EXPERIMENTAL INVESTIGATION ON CARBON DIOXIDE POLLUTANT REDUCTION CHARACTERISTICS OF CONCRETE BY ZEOLITE AIDED CHEMICAL PROCESS

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Abstract

The construction industry is a significant contributor to global carbon dioxide (CO_2) emissions and only cement industry contributes about eight percentage of global carbon dioxide emissions, exacerbating the challenges of climate change. To address this issue, research has focused on environmentally friendly concrete solutions that can mitigate CO_2 emissions during production and use. One area of investigation is the utilization of zeolite in concrete, which has shown promise in reducing CO_2 emissions. Zeolite, with its unique crystalline structure, could capture CO_2 from the atmosphere. By analyzing the compressive strength of concrete mixed with different zeolite ratios, as well as conducting Scanning Electron Microscope (SEM) analysis to examine the microstructure of the CO_2 captured concrete surface. CO_2 test was conducted in a glass observation chamber using CO_2 gas cylinders and gas analyzer. Maximum CO_2 reduction was observed about 25%. This study demonstrates that incorporating zeolite can enhance both the compressive strength and CO_2 reduction capacity of the concrete. From the visual inspection of SEM images, a noticeable difference has been observed between the surface microstructure of conventional concrete and zeolite-based concrete. Additionally, a cost comparison is performed for different concrete mixes, providing insights into the economic feasibility of incorporating zeolite. This research highlights the potential of zeolite as a sustainable solution for the construction industry, offering a way to reduce CO_2 emissions while improving concrete performance and can be sustainable solution for ever increasing global air pollution problems.

Keywords – Air Pollution, CO_2 Emission, Concrete, Compressive Strength, Direct Air Capture (DAC), Pollutant, Scanning Electron Microscope (SEM), Zeolite

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1. Introduction

The construction industry plays a significant role in global carbon dioxide emissions, accounting for approximately 36% of total global energy use and 39% of energy-related CO_2 emissions. Concrete production and utilization are major contributors to these emissions due to the high demand for construction materials. As the need for new buildings and infrastructure continues to rise, there is a pressing need to find sustainable solutions that minimize the environmental impact of the construction sector. In this context, the utilization of environmentally friendly concrete has emerged as a promising approach.

Zeolite, a natural volcanic mineral, has garnered attention for its potential to enhance the properties of concrete while reducing CO_2 emissions. Zeolite possesses a unique porous structure that enables it to adsorb gases, including CO_2. Incorporating zeolite into concrete has shown promising results in improving its compressive strength and CO_2 adsorption properties. This research aims to explore the application of zeolite in concrete to mitigate CO_2 emissions and enhance its structural performance.

By investigating the effects of zeolite on concrete properties, such as compressive strength and CO_2 adsorption, this study seeks to contribute to the development of sustainable practices in the construction industry. The findings will provide valuable insights into the feasibility and benefits of incorporating zeolite as a key component in concrete production, paving the way for more environmentally friendly construction materials and practices. Ultimately, this research aims to promote a greener and more sustainable future for the construction industry by addressing the crucial challenge of reducing CO_2 emissions and improving the performance of concrete structures.

2. Chemical reactions for zeolite aided concrete

The strength of concrete primarily relies on calcium silicate hydrates formed during hydration reactions, where calcium silicates react with water. These reactions can be represented as:

- $2\ C_3S + 7\ H_2O \rightarrow C_3S_2H_4 + 3\ Ca(OH)_2$
- $2\ C_2S + 5\ H_2O \rightarrow C_3S_2H_4 + Ca(OH)_2$

During weathering and neutralization, components like calcium hydroxide and calcium silicate hydrate can react with carbon dioxide to produce calcium carbonate. This reaction can be expressed as:

- $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Carbon dioxide capture and storage (DAC) can be achieved through these reactions, including:

- $C_3S_2H_4 + 3\ CO_2 \rightarrow 3\ CaCO_3 + 2\ SiO_2 + 4\ H_2O$

Utilizing these reactions offers opportunities for DAC, contributing to sustainability and environmental conservation.

