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An Experimental Investigation on Nano-Enhanced Tertiary Blended Concrete Incorporating Industrial Wastes

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ABSTRACT

Concrete is a crucial material in the construction industry; however, its production process releases carbon dioxide into the atmosphere. Undoubtedly, the building sector's increasing global interest unveils a challenge to its ability to withstand cement alternatives and manage the resulting outflows. Fly ash, GGBS (ground granulated blast furnace slag), Zeolite, rice husk, silica fume, metakaolin, and various industry by-products can typically replace cement. This research study aims to replace cement with multiple cementitious materials, individually and in combination, to evaluate the strength characteristics of blended concrete. The replacement percentages ranged from 0 to 30% for each substitute material, such as fly ash, GGBS, and Zeolite, and strength tests were done to assess the performance of the modified concrete after 7 and 28 days of water curing. Ordinary Portland Cement (OPC) is used to create M30 and M50 grades of concrete. Similarly, cement was replaced with fly ash, GGBS, and Zeolite in amounts ranging from 10 to 30% for M30 and M50 grades, and their strength was evaluated after 7 and 28 days of curing. The most efficient percentage of substitution for both the concrete grades is determined, and the corresponding replacement ratio is used to produce the blended concrete, which incorporates cement, fly ash, GGBS, and Zeolite. The overall findings reveal that the composite concrete, comprising four binding materials, demonstrated superior strength for the concrete grade compared to alternative substitutes. The optimal mixture ratios for M30 concrete after 28 days consist of 20% fly ash, 20% GGBS, and 10% zeolite. Moreover, different ratios of Zeolite-10%, Fly-Ash-30%, and GGBS-20% were used to produce M50 concrete.

Keywords: Blended concrete; Fly ash; GGBS; Zeolite; Strength characteristics.

1. INTRODUCTION

Using supplementary cementitious materials replaces a substantial amount of Portland Blended cement created by comprehensively mixing ordinary Portland cement (OPC) with one or more supplemental cementitious materials (SCMs). Industrial by-products, such as ground-granulated blast furnace slag (GGBFS) or fly ash (FA), are commonly used as SCMs. Typically, cement does not rely solely on these materials. However, when combined with OPC (ordinary Portland cement), they greatly enhance the cementing characteristics of hardened concrete through hydraulic or pozzolanic activity (Tural *et al.* 2024). SCMs are increasingly employed in concrete because of the advantages (Pacewska and Wilińska, 2020) of mitigating economic and environmental problems using industrial waste, decreasing carbon dioxide emissions, and reducing energy needs for OPC clinker manufacture. Using supplementary cementitious materials replaces a substantial amount of Portland cement in the construction sector. Fly ash, a by-product of thermal power plants is the world's most widely available additional cement ingredient. However, such concrete must function similarly to OPC while being cost-effective. CANMET developed concrete in 1985 that incorporates considerable levels of fly ash while maintaining all of the features of high-performance concrete, such as enhanced durability, low permeability, and great mechanical properties. Furthermore, the Liu Centre for the Study of Global Issues was constructed using sustainable design principles to minimize its impact on the environment and existing infrastructure. Because of the beneficial impacts of this type of concrete on the environment, his findings and those principles allow for the use of high-volume fly ash concrete in particular construction sites. Enhancements in the characteristics of concrete, such as its capacity to be easily worked with, resistance to water penetration, maximum strength, and long-lasting nature, include an improved ability to withstand alkali-silica reactions, steel corrosion, salt scaling, delayed ettringite production, and sulphate assault. However, real-world evidence shows that the type and amount of supplementary cementitious materials (SCMs) used affect how well concrete works, such as how easy it is to work with, how stable it is with air, and how strong it gets over time. The construction industry uses concrete as its primary and crucial material. The fundamental components of cement, sand, aggregates, and water are inherent, cost-effective, and readily accessible. The increasing demand for concrete prompted the development of novel manufacturing techniques and materials. Cement is the world's second most widely used construction material, following water. Nevertheless, it contributes to environmental issues by directly emitting CO_2 into the atmosphere, perhaps contributing to ozone depletion.

