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Enhancement of Thermal Insulation and Mechanical Properties of Concrete by Expanded Polystyrene Beads

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The aim of this work has to study the thermal properties of concrete by adding Expanded Polystyrene Beads (EPS) in the normal concrete. EPS and granite dust have replaced for fine aggregate by 25% and cement by 10% by weight. Glass fibres have also added at 0%, 0.05%, 0.1%, 0.15%, 0.2%, 0.25%, 0.3% and 0.6% by the weight of cement. The effect of EPS, granite dust and fibres on mechanical properties, durability and thermal conductivity have studied. The results have showed that on adding EPS, reduced the thermal conductivity, weight, water absorption and strength of the concrete than the normal concrete. The reduction in strength of nominal concrete by the addition of EPS was15%, which have compensated by adding 0.15 % of glass fibre.

Keywords: Expanded polystyrene beads, Granite dust, Glass fibre, Thermal conductivity

1 Introduction

Energy consumption is the one of the greatest problems the world is facing. Reducing the energy consumption has given first priority in sustainable development. So creating energy savings in buildings leads to the development of low energy buildings. Thermal insulation can be done in buildings to prevent the energy loss from structures. It could be done by sandwiching materials or by reducing the density. So creating energy savings in buildings leads to the development of low energy buildings.Thermal insulation can be done in buildings to prevent the energy loss from structures. It can be done by sandwiching materials or by reducing the density. Also reducing the thermal conductivity of materials helps to prevent the heat loss by decreasing the conduction. Sustainable development means to reuse the wastes produced. Construction industry is one of the industries to use most of the solid wastes like plastic wastes, rubber, recycled concrete, EPS, steel, wood waste etc for one or other purpose.

Granite wastes which produced as a result of polishing, grinding of granite and it leads huge amount of wastes into environment. This can pollute reservoirs, clog soil, when inhaled can cause several health problems to humans. Nowadays these wastes are recycled in construction industry. EPS beads are the wastes from industry and are used as a packaging material. It consists of 98% of air and 2% polystyrene. Use of these polystyrene in concrete helps to reduce the wastes since they are non-biodegradable. They are usually used in light weight concrete as replacement of course or fine aggregate. Also, EPS beads have very less thermal conductivity and light weight.

The conventional concrete is brittle in nature and has poor resistance to crack opening and propagation. In order to avoid these problems fibres are incorporated in concrete this leads to the development of fibre reinforced concrete. It helps to increase the mechanical properties, crack resistivity, good impact strength etc. The use of granite dust and EPS beads in concrete not only reduce the wastes from environment but also help to reduce the impact of cement industry and aggregates on nature. It has attracted the attention because of reducing the production costs and reuse of secondary wastes.

Replacement or addition of granite dust in concrete helps to improve the properties of the concrete, also reduction of corrosion and the cracking time has observed by Elmoaty et al.[1]. Granite dust can also be used as an additive in concrete. Allam et al.[2] has illustrated that the replacement of sand by granite dust gives higher compressive strength. Imran et al.[3] has replaced sand by granite residue at different percentages found that granite residue enhanced the strength of concrete and also found out that it can act as filler. Experiments results of Aman Mulla[4] and Thomas Tamut[5] have demonstrated that the use of

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EPS beads help to decrease the weight of concrete but also decrease the strength of the concrete. The thermal conductivity can be enhanced by the use of EPS beads[6]. Srinivasa Rao[7] has studied the presence of alkali resistant glass fibres in concrete and found that they enhance the mechanical properties and durability of concrete. Chandramouli et al.[8] has studied the optimization of fibres used in concrete for enhancing the properties of concrete by using glass and steel fibres and proved that fibres helps to promote the mechanical properties of concrete.

From the past research it was observed that a lot of work were done on granite dust and EPS beads. But study on thermal conductivity without compromising the strength and the utilization of wastes is not widespread. The properties of granite dust and EPS beads in replacement of cement and fine aggregate respectively may improve the properties of concrete. Also, the glass fibres help to increase the mechanical and thermal properties of concrete. The main objective of this study has to experimentally investigate the effect of granite dust, EPS beads and glass fibres on the mechanical and thermal properties of concrete.

