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ORIGINAL CONTRIBUTION

Effect of Lime on Mechanical and Durability Properties of Blended Cement Based Concrete

Prasanna Kumar Acharya[1] · Sanjaya Kumar Patro[2] · Narayana C. Moharana[3]

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Abstract This work presents the results of experimental investigations performed to evaluate the effect of lime on mechanical and durability properties of concrete mixtures made with blended cement like Portland Slag Cement (PSC) and Portland Pozzolana Cement (PPC) with lime content of 0, 5, 7 and 10 %. Test result indicated that inclusion of hydraulic lime on replacement of cement up to 7 % increases compressive strength of concrete made with both PSC and PPC. Flexural strength increased with lime content. Highest flexural strength is reported at 7 % lime content for both PSC and PPC. Workability is observed to decrease with lime addition which could be compensated with introduction of super plasticizer. Acid and sulphate resistance increase slightly up to 7 % of lime addition and is found to decrease with further addition of lime. Lime addition up to 10 % does not affect the soundness of blended cements like PSC and PPC.

Keywords Portland slag cement · Portland pozzolana cement · Blended cement · Lime

Introduction

At this age, cement concrete has been proved to be the most important building material. In spite of profuse use in construction industry over a century, it still suffers from many shortcomings such as lower compressive strength, low tensile and flexural strength, poor bonding, porosity and permeability, poor resistance to acid and other aggressive chemicals, poor elastic modulus, shrinkage and poor flexibility. Compressive, tensile and flexural strength of cement concrete can be improved by mechanical means such as introducing reinforcement and some mineral admixtures such as fly ash, lime, slag etc., whereas other short comings are overcome by adding some chemical admixtures. Lime has played a vital role as a binding material for structural works since ancient age. Lime stone powder as a filler material in concrete is a common practice in many countries. Lime is cheaply and sufficiently available in nature. Lime stone dust produced due to massive quarry operations is not only occupying the valuable land but also creating manifold environmental problems. The disposal and utilization of lime dust is one of the subjects of the current interest today. Considering the problems of lime dust disposal, use of lime in small quantity varying from 5 to 10 % of weight with blended cement is studied in present work. This work presents an experimental investigation on mechanical properties and durability of concrete made with blended cement on addition of lime in different percentages. The blended cements used under this investigation are PSC conforming to IS 455-1989 and (PPC) conforming to IS 1489-1991.

Pozzolanic materials added to blended cements are siliceous or non-siliceous and aluminous materials, which by themselves have little or no cementitious value. But these materials on reacting with Calcium Hydroxide [$Ca(OH)_2$] in presence of moisture at ordinary temperature possess cementitious properties. Due to hydration of Tri-Calcium Silicate and Di-Calcium Silicate, Calcium Silicate Hydrate (CaO, SiO_2, H_2O) and Calcium Hydroxide $Ca(OH)_2$ are formed.

✉ Sanjaya Kumar Patro
litusanjay@yahoo.com

1 Public Works Department (R&B), Division II, Bhubaneswar, India

2 Department of Civil Engineering, Veer Surendra Sai University of Technology, Burla, Odisha, India

3 School of Civil Engineering, KIIT University, Bhubaneswar, India

Calcium Silicate Hydrate is known as C–S–H gel and results to significant strength gain. On the other hand, [$Ca(OH)_2$] is an unwanted product having no cementitious value. It is soluble in water and leaches out making the concrete porous. But this unimportant, non cementitious water soluble Calcium Hydroxide can be converted to insoluble cementitious materials by adding finely divided pozzolanic material.

Many times there is a chance of surplus SiO_2 after consumption of Calcium Hydroxide. If additional Calcium Hydroxide is made available, there is chance of further creation of C–S–H gel. So, with a dose of Calcium Hydroxide in form of hydraulic lime, possibility of further formation of C–S–H gel and thereby strength gain can be expected. This possibility has been explored in the present study.

