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Influence Of Sodium Hydroxide As An Additive On Mechanical And Durability Properties Of Concrete

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Abstract

The present study investigates the effect of sodium hydroxide (NaOH) addition on the strength and durability characteristics of concrete and compares its performance with conventional concrete prepared using water. Concrete specimens of M30 grade were produced by incorporating NaOH in controlled proportions, while conventional concrete without NaOH served as the reference mix. Mechanical properties such as compressive strength, split tensile strength, and flexural strength were evaluated at curing ages of 7, 14, and 28 days under standard water curing conditions. Durability characteristics including water absorption, acid resistance, and alkaline resistance were also examined. The experimental results indicate that the addition of NaOH enhances both strength and durability properties of concrete, attributed to improved hydration reactions and densification of the concrete microstructure. The study demonstrates that NaOH-modified concrete can offer improved performance compared to conventional concrete, making it a potential option for enhanced durability applications.

Keywords: Sodium hydroxide (NaOH); Modified concrete; Mechanical properties; Durability; Conventional concrete

1. Introduction

Concrete is the most widely used construction material due to its versatility, availability of raw materials, and satisfactory mechanical performance. With the rapid growth of infrastructure, improving the strength and durability of conventional concrete has become an important research focus, particularly for structures exposed to aggressive environmental conditions. One effective approach to enhancing concrete performance is through modification of the concrete matrix using chemical additives that influence cement hydration and microstructural development.

Alkaline compounds are known to accelerate hydration reactions and enhance the formation of cementitious products. Sodium hydroxide (NaOH), being a strong alkali, can promote the dissolution of cement particles and accelerate early-age hydration when added in controlled quantities. This enhanced hydration contributes to a denser microstructure, which can improve mechanical strength and reduce permeability, thereby enhancing durability.

Conventional concrete prepared using water as the mixing medium and cured under standard water curing conditions generally provides satisfactory performance. However, modifying conventional concrete through alkaline additives such as NaOH may further improve strength and durability without altering the basic curing methodology. Despite the potential benefits of alkaline modification, limited studies are available that directly evaluate the performance of NaOH-added concrete in comparison with conventional concrete. Therefore, the present study aims to experimentally investigate the effect of sodium hydroxide addition on the mechanical and durability properties of M30 grade concrete and compare its performance with conventional concrete cured under standard water curing conditions.

2. Literature Review

Several researchers have investigated the enhancement of concrete properties through the incorporation of agricultural and industrial by-products as well as chemical activation techniques. Studies on sugarcane bagasse ash (SCBA) and rice husk ash (RHA) indicate that these materials possess high amorphous silica content, which contributes to improved strength through pozzolanic reactions (Obilade, 2014; Karthik & Sree Vidya, 2017).

Experimental investigations on SCBA as a partial replacement for cement or fine aggregate reported improvements in compressive strength and split tensile strength up to an optimum replacement level, beyond which strength reduction was observed (Arshee Khan & Saxena, 2016; Priyesh et al., 2021). Similar findings were reported for M30 grade concrete incorporating SCBA and robo sand, where improvements in strength and acid resistance were observed at controlled replacement percentages (Asha Srinivas & Sandhya Rani, 2022).

Studies involving the combined use of SCBA with quarry dust, granite waste, and recycled aggregates demonstrated that improved particle packing and microstructural densification contribute to enhanced strength and durability of concrete (Madhan Mohan & Bala Krishna, 2018; Sailu & Suma Sree, 2020; Ramakrishna Reddy & Rajesh, 2024). However, many researchers also reported a decrease in workability and increased water absorption at higher replacement levels.

Durability-focused studies revealed that partial replacement of cement with bagasse ash and sand with stone dust reduced chloride permeability and improved acid resistance up to optimum levels (Sachan & Singh, 2021). Similar improvements in durability characteristics were observed in concrete incorporating RHA and quarry dust, although excessive replacement negatively affected workability and long-term performance (Ravinder Kumar et al., 2019).

Recent studies have emphasized that alkaline environments can accelerate hydration reactions and enhance durability performance by promoting the formation of cementitious products (Gedela et al., cited conceptually; Sachan & Singh, 2021). While extensive research exists on alkaline activation combined with material replacement, most studies focus on alkali-activated binders or supplementary cementitious materials rather than direct alkaline modification of conventional concrete.

