CRUSHING STRENGTH PROPERTIES OF FURNACE SLAG-FLY ASH BLENDED LIGHTWEIGHT AGGREGATES

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ABSTRACT

Crushing strength of lightweight aggregates depends on the efficiency of production, type of binder used and size of the aggregate formed. Fly ash based slag pellets were produced in the present study by pelletization process. The pellets consist of fly ash and furnace slag as binder substituted at 10%, 20% and 30% by the weight of fly ash. A disc pelletizer was set to an angle of 36º with a speed of 55 rpm and pelletization duration of 10 minutes and 15 minutes was adopted. Hardening of cold bonded fly ash aggregate was carried out in hot air oven at 100ºC. The crushing strength of different size ranges of cold bonded aggregate was tested at different ages. Test results showed that the strength gain of pellet depends on the percentage of binder added and pelletization duration. A significant strength improvement is noticed at higher duration (15 minutes) (mix combination of 80% fly ash and 30% furnace slag added with concentration of 10M of NaOH) compared to 10 minutes pelletization duration. Also, the strength reduction was noticed with the increase in the size of pellets; due to size effects. The crushing strength of smaller size pellets (6 mm diameter, 30G2) exhibited higher strength (43.88%) than the larger size aggregate (16 mm diameter, 30G2) and a significant reduction in strength was noted for bigger sized aggregates due to size effect.

Keywords: blast furnace slag, fly ash, size effect, agglomeration, lightweight aggregate, individual crushing strength.

INTRODUCTION

Fly ash is one of the combustible mineral additives widely used for various civil engineering applications such as supplementary cementitious material, replacement for clay in brick manufacturing and partial or full replacement of fine aggregate in concrete etc. However, the recent attempt is the production of fly ash lightweight aggregate for replacing coarse aggregate which helps to reduce the self weight of the structure finds it to be a versatile waste material in construction [1]. The lightweight aggregate is divided into two categories based on the natural lightweight such as pumice, scoria, etc and also based on artificial lightweight aggregate such as fly ash lightweight aggregate, using clay binders etc. Research studies showed the adequacy of the use of natural and artificial lightweight aggregate concrete having suitable mechanical characteristics for structural applications [2]. The normal weight aggregate concrete turns to be an uneconomical solution for a structural material as compared to the fly ash lightweight aggregate concrete. The real benefits of structural lightweight aggregate concrete can result in the structural design of the member with reduced self weight thereby an increase in the number of floors can be achieved [3]. The use of fly ash waste in production of artificial aggregates can restore the depletion of natural resources [4].

Extensive studies had been carried out to beneficiate the use of industrial waste materials such as fly ash for the manufacturing of lightweight aggregate using various methods. Agglomeration is a process involved in the production of lightweight aggregate. Cold-bonded and sintering are two main processes of production in order to obtain sufficient hardening of the lightweight aggregate. The production of artificial lightweight aggregate has revealed that the angle, speed of disc pelletizer, moisture content and binder dosage affects the formation of pellet [5]. Formation of pellets also depends on the fineness of binder and the surface moisture present during the gradual rotation by the thumbing force rather than the external force. The disc pelletizer proves to be an effective method to produce pellets easier than compared to drum pelletizer or cone pelletizer [6]. The efficiency of pellets is more efficient on the pelletizer angle and speed of disc. On the other hand angle of pelletizer lower than 35^o or greater than 45º can result in the fly ash aggregate could not made a higher strength pellets [7]. The strength of conventional aggregates can be obtained by a crushing test however it is impossible to obtain the strength of artificial lightweight aggregate. The testing of LWA is obtained the compressive strength by using the theory of granular mechanics [8]. The slag based LWA examination showed that higher percentage of external porosity of pore diameter greater than 0.1 mm [9]. The concrete produced with cold-bonded fly ash aggregate shows relatively lower performance due to the present of large voids in the aggregate [10]. The present study focused on the strength properties of the individual crushing strength based on the size of pellets, percentage of binder content and duration of pellet. A comparative analysis was then made for the different size ranges and types of pelletized aggregates.

Production methodology

A fabricated disc pelletizer shown in Figure-1 was used for the production of flyash pellets. The low calcium fly ash conforming to ASTM C618 [11] having specific gravity of 2.1 and Blaine's fineness of 400 m^2/kg was used and the chemical properties are given in Table-1. The influence of furnace slag on the pelletization efficiency was studied which had a specific gravity of 2.1 and Blaine fineness of 400 m^2/kg.

Figure-1. Fabricated disc pelletizer.

Table-1. Chemical properties of fly ash and furnace slag.