Literature Study

High lime fly ash is a type of sub-bituminous fly ash which is self cementing as well as pozzolanic in nature. Its fineness and carbon content properties provide potential benefit to concrete because they affect the air content and water demand which in turn greatly affect the durability and strength of concrete. Replacement of high lime fly ash in concrete increases the ultimate strength of concrete. Concrete with 25–35 % fly ash provides optimal compressive strength. Beyond 35 % fly ash replacement, the rate of gain of compressive strength decreases but maintains its strength value above the designated strength [1]. Addition of hydrated lime and silica fume improves early age compressive strength of fly ash concrete. The air permeability of fly ash concrete containing hydrated lime and silica fume decreased when compared to control concrete. Addition of lime and silica fume also improved the sorptivity. It lowers the total porosity of fly ash cement paste [2]. Compressive strength values of hydrated lime–silica fume paste increases with increasing time of hydration. As hydration proceeds more hydrated calcium silicates are formed and deposited in open pore system of the hardened paste leading to continuous increase in compressive strength of hardened paste [3]. Addition of a small quantity up to 5 wt% of unspecified filler such as lime stone is a common practice in many European countries such as France since 1979. Development of a new process and better quality control is expected to increase the reactivity of cement. To achieve this goal, addition of filler material would be essential. Substitution of 4–6 wt% of clinker by lime stone to low heat Portland cement is shown to improve the rate of hydration up to 90 days. Addition of lime stone increases the heat of hydration and free lime content is slightly enhanced. The total porosity decreases and compressive strength is seen to enhance at early age. Addition of 10 wt% of lime stone to sulphate resistant cement increases the rate of hydration from 3 up to 90 days curing time. Addition of 5 wt% of both lime stone and silica fume to cement paste gives good mechanical properties at all curing periods. Consistency as well as setting time is observed to decrease slightly with lime stone content due to increase in plasticity of cement paste. This may be attributed to the effect of lime stone as an active component in the hydration of Portland cement. The rate of hydration increases and the amount of hydrated products enhances. Consumption of calcite, the formation of carboaluminates, the accelerating effect on the hydration C_3A, C_3S, change in the C–S–H and formation of transition zone between the filler and the cement paste are all facts attributable to the reactivity of lime stone fillers [4].

Fly ash, a by-product of thermal power stations has been used successfully to replace cement up to 30 % without adversely affecting the strength and durability of concrete [5]. The main reason for low early strength development of fly ash concrete is the unavailability of $Ca(OH)_2$ to react with fly ash particles. Hence there is possibility of improving the pozzolanic reaction of fly ash by adding hydrated lime [6]. Different methods have been used to accelerate the pozzolanic reaction of fly ash to achieve early strength. These are mechanical treatment (grinding), accelerated curing, autoclaving and chemical activation. However alkali activation used in concrete may lead to alkali silica reaction [7].

In spite of large literatures available, less is known on the effect of lime on the mechanical properties and durability of concrete prepared with blended cement consisting of fly ash and slag. The present investigation is an attempt to bridge the knowledge gap.

Experimental Program

Following sections describe the experimental investigations carried out.

Materials

The ingredients used are: (a) PSC (b) PPC (c) Fine aggregate (d) Coarse aggregate (e) Hydraulic lime (f) Polycarboxylate based super plasticizer.

Portland Slag Cement (PSC)

The constituents of PSC are Portland cement clinker, gypsum, granulated blast furnace slag. In general, this cement possess physical properties like low heat of hydration, refinement of pore structure, reduced permeability, increased resistance to chemical attack, better

Table 1 Physical properties of PSC and PPC

Physical properties	Observed value		Requirement as per code	
	PSC	PPC	IS 455:1989 PSC	IS 1489:1991 (Part-1) PPC
Soundness, mm	0.50	1.00	Maximum 10.00	Maximum 10.00
Initial setting time, min	94	60	Not less than 30	30
Final setting time, min	219	178	Not more than 600	600
Comp. strength, MPa—3 days	24.10	21.00	16.00	16.00
Comp. strength, MPa—7 days	34.30	32.00	22.00	22.00
Comp. strength, MPa—28 days	45.80	42.00	33.00	33.00
Standard consistency, %	34.00	35	34.00	35
Fineness, m^2/kg	373.4	357	225.00	Not less than 300

Table 2 Physical properties of fine and coarse aggregates

Properties	Observed value	
	Fine aggregate	Coarse aggregate
Bulk density, kg/m^3	1652.00	1698.00
Specific gravity	2.70	2.83
Water absorption, %	0.73	0.20
Fineness modulus	2.39	6.47
Abrasion value, %	–	18.60
Impact value, %	–	15.30