2 Materials and Methods

The properties of materials used were as follows. Flyash based Portland Pozzolana cement of brand Shankar owned by Indian Cements Limited at Tamil Nadu, India and the specific gravity of cement according to IS 4031:1988 is 2.86. Fine aggregate used was M sand with a specific gravity of 2.66 according to IS 2386 part 39 and belongs to zone II as per IS 383, Coarse aggregate used have a nominal size of 20mm with specific gravity of 2.68 according to IS 2386. The fineness modulus of the fine and coarse aggregate was 2.88 and 9.58 respectively. Granite slurry, waste product from granite stone processing industry at Chavarkod, Kollam, Kerala, India was used. The slurry was dried and the dust was used in concreting. It has white colour, odorless, specific gravity 2.54 and passed through 90-micron sieve. EPS used were white colored and the size was less than 3mm and was purchased from the Adhitya Marketing, Chennai, India. It has a density of 18g/l and specific gravity 0.018. Glass fibre used was alkali resistant glass fibre and was purchased from Nippon electric glass limited, India. The aspect ratio of the fibre was and specific gravity was 923 and 2.72 respectively. Superplasticizer used was naphthalene based Conplast SP430 from Fosroc. Grade of concrete used was M25 with a water cement ratio of 0.38. The glass fibre was added at 0%, 0.05%, 0.1%, 0.15%, 0.2%, 0.25%, 0.3% and 0.6%. Cement was replaced with granite dust by 10% (Table. 1) and fine aggregate was replaced by 25% of EPS beads.

Concrete was prepared by mixing coarse aggregate, fine aggregate, EPS, cement, granite dust, glass fibre, superplasticizer and water. Cement was replaced by 10% of granite dust by weight; it was obtained experimentally based on 29th day compressive strength by replacing cement by 5%, 7.5%, 10% and 12.5% of granite dust as shown in Table1. Compressive strength of the concrete was found to find the optimum amount of granite dust since as compressive strength increases all other mechanical properties also increases. Also, 25% of fine aggregate was replaced by EPS by weight and weight in volume respectively. Glass fibres were added at 0%, 0.05%, 0.1%, 0.15%, 0.2%, 0.25%, 0.3% and 0.6%. In order to avoid the segregation and bleeding the water cement ratio used was 0.38. Cubes, cylinders and beams were casted having granite dust, EPS and at different percentages of fibres.

In this study 8 mixes were used with different percentage fibre from 0.05% to 0.6%. Large amount of fibre can cause bad distribution and water cement ratio used was 0.38 to minimize segregation of EPS and aggregates. In this M25 concrete without any addition or replacement is denoted as the nominal. Concrete having 10% granite dust and 25% EPS are denoted as 0% fibre. Concrete with different percentages of fibre added were denoted as 0.05% fibre, 0.1% fibre, 0.15% fibre, 0.2% fibre, 0.25% fibre, 0.3% fibre and 0.6% fibre respectively. For example, 0.05% fibre concrete indicates concrete having 10% replacement of cement with granite dust, 25% of fine aggregate with EPS and 0.05% fibre as addition. Table 2 describes the different mixes used.

Compressive strength was found according to IS 51610, Split tensile and flexural strength were determined according to IS 5816:1999 and the specimens were cylinders and beams. Ultrasonic pulse velocity is found out according to IS 1311:1992

Table 1 — Compressive strength of cubes having granite dust

Percentage of granite dust	28 day compressive strength(N/mm²)
5%	18.2
7.5%	21.9
10%	27.3
12.5%	17.8

