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Packing Models and Proportioning Methodology for Fly Ash-Metakaolin Light Weight Aggregate Concrete

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Abstract: This paper investigates on production technology and concrete proportioning methods for lightweight aggregate concrete containing fly ash-metakaolin material. The aggregates were cured in different curing regime such as water curing and hot air oven curing at 100°C. An empirical formula was developed to arrive at the mixture proportions of lightweight aggregate concrete (LWAC). The important factors considered for the selection of mixture proportions were volume of coarse aggregate (%), volume of mortar (%) and pre-wetting of aggregates in the mixture. The concrete specimens were casted with various volume proportions of coarse aggregate (20, 30 and 40%). Theoretical packing models were developed to determine the proportions of the concrete mixtures. Concrete test specimens were casted for determination of the compressive strength and split tensile strength. The maximum compressive strength of fly ash alkali activated aggregate concrete was found to be around 27.4 MPa which satisfies the minimum strength requirement of structural lightweight aggregate concrete.

Key words: Fly ash · Lightweight aggregate concrete · Metakaolin · Packing model · Pelletization

INTRODUCTION

The focus on use of alternative materials in construction is on high demand due to the limited availability of natural resources and hence a better insight is needed for the production of artificial lightweight aggregates for the concrete production. The lightweight aggregate materials used in concrete production such as cold-bonded fly ash aggregate, sintered aggregate, expanded clay, solid sludge waste etc. In many cases, natural and artificial lightweight concrete have the same properties. Pumice lightweight aggregate was formed from the volcanic eruption, used to development structural lightweight aggregate concrete [1]. Another type of lightweight aggregate was produced using expanded glass aggregates in concrete. the compressive strength of expanded glass aggregate are increase (87%) the lies the density range between 1200-1550 kg/m^3 and compared to higher density range 2200-2450 as 58% [2]. Many research studies investigated towards developing the cost effective method for producing artificial lightweight aggregate using fly ash at low energy consumption. Hence to increase the strength properties of concrete various type of lightweight aggregate were investigated when constant water cement ratio and the cement content increases from 300kg/m^3 to 450 kg/m^3 [3]. Various curing process exist such as cold bonded fly ash lightweight aggregate concrete such as water curing, steam curing, autgenous curing mist curing, sealed curing and air curing [4]. Influence of autogenous curing on compressive strength of cold bonded aggregate concrete had shown marginal effect. According to the unit weight of concrete value must be 1551 to 2314 kg/m^3, the size and shape effects of artificial lightweight aggregates on concrete compressive strength were investigated. The compressive strength of lightweight aggregate concrete using expanded shale achieved 66.5 MPa at 365 days [5]. However, the models for the size effects were based on the crack band theory of fracture mechanics, which depends on the aspect ratio, lateral depth of the specimen and unit weight of concrete [6]. The improvement in concrete to incorporate 20% pozzolan had higher compressive, split tensile, flexural strengths than the controlled concrete [7]. The stress transfer in normal weight aggregate concrete, which contains more rigid aggregates than mortar, failure occur through the aggregates and intermediate layers of mortar [8]. This paper aims to describe the standard mix design procedure

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adopted for designing a lightweight aggregate concrete. Experimental work was carried out to examine the mechanical properties of various fly ash lightweight aggregate concrete containing metakaolin.

MATERIALS AND METHODS

Materials Used: Two different types of fly ash based lightweight aggregates were produced in the disc pelletizer machine. Class–F fly ash and metakaolin were used as the raw materials for the production. The physical and mechanical properties of materials used for the lightweight aggregate concrete are given in Table 1. The disc machine is set at an angle of 36° and the speed of disc rotating was kept at 55 rpm. Initially the fly ash and metakaolin binder are mixed in the disc machine and water is sprayed at 25% by the weight of total binder in the disc pelletizer. The formation of aggregate pellets was improved with the addition of sodium hydroxide (10 and 12M) and a good bonding effect was realized during the pelletization process. The important factor was considered for improving the strength of aggregate such as pelletization duration, speed and angle of the disc (Figure 1).

Preparation and Curing of Lightweight Concrete: The various mix proportions of fly ash lightweight aggregate concrete are given in Table 2. In lightweight aggregate concrete additional water is required for obtaining the desired level of workability. Lightweight fly ash aggregate was first immersed in water for 30 minutes for the initial saturation of the surface. Concrete was mixed in a laboratory pan mixer and the saturated-surface dry lightweight aggregate was mixed with the Portland cement and fine aggregate. Concrete specimens were casted in three 100 mm size cubes for compressive strength as well as 100 mm diameter by 200 mm height cylinder for split tensile strength as shown in Figure 2.

