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METHODS TO IMPROVE THERMAL STABILITY OF CONCRETE BASED ON MINERAL AND CHEMICAL ADMIXTURES

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Abstract: This paper presents methods for improving the thermal stability of concrete used in high-temperature environments such as road pavements, industrial furnaces, power plants, and solar energy facilities. The scientific novelty lies in the combined use of mineral admixtures (metakaolin, microsilica, slag) and chemical admixtures (polycarboxylate-based superplasticizer and hydrophobic agent) and in the comprehensive analysis of their effects on the microstructure of concrete. Concrete mixes were prepared using PC 400 D0 and PC 500 D0 cements and cured for 28 days before being subjected to thermal exposure between 100°C and 800°C. Compressive strength, elasticity modulus, mass loss, water absorption, and microstructural analyses were performed. Results showed that the combination of 20% metakaolin, 0.8% superplasticizer, and 0.5% hydrophobic additive maintained 80–85% of compressive strength up to 600°C. Even at 800°C, strength reduction was limited to 15–20% compared to ordinary concrete. The hydrophobic agent reduced internal vapor pressure and prevented cracking, while microsilica enhanced C–S–H phase formation and decreased microporosity. The findings are applicable to developing thermally stable concretes suitable for Uzbekistan's climate and local raw materials.

The behavior of concrete at high temperatures depends on hydration products, mainly C–S–H and $Ca(OH)_2$. With rising temperature, these phases decompose, increasing porosity and microcracking, which leads to reduced strength and stiffness. Ordinary Portland cement concrete starts losing strength above 200–300°C, while between 400–600°C $Ca(OH)_2$ decomposes and above 600°C C–S–H phases disintegrate. Therefore, improving thermal resistance requires well-chosen mineral and chemical admixtures. The study aims to enhance thermal stability through combined use of metakaolin, microsilica, slag, polycarboxylate superplasticizer (PCE), and hydrophobic agents. The hypothesis suggests that mineral admixtures create a denser structure, PCE maintains low water-cement ratio, and the hydrophobic agent lowers internal vapor pressure, ensuring better performance under heat.

Previous studies confirm that metakaolin and microsilica improve concrete durability due to their pozzolanic reactivity. Metakaolin reacts with $Ca(OH)_2$ to form secondary C–S–H, while microsilica refines the matrix and strengthens the interfacial transition zone. Slag partially replaces cement and reduces heat generation. Polycarboxylate-based superplasticizers reduce water demand while maintaining workability. Hydrophobic agents minimize capillary water transport, decreasing vapor pressure and reducing cracking risk. International research indicates that the combined use of metakaolin, microsilica, and PCE yields promising results in heat-resistant concrete.

The experiment used PC 400 D0 and PC 500 D0 cements, washed river sand, gravel, and potable water. Mineral admixtures included 10–20% metakaolin, 5–10% microsilica, and 15–25% slag. Chemical admixtures consisted of 0.6–1% superplasticizer and 0.3–0.7% hydrophobic agent. Each mix was cast into 100×100×100 mm cubes and cured in a moist environment for 28 days. Afterwards, specimens were heated to 100, 200, 400, 600, and 800°C for two hours and then cooled naturally. Compressive strength, elasticity modulus, mass loss, and water absorption were measured, while XRD and SEM analyses were used to evaluate phase composition and microstructure.

The use of PCE maintained the water-cement ratio between 0.31 and 0.33, ensuring good workability. At 200°C, concrete strength remained almost unchanged; at 400°C, ordinary concrete lost about 15% of strength, while modified concretes lost only around 7–10%. At 600°C, mixtures with metakaolin, microsilica, and hydrophobic agents retained 80–85% of strength. At 800°C, modified concretes still outperformed the control by 15–20%. Water absorption dropped to 1.2–1.5%, and SEM micrographs revealed a denser ITZ with fewer and finer cracks. XRD results confirmed reduced $Ca(OH)_2$ peaks and higher proportions of C–S–H and calcite phases.

The synergy between mineral and chemical admixtures significantly improved thermal resistance. Metakaolin and microsilica produced additional C–S–H phases, PCE provided low water-cement ratio and high density, and hydrophobic additive reduced vapor-induced stress. These combined effects minimized cracking and enhanced durability. For Uzbekistan’s hot and dry climate, such compositions are particularly effective in roads, energy plants, and industrial facilities. The partial replacement of cement with mineral additives also reduces CO_2 emissions and improves sustainability.

The combination of metakaolin, microsilica, PCE superplasticizer, and hydrophobic agent substantially enhances the thermal resistance of concrete. Strength retention up to 600°C, reduced water absorption, and improved microstructural integrity make these concretes suitable for high-temperature environments. For Uzbekistan, concretes based on PC 400 D0 or PC 500 D0 cement containing 20% metakaolin, 0.8% PCE, and 0.5% hydrophobic additive are recommended for practical applications.