Table 2 — Description of mixes

Type of mix	Contents
0 % fibre	10% granite dust + 25% eps +0% fibre
0.05%fibre	10% granite dust + 25% eps +0.05% fibre
0.1% fibre	10% granite dust + 25% eps +0.1% fibre
0.15% fibre	10% granite dust + 25% eps +0.15% fibre
0.2% fibre	10% granite dust + 25% eps +0.2% fibre
0.25% fibre	10% granite dust + 25% eps +0.25% fibre
0.3% fibre	10% granite dust + 25% eps +0.3% fibre
0.6% fibre	10% granite dust + 25% eps +0.6% fibre

PART 1. Rebound hammer test is an NDT test from which rebound number is obtained and is used to compare the quality of concrete and uniformity. The test was done according to IS 1311(II):1992. The resistance of concrete to sulphate attack was also tested in the laboratory by storing specimens in a solution of sodium or magnesium sulphate or in a mixture of two. The sulphate attack was conducted on 150x150x150 mm cubes. The cubes were immersed in $MgSO4$ and Na_2SO4 by 5% weight of water and are tested for its loss in compressive strength after 28 days. Water absorption of concrete is found out by water absorption test. This was done on 150x150x150 mm cubes. Three full size blocks shall be completely immersed in clean water at room temperature for 24 hours. The blocks shall then bere moved from the water and allowed to drain for one minute by placing them on a 10 mm or coarser wire mesh, visible surface water being removed with a damp cloth, the saturated and surface dry blocksare immediately weighed. After weighing all blocks, it was oven dried at 100 to 115°C for not less than 24 hours and until two successive weighing at intervals of 2 hours show an increment of loss not greater than 0.2 percent of the last previously determined mass of the specimen. Thermal conductivity of concrete was found by using a cylindrical specimen of 50mm diameter and 100mm length. The experimental set up consists of a heating unit, power supply and display unit as shown in Fig. 1. Here one end of the specimen was heated using a source and the heat supplied can be found out from the sensors attached to the heating element. At a particular distance two sensors were placed in order to find out the temperature difference between those points. From the heat supplied, temperature difference and the area of specimen thermal conductivity can be determined by the below equation.

$$k=\frac{q*d}{A(T^{'}-T^{2})} \qquad \ldots (1)$$

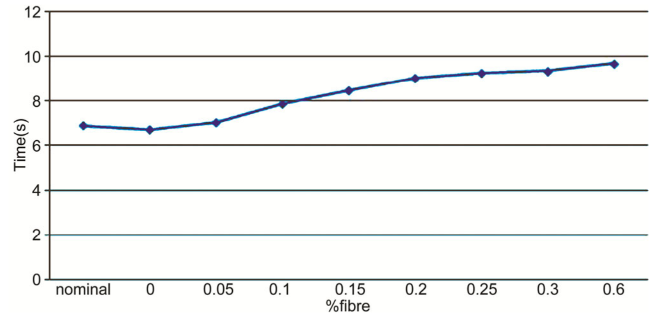

Fig. 1 — Fresh concrete properties – Vee Be

Where
k = thermal conductivity of the specimen, W/mK;
q= quantity of heat passed (W);
d = distance between the sensors (m);
A= area of the specimen (m^2);
T'= temperature at first point (K);
T^2= temperature at second point (K).

3 Results and Discussion

Fresh concrete properties were evaluated by Vee Bee Consistometer according to IS 1199:1959 and the mechanical properties such as compressive strength, split tensile, flexural strength, pulse velocity, rebound number and dynamic modulus of elasticity were evaluated. Durability of concrete were studied by conducting water absorption, sulphate attack and alkaline attack tests. Fig. 1 explains the effect of granite dust, EPS beads and glass fibres on the workability of concrete.The results show that the mix is stiff. Fig. 1 also indicates that fibre reduces the workability whereas EPS increased the workability, this is because the lubricating effect of the cement paste decreases with the increase in fibre content and also due to the friction between aggregates and fibres.

