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CHARACTERIZATION ON THE STRENGTH PROPERTIES OF PELLETIZED FLY ASH AGGREGATE

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ABSTRACT

The present study focused on the production of alkali activated flyash lightweight aggregate by means of pelletization. The basic physical properties and mechanical characteristics of lightweight aggregate produced were analyzed systematically. Factors affecting the efficiency of pelletization process such as type of binder, moisture content, process duration and alkali content were evaluated. Further, characterization of aggregates was evaluated based on the specific gravity, gradation, density and aggregate crushing strength. It was observed from the test results that the pelletization efficiency of different aggregates was found to be maximum when the angle of pelletizer is set to 36º with an optimized speed of 55 rpm. Also, compared to other types of pelletized flyash aggregates, the aggregates containing flyash mixed with 20% cement and 12M NaOH exhibited a higher crushing strength of 13.72 MPa with minimum water absorption of 18.33%. With the optimum addition of water upto 31% during pelletization, the efficiency and strength of aggregates were found to be increased. In addition, the optimum pelletization duration (15 to 20 minutes) resulted in higher compaction energy with uniform size of aggregates. Also, the addition of alkali (NaOH) to flyash aggregates showed higher strength gain within shorter curing period in hot air oven.

Keywords: pelletization, geo-polymer aggregate, crushing strength, alkali activator, flyash, lime, duration, efficiency, moisture content.

1. INTRODUCTION

Fly ash from thermal power plant is being beneficially utilized for various engineering purpose for the production of pozzolana cement, flyash bricks, light weight blocks as well as producing artificial lightweight aggregates [1]. The production of artificial fly ash lightweight aggregate is effectively carried out by two techniques namely granulation and compaction. The processing of agglomeration theory was developed in 1940's [2]; Granulation technique involves in the formation of solid pellets by addition of moisture and further with the application of rotating force. Whereas, the compaction techniques involves the formation of pellet and well compacted by using briquettes apparatus for hard pressing.

Flyash aggregates produced can be used either as such as produced in cold-bonding method or by further strengthening using sintering at high temperature beyond 900ºC. The sintering process envisages the particles to fuse together at higher temperature range of 900 to 1200 ºC. Mostly the disc or pan type pelletizer machine was easy to operate and produce different gradation of aggregates as compared to other type of pelletizer machine. The fabricated disc pelletizer machine adopted in different research studies showed that the angle can be adjusted between 36º to 45 º, speed of 45 to 55 rpm, 0.5 m diameter and 0.25 m side depth. Cold-bonded, autoclaving and sintering process were the three different methods adopted for further hardening of a pellet. Normally class F fly ash is always preferred for sintering process and class - C fly ash for cold-bonding process [3]. Efficiency of pellet depends on the fineness value of fly ash [4]. Also, the research study showed that the effects of binder material did not result in the change in chemical composition but enhanced the microstructure of the aggregate thereby improving the mechanical properties of aggregates. [5]. The cold-bonded fly ash aggregate was studied on the partial replacement of cement as fly ash and replacement of sand with fly ash to study the properties of concrete [6]. The water absorption of lightweight aggregate concrete reported to be substantial and thus affects the strength of concrete [7]. The increase in speed of pelletizer resulted in less water absorption of the artificial aggregate [8]. The reduction of porosity of lightweight aggregate was not fully followed by the crushing strength of aggregate and its additional influencing mineral changes and internal thermal stress [9].

The effects of curing in cold-bonded fly ash aggregate were examined in normal water and auto clave curing and showed a reasonable improvement in strength [10]. The crushing strength of hardened pellet was higher for smaller sized aggregates compared to larger size. Moisture content of fly ash aggregate vary from 15% to 35% (high); however, with increased moisture muddy balls are formed instead of smaller pellets.

