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Research paper

Elevated Temperature Performance of Expanded Perlite Aggregate Cement Mortar as a Protective Cover for Concrete

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Abstract

This Paper reports the effect of elevated temperature performance of concrete specimen cube of sizes 100mm x 100mm x100mm coated with 10 mm thickness of mortar shield made of in the proportion 1:3 sand and cement (SC), sand cement and GGBS (SCG), sand, cement and flyash (SCF), expanded perlite aggregates, cement (PC), expanded perlite aggregates, cement and GGBS (PCG), expanded perlite aggregates, cement and flyash (PCF) were subjected varying temperatures of from 200°C to 800°C for 2hour. After specimen were cooled to room temperature in the furnance. The compressive strength were determined. The test results showed that replacement of sand with expanded perlite aggregates acts as a good thermal barrier and protect the structural concrete.

Keywords: *Expanded perlite aggregate, compressive strength; sieve analysis; specific gravity; moisture loss; ambient temperature; elevated temperature, fire*

1. Introduction

Concrete is a very popular construction materials and its application in all civil engineering fields. Its properties such as mouldability, high compressive strength and good resistance to heat, no toxic fumes are emitted from concrete surface under high temperature[1], [2], [3]. Expanded perlite aggregate is a white, ultra-lightweight aggregate ranging from a very fine powdered aggregate with a particle size up to 6mm. It has excellent thermal insulation properties over an extremely wide temperature range from cryogenics at minus 273°C (absolute zero) up to refractory applications at over 1000°C. It also has a highly heat adsorbent surface and a very low bulk density which makes it an ideal carrier or low cost filler for many compound formulations. Plastering of concrete elements is an usual practice in order to render a smooth finish and to enhance architectural features. The expanded perlite aggregates to protect the existing structural elements if made with materials that can resist high temperatures, can protect the structural element. In an experimental investigation is made on efficacy of use of expanded perlite aggregates in mortar used for plastering [4] The results of which are presented in this paper.
Use of expanded perlite aggregates as a means to protect the existing structural elements is also discussed. The mortar used for plaster, made with materials that can resist high temperatures, can protect the structural element.

2. Literature Review

1. Ahmed, et al (2004) have found that the compressive and bond strength of cement mortar decrease with the increase of temperature. The Bond strength of cement mortar completely vanishes and compressive strength of mortar reaches its minimum value at 600°C [1].
2. ApehAbah joseph (2013) has found that the residual compressive strength of concrete decreases with increase in temperature and when quenched in water. This aspect has importance in designing for the recovery of structural elements [3].
3. Kishor S. Kulkarni et.al (2013) have found that High Performance Concrete (HPC)containing Ground Granulated Blast furnace Slag (GGBS) performs better than that of HPC containing silica fumes [5].
4. Amol P, Patil. et.al (2015) have found that the compressive strength and split tensile strength of M60 grade high strength concrete is decreased with the increase of temperature from 100°C to 500°C for 2hours[6].
5. Ashok, et.al (2015) have found that up to 500°C strength reduces gradually and the fire affected structural members remain serviceable although the factor of safety would come down [2].
6. Amol P Patil Bernadette Dębska. et.al (2017 have found that the expanded perlite aggregate material has good chemical resistance, low water absorption and good thermal insulation [4].

3. Materials and Methodology

3.1 Cement

For the experimental work, commercial brand of Ordinary Portland Cement (OPC) 43 grade was used. The cement was tested for its conformation to IS codal provisions. Specific gravity is 3.12 compressive strength is 3days ,7days and 28 days 34, 51and 61 Mpa. Physical tests such as normal consistency is 29%

and setting times Initial is 66 and Final is 275 were conducted on cement sample and Fineness is 332

Specific gravity is 3.12 compressive strength is 3days ,7days and 28 days 34, 51and 61 Mpa. Physical tests such as normal consistency is 29% and setting times Initial is 66 and Final is 275 were conducted on cement sample and Fineness is 332 test was conducted by Blaine's permeability method as per IS 4031(Part 2):1999. Soundness of the cement is 2.50 sample was found by following the procedure mentioned in IS 4031(Part 3):1988

3.2 Fine Aggregates

Locally available River sand conforming to zone III (I.S 383-1970 grading requirements) with specific gravity 2.65 is used. The physical properties of fine aggregates were determined. For the casting of concrete the sand passing through 4.75mm IS sieve is used. For mortar preparation sand passing through 2.36 mm IS sieve was used.