Observation	Fly ash - Class F	Furnace slag
SiO_2	56.2	32.3
Al_2O_3	25.8	10.48
Fe_2O_3	6.8	-
CaO	3.67	37.47
MgO	1.76	4.4
SO_3	0.47	-
Na_2O	2.06	-
K_2O	0.01	-
Cl^-	0.52	-
Loss on ignition	-	-

Binder proportions and moisture content

The detailed mix proportions of various flyash aggregates produced in the study are given in Table-2. In all the mixtures selected the water content (25% by the weight of fly ash-slag) was kept constant after initial trials based on pelletization efficiency. The percentage of furnace slag-binder added to fly ash mixture is adopted in order to ensure the bonding strength of a lightweight aggregate. Fifteen types of lightweight aggregate were produced with the fly ash: slag proportion of 90:10, 80:20 and 70:30 and an alkali-activator (sodium hydroxide) was added at 8M, 10M and 12M by weight of water.

Table-2. Mix proportions of lightweight aggregate production.

Mix ID	Fly ash (%)	Furnace slag (%)	Sodium hydroxide (molarity)	Water content (%)
10G1	90	10	8	25
20G1	80	20	8	25
30G1	70	30	8	25
10G2	90	10	10	25
20G2	80	20	10	25
30G2	70	30	10	25
10G3	90	10	12	25
20G3	80	20	12	25

Agglomeration process

The formation of pelletization involved in the following steps: (1) the raw material is continuously wetted on the rotary disc; (2) due to the rotary motion the wetted fly ash particles forms a small seed (path 1); (3) with the increase in duration, the size of aggregate increases due to agglomeration (path 2); (4) the pellets grow into larger size due to gain in mass and are discharged (path 3) from the rotating disc. The selection of moisture content was more important for the formation of pellet. However additional moisture content and prolonged pelletization duration beyond optimum value results in the undesirable formation of bigger size balls. On the contrary too little water content less than optimum value results in the formation of muddy ball. Hence, after initial studies the pelletization efficiency was obtained based on the angle of disc kept at 45º and speed around 55 rpm. Based on the trial and error the efficiency of production was higher and perfect shape of the pellet, when the disc were kept at an angle 36º and speed as 55 rpm the mixture was pelletized to a disc pelletizer to make the aggregate perfect spheres. The pellets were formed in the rotary disc until two varying duration such as 10 and 15 minutes and based on the duration different size ranges of the particles were obtained.

Curing process

Alkali based fly ash aggregates show accelerated strength improvement at higher temperature due to effective polymerization. In the study, effective curing was also carried out in hot air oven at 100ºC for a period of 7 days.

Crushing strength test

The crushing strength of individual fly ash aggregates were determined by loading the aggregates in diametral direction using a CBR testing machine (shown in Figure-2). A total of 30 samples of same aggregate size were tested for crushing strength in each type of aggregates. The size of the aggregate used for testing consists of 6 mm, 8 mm, 10 mm, 12 mm, 14 mm 16 mm, 18 mm and 20 mm diameter. The crushing strength of the pellet was determined using the formula given below:

$$\sigma = \frac{2.8 * P}{\pi * X^2} \quad (1)$$

Where X is the distance between the two plates, P is the fracture load (N) and σ is the crushing strength (MPa) [10]. The various sizes of the aggregates that were tested for crushing strength are given in Tables 3 to 5.

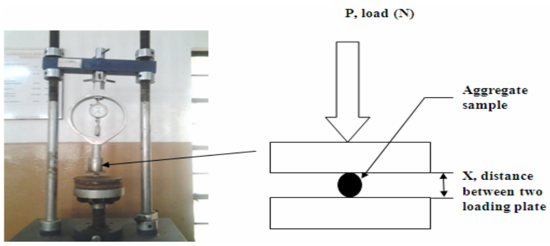

Figure-2. CBR testing machine

EXPERIMENTAL TEST RESULTS AND DISCUSSIONS

Analysis of duration of made pellets

The crushing strength test results are presented in Tables 3 to 5, the strength reduces with the increase in the size of aggregate. At 7 days curing, the strength of fly ash aggregate (30G2) was enhanced by 41 % higher compared to that of 1 day curing. The crushing strength of 6 mm size of fly ash aggregate (30G2) showed an increase of 17.36% compared to 8 mm diameter, 34.72% that of 10 mm diameter, 38.71% that of 12 mm diameter, 43.84% that of 14 mm diameter and 43.88% that of 16 mm diameter for a 15 minutes pelletization duration at the age of 7 days curing.

Table-3. Maximum crushing strength of fly ash-furnace slag aggregate with concentration of 8M of alkali activator.