Fly ash is a finely grounded, grey powder composed of spherical particles generated as a by-product of the coal industry. It enhances the plasticity of new concrete. The potential for using fly ash as an additional cementitious material in concrete was understood in the middle of the 1900s. In 2005, about 15 million tons of concrete, concrete products, and grouts were in the United States with partial cement replacement by fly ash. Electricity consumption has grown dramatically in recent years. Fly ash is a by-product of burning pulverized coal in power plants. The flue gases carry the unburned waste out of the burning area of the boiler, where it is subsequently collected using mechanical or electrostatic separators. Bottom ash is the unburned material that collects at the bottom of the furnace. Although using this material as a cementitious concrete component is often inappropriate, it is used to create concrete masonry blocks. Fly ash is a silt-sized, reflective, abrasive, naturally occurring material. It generally consists of glassy, hollow, spherical particles smaller than cement. The blast furnace process produces GGBS or ground-granulated blast furnace slag. The iron industry produces the substance as a residual product. We use it to fabricate durable concrete structures by combining conventional Portland cement with pozzolanic materials. Organic zeolites are hydrated mineral aluminosilicates that include alkaline and alkaline earth metals. Volcanic ash primarily alters them. Zeolites exhibit much higher levels of dissolved SiO_2 compared to conventional materials and other glassy mixers. The synthesis of more hydrated products, which in turn contributes to the development of greater strength. Substituting cement with fly ash leads to an increase in compressive strength. As the proportion of fly ash increases, the compressive strength also increases. Additionally, it improves compression's ultimate efficiency. Prolonged hydration results in a decrease in strength and a reduction in the duration of the effect. As the amount of fly ash increases, the intensity reaches an appropriate level. The elimination of fly ash leads to a reduction in intensity.

According to the study groups, the maximum allowable proportion of fly ash in cement is approximately 20 %. Combining fly ash, GGBS, Zeolite, and cement in different proportions produces superior outcomes to conventional concrete.M30 (consisting of 20 % fly ash, 20 % GGBS, 10 % zeolite, and 50 % OPC) ensures excellent workability and strength even at low quantities. A combination of M50 mixed with a high-volume replacement of 30 % fly ash, 20 % GGBS, 10% zeolite, and 40 % OPC results in excellent performance and strength. At every stage of development, this study shows that the low-volume substitution M 30 mix (which is 20 % fly ash, 20 % GGBS, 10 % zeolite, and 60 % OPC) works better than the high-volume repositioning M50 mix (which is 30% fly ash, 20% GGBS, 10 % zeolite, and 40 % OPC) SCM concrete often displays slow hydration, leading to delayed setting and decreased early-age strength. This phenomenon becomes more prominent as the ratio of supplementary cementitious materials (SCMs) in the blended cement increases and the concrete undergoes low-temperature curing. Hence, further investigation is required to gain a more comprehensive understanding of the impact of blended cement ingredients on concrete performance under varying material, construction, and service situations. The concrete maturity is measured by having a datum temperature for the concrete, the temperature below which the concrete does not develop any strength. The specific combination of concrete ingredients and mix proportions, nevertheless, the absence of test data for SCM concrete necessitates the adoption of a standard datum temperature of -10°C for typical OPC concrete in practical applications, irrespective of the specific ingredients and mix proportions utilized. Every metric ton of cement release approximately 900 kilograms of carbon dioxide into the atmosphere, leading to environmental degradation. The studies mentioned by the author (Xie *et al.,* 2019) examined the impact of fly ash and GGBS on the properties of fresh and hardened cement concrete. They observed that fly ash and GGBS caused partial dissolution of the cement. The primary aim of this study is to examine the characteristics of fresh and hardened M 30 concrete, as well as concrete with partial fly ash and various percentages of GGBS replacement. The research findings show that using a limited volume replacement (20 percent fly ash, 20 percent GGBS, and 60 percent OPC) results in high performance and strength. (Arimi, 2017) investigated over 100 remaining deposits of zeolite minerals. They discovered that Zeolite is present in over 21 provinces, predominantly in China. Common zeolites make up a frame's connections. Structured silicate alumina hydrates. We utilize Zeolite for effective adsorption and ion exchange.

