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The impact of oxides of cementitious materials on mortar strength: A machine learning perspective

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ABSTRACT

This study uses machine learning to predict the compressive strength of cement-sand mortar incorporating supplementary cementitious materials (SCMs). The research addresses a gap in the literature by specifically examining how the oxide composition of SCMs influences mortar strength. Using a dataset of various mortar mixes, several machine learning models were tested, with the extreme gradient boosting (XGB) model emerging as the most effective, achieving a testing R^2 of 0.90. The results show that the curing period is the most influential factor on compressive strength, followed by the oxide compositions of the SCMs. This work highlights the potential of machine learning for enhancing material performance predictions and supports the development of more sustainable and durable construction practices.

1. Introduction

Cement-sand mortar is a critical material in construction, comprising a mixture of cement, sand, and water, primarily as a binding agent for masonry units such as bricks and stones (Nasr et al., 2020). Its functional purposes extend beyond mere adhesion; it facilitates load distribution, offers water resistance, and enhances the aesthetic quality of structures. Incorporating supplementary cementitious materials (SCMs) into cement-sand mortar is increasingly recognized for its significance in promoting sustainability and improving material performance (Huang et al., 2025). SCMs, such as fly ash, silica fume, ground granulated blast furnace slag (GGBFS), and natural pozzolans, not only reduce the reliance on Portland cement, thereby lowering the carbon footprint of construction, but also enhance the durability and workability of the mortar (Mo et al., 2017; Hafez et al., 2024). The effects of SCMs on compressive strength are noteworthy; at the same time, some may initially result in lower early strength, but they often contribute to superior long-term strength and durability as the mortar cures (Hafez et al., 2024; Tan et al., 2024). This dual benefit underscores the importance of SCMs in developing high-performance cement-sand mortar, fostering economic and environmental advantages in modern construction practices (Chen et al., 2024; Sathiparan and Subramaniam, 2025).

The oxides present in supplementary cementitious materials (SCMs) and the binder mix play a crucial role in determining the compressive strength of cement mortar. Key oxides, such as silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and calcium oxide (CaO), influence the hydration reactions that occur when water is added to the mix (Sathiparan et al., 2024a). Silica, for example, reacts with calcium hydroxide to form additional calcium silicate hydrate (C–S–H), which significantly enhances strength (Sathiparan et al., 2024b; Adegbemileke et al., 2024). Similarly, alumina contributes to forming complex hydrates that improve binder properties (Liu et al., 2025). Therefore, the specific oxide composition of the SCMs and the primary binder directly impacts the microstructure and mechanical properties of the resulting mortar. Accurate prediction of compressive strength is essential for designing structures that

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