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Research Article

Cold Bonded Fly Ash Lightweight Aggregate Containing Different Binders

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Abstract: The potential applications of artificial aggregate in light weight concrete construction and prefabricated concrete elements are on the huge demand. This study investigates the production of alkali activated flyash aggregate containing different types of binders such as metakaolin, furnace slag and bentonite. The lightweight aggregate properties are greatly altered with the addition of binder material which can result in good binding properties to the flyash aggregate. The production of activated fly ash aggregate depends on the type and dosage of binders in the pelletizer. Pelletization process depends on the efficiency of production, gradation and crushing strength of aggregates which depends on the type and percentage of binder used, angle of disc, speed of disc and duration of pellet formation. The fly ash aggregates were produced and the effects of various binder materials (furnace slag (GGBS), bentonite and metakaolin) substituted at 10, 20 and 30% respectively of total binder material for various time duration were studied. The effect of alkali activator (sodium hydroxide) at a concentration of 8, 10 and 12 M, respectively were studied in flyash aggregates and the aggregates were cured in the hot air oven at 100ºC up to 7 days. Test results also exhibited that water absorption flyash aggregates made using GGBS binder was found to be lower than (12.88%) compared to bentonite (16.39%) and metakaolin (17.86%). The crushing strength test results showed that a maximum strength of 22.81 MPa was obtained in the case of fly ash-furnace slag aggregate, 17.62 MPa for fly ash-metakaolin aggregate and 14.51 MPa for fly ash-Bentonite aggregate.

Keywords: Agglomeration process, alkali activator, clay binder, clay binders, cold bonded fly ash aggregate, furnace slag, pelletizer

INTRODUCTION

The cost effective production strategies for obtaining alternative aggregates using fly ash can be a real sustainable material for future construction. Pelletization of aggregates is a promising technology that can be adopted for mass aggregate production. Agglomeration process is one mechanism that envisages the formation of pellets from a powder material with more stable spherical balls (Baykal and Doven, 2000). The hardened pellets were dried by normal air curing or by heating in hot air oven. The effects of curing process of cold-bonded fly ash aggregate were also investigated earlier under accelerated curing and autoclave curing. The autoclave curing and accelerated curing showed a marginal improvement in the strength properties of aggregate (Manikandan and Ramamurthy, 2008). The production of high strength concrete (45 to 75 MPa) using lightweight flyash aggregate depends on achieving a density of concrete in the range of 1600 to 1950 Kg/m^3 (Hugo *et al*., 2012). The agglomeration of the pellets follows three paths due to the thumbing force, excluding the external compaction (Bijen, 1986). Further enhancements of strength of cold bonded aggregates were carried out using sintering process which involves burning at 1000°C in a muffle furnace (Tommy *et al*., 2007). The properties of fly ash lightweight aggregate were enhanced with the addition of binder which alters the microstructure of the aggregate. The production of LWA depends on the fineness of fly ash, water added for pelletization and the type of binder. Addition of binder plays an important role in the formation of fly ash aggregates which can lead to ball ability and increased efficiency of production (Ramamurthy and Harikrishnan, 2006). The physical and mechanical properties of pellets depend on the particle size, shape and porosity of the aggregate (Swamy and Lambert, 1981). The objective of this study was to evaluate the production efficiency, water absorption, bulk density, gradation and individual crushing strength of fly ash lightweight aggregate. The fly ash aggregates were produced and the effects of various binder materials (furnace slag (GGBS), bentonite and metakaolin) substituted at 10, 20 and 30% respectively of total binder material for various time duration were studied.

