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Research paper

A study on utilization of zeolite as partial replacement to cement for M40 grade concrete

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Abstract

Cement plays an essential role for the concrete production. Production of cement emits a greenhouse gas CO_2 during the calcination of limestone. CO_2 emissions can be reduced by using supplementary cementitious material (SCM) as replacement to cement in concrete. Use of supplementary cementitious material also improves the performance of concrete. One such naturally available supplementary cementitious material, natural zeolite was been used in the present investigation. In the present experimental investigation, 15% of cement content (by weight) in standard concrete of grade M40 is replaced with zeolite. The important parameters that influence the strength of concrete such as water-binder ratio (0.37, 0.38, 0.39, and 0.40) and binder content (440, 450, 460, and 470 kg/m3) are considered for the investigation. Total 16 mixes were cast and tested for compressive strength as per IS 516. The compressive strength of concrete was tested on a cube of 150 X 150 X 150 mm size at the age of 7 and 28 days. From the obtained experimental results, water-binder ratio of 0.37 and binder content 440 kgs per cubic meter (85% cement + 15% zeolite) were found enough for the production of M40 grade concrete.

Keywords: *Supplementary Cementitious Materials; Zeolite; Water-Binder Ratio; Binder Content and Compressive Strength.*

1. Introduction

Cement is one of the major ingredient for concrete production. The production of cement emits CO_2 around 5 to 7 % of the world emissions [1]. It is an essential need to go with the alternate or supplementary cementitious material which intern results in decrease in CO_2 emissions. The commonly used alternate or SCM in concrete production as replacement to cement are Fly ash, Silica fume, Ground granulated blast furnance slag, Metakaolin and Natural zeolite [2]. Use of such SCM'S improves the durability and mechanical properties of concrete with minimum amount of cement [3].

In this investigation zeolite is considered as SCM which has unique properties when compared with other SCM's. Zeolite is a natural pozzolana, contains a high amount of reactive SiO_2 and Al_2O_3 when compared with fly ash, silica fume and metakaolin [4]. From the past studies it has been found that incorporation of such highly pozzolanic SCM will combine with free calcium hydroxide and forms CSH and CAH gel phases, which results in improved hardened and durability properties of concrete [5 - 7].

2. Literature review

M. Sedlmajer et al., [1] reported that slump of concrete decreases as the zeolite content increases. Zeolite is replaced with cement in concrete for 7, 15, 22 and 30 %. Air content percent in fresh concrete has found more than control mix. Compressive strength after 28 and 90 days has revealed high values due to the later gain in strength due to pozzolanic reaction. Study also concluded that the resistance of cement concrete surface to defrosting chemicals and water will have increased flaked-off material with increased percent of zeolite. More ever for up to 30 % replacement the flaking is still within the limits of 1000 g/m^2 for 100 cycles of experiment.

Nalleni Sreeharsha et al., [2] studied the effect of zeolite for M35 grade concrete when replaced with cement by about 10, 15, 20 and 25 %. 15 percent replacement has shown maximum compressive strength of 30.8 and 47.40 MPa at 7 and 28 days respectively.

Babak ahmadi et al., [5] investigated on pozzolanic action of zeolite and silica fume with increase in age for fixed $Ca(OH)_2$. At initial age of about 3 days the pozzolanic reactivity for zeolite is very less compared to silica fume and at later age from 15 to 28 days the pozzolanic reactivity of zeolite increases and finally reaches same as that of silica fume. 15 % zeolite as replacement to cement has shown increased compressive strength of concrete.

Taras Markiv et al., [6] have conducted investigation on concrete when natural zeolite was been replaced with cement by 10 %. Superplasticizer and air-entraining admixtures were been used in addition to zeolite. From the investigation it has been found that incorporation of 10 % zeolite, 1.64 % superplasticizer and 0.3 % air-entraining admixtures has decreased the compressive strength and flexural strength at 1, 28, 56, 90 and 180 days. While incorporation of zeolite in addition with superplasticizer and air-entraining agent has increased the Freeze-thaw resistance, decreased water penetration depth and drying shrinkage.

