for figures.