MATERIALS USED

Class-F fly ash obtained from Ennore thermal power plant and binders such as bentonite, metakaolin

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Fig. 1: Fabricated disc pelletizer machine

and furnace slag were added at 10, 20 and 30%, respectively used in the present study for the aggregate production. The moisture content for pelletization was optimized at 25% of binder and alkali activator (sodium hydroxide) of molarity 8, 10 and 12 M, respectively was used. A fabricated disc pelletizer (Fig. 1) was used for the flyash pellets production which has a disc diameter of 500 mm and a draft of 250 mm. The angle of disc pelletizer was set at 36ºC and speed maintained at 55 rpm. Pelletization was carried out for two different time duration at 10 and 15 min followed by curing the aggregate either normal air drying or in hot air oven at 100ºC up to 7 days as shown in Fig. 2. Totally 30 different types of aggregate were produced with different flyash-binder proportions (Table 1). The physical properties and chemical properties of fly ash and binder material are given in Table 2.

RESULTS AND DISCUSSION

Production efficiency of fly ash aggregate: The efficiency of pelletization (Fig. 2) depends on the

Table 1: Mix combination of various type of fly ash lightweight aggregate

			Binders content (%)			
Mix type	Duration (min)	NaOH (molarity)	Fly ash	Bentonite	Metakaolin	Furnace slag
$20B_1$	10	8	80	20	0	0
$20B_1$	15	8	80	20	0	0
$20B_2$	10	10	80	20	0	0
$20B_2$	15	10	80	20	0	0
$20B_3$	10	12	80	20	0	0
$20B_3$	15	12	80	20	0	0
$10MT_1$	10	8	90	0	10	0
$10MT_1$	15	8	90	0	10	0
$20MT_1$	10	8	80	0	20	0
$20MT_1$	15	8	80	0	20	0
$20MT_2$	15	10	80	0	20	0
$20MT_3$	15	12	80	0	20	0
$30MT_1$	10	8	70	0	30	0
$30MT_2$	15	10	70	0	30	0
$30MT_3$	15	12	70	0	30	0
$10G_1$	10	10	80	0	0	10
$10G_1$	15	12	80	0	0	10
$10G_2$	10	12	80	0	0	10
$10G_2$	15	8	70	0	0	10
$10G_3$	10	8	70	0	0	10
$10G_3$	15	10	70	0	0	10
$20G_1$	10	10	70	0	0	20
$20G_1$	15	12	70	0	0	20
$20G_2$	10	12	70	0	0	20
$20G_2$	15	8	90	0	0	20
$20G_3$	10	8	90	0	0	20
$30G_1$	10	10	90	0	0	30
$30G_1$	15	10	90	0	0	30
$30G_2$	10	12	90	0	0	30
$30G_2$	15	12	90	0	0	30

Table 2: Physical properties and chemical analysis of various binder materials

Observation	Fly ash-class F	GGBS	Bentonite	Metakaolin
Specific gravity	2.10	2.86	2.64	2.52
Blaine's fineness (m^2/kg)	400	400	-	800
Chemical properties				
SiO_2	56.20	32.30	47.84	41.40
Al_2O_3	25.80	10.48	14.85	30.50
Fe_2O_3	6.80	-	9.61	1.00
CaO	3.67	37.47	2.29	0.30
MgO	1.76	4.40	2.20	1.80
SO_3	0.47	-	-	0.90
Na_2O	2.06	-	2.88	0.90
K_2O	0.01	-	1.45	-
Cl^-	0.52	-	-	-
Loss on ignition	-	-	19.73	18.16

Fig. 2: Hot air oven curing for fly ash activate aggregate

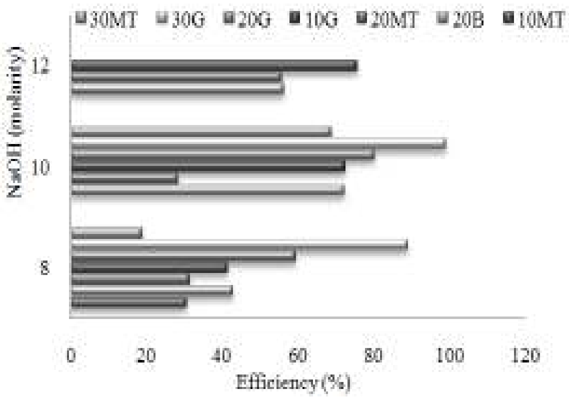

Fig. 3: Efficiency of pellet production for various types of fly ash activator aggregate (formation of aggregate 15 min duration)

