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Prediction of concrete residual compressive strength under elevated temperatures: Response surface methodology (RSM) approach

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ABSTRACT

Exposure of concrete to elevated temperatures causes irreversible damage to the concrete structure and poses a serious threat to its service life. Due to the importance of concrete fire performance, extensive research has been conducted to investigate its behavior under different conditions of elevated temperatures. The properties of concrete are significantly affected by various factors, including heating temperatures, heating durations, and cooling methods. Among these factors, the residual compressive strength of concrete is considered the most crucial characteristic after exposure to elevated temperatures. This paper aims to develop mathematical models for analyzing and predicting the relative residual compressive strength of concrete at high temperatures. Three independent factors were identified in this study: heating temperatures, heating duration, and cooling method. Two groups of datasets on the relative residual compressive strength of concrete under elevated temperatures were reviewed and collected from previous studies, serving as the benchmark dataset and validation dataset, respectively. Response Surface Methodology (RSM) was employed to analyze the datasets. The results of various statistical parameters, such as the coefficient of determination, sum of squares, F-value, and P-value, indicate the significance of the predicted model for estimating concrete's relative residual compressive strength under elevated temperatures. The RSM analysis reveals that heating temperatures have the most significant effect on the relative residual compressive strength of concrete. In summary, the RSM model shows a strong correlation with the validation datasets, with a coefficient of determination (R^2) of 0.7869.

1. Introduction

Concrete is the most commonly used structural component worldwide, employed in a wide range of structures such as residential buildings and bridges. These structures utilize either high-strength or normal-strength concrete. However, it is widely acknowledged that concrete structures undergo irreversible deterioration when exposed to high temperatures [1,2]. The extent of damage experienced by a concrete structure at high temperatures varies, depending on factors such as residual material properties, fire characteristics, structural design, and applied loads. When subjected to elevated temperatures, concrete structures undergo changes in the physical and chemical properties of the cement paste and aggregates, resulting from expansion and chemical decomposition [3]. Previous research has shown that the mechanical properties of concrete structures begin to deteriorate after reaching temperatures of 300 °C [4].

Regarding fire characteristics, previous studies have investigated the influence of various factors on the compressive strength of concrete at high temperatures during the heating and cooling process. These factors include heating temperatures, heating durations, heating rate, phase transformations, and cooling conditions [5–7]. Zhai et al. [8] observed that the compressive strength of concrete exhibits minimal changes when exposed to temperatures below 300 °C. Kou et al. [9] also noted an improvement in residual compressive strength when concrete was subjected to temperatures up to 300 °C. This increase in strength can be attributed to the hydration of non-hydrated products in the concrete. However, further increases in temperature lead to a significant decrease in the residual compressive strength of concrete. This decrease occurs due to dehydration, conversion of calcium hydroxide into calcium oxide in the cement paste, and volume expansion of the aggregates [10,11].

Nazri et al. [12] investigated the compressive strength of concrete after exposure to elevated temperatures ranging from 30 to 150 min at temperatures up to 600 °C. They found that the residual compressive strength decreased with longer heating durations. Similar experiments were conducted by Ukala [13], who also observed a greater reduction in residual compressive strength with longer exposure to elevated

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