Dzigita Nagrockiene et al., [7] have conducted experimental studies on concrete with partial replacement of natural zeolite with cement from 2.5 to 10 % with an increment of 2.5 %. It has been found that increase in zeolite content has shown increased compressive strength and ultrasonic pulse velocity compared with conventional mix. Also, increase in zeolite content has found decrease in water absorption and increase in Freeze-thaw resistance of concrete. Addition of 10 % zeolite as replacement to cement in concrete has increased the compressive strength by 13 % and 11 % when compared with conventional mixes at 7 and 28 days.

Alena sicakova et al., [8] studied when zeolite replaced by 50 % with cement in cement paste. The initial setting time is 3 times more than that of paste with ordinary Portland cement OPC. Concrete with zeolite as replacement to cement by 8, 13 and 25 % has been investigated for compressive strength and density at 28, 365, 730 and 1095 days. The compressive strength is found higher for 13 % replacement at 28 days.

Juan Carlos de la Cruz et al., [9] studied on compressive strength of concrete when 15 % zeolite was partially replaced with cement. From his study it has been found that compressive strength of concrete increased significantly for age up to 28 days as 38 MPa later from 28 to 90 days the strength increased only about 7 %.

Meysam Najimi et al., [10] conducted durability studies on concrete containing zeolite as replacement to cement by 15 and 30 %. Durability properties of concrete incorporated with zeolite were compared with conventional mix. From the study it has been concluded that addition of 15 % zeolite has shown decrease in water penetration depth, drying shrinkage, chloride ion penetration and corrosion rate when compared with conventional mix.

3. Materials

3.1. Cement

Ordinary Portland Cement (OPC) of 53 grade complying with IS 12269 [11] was used for present investigation. The specific gravity, consistency, initial setting time, final setting time and 28 days compressive strength were 3.10, 30 %, 45 minutes, 410 minutes and 54.2 MPa respectively.

3.2. Zeolite

Zeolite which is commonly called as clinoptilolite was been used as supplementary cementitious material in this study. The specific gravity of zeolite was found as 2.74. The oxides present in the zeolite were shown in below Table 1.

Table 1: Chemical Properties of Zeolite

Oxides	Weight in percentage
SiO_2	63.9
Al_2O_3	8.21
Fe_2O_3	1.7
CaO	1.79
MgO	0.07
K_2O+Na_2O	4.55
SO_3	0.05
Loss on Ignition	18.93

3.3. Fine aggregate

Natural River Sand obtained from a nearby quarry was used as fine aggregate, confirming to Zone-II of IS 383 [11]. The physical properties of fine aggregate when tested as per IS 2386-3 [12] were found as below.

Specific gravity – 2.73.

Water absorption – 1 %.

Fineness modulus – 2.86.

3.4. Coarse aggregate

The coarse aggregate used were natural crushed gravel, confirming to IS 383 [11].

Specific gravity – 2.74.

Water absorption – 0.61 %.

4. Experimental investigation

4.1. Mix proportions

In the present experimental investigation, natural zeolite was replaced as substitute to cement by about 15 % (by weight) for the designated cement contents of 440, 450, 460, and 470 kg/m^3 respectively. Four water-binder ratios as 0.37, 0.38, 0.39 and 0.40 were considered for the present investigation. Ordinary Portland cement of 53 grade confirming to IS 12269 [11] was considered for present study. The combined weight of aggregates considered were 1848 kg/m^3 for one cubic meter quantity. The ratio of weight of coarse aggregate to combined aggregate weight considered in this study was 0.65. Therefore, the weight of coarse aggregate and weight of fine aggregate for one cubic meter were 1201.2 and 646.8 kgs respectively. The designated mix proportions are shown in below Table 2. The preparation of mix consists of adding coarse aggregate and fine aggregate of desired quantity into a pan mixer of capacity 50 liter and allowing for mix for about 30 s. Later, cement and zeolite were added and allowed for again 30 s mix. Water about half the quantity was been added and allowed to mix for 1 min duration in the mixer. Remaining quantity of water was added and allowed again to mix for 1 min duration. Below Fig. 1 shows the casting of cubes after gaining uniform mix in pan mixer.