The porosity of fly ash lightweight aggregate was found to be reduced with curing and resulted in gradual reduction in the water absorption [11]. The strength of lightweight aggregate concrete depends on the strength of fly ash aggregate and improved bonding effect on aggregate/cement matrix in the transition zone [12]. The motivation of the present study is on the production of different type of geo-polymer based aggregate and to identify the factors influencing the efficiency of production such as duration, strength of NaOH added in fly ash and type of binder used. Also, the relative assessment of the flyash aggregates was made from specific gravity, water absorption, bulk density, gradation and individual crushing strength properties.

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2. PRODUCTION TECHNIQUES OF AGGREGATE USING PELLETIZER

2.1. Agglomeration technique - cold bonding

The manufacturing of flyash lightweight aggregate was carried out using class-F fly ash with the addition of cement and lime. A specially fabricated disc pelletizer as shown in Figure-1 was used in this study which has a disc diameter of 500 mm and depth 250 mm. The angle of the disc can be adjusted between 35° to 50° and speed of 55 rpm.

Figure-1. Fabricated disc pelletizer machine.

The physical properties and chemical analysis of the class F flyash used in the study is given in Table-1. Trial studies were conducted to optimize the speed, angle of the pelletizer and moisture content. The addition of water content is an important factor for agglomeration effect. The influence and strength of alkali (8M, 10M and 12M of NaOH) in the production of fly ash lightweight aggregate were also investigated in this study. The shape and size of the pellets produced based on the duration (10, 15 and 20 minutes) of pelletization process were studied systematically.

Table-1. Physical and chemical properties of various binder materials used.

Observation	Class - F fly ash	Cement	Lime
Specific gravity	2.1	3.13	2.26
Blaine's fineness: m^2/kg	400	325	-
Chemical properties			
SiO_2	56.2	18.5	0.5
Al_2O_3	25.8	5.24	<0.4
Fe_2O_3	6.8	5.9	-
CaO	3.67	60.9	70
MgO	1.76	1.1	0.6
SO_3	0.47	1.5	-
Na_2O	2.06	-	-
K_2O	0.01	-	-
Cl^-	0.52	0.002	-
Loss on ignition	-	0.80	+93
Insoluble residue	-	0.25	-

The various aggregate constituent proportions using binder materials are provided in Table-2. Initially the flyash powder along with the binder is mixed for 2 to 3 minutes duration in the disc pelletizer, and the required mix water is sprayed inside the disc.

Table-2. Different material constituents of pelletized aggregate production.

Aggregate type	Fly ash (%)	Cement (%)	Lime (%)	Water content (%)	Molarity of NaOH
NF1	100	0	0	25	8
NF2	100	0	0	25	10
NF3	100	0	0	25	12
NL1	80	0	20	25	8
NL2	80	0	20	25	10
NL3	80	0	20	25	12
NC1	80	20	0	25	8
NC2	80	20	0	25	10
NC3	80	20	0	25	12
C1	80	20	0	25	-
C2	80	20	0	25	-
C3	80	20	0	25	-
L1	80	20	0	25	-
L2	80	20	0	25	-
L3	80	20	0	25	-

The growth of pellets is defined in three different stages as shown in Figure-2. Initially the addition of water in the ash particles forms a small seed in stage 1 of Figure-2(a) and with the increase in the duration of the process; the seed particle grows into large size as seen in the stage 2 of Figure-2(b). Further upon, the growth of pellets reaches a stable condition and results in taking a shortest rotating path due to gain in mass as seen in Figure-2(c). The pelletized aggregates formed for 15 minutes duration for flyash-lime and flyash-cement binder is shown in Figure-3.

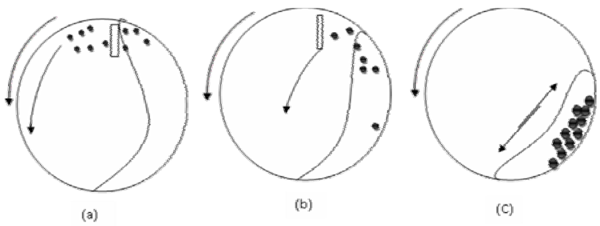

Figure-2 (a, b and c). Three stages for growing of pellets.