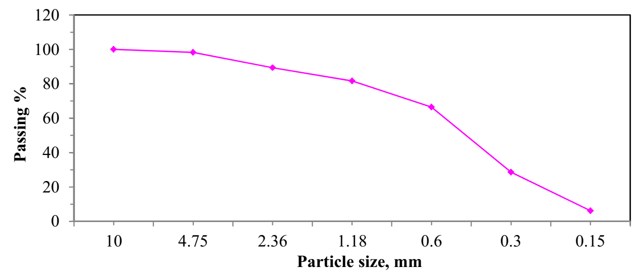

Fig. 1 Sieve analysis of fine aggregates

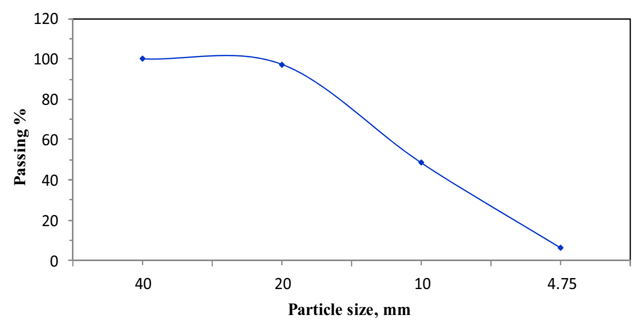

Fig. 2 Sieve analysis of coarse aggregates

resistance to corrosion of steel reinforcement. The cement used conforms to IS 455-1989.

Portland Pozzolana Cement (PPC)

The constituents of PPC are OPC clinker and pozzolanic materials such as fly ash, calcinated clay or other siliceous and aluminous materials. It possesses physical properties like low heat of hydration and greater resistance to the attack of aggressive water. The PPC used conforms to IS 1489-1991. Tests results of PSC and PPC are reported in Table 1.

Fine Aggregates

Natural sand collected from local river bed having maximum size 4.5 mm was used as fine aggregate in the research work. The physical properties and sieve analysis are presented in Table 2 and Fig. 1. Fine aggregate sample conforms to grading Zone III of IS: 383-1970.

Coarse Aggregates

Black, hard coarse crusher broken granite natural stone aggregates of maximum 20 mm size were used in this study. Properties of coarse aggregates are summarized in Table 2 and Fig. 2. The coarse aggregate sample conforms to 20 mm graded aggregates of nominal size as per IS: 383-1970.

Hydraulic Lime

Commercially available hydraulic lime was collected from local market. X-ray diffraction study of lime was carried out using Shimat Zu 6100 difractometer with Cu-Kα 1–1.54 Å radiation. XRD report shows that hydraulic lime is rich in $Ca(OH)_2$ as shown in Fig. 3. Calcium hydroxide reacts with pozzolanic materials (SiO_2 and Al_2O_3) in presence of moisture at ordinary temperature to form C–S–H gel.

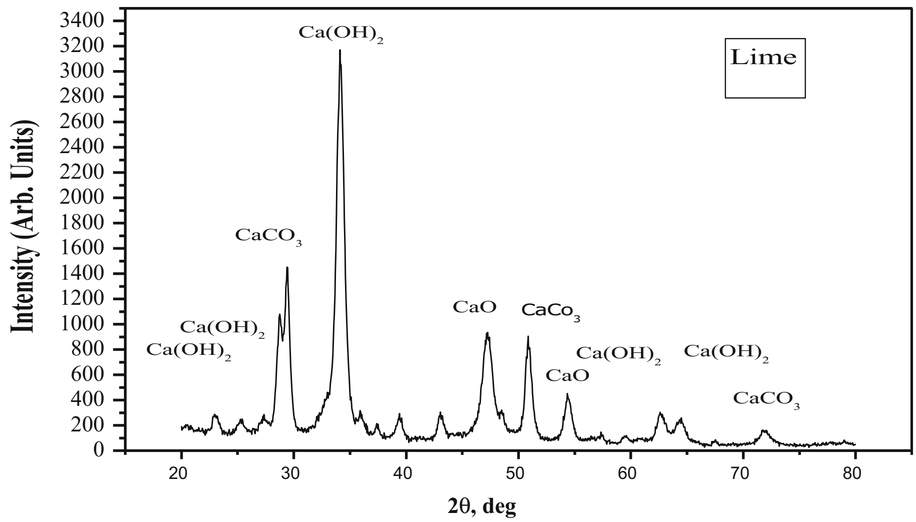

Fig. 3 XRD analysis of hydraulic lime

Table 3 Properties of water

Properties	Observed value
pH value	7.1
Dissolved solids (mg/l)	290
Suspended solids	Nil
Chlorides (mg/l)	20
Sulphates (mg/l)	74
MPN value/100 ml	Nil