The compressive strength at 7day, 28day and 56 day on varying amount of fibre were shown in Fig. 2. The trend is same at different ages of curing. After the addition of EPS, a decrease of 15.8% in strength of concrete which was compensated nearly by the addition of fibre. It was found that there was an increase of 12.1% in compressive strength with addition of fibre compared to 0% fibre at 28 day.The maximum strength was obtained at 0.15% of fibre and was due to the bridging effect as well as the load carrying capacity of fibres. After 0.15% fibre, the decrease in strength was due to the bad distribution, balling of fibres, reduces workability resulting in less compaction and increases the ITZ zone between fibre and the matrix. The compactness of concrete was

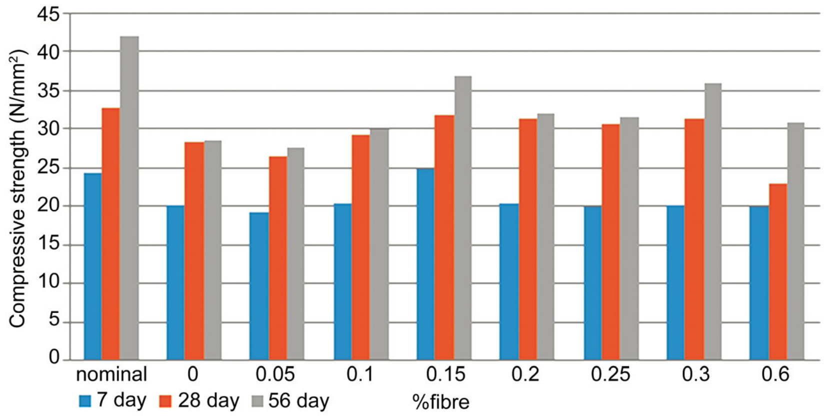

Fig. 2 — Compressive strength of concrete at different stages.

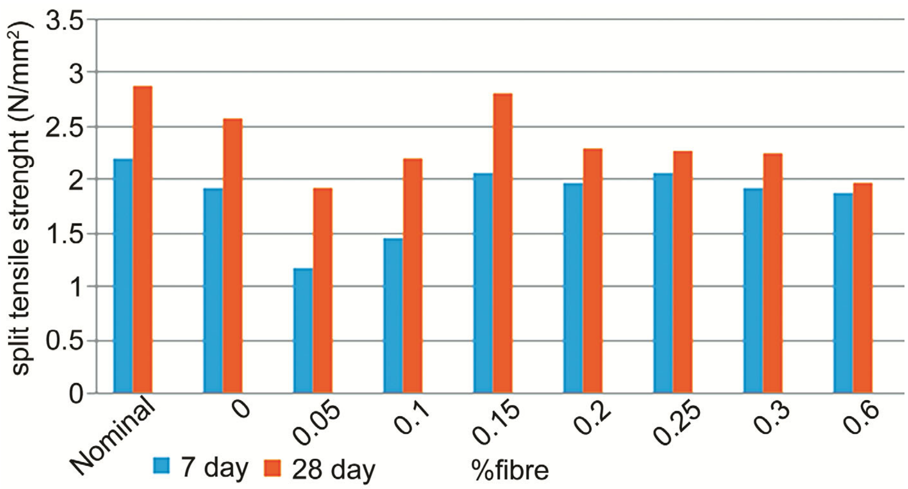

Fig. 3 — Split tensile strength of concrete.

inversely proportional to porosity. Increase in porosity leads to decrease in strength. For 0% fibre there was a sudden reduction in strength because EPS reduce the weight of the concrete and density. The strength decrease at 0.05% fibre was attributed by less workability and non-bonding between the fibre and EPS are not compensated by the increase in strength due to the glass fibre.