effectiveness of agglomeration process and was found to be directly dependent on the binder content. The formation of flyash balls was much earlier with the increased addition of any type of binder. The pellets were formed in the disc within the 7th min duration and become stable balls after 10th min. The optimum percentage of bentonite binder was obtained as 20% by the weight of fly ash with alkali activator (10 M of NaOH). However with the increased concentration of alkali (12 M) fly ash the pellets formed were found to be very sticky and cohesive. Therefore, the maximum efficiency of pellet production was obtained from the bentonite binder containing 25% moisture content with 10 M of activator. The efficiency of pellet production depends on the type of binder added in the fly ash and also activator range. The flyash-GGBS ($30G_2$) binder showed higher efficiency than the other two binders. The efficiency of production was increased when flyash mixed with 30% GGBS ($30G_2$ 15 min) which can be seen in Fig. 3.

The bulk density of various type of flyash lightweight aggregate is given in Table 3. The bulk density of flyash-slag pellets was found to be lower (660 Kg/m^3) at 10 min duration with lower production efficiency. A similar trend was observed for the other binders with the bulk density increasing with the concentration of alkali and duration of pelletization period as well as improved pore structure; which results in less water absorption of the aggregates.

Table 3: Physical characterization of cold-bonded fly ash lightweight aggregate

Type of aggregate	Duration (min)	Specific gravity SSD	Specific gravity OD	Loose bulk density (Kg/m^3)	Water absorption (%)	Efficiency (%)
$20B_1$	10	1.96	1.49	867.52	30.90	38.85
$20B_1$	15	2.17	1.67	933.76	29.90	42.82
$20B_2$	10	1.97	1.59	951.51	23.76	35.91
$20B_2$	15	1.95	1.62	949.68	16.39	72.24
$20B_3$	10	2.10	1.77	1005.39	18.40	43.72
$20B_3$	15	2.04	1.70	964.33	20.14	56.28
$10MT_1$	10	1.50	1.16	793.45	29.75	44.50
$10MT_1$	15	1.62	1.27	914.37	27.62	30.74
$20MT_1$	10	1.47	1.15	675.16	28.44	34.44
$20MT_1$	15	1.51	1.22	778.34	23.48	31.53
$20MT_2$	15	1.72	1.38	891.72	24.90	28.38
$20MT_3$	15	1.78	1.46	950.96	21.91	55.90
$30MT_1$	10	1.48	1.11	813.16	32.89	29.56
$30MT_2$	15	1.77	1.43	867.52	24.29	18.89
$30MT_3$	15	1.80	1.53	848.41	17.86	68.74
$10G_1$	10	1.81	1.39	723.57	30.34	50.28
$10G_1$	15	1.85	1.46	771.97	26.67	41.42
$10G_2$	10	1.84	1.44	840.13	28.04	59.66
$10G_2$	15	1.88	1.54	898.73	22.10	72.45
$10G_3$	10	1.90	1.53	910.27	24.74	69.84
$10G_3$	15	1.58	1.40	1022.51	12.97	75.70
$20G_1$	10	1.89	1.55	839.49	22.34	57.18
$20G_1$	15	1.94	1.62	838.22	19.79	59.49
$20G_2$	10	1.93	1.64	660.30	17.48	86.56
$20G_2$	15	1.66	1.46	985.35	13.40	80.36
$20G_3$	10	1.97	1.70	975.10	16.07	95.85
$30G_1$	10	2.01	1.78	943.95	12.88	79.15
$30G_1$	15	1.91	1.69	930.57	12.94	89.22
$30G_2$	10	1.95	1.71	909.80	13.89	86.98
$30G_2$	15	1.98	1.75	983.44	13.01	99.07

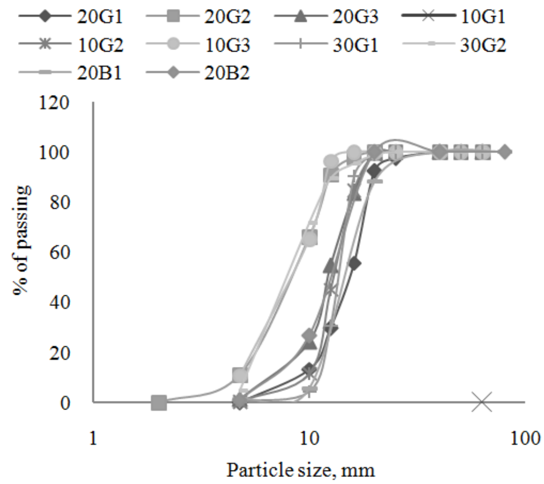

Fig. 4: Gradation of FLWA at 10 min pelletization duration

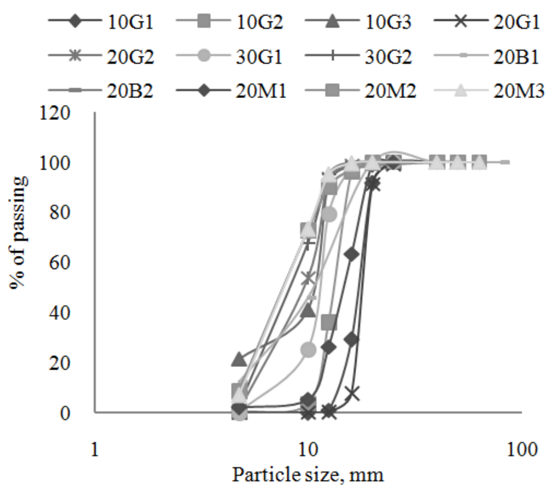

Fig. 5: Gradation of FLWA which formed an aggregate with 15 min duration

The gradation curve for various fly ash aggregate samples are represented and shown in Fig. 4 and 5. It can be noted that different size ranges of aggregates were formed and achieved a uniform spherical shape. Also, from the gradation curve it can be seen that for flyash-GGBS combination a well gradation is achieved as compared to flyash-metakaolin aggregates at 15 min duration (IS: 2386 Part I, 1963).

The experimental results on water absorption of various types of fly ash lightweight aggregate are given in Fig. 6. It can be noted that water absorption of all types of aggregates showed higher porosity and thereby considerable increase in water ingress. However, compared to various flyash-binder combinations the addition of slag binder exhibited a considerable reduction. The increase in micro structural formation due to higher compaction forces leads to reduced porosity and this could be possibly due to fineness of

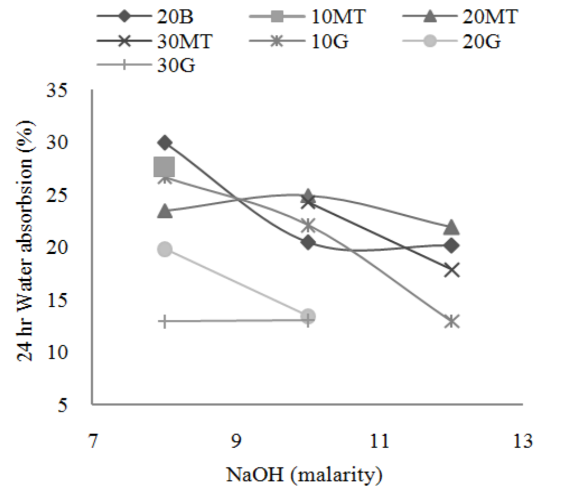

Fig. 6: Water absorption of various type of binder used in fly ash aggregate formed at 15 min duration

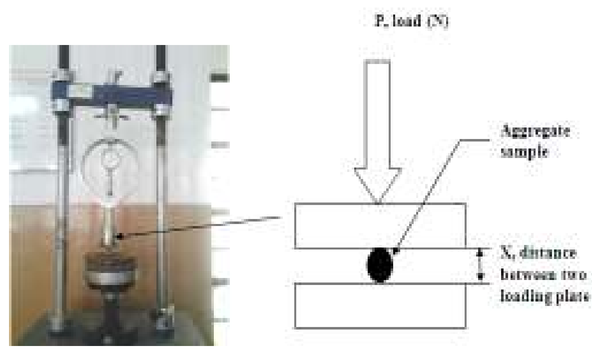

Fig. 7: CBR testing machine

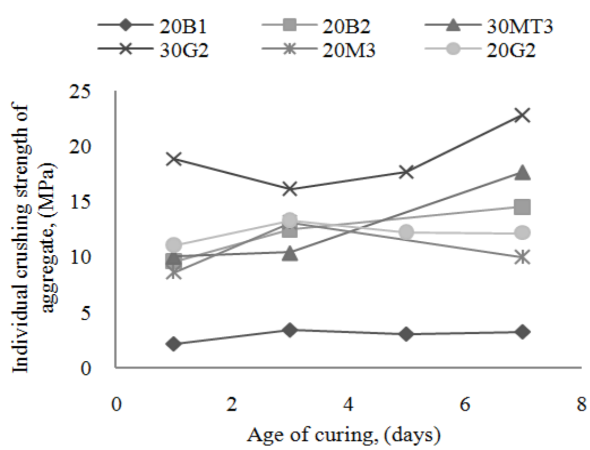

Fig. 8: Individual crushing strength of fly ash aggregate at 1, 3, 5 and 7 days (15 min duration)

slag material compared to bentonite and metakaolin. Also, the water absorption of aggregates at longer time duration of pelletization showed reduced water absorption (16.39%) as compared to 10 min duration (23.76%). Similarly, the addition of alkali

Table 4: Individual crushing strength test results of fly ash aggregates at 1 day in hot air oven curing

Type of aggregate	Duration (min)	Individual crushing strength of AAFA (MPa) 6 mm	8 mm	10 mm	12 mm	14 mm	16 mm	18 mm	20 mm
$10G_1$	10	-	6.01	5.38	4.12	3.75	3.63	2.30	-
	15	-	-	-	6.35	5.09	3.79	3.78	2.52
$20G_1$	10	12.80	10.41	6.41	5.96	3.66	3.94	3.37	0.79
	15	-	-	-	6.90	5.46	4.26	4.22	2.61
$30G_1$	10	9.20	8.40	6.94	6.70	5.65	4.61	9.20	8.40
	15	-	-	12.44	10.49	10.45	6.08	4.88	12.44
$10G_2$	10	-	-	5.04	5.69	4.92	4.02	3.37	2.56
	15	-	11.67	9.52	7.80	6.32	-	-	-
$20G_2$	10	11.10	10.83	7.09	6.26	6.09	4.57	3.15	11.10
	15	13.86	12.09	9.64	7.95	7.55	5.55	4.52	13.86
$30G_2$	10	15.60	14.30	8.49	7.56	-	-	-	-
	15	16.13	15.16	13.70	12.35	12.20	7.83	16.13	15.16
$10G_3$	10	-	6.97	6.47	4.58	3.63	-	-	-
	15	-	7.16	6.72	6.16	5.17	-	-	-
$20G_3$	10	-	13.22	7.66	8.42	8.25	6.49	-	-
$10M_1$	10	-	2.66	2.03	2.07	-	-	-	-
	15	-	-	-	-	1.94	0.87	0.94	-
$20M_1$	10	-	-	1.58	1.53	1.46	-	-	-
	15	-	-	-	1.47	1.43	1.31	-	-
$30M_1$	10	-	-	1.62	1.21	1.08	-	-	-
$20M_2$	15	-	5.49	4.76	4.13	4.82	-	-	-
$30M_2$	15	5.18	3.56	-	-	-	-	-	-
$20M_3$	15	8.64	6.61	-	-	-	-	-	-
$30M_3$	15	10.02	7.08	6.18	-	-	-	-	-
$20B_1$	10	-	-	-	-	3.26	2.96	-	-
	15	-	-	-	1.65	1.89	-	-	-
$20B_2$	10	-	-	2.11	2.53	-	-	-	-
	15	9.59	7.05	7.09	2.08	-	-	-	-
$20B_3$	10	-	-	-	3.99	4.87	4.76	5.37	-
	15	-	-	4.10	3.22	2.83	-	-	-

Denotes particular size of aggregate not available

activator at higher concentration resulted in the reduction of porosity of flyash aggregates.

Individual crushing strength of fly ash aggregate: The crushing strength of individual pellets tested using CBR testing machine shown in Fig. 7 and the results are given in Fig. 8. To arrive at a more reliable estimate a total of 30 numbers of pellets from each aggregate types were calculated using the strength index formula given below:

$$\text{Individual crushing strength of pellet} = \frac{2.8 * P}{\pi * X^2}$$

where,
P = The failure load
X = The distance between the two plate of the pellet (Niyazi and Turan, 2010)

A highest crushing strength of 22.81 MPa was recorded for flyash-slag aggregate at 7 days curing compared to other binder The crushing strength of 30 different types of aggregate was found for various sizes of individual aggregate particles. It can be noted from Table 4, that maximum crushing strength (16.12 MPa) was obtained for flyash-slag pellets and as the size of the pellets increase the crushing strength decrease. However, the test results show a high degree of variance of the actual diameter to be tested as well as due to non-uniformity of surface.

The fly ash-slag binder ($30G_2$) reported an improved crushing strength for 10 min duration as compared to other binder which can be seen in Fig. 9. Similarly flyash-bentonite pellets at 10 M sodium

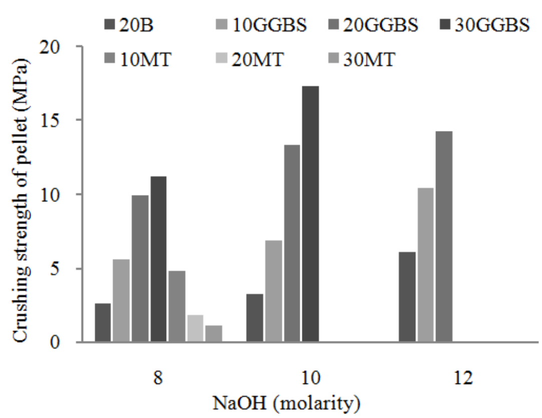

Fig. 9: Variation of crushing strength of aggregate for 10 min duration at 3 days curing

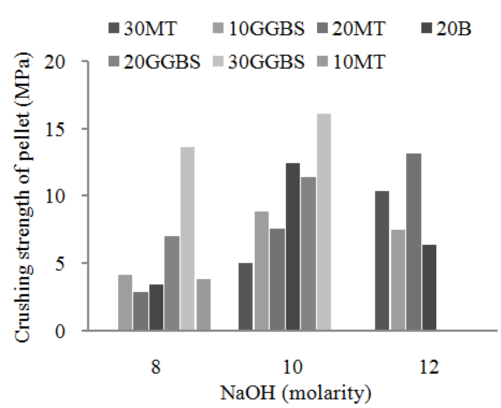

Fig. 10: Variation of crushing strength of flyash aggregate for 15 min duration at 3 days curing

hydroxide showed a maximum strength for 15 min duration as seen in Fig. 10.

CONCLUSION

- Pelletization process of flyash based aggregates can be a viable alternative; as well as the properties are on par with that of natural aggregates.
- The efficiency and strength of pelletization increases with the addition of binder materials such as bentonite, furnace slag and metakaolin.
- The addition of alkali activators during pelletization gives a more stable formation of pellets as well as improved the strength properties.
- An optimum addition of binder (30% slag, 20% bentonite) results in good binding properties as well as strength.
- The water absorption of fly ash aggregate mixed with GGBS binder showed lower water absorption (12.88%) as compared to the other two binders.
- A maximum crushing strength was reported for GGBS ($30G_2$) around 22.81 Mpa, 17.62 MPa for Metakaolin ($30M_3$) and 14.51 MPa for bentonite ($20B_2$) at 7 days curing.
- The bulk density of fly ash-slag aggregate was found to be lower (660 Kg/m^3) for 10 min pelletization duration and also resulted in lower production efficiency.

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