Table 4 Properties of super plasticizer

Properties	Observed value
Appearance	Light yellow
pH value	6.50
Specific gravity	1.077
Volumetric mass@200c, kg/l	1.09
Chloride content, %	<0.1
Alkali content, g/l	<1.5

Water

Properties of water used in this research work are presented in Table 3.

Super Plasticizer

Polycarboxylate based super plasticizer was used in this research work. Properties of above super plasticizer are reported in Table 4.

Mix Proportions

The investigation was carried out in two series namely Series 1 and Series 2 each addressing use of PSC and PPC respectively. Series 1 comprised four trials, M-1 with addition of 0 % lime, M-2 with addition of 5 % lime, M-3 with addition of 7 % lime and M-4 with 10 % lime. Similarly Series 2 comprised four trials using with 0, 5, 7 and 10 % lime addition and denoted M-5, M-6, M-7 and M-8 respectively. A mix proportion of 1:2:4, stated in terms of cement: fine aggregate: coarse aggregate was adopted with varying lime content as per Table 5. Water cement ratio of 0.45 was maintained for all mixes. A dry mix of cement, aggregates and lime in different proportion as per requirement was prepared by using concrete mixer for 3 min. This was followed by further 5 min mixing with water and super plasticizer @ 0.50 % by weight of cement and lime.

Test Specimen

Based on above mix proportion cubes of 15 cm size were cast for each trial (Trials M-1, M-2, M-3, M-4, M-5, M-6, M-7 and M-8) as explained in Table 5. All specimens were cast in three layers and compacted on a vibrating table till removal of all air bubbles from the concrete. The specimen were covered with plastic sheets and kept for 24 h at room temperature of 27 °C. After 24 h the specimen were demoulded and immersed in water vat at 27 ± 2 °C for curing till their testing at different ages. Similarly, prisms of size (100 × 100 × 500) mm were cast for testing of flexural strength and cured in the same manner till their test at the age of 28, 35 and 42 days respectively.

Test Procedure

Physical properties of PSC and PPC were determined as per IS 455:1989 and IS 1489:1991(Part-I). Similarly, physical properties of aggregates were determined as per IS: 383:1970 and IS: 2386 (Part 1)-1963. Properties of water were determined as per of IS: 456-2000 and those of super plasticizer were ascertained as per IS: 9103:1999. Mix

Table 5 Concrete mix proportions

Type of cement/Series	PSC/Series 1				PPC/Series 2			
Mix designation	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8
Cement, kg/m^3	330.0	313.5	306.9	297.0	330.0	313.5	306.9	297.0
Fine aggregate, kg/m^3	660.0	660.0	660.0	660.0	660.0	660.0	660.0	660.0
Coarse aggregate, kg/m^3	1320	1320	1320	1320	1320	1320	1320	1320
Lime, %	0	5	7	10	0	5	7	10
Lime, kg/m^3	0.00	16.50	23.10	33.00	0.00	16.50	23.10	33.00
W/C ratio	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Super plasticizer, kg/m^3	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Slump, mm	90	60	45	22	68	42	25	16

design for above investigation was carried out as per the stipulations of IS: 10262-1982. Setting time was determined by Vicat apparatus as per IS: 5513-1996 and IS: 8142-1976. The workability of fresh concrete was measured by slump test as per IS: 7320-1974 and IS: 1199-1959. Standard consistency was determined as per the provisions of IS: 5513-1996. The soundness test was done with Le-Chatelier apparatus according to the provisions of IS: 5514:1996 and IS: 4031(Part-3)-1988. Compressive strength of 15 cm cubes were tested as per the provisions of IS: 516-1959. Flexural strength of beams of size 100 mm × 100 mm × 500 mm were determined as per the provisions of IS: 516-1959. Durability tests such as resistance to sulphate and acid were conducted by immersing cubes in 1 % magnesium sulphate solution ($MgSO_4$) and 1 % Sulphuric acid solution. Three cubes from each trial were kept unmerged to serve as reference and comparison of strength loss. Weight of cubes was measured before immersion and after immersion for computation of weight loss.