Also on breaking the specimen all the EPS beads get broken, this shows that there was good bonding between EPS and cement paste. While some aggregates break at the inter transition zone, those breaking at ITZ shows that the cement bonding was less than the strength of aggregate at some percentages. Split tensile strength at the age of 7 day and 28 day is shown in Fig. 3. Figure 3 shows the effect of granite dust, EPS beads and different percentages of fibre on the spilt tensile strength of concrete. After the addition of EPS beads there was a decrease of 11.8% strength at 0% fibre and after the addition fibres there was an increase of 9.1% in strength at

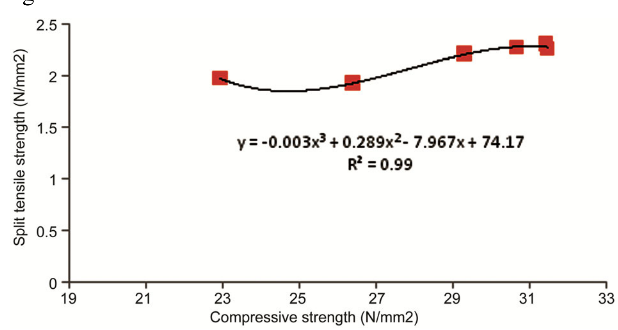

Fig. 4 — Correlation between compressive strength and split tensile strength.

0.15% fibre. Also a correlation given by equation (2) was formed between the 28-day compressive strength and split tensile strength. Figure 4 show the relation between compressive strength and split tensile strength and are expressed in the following equation (R2 =0.918). From this it was understood that split tensile and compressive strength were directly related.

$$y = 0.0069x2 - 0.3365x + 6.01 \quad \ldots (2)$$

Figure 5 shows the flexural strength for varying percentages of fiber at the age of 28 days. This show that 0% fibre has a decrease of 22.5% in strength than the nominal. The 0.15% fibre has an increase of 25% in strength compared to the 0% fibre. Also, the flexural strength of 0.15% fibre was 2.06% greater than the nominal concrete. This was because on decreasing the size of the fibres it has more capacity to withstand the bending forces. So, this concrete withstands more tension forces than the compressive forces and it can be used mostly for structures subjected to tension and flexural forces like beams, slabs etc.

Pulse velocity was used to find the compactness, strength, modulus of elasticity, homogeneity, integrity as well as condition of stress and strain without damaging the concrete. Figure 6 shows the pulse velocity of the mixes at 28day. The value of pulse velocity was greater than 4 km/s, which shows that the quality of concrete was very good. The 0.15% of glass fibre has nearly same velocity as the nominal concrete. Hence, shows that on adding fibre the quality was retained. The velocity increases due to decrease in voids and increasing density but after the optimum value velocity decreases due to uneven distribution of fibre and due to presence of voids. This change in velocity of the wave is because the waves travel faster on a dense medium. Concrete is a heterogeneous mixture consisting of cement paste, voids, aggregates, fibres, water etc, but the velocity of waves through each of them is different. There will be a reduction in velocity when the waves enter less density medium like cracks, voids and air.Thus, there was variation in the pulse velocity. If pulse velocity high means the presence of cracks or voids are less. So, it was understood that 0.15% has fewer voids and was denser.

A correlation equation (3) was formed between compressive strength and pulse velocity. The trend in upv values increases with the increase in compressive strength. Figure 7 clearly shows that for mixtures the correlation between the UPV values and compressive strength was too strong (R2 = 0.954). The correlation can be expressed as follows.

$$y = -56.53x^2 + 540.0x - 1257 \quad \dots (3)$$

The pulse velocity and density were used to calculate dynamic modulus of elasticity. The dynamic elastic modulus was used primarily to evaluate soundness of concrete in durability tests; it is more appropriate to use when concrete is to be used in structures subjected to dynamic loading. Fig. 8 shows that the maximum value of dynamic modulus of elasticity was obtained on 0.15% fibre and was greater than the nominal mix. The modulus of elasticity was directly proportional to the strength of concrete, pulse velocity and depends upon the density. The results obtained also prove the same.

The higher value of dynamic modulus of elasticity show that the concrete has higher resistance to vibrations of waves which may cause destruction. So, it can withstand the vibrations and frequencies generated from machines and equipment's which can cause destruct the machine foundation.