Zeolite is a mineral mixture that specifically functions as an antibacterial agent, enhancing the prevention of materials created by a combination of alkaline substances commonly used in cement production due to the limited literature available in this field. The author of (Knight *et al.* 2023) research investigated how cement affects the environment and suggested other options, like using extra cementitious materials (SCM), such as fly ash, silica fume, blast furnace slag, or metakaolin. According to another researcher (Ramzi and Hajiloo, 2023), their investigation revealed that SCMs have the potential to effectively substitute up to 30% of the cement in concrete, based on weight. Another thing is that adding extra cementitious materials (SCMs) like silica fume, fly ash, and blast furnace slag to the same amount of cement by weight makes the concrete much stronger (Yaseen *et al.,* 2024). These supplementary cementitious materials (SCMs) mixtures are commonly called blended cement. Research has shown that using a single supplementary cementitious material to replace a small portion (10 or 20 %) of the cement may not significantly improve the strength and durability of concrete (Toutanji *et al.* 2004). Simultaneously, another group of writers discovered that ternary blends significantly improve concrete's overall durability qualities than binary blends (Chiranjeevi *et al.* 2023). In continuation of the background study of fly ash, several studies have been conducted on the usage of fly ash since 1980, raising concerns regarding the strength and longevity of concrete buildings (Park *et al.* 2021; Zhou *et al.* 2020; Sridhar *et al.* 2023). Following that, various nations that are significant fly ash producers have widely used additional fly ash in concrete, commonly known as "High Volume fly ash Concrete." Research has also been conducted on fly ash and its impact on different systems. Fly ash, an unconventional construction material (Poloju *et al.* 2023), may create new materials and technology. It is focused on products that may meet the demands of the building sector in various contexts. For the M-25 mix with a 0.46 water-to-cement ratio in this research, fly ash has been substituted for cement in the following 12 ranges: 0-100% with a 10% interval of cement. Concrete mixes were created and tested, and their compressive strengths were compared. It was found that the strength of Portland Pozzolana Cement was 20% replacement by fly ash rise (1.9% to 3.2%) after 28 and 56 days. Additionally, it was shown that after 56 days, the strength of fly ash substituted for up to 30% of PPC is almost like concrete used as a reference. PPC increased in strength because of the delayed hydration process after 56 days of curing. However, using low-quality raw ingredients, such as fly ash and readily available crushed aggregates, it was possible to produce high-performance concrete (HPC) with a 28-day strength of up to 60 MPa (Soundararajan *et al.* 2023). This way, saving natural resources and significantly reducing Portland cement consumption would be possible. Blended cement has enormous benefits, as presented in Figure 1.

By replacing 0, 20%, 40%, and 60% of the cement in mixes with different amounts of the total binder of 400kg/m^3 to 600kg/m^3, the effects of the fly ash content were evaluated. In addition, they examined concretes' workability, mechanical, and durability characteristics. Results show that by substituting up to 40% of the cement with fly ash and utilizing locally accessible crushed granite aggregates, it is feasible to make HPC with up to 60 MPa. This project aims to analyze the compressive strength properties of tertiary blended concrete consisting of fly ash, Zeolite, and blast furnace slag mixes. A M30 and M50 grade reference mix is prepared and evaluated to compare their strengths.

