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EXPERIMENTAL INVESTIGATION ON PARTIAL REPLACEMENT OF CEMENT BY ZEOLITE AND SILICA FUME IN FIBER REINFORCED CONCRETE

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Abstract: Several types of industrial byproducts are generated which needs proper utilization. With increased environmental awareness and its potential hazardous effects, utilization of industrial byproducts has become an attractive alternative to disposal. One such by-product is silica fume (SF), which is a byproduct of the smelting process in the silicon and ferrosilicon industry. The present investigation aims to prepare and characterize a sustainable concrete material using zeolite and silica fumes as partial replacement to cement and pond ash as partial replacement of sand. Zeolite was mixed in the concrete as partial replacement of cement by 5%, 10%, & 15% whereas silica fume was mixed as partial replacement of cement by 10%. Fine aggregate was replaced by pond ash at constant proportion of 20%. A fixed quantity of polypropylene fiber, 600 g/m^3, has been added to assess the combined impact on the characteristics of the concrete. To investigate the impact in the concrete, experimental tests were conducted on both fresh concrete (workability) and hardened concrete (compressive strength, split tensile strength, and rebound number). Based on the test results of hardened properties, combined addition of zeolite (10%) and silica fumes (10%) in the presence of polypropylene fiber showing better results as compared to other mix proportions. Moreover, the developed statistical model represents the good correlation (R2 = 0.86) between compressive strength and split tensile strength with rebound number with high statistical reliability.
Keywords: ***Zeolite, Silica fume, polypropylene fiber, compressive strength, split tensile strength, rebound number, statistical model.***

1. Introduction:

Zeolites are crystalline aluminosilicate minerals with a unique porous structure that gives them properties like molecular sieves. This structure allows them to selectively adsorb molecules based on size, shape, and polarity. Their high absorption capacity at low pressures makes them effective in various applications, such as water purification, gas separation, and catalysis. Additionally, zeolites exhibit a low dependence on temperature, meaning their absorption capacity remains relatively stable across a wide range of temperatures, which enhances their versatility in different environmental conditions. These properties make zeolites valuable materials in industries ranging from petrochemicals to environmental remediation (Girskas et al., 2016). They tested a natural material called clinoptilolite to see if it can capture CO_2 from factories. Clinoptilolite did better at trapping CO_2 than a commercial product called zeolite 13X at higher temperatures. They found out clinoptilolite works well because it does not need a lot of energy to trap CO_2. They looked at the surface of clinoptilolite and found out how CO_2 sticks to it. Clinoptilolite seems like a good choice for removing CO_2 from factory smoke at warmer temperatures (Piumetti et al., 2020). Table 1 represents the chemical composition of zeolite, cement, and silica fumes.

Table 1 Chemical composition of zeolite, cement, and silica fumes (Piumetti et al., 2020).

Composition	Cement	Zeolite	Silica Fume
CaO (%)	63.00–66.80	1.68–3.67	0.20–1.68
SiO_2 (%)	18.30–34.00	62.78–75.34	86.46–97.00
Al_2O_3 (%)	2.40–5.55	8.77–15.28	0.20–1.13
Fe_2O_3 (%)	2.30–6.70	0.40–4.20	0.50–4.63
MgO (%)	0.90–3.91	0.48–1.19	0.40–1.80
Na_2O (%)	0.10–1.65	0.35–2.04	0.10–1.00
K_2O (%)	0.40–1.75	0.74–3.60	0.45–1.25
SO_3 (%)	1.24–3.21	0.02–0.52	0.05–0.87
TiO_2 (%)	–	0.14–0.20	<=0.01

It deals with the effect of silica fume on the permeability, freezing and thawing resistance, corrosion, sulfate resistance, carbonation, and alkali-aggregate resistance of concrete (Siddique et al., 2011). Table 2 represents the application of zeolites in concrete.

