Structural Engineering and Mechanics, *Vol. 63, No. 2 (2017) 217-223*
DOI: https://doi.org/10.12989/sem.2017.63.2.217

Formulation of an alternate concrete mix for concrete filled GFRG panels

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(Received August 10, 2016, Revised November 6, 2016, Accepted December 26, 2016)

Abstract. Glass fiber reinforced gypsum panels (GFRG) are hollow panels made from modified gypsum plaster and reinforced with chopped glass fibers. The hollow cores of panels can be filled with in-situ concrete/reinforced concrete or insulation material to increase the structural strength or the thermal insulation, respectively. GFRG panels are unfilled when used as partition walls. As load bearing walls, the panels are filled with M 20 grade concrete (reinforced concrete filling) in order to resist the gravity and lateral loads. The study was conducted in two stages: First stage involves formulation of the alternate light weight mix by conducting experimental investigations to obtain the optimum combination of phosphogypsum and shredded thermocol. In the second stage the alternate mixes are filled in GFRG panels and experimental investigations are conducted to compare the performance against panels filled with conventional M 20 mix.

Keywords: hollow panels; phosphogypsum; shredded thermocol; light weight; low cost

1. Introduction

Concrete is considered as the second largest material consumed after water. The popularity of concrete is mainly due to its versatility, general availability of raw materials, good compressive strength and adaptability. The growth in infrastructure has led to the shortage of raw materials for concrete. This paved way to new innovations in concrete. Apart from that the need for sustainable development has led to the development of new eco- friendly building materials. Glass fiber reinforced gypsum (GFRG) panel is an eco friendly product. These panels can be used as alternative building material to replace bricks or concrete blocks. They are also known as rapid walls/gypcrete. They are machine made hollow panels. It was first developed in Australia and used since 1990. A lot of research works were conducted (Wu 2004, Wu and Mike 2004, Janardhana *et al*. 2006, Wu 2009) and it is has been found that the panels when filled with plain/ reinforced concrete possess suitable strength to act as load bearing and shear walls. These panels can also be filled with various materials like insulation materials to provide thermal and sound insulation to the walls. The glass fibers used in the production of panels are about 300-350 mm and the fiber volume is 0.8 kg/m^3. The glass fibers are randomly distributed in the panel skins and ribs. Presently the panels are manufactured to a length of 12 m, a thickness of 124 mm, and a height of 3 m. Although its main application is in the construction of walls, it can also be used in floor and roof slabs in combination with reinforced concrete (Menon and Meher 2013). Various researches have been conducted by IIT Madras (Structural Design Manual 2013) and they have developed a structural design manual for conducting the design of buildings made with GFRG.

Phosphogypsum is an industrial by-product of phosphate fertilizer production from phosphate ore or fluorapatite (Gawatre 2013). About 15% of phosphogypsum produced is being utilized in the manufacture of fertilizers, building materials, soil stabilization agent etc. The rest of the phosphogypsum is being discarded in the vicinity of factories without any treatment and this can cause serious environmental damage. In India, Phosphogypsum is currently being disposed into open sandy yards or in ponds close to the plants in the form of slurry made by pumping phosphogypsum with sufficient quantity of water. After percolation and drying, the phosphogypsum is stockpiled for future use (Bhatia and Rajesh 2006). So it is an important matter to find an alternative method for making use of this phosphogypsum so that the wastage of land and environmental pollution can be reduced.

Thermocol is the expanded form of polystyrene. It is also known as expanded polystyrene (EPS). It is widely used in the packing industry, model and craft industry as well as in construction and insulation industry. Due to its extremely low density it can be used as light weight aggregates. However, EPS lightweight concrete has not been used for structural concrete because of its generally low strength (Kan and Ramazan 2009) but it can be used in the production of non structural members or as an infill in prefabricated panels. According to statistics, on a volume basis, EPS forms nearly 7% of solid waste in landfills in some countries (Kekanović *et al*. 2014). Being a non-biodegradable material, EPS contributes significantly to the pollution of the environment. This has led to the need of reuse and recycle of thermocol. Since it occupies a lot of volume it can be shredded into coarse as well as fine particles and reused. Usually polystyrene concrete is being

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http://www.techno-press.com/journals/sem&subpage=7 ISSN: 1225-4568 (Print), 1598-6217 (Online)

Fig. 1 Phosphogypsum

Fig. 2 Shredded Thermocol

made using expanded polystyrene beads. But the waste EPS/ shredded thermocol can also be used in the production of light weight concrete. These shredded thermocol can be used either as such or their properties can be modified for the usage of light weight concrete production. Kan and Ramazan (2009) and Herki *et al.* (2013) modified the properties of waste EPS and used it in the production of light weight concrete.