This research emphasizes the advantages of incorporating supplementary cementitious materials (SCMs) such as fly ash, ground-granulated blast furnace slag (GGBFS), and zeolite into concrete, underscoring their contributions to enhancing strength, durability, and sustainability. The research evaluates the performance of M30 and M50 concrete mixtures with varying SCM proportions, showing that these blended cements significantly improve mechanical characteristics while lowering the environmental footprint. This study also highlights the ability of SCMs to decrease CO_2 emissions, energy requirements, and dependence on ordinary Portland cement (OPC).

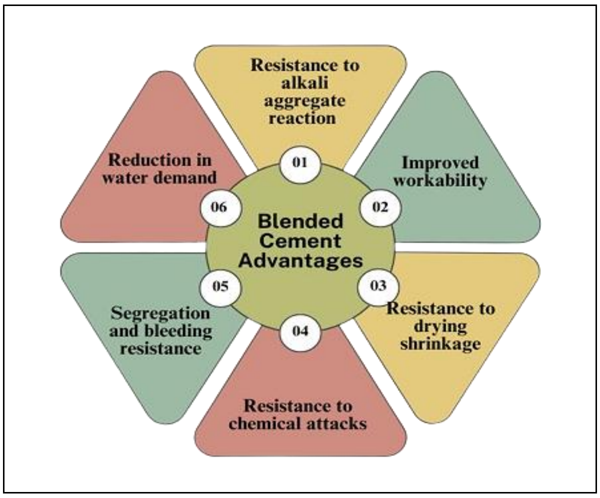

Fig. 1: Blended cement advantages

Table 1. Chemical composition of different cementitious materials

S. No.	Details	Fly ash	GGBS	Zeolite
1	SiO_2	56.01	32.97	63.72
2	Al_2O_3	29.80	17.97	11.40
3	Fe_2O_3	3.58	0.72	2.73
4	TiO_2	1.75	-	0.29
5	CaO	2.36	35.08	3.29
6	MgO	0.30	10.31	0.05
7	K_2O	0.73	-	2.83
8	Na_2O	0.61	-	1.02
9	SO_3	Nil	0.72	0.13

2. MATERIALS AND METHODS

2.1 Materials and Methods

Blended concrete is produced from cement, fly ash, GGBS, zeolite, fine aggregate, coarse aggregate, and water. This study employed fly ash, ground granulated blast slag (GGBS), and Zeolite as partial substitutes for cement. Table 1 shows the chemical composition of different cementitious materials.

53 grade OPC is used with a specific gravity of 3.14. The cement is available in the local market. Superplasticizer of category Sulphonated Naphthalene Formaldehyde is used to increase the workability of concrete in conjunction with an alkaline activator. Fine aggregate conforming to Zone II and coarse aggregate passing from 20 mm to 12 mm sieve was employed. Fly ash of class 'C' is used in this present study. The methodology proposed for this study involves substituting cement in M30 and M50 grade concrete. Compressive strength tests are performed after 7 and 28 days of water curing to assess the performance of the modified concrete mixtures. The optimal replacement ratios for each grade of concrete are determined through these tests. Subsequently, a composite concrete mixture is produced, incorporating all four binding materials. The strength of this composite concrete is then compared to that of concrete mixtures containing individual or combined substitutes to identify the most effective formulation.

3. MIX PROPORTION

Two different mix proportions were developed for traditional concrete during this experiment: Mix A M30 grade and Mix B M50 grade, and the same mixing proportions were used for blended concrete. The ratio was set to 1:1.4:2.5 for mix A, and Mix B consists of 1:1.4:2.5. The hybrid construction is the same as traditional concrete in reinforced materials. The cement is partially replaced by fly ash, GGBS, and Zeolite in two different mixtures with differing proportions.

3.1. Experimental Programme

Fly ash, Zeolite, and GGBS are weighed and thoroughly mixed until they have a uniform colour. Then, add the aggregates and stir for 3-5 minutes. The water and superplasticizer are then combined for 5 minutes for optimal workability. Before filling the concrete mix, the specimens are cleaned and applied with oil. Adequate strength and elimination of gaps in concrete are achieved by the cubes being properly compacted and vibrated for 2-3 minutes. These cast cubes are left to cure in water for 7 and 28 days.

Hence, the current research studies replacement cement to attain the needed goal strength using binder ingredients such as fly ash, Zeolite, and GGBS. The strength characteristics of mixed cement concrete have been investigated in this study. Concrete cube specimens (150 mm x 150 mm x 150 mm) were cast and tested on the compression testing machine to assess the desired properties of blended concrete using different materials as substitutes for the cement.

4. RESULTS AND DISCUSSION

In this research compressive strength is taken as parameter to study the influence of different pozzalonic materials in conventional concrete. The compressive strength results of conventional concrete containing different percentage of fly ash, GGBS and Zeolite are discussed in this section and also the test results of blended concrete are also discussed elaborately.

4.1. Compressive Strength of Conventional Control Mix

The results of M30 and M50 grades of conventional concrete are presented in Table 2.

Table 2. Compressive strength of conventional control mix

S. No	Grade	Compressive Strength (MPa)			
		7 Days		28 Days	
		22.43		39.36	
1	M 30	23.07	24.89	34.36	37.07
		29.18		37.50	
		32.52		56.24	
2	M 50	33.42	33.32	55.97	56.54
		34.02		57.41	

4.2. Compressive Strength of Mix Containing Fly Ash

The concrete research specimens of grades M30 and M50 are cast by substituting 10%, 20%, and 30% of fly ash with cement. Table 3 and Figure 2 reveal the evaluation findings numerically and graphically.

Table 3. Compressive strength of mix containing fly ash

S. No	Grade	% of replacement	Compressive Strength (MPa)	
			7 Days	28 Days
1	M30	10	36.15	42.07
2	M30	20	36.41	44.60
3	M30	30	29.63	38.22
4	M50	10	45.04	52.45
5	M50	20	43.11	54.57
6	M50	30	56	57.48

The test results above showed that the strength attained with only cement is less than fly ash, which has 10%, 20%, and 30% replacements. However, the results showed better results with 20% replacement for 7 days, and a similar trend followed for 28 days with 30% replacement compared to the conventional concrete and zeolite replacement specimens. Further cementitious compounds are formed when fly ash and calcium hydroxide, produced by cement hydration, react pozzolanically. However, this reaction happens more slowly than the first cement hydration. Substituting some of the cement with fly ashcan result in a modest drop in the early strength of M30 concrete (up to 28 days) (Ambrus and Mucsi, 2023). Fly ash has certain characteristics that can affect its ability to react and contribute to strength development, such as its fineness and chemical makeup. Improved initial and over time strength can be achieved, for instance, by using fly ash particles that are finer and more reactive. M50 concrete has more calcium hydroxide, facilitating a more efficient chemical reaction with fly ash. Comparing this to standard M50 concrete may help preserve or slightly increase the early strength (Rishi and Aggarwal, 2023).

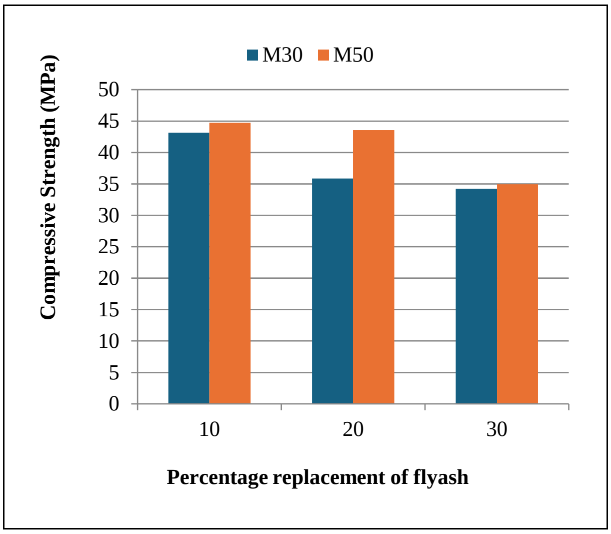

Fig. 2: Compressive strength of mix containing fly ash

Table 4. Compressive strength of mix containing GGBS

S. No	Grade	% of replacement	Compressive Strength (MPa)	
			7 Days	28 Days
1	M30	10	37	46.46
2	M30	20	39.43	51.7
3	M30	30	35.26	45.62
4	M50	10	51.70	62.37
5	M50	20	60.59	64.39
6	M50	30	50.78	59.2

4.3. Compressive Strength of Mix Containing GGBS

Concrete test specimens of M30 and M50 grades are cast by replacing the cement with GGBS of 10%, 20%, and 30%. The test results are presented in Table 4 and Figure 3 respectively.

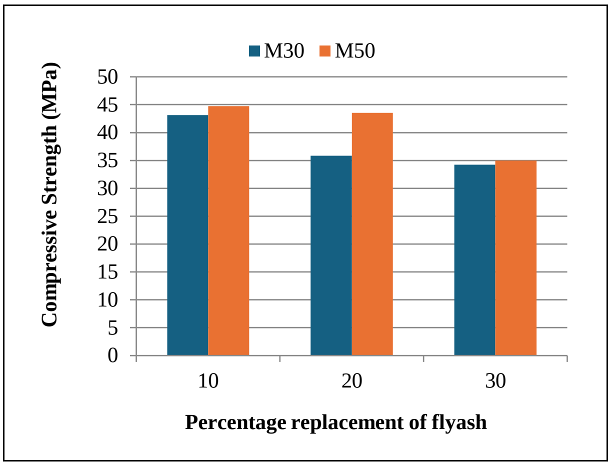

Fig. 3: Compressive strength of mix containing GGBS

However, GGBS-replaced specimens showed higher results with 10%, 20%, and 30 % replacement than any other specimens for 7- and 28-day curing because of the higher calcium and aluminium available in the GGBS. Moreover, the water required is higher than other specimens as the GGBS particles are flaky, and fly ash particles are spherical. GGBS interacts with water to generate its hydration products, unlike fly ash. Although these enhance long-term strength, GGBS hydrates more slowly at first than Portland cement (Korde *et al.* 2019). When the replacement amount surpasses 20% at 28 days, the early strength development may be hindered due to the delayed hydration of GGBS compared to cement (Kumar *et al.,* 2024). Elevated GGBS replacement may impact the mix's overall composition and lead to more porosity in the concrete, making early strength development even more difficult (Munjal *et al.,* 2021).

4.4. Compressive Strength of Mix Containing Zeolite

Concrete test specimens of M30 and M50 grades are cast by replacing the cement with Zeolite in 10%, 20%, and 30%. The test results are presented in Table 5 and Figure 4. In the early stages of the pozzolanic reaction, there might not be sufficient $Ca(OH)_2$ readily available if there is an excessive replacement of Zeolite (Caputo *et al.* 2008). For a maximum of 28 days, this may impede early strength development. Particles of Zeolite can be used to fill gaps in the concrete framework and may strengthen the packing density at high substitute levels.

Table 5. Compressive strength of mix containing Zeolite

S. No	Grade	% of replacement	Compressive Strength (MPa)	
			7 Days	28 Days
1	M30	10	36.87	43.14
2	M30	20	32.88	35.85
3	M30	30	30.81	34.22
4	M50	10	41.63	44.74
5	M50	20	36.15	43.56
6	M50	30	32	34.96