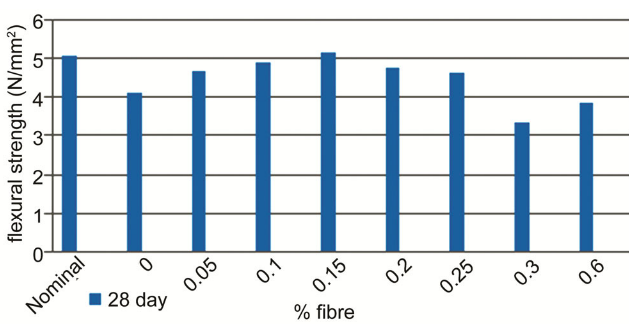

Fig. 5 — Flexural strength of concrete at 28 days.

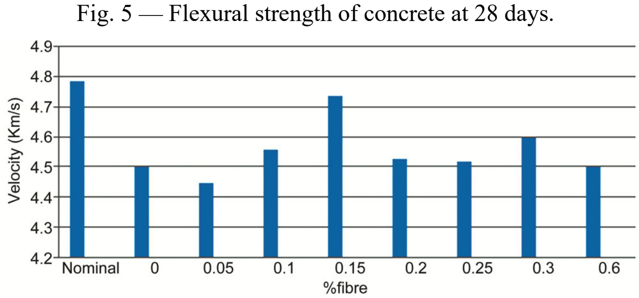

Fig. 6 — Pulse velocity of concrete at 28 day.

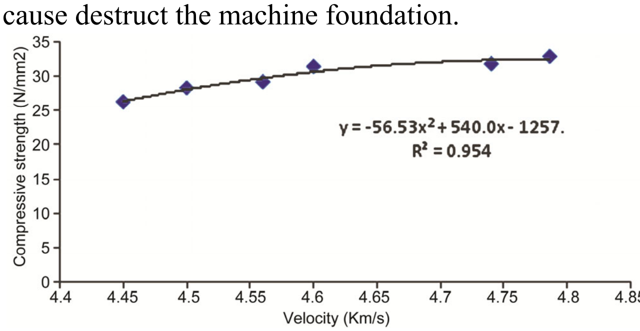

Fig. 7 — Correlation between upv.

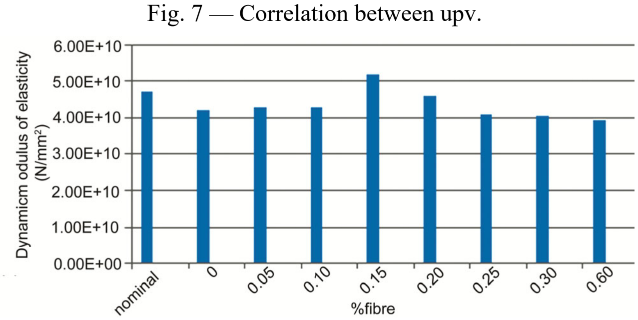

Fig. 8 — Dynamic modulus of elasticity of concrete compressive strength.

From Fig. 9 Rebound number obtained was greater than 30. It shows the quality of the concrete was good. The 0.15% glass fibre has the largest rebound value. It shows that the impact strength of concrete was greater because the fibre could absorb the impact energy. The value of strength obtained from rebound number was more or less same to the compressive strength. Figure 10 shows the compressive strength obtained from the rebound number. The strength increases up to 0.15% fibre and then decreases which was similar to results obtained from the compressive strength test.

Table 3 shows the percentage change in compressive strength due to sulphate and alkaline attack. The positive value shows that there was a loss in compressive strength while the negative sign shows that there was an increase in compressive strength on 56 days. On increase in fibre there

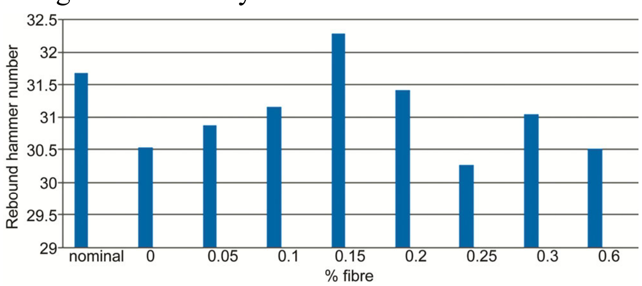

Fig. 9 — Rebound number.