Figure-3. Pelletized fly ash aggregate for 15 minutes duration.

2.2. Individual crushing strength of pellet

The crushing strength of individual fly ash aggregate was determined using a crushing testing machine as shown in the Figure-4. The individual crushing strength (σ) of pellet can be obtained from the equation given below:

$$\sigma = \frac{2.8 * P}{\pi * X^2}$$

Where P represents the failure load of the sample, X is the distance between the two plates [13, 14]. The crushing strength of aggregates was tested in a batch which has a sample size of 30 numbers and the average diameter of the pellet in the range of 10 to 16 mm.

Figure-4. Crushing test machine.

The crushing strength of aggregates was tested based on three parameters such as duration of pelletization, moisture content, strength of NaOH and type of binder used in the fly ash aggregate. Flyash aggregates produced using alkali activator were cured in a hot air oven at a temperature of 100ºC up to 7 days and the crushing strength was determined for various curing ages (1, 3, 5, 7 and 14 days) of flyash aggregates.

3. RESULTS AND DISCUSSIONS

3.1. Efficiency of pelletization

The production efficiency of pelletization for various types of fly ash aggregates for different time duration is provided in Table-3. The efficiency, size and shape of aggregate were affected by the duration of pelletization, as it was observed that during the first 10 minutes the pellets were formed with perfect shape and subsequently turns into irregular shape. Also, with the increase in the duration of pelletization the compaction pressure increases with the formation of larger size. The further increase in duration beyond 20 minutes resulted in the formation of muddy flyash balls with uneven size. Hence it can be concluded that an optimized interval of 10 to 15 minutes leads to a more stable formation of pellets with uniform size and higher strength index. Based on the trial studies conducted initially an overall efficiency of pelletization was obtained when the angle was set to 36° and speed of pelletizer set to 55 rpm.

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Table-3. Efficiency of pelletization duration on the production of various types of flyash aggregate.

Type of aggregate / Duration	Efficiency of production (%)			Overall Efficiency (%)
	10 minutes	15 minutes	20 minutes	
NF1	34	22.51	16.04	72.55
NF2	34.42	28.51	0	62.93
NF3	52.86	47.14	#	100
NC1	41.14	30.44	22.79	94.38
NC2	29.96	68.39	1.65	100
NC3	100	#	#	100
NL1	24.64	12.24	0	36.88
NL2	32.91	19.21	0	52.12
NL3	30.83	18.64	8.03	57.5
C1	15	5	0	20
C2	36.48	5.57	0	42.05
C3	37.59	62.41	#	100
L1	21.06	3.27	0	24.33
L2	36.32	9.12	0	45.44
L3	43.55	56.45	#	100

Note: # - denotes empty condition of powder in the drum at that time since maximum pellets formed before only

The overall efficiency of pelletization with cement binder with alkali (NC1) showed 94.38% as compared to that of geo-polymer based fly ash aggregate containing lime binder with alkali (NL1) showed 36.88%. However the fly ash aggregates containing cement and 12M NaOH (NC3) were found to exhibit higher efficiency compared to the other type of aggregate. It can be noted that the production of aggregates were found to be higher with the increase in moisture content and use of cement binder as a result of good mixing and further agglomeration. This can be evidently seen from Figure-5 that, in the case of fly ash-cement binder (NC3) a maximum number of pellets around 317 no's were formed as compared to that of flyash-lime binder (NL3) which was around 107 no's for 10 minutes of pelletization duration. However, with the addition of alkali (NaOH) at higher strength of 12M, efficiency of production increased but beyond 10 minutes of pelletization the loss in consistency occurred. In general, it can be concluded that the use of cement binder at higher water content (31%) resulted in the formation of round and uniform size of aggregates.