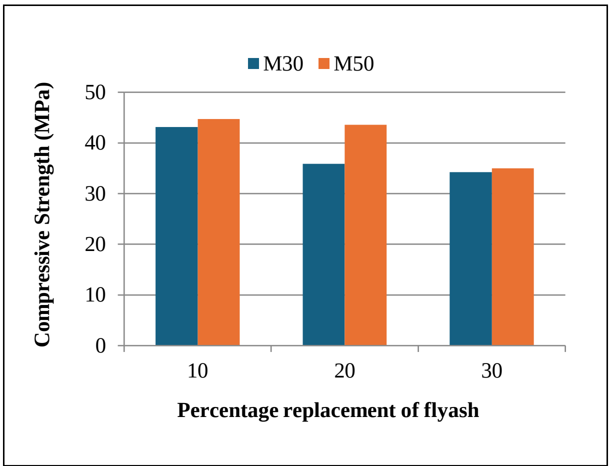

Fig.4: Compressive strength of mix containing Zeolite

Still, it may also prevent a robust and well-bonded network of hydration products from forming, which could compromise the structural integrity of the concrete (Rahman and Lu, 2024). While both grades lose strength when zeolite replacement increases, M30 concrete may be slightly more susceptible because of its naturally lower cement content. M50 concrete buffers the limits brought up by zeolite addition with a bigger initial pool of $Ca(OH)_2$ (Mola-Abasi and Shooshpasha, 2016).

4.5. Optimum Dosages of Blended Concrete Composites

The available results indicate that the Optimum dosages to produce a blended concrete for M30 and M50 grades are Fly ash, GGBS, and Zeolite at 20%:20%:10% and 30%:20%:10%, respectively. These optimal dosages are the percentage of cement composite replacement at which maximum compressive strength is achieved. The ideal dosages of combination cement composites for mixed cement concrete are then cast and checked with appropriate dose test specimens. The details of these experiments are presented in Table 6 respectively.

Table 6. Compressive strength of blended cement concrete

S. No	Grade	% of replacement	Compressive Strength (MPa)	
			7 Days	28 Days
1	M30	Fly-Ash-20% GGBS-20% Zeolite-10%	34	48.04
2	M50	Fly-Ash-30% GGBS-20% Zeolite-10%	43.31	68.92

Due to several synergistic effects, adding 30% of the mixture of fly ash, 20% GGBS, and 10% Zeolite to M50 grade concrete increases its strength and 50% cement (Phul *et al.* 2019). Eating calcium hydroxide and producing more C-S-H, fly ash, and GGBS aid in the pozzolanic reaction, strengthening the concrete's microstructure and durability (Hamada *et al.* 2024; Golewski, 2022). Zeolite decreases the permeability of the concrete framework and increases packing density due to its tiny particle size and high silica concentration. Combining these two elements makes the structure denser and more compact, lowering voids and increasing compressive strength. These additional cementitious ingredients strengthen the concrete's defences against thermal cracking and chemical attacks, making M50-grade concrete stronger and longer-lasting.

5. CONCLUSION

This study employed an experimental program to investigate the strength properties of blended concrete cement and assessed the appropriate dosages for varying percentages of fly ash replacement, GGBS, and Zeolite. Zeolite. The utilization of supplemental cementitious materials (SCMs) in conjunction with cement, specifically the use of fly ash (30%), the GGBS (20%), and Zeolite (10%), presents intriguing opportunities for the increase of concrete strength. Although pozzolanic reactions provide long-term strength gains for all SCMs, the effects on initial strength are not the same. Early strength may be slightly reduced by fly ash, but it may be maintained or increased by GGBS, especially in mixes with a greater cement percentage, such as M50 concrete. The amount of calcium hydroxide that is available due to cement hydration determines the effect of Zeolite. It might not materially impair early strength at the suggested levels. However, more research is needed to determine the cumulative impact on early strength. The interplay of these SCMs will probably be advantageous for long-term strength growth. Over time, Zeolite's pozzolanic activity and fly ash will produce a denser and more resilient concrete matrix. Further enhancing long-term strength is GGBS's line of hydration solutions. Mix design optimization and consideration of each SCM's unique qualities are essential to fully realize this combination's potential for reaching targeted sustainability and strength goals in concrete.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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