Table 2: Application of zeolites in concrete with optimum proportions

S. No.	**Application**	**Optimum Proportion (%)**	**Description**
1	Pozzolanic Material	10-30	Zeolite can act as a supplementary cementitious material, enhancing the strength and durability of concrete by reacting with calcium hydroxide to form additional binding phases.
2	Improved Workability	5-10	Incorporating zeolite in concrete mixtures can improve workability, making it easier to place and compact, potentially reducing the need for excess water.
3	Reduced Permeability	10-20	Zeolite-modified concrete can exhibit reduced permeability due to the formation of a denser microstructure, offering enhanced resistance against water and chemical ingress.
4	Alkali-Silica Reaction (ASR) Mitigation	10-15	Zeolite's ability to adsorb alkalis can mitigate the risk of ASR in concrete, preventing expansion and cracking caused by the reaction between alkalis and certain siliceous aggregates.
5	Thermal Insulation	5-15	Zeolite-incorporated lightweight concrete can provide improved thermal insulation properties, reducing energy consumption for heating and cooling in buildings.

The present investigation aims to prepare and characterize a sustainable concrete material using zeolite and silica fumes as partial replacement to cement and pond ash as partial replacement of sand. The main objectives of the present study are listed below:

a) To study the fresh and hardened properties of concrete as partial replacement of cement and fine aggregate by zeolite and pond ash respectively.

b) To study the fresh and hardened properties of concrete as partial replacement of cement and fine aggregate by silica fume and pond ash respectively.

c) To study the fresh and hardened properties of concrete as partial replacement of cement by combined zeolite and silica fume, and fine aggregate by pond ash respectively.

d) To develop the statistical model for the corelation between compressive strength and split tensile strength with rebound number respectively.

2. MATERIAL AND METHODOLOGY

2.1 Cement

Ordinary Portland cement (OPC) of 43 grade used cement it is most widely used type of cement in general construction. It’s a fine powder produced by heating limestone and clay minerals in a kiln, grinding the resulting clinker, and adding a small amount of gypsum. The physical properties of cement are shown in Table 3.

***Table 3**: Physical properties of cement*

S. No.	Property	Result
1	Standard Consistency	31.5%
2	Initial setting Time	105min
3	Final setting Time	221 min
4	Fineness by Sieving (90 micron)	5%
5	Specific Gravity	3.14
6	Soundness	2mm
7	Compressive strength (28 Days)	54 N/mm^2

2.2 Coarse Aggregate:

Coarse aggregate, also known as crushed stone or gravel, is one of the most essential ingredients in concrete. It forms the 60-80% volume of concrete, providing the bulk and strength that concrete needs to withstand various loads and stresses. The aggregate utilised in the present study conforms to IS 383-1970 Zone 2 and the aggregate is passing through a 20,10,4.75 mm sieves. The combine grading of the course aggregate is presented in Table 4.

Table 4: Combine Grading of Coarse Aggregate

BIS Sieve size	Percentage passing (%)	Desirable grading as per IS: 383-2016
40.0 mm	100	100
20.0 mm	98	95-100
10.0 mm	42	25-55
4.75 mm	5	0-10

2.3 **Fine Aggregate:**

Locally available Kharun river sand was procured from local supplier and to protect it from dust it was stored in clean cement bags. According to 2386- I 963 the various physical properties of fine aggregate such as sieve analysis, loose, rodded, and vibrated bulk densities, percentage voids, specific gravity, water absorption and silt content were tested.

The fine aggregate is partially replaced by 20% pond ash. The combined gradation of the mix comprising 80% sand and 20% pond ash is presented in Table 5.

Table 5: Combine Grading for 80% Fine Aggregate and 20% Pond Ash

BIS Sieve size	Percentage passing
10mm	100
4.75mm	95.00
2.36mm	92.00
1.18mm	88.00
600µm	65.00
300 µm	35.00
150µm	11.00

2.4 Silica Fume

Silica fume (SF) is a byproduct of the smelting process in the silicon and ferrosilicon industry. It is also known as micro silica condensed silica fume, volatilized silica or silica dust. Silica fume colour is either premium white or grey. Silica Fume consists of very fine vitreous particles with a surface area between 13,000 and 30,000m^2/kg. Its particles are approximately 100 times smaller than the average cement particle. Because of its extreme fineness and high silica content, silica fume is a highly effective pozzolanic material. Silica fume is used in concrete to improve its properties. It has been found that silica fume improves compressive strength, bond strength, and abrasion resistance; reduces permeability; and therefore, helps in protecting reinforcing steel from corrosion.