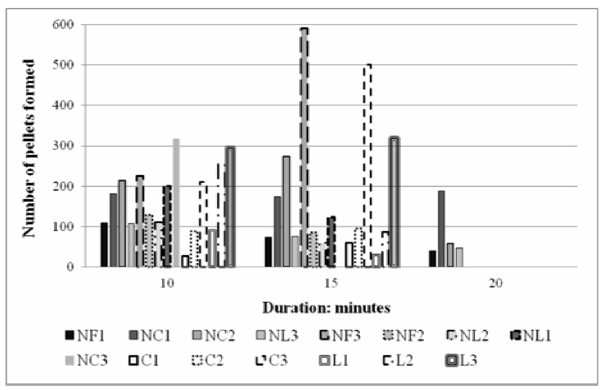

Figure-5. Number of pellets formed in various type of fly ash lightweight aggregate.

3.2. Specific gravity, bulk density and water absorption of fly ash aggregates

The test results on the specific gravity, density and water absorption of different fly ash aggregates manufactured in the study are given in Table-4. It can be noted that the specific gravity of fly ash aggregates with cement binder (NC3) was observed to be higher (2.12) than other types of aggregates. The lowest specific gravity (1.68) was observed for fly ash aggregates without binder (NF1) and for lime binder (NL1) it was around 1.83. With the increase in duration of pelletization the specific gravity was found to be higher due to higher compaction force. The loose bulk density and compacted bulk density of various type of fly ash lightweight aggregate are provided in Table-4. It is observed that the bulk density of aggregates was found to increase for cement binder compared to other types of fly ash binder combinations. Also, the bulk density was found to increase with the increase in alkali concentration from 8M to 12M. It can be noted from Table-4, that the bulk density was found to be higher (942.68 kg/m^3) for flyash aggregates containing cement (NC3) and lower (686.06 kg/m^3) for fly ash lime combination (NL1). Also, it can be noted that with the increase in the duration of pelletization, the density of aggregates was found to be increased.

Table-4. Physical properties of different types of fly ash aggregate.

Type of aggregate	Duration minutes	Specific gravity		Bulk density (kg/m^3)		24hr water absorption (%)
		SSD	OD	LBD	CD	
NF1	10	1.68	1.21	714.65	802.55	39.01
	15	1.67	1.2	692.36	752.56	38.9
	20	1.66	1.18	718.68	770.02	40.79
NF2	10	1.88	1.66	815.84	842.78	12.77
	15	1.88	1.44	746.71	814.69	30.42
NF3	10	1.96	1.53	864.97	950.51	28.28
	15	1.99	1.12	930.57	1041.4	77.03
NL1	10	1.83	1.34	686.08	706.26	37.02
	15	1.86	1.45	666.06	699.36	24.32
NL2	10	1.93	1.34	692.99	1259.73	43.6
	15	1.94	1.3	722.96	768.96	48.75
NL3	10	1.91	1.31	717.2	779.56	45.45
	15	1.94	1.40	824.84	978.34	21.82
	20	1.96	1.37	834.73	906.28	50.23
NC1	10	1.99	1.67	792.99	894.27	19.7
	15	2.04	1.72	842.68	963.06	18.43
	20	1.9	1.54	924.95	1013.04	23.8
NC2	10	2.10	1.95	902.61	927.01	20.75
	15	2.05	1.64	871.9	923.19	25.24
	20	1.88	1.28	607.22	728.66	46.79
NC3	10	2.12	1.79	942.68	1001.27	18.33
C1	10	1.7	1.25	740	789.06	36.21
	15	1.66	1.17	690.3	720.1	41.61
C2	10	1.78	1.33	712	760.04	33.33
	15	1.67	1.19	637.93	650.12	40.07
C3	10	1.81	1.59	826.75	915.29	13.75
	15	1.88	1.66	867.52	967.52	12.63
L1	10	1.64	1.17	622.93	667.34	40.34
L2	10	1.73	1.31	726.11	736.45	31.54
	15	1.68	1.3	811.46	838.23	30.36
L3	10	1.77	1.37	799.5	812.45	29.03
	15	1.77	1.47	810.9	827.13	20.33

Note: SSD - Saturated surface dry specific gravity, OD - Oven dry specific gravity, LBD - Loose bulk density, CD - Compacted density

ARPN Journal of Engineering and Applied Sciences

Further, the test results on the water absorption of fly ash aggregate with alkali (NF2) showed the least value (12%) and were higher (77%) for fly ash aggregate with alkali (NF3). The water absorption of fly ash aggregates were found to decrease for longer duration and higher binder content - due to closer packing and density of aggregates.