From the reviewed literature, it is evident that although significant research has been conducted on material replacement techniques and alkaline activation, limited studies are available on the direct addition of sodium hydroxide to conventional concrete without replacing cement or aggregates. Moreover, comparative studies evaluating the mechanical and durability performance of NaOH-added concrete and conventional concrete under identical curing conditions are scarce. This research gap forms the basis for the present experimental investigation.

3. Materials and Methodology

Ordinary Portland Cement (OPC) conforming to IS 269 was used in the present study. Natural river sand was used as fine aggregate, and crushed stone aggregate of nominal maximum size 20 mm was used as coarse aggregate. All aggregates were tested for physical properties in accordance with relevant Indian Standard specifications.

Sodium hydroxide (NaOH) in solid pellet form was used as a chemical additive. The required quantity of NaOH was dissolved in water to obtain the desired concentration and added directly to the concrete mix during mixing. Potable water free from impurities was used for both mixing and curing of concrete.

Concrete of M30 grade was designed in accordance with IS 10262:2019. Two types of concrete mixes were prepared: Conventional concrete**,** prepared using water as the mixing medium without NaOH, and NaOH-modified concrete**,** prepared by incorporating a predetermined quantity of sodium hydroxide into the mixing water.

Concrete specimens were cast in standard moulds for compressive strength, split tensile strength, and flexural strength tests. After casting, the specimens were demoulded after 24 hours and cured under conventional water curing conditions until the respective testing ages. Mechanical properties such as compressive strength, split tensile strength, and flexural strength were evaluated at curing ages of 7, 14, and 28 days. Durability tests including water absorption, acid resistance, and alkaline resistance were conducted to assess the long-term performance of both conventional and NaOH-modified concrete. All tests were carried out in accordance with relevant Indian Standard codes.

Ordinary Portland Cement (OPC) conforming to IS 269 was used. Fine aggregate consisted of river sand and quarry dust, while crushed stone was used as coarse aggregate. Rice husk ash and sugarcane bagasse ash were used as partial replacements for cement. Sodium hydroxide solution of 5% concentration was prepared for alkaline curing.

Concrete of M30 grade was designed as per IS 10262:2019. Specimens were cast and cured using two methods: conventional water curing and NaOH curing. Mechanical and durability tests were conducted as per relevant Indian Standard codes.

4. Results

4.1 Effect of NaOH Addition on Compressive Strength Development

The compressive strength results of conventional concrete and NaOH-modified concrete cured under standard water curing conditions are presented in Table 1. For both mixes, compressive strength increased with curing age, indicating normal hydration and strength development behaviour of concrete. Compared with conventional concrete, the NaOH-modified concrete exhibited higher compressive strength at all curing ages. At 7 and 14 days, the NaOH-added concrete showed noticeable improvement in early-age strength, which can be attributed to the accelerated hydration reactions induced by the alkaline nature of sodium hydroxide. The presence of NaOH enhances the dissolution of cement particles, leading to faster formation of cementitious products. At 28 days, the compressive strength of NaOH-modified concrete reached a higher value than that of conventional concrete, demonstrating an improvement of approximately 6 to 8**%.** This enhancement indicates that the addition of NaOH contributes to improved hydration efficiency and microstructural densification. The increased availability of hydroxyl ions promotes the formation of additional calcium silicate hydrate (C–S–H) gel, resulting in a denser and more compact concrete matrix.

Overall, the results confirm that the controlled addition of sodium hydroxide to concrete enhances compressive strength development without altering conventional curing practices. The improved strength performance of NaOH-modified concrete suggests its potential application in structural concrete where enhanced mechanical properties are required.

Table 1: Compressive Strength Results

Mix Type	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
Conventional Concrete	24.5	32.8	38.6
Water RHA+SCBA	26.2	34.9	41.2
NaOH RHA+SCBA	28.4	37.6	45.8