2.5 Zeolite

Zeolites are crystalline aluminosilicates with open 3D framework Structures built of O4 tetrahedra and are classified According to SiO_2:Al_2O_3 ratio. The advantageous properties of Zeolites are: regular structure, large inner specific surface area (approx. 600–800 m^2/g), uniform size pores, good thermal stability. These pores give zeolites their unique properties, allowing them to act as molecular sieves and catalysts. zeolites have a high surface area and porosity, allowing them to adsorb and trap molecules within their structure. this property makes them valuable in applications like air filtration, Odor control.

The grade of mix was M30. In this study the water cement ratio of 0.4 has been used. The concrete mix proportions are made as per IS:10262-2019 Standards. The mix proportions are listed in Table 6.

Table 6 Mix Proportion (kg/m^3)

Mix proportion	Cement (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Pond Ash (kg)	water	Silica fume(kg)	zeolite (kg)	Fiber (kg)
CM	396.5	1110	802.7	0	157.72	-	-	
SE10	356.9	1110	640	152.5	157.72	39.6	-	0.6
ZT5	376.67	1110	640	152.5	157.72	-	19.82	0.6
ZT10	356.9	1110	640	152.5	157.72	-	39.6	0.6
ZT15	337.02	1110	640	152.5	157.72	-	59.48	0.6
SE10ZT5	337.22	1110	640	152.5	157.72	39.6	19.87	0.6
SE10ZT10	317.3	1110	640	152.5	157.72	39.6	39.6	0.6
SE10ZT15	297.38	1110	640	152.5	157.72	39.6	59.48	0.6

3. METHODOLOGY

3.1 Workability Test:

The slump cone test is a popular tool for characterizing material consistency. Determining a suggested mix's homogeneity is highly helpful. Slump measures the ease with which the concrete mix flows when new concrete is being placed. A slump cone test was used to determine how workable fresh concrete was. Four layers of concrete were poured into the cone and it was set on a flat surface. Each layer was appropriately put into the cone and tamped 25 times using a standard steel rod with a 16 mm diameter, as per **IS 1199:2018**. Following the filling of the cone, the top surface was removed using a trowel, and the slump height was promptly recorded by gently raising the cone vertically

3.2 Compressive Strength Test

To make concrete, the necessary amounts of cement, fine aggregate, and coarse aggregate (up to 38 mm) are weighed in the field and thoroughly mixed with the necessary quantity of water until the concrete looks uniform. The test SPCIMENS are cast in the necessary shapes, either as 150 x 150 x 150 mm cubes or as 150 mm diameter and 300 mm height cylinders. [1/2 for D/H] Test specimens are kept for a full day at room temperature after the water is added to the dry components. Specimens are then taken out of the moulds and submerged in water, where they remain until the day of the test. Although IS: 456 recommends just 28 days of strength, specimens are often evaluated for seven or twenty-eight days. A specimen is positioned in between the compression testing machine's plates, and a force is progressively applied at a rate of 14 N/mm2/minute until the specimen falls. The compressive strength of concrete is determined by averaging the values of three specimens, with each deviation not exceeding +/- 15% of the average. In general, the strength of a cube specimen is around 1.25 times that of a cylindrical specimen.

3.3 Rebound Hammer Test:

For this test, a rebound hammer also called Schmidt hammer, which weighs about 1.8 kg is required and the test is suitable for both laboratory and field work. The Schmidt hammer has a spring-controlled hammer mass that slides on plunger with a tubular casing The hammer is forced against the surface of the concrete by the spring and the distance of rebound is measured on a scale of the instrument which gives indication of concrete strength. This test is suitable for the concrete having strength in the range of 20 – 26 MPa.