Zeolite is a porous crystalline material depicted in Figure 1.1, characterized by a three-dimensional framework of interconnected channels and cages. Its unique structure allows for efficient capture of CO_2 from the atmosphere. Zeolite achieves this by adsorbing CO_2 molecules onto its large surface area through physical adsorption and/or chemi-sorption mechanisms. The porous nature of zeolite facilitates the diffusion and capture of CO_2, making it a promising material for direct air capture applications, with potential implications for mitigating greenhouse gas emissions and addressing climate change.

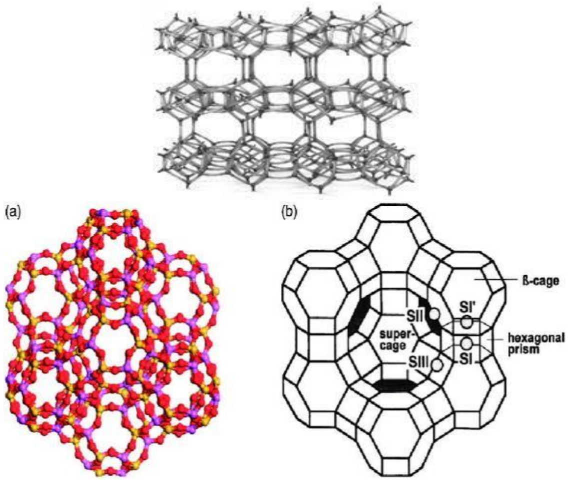


Fig 1. Structure of Zeolite

3. Experimental materials and mix design

The materials used during the present research are Zeolite powder, cement, fine aggregate coarse aggregate and water.

3.1 Zeolite powder

In this research natural zeolite powder is used as partial replacement of cement. Following figure 2 shows zeolite powder and table 1 indicates chemical and physical properties zeolite powder.

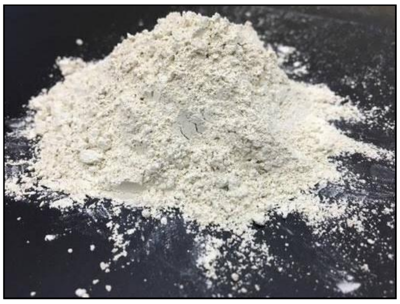


Fig 2. Zeolite powder

Table 1 Chemical and physical properties of zeolite powder

Chemical properties	Values for TiO_2 (%)	Physical properties	Values forzeolite
Na_2O	0.42	Normal Consistency	38%
MgO	0.187	Initial setting time (min.)	55
Al_2O_3	35.958	Final setting time (min.)	410
SiO_2	58.223	Specific gravity	2.98
P_2O_5	0.089	Fineness	40µ
SO_3	0.113		
K_2O	0.718		
CaO	0.643		
TiO_2	1.882		
Fe_2O_3	1.712		
NiO	0.019		
ZnO	0.023		
SrO	0.013		

3.2Cement

In this research work OPC 53 Grade cement conforming to IS: 12269-1987 was utilized forall concrete mixes which purchased from local market, Anand, Gujarat. Table 2 shows properties of cement.

Table 2 Physical properties of cement

Property	Values for Cement	Codal provisions
Initial setting time	35 min	30 minutes minimum
Final setting time	178 min	600 minutes maximum
Specific gravity	3.15	3.10-3.15

3.3Fine aggregate

As per IS 383:1970 an aggregate which is retain on IS 4.75mm sieve is called fine aggregate. Sand is shining yellow, off white, and rounded. The construction cost of sand is nil due to its normal availability but its transportation cost is more. Table 3 shows the properties of fine aggregate which procured from the local market, Bodeli, Gujarat.