Results and Discussion

Result of experimental investigations carried out to study the influence of lime content in PSC and PPC on the mechanical properties and durability of concrete have been discussed in this work.

Physical Properties

Physical properties such as consistency, setting time and soundness of PSC and PPC blended with various % of lime were determined and the results have been discussed in this work.

Consistency

Consistency percentage increases with addition of lime to both PSC and PPC. Higher the lime content, higher consistency is reported for both PSC and PPC. However it is found that at 10 % lime content, consistency for both cements is same (Fig. 4). The reason of more demand of water is due to rapid hydration process in presence of lime.

Setting Time

Setting time decreases with addition of lime. Higher the percentage of lime lower is the setting time. Initial setting time and final setting time of PSC and PPC are presented in Figs. 5 and 6. Results indicated early start and completion of chemical reaction between cementitious material and water. This is attributed to the effect of lime as an active component in process of hydration and increases the rate of

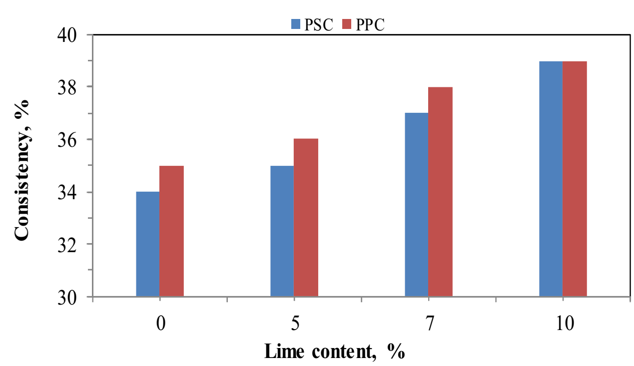

Fig. 4 Normal consistency of PSC and PPC

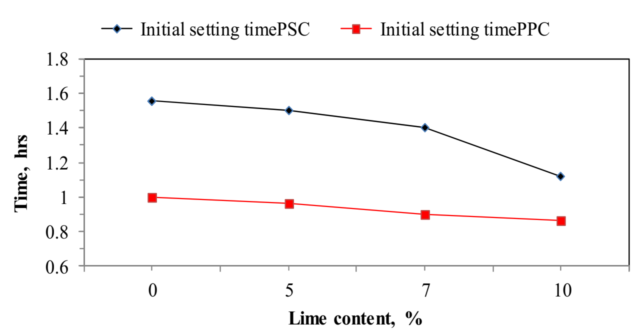

Fig. 5 Initial setting time of PSC and PPC

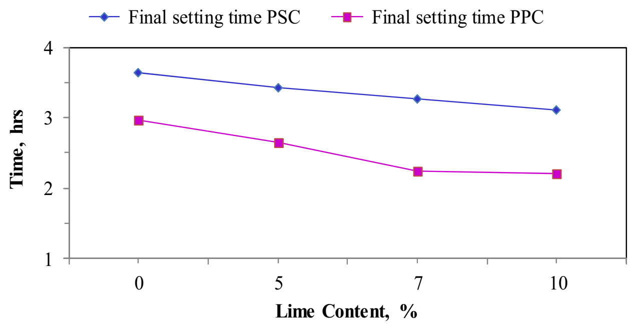

Fig. 6 Final setting time of PSC and PPC

hydration. Formation of carboaluminate due to inclusion of lime speeds up the setting time also.

Soundness

Soundness as determined by Le-Chatelier apparatus has shown difference of initial and final reading, at range of 0.5–2 mm with different % of lime for PSC; while only 1.00 mm difference is seen for all % of lime addition in PPC. The required difference should be less than 10 mm, and hence both PSC and PPC are found sound with addition of lime up to 10 % as indicated Fig. 7.

Fresh Properties

Fresh property of concrete in terms of slump using slump cone was determined.

Workability

Slump tests were carried for each batch of concrete pertaining to all trials. It is observed that the workability decreases with addition of lime both for PSC and PCC. Higher the percentage of lime, lower is the workability. This happened due to rapid hydration process and increase in surface area of cementitious materials. This shortcoming could be compensated with introduction of plasticizer. The slump values are presented in Fig. 8.