Fig. 1: Casting of Cubes after Obtaining Uniform Mix in Pan Mixer.

Table 2: Mix Proportions of 16 Mixes for 1 M^3

Mix No.	W/B ratio	Binder content in kgs	Cement content in kgs	Zeolite in kgs (15%)	Water in kgs	Coarse aggregate in kgs	Fine aggregate in kgs
1	0.40	470	399.5	70.5	188	1201.2	646.8
2	0.40	460	391	69	184	1201.2	646.8
3	0.40	450	382.5	67.5	180	1201.2	646.8
4	0.40	440	374	66	176	1201.2	646.8
5	0.39	470	399.5	70.5	183.3	1201.2	646.8
6	0.39	460	391	69	179.4	1201.2	646.8
7	0.39	450	382.5	67.5	175.5	1201.2	646.8
8	0.39	440	374	66	171.6	1201.2	646.8
9	0.38	470	399.5	70.5	178.6	1201.2	646.8
10	0.38	460	391	69	174.8	1201.2	646.8
11	0.38	450	382.5	67.5	171	1201.2	646.8
12	0.38	440	374	66	167.2	1201.2	646.8

13	0.37	470	399.5	70.5	173.9	1201.2	646.8
14	0.37	460	391	69	170.2	1201.2	646.8
15	0.37	450	382.5	67.5	166.5	1201.2	646.8
16	0.37	440	374	66	162.5	1201.2	646.8

4.2. Test procedure

For each mix six cubes were been cast of size 150 X 150 X 150 mm and tested at 7 and 28 days respectively. Test procedure consists of removing cubes from the curing tanks at the respective testing age and wiped with cotton on all the sides. Each cube was aligned centrally to the axis of platens of the compression testing machine of capacity 2000 kN. The load on the cube were applied at the increasing rate of 140 kg/sq.cm/min as per IS 516 [14].

5. Results and discussions

5.1 Compressive strength

The compressive strength of 16 mixes was tested confirming to IS 516 [14] and as shown in below Fig. 2. Three cubes were been tested at 7 days and another three cubes were been tested at 28 days. The average compressive strength values of the cubes corresponding to 7 and 28 days was shown in the below Table 3. From the below Fig. 3 and 4 it is found that mixes with water-binder ratio of 0.37 has shown higher compressive strength at the age of 7 and 28 days. The compressive strength corresponding to 0.37 water-binder ratio at the age of 7 days found as 35.23, 38.59, 40.62 and 42.41 MPa for 440, 450, 460 and 470 kgs of binder contents. Similarly, the compressive strength at 28 days found as 49.07, 51.34, 52.17 and 53.20 MPa for 440, 450, 460 and 470 kgs of binder contents. The percentage increase in compressive strength for w/b ratios of 0.37, 0.38, 0.39 and 0.40 for 470 kgs of binder content when compared with 440 kgs of binder is found as 20.38, 10.05, 14.32 and 16.07 % at 7 days respectively. At the age of 28 days for water-binder ratio of 0.37, 0.38, 0.39 and 0.40 for 470 kgs of binder content when compared with 440 kgs of binder the percentage increase in compressive strength were 8.41, 9.98, 19.98, 17.60 % respectively.

Fig. 2: Testing of Cube as Per IS 516.

Table 3: Compressive Strength of Mixes at 7 and 28 Days

Mix No.	W/B ratio	Binder content in kgs	Compressive strength at 7 days in MPa	Compressive strength at 28 days in MPa
1	0.40	470	34.87	47.09
2	0.40	460	33.44	45.47
3	0.40	450	32.13	42.87
4	0.40	440	30.04	40.04
5	0.39	470	35.28	49.06
6	0.39	460	33.85	45.78
7	0.39	450	32.67	43.21
8	0.39	440	30.86	40.89
9	0.38	470	36.44	52.44
10	0.38	460	35.78	51.76
11	0.38	450	34.29	50.11
12	0.38	440	33.11	47.68
13	0.37	470	42.41	53.20
14	0.37	460	40.62	52.17
15	0.37	450	38.59	51.34
16	0.37	440	35.23	49.07