Table 3 Physical properties of fine aggregate

Property	Values for Fine Aggregate
Source	Bodeli, Gujarat
Fineness modulus	3.16

3.4Coarse Aggregate

Washed natural gravel obtained from Sarigam region in Gujarat was used throughout this work. The table below shows the grading of coarse aggregate used and conformed to the limits specified by IS 383:1970. Angular aggregates of effective size 10 to 20 mm were used. Density of coarse aggregate used was 2840 kg/m^3. Table 4 shows the properties of coarse aggregate which is procured from the local market, Sarigam, Gujrat.

3.5Water

Ordinary portable water available locally was used for casting and curing of all specimen of this research. Water plays a vital role within the reaction with cement.

Table 4 Physical properties of coarse aggregate

Property	Values for Coarse Aggregate
Source	Sarigam, Gujarat
Fineness modules	7.13

3.6 Concrete mix design (IS: 10262:2019)

For this research study concrete mix of M40 grade has been prepared according to IS:10262:2019. In the concrete mix zeolite powder is replaced as a partial replacement with 10, 15 and 20 percentages. Concrete cubes are casted for compressive strength test and CO_2 reduction test. Following table 5 and table 6 shows calculated material quantity of M40 grade concrete mixes for one cubic meter and Nomenclature for various design mixes respectively.

Table 5 Calculated material quantity of M40 concrete mixes for one cubic meter

For 1 m^3 Concrete Mix	
Cement	462.93
Fine Aggregate	569.485
Coarse Aggregate	1125.65
Water Content	208.32

Table 6 Nomenclature for various design mixes

Concrete Mix	Description
N	Conventional concrete mix of M40 without zeolite powder
A	Cement concrete mix M40 with 10 % of zeolite powder
B	Cement concrete mix M40 with 15 % of zeolite powder
C	Cement concrete mix M40 with 20 % of zeolite powder

4. Experimental methodology

In this research, concrete mix zeolite powder is replaced as a partial replacement with 10, 15 and 20 percentages. Concrete cubes are casted for compressive strength test and CO_2 reduction test including scanning electron microscopy test.

4.1 Compressive strength test on cement concrete (IS 516-1959)

According to IS:516-1959 concrete cubes 150 mm^3 concrete cubes were casted by using M40 grade mix concrete. Cubes with OPC means normal concrete cubes by incorporated with zeolite 10%, 15% and 20% correspondingly using in M40 grade of concrete mix. During casting, the cubes are vibrated by means of mechanical vibrator. After curing, the cubes are tested for compressive strength employing a standardized compressive test machine. The compression test is conducted on cubes at seven and twenty-eight days of curing. Following figure 3 indicates the testing mechanism and procedure adopted for testing of compressive strength of concrete cubes.

Fig 3. Compressive strength test

4.2 Carbon dioxide (CO_2) reduction test

Fig 4. Experimental setup of CO_2 reduction test

Carbon reductions by direct air capture approach (DAC) is crucial for mitigating climate change, and concrete has emerged as a potential solution for DAC. Researchers conduct CO_2 reduction tests on concrete to evaluate its effectiveness. These tests involve exposing concrete samples to a CO_2 gas chamber and measuring the amount of CO_2 captured using a portable CO_2 detector. Studies have shown that the addition of zeolite in concrete enhances its CO_2 capture capacity, and increasing the zeolite percentage further improves CO_2 capture. These findings highlight the potential of incorporating zeolite into concrete mixes as an effective means of capturing and storing CO_2. Concrete, with optimized zeolite content, can play a significant role in a comprehensive strategy to mitigate climate change through DAC. Following figure 4 indicates the reaction chamber setup adopted for CO_2 reduction test along with portable CO_2 detector used for the pollutant measurement.