3.4 Split Tensile Strength Test:

A split tensile strength test can be used to determine the tensile strength. A few indirect methods are devised to assess the tensile strength of concrete because it is practically very difficult to apply a uniaxial tensile load. The split tensile strength test is one example.

In a split tensile strength test, the specimen is subjected to a compressive force until tensile stresses are created and the specimen fails. The specimen is shaped like a cylinder and has a minimum diameter of 150mm. Generally, length is twice as large as diameter (30 mm). The specimen's tensile strength is computed indirectly by recording the greatest load at which the specimen fails.

4. RESULTS AND DISCUSSIONS

4.1 Fresh Properties:

The fresh property of concrete was evaluated by conducting slump cone test for all the mix proportions mentioned in Table 7. After the concrete has been mixed, the slump cone test was performed on every batch. The slump value obtained from various mix is presented in Table 7. It can be seen from Table 7 that adding zeolite to concrete reduces its slump value. The variation in slump value is presented in Fig. 1. The slump value of concrete is 4% lower when 5% zeolite is added in place of cement as compared to the control mix. The slump value of concrete is decreased by 7.2% and 12.10 % when 10% and 15% zeolite were added in place of cement respectively. Zeolite's porous nature is the reason for the decrease in workability of concrete. It reduces the quantity of water available in the concrete mix and absorbs more water. Thus, the workability of concrete reduces. Further, the addition of silica fume enhances the workability of concrete. The addition of 10% silica fumes in concrete improves the slump value by 5.64%.

Table 7 Slump Test Results

S. NO	Mix Details	Slump
1	CM	124
2	ZT5	119
3	ZT10	115
4	ZT15	109
5	SE10	129
6	SE10ZT5	127
7	SE10ZT10	125
8	SE10ZT15	120

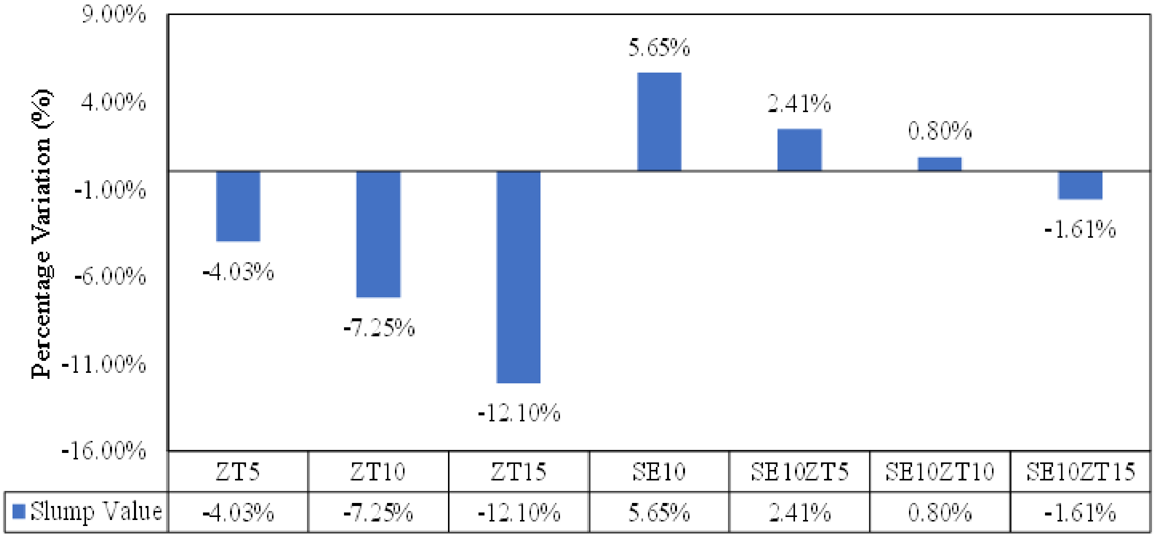

Fig 1 Variation in Slump Value (Percentage) with respect to control mix.

It is evident by comparing the concrete mix to the control that the zeolite addition significantly improved workability, a tendency that intensified with increased zeolite concentration. When silica fume was added in addition to zeolite, this improvement was even more noticeable, showing a similar pattern of increased workability. This improvement was made possible, in large part, by the soft texture present in both zeolite and silica fume, which allowed the concrete mix to have a smoother, more controllable consistency. Because of its soft texture, the mixture's particle dispersion and lubrication were probably improved, which decreased friction and made handling the material simpler throughout the placement and finishing stages. All things considered, the zeolite and silica fume combination boosted workability and could have improved other qualities like strength and durability. This makes it a viable method for maximizing the performance of concrete in a range of building applications. Furthermore, the use of silica fume and zeolite could have lessened bleeding and segregation in the concrete mixture. As a result, the aggregates and additives may be distributed more uniformly, producing a homogeneous product with better structural integrity.

Additionally, the combination of zeolite and silica fume may have produced more hydration products, which would have improved the concrete's overall binding capacity and possibly increased its resistance to corrosion and other environmental factors as well as long-term durability.

4.2 COMPRESSIVE STRENGTH CHARACTERISTICS

CTM was used to evaluate the compressive strength of all mix cubes at different ages. Over the course of 7,28 days, the test was designed to assess the differences in compressive strength for various concrete mix amounts, as indicated in Table 8. The efficacy of different material combinations and proportions employed in the concrete mix for 7 and 28 days, respectively, will be determined by this assessment, which is essential. This analysis is crucial to figuring out how different material combinations work best to achieve the required strength characteristics in the allotted amounts of time. The fact that SE 10%, ZT 10%, and SE10% ZT5%, SE10%ZT10% mix proportions were able to achieve the criteria for compressive strength at 7,28 days highlights their potential use in situations when early strength is required.

Table 8 Compressive Strength of all mix proportions

S. No	Mix Details	7 Days (MPa)	28 DAYS (MPa)
1	CM	25.50	38.50
2	ZT5	26.20	40.25
3	ZT10	27.50	42.50
4	ZT15	26.00	40.15
5	SE10	25.75	39.80
6	SE10ZT5	26.20	40.50
7	SE10ZT10	28.00	43.50
8	SE10ZT15	26.00	40.05

Fig. 2 represents the variation in compressive strength of all the mix proportions with respect to control mix. It can be observed from Fig 2 that with addition of zeolite i.e. 5,10, & 15%, the compressive strength of CM was improved by 4.5, 10.4, and 4.3% respectively with polypropylene fiber. Because of its large surface area and small particle size, zeolite can increase the packing density of the concrete mixture. Due to its pozzolanic characteristics, zeolite may react with calcium hydroxide, a result of cement hydration, to produce more calcium silicate hydrate (C-S-H) gel when water is present. By filling up the pores and crevices in the concrete matrix, this gel increases the strength and longevity of concrete.

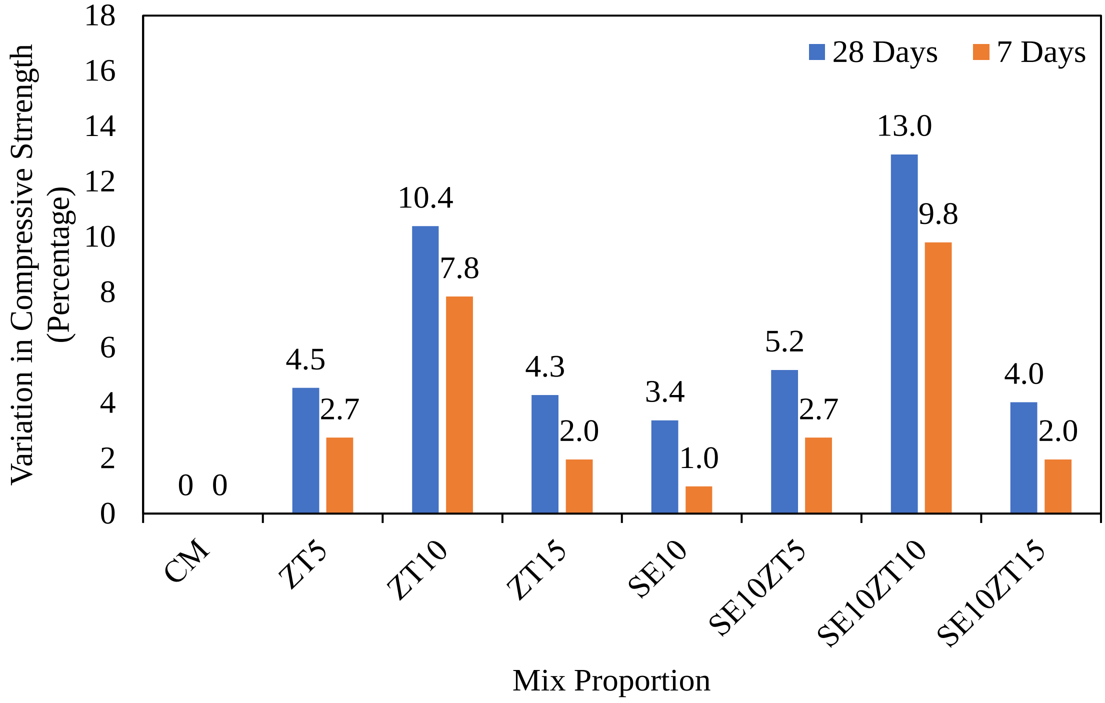

Fig. 2 variation in compressive strength of all the mix proportions

The presence of polypropylene fiber helps to significantly improves the strength of concrete. It can also observe that very small improvement in early age strength (7 days) were observed for all mix proportions. The addition of silica fumes in CM helps to slight improvement in compressive strength. However, the best results i.e. 13% improvement in compressive strength was obtained in case of combined addition of zeolite (10%) and silica fumes (10%) showing better results as compared to other mix proportions.

When zeolite and silica fume are combined, their qualities might complement one another. While zeolite promotes pozzolanic reactions and decreases water consumption, silica fume increases particle packing density and total concrete matrix strength. When these effects are combined, they can result in synergistic increases in compressive strength that exceed what any additive can produce on its own. zeolite alone may reduce workability due to its water absorption characteristics; silica fume can enhance the workability of concrete by acting as a lubricant and reducing the water-to-cement ratio. By combining these additives judiciously, it's possible to achieve a balance between workability and strength, resulting in concrete mixes that are easier to handle during placement and compaction while still achieving high compressive strength.

4.3 REBOUND HAMMER TEST

The rebound value is read from a graduated scale and designated as the rebound or rebound index. The rebound reading on the indicator scale has been calibrated by manufacture of the rebound hammer for horizontal impact. The test results of rebound hammer of all mix proportions are presented in Table 9.

Table 9 Rebound Hammer Test

S. No	Mix Details	28 Days
1	CM	39
2	ZT5	42
3	ZT10	44
4	ZT15	41
5	SE10	40
6	SE10ZT5	43
7	SE10ZT10	45
8	SE10ZT15	40

Based on the graph depicting Rebound hammer test results of various concrete mixes, it's evident that incorporating certain additives as replacements for cement yields significant improvements in the Rebound number compared to the control mix. There is a clear correlation observed between compressive strength and Rebound number, with an increase in compressive strength corresponding to higher Rebound numbers. Conversely, a decrease in compressive strength results in lower Rebound numbers. Among all the mixtures, SE10ZT10 stands out with the highest Rebound number, indicating superior rebound properties and potentially better resistance against deformation and cracks. This suggests that the combination of silica fume and ZT10 additive at the specified proportions significantly enhances the rebound performance of concrete, potentially leading to improved overall durability and structural integrity.

There is a definite connection between compressive strength and rebound number, with increasing compressive strength resulting in larger rebound numbers. In contrast, a decrease in compressive strength leads in lower Rebound values. SE10ZT10 has the greatest Rebound number of any of the blends, suggesting higher rebound capabilities and perhaps improved resistance to deformation and cracking. This implies that combining silica fume and zeolite additive in the prescribed quantities improves concrete rebound performance, perhaps leading to increased overall durability and structural integrity. The addition of 10% zeolite and 10% silica fumes in the presence of polypropylene fiber improves the rebound number by 15.358%. The percentage variation in rebound number of all mix proportions as compared to control mix is presented in Fig. 3.

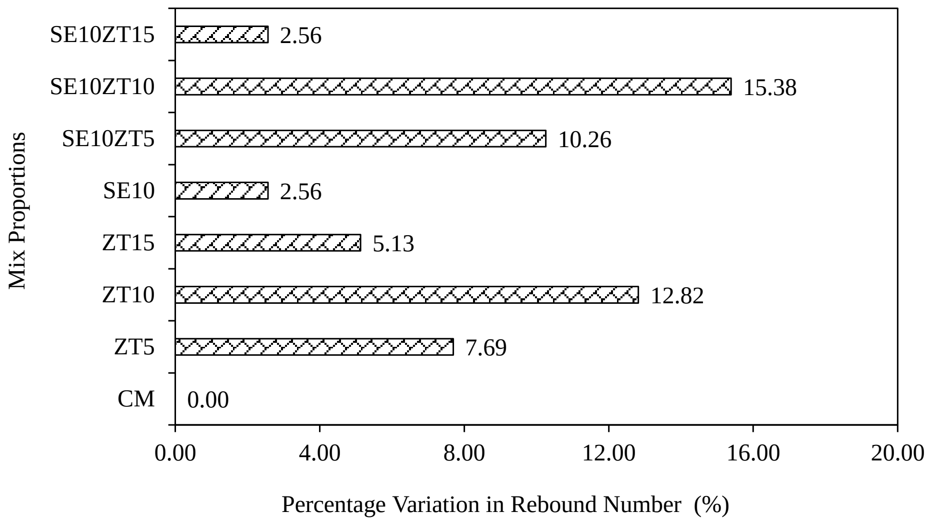

Fig. 3 Percentage variation in rebound number compared to control concrete

4.4 SPLIT TENSILE STRENGTH

The split tensile strength of mix proportions is presented in Fig. 4. The conducted test aimed to evaluate the tensile strength variations among different concrete mix proportions, particularly focusing on their performance at the crucial 28-day. In this study, silica fume emerged as a critical component in enhancing tensile strength. Silica fume, known for its fine pozzolanic properties, significantly contributes to boosting the binding capacity of concrete. This enhancement results in the formation of a denser and more cohesive microstructure within the concrete matrix. Consequently, the concrete becomes more resistant to cracks and deformations induced by internal stresses, thereby improving its overall durability and structural integrity.

Among the tested concrete mixes, those incorporating silica fume, denoted as SE10% and ZT10%, exhibited efficient workability characteristics. This means that these mixes were easier to handle and manipulate during construction activities, contributing to smoother placement and finishing processes. Furthermore, the addition of silica fume in the SE5% ZT10%, SE10% ZT10% mixes further enhanced their workability while concurrently reducing water demand. This reduction in water demand is crucial as it leads to a more compact and densely packed concrete structure.

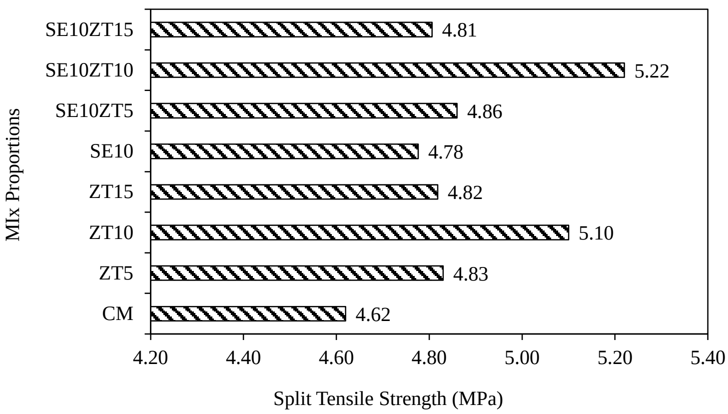

Fig. 4 Split Tensile Strength (MPa) value of all mix proportions

Consequently, this denser microstructure contributes to additional strength gains, thereby improving the overall mechanical properties of the concrete. The maximum tensile strength was observed for mix proportions containing 10% zeolite and 10% silica fumes in the concrete with polypropylene fiber.

In summary, the incorporation of silica fume in concrete mixtures not only enhances tensile strength but also improves workability and reduces water demand. These benefits collectively contribute to the development of more durable and structurally sound concrete, capable of withstanding various external and internal stresses over time.

4.5 Statistical Model:

Statistical model has been developed to relate the compressive strength and split tensile strength with rebound number for the present study. Based on the data of 28 days compressive strength and rebound number following equation (Equation 1) has been developed.

CS= 11.55+ 0.697* RN ***(1)***

Where, CS = 28 Days compressive strength; RN = Rebound Number

The characteristics of the equation is presented in Table 10 and 11. Based on the values of coefficient of regression (R^2 = 0.86), the developed model represents the good corelation between compressive strength and rebound number for the present work.

Table 10: Coefficient of regression of present model

Regression Statistics	
Multiple R	0.93
R Square	0.86
Adjusted R Square	0.84
Standard Error	0.62
Observations	8

Table 11: Coefficient of the developed equation

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	11.54722222	4.679924164	2.467395158	0.04862918
X Variable 1	0.697222222	0.111967598	6.226999884	0.000793075

Similarly, the rebound number was correlated with the split tensile strength at 28 days. the developed model is presented in Equation 2.

STS = 1.38+ 0.083 * RN ***(2)***

Where STS = Split tensile strength; RN = Rebound Number

The regression coefficient and characteristics of the data are presented in Table 12 and 13 respectively. Based on the R^2 value = 0.86, the developed model represents good relationship between STS and RN.

Table 12 Regression statistics

Regression Statistics	
Multiple R	0.93
R Square	0.86
Adjusted R Square	0.84
Standard Error	0.07
Observations	8

Table 13 Coefficient of the developed equation

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.385666667	0.5615909	2.467395	0.048629
X Variable 1	0.083666667	0.013436112	6.227	0.000793

5. CONCLUSIONS:

Based on the present studies, the followings conclusions are highlighted below.

- The slump value of concrete is decreased by 7.2% and 12.10 % when 10% and 15% zeolite were added in place of cement respectively. Zeolite's porous nature is the reason for the decrease in workability of concrete.
- The addition of 10% silica fumes in concrete improves the slump value by 5.64%. zeolite and silica fume can have opposing effects on the workability of concrete when used individually, their combined use requires careful consideration of dosage and mix design to optimize workability while still achieving the desired strength and performance properties.
- The addition of zeolite i.e. 5,10, & 15%, the compressive strength of CM was improved by 4.5, 10.4, and 4.3% respectively with polypropylene fiber. Because of its large surface area and small particle size, zeolite can increase the packing density of the concrete mixture.
- The best results i.e. 13% improvement in compressive strength was obtained in case of combined addition of zeolite (10%) and silica fumes (10%) showing better results as compared to other mix proportions.
- .SE10ZT10 has the greatest Rebound number of any of the blends, suggesting higher rebound capabilities and perhaps improved resistance to deformation and cracking. This implies that combining silica fume and zeolite additive in the prescribed quantities improves concrete rebound performance, perhaps leading to increased overall durability and structural integrity.
- The addition of 10% zeolite and 10% silica fumes in the presence of polypropylene fiber improves the rebound number by 15.358%.
- The maximum tensile strength was observed for mix proportions containing 10% zeolite and 10% silica fumes in the concrete with polypropylene fiber.
- The developed statistical model represents the good correlation (R^2 = 0.86) between compressive strength and split tensile strength with rebound number with high statistical reliability.

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