Age of curing (days)	**Aggregate type**	**Duration** (minutes)	**Maximum crushing strength of individual aggregate** (MPa)							
			6 mm	**8 mm**	**10 mm**	**12 mm**	**14 mm**	**16 mm**	**18 mm**	**20 mm**
1	10G1	10	-	6.01	5.38	4.12	3.75	3.63	2.3	-
		15	-	-	-	6.35	5.09	3.79	3.78	2.52
	20G1	10	12.8	10.41	6.41	5.96	3.66	3.94	3.37	0.79
		15	-	-	-	6.9	5.46	4.26	4.22	2.61
	30G1	10	-	9.2	8.4	6.94	6.7	5.65	4.61	-
		15	-	-	12.44	10.49	10.45	6.08	4.88	-
3	10G1	10	6.62	5.6	4.38	3.84	3.82	2.59	6.62	-
		15	-	-	-	6.99	5.41	4.86	2.67	3.48
	20G1	10	13.5	11.74	7.34	5.97	4.44	4.11	3.19	1.09
		15	-	-	-	7.05	5.58	4.5	4.27	3.72
	30G1	10	-	12.10	11.20	8.63	7.77	6.14	4.84	-
		15	-	-	-	12.95	10.87	10.79	6.78	5.2
5	10G1	10	7.24	5.94	4.64	4.19	4.08	2.88	7.24	-
		15	-	-	-	7.69	5.73	5.17	4.15	3.89
	20G1	10	14.20	13.07	8.42	7.34	5.49	4.19	3.39	1.39
		15	-	-	-	7.60	6.57	4.75	4.58	3.98
	30G1	10	-	12.9	12.60	10.33	8.83	6.63	5.08	-
		15	-	-	-	13.62	11.28	11.11	7.78	5.45
7	10G1	10	7.83	6.27	4.55	4.73	4.2	3.47	7.83	-
		15	-	-	-	8.64	6.35	5.48	5.17	4.31
	20G1	10	14.90	14.97	9.95	7.52	6.02	4.36	2.48	1.68
		15	-	-	-	8.11	7.36	5.84	5.17	4.84
	30G1	10	-	13.5	13.3	10.69	8.96	7.14	5.32	-
		15	-	-	-	13.81	13.02	11.78	8.55	5.49

VOL. 8, NO. 4, APRIL 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Table-4. Maximum crushing strength of fly ash-furnace slag aggregate with concentration of 10M of alkali activator.

Age of curing (days)	**Aggregate type**	**Duration** (minutes)	**Individual crushing strength** (MPa)							
			6 mm	**8 mm**	**10 mm**	**12 mm**	**14 mm**	**16 mm**	**18 mm**	**20 mm**
1	10G2	10	-	-	5.04	5.69	4.92	4.02	3.37	2.56
		15	-	11.67	9.52	7.8	6.32	-	-	-
	20G2	10	11.1	10.83	7.09	6.26	6.09	4.57	3.15	-
		15	13.86	12.09	9.64	7.95	7.55	5.55	4.52	-
	30G2	10	15.6	14.3	8.49	7.56	-	-	-	-
		15	16.13	15.16	13.7	12.35	12.2	7.83	-	-
3	10G2	10	-	-	6.28	6.91	5.01	4.17	3.65	2.77
		15	-	12.27	10.38	7.95	6.92	-	-	-
	20G2	10	12.5	11.27	9.39	8.02	7.81	5.08	3.59	-
		15	15.1	13.12	11.36	8.41	8.12	5.88	4.88	-
	30G2	10	17.3	15.18	9.45	8.45	-	-	-	-
		15	17.65	16.13	14.18	12.59	12.25	10.33	-	-
5	10G2	10	-	-	7.48	7.19	5.08	4.25	3.79	3.02
		15	-	12.87	10.99	8.34	7.77	-	-	-
	20G2	10	13.2	12.25	9.56	8.23	8.32	5.59	4.03	-
		15	16.3	14.15	12.22	8.94	8.48	7.65	5.72	-
	30G2	10	18.2	16.06	10.29	9.34	-	-	-	-
		15	18.85	17.5	14.66	12.83	12.53	11.55	-	-
7	10G2	10	-	-	8.66	7.5	5.84	4.33	3.94	3.25
		15	-	13.47	11.62	9.35	9.13	-	-	-
	20G2	10	13.9	13.32	10.45	10.23	8.58	6.14	4.48	-
		15	17.28	15.18	13.08	10.16	-	-	-	-
	30G2	10	19.1	16.72	10.71	10.23	-	-	-	-
		15	22.81	18.85	14.89	13.98	12.81	12.80	-	-

Table-5. Maximum crushing strength of fly ash-furnace slag aggregate with concentration of 12M of alkali activator.