3.3. Aggregate gradation

The size and shape of the aggregates is an important factor in the mix design and was determined as per IS: 2386 (Part 1, 1986) [15]. The particle size ranges and gradation curve for various pelletized aggregates are represented in Figure-6. The mean diameter of pellet formed for different types of aggregate manufactured is shown in Figure-7. It can be observed from the test results that the fly ash aggregates produced were having a uniform round shape and the growth in size of pellets depends on the duration of pelletization. It can be noted that initially during the pelletization process the size of particles were small, however; with the increase in duration, the size of the pellets increased due to increased agglomeration. The increase in moisture content increased the formation of uniform size ranges and the higher alkali concentration decreased the formation of pellets. A well graded aggregate size formation was observed in the case of fly ash aggregate containing cement (NC3) for shorter duration of 10 minutes. In general, it can be concluded that size of pellets formed depends on the duration and type of binder for getting an efficient agglomeration.

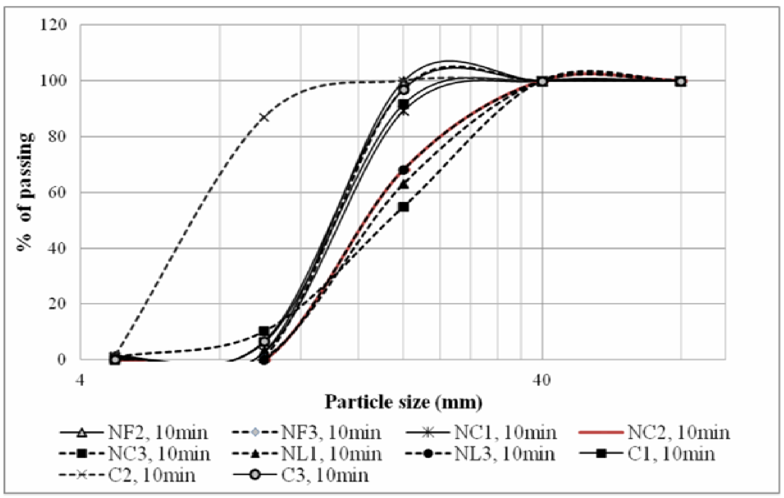

Figure-6. Particle size distribution of different types of fly ash aggregate with 10 minutes duration.

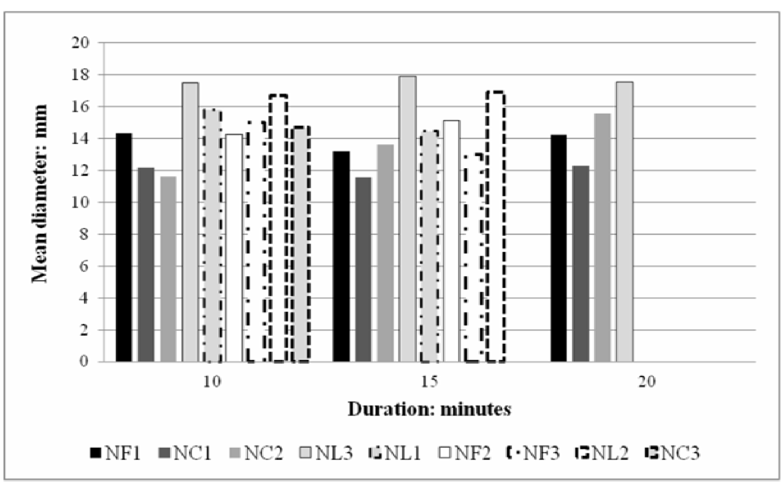

Figure-7. Mean diameter of pellet produced for various type of fly ash aggregate evaluate the maximum crushing strength with different duration.