3.3 Coarse Aggregates

The physical tests were conducted to evaluate the properties of coarse aggregate such as specific gravity 2.77, bulk density Loose 1360kg/m^3 Compact 1527kg/m^3 and sieve analysis as per I.S 383-1970 grading requirements satisfied.

3.4 Bonding Agent

Commercially available Latex based bonding agent with brand name Algibond Latex is used to ensure proper bond between the mortar and the concrete surface. Physical and chemical properties of the bonding agent are type SBR Latex , Colour is White, State Liquid and Specific Gravity is 1.01±.0.01..

3.5 Flyash

Flyash used in the present investigation was procured from state-owned Nandikur Thermal Power Plant Udupi District Karnataka. The comparison of results of chemical analysis on this fly ash (Table 1) with the BIS standards (IS 3812-2003) shows that the material is siliceous based. As the quality of fly ash may vary with the source and time of supply of the raw material (coal), entire material required for the investigation is collected in a single batch to avoid any inconsistencies in chemical composition. Specific gravity of flyash is 2.18.

3.6 Ground Granulated Blast Furnace Slag

Commercially available GGBS with fineness of 410m^2/kg and specific gravity of 2.9 is used in this study. The chemical composition of GGBS is given in Table 1.Physical properties and chemical composition of flyash and GGBS (% mass)

Table 1: Physical properties and chemical composition of flyash and GGBS

Oxide	Fly ash	GGBS
CaO	1.79	40
SiO_2	58.87	35
Al_2O_3	32.17	12
FeO	2.93	0.2
K_2O	1.14	-
Na_2O	0.37	-
Na_2O_3	1.12	-
MgO	0.92	10
SO_3	0.49	-

3.7 Expanded Perlite Aggregate

Chemical Properties: Conditions are chemically inert. Typical composition of expanded perlite aggregate is Silicon (SiO_2) 73%, Aluminium (Al2O3) 15%, Iron (Fe_2O) 2%,Sodium (Na_2O) and Potassium (K_2O) 1%, pH 6.5 – 7.5 Calcium plus Magnesium (CaO+MgO) 1% and Organic Matter nil.

3.8 Physical Properties:

As per the method of expansion, the actual specific gravity of the mineral fraction is between 2.2 and 2.4. The bulk density dispends of the density of each particle and their grading. As per the bulk density ranges from 40 to 120 kg/m3 when poured and 50 to 150 kg/m3 when compacted. Softening Point is 890 - 1100^{o}C and Fusion Point 1280 - 1350^{o}C, Specific Heat 0.20 and Refractive Index 1.5.

Fig. 1: Expanded perlite aggregate

3.9 Water:

Clean Tap water was used throughout this work for both mixing and curing of concrete.

4. Methodology

4.1 Concrete Mix Design

Concrete Mix is prepared using Ordinary Portland Cement (OPC – 43 Grade), crushed granite aggregates (10 mm down and 20 mm down) and river sand. Mix design of concrete is based on the guidelines given in IS 10262-2009. The mix proportion adopted for the present investigation is as shown in table 2

Table 2: Concrete Mix design

Water	Cement	Fine aggregate	Coarse aggregate	
0.45	1	1.198	2.923	
			30 % 10mm= 0.877	70% 20mm= 2.046

In this study 100 x 100 x 100mm sized specimen were used for the entire experimental investigation. The concrete is mixed in the mixer and poured in the moulds of size 100 x 100 x 100mm. All the cubes were cured in a curing tank for curing. The slandered curing period was maintained as 28 days & then tested. The 3 specimens were tested for compressive strength at room temperature and results were tabulated. Same procedure was repeated for specimens at 200°C, to 800°C temperature. However at these cubes tested at 200°C to 800°C.the cubes were heated for 2hours only. The first step of the experiment was conducted to evaluate the strength deterioration when the concrete is subjected to various elevated temperatures for various exposure durations and cooled to the room temperature in the furnace. The cube specimen were tested for compressive strength were determined as per the guidelines given in IS 516 1959 in the digital compression testing machine.

The concrete specimen concrete cube of sizes 100mm x 100mm x100mm with 10 mm thickness mortar made of in the proportion of 1:3 sand and cement (SC) sand, cement and GGBS (SCG), sand cement and fly ash (SCF), expanded perlite aggregate and cement (PC) expanded perlite aggregate, cement and GGBS (PCG),expanded perlite aggregate cement and fly ash (PCF) were subjected to varying temperature of 200^{0}C to 800^{o}C for 2hour. After the specimens were cooled to room temperature in the furnace. The compressive strength were determined .

The concrete mixes with expanded perlite aggregates PC, PCG and PCF performed extremely well under elevated temperature conditions. They showed no signs deterioration such as cracking till 600°C. Figure 2 shows the surface of plastered concrete cube subjected to 600°C. Plastered concrete cube exposed to 700°C experienced minor cracks on the plaster surface. However, there was no delaminating of the plaster surface till 800°C. The expanded perlite aggregate plaster acted as a good thermal barrier and prevented the heat to penetrate to the concrete cube.

The Six plaster combinations and total number of test cubes 126. Experiment involved studying the efficacy of various plaster combinations as heat shields. Six plaster combinations and mortar mix proportions are presented in Table 3.

SC – Cement + Sand

SCG – Cement +sand + GGBS (Ground Granulated Blast furnace Slag)

SCF – Cement +sand + FA (Flyash)

PC – Cement + Expanded perlite aggregates

PCG – Cement + Expanded perlite aggregates + GGBS (Ground Granulated Blast furnace Slag)

PCF – Cement + Expanded perlite aggregates + FA (Flyash)

Mix proportions of the mortar having different heat shields are presented in Table No 3

Table 3: Mortar mix proportions

Mix Id	Cement (gms)	Bonding agent (ml)	Water (ml)	GGBS (gms)	Flyash (gms)	River sand (gms)	Expanded perlite aggrigate (gms)
SC	400	40	120	-	-	1200	-
SCG	200	40	120	200	-	1200	-
SCF	200	40	120	-	200	1200	-
PC	400	40	525	-	-	-	214
PCG	200	40	525	200	-	-	214
PCF	200	40	525	-	200	-	214

5. Strength of Concrete Cubes Coated with Different Mortars

Concrete cube plastered with mortar containing river sand and perlite as aggregates were subjected to elevated temperatures. Residual strengths of the concrete cubes were determined after removing the damaged plaster coat.

5.1. Concrete Cube Coated with Sc Mortar

Comparison of residual strengths of plastered specimen and unplastered concrete specimen is shown in figure.1.The concrete cube coated with SC mortar exposed to 200°C retains 99% of the ambient strength as against 97.29% for the unplastered concrete. Similarly the concrete exposed to 300°C retained about 97.78% of the ambient strength as against 88.92% for the unplastered concrete cube. The plastered concrete exposed to 400°C retained about 88% of the ambient strength, 81% for unplastered concrete strength.

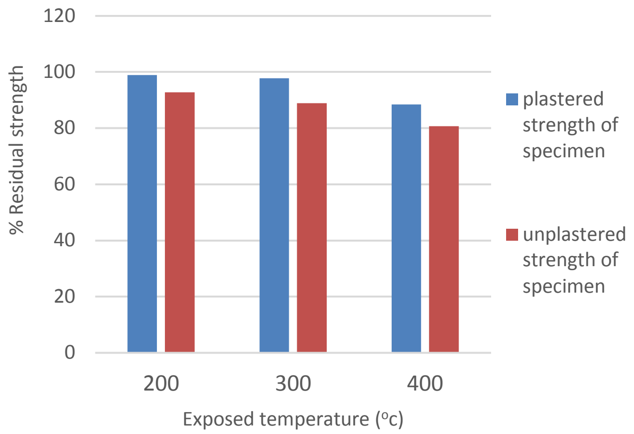

Fig. 2: Residual strength of concrete cube coated with SC mortar against Exposure Temperature

5.2 Concrete Cube Coated with SCF Mortar

The concrete cubes coated with SCF mortar exposed to 200°C retains 98.89% of the ambient strength as against 92.79% for the unplastered concrete as it appears in figure 3. The plastered concrete exposed to 400°C retained about 88.4%, while for unplastered concrete strength was 80.66% of the ambient strength, because the concrete had lost the coating of plaster and the concrete was exposed to heat. For the case of 400°C exposed the plaster had experienced heavy cracking and separation of plaster at about 350°C, which let the heat to penetrate into the plaster coat.