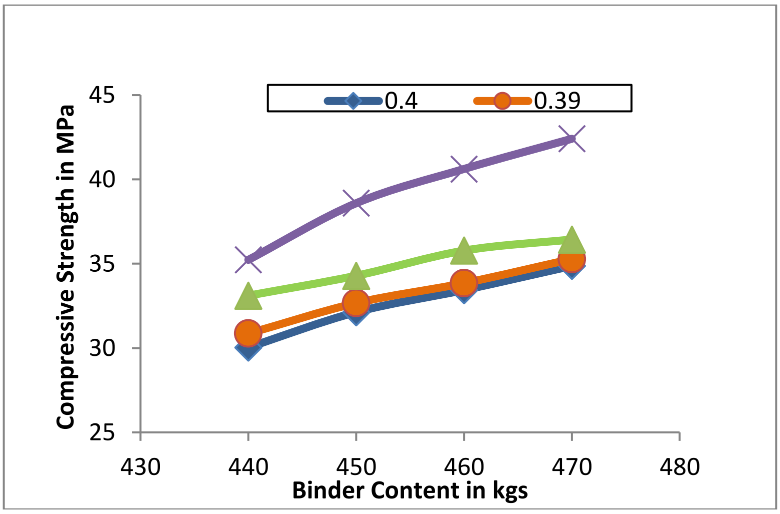

Fig. 3: Binder Content to Compressive Strength Variation for Different W/B Ratios at 7 Days.

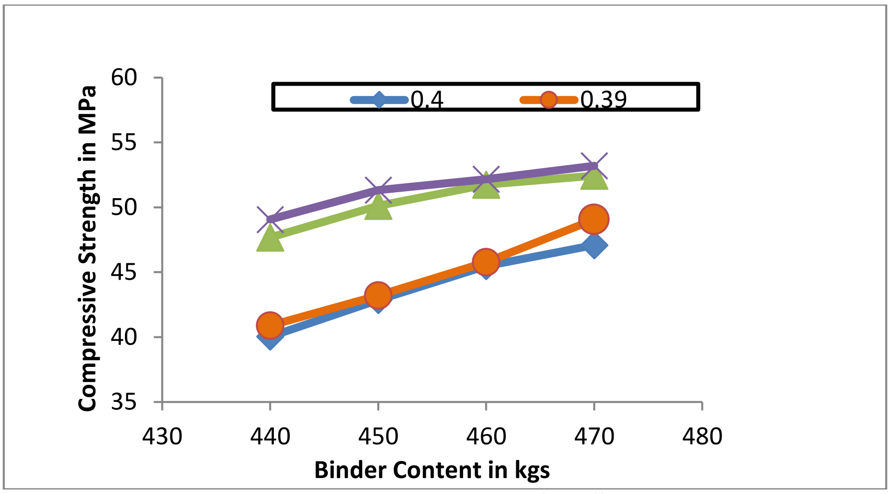

Fig. 4: Binder Content to Compressive Strength Variation for Different W/B Ratios at 28 Days.

5.2. Effect of water-binder ratio on compressive strength

In present investigation four water-binder ratios were been considered. It has been observed from below Fig. 5 that increase in water-binder ratio has decreased compressive strength of mixes at 7 and 28 days respectively. The increase in water-binder ratios from 0.37 to 0.40 has shown 16.80 and 14.73 % decreased compressive strength of mixes at 7 and 28 days respectively. The R^2 values at the age 7 and 28 days for decrease in water-binder ratio were observed as 0.864 and 0.896 respectively.