Age of curing (days)	**Aggregate type**	**Duration** (minutes)	**Maximum crushing strength** (MPa)							
			6 mm	**8 mm**	**10 mm**	**12 mm**	**14 mm**	**16 mm**	**18 mm**	**20 mm**
1	10G3	10	-	6.97	6.47	4.58	3.63	-	-	-
		15	-	7.16	6.72	6.16	5.17	-	-	-
	20G3	10	19	13.22	7.66	8.42	8.25	6.49		
3	10G3	10	-	7.05	6.35	5.55	2.54	-	-	-
		15	-	7.28	7.46	6.66	5.67	-	-	-
	20G3	10	19.7	14.22	8.43	9.52	9.1	7.6		
5	10G3	10	-	7.13	6.22	5.63	2.67	-	-	-
		15	-	7.56	8.58	7.36	6.17	-	-	-
	20G3	10	20	14.72	9.21	10.63	9.95	8.71	-	-
7	10G3	10	-	7.19	7.01	6.89	4.01	-	-	-
		15	-	8.11	8.81	8.69	6.77	-	-	-
	20G3	10	20.4	15.22	12.63	11.72	10.82	9.83	-	-

The strength of furnace slag-fly ash aggregate (6mm size) was found to be higher for longer pelletization duration i.e., 22.81 Mpa (30G2, 15 minutes) and exhibited the minimum strength as 13.9 Mpa (20G2, 10 minutes). For 20 mm size of aggregate, the maximum strength range was found to be 4.84 Mpa (20G1, 15minutes) and 3.25 Mpa (10G2, 10minutes), and the minimum strength range was found to be 4.31Mpa (10G1, 15minutes) and 1.68 Mpa (20G1, 10 minutes).

The strength of fly ash aggregates were found to be increased depending on the longer duration of formation of pellets and are shown in Figure-3. Effects of longer duration of pellet formation resulted (30G2, 15 minutes) in increased strength by 1.194 times higher than for lower duration (30G2, 10 minutes). The Figure-3 show that the crushing strength of 6mm size of fly ash aggregate for 10 and 15 minutes duration and revealed that the strength of 15 minutes pelletization duration of 20G2 type aggregate were found to be 1.243 times higher than 10 minutes pellets duration.

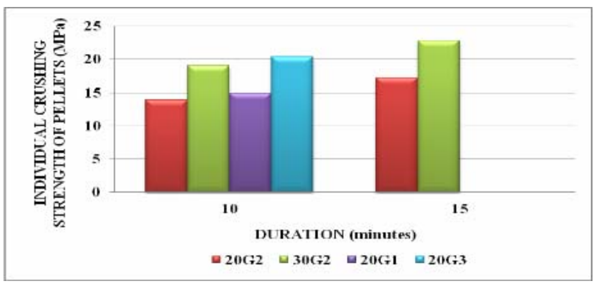

Figure-3. Comparison of crushing strength of individual fly ash-furnace slag aggregate with varies duration cured at a period of 7 days strength (6 mm diameter of pellet).

Analysis for percentage of binder used in fly ash

In order to ascertain the various size of fly ash aggregates the crushing strength up to a period of 7 days curing is shown in Figures 4 to 9. The optimum percentage of binder (30G2, 15minutes) resulted in strength increase of 24.24% for 20% binder (20G2, 15minutes) and 40.94% for 10% binder (10G2, 15minutes) which can be seen from Figure-5.

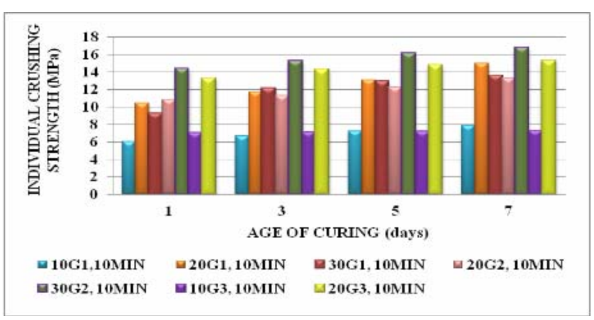

Figure-4. Comparison of crushing strength of individual fly ash-furnace slag aggregates at different curing days (10 minutes duration and 8 mm diameter of pellet).