4.3 Microstructure analysis - scanning electron microscope test

Scanning electron microscope is employed for examining the structural morphology at very high magnifications level. SEM inspection is usually utilized in the examination of cracks and fracture surfaces, bond failures, and physical defects. After performing pollutant reduction test on conventional and zeolite based concrete cubes, the specimens were tested for SEM at multiple magnification levels to know the occurred changes in their surface microstructure.

5. Experimental results and discussion

The obtained experimental results of various test are discussed as follows:

5.1 Compressive strength test on concrete

The following figure 5 and table 6 shows the compressive strength results for concrete cubes containing different percentages of zeolite percentages as compare to conventional concrete mix proportions. The results are showndetermined for 7 and 28 days.

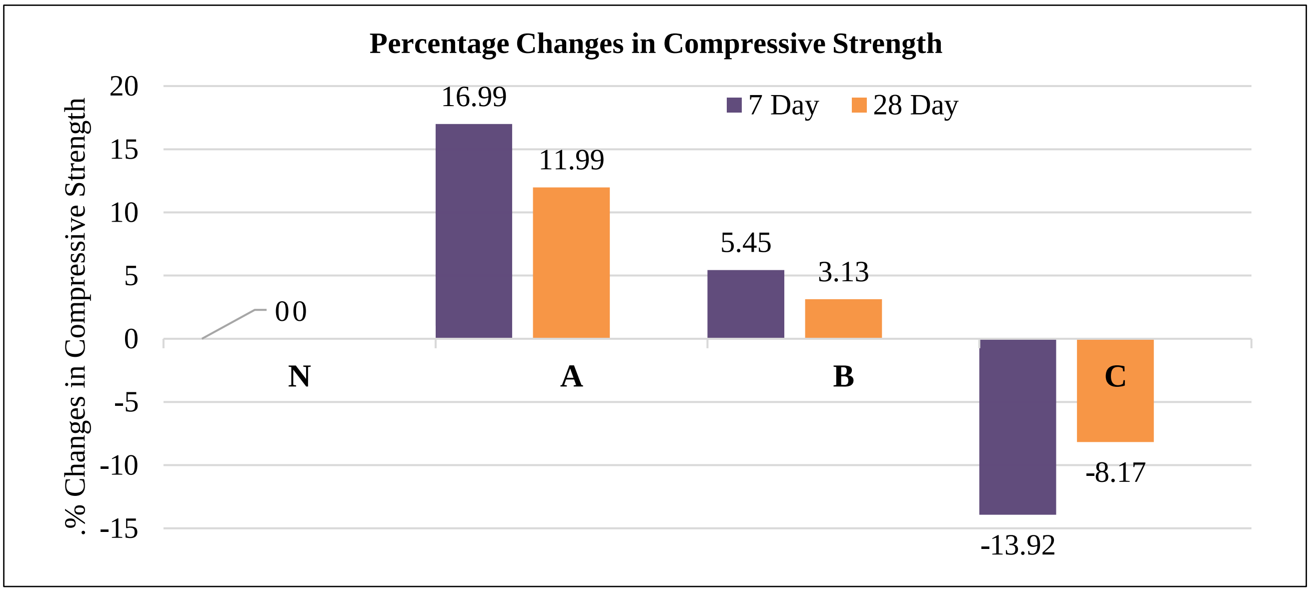


Fig 5. Percentage changes in compressive strength

Table 7 Compressive strength and change in compressive strength at 7 and 28 days

Concrete Mixes	Compressive Strength			
	7 Days (N/mm^2)	% Change in Strength at 7 Days	28 Days(N/mm^2)	% Change in Strength at 28 Days
N	38.40	--	47.53	--
A	44.93	(+)16.99%	53.22	(+)11.99%
B	40.49	(+)05.45%	49.02	(+)03.13%
C	33.05	(-)13.92%	43.65	(-)08.17%

From the results of compressive test on zeolite-based concrete it has been observed that initially by adding zeolite powder 10 %, the strength tends to increase, at 15% addition of zeolite the strength approached that of conventional concrete and by further adding of zeolite, the strength tends to decreases as compared to conventional concrete.

5.2 CO_2 reduction test

Table 8 presents the measured CO_2 levels in parts per million (ppm) at the beginning of the test and at one-hour intervals up to 5 hours. The difference between these readings represents the reduction of CO_2 pollutants by concrete cubes. The effective-ness of CO_2 reduction is evaluated.

based on the area of the concrete cubes' surface, which is standardized to 2250 cm^2. Figure 6 illustrates the percentage reduction of CO_2 achieved by various concrete mixes. These measurements and visual representations provide valuable insights into the CO_2 reduction potential of concrete.

Table 8 CO_2 reduction by various concrete mixes in ppm

Time Interval (Hours)	Observations		CO_2 Reduction (PPM)	
	Conventional concrete	Concrete with 15% zeolite	Conventional concrete	Concrete with 15% zeolite
0	8263	8325	0	0
0-1	7377	6230	886	2095
1-2	6746	4870	631	1360
2-3	6221	3891	525	979
3-4	5836	3215	385	676

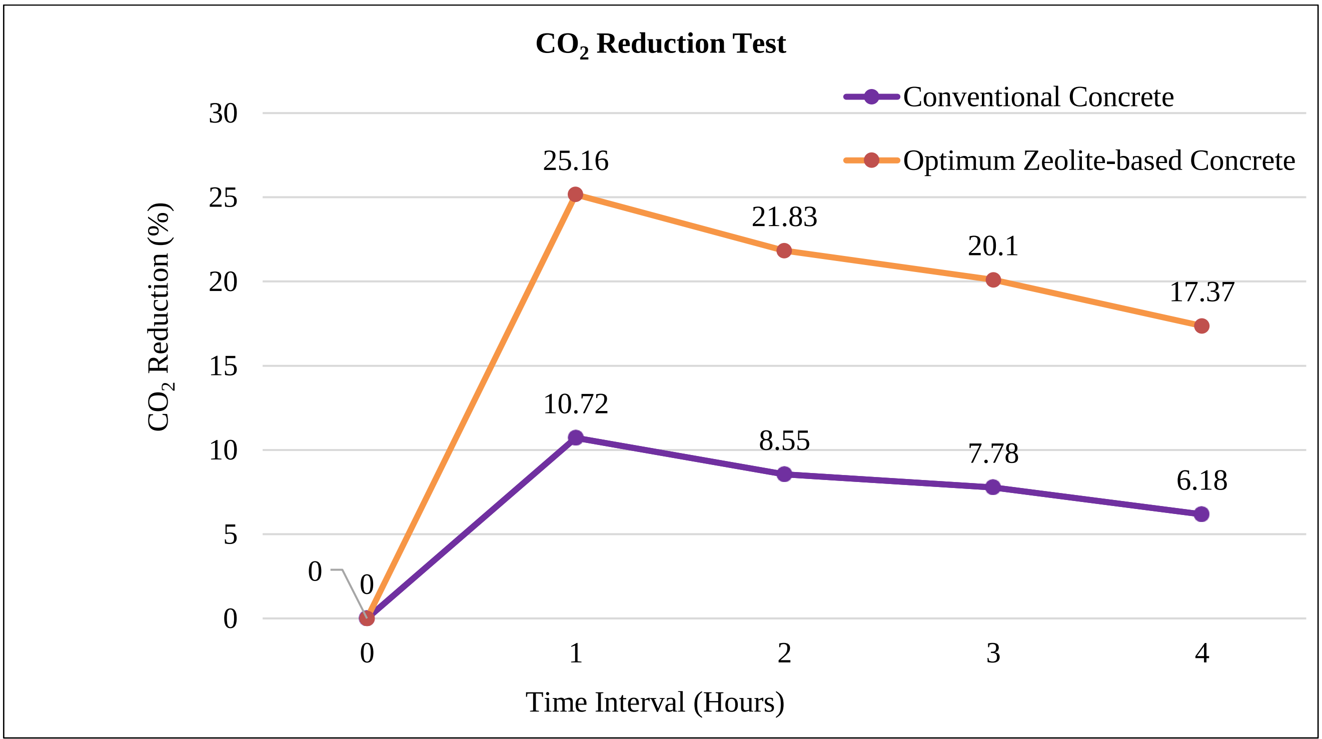
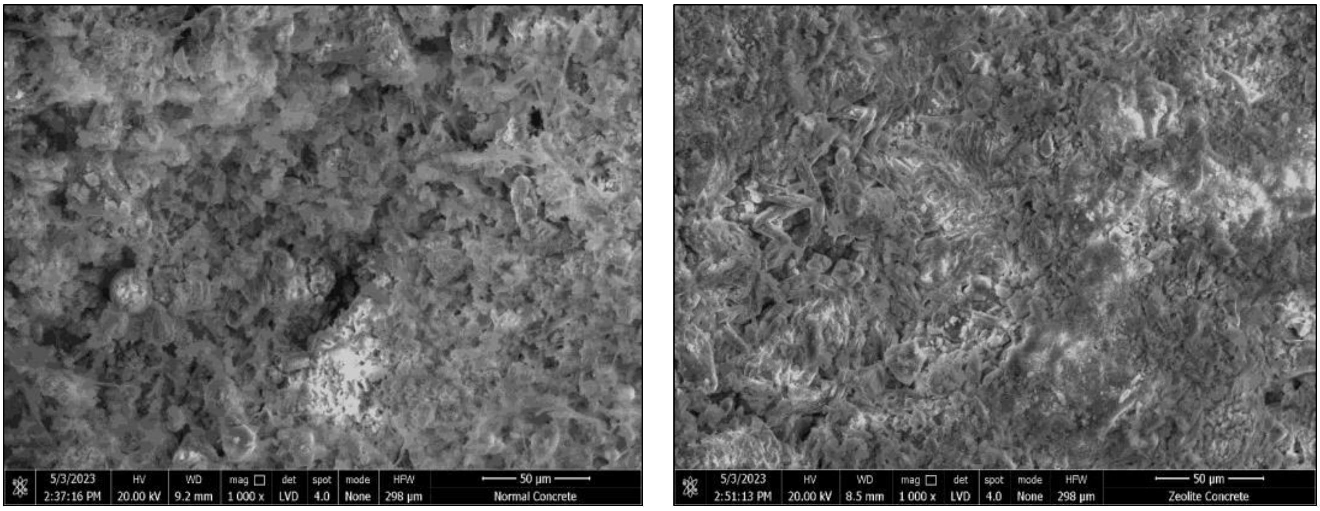


Fig 6. Percentage reduction of CO_2 by various concrete mixes

From the results of CO_2 reduction on zeolite-based concrete it has been observed that as compared to conventional concrete, concrete having zeolite reduces the CO_2 very effectively and at rapid rate. Also, it has been observed that with the higher amount of zeolite in concrete results in higher amount of CO_2 reduction.