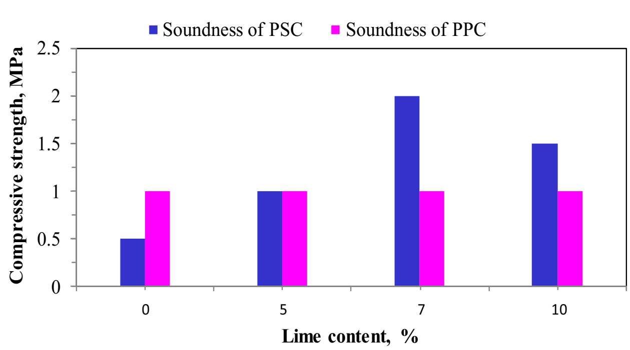

Fig. 7 Soundness of PSC and PPC

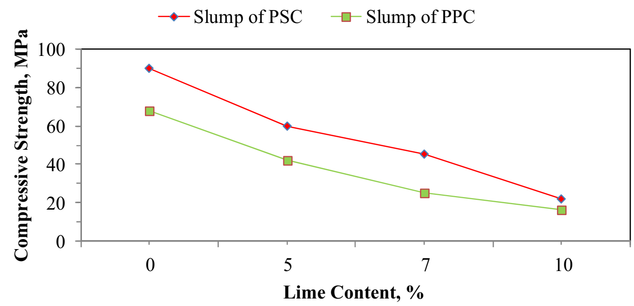

Fig. 8 Workability of lime blended concrete made with PSC and PPC

Mechanical Properties

Results of mechanical properties on various trials are reported and discussed in this work.

Compressive Strength

The compressive strength was determined at 28, 35 and 42 days for specimen cast in different trials. The results are discussed under following heads:

Compressive Strength Comparison with Respect to Variation of Lime The strength of PSC with 5 and 7 % lime is found to increase and with addition of 10 % lime, the same decreases for all ages of 28, 35 and 42 days (Fig. 9). With 5 and 7 % lime addition to PSC there is 1.85 and 3.23 % increase in compressive strength. But on addition of 10 % lime there is a decrease in compressive strength up to 4.61 %. Similar trends in results were observed in case of PPC also (Fig. 10). However percentage of variation was slightly different for PSC and PPC.

Compressive Strength Comparison with Respect to Age On inclusion of 5, 7 and 10 % lime to both PSC and PPC there is increase in strength due to age. Specimen tested at 35 and 42 days indicate clear increase in compressive strength over the specimen tested at 28 days as per Figs. 9 and 10. Highest strength is obtained at 7 % lime content at

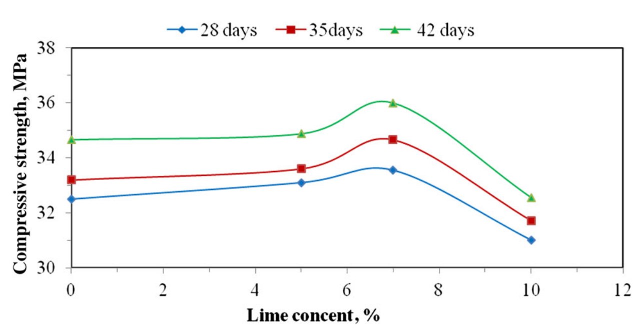

Fig. 9 Compressive strength of PSC

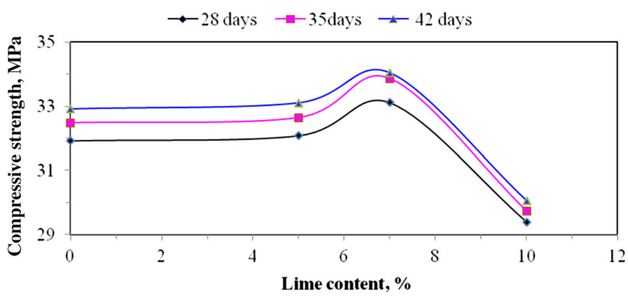

Fig. 10 Compressive strength of PPC

all ages. In between 28 and 42 days concrete containing 7 % lime made with PSC and PPC gained compressive strength 7.94 and 2.80 % respectively.