Geethu and Renjith (2015) have conducted experiments on formulating a light weight concrete mix using expanded polystyrene (EPS) beads for concrete filled glass fiber reinforced gypsum panels. But EPS beads are finished product rather than a waste material. Therefore this study focuses on the use of shredded thermocol in lieu of EPS beads for partial replacement of fine aggregates and phosphogypsum for partial replacement of cement thereby striving for a possible alternative to deal with these two materials and at the same time attempting to formulate an alternate light weight concrete mix.

2. Scope of work

The effective utilization of phosphogypsum is done by the manufacture of Glass Fiber Reinforced Gypsum (GFRG) panel, also known as Rapid wall. These can be used as load bearing as well as non load bearing structures. While using it as load bearing structures, it is being filled with M 20 grade concrete so as to resist the gravity and lateral loads. M20 grade concrete is used in these panels in order to satisfy the minimum requirements stipulated in IS 456 (2000). In this work, phosphogypsum and shredded thermocol are used as partial replacement of cement and fine aggregates respectively and formulating an alternate light weight mix equivalent in strength to that of M 20 grade concrete. Experimental investigations are conducted by varying the percentages of phosphogypsum and shredded thermocol. In the second stage, the trial mixes were filled in GFRG test specimen and compared with GFRG specimens filled with conventional concrete.

3. Materials and properties

The materials used in making concrete mixes include

Table 1 Properties of shredded thermocol

Sl. No	Particulars	Description
1	Appearance	White Emulsion
2	Specific gravity	0.033
3	Compatibility	Can be used with all types of Portland cement

Table 2 Properties of Superplasticizer

Sl. No	Properties	Values
1	Supply form	Liquid
2	Colour	Brown
3	Specific Gravity	1.2
4	Chloride content	Free

Ordinary Portland cement, fine aggregate, coarse aggregate, phosphogypsum, shredded thermocol, water and superplasticizer. Their properties are tested according to the relevant IS codes.

Cement: Ordinary Portland cement of grade 43 affirming to IS 8112 (2013) is used. The cement is tested for various properties as per IS 4031 (1967). The different properties of cement are: specific gravity- 3.2, normal consistency- 33%, initial setting time-60 minutes and final setting time- 360 minutes.

Fine Aggregate: M sand was used as fine aggregate. Tests were conducted on fine aggregate as per IS 2386 (Part III) (1963). Different properties of M sand are: fineness modulus- 2.67, Zone of aggregate- Zone II and specific gravity- 2.61.

Coarse Aggregate: In the construction of GFRG panels, coarse aggregate used is having a maximum size of 12.5 mm. The properties of coarse aggregate are: specific gravity- 2.67, fineness modulus- 6.901 and bulk density- 1.531.

Phosphogypsum: Phosphogypsum used was obtained from FACT-RCF building products Ltd, Kochi, Kerala and is shown in Fig. 1.

Shredded thermocol: It is obtained by shredding the polystyrene waste. Shredding machine with dust separator is used to shred the rejected thermocol scrap. The shredded thermocol was obtained from Mane Electricals, Pune and is shown in Fig. 2. The properties of shredded thermocol are shown in Table 1.

Table 3 Mix proportioning

Mix	Cement	Water (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	w/b ratio
M 20	384	200	679	1041	0.52
M_R	384	160	792	1078	0.41

Table 4 Mix Proportions of Various Percentages of Phosphogypsum

Mix	PG (%)	Cement (kg/m^3)	PG (kg/m^3)	Fine Aggre-gate (kg/m^3)	Coarse Aggre-gate (kg/m^3)
M_R	0	384	0	792	1078
$M_{R\ 2.5}$	2.5	374.4	9.6	792	1078
$M_{R\ 5}$	5	364.8	19.2	792	1078
$M_{R\ 7.5}$	7.5	355.2	28.8	792	1078
$M_{R\ 10}$	10	345.6	38.4	792	1078

where, M_{RX} refers to reference mix with x% replacement of phosphogypsum

Superplasticizer: Water reducing plasticizer SP Cera Plast 300 is used to optimize the workability, water cement ratio and hence the strength. About 20- 25% water reduction can be obtained while using it. It exhibits excellent workability. The properties of superplasticizer are given in Table 2.