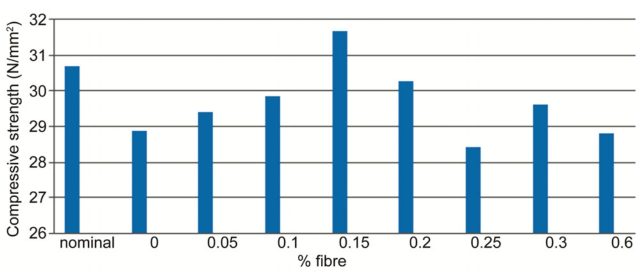

Fig. 10 — Compressive strength from rebound Number.

was a reduction in the percentage loss of strength that shows the fibres help in resisting the sulphate attack and also at 0% fibre there was an increase in strength which shows the EPS resists the sulphate attack. The loss in strength was due to the presence of voids which increases the permeability of concrete, water absorption and helps in sulphate attack.

This was conducted to determine the resistance of various concrete mixtures to alkaline attack. After 28 days curing the cubes of size 150x150x150 mm were immersed in a solution having 5% NaOH by weight of water for 28 days. The alkalinity of water was kept maintained throughout the period. After 28 days the cubes were taken out and tested for compressive strength.

The resistance of concrete to alkaline attack was found by the % loss of compressive strength on immersion of cubes on alkaline water. Table 4 show the change in compressive strength due to alkali attack after 56 days. The positive and negative value represents the loss and gain in the compressive strength at 56 days respectively. There was a reduction in the loss in strength due addition of EPS beads since it was resistant to alkali. While on adding glass fibre results in the gain in strength and shows no sign of alkali attack. This might be due to the use of alkali resistant glass fibre. These alkali resistant glass fibres made of zincronium, when they were immersed in NaOH solution the Zr/Si ratio on the surface of the fibres increases. It was found that these fibres have an affinity towards Ca(OH)2 and calcium get deposited on its surface14, 15. The reaction between the fibres, cement paste and the outside solution results in the formation of C-S-H, Ca(OH)2 and a layer of hydroxylated glass at the ITZ zone. This local densification of the cement matrix improves the strength of concrete.

Table 3 — Percentage change in strength due to sulphate attack

Type of concrete	Sulphate Attack					
	Compressive strength(N/mm^2) 56 days	Compressive strength after attack (N/mm^2)	% Change in strength	Compressive strength (N/mm^2) 56 days	Compressive strength after attack (N/mm^2)	% Change in strength
Nominal concrete	42.2	40.0	5.5	42.2	41.1	2.69
0% fibre	28.70	35.30	-18.69	28.70	28.00	2.50
0.05% fibre	27.60	24.40	13.11	27.60	31.10	11.24
0.1% fibre	30.00	27.10	10.70	30.00	32.40	7.40
0.15% fibre	37.00	34.60	6.94	37.00	39.20	5.61
0.2% fibre	32.00	31.11	2.86	32.00	34.88	8.25
0.25% fibre	31.68	30.89	2.55	31.68	34.20	7.36
0.3% fibre	36.00	35.11	2.53	36.00	36.44	1.21
0.6% fibre	30.88	35.50	13.01	30.88	29.70	3.97

Table 4 — Water absorption and thermal Conductivity of Concrete

Type of concrete	% Absorption	Thermal conductivity (W/mK)	Percentage decrease in k
Nominal concrete	2.98	1.4301	-
0% fibre	1.73	1.4270	0.20
0.05% fibre	1.79	1.4250	0.35
0.1% fibre	1.40	1.4225	0.53
0.15% fibre	1.33	1.4204	0.68
0.2% fibre	1.21	1.4179	0.86
0.25% fibre	1.54	1.4129	1.21
0.3% fibre	0.88	1.4124	1.25
0.6% fibre	1.70	1.4104	1.40