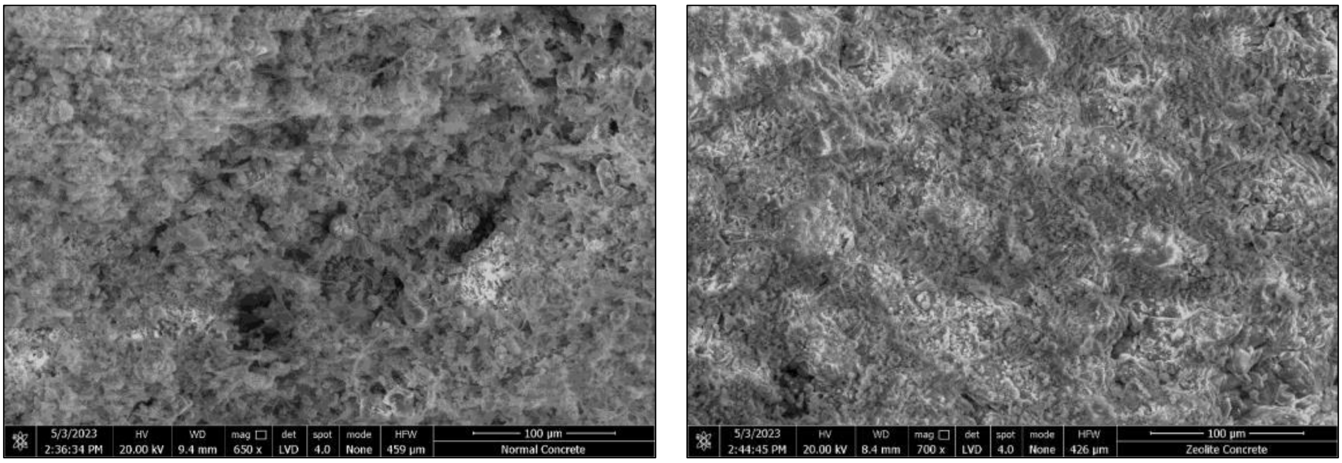
5.3Scanning electron microscope test

After performing CO_2 reduction test the tested specimen was analyzed for change in its surface microstructure. SEM test was performed at 1000x and 700x magnification levels to get visible evidence of $CaCO_3$. Following figure 7 and figure 8 shows the SEM images at various magnification level as stated above.



(a) Normal concrete (b) Zeolite-based concrete

Fig 7. SEM images at 1000x magnification level



(a) Normal concrete (b) Zeolite-based concrete

Fig 8. SEM images at 700x magnification level

The SEM images in figures 7 and 8 compare normal concrete (a) to zeolite-based concrete (b). Zeolite concrete exhibits a distinctive grass-like microstructure on its surface, indicating improved microstructure and denser composition. Scanning Electron Microscopy analysis reveals the formation of calcium carbonate precipitates on the concrete surface because of the reaction between calcium hydroxide ($Ca(OH))_2$) and atmospheric carbon dioxide. These $CaCO_3$ precipitates can be easily removed by washing the concrete surface with distilled water or a brine solution, without compromising durability. The zeolite as an additive positively impacts concrete by enhancing microstructure, sustain- ability, and ease of maintenance.

6. Cost comparison

Following table 9 shows the cost of various experimental materials per unit and table 10 indicates the cost of various concrete mixes per cubic meter. Figure 9 indicates the cost for per cubic meter for various concrete mixes.

Table 9 Cost of various experimental materials per unit for M40 concrete mix

Experimental Materials	Cost in Rupees
Cement (kg)	6.40 ₹
Fine Aggregate (kg)	0.45 ₹
Coarse Aggregate (kg)	0.64 ₹
Zeolite (kg)	11 ₹

Table 10 Cost of various concrete mixes per cubic meter

Concrete Mixes	Cost of Concrete per m^3 inRupees	Percentage Change inCost
N	3889.14 ₹	--
A	4276.14 ₹	(+) 5.05
B	4469.64 ₹	(+) 7.40
C	4663.15 ₹	(+) 9.62