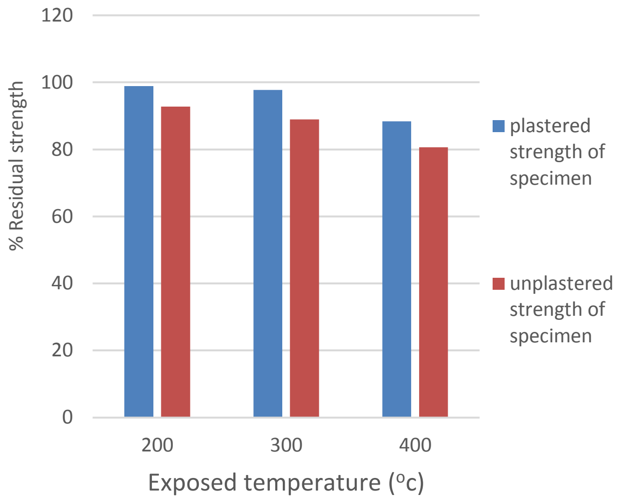

Fig. 3: Residual strength of concrete cube coated with SCF mortar against Exposure Temperature

5.3. Concrete Cube Coated with SCG Mortar

The concrete cube coated with SCG mortar and exposed to 200°C retains 98.67% of the ambient strength as against 92.64% for the unplastered concrete. Similarly the concrete exposed to 300°C retained about 85.72% of the ambient strength as against 79.87% for the unplastered concrete cube. The plastered concrete exposed to 400°C retained about 85% of the ambient strength as observed from figure 4.

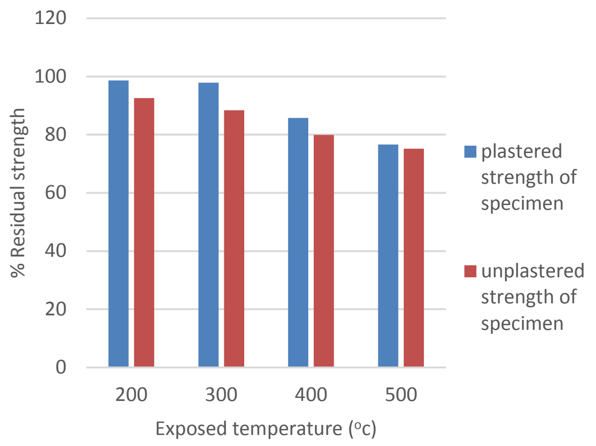

Fig. 4: Residual Strength of concrete cubes coated with SCG mortar against Exposure Temperature

5.4 Concrete Cube Coated with Pc (Cement + Expanded Perlite Aggregate) Mortar

From the figure 5 it is evident that PC mortar provided excellent protection for the concrete up to the exposure temperature of 500°C. The concrete coated with PC mortar, exposed to 600°C experienced cracking all over the plaster surface. This allowed the heat to penetrate to the concrete. The PC plastered concrete retained about 77% of ambient strength as against 71.41% of ambient strength for unplastered concrete cubes. The concrete exposed to 700°C retained about 57.5% of ambient strength, while the concrete coated with PC mortar retained 69.42% of the ambient strength. The plastered surface had cracked heavily however there was no de-bonding from the concrete. Even for temperatures of 600°C and 700°C the strength of plastered surface is higher than the unexposed strength.

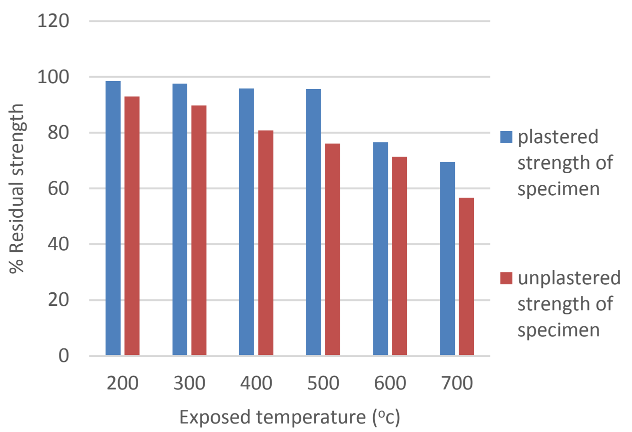

Fig 5: Residual Strength of concrete cube coated with PC mortar against Exposure Temperature.

5.5 Concrete Cube Coated with PCF (Cement + Expanded Perlite Aggregate+ Fly Ash) Mortar

The performance of PCF mortar is also encouraging and it provides protection to the encased concrete. The concrete coated with PCF mortar and exposed to 600°C experienced cracking all over the plaster surface. Even though the PCF plastered concrete had undergone cracking, it could retain about 76.52% of ambient strength as against 73.28% of ambient strength for un plastered concrete cubes.

The concrete exposed to 700°C retained about 55.72% of ambient strength, while the concrete coated with PCF mortar retained 71.09% of the ambient strength.

