EcoForge: Novel Sustainable Geopolymer Alternative to Concrete Optimized With Machine Learning for Compressive Strength and Pollution Mitigation

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The concrete industry is a significant contributor to global CO2 emissions, primarily due to cement production. Furthermore, plastic, glass, fly ash, and slag often end up in landfills, contaminating waterways and ecosystems. This study presents a novel geopolymer that replaces cement with a sodium hydroxide solution and incorporates waste materials alongside carbon-rich ingredients such as biochar, bamboo, and cellulose. Several tree-based algorithms were trained on a dataset of 200 unique geopolymer recipes to predict compressive strength and CO2 absorption values with associated confidence scores. The initial prototyping was promising, with 75% of samples achieving compressive strengths above 2500 PSI using the rebound hammer test, the industry standard for sidewalks and residential roadways. Several samples achieved CO2 absorption exceeding 20% through a sealed container test with an MQ-135 sensor. Additionally, the mix calculated by the machine learning models predicted within 300 PSI of the true value and 3% of the true carbon sequestration. The models also revealed key ingredient contributions to each performance metric. Furthermore, this geopolymer achieves a similar economic cost to traditional concrete as it does not require water curing. Critically, this geopolymer can store 4 grams of carbon per cubic inch: a 100-meter-long by 1-meter-wide by 10-centimeter-thick residential sidewalk stores the equivalent of the annual sequestration of 121 trees' worth of carbon. This work creates one of the first high-quality datasets for sustainable concrete mixes and demonstrates the potential of machine learning in the concrete industry, where data is not readily available and the environment is not a main concern of the profit-driven industry.

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