4. Experimental procedure

4.1 Mix proportioning.

A control mix corresponding to M 20 grade was prepared and tested to satisfy the codal requirements (IS 10262 2009). Superplasticizer Cera Plast 300 was used to reduce the w/c ratio by 20% without adversely affecting the workability of the mix. This mix possesses slightly high strength characteristics compared to the M 20 mix and is considered as the reference mix (MR) for the further experiments. The details of mix proportioning of concrete is shown in Table 3.

4.2 Partial replacement of cement with phosphogypsum

The reference mix is then modified by partially replacing cement with phosphogypsum at varying percentages - 2.5%, 5%, 7.5%, 10%. Partial replacement of phosphogypsum is limited to 10% since after this point the minimum cement content criteria stipulated in IS 456 (2000) cannot be satisfied. Phosphogypsum is replaced in terms of weight. The details of mix proportioning of partial replacement of cement with phosphogypsum (PG) is shown in Table 4.

4.3 Partial replacement of fine aggregate with shredded thermocol

Table 5 Partial replacement of cement and fine aggregate with shredded thermocol

Mix	Cem-ent (kg/m^3)	PG (kg/m^3)	Fine Aggre-gate (kg/m^3)	ST (kg/m^3)	Coarse aggre-gate (kg/m^3)
M_R	384	0	792	0	1078
$M_{R\ 10,0}$	345.6	38.4	792	0	1078
$M_{R10,5}$	345.6	38.4	752.4	0.50	1078
$M_{R\ 10,10}$	345.6	38.4	712.8	1.00	1078
$M_{R\ 10,15}$	345.6	38.4	673.2	1.50	1078
$M_{R\ 10,20}$	345.6	38.4	633.6	2.00	1078
$M_{R\ 10,25}$	345.6	38.4	594	2.28	1078

Table 6 Details of test specimens

Sl. No	Specimen	Size (mm)
1	Cube	150×150×150
2	Beam	100×100×500
3	Cylinder	150×300
4	GFRG	300×300×124

Fig. 3 Test specimens prepared

The mix with optimum percentage of phosphogypsum is then used to find the optimum percentage of shredded thermocol which can be used for partial replacement of fine aggregate. Fine aggregate is partially replaced with 5%, 10%, 15%, 20% and 25% of shredded thermocol and experimental investigations are continued. Shredded thermocol is replaced in terms of volume. The details of mix proportioning of partial replacement of fine aggregate with shredded thermocol (ST) is shown in Table 5.

4.4 Testing of specimens

In first part of the experimentation the concrete specimens were tested. The fresh and hardened properties of the specimens were tested. Workability was tested by compaction factor test. The strength parameters such as compressive strength, flexural strength and split tensile strength were tested. In the second stage the GFRG specimens were filled with alternate concrete mixes and tested. The strength parameters of GFRG specimens were determined by doing compression test on panels of size 300 mm×300 mm×124 mm. Also the density of concrete cubes and panels were noted. The details of the test specimens are

Fig. 4 GFRG panels

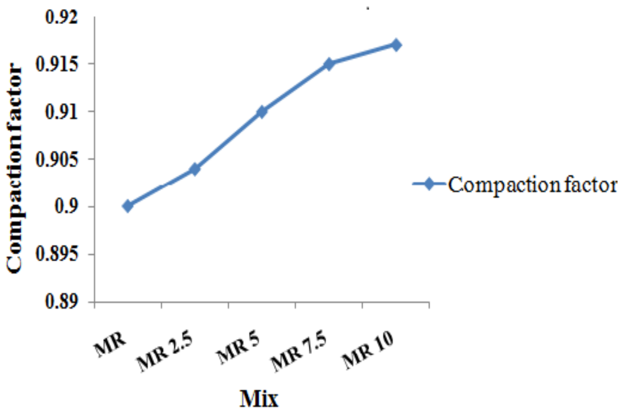

Fig. 5 Compaction factor for different percentages of phosphogypsum

furnished in Table 6. Fig. 4 shows GFRG panels used for testing. The specimens used for testing are shown in Fig. 3.

5. Results and discussions

5.1 Workability

The workability of various mixes was assessed as per IS 1199 (1959) specification. Compaction factor test was done. The results of workability test for various percentage replacements of cement and fine aggregates with phosphogypsum and shredded thermocol are shown in Figs. 5 and 6.