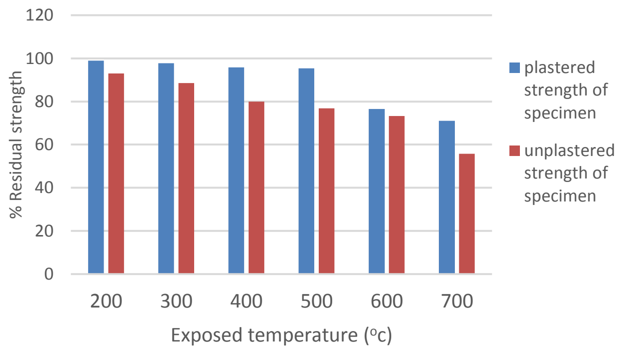

Fig. 6: Residual Strength of concrete cubes coated with PCF mortar against Exposure Temperature

5.6 Concrete with PCG (Cement + Expanded Perlite Aggrigate + GGBS) Mortar

Concrete cube plastered with PCG mortar retained more than 92% of the ambient strength for the exposure temperatures up to 500°C. Figure 5 shows that the plastered concrete performs better at all the temperatures up to 700°C.

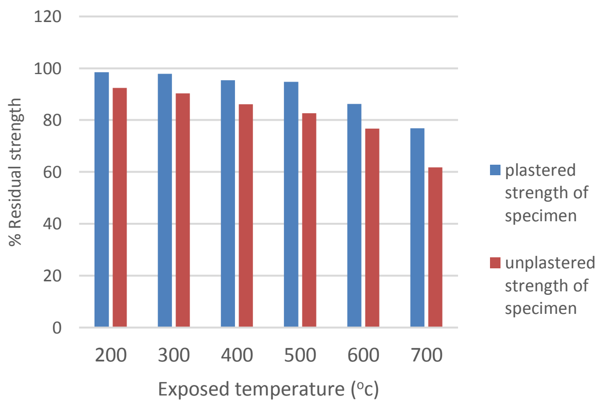

Fig. 7: Residual Strength of concrete cubes coated with PCG mortar against Exposure Temperature

6. Comparison of Performance of Various Mortars Studied as Thermal Barrier

Figure 8 shows the strength retained expressed in percentage of ambient strength for the concrete cubes coated with six mixes of mortar. The trend of strength deterioration with increase in exposure duration, for SC, SCF and SCG mortars is different from the trend of strength.

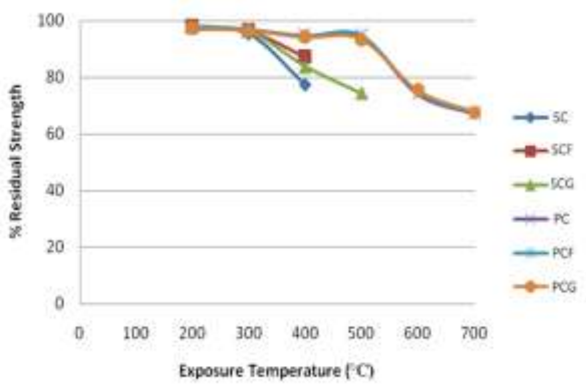

Fig 8: Residual strength of concrete cubes coated with various mortar subjected to elevated temperatures

Replacement of sand with expanded perlite aggrigate aggregates proved to be beneficial in protecting the concrete against thermal exposure. Concrete coated with PC mortar performed well when subjected to elevated temperatures and did not experience de-bonding till 700°C. The plaster surface did not experience cracking till 500°C, hence the concrete could retain about 94% of the ambient strength for 500°C. However sudden drop in strength is observed for 600°C, this is due the cracking that was observed on the plaster surface which allowed the heat to penetrate into the mortar coating reaching the concrete cube. For 700°C the strength retained is about 70%.

The trend of strength deterioration is similar for the concrete specimen coated with PCF and PCG mortar. The graphs of PC, PCF and PCG almost coincide. This shows that mortar made of Expanded perlite aggregates performs extremely well as a thermal barrier and protects the concrete against thermal exposure.

Plastering can play an important role in protecting the structural concrete against thermal exposure. Performance of six kinds of mortars were studied and it is found that mortar made of Expanded perlite aggregates act as good thermal barrier and protect the structural concrete without undergoing cracking upto 500°C.

7. Conclusions

- The mortar made with sand as aggregates lost the bond with concrete at temperatures of 290°C to 360°C.
- SC mortar lost the bond with concrete and experienced violent separation when the exposure temperature reached 290°C.SCF and SCG mortars maintained their bond with concrete till 400°C.
- Mortar made with Expanded perlite aggregates does not show any signs of damage such as cracking till 600°C.
- Replacement of sand with Expanded perlite aggregates provides good thermal protection to the concrete. The concrete maintains more than 90% of its ambient strength for exposure temperatures upto 600°C.

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