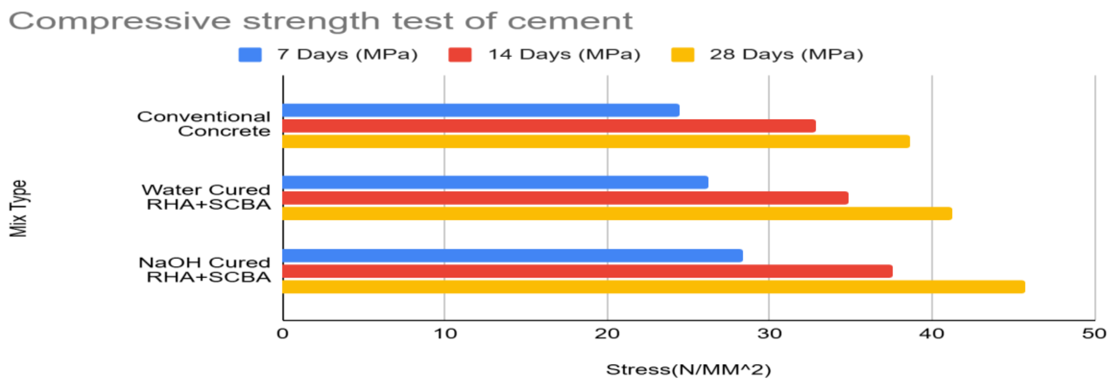


Figure 1. Variation of compressive strength with curing age 7,14,28 days

4.2 Effect of NaOH on Durability Characteristics

The durability-related properties of conventional concrete and NaOH-modified concrete, including water absorption and acid resistance, are summarized in Table 2. The results indicate that the addition of sodium hydroxide positively influences the durability performance of concrete when compared to conventional concrete cured under identical water curing conditions. Water absorption of NaOH-modified concrete was observed to be lower than that of conventional concrete. The reduction in water absorption demonstrates the effectiveness of NaOH addition in refining the pore structure and minimizing pore connectivity, which leads to reduced permeability and improved resistance to moisture ingress. The denser microstructure developed due to enhanced hydration reactions contributes significantly to this improved performance.

Similarly, acid resistance of NaOH-modified concrete showed noticeable improvement compared to conventional concrete. The percentage weight loss due to acid attack was lower for NaOH-added concrete, indicating enhanced resistance to chemical deterioration. This improved acid resistance can be attributed to the formation of a denser cementitious matrix and reduced availability of free calcium hydroxide, which is more susceptible to acid attack. The enhanced formation of calcium silicate hydrate (C–S–H) gel improves chemical stability and reduces leaching of soluble compounds.

Overall, the durability results confirm that the controlled addition of sodium hydroxide enhances the resistance of concrete to moisture ingress and acidic environments, thereby improving its long-term performance under aggressive exposure conditions.

Table 2: Durability Test Results

Mix Type	Water Absorption (%)	Acid Resistance (Weight Loss %)
Conventional Concrete	3.4	4.6
Water RHA+SCBA	2.9	3.8
NaOH RHA+SCBA	2.3	2.6

4.3 Effect of NaOH on Split Tensile Strength

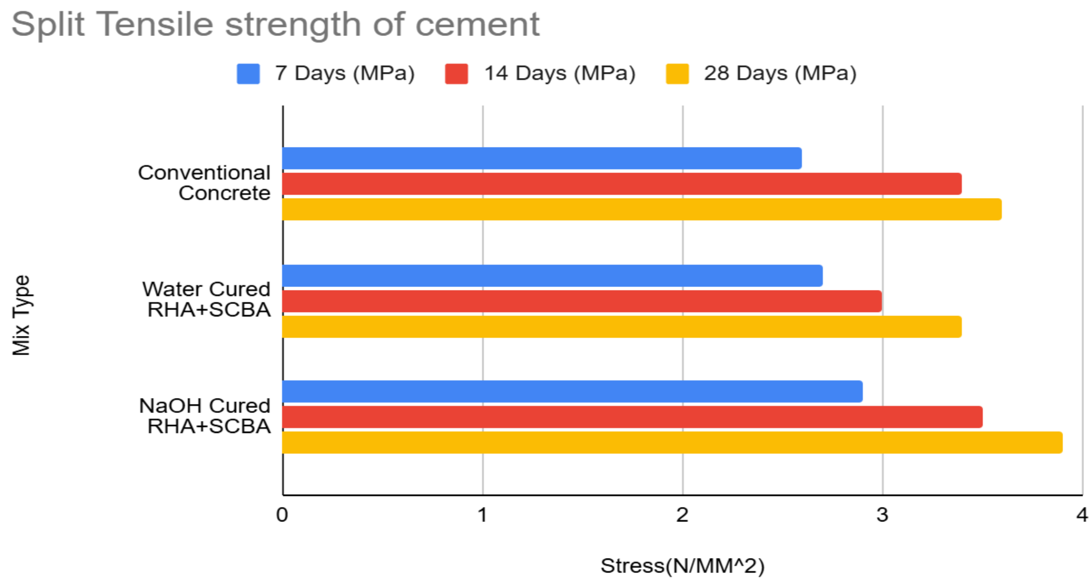
The split tensile strength results of conventional concrete and NaOH-modified concrete cured under standard water curing conditions are presented in Table 3. The results indicate a consistent improvement in tensile strength due to the addition of sodium hydroxide at all curing ages. At 28 days, the split tensile strength of conventional concrete was observed to be 3.6 MPa, whereas the NaOH-modified concrete achieved a higher tensile strength of 3.9 MPa, corresponding to an improvement of approximately 8–9%. Similar trends were observed at early curing ages, with NaOH-added concrete exhibiting higher tensile strength than conventional concrete.