An increase in workability of the mix was observed with the addition of phosphogypsum and a decrease in workability was obtained with the addition of shredded thermocol. The decrease in workability is due to the increase in air voids.

5.2 Compressive strength of concrete cubes

The compressive strength of cubes was tested according to IS 516 (1959). The compressive strength of mixes with replacement of cement with phosphogypsum is given in Fig. 7. A gradual increase in strength is observed up to 5% replacement of cement with phosphogypsum, followed by a decrease. The optimum percentage of phosphogypsum was evaluated based on two criteria: maintaining minimum

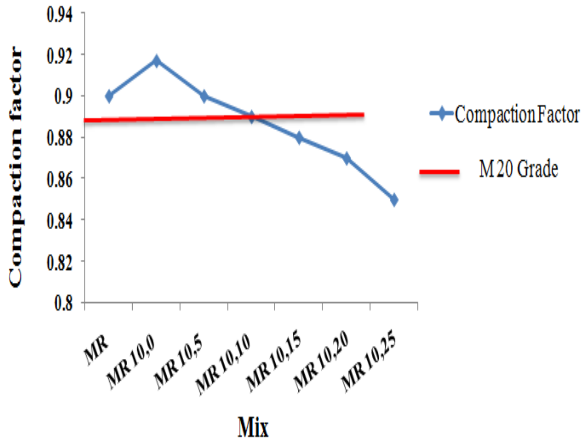

Fig. 6 Compaction factor of concrete with different percentages of shredded thermocol

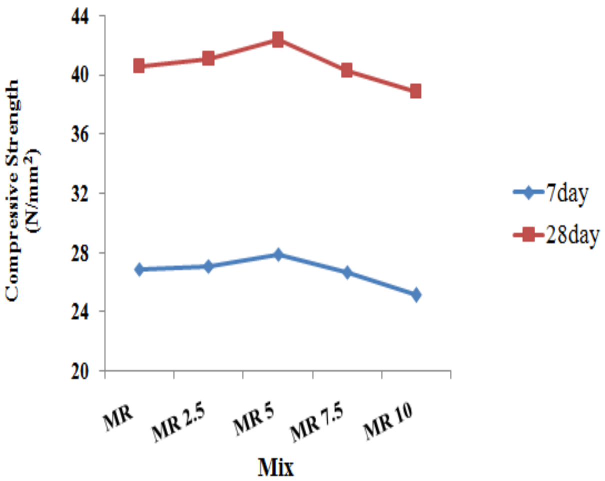

Fig. 7 Compressive strength of concrete with varying percentage of phosphogypsum

cement content and obtaining target mean strength (M 20). Even though a strength reduction is observed above 5% replacement of cement the above criteria are satisfied up to 10% replacement of cement. Hence 10% is taken as the optimum percentage of phosphogypsum which can be added to partially replace the cement.

The variation in cube compressive strength for the concrete mix with various percentages of phosphogypsum and shredded thermocol (replacing fine aggregate) is furnished in Fig. 8. The cubes were tested to determine the 7th, 28th, 56th and 90th day compressive strength. It was observed that the compressive strength decreased as the percentage of shredded thermocol was increased but the replacement till 20% showed strength greater than the target mean strength (26.67) of M 20 grade concrete mix.

5.3 Split tensile strength

The results of split tensile strength are shown in Fig. 9. Addition of shredded thermocol to the concrete results in the reduction in strength of concrete for all the mixes. Though the split tensile strength reduced with the addition of shredded thermocol to the concrete, the values exceeded