3.4. Crushing strength properties of fly ash aggregate

The test results on the crushing strength of individual fly ash aggregate is given in Table-5 and the strength analysis was studied based on duration, strength of NaOH and type of binder used. Also, the variation of strength for different size of the aggregates is given in

Table-6 and can be noted that for the minimum size of aggregate (10 to 11 mm) an increase in strength of 26.89% was observed compared to maximum diameter of pellet (20 to 21 mm). It was also observed from the results that, the strength of fly ash aggregate increased with the increase in duration and at higher alkali concentration.

Table-5. Crushing strength of various types of fly ash aggregate for different pelletization duration.

Type of aggregate	**Duration** (minutes)	**Maximum crushing strength** (MPa)					
		1 day	**3 day**	**5 day**	**7 day**	**14 day**	**28 days**
NF1**	10	2.24	1.71	1.57	2.28	2.37	2.44
	15	2.03	1.07	1.5	1.03	1.67	2.05
	20	1.35	1.05	1.64	1.43	1.56	1.63
NF2**	10	3.49	4.11	3.99	4.10	4.66	4.68
	15	4.01	4.01	4.63	5.58	4.32	5.20
NF3**	10	6.21	6.85	7.27	6.32	4.98	7.56
	15	8.52	8.77	7.36	7.8	9.72	9.89
NC1**	10	4.02	4.9	4.15	4.69	5.07	5.23
	15	4.88	5.21	5.98	5.4	7.63	7.87
	20	5.54	5.01	6.75	5.61	6.63	7.02
NC2**	10	4.27	7.06	4.13	5.24	4.84	5.13
	15	6.98	7.02	5.98	7.64	6.62	7.91
	20	3.84	3.63	3.76	6.27	6.54	6.89
NC3**	10	9.49	10.11	10.09	8.34	13.52	13.72
NL1**	10	0.89	0.99	1.28	1.27	1.35	1.75
	15	1.6	1.83	1.11	1.92	1.72	1.98
NL2**	10	0.87	1.19	1.35	0.98	1.12	1.23
	15	1.0	1.04	0.75	0.86	1.02	1.12
NL3**	10	0.7	0.97	1.41	1.21	1.35	1.45
	15	1.13	1.38	1.41	1.28	1.38	1.57
	20	1.43	1.52	1.18	1.55	1.58	1.65
C1*	10	0.45	0.68	1.12	1.49	1.73	2.32
	15	0.26	0.34	0.44	0.57	0.89	0.78
C2*	10	1.02	1.18	1.22	1.23	2.48	2.05
	15	0.34	0.56	0.60	0.67	0.93	1.52
C3*	10	2.56	3.14	3.18	3.22	3.55	3.48
	15	3.11	3.48	3.42	3.41	4.29	4.63
L1*	10	0.12	0.15	0.18	0.2	0.43	0.55
	15	0.09	0.12	0.13	0.15	0.2	0.25
L2*	10	0.1	0.24	0.32	0.47	0.7	0.98
	15	0.13	0.22	0.28	0.32	0.41	0.55
L3*	10	0.1	0.23	0.45	0.92	1.54	1.59
	15	0.21	0.58	0.76	1.49	1.52	2.24

Note: ** - Oven curing at 100ºC, * - Normal water curing

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Table-6. Mean crushing strength for various size of fly ash aggregate at 7 days curing.