Method of Concrete Testing: The LWAC testing was carried out on the compressive strength and split tensile strength of concrete (Figures 3 and 4). The density of concrete was measured at 1, 3, 7 and 28 days (wet), 3 days (oven curing at 100°C), 7 days (oven curing at 100°C) and 28 days (7 days oven at 100°C and 21 days dry at room temperature). Compressive strength of concrete was tested at 3, 7 and 28 days on cubes cured with two different curing such as water curing and hot air oven curing at 100°C. The split tensile strength was determined at 7 and 28 days on cylinder cured with water curing and hot air oven curing at 100°C.

Table 1: Physical and chemical properties of various materials

Observation	Fly-ash-class F	Cement	Metakaolin
Specific gravity	2.1	3.13	2.52
Blaine's fineness (m^2/kg)	400	325	800
SiO_2	56.2	18.5	41.4
Al_2O_3	25.8	5.24	30.5
Fe_2O_3	6.8	5.90	1.0
CaO	3.67	60.9	0.3
MgO	1.76	1.10	1.8
SO_3	0.47	1.50	0.9
Na_2O	2.06	-	0.9
K_2O	0.01	-	-
Cl^-	0.52	0.002	-
Loss on ignition	-	0.80	18.16

Fig. 1: Fly ash lightweight aggregate

Fig. 2: Water Curing of casted specimen

Fig. 3: Compressive testing machine

Fig. 4: Split tensile strength of LWAC

Table 2: Mix proportions of different types of LWAC

Mix id	Type of curing	Cement content (kg/m^3)	Sand content (kg/m^3)	Coarse aggregate content (kg/m^3)	W/C ratio	V_{CA} (%)	SP (%)
40MT-WC	Water curing	317.70	635.40	720.00	0.4	40	1.5
40MT-OV	Oven curing	317.70	635.40	720.00	0.4	40	1.5
30MT-WC	Water curing	370.44	741.24	540.00	0.4	30	1.5
30MT-OV	Oven curing	370.44	741.24	540.00	0.4	30	1.5
20MT-WC	Water curing	423.54	847.08	360.00	0.4	20	1.5
20MT-OV	Oven curing	423.54	847.08	360.00	0.4	20	1.5
40FL-WC	Water curing	317.70	635.40	720.00	0.4	40	-
40FL-OV	Oven curing	317.70	635.40	720.00	0.4	40	-
30FL-WC	Water curing	370.44	741.24	540.00	0.4	30	-
30FL-OV	Oven curing	370.44	741.24	540.00	0.4	30	-
20FL-WC	Water curing	423.54	847.08	360.00	0.4	20	-
20FL-OV	Oven curing	423.54	847.08	360.00	0.4	20	-

RESULTS AND DISCUSSION

Compressive Strength of LWAC: The test results on the mechanical properties of LWAC are provided in Table 3 and the distribution of aggregate pellets are shown in Figure 5. The concrete specimen showed aggregate failure which can be seen in Figure 5 and the compressive strength results for different curing methods are shown in Figures 6 to 11. The compressive strength of concrete increased gradually with the decrease in the volume of coarse aggregate percentage in the concrete mixture. The highest compressive strength was obtained in case of concrete containing 20% of fly ash based aggregates of the total volume of the concrete. The strength of 20% fly ash based aggregate showed a higher strength value of 28.83% than 40% fly ash aggregate concretes which is represented in Figures 8 to 9. The strength of alkali-activated aggregate concrete (Figure 11) showed a significant increase up to 40.87% in oven curing compared to water curing.

Fig. 5: Failure occur on the concrete cylinder specimen

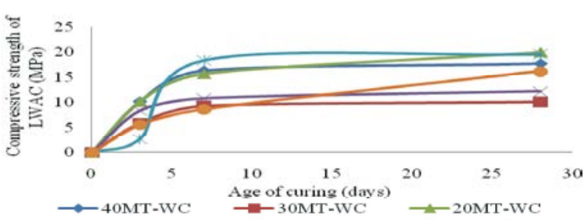

Fig. 6: Compressive strength of LWAC of different days curing at 3d, 7d and 28d (water curing)

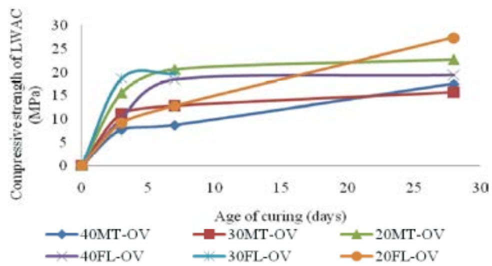

Fig. 7: Compressive strength of LWAC for different ages of curing in Hot air Oven curing at 100°C (3d, 7d and 28d)

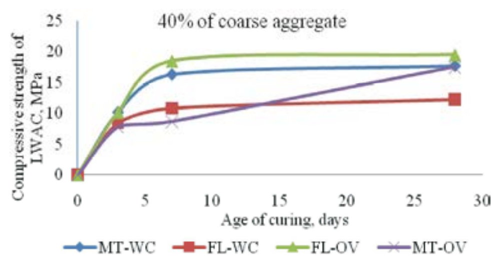

Fig. 8: Comparison for compressive strength of LWAC with 40% of volume of coarse aggregate

