International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.8, No.2, pp 519-523, 2015

Compressive Strength of High Performance Light Weight Concrete made with Air Entraining Agent and Expanded Clay

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Abstract: High Performance Lightweight Concrete (HPLWC), could be considered as a combination of high performance concrete and structural lightweight concrete. In the present work HPLWC was produced by two ways. One was using air entraining agent and the other was using light weight aggregate (expanded clay). In the former case, air entraining agent was added as additive in different percentages and in the later case the coarse aggregate was partially replaced with different percentages of expanded clay as light weight aggregate. In both the mixes, cement was replaced partially with ground granulated blast furnace slag (GGBFS) and Metakaolin (MK) in two different percentages. In total there were eight different combinations of mixes were studied at three different ages of concrete namely 7, 14 and 28 days of concrete. Among the different mixes prepared, compressive strength of concrete with 0.4% air entraining agent with 10% metakaolin and 30% GGBFS yielded better compressive strength. Similarly, when expanded clay of 25% used as light weight aggregate with 12% metakaolin and 28% GGBFS gave the better results. Comparing results of both, HPLWC produced with air entraining agent found to be better than that of concrete produced with light weigh aggregates.
Keywords: High Performance Light Weight Concrete, GGBS, Metakaolin, Expanded Clay compressive strength.

Introduction

Concrete is the most used material for construction in India. Many high raised buildings are evolved in recent years which increase the usage of High Performance concrete (HPC). In general the density of HPC is high which increases the dead load of superstructure. The compressive strength of HPC lies in the range 60 - 100MPa.and the density of HPC is in the range of 2500- 2700kg/m^3 [1]. The one or more parameters of concrete are supreme then the concrete is said to be HPC. In order to reduce the density of concrete it is suggested to use High Performance Light Wight Concrete (HPLWC).

The high performance of concrete can be achieved by replacing partially of cement with mineral admixtures like Metakaolin (MK), Ground Granulated Blast Furnace Slag (GGBS). By using these mineral admixtures leads to lowering the global warming [2-5].

Lightweight concrete (LWC) can attained by lowering the density of concrete bye replacing coarse and fine aggregates with locally available natural or artificial light weight aggregates like Pumice, Perlite, Scorcia, Expanded Clay, Fly ash, etc.. By expanding the clay at 1200° C, the expanded clay is obtained. The gases in the clay are expanded at this high temperature results to create many voids in the aggregates which leads to decrease in the weight aggregates[6-10]. The another way to produce LC is by adding Air-Entraining Agent (AEA) which is referred as lightweight aerated concrete. The AEA develops the number of micro air pockets of less than 2mm diameter which reduces self-weight and also more durable at secure weather conditions. This MK was produced by calcining the kaolin clay at high to dismiss the water bond with kaolin crystalline structure. Several studies results that when Mk is added with cement which increases the compressive strength when compared with normal concrete. As per studies optimum replacement of Mk will around 5-15%[8, 11].

The addition of GGBS makes concrete more durable, due to its lower setting time the heat of hydration is lowered. GGBS contains silicates and alumino-silicates of calcium and is a by-product of iron manufactured in a blast furnace. The GGBS can be replaced with cement up to 10-50%.

The present study deals with compressive strength of HPLWC. The different mixes of concrete with two different percentages of MK of 10 and 12% and GGBFS of 28 and 30% respectively were used as replacer for cement. On the other side the coarse aggregates was replaced with two different percentages of expanded clay namely 25 and 30% in the above mixes. The AEA was added to concrete of 0.4% and 0.5% as per the guidelines. The 7, 14 and 28 days compressive strength was found for the above different mixes.

Experimental Investigations

Materials and Methods

Ordinary Portland Cement (OPC) of ASTM Type I[12] and ground granulated blast furnace slag (GGBFS) obtained from near by steel industries were used in the present work. Fine aggregate used was river sand. The specific gravities of cement, GGBFS and MK were found to be 3.1, 2.81 and 2.7 respectively. Similarly, the specific gravity of fine aggregate and coarse aggregate was found to be 2.65 and 2.7 respectively. Specific gravity of coarse aggregate was done using wire basket method as per ASTM C 127[13]. The mix design was done as per the guidelines of ACI 211.1[14] to get concrete with a characteristic compressive strength of 70 MPa and the corresponding mix proportion was 1:1.69:2.03 [Binder (cement + MK + GGBFS): Fine aggregate: Coarse aggregate] with a w/b ratio of 0.33. Use of high range water reducer reduced the w/c ratio from 0.36 to 0.33 and the workability was verified with slump cone test according to ASTM C143[15]. The air entraining agent was used in two different percentages of 0.4 and 0.5 to assess the effect of AEA on strength of light weight concrete. Coarse aggregate was replaced with two different percentages of LWA namely expanded clay (25 and 20%). The details of mixes are given in Tables 2 and 3. To cast the concrete specimens following procedure was adopted: High range water reducer and AEA was added with water and stirred for a minute to have homogeneity. Then dry mix of cement, MK and GGBFS were mixed. Then sand was added to the fine mix and dry mortar mix was prepared. Prepared mix was added with coarse aggregate. After preparation of dry mix, water was added with required quantity to get a desired workability.