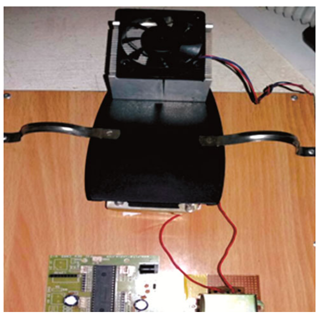

Fig. 11 — Experimental set up for thermal conductivity

Table 4 shows the water absorption of concrete obtained. Water absorption decreases with the increase in fibre. There was a reduction of 42% in water absorption on adding fibre. This was because of the nonabsorbent nature of the Eps beads and fibre. The concrete containing 0.2% fibre has very low water absorption.

Above that percentage water absorption is greater because of change in porosity due to % variation in fibre. Since it has less water absorption it makes the concrete more durable, cause less erosion and corrosion to the concrete and reinforcement. Thus, helps in increasing the lifespan of concrete. Also it can be used as damp proof course in buildings.

Figure 11 shows measurement of thermal conductivity is done at transient condition. Thermal conductivity decreases on increasing fibre and Eps beads. From Table 4 it was found that there is a decrease of 0.2%, 0.68% and 1.4% in thermal conductivity for 0%, 0.15% and 0.6% respectively. It was noted that there was only a slight decrease in thermal conductivity. K value decreases due to the use of thermal insulting Eps and glass fibre. Thermal conductivity depends on the density, pores, properties of aggregates, water cement ratio etc.

4 Conclusion

The study was conducted to find the mechanical, durability properties and thermal conductivity of concrete having granite dust, EPS beads and glass fibres to ensure its strength and resistivity against aggressive environments. Based on the experimental results the following conclusions were made.

- The weight of the concrete after adding EPS was reduced about 7.2% compared to the nominal M25 concrete.
- Decreased workability due to addition of fibres was the result of increased friction which leads to the reduction in lubricating effect of cement paste.
- On adding EPS beads there was a reduction of 15.8%, 11.83% and 22.4% in compressive, split tensile and flexural strength respectively. This was contributed by the reduction in density and weight of concrete.
- Addition of glass fibres enabled to increase the strength about 12.10%, 9.1% and 25% in compressive, split tensile and flexural strength respectively. This increase was the result of bridging effect of fibres which helps to carry loads.
- The maximum strength was obtained at 0.15% fibre. Significant losses in strength was observed after 0.15% fibre because of bad distribution and balling of fibres. The addition of fibres compensated the strength reduction due to EPS beads.
- The UPV values were nearly equal to the nominal mix and the concrete was qualified as good since the velocity was greater than 4 km/s. Results of dynamic modulus of elasticity obtained from the upv test proves that the modulus of elasticity was proportional to strength of concrete.
- The values of rebound number obtained indicate that the quality of concrete obtained was good. Also compressive strength obtained from the rebound number was more or less same to the compressive strength obtained from the compression test.
- The values of sulphate attack for 0.2%, 0.25%,0.3% were less than the nominal concrete. There was an increase in strength for 0% fibre mix which means the mix without fibre does not show any sign of sulphate attack.
- Alkali attack results was shows that for all mixes other than the nominal mix and 0% fibre shows no sign of alkali attack. This might be contributed by the use of alkali resistant glass.

- Water absorption of concrete were decreased after the addition of fibres upto 0.2% and then increased due to the addition of fibres.
- The addition of fibres and EPS beads results in the decrease in thermal conductivity at a small rate without compromising the strength. Reduction in thermal conductivity was 0.2%, 0.68% and 1.4% for 0%, 0.15% and 0.6% respectively.
- It was recommended that the increased replacement of fine aggregate by EPS shows significant reduction in the thermal properties.

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