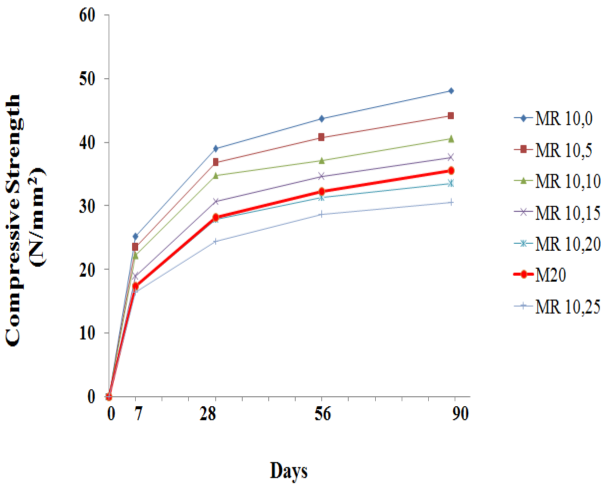

Fig. 8 Compressive strength of GFRG panels

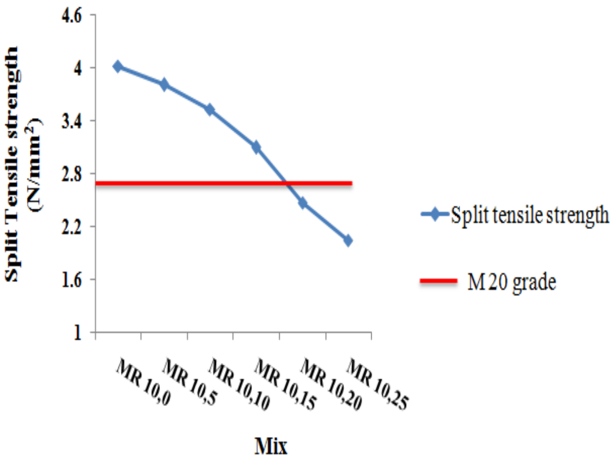

Fig. 9 Split Tensile strength for different mixes

Fig. 10 Cross section of cylinder after split tensile test

that of M 20 grade concrete up to the addition of 15% of shredded thermocol. The cross section of a cylindrical specimen after split tensile test is furnished in Fig. 10.

5.4 Flexural strength

Flexural strength also decreases with the addition of shredded thermocol. The results of flexural strength obtained are shown in Fig. 11.

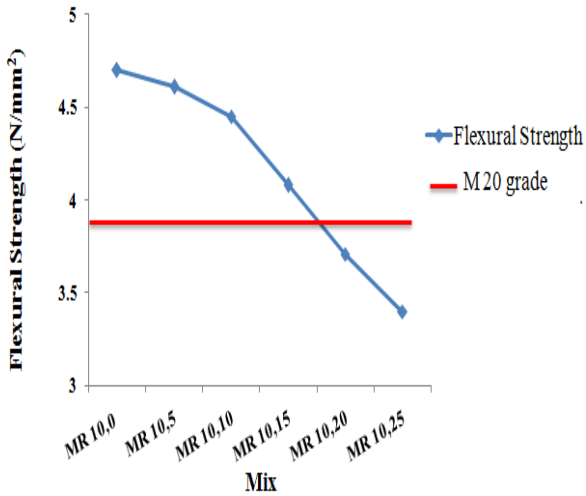

Fig. 11 Flexural strength for different mixes

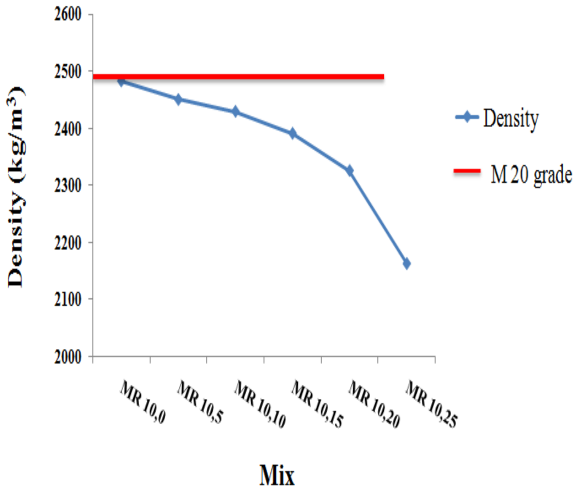

Fig. 12 Density of concrete mixes

5.5 Density of concrete cubes

Density of concrete prepared using various percentages is illustrated in Fig. 12. The density of concrete cubes decreases with the addition of shredded thermocol since the shredded thermocol is light in weight.

5.6 Compressive strength of GFRG panels

The compressive strength of concrete filled GFRG panels decreased with the addition of shredded thermocol to the concrete. Fig. 13 shows the typical failure pattern of concrete filled GFRG test specimen under uniaxial compression.

The variation in compressive strength of GFRG panel for the concrete mix with various percentages of phosphogypsum and shredded thermocol is furnished in Fig. 14.