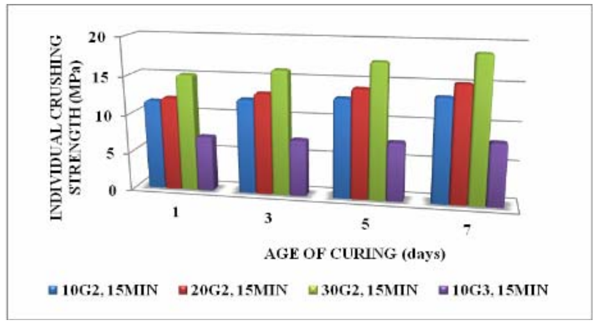

Figure-5. Comparison of crushing strength of individual fly ash-furnace slag aggregate at different curing days (15 minutes duration and 8 mm diameter of pellet).

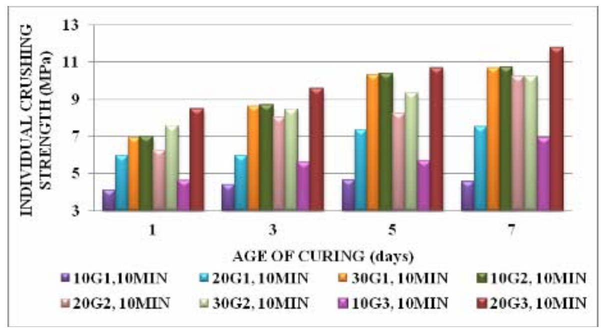

Figure-6. Crushing strength of individual fly ash-furnace slag aggregate for 12 mm size of pellets with 10 minutes duration.

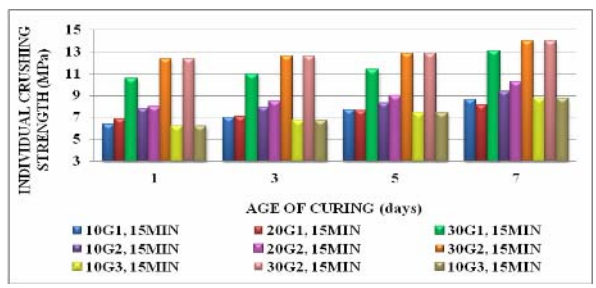

Figure-7. Crushing strength of individual fly ash-furnace slag aggregate for 12mm size of pellets with 15 minutes duration.

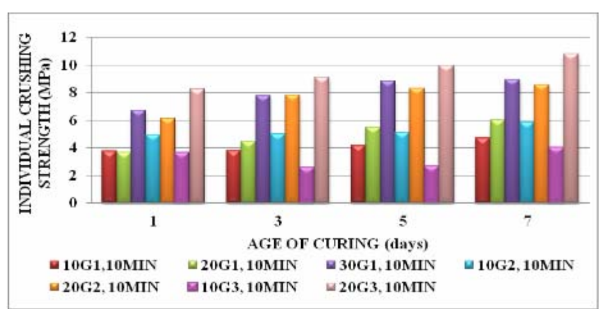

Figure-8. Maximum crushing strength of fly ash-furnace slag aggregate for 14 mm size of pellets with 10 minutes duration.

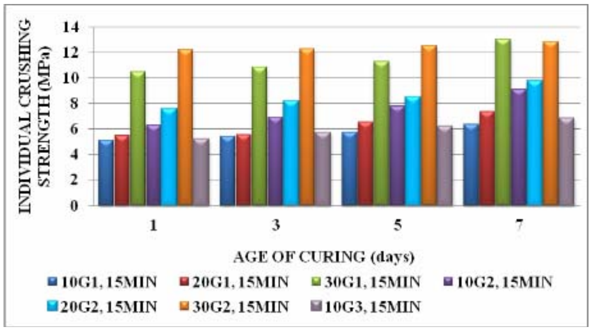

Figure-9. Maximum crushing strength of fly ash-furnace slag aggregate for 14 mm size of pellets with 15 minutes duration.

CONCLUSIONS

Following conclusions are drawn from the present study with respect to pelletization duration and the strength of aggregate for various size ranges thus produced:

a) Pelletization efficiency depends on the type of binder, duration of the process, moisture content, size of pellets formed.
b) Longer pelletization duration for 15 minutes duration resulted in higher strength and also stable formation of pellets.
c) Significant improvement in crushing strength was observed for furnace slag-flyash aggregates at 15 minutes duration at 1.194 times higher than 10 minutes pelletization duration.
d) The smaller size of flyash aggregates resulted in higher strength as compared to that of larger sized pellets.
e) The addition of 30% binder resulted in the optimal strength of the pellet as well as formation of smaller sized aggregates.
f) Cold bonded fly ash aggregates with slag based binder at optimum process duration can yield high efficiency of aggregate formation and can be an ideal choice for using in building construction.

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