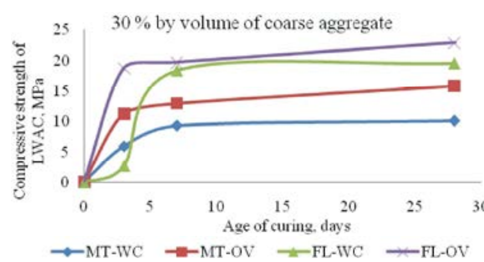

Fig. 9: Comparison for compressive strength of LWAC with 30% of volume of coarse aggregate

Split Tensile Strength of LWAC: The variation of split tensile strength versus volume of coarse aggregate (%) in concrete mixture at 28 days curing is presented in Figure 12. From the test results it can be observed that with a increase in volume of coarse aggregate (%) the split

Table 3: Mechanical properties of different proportion of LWAC

MIX ID	Compressive strength of LWAC, MPa 3 days	7 days	28 days	Split tensile strength of LWAC, MPa 7 days	28 days	Density of LWAC (kg/m^3)
40MT-WC	10.2	16.3	17.7	0.573	0.987	1974.67
40MT-OV	7.8	8.7	17.5	0.732	0.924	
30MT-WC	5.9	9.3	10.1	0.796	1.592	1917
30MT-OV	11.2	12.9	15.8	1.019	1.656	
20MT-WC	10.2	15.7	20	1.210	1.847	2089
20MT-OV	15.6	20.7	22.8	1.369	1.975	
40FL-WC	8.4	10.8	12.2	1.274	-	2024.33
40FL-OV	10.2	18.5	19.5	1.115	-	
30FL-WC	2.7	18.4	19.6	1.242	1.947	2113.67
30FL-OV	18.7	19.7	22.9	1.783	2.006	
20FL-WC	5.6	8.7	16.2	1.975	2.166	2089
20FL-OV	9.2	12.8	27.4	1.433	2.229	

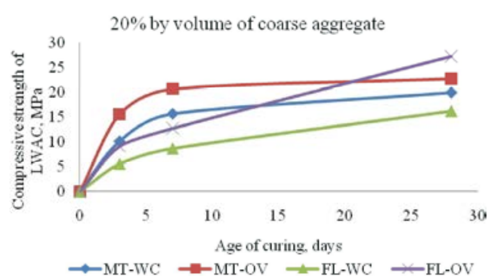

Fig. 10: Comparison for compressive strength of LWAC with 20% of volume of coarse aggregate

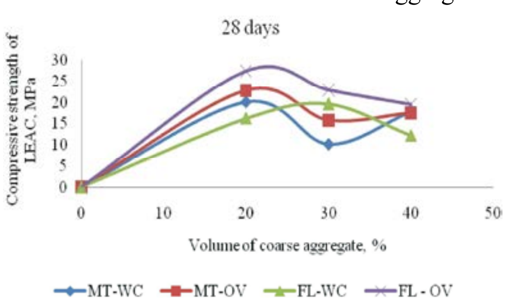

Fig. 11: Comparison for compressive strength of LWAC for various curing methods lightweight aggregate concrete.

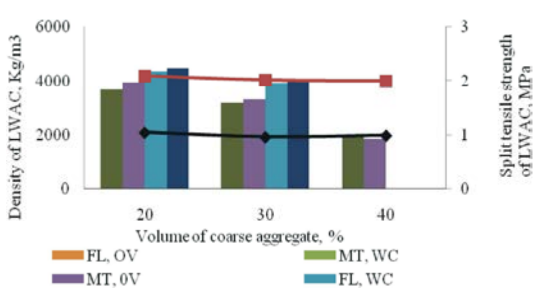

Fig. 12: Comparison for Split tensile strength and density of LWAC verses different volume of lightweight aggregate (%)

tensile strength value showed a reduction whereas, the alkali activated fly ash aggregate showed an increase of 11.39% compared to fly ash-Metakaolin aggregate concrete.

CONCLUSIONS

The following observations are noted from the present experimental study.

- Workability of the concrete mixes was enhance with decrease in the volume of aggregate and reduction of cement content was observe that the maximum packing was ensure however in increase the binder content the strength of the concrete was higher.
- Fly ash based Aggregate concrete cured in hot air oven showed higher strength as compared to water curing.
- The alkali activated fly ash lightweight aggregate concrete containing 20% coarse aggregate volume showed higher compressive strength than concrete with 40% coarse aggregate volume.
- The compressive strength of Metakaolin-fly ash lightweight aggregate concrete showed lesser value than fly ash lightweight aggregate concrete.
- Also split tensile strength of fly ash alkali-activated lightweight aggregate concrete showed 11.39% higher than metakaolin lightweight aggregate concrete.
- It can be concluded that with the increase in density of aggregate a gradual increase in the strength of concrete was noticed.

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