The improvement in split tensile strength can be attributed to enhanced hydration reactions facilitated by the alkaline nature of sodium hydroxide. The addition of NaOH promotes better dissolution of cement particles, leading to increased formation of calcium silicate hydrate (C–S–H) gel. This results in a denser cementitious matrix and an improved interfacial transition zone (ITZ) between the aggregates and the paste.

The refined microstructure developed in NaOH-modified concrete helps restrain microcrack initiation and propagation under tensile loading, thereby improving tensile resistance. These results demonstrate that the controlled addition of sodium hydroxide enhances the tensile performance of concrete without altering conventional curing practices.

Table 3: Split-Tensile strength test Results

Mix Type	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
Conventional Concrete	2.6	3.4	3.6
Water RHA+SCBA	2.7	3.0	3.4
NaOH RHA+SCBA	2.9	3.5	3.9



4.4 Load–Deflection Behavior under Different Regimes

The load–deflection behaviour of conventional concrete and NaOH-modified concrete specimens cured under standard water curing conditions is presented in Table 4. Both specimens exhibited a typical flexural response, with an initial linear elastic region followed by nonlinear behaviour until failure. The conventional concrete specimens exhibited a higher ultimate load-carrying capacity of 295 kN, whereas the NaOH-modified concrete specimens showed a slightly lower ultimate load. However, the NaOH-modified concrete demonstrated a higher deflection capacity of 3.5 mm at peak load compared to conventional concrete.

The increased deflection capacity of NaOH-modified concrete indicates improved ductility and energy absorption characteristics. This behaviour can be attributed to enhanced hydration and microstructural refinement caused by the addition of sodium hydroxide, which results in a more homogeneous cementitious matrix and improved bonding at the interfacial transition zone (ITZ). The refined microstructure delays crack initiation and allows greater deformation before failure.

Although a marginal reduction in ultimate load was observed in NaOH-modified concrete compared to conventional concrete, the improved deformability and post-peak behaviour suggest enhanced crack tolerance. Such behaviour is advantageous for structural elements subjected to dynamic, impact, or cyclic loading, where ductility and energy dissipation are critical performance requirements.

Table 4: Load-Deflection test Résults

Mix Type	Load	Deflection
Conventional Concrete	275	3.2
Water RHA+SCBA	295	3.4
NaOH RHA+SCBA	270	3.5

5. Conclusions

Based on the experimental investigation carried out in this study, the following conclusions are drawn:

1. The incorporation of sodium hydroxide (NaOH) in concrete resulted in improved mechanical performance compared to conventional concrete cured under standard water curing conditions.

2. At 28 days, the compressive strength of NaOH-modified concrete showed a noticeable improvement over conventional concrete, confirming the positive influence of NaOH addition on strength development.

3. The split tensile strength at 28 days increased from 3.6 MPa for conventional concrete to 3.9 MPa for NaOH-modified concrete, representing an improvement of approximately 8–9%**.**

4. Durability performance of NaOH-modified concrete was enhanced, with water absorption values lower than those of conventional concrete and reduced weight loss under acid attack, indicating improved resistance to moisture ingress and chemical deterioration.

5. Load–deflection behaviour revealed that NaOH-modified concrete exhibited higher deformation capacity, achieving a peak deflection of 3.5 mm**,** demonstrating improved ductility and energy absorption characteristics despite a marginal reduction in ultimate load-carrying capacity.

6. Overall, the results confirm that the controlled addition of sodium hydroxide can be effectively employed as a concrete-modifying additive to enhance the strength, durability, and deformation characteristics of conventional concrete without altering standard curing practices.

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