The gain in strength is probably due to formation of more C–S–H gel on utilization of surplus SiO_2 and Al_2O_3 in presence of lime. Calcium carboaluminate formed; due to reaction of lime with alumina phase of cement, modifies the pores. More over filling effect of lime makes the interfacial transition zone between matrix and aggregate denser for which there is positive impact on properties of concrete.

Flexural Strength

The flexural strength of PSC and PPC concrete was determined at 28, 35 and 42 days with 5, 7 and 10 % of lime.

Flexural Strength Variation for PSC and PPC with Lime Content For PSC, the flexural strength increased with lime content. Maximum flexural strength is recorded at 7 % lime content. On addition of 7 % lime flexural strength increased by 28, 26.92 and 25.92 % at 28, 35 and 42 days respectively over the corresponding values of 0 % lime (Fig. 11).

For PPC the flexural strength also increased with lime content. It is also highest at 7 % lime content. At 7 % lime content flexural strength of PPC increased by 13.04, 12.5 and 20 % at 28, 35 and 42 days respectively over the corresponding values of control concrete (Fig. 12).

Flexural Strength Variation for PSC and PPC with Age For PSC, flexural strength on addition of lime is found to

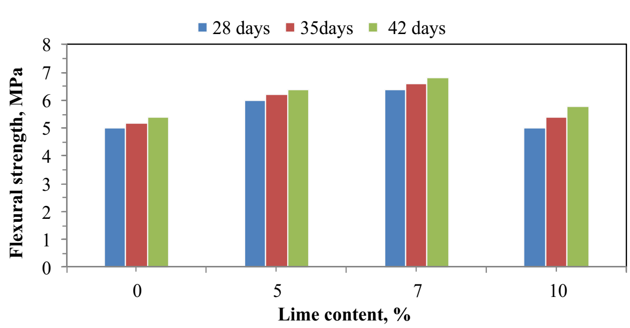

Fig. 11 Flexural strength of PSC

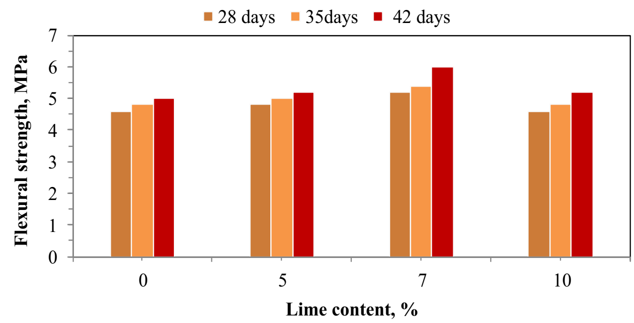

Fig. 12 Flexural strength of PPC

increase with age. On 7 % lime content at the age of 42 days flexural strength increased 6.25 % over corresponding strength of 28 days (Fig. 11). For PPC same behavior as in case of PSC for flexural strength is observed. Maximum flexural strength is recorded at lime content 7 % at all ages. Flexural strength increased to 15.38 % at 42 days over 28 days (Fig. 12).

The reason of improvement in flexural strength of lime blended cement concrete is attributed to refinement of pore structure due to filling effect of lime. Consumption of calcite, accelerating effect on the hydration and formation of transition zone between the filler and the cement paste are other reasons of development in strength properties.

Durability Properties

Durability properties such as acid resistance and sulphate resistance of concrete cubes with and without lime were addressed in terms of strength loss and weight loss. 28 days water cured cubes were further cured in 1 % sulphuric acid solution and 1 % magnesium sulphate solution for another period of 28 days. After 28 days the strength loss and weight loss of concrete cubes caused due to attack of acid and sulphate are compared with that of water cured concrete cubes.

Acid Resistance

Strength Loss Strength loss of cubes with various percentage lime content for both PSC and PCC immersed in 1 % sulphuric acid solution are reported in Fig. 13. On inclusion of lime up to 10 % in concrete made of PSC and 7 % in concrete made of PPC, the acid resistance in terms of strength loss improved. Best result with minimum strength loss is obtained at 7 % lime content in PSC and PPC made concrete.