Cube specimens were cast with a size of 100 mm x 100 mm x 100 mm to test at different ages of concrete as per BS 1881[16]. For testing compressive strength of concrete, a total number of 81 specimens were cast [3 ages x 9 combinations of mixes x 3 numbers of specimen]. Compressive strength of concrete at the ages of 7, 14 and 28 days were tested to understand the effect of age of concrete. The test to assess compressive strength was conducted using digital compression testing machine of 3000 kN capacity with 200 kN/min as rate of loading.

Table 1: Material composition of AEA mixes

Mix	Cement (%)	Metakaolin (%)	GGBFS (%)	Air Entraining Agent (%)
M10S30A0.4	60	10	30	0.4
M10S30A0.5	60	10	30	0.5
M12S28A0.4	60	12	28	0.4
M12S28A0.5	60	12	28	0.5

Table 2: Material composition of LWA mixes

Mix	Cement (%)	Metakaolin (%)	GGBFS (%)	Expanded Clay (%)
M10S30E25	60	10	30	25
M10S30E20	60	10	30	20
M12S28E25	60	12	28	25
M12S28E20	60	12	28	20

Results and Discussion

Characterization of Materials Used

XRF

The chemical composition was obtained by X-Ray Fluorescence test using XRF-analyzer of model Tiger 88 to determine major and trace elements in solids. Table 3 shows the main elements (expressed as oxides) present in cement, GGBFS and MK. Cao and Silica (SiO_2) constituted 75 percentages and were the major components in slag, followed by Al_2O_3 and MgO with 12 and 10% respectively. All the other components constituted only 3%. In the case of MK, composition dominated by SiO_2 and Al_2O_3 with 94.5% and remaining components was found to be only 5.5%. CaO and MgO were found to be very less in MK.

Table 3: Chemical composition of Cement, GGBHS and Metakaolin

Oxide Component (%)	OPC	GGBS	Metakaolin
CaO	62.8	40	0.8
Fe_2O_3	3.9	0.2	1.6
Al_2O_3	5.4	12	40.8
SiO_2	20.3	35	53.7
Na_2O	0.14	0.1	0.18
MgO	2.7	10	0.3
K_2O	0.53	0.11	0.11

Variation of mass due to air entraining agent and expanded clay

The mass of the control specimen (without AEA and expanded clay as light weight aggregate) was found to be 2.538 kg and gets reduced due to the addition of AEA. When AEA was added with 0.4% in the concrete with 10% MK and 30% GGBFS was found to be 2.174 kg and about 14% reduction with control concrete. The mass of concrete was about 2.183 kg for AEA with 0.5% addition and was slightly more than the earlier case. Similar trend was observed for concrete with 12% MK and 28% GGBFS. The mass of concrete with cement replacement with GGBFS + MK and coarse aggregate replacement with expanded clay ranges from 10 to 12% reduction compared to control concrete. Comparing mass of control concrete with HPLWC, AEA was effective in reducing the mass and give better results in terms of compressive strength of concrete.

Compressive strength

Effect of Air Entraining Agent

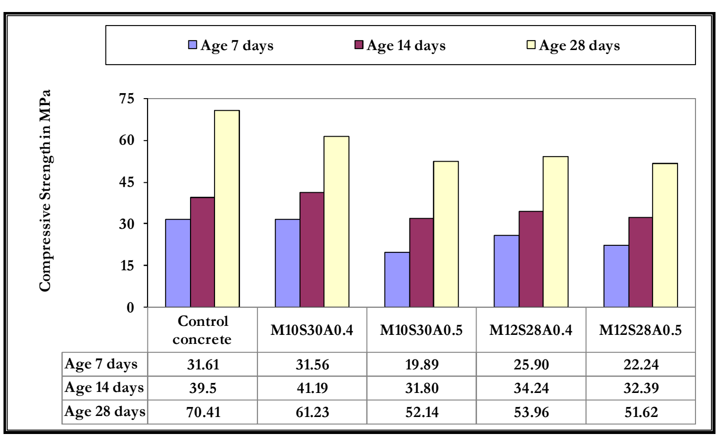

Figure 1 Effect of Air Entraining Agent on compressive strength

The variation of compressive strength due to addition of air entraining agent for different ages of concrete was depicted in Figure 1 to understand the effect of age of concrete. Increase in age of concrete increases compressive strength. At the age of 28 days, control concrete yielded 70 MPa. For mixes with 10%