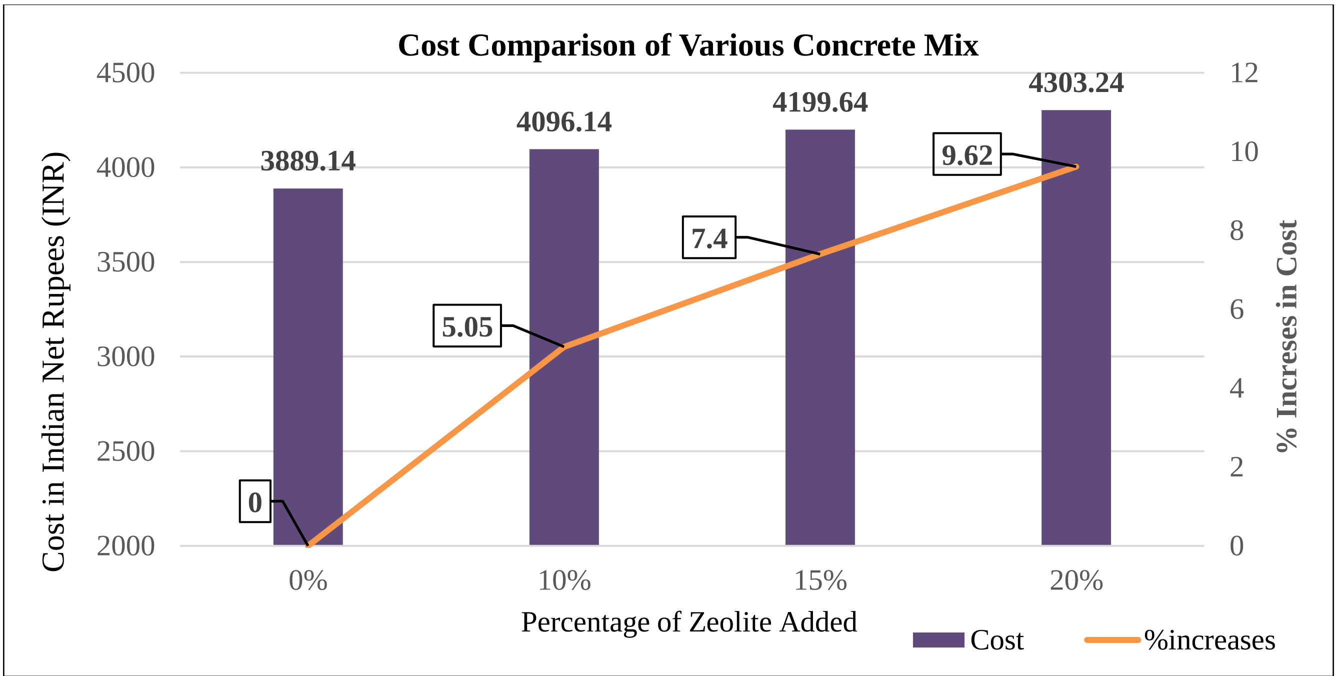


Fig 9. Cost comparison of various concrete mix

7. Conclusion

The conclusions based on performed experimental investigation are as follows:

- The compressive strength of concrete block increased as the percentage of addition increased, but zeolite-based concrete developed relatively higher compressive strength than the conventional concrete up to about 15% of zeolite powder replacement.
- The results shows that there is no negative effect in terms of compressive strength of concrete block prepared by zeolite powder as a partial replacement of the cement up to 15% of zeolite powder.
- By prioritizing the CO_2 reduction phenomenon, the concrete blocks having 15% zeolite powder has been selected for CO_2 reduction study as it has the higher amount of zeolite which evidently does not decreases the strength of the zeolite-based concrete.
- The addition of zeolite to the concrete mix can significantly reduce CO_2 gas emissions from atmosphere, with the maximum is about 25%. resulting in a substantial reduction in this study. concrete mix results in a corresponding increase in CO_2 reduction, providing an effective way to reduce carbon emissions.
- As the percentage of zeolite in concrete is increased, the cost of production may also increase slightly, but the environmental benefits of reducing CO_2 emissions make it a worthwhile sustainable solution, hence this can be utilized in a wider application.
- The zeolite block can be used in the road pavements, chimney of factory as well as at the faces of building and all the elements which are directly exposed to the air and environment.

Conflict of interest

The authors declares that there is no conflict of interest.

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