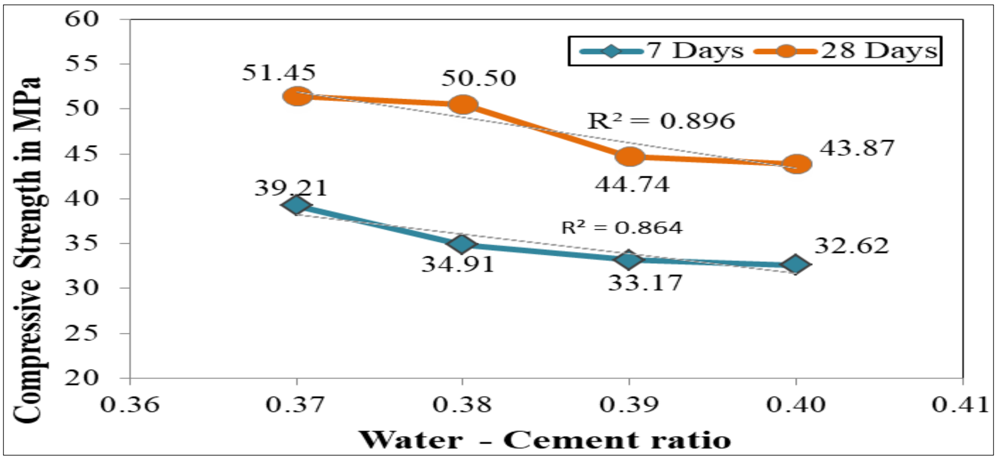

Fig. 5: Water-Binder Ratio to Compressive Strength Variation at 7 and 28 Days.

5.3. Effect of zeolite on compressive strength

Four binder contents as 440, 450, 460 and 470 considered for each water-binder content. The average compressive strength of four binder contents for individual water-binder ratio are shown in the below Fig. 6. For each binder content zeolite were been replaced with 15 % by weight. From the below Fig. 6 it has been observed that increase in binder content has shown increased compressive strength at 7 and 28 days respectively. Addition of zeolite as replacement to cement by 15% has found suitable with respect to compressive strength at both 7 and 28 days.

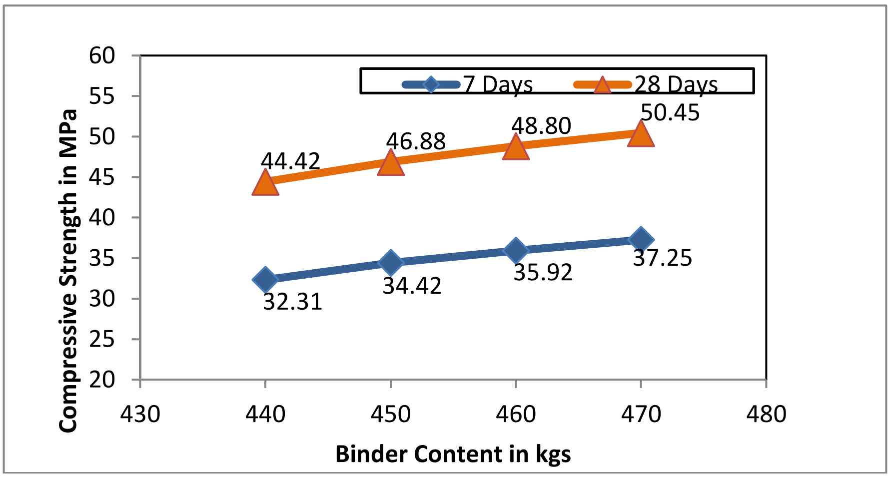

Fig. 6: Binder Content to Compressive Strength Variation at 7 and 28 Days.

6. Conclusions

- Decrease in the water-binder ratio has shown increased compressive strength, i.e., 0.37 has shown higher compressive values when compared with 0.38, 0.39 and 0.40 water-binder contents.
- At 7 days the percentage increase in compressive strength between 440 and 470 kgs of binder content found highest for 0.37 water-binder ratio as 20.38 %.
- When compared with 28 days the percentage increase in compressive strength between 440 and 470 kgs of binder content found highest for 0.39 water-binder ratio as 19.98 %.
- The partial replacement of cement with 15% zeolite has shown compatible for compressive strength of concrete for 0.37, 0.38, 0.39 and 0.40 water-binder ratios.

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