MK and 30% GGBFS as replacement for cement with 0.4% AEA gave 61.23 MPa and for concrete with 12% MK and 28% GGBFS with same 0.4% AEA was found to be 52.14 MPa. Similar trend was observed for other mixes with increase in AEA of 0.5%. Hence it was understood that increase in AEA beyond 0.4% made further reduction compressive strength of concrete. Around 13% of compressive strength got reduced due to addition of 0.4% AEA, which was very much acceptable if we are going to light weight sections. The rate of reduction of compressive strength increases further for AEA = 0.5 % and increased content of MK from 10 to 12%. The reduction went upto 27% for other cases and hence concrete with 10% MK and 30% GGBFS and AEA with 0.4% was found to be optimum values. In the above case cement was replaced about 40% and hence total cost per unit quantity will be reduced.

Effect of Expanded Clay as light weight aggregate

The variation of compressive strength due to replacement of coarse aggregate with expanded clay as light weight aggregate for different ages of concrete was depicted in Figure 2 to understand the effect of age of concrete. Use of expanded clay as light weight aggregate gave lesser compressive strength at all the ages of concrete irrespective the combination of mix compared to control concrete. Concrete with 25% expanded clay gave slightly higher compressive strength than that of concrete with 20% expanded clay. The rate of reduction compared to control concrete was about 33% and 35% for LWA with 25% and 20% respectively in concrete with 10% MK and 30% GGBFS. The rate of reduction comes down to 26% and 30% for LWA with 25% and 20% respectively in concrete with 12% MK and 28% GGBFS. Similar trend was observed in earlier age of concrete also.

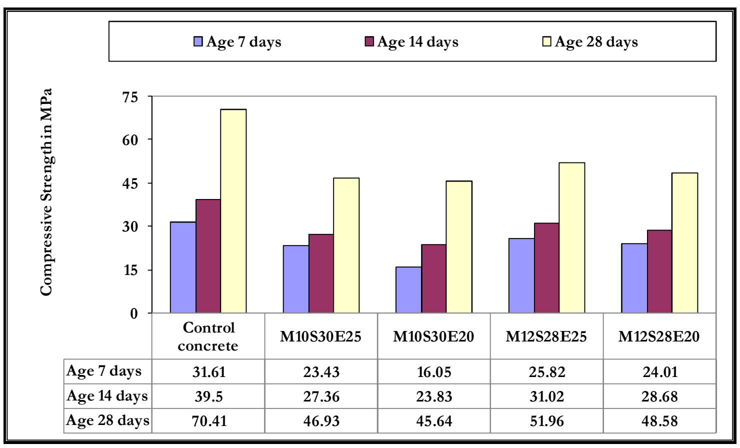

Figure 2 Effect of Light Weight Aggregate on compressive strength

Conclusions

From the experimental investigations conducted on concrete with air entraining agent and expanded clay to produce high performance light weight concrete on its compressive strength, following were the conclusions:

- A reduction of compressive strength of 13% only was observed in high performance light weight concrete with air entraining agent with 0.4%. This reduction of 13% was acceptable in the field ensuring the reduction in weight of the concrete. In this mix cement was replaced with MK and GGBFS to an extent of 40%, which will reduce the overall cost of concrete per unit quantity.
- Higher reduction was observed in compressive strength when light weight aggregate (expanded clay) used as partial substitute to coarse aggregate irrespective of its percentage. Maximum reduction of 35% was observed. Use of 25% of expanded clay as LWA with 12% MK and 28% GGBFS yielded 26% reduction in compressive strength compared to control concrete. Hence when CA to be replaced with LWA, 25% may be permitted.
- Resistance for sulphate attack and acid attack was found to be more in nano slag based concrete and also found that nano slag based concrete offered better resistance against acid attack compared to resistance against sulphate attack. The resistance of nano slag concrete in aggressive environment was found to be 26% less than concrete in normal environment.

- It is suggested that, if concrete with a characteristic compressive strength of 60 MPa is required in the field mix design to be done for 70 MPa when high performance light weight concrete produced with air entraining agent. Similarly for the concrete with expanded clay used as partial substitute to coarse aggregate, mix design to be done for 70 MPa to get a compressive strength of 50 MPa.

Acknowledgements

The authors would like to thank the Vice Chancellor of SASTRA UNIVERSITY for the providing experimental facilities in the School of Civil Engineering to do this research work and also for the continuous support and encouragement given throughout this research work.

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