The reason for failure of panels as shown in Fig. 13 is due to the weak connection existing between bottom flange and web of GFRG panels. During the process of manufacturing the panels the glass fibers are laid over the aluminum plug (which serves as a provision for providing

Fig. 13 Crack pattern of GFRG panel

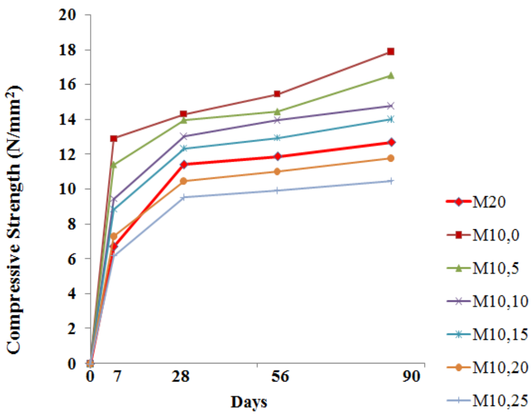

Fig. 14 Compressive strength of GFRG panels

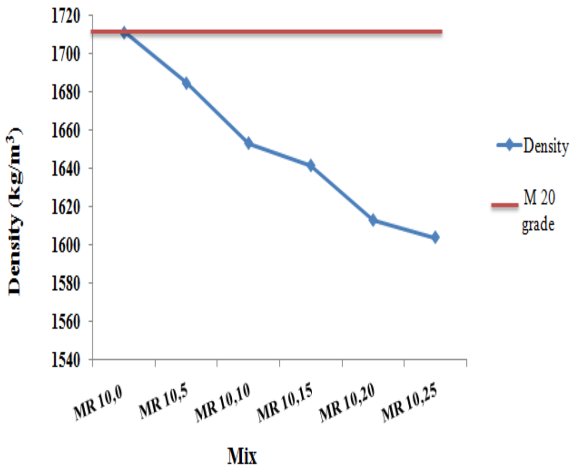

Fig. 15 Density of concrete mixes

Table 7 Cost comparison

Mix	Cement (kg/m³)	Phosphogypsum (kg/m³)	Fine Aggregate (kg/m³)	Shredded Thermocol (kg/m³)	Coarse aggregate (kg/m³)	Cost ($)
M20	384	0	679	0	1041	66.35
M_R	384	0	792	0	1078	70.88
$M_{R\,10,0}$	345.6	38.4	792	0	1078	65.97
$M_{R\,10,5}$	345.6	38.4	752.4	0.50	1078	65.46
$M_{R\,10,10}$	345.6	38.4	712.8	1.00	1078	64.98
$M_{R\,10,15}$	345.6	38.4	673.2	1.50	1078	64.48
$M_{R\,10,20}$	345.6	38.4	633.6	2.00	1078	63.99
$M_{R\,10,25}$	345.6	38.4	594	2.28	1078	63.50

hollow cavities in GFRG panels). Then tamping rods with cutting edges are used to tamp the glass fibers to the rib portion so as to ensure the continuity of glass fibers in GFRG panels. But the fibers inserted in such a manner create an improper bonding between the bottom flange and web of GFRG panels.

5.7 Density of GFRG panels

The density of GFRG panels were noted to find out the reduction in weight .Density of GFRG test specimens filled with alternate concrete mixes is illustrated in Fig. 15. The density of panels decreases with the addition of shredded thermocol to the concrete mixes.

5.8 Cost comparison

The cost of materials for one cubic meter of concrete for different mixes is given in the Table 7. It can be observed that the cost of the reference mix is higher than that of M 20 grade concrete and when phosphogypsum partially replaces cement the cost of the mix is reduced. Further the replacement of fine aggregate with shredded thermocol has also reduced the cost of the subsequent mixes. Reduction in cost by 4.29% was observed up to 25% of replacement of fine aggregate.

6. Conclusions

- Optimum percentage of phosphogypsum which can be used as partial replacement of cement to formulate a mix equivalent to M 20 grade is observed to be 10% as per the obtained results.
- Though the strength characteristics and workability of the concrete mix decreased with the addition of shredded thermocol, the results were found to be equivalent or greater than M 20 mix up to 15% replacement of fine aggregate with shredded thermocol.
- Therefore mix with 10% phosphogypsum and 15% shredded thermocol as partial replacement of cement and fine aggregate respectively can be used as an alternative to M 20 grade concrete.
- The alternate mix thus formulated was found to be 3.9% lighter than the conventional M 20 grade mix and there is a direct reduction in cost by 2.8%, in addition to the reduction in structural load due to the reduced self weight.

• GFRG specimens filled with alternate mix formulated in stage 1 yielded better result when compared to that filled with M 20 grade concrete.

• The reduction in density of the alternate mix resulted in a proportional reduction in density and cost of the alternate mix resulted in a proportional reduction in density and cost in case of GFRG test specimens filled with alternate mix.

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