Weight Loss Weight loss of specimen immersed in 1 % sulphuric acid solution is summarized in Table 6. Positive impact against acid attack in terms of weight loss is noticed

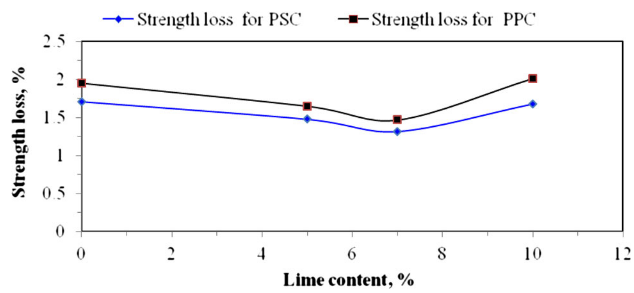

Fig. 13 Strength loss in sulphuric acid solution

Table 6 Weight loss in sulphuric acid solution

Cement	0 % Lime	5 % Lime	7 % Lime	10 % Lime
PSC (weight loss %)	0.12	0.11	0.09	0.14
PPC (weight loss %)	0.12	0.13	0.12	0.14

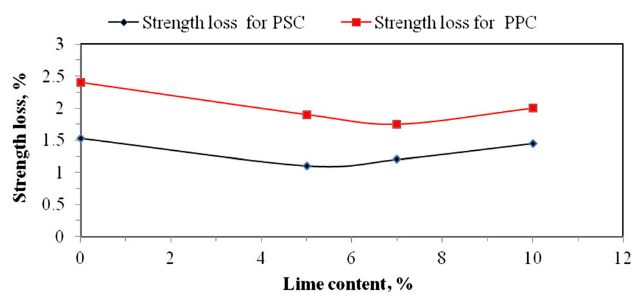

Fig. 14 Strength loss in magnesium sulphate solution

Table 7 Weight loss in magnesium sulphate solution

Cement	0 % Lime	5 % Lime	7 % Lime	10 % Lime
PSC (weight loss %)	0.13	0.11	0.06	0.09
PPC (weight loss %)	0.11	0.11	0.08	0.09

on inclusion of lime. Control concrete without lime suffered highest weight loss. At 7 % lime content weight loss is reported minimum both in PSC and PPC made concrete. However at 10 % lime content, the weight loss increased and acid resistance decreased in comparison to control concrete.

Sulphate Resistance

Strength Loss Strength loss of cubes with different lime content for both PSC and PCC immersed in 1 % magnesium sulphate solution are reported in Fig. 14. The strength loss in concrete with 0 % lime reported 1.53 % in PSC and 2.4 % in PPC made concrete. On inclusion of lime 5–10 %, it varied from 1.1 to 1.45 % in PSC and 1.90 to 2.00 % in PPC made concrete, showing improvement in sulphate resistance.

Weight Loss Weight loss of specimen immersed in 1 % magnesium sulphate solution is reported in Table 7. On inclusion of lime the sulphate resistance increased with decrease in weight loss. Minimum weight loss is reported in concrete made of PSC and PPC containing 7 % lime. At 10 % lime content weight loss increased when compared to that of 7 % lime content but remained lower than control concrete, containing 0 % lime. Control concrete with 0 % lime suffered highest weight loss due to sulphate attack in comparison to all other mixes containing lime.

Conclusions

Following conclusions are drawn from the present study with respect to materials used and parameters studied:

- The compressive strength of concrete made of PSC and PPC increases on inclusion of lime up to 7 % at all ages, studied at the age of 28, 35 and 42 days. At 10 % lime content the compressive strength decreased in comparison to control concrete at all ages.
- The flexural strength of PSC and PPC made concrete increases with lime content up to 10 %. However at 7 % lime content, it is highest for both PSC and PPC concrete measured at the age of 28, 35 and 42 days.
- Consistency is seen to increase with increase in lime content. This indicates more water demand.
- Initial setting time decreases with addition of lime indicating early start of chemical reaction between cement and water. Final setting time decreases with addition of lime indicating early completion of chemical reaction.
- Soundness increases with addition of lime. The highest increase is 2 mm with 10 % lime addition measured in Le-Chatelier apparatus against the permissible limit of 10 mm. Hence, addition of lime up to 10 % does not affect the soundness.
- Workability in terms of slump decreases with addition of lime for both PSC and PPC. It indicates lime addition demands more water. This can be compensated by introducing water reducing admixture, like Plasticizer and Super Plasticizer.
- Both acid and sulphate resistance increases slightly up to 7 % lime content and thereafter, resistances are seen to decrease.

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