Type of aggregate	Duration: minutes / Mean diameter (mm)	Mean crushing strength (MPa)										
		10 to 11	**11 to 12**	**12 to 13**	**13 to 14**	**14 to 15**	**15 to 16**	**16 to 17**	**17 to 18**	**18 to 19**	**19 to 20**	**20 to 21**
NF1	10	0.47	-	0.44	0.88	2.28	-	1.21	1.74	1.38	1.39	0.90
	15	-	1.03	0.69	1.89	-	-	-	0.73	0.23	-	0.23
	20	-	-	1.3	1.43	1.11	1.15	0.49	-	-	-	-
NF2	10	-	2.51	3.03	4.1	3.71	4.00	3.76	2.91	-	-	-
	15	-	-	5.58	3.45	3.51	5.12	3.86	4.32	3.13	-	-
NF3	10	-	-	6.32	5.9	5.21	2.45	-	5.73	4.81	-	-
	15	4.73	5.55	6.16	7.8	5.68	6.53	4.81	-	-	-	-
NC1	10	3.23	4.4	4.69	3.65	3.48	1.88	-	-	-	-	-
	15	-	-	-	5.4	5.15	4.89	3.32	-	-	-	-
	20	5.61	4.23	5.50	4.81	3.77	3.95	4.42	-	-	-	-
NC2	10	5.24	3.40	3.50	1.99	-	-	-	-	-	-	-
	15	-	-	5.35	7.64	6.98	2.81	4.27	-	-	-	-
	20	6.26	6.27	-	5.87	-	-	4.82	-	-	-	-
NC3	10	6.58	7.90	6.32	8.34	4.38	3.87	4.25	-	2.84	3.53	1.77
NL1	10	-	-	-	0.92	1.92	1.23	1.04	0.78	-	-	-
	15	-	-	-	0.89	-	0.50	1.28	0.65	0.73	0.66	-
NL2	10	-	-	-	-	0.77	0.70	0.94	0.97	-	-	0.98
	15	-	-	-	-	-	-	0.86	0.77	0.71	-	0.26
NL3	10	-	-	-	0.39	-	0.33	0.57	1.21	0.70	0.67	0.49
	15	-	-	-	-	0.62	1.28	0.48	-	0.65	-	0.44
	20	-	-	0.52	-	-	0.51	0.75	0.32	0.88	1.55	0.85
C1	10	-	0.73	-	1.33	1.31	1.49	1.21	1.06	1.08	-	-
C2	10	-	-	-	-	-	0.75	1.33	1.05	1.23		0.44
C3	10	2.76	3.22	2.94	2.48	2.38	2.64	-	-	-	-	-
	15	-	3.30	2.79	3.41	2.44	2.71	-	-	-	-	-
L1	10	-	-	-	-	-	0.18	0.55	0.27	0.38	0.33	0.21
	15	-	-	-	-	-	-	-	-	0.19	0.2	0.21
L2	10	-	-	0.63	0.56	0.65	0.7	0.49	0.17	-	-	-
	15	-	-	0.21	0.37	0.35	0.38	0.40	0.37	0.39	0.41	-
L3	10	-	0.86	0.74	0.86	0.68	0.92	0.27	-	-	-	-
	15	0.92	1.49	0.86	0.95	0.88	0.59	-	-	-	-	-

Note: - denotes the aggregate size was unavailable in that specified range for crushing test

Also, the flyash aggregates containing cement binder and alkali (NC3) reported highest strength of 13.72 Mpa (as seen in Figure-8). Depending on the type of binder used in the aggregate, the crushing strength of fly ash-cement aggregates with 8M of NaOH (NC1) aggregate were found higher than the fly ash without binder and 8M of NaOH (NF1). A strength increase of 66.14% was observed for longer duration (15 minutes) of pelletization in the case of lime binder with 8M of NaOH (NL1) than for 10 minutes pelletization duration at 7 days strength (as seen in Figure-9). Also, a maximum strength gain of 96.3% was reported for 20 minutes duration of pelletization in the case of flyash aggregates with cement binder and 8M of NaOH (NC1). The addition of NaOH added in the various type of aggregate were found to improve the strength and efficiency of pelletization; cement with 12M of NaOH (NC3) aggregate showed higher strength as compared to cement with 10M and 8M of NaOH (NC2 and NC1) for 10 minutes duration at 7 days curing (Figure-9). Also, fly ash aggregates containing 12M of NaOH (NF3) