Effectiveness of Nano-Engineering-Infused Repair Mortars in Restoring Structural Integrity of Concrete Exposed to High Temperatures

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Abstract: This study evaluates the effectiveness of nano enriched repair mortars in restoring the mechanical and durability performance of concrete exposed to elevated temperatures. Concrete structures subjected to fire or thermal loading experience significant strength loss, deterioration of bonding zones, and increased permeability, which complicate post fire rehabilitation and long-term service performance. An experimental program was carried out in which concrete specimens were cast and cured under controlled conditions, then heated to 200, 400, and 600 degrees Celsius to simulate thermal damage. After natural cooling, the specimens were repaired using a 20-millimeter-thick mortar containing 1 percent nano silica, followed by curing and testing. The evaluation included compressive strength tests on cube specimens, split tensile strength tests on cylindrical specimens, and durability assessment through pull off bond strength, water absorption, and sorptivity. Compressive strength increased from 28.5 to 33.4 MPa at 200 degrees Celsius, from 19.7 to 28.1 MPa at 400 degrees Celsius, and from 11.3 to 17.6 MPa at 600 degrees Celsius after repair. Split tensile strength improved from 0.95 to 1.65 MPa at 600 degrees Celsius. Pull off bond strength reached 1.72 MPa at 200 degrees Celsius and 0.86 MPa at 600 degrees Celsius. Water absorption ranged from 4.2 percent to 7.9 percent, and sorptivity increased from 0.18 to 0.31 with rising temperature. The results confirm that nano enriched repair mortars can substantially recover strength and durability in heat damaged concrete, providing quantitative evidence for their application in post fire structural rehabilitation.

Keywords: Nano mortars, strength recovery, bond performance, durability

1. Introduction

Concrete structural elements exposed to high temperatures–such as during fires or industrial thermal loads–suffer from deterioration in microstructure, spalling, and significant loss in mechanical capacity. For instance, exposure to 400 °C or more can reduce the residual compressive strength of conventional concrete by up to 60 percent due to dehydration of cementitious gels and micro-cracking (1). Repair of such heat-damaged substrates is a major challenge because degraded concrete surfaces present compromised bonding zones, irregular cracking networks, and weakened substrate strength. The application of advanced repair mortars enriched with nano-engineered materials such as nano silica is gaining interest as a means to restore structural integrity, enhance bonding performance, and reduce long-term durability issues in post-fire repairs(2).

Recent research continues to demonstrate that nano-silica significantly enhances the performance of cementitious materials by refining pore structure and promoting stronger microstructural development in concrete. It has found that adding small amounts of nano silica, usually between 1 and 3 percent of the binder's weight, can noticeably improve the strength and durability of concrete. These improvements are seen across different water to binder ratios, mainly because nano silica helps the particles fit together more tightly and encourages the creation of more calcium silicate hydrate, which is essential for concrete's strength. By making the internal structure denser, nano silica also reduces the ways that water and harmful substances can enter the concrete, leading to better long-term performance compared to mixes that do not use nano silica. Highlighting these findings shows why it is so important to explore nano engineered repair mortars, especially for repairing concrete that has weakened due to heat exposure or other types of damage (3).

Earlier studies on concrete blended with nano silica and exposed to high temperatures report noticeable improvements in its ability to retain strength after heating. In this investigation (4), specimens incorporating nano silica achieved a compressive strength of 19.2 MPa at 800 °C after 28 days, whereas the conventional mix reached only 13.9 MPa under the same conditions. This corresponds to nearly 38 percent higher strength retention in the nano modified concrete. Another study (5) observed that although concrete containing nano additives showed an overall reduction in mechanical properties of about 60 percent when subjected to temperatures between 800 °C and 1000 °C, it still preserved a greater share of its original strength compared with unmodified concrete. Together, these findings indicate that nano based modifications can contribute to improved thermal resistance. However,

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much of the existing work has concentrated on original concrete elements rather than on repair mortars applied to substrates that have already been damaged by fire or high temperature exposure (6).

Recent research on cement-based materials incorporating nano silica indicates that these fine scale additions do more than improve strength and durability under normal service conditions. They also play an important role in maintaining performance after exposure to high temperatures. In a 2025 investigation on ultra-high performance cementitious composites 7, the inclusion of about 1 percent nano silica enhanced tensile behavior and preserved microstructural stability when specimens were heated up to 800 °C. Compared with conventional mixtures, the modified composites exhibited fewer visible cracks after cooling and retained a higher load carrying capacity. The improved response was attributed to a denser pore structure and slower crack development resulting from the interaction between nano silica and the cement matrix. This interaction helped limit heat induced internal damage across different temperature ranges. Placing the present study in the context of these recent findings highlights the importance of examining nano engineered repair mortars as a practical strategy for restoring strength and durability in concrete that has already been subjected to severe thermal exposure (7).

When concrete is subjected to high temperatures, its internal structure begins to deteriorate as hydration products decompose and pore spaces widen. Once temperatures exceed roughly 400 °C, both compressive and tensile strengths tend to decline sharply due to this internal damage. Recent studies on nano modified concrete report that incorporating nano silica helps create a denser and more integrated microstructure. This occurs through pore refinement and increased formation of calcium silicate hydrate phases, which strengthen the cement matrix. As a result, specimens containing nano silica have demonstrated improved residual compressive strength and better microstructural stability after exposure to temperatures of 600 °C and even 800 °C compared with conventional mixes. Positioning the present research within this context clarifies the need to assess nano engineered repair mortars as a practical solution for restoring mechanical performance and durability in concrete structures that have already been weakened by thermal exposure (8).

Although several investigations have explored how nano modified concrete behaves under thermal loading, only a limited number of studies have examined repair mortars applied to concrete that has already been exposed to high temperatures (9). Most available work concentrates on original concrete mixes rather than on rehabilitation strategies for fire affected substrates. For instance, one review (5) reported that incorporating 2 percent nano silica led to an increase in residual compressive strength of about 7 percent at 250 °C and around 3 percent at 500 °C when compared with conventional concrete. These findings suggest some improvement in thermal resistance, yet they do not fully address post damage repair performance. In contrast, the present study evaluates a nano engineered repair mortar layer applied to concrete specimens previously heated to 200 °C, 400 °C, and 600 °C. This approach enables a direct assessment of mechanical strength recovery, bond durability, and restoration of structural capacity, areas that remain insufficiently addressed in earlier research.

Against this background, the present study aims to address this gap by examining how repair mortars enriched with nano engineered materials can help recover the strength, bonding performance, and durability of concrete that has been weakened by high temperatures. The objective is not only to measure mechanical improvement but also to understand how effectively the repaired system performs as an integrated unit. The outcomes of this work are intended to provide practical insight for repairing structures after fire exposure and to support the development of more resilient concrete infrastructure in the long term.

There remains a distinct research gap in how nano-engineered repair mortars perform in real-world fire- or high-temperature-exposed concrete structures, as most studies focus on standard normal-temperature conditions. Although incorporation of nano silica and other nano-additives has shown promise in enhancing microstructure and strength of concrete at moderate temperatures such as up to 200 °C (10), their effectiveness in restoring concrete that has already undergone severe thermally-induced damage such as, microcracking, phase changes, loss of hydration remains poorly quantified. Furthermore, while research explores nanomaterials in fresh or intact concrete, there is limited data on long-term durability and mechanical recovery of such repair mortars when applied to spalled, heat-damaged substrates with compromised bonding zones(11). Finally, design guidelines for optimum dosage, type, and distribution of nano-additives specifically for repair mortars exposed to high thermal stress are underdeveloped, leaving practical application parameters undefined.

When concrete components are exposed to high temperatures, their internal structure undergoes serious damage. Micro cracks develop, binding phases decompose, and the material gradually loses its ability to carry loads effectively (12). In practical situations such as fire affected buildings or industrial installations, the remaining concrete substrate often has an uncertain level of internal damage before any repair work begins. Research indicates that heating beyond 400 °C can reduce residual compressive strength by roughly 60 percent or even more. Such exposure is also associated with increased mass loss and surface spalling, which raise important concerns regarding safety and long-term service performance (5). Although interest in nano modified repair mortars has grown in recent years, there is still limited systematic evidence on how effectively these materials can restore the structural integrity of concrete that has been degraded by high temperature exposure under field conditions. This shortfall in available data highlights a clear gap in current knowledge.

The purpose of this research is to investigate how nano engineered repair mortars can help restore the strength and bonding characteristics of concrete that has been weakened by exposure to high temperatures. The study is structured around the following specific objectives. 1. To evaluate the mechanical performance of nano enhanced repair mortars when applied to concrete that has undergone thermal deterioration. 2. To examine the durability of the repaired sections under controlled laboratory conditions that simulate realistic service environments.3. To determine how effectively these repair mortars can recover the structural load carrying capacity of concrete affected by elevated temperatures.

2. Research Methodology

The investigation was designed as an experimental study to understand how effectively a nano enriched repair mortar can restore the performance of concrete that has been exposed to high temperatures. The procedure began with casting concrete specimens, subjecting them to controlled heating, repairing the damaged surfaces, and then carrying out mechanical and durability tests to measure recovery in performance. The base concrete was prepared using 380 kilograms per cubic meter of cement, 620 kilograms per cubic meter of fine aggregate, 1180 kilograms per cubic meter of coarse aggregate with a maximum size of 20 millimeters, and 171 kilograms per cubic meter of water. This corresponded to a mix proportion of 1: 1.63: 3.11 and a water to cement ratio of 0.45. The repair mortar was produced separately using 450 kilograms per cubic meter of cement, 1100 kilograms per cubic meter of fine sand, 198 kilograms per cubic meter of water, and nano silica at 1 percent of the cement content by weight. The resulting mix proportion was 1: 2.44 with a water to cement ratio of 0.44. Cube specimens measuring 150 by 150 by 150 millimeters and cylindrical specimens with a diameter of 100 millimeters and a height of 200 millimeters were cast. All specimens were cured for 28 days to establish consistent reference properties before thermal exposure. After curing, the specimens were placed in an electric furnace and heated to target temperatures of 200, 400, and 600 degrees Celsius at a rate of 10 degrees Celsius per minute. Once the required temperature was reached, it was maintained for one hour to allow uniform heat distribution throughout the specimen. The samples were then allowed to cool naturally to room temperature so that the resulting damage would reflect conditions similar to those experienced during fire events. Only after complete cooling were the repair procedures carried out. The heated surfaces were treated with a 20-millimeter-thick layer of nano enriched mortar. The repaired specimens were cured again prior to testing, after which mechanical strength and durability assessments were performed to evaluate the effectiveness of the repair system.

The assessment first focused on mechanical performance. Compressive strength was measured using cube specimens of 150 × 150 × 150 millimeters. Each cube was carefully positioned at the center of the compression testing machine to ensure uniform load distribution over the top surface. The load was applied gradually at a rate of approximately 140 kilograms per square centimeter per minute until failure occurred. The highest load indicated by the machine at the moment of crushing was noted. This value was then divided by the loaded area of the cube to calculate the compressive strength for both the unrepaired and repaired specimens at each temperature level. Split tensile strength was determined using cylindrical specimens with a diameter of 100 millimeters and a height of 200 millimeters. The cylinders were placed horizontally between the loading platens. Thin strips were positioned along the top and bottom lines of contact to provide uniform load transfer. The load was applied steadily at a rate of about 12 kilograms per square centimeter per minute until the specimen fractured along its vertical diameter. The maximum load at the point of splitting was recorded and used to compute the tensile strength of the concrete.

For bond strength, a core disc of 50 millimeters in diameter was attached to the repaired surface using a high strength adhesive. After the adhesive had fully hardened, the pull off apparatus was connected to the disc. A tensile force was then applied perpendicular to the surface in a gradual and controlled manner. Loading continued until the disc separated from the surface. The maximum force recorded at failure was noted, and bond strength was determined by dividing this force by the cross-sectional area of the disc. The mode of failure was also examined to identify whether separation occurred at the interface, within the repair mortar, or inside the original concrete substrate. Water absorption was evaluated using disc specimens measuring 100 millimeters in diameter and 50 millimeters in thickness. Each specimen was first dried in an oven until a constant mass was achieved. After cooling to room temperature, the dry mass was recorded. The discs were then immersed in water for 24 hours, after which the saturated mass was measured. The difference between the wet and dry masses was used to calculate the percentage of water absorbed, indicating the material's capacity to take in moisture. Sorptivity was measured using the same disc specimens. The bottom surface of each disc was placed in shallow water so that only a small depth of the specimen was in contact with water. The mass was recorded at intervals of 5, 10, 20, 30, and 60 minutes to track the rate of water movement through capillary action. The increase in mass plotted against the square root of time was used to determine the sorptivity value, which represents the rate at which the repaired concrete absorbs water through capillary suction.

In the final phase, the extent of structural recovery was evaluated by comparing the performance of repaired specimens with that of heated but unrepaired concrete at 200, 400, and 600 degrees Celsius. The comparison considered compressive strength, split tensile strength, and bond performance. By examining these values side by side, the study was able to determine how much strength and adhesion were regained after repair. This approach provides a clear measure of the effectiveness of the nano enriched repair mortar in restoring the mechanical behavior of concrete that had been weakened by high temperature exposure. Only the essential testing parameters are mentioned, while routine laboratory procedures are kept brief so that the emphasis remains on the experimental findings and their interpretation.

The results presented in this study represent the average of multiple tests carried out under the same controlled conditions. Throughout the experimental program, attention was given to maintaining uniformity in specimen preparation, curing, heating, and testing to ensure reliable outcomes. The patterns observed in the data were consistent across repeated trials, reflecting good repeatability and minimal variation within the limits of the investigation.

3. Results and Discussion

This section discusses the experimental results by examining how both unrepaired and repaired concrete specimens performed in terms of mechanical strength and durability after exposure to different temperature levels. The comparison helps clarify the influence of repair on concrete that has undergone thermal damage.

To obtain the results presented in this study, an experimental program was carried out in which concrete specimens were exposed to temperatures of 200 °C, 400 °C, and 600 °C. After heating and cooling, the damaged surfaces were repaired using a nano engineered mortar. Compressive strength was measured on cube specimens of 150 × 150 × 150 millimeters, while split tensile strength was determined using cylindrical specimens of 100 millimeters in diameter and 200 millimeters in height. In addition to these mechanical tests, durability was evaluated through pull off bond strength, water absorption, and sorptivity measurements. This systematic approach allowed a clear comparison between repaired and unrepaired specimens under elevated temperature conditions.

The discussion focuses on the trends observed in the results and the numerical differences between specimens, rather than restating experimental procedures. This approach helps provide a clearer understanding of how effective the repair system was under different temperature conditions. The selection of concrete and repair mortar proportions plays a central role in the study, since the mix composition directly influences the initial strength of the substrate and the performance of the repair layer. Table 1 outlines the quantities of each material used in both the base concrete and the nano enriched repair mortar. These proportions establish the basis for all mechanical and durability evaluations carried out in the investigation.

Table 1. Material composition of the base concrete and the nano enriched repair mortar

Table 1 outlines the material proportions used for the base concrete and the nano enriched repair mortar. It shows that the repair mix contains 450 kg per cubic meter of cement, compared with 380 kg per cubic meter in the base concrete, along with a 1 percent addition of nano silica by weight of cement. The increased cement content in the repair mortar contributes to a denser and more compact matrix. The presence of nano silica further enhances this effect by refining the pore system and promoting the formation of additional calcium silicate hydrate within the cement paste. Previous studies have reported that nano silica can improve early age strength by approximately 20 to 25 percent when incorporated at dosages of 2 to 3 percent (13). These differences in mix composition create a clear distinction in material response and provide a basis for understanding the improvements observed later in terms of strength and durability.

The response of both repaired and unrepaired specimens under mechanical loading offers a clear understanding of how elevated temperatures reduce strength and how much of that strength can be regained through repair. By comparing these results, it becomes possible to assess the extent of damage caused by heating and the effectiveness of the applied repair layer. Table 2 presents the compressive and tensile strengths of concrete subjected to different temperature levels. The data highlight the improvements achieved after applying the nano engineered repair mortar. This comparison clearly shows the difference between the weakened substrate and the level of strength restored through the repair process.

Table 2 reports compressive strength values of 28.5 MPa (unrepaired) and 33.4 MPa (repaired) at 200 °C, and declines down to 11.3 MPa (unrepaired) and 17.6 MPa (repaired) at 600 °C, along with similar trends in split tensile strength. The fact that repaired specimens consistently outperform unrepaired ones confirms that the nano-engineered repair mortar contributes to mitigating strength loss due to heating, which aligns with literature showing that nano silica-enhanced mixes retain higher residual strength after heating. For instance, a 11.5 % increase in peak stress with 1 % nano silica at elevated temperatures (14). Mechanistically, the improved performance is attributed to micro-filler effect, nucleation sites for hydration and enhanced interfacial transition zone quality, which become especially valuable when the substrate has been thermally damaged.

Although direct microstructural characterization was not included in the present study, the observed recovery in mechanical performance can be attributed to well documented nano scale mechanisms reported in the literature. Nano silica is known to refine pore structure, enhance calcium silicate hydrate formation, and improve the quality of the interfacial transition zone, which together contribute to improved strength and bonding in repaired concrete. The consistency between the experimental trends observed in this study and reported microstructural findings supports the proposed recovery mechanisms.

The numerical values were obtained by recording the load at the point of failure for each specimen during compression and tensile testing and converting those readings into strength values using the corresponding specimen dimensions is calculated by using formula in eq. (1,2). In Table 2, the reported values correspond to the actual strength results obtained for both unrepaired and repaired concrete specimens at each temperature level. These figures reflect the measured performance after testing and form the basis for comparison between damaged and restored conditions.

Compressive Strength

$$f_c = \frac{P}{A} \qquad (1)$$

Where:

f_c= compressive strength (MPa)

P= maximum load at failure (N)

A= loaded area of cube

Split Tensile Strength

$$f_t = \frac{2P}{\pi DL} \qquad (2)$$

Where

f_t= split tensile strength (MPa)
P= load at failure (N)
D = diameter of cylinder
L = length or height of cylinder

Evaluating durability is important to determine how repaired concrete will perform over time under service conditions. Table 3 presents the measured values of pull off bond strength, water absorption, and sorptivity after specimens were exposed to progressively higher temperatures. These results provide a clearer understanding of how the repair layer behaves when subjected to heat induced damage. The reported parameters reflect changes in bonding quality, moisture movement within the material, and the overall condition of the repaired surface.

Table 3. Durability properties of the repaired concrete specimens

Table 3 presents the measured durability results of the repaired specimens. The pull off bond strength decreased from 1.72 MPa at 200 °C to 1.38 MPa at 400 °C and further to 0.86 MPa at 600 °C. At the same time, water absorption increased from 4.2 percent to 7.9 percent, while sorptivity rose from 0.18 to 0.31 mm/min$^{1/2}$. The increase in absorption and sorptivity, along with the reduction in bond strength, reflects the progressive opening

Table 2. Mechanical behavior of repaired and unrepaired concrete

of pores, growth of micro cracks, and weakening of the interface caused by higher temperature exposure. Even so, the repaired surfaces-maintained performance levels that are comparatively strong for substrates subjected to severe thermal damage. This trend aligns with earlier findings that nano silica can reduce sorptivity and water absorption in cement-based materials (14). Overall, the repair layer contributes not only to strength recovery but also to improved resistance against moisture ingress. This improvement can be attributed to a denser internal structure and reduced continuity of capillary pores within the repaired zone.

When the results are viewed alongside findings reported for conventional cement-based repair mortars, the nano enriched system examined in this study shows noticeably better recovery in terms of both mechanical strength and durability performance, especially at elevated temperature levels. Traditional repair mortars tend to retain lower bond strength and allow greater moisture penetration when applied to concrete that has been exposed to high temperatures. In contrast, the nano modified repair mortar used here demonstrates stronger adhesion and lower rates of water movement. These differences point to the practical advantages of incorporating nano scale materials in repair applications for fire affected concrete structures.

The durability values were produced by measuring the force needed to detach the repair layer, the mass gained after immersion, and the water absorbed at fixed time intervals and then converting these measurements into bond strength, absorption percentage, and sorptivity is calculated by using formula in eq.(3,4,5). In Table 3 these values reflect the recorded responses of each specimen to moisture movement and interface tension after exposure to elevated temperatures.

Pull Off Bond Strength

$$f_{bond} = \frac{P}{A} \quad (3)$$

Where:

P= maximum tensile load at failure (N)

A= area of 50 mm diameter core

$$\textbf{Water Absorption}(\%) = \frac{W_{\text{wet}} - W_{\text{dry}}}{W_{\text{dry}}} \times 100 \quad (4)$$

Sorptivity

$$S = \frac{I}{\sqrt{t}} \quad (5)$$

Where:

I= cumulative water absorbed per unit area (mm)

t= time (5, 10, 20, 30, 60 minutes)

The extent of structural recovery was evaluated by comparing key performance indicators that reflect how well the repair system restored the damaged concrete. These measures provide a practical way to judge the effectiveness of the intervention. Table 4 summarizes the strength recovery index, bond recovery index, and surface condition ratings for specimens exposed to the three temperature levels. Together, these values show how much of the original performance was regained after repair. The indices offer a straightforward representation of the repair mortar's role in restoring functional capacity following high temperature exposure.

Table 4. Recovery of structural capacity

Table 4 quantifies recovery of structural capacity through strength recovery indices of 1.17, 1.43 and 1.56 for 200 °C, 400 °C and 600 °C and bond recovery indices of 1.00, 0.80 and 0.50, together with surface ratings of 5, 3 and 2. These indices show that while the repair mortar is highly effective at moderate damage levels (400 °C), performance drops at the most severe exposure (600 °C) where substrate damage dominates a trend also noted by prior reviews that mechanical and durability properties decay rapidly beyond 400 °C despite nano-additive inclusion (15). Mechanistically this reflects that the repair layer can only do so much when the concrete substrate is extensively degraded, but the quantified indices provide a transparent measure of how much recovery is achievable.

The values were generated by comparing the repaired concrete readings with the corresponding unrepaired values at each temperature and by assigning surface ratings based on visual observations after testing and the values of strength recovery, bond recovery is calculated by using formula in eq. (6,7). In Table 4 the numbers show the proportion of strength and bond regained and the condition of the repaired surface when evaluated against the behavior of the heated concrete.

Strength Recovery Index

$$\frac{\text{Repaired Compressive Strength}}{\text{Unrepaired Compressive Strength}} \quad (6)$$

Bond Recovery Index

$$\frac{\text{Repaired Pull Off Strength}}{\text{Pull Off Strength at 200 °C}} \quad (7)$$

Surface Condition Rating was assigned according to visual inspection using a scale ranging from 1 to 5, where the score reflects the observed condition of the concrete surface.

4. Comparison of the Present Findings with Published Research

The findings of this study show a clear improvement in both compressive and tensile strengths of concrete that had been weakened by high temperature exposure after it was treated with a nano silica-based repair mortar. This outcome is consistent with observations reported in earlier research, where the inclusion of nano silica enhanced the residual mechanical performance of concrete subjected to elevated temperatures. Previous studies have noted that concrete modified with nano silica retains higher residual compressive strength and experiences less crack growth than conventional concrete after exposure to temperatures reaching 600 °C. These improvements are generally linked to the ability of nano silica to densify the cement matrix and promote the formation of more stable calcium silicate hydrate phases that can better withstand thermal stress. Placing the present results alongside these findings highlights the value of nano silica not only in improving fresh concrete mixes but also in strengthening repair systems intended for thermally damaged structures (16).

The improvements recorded in the residual properties of the repaired specimens follow patterns that have been reported by other researchers studying nano silica in concrete exposed to high temperatures. In one investigation on engineered cementitious composites, the inclusion of about 1 percent nano silica by weight produced the highest residual compressive strength when compared with control mixtures after thermal exposure. The modified specimens maintained noticeably higher strength even after being heated beyond 400 °C. This observation is in line with the present experimental results, where concrete damaged by heat and subsequently repaired with a nano silica-based mortar regained a considerable share of its original mechanical capacity. The findings suggest that even a small amount of well dispersed nano silica can play a meaningful role in preserving strength under thermal stress. The close numerical agreement with earlier studies supports the explanation that reduced porosity and improved internal stability are key factors behind the observed recovery in compressive and tensile performance (17).

While the present findings are in agreement with earlier reports that nano silica contributes to improved residual strength after exposure to high temperatures, published research also shows that the level of improvement depends strongly on temperature and dosage. In one study on concrete reinforced with hybrid fibers and nano silica, the inclusion of 1.5 percent nano silica increased residual compressive strength by about 18 percent at 600 °C and 26 percent at 800 °C compared with mixes without nano silica. Even so, the remaining strength at 800 °C was only about 37 percent of the original ambient value because of the breakdown of hydration products and internal structural damage. This pattern is comparable to the results observed in the present work. The selected nano silica repair mix restored a meaningful portion of the lost strength after heating, yet specimens exposed to higher temperatures still experienced unavoidable reductions in mechanical performance. Such evidence highlights that mix proportioning, nano silica content, and the applied temperature range collectively determine the balance between strength recovery and degradation. Although the formulation adopted in this study demonstrates clear advantages, further investigation into dispersion quality and variations in nano silica content could provide deeper insight into optimizing residual performance (18).

5. Conclusions

This study evaluated the effectiveness of a nano enriched repair mortar in restoring the mechanical and durability performance of concrete that had been exposed to high temperatures. The investigation followed a systematic experimental program that included controlled heating, surface repair, and detailed post repair testing. Concrete specimens were heated to 200, 400, and 600 degrees Celsius, then repaired using a 20-millimeter-thick mortar containing 1 percent nano silica. Their performance was assessed through compressive strength, split tensile strength, pull off bond strength, water absorption, and sorptivity measurements to quantify the level of recovery achieved. The results allowed a direct comparison between unrepaired and repaired conditions. Compressive strength increased from 28.5 to 33.4 MPa at 200 degrees Celsius, from 19.7 to 28.1 MPa at 400 degrees Celsius, and from 11.3 to 17.6 MPa at 600 degrees Celsius after repair. Split tensile strength also improved, rising from 2.65 to 3.05 MPa at 200 degrees Celsius and from 0.95 to 1.65 MPa at 600 degrees Celsius. Durability results supported these findings. Pull off bond strength reached 1.72 MPa at 200 degrees Celsius and 0.86 MPa at 600 degrees Celsius. At the same time, water absorption increased from 4.2 percent to 7.9 percent and sorptivity rose from 0.18 to 0.31 as the degree of thermal damage intensified. Strength recovery indices between 1.17 and 1.56 confirmed that a considerable share of the lost structural capacity was regained at all temperature levels. Overall, the experimental program clearly captured both the degradation caused by heat and the improvement achieved through repair. The presence of nano silica contributed significantly to strength recovery and improved bonding performance in thermally damaged concrete. These findings suggest that nano enriched repair mortars offer a reliable solution for rehabilitating concrete elements affected by fire and enhancing their remaining service life. Further studies should explore different nano silica contents and variations in repair layer thickness to refine recovery performance. Long term durability assessments under environmental conditions such as wetting drying cycles and carbonation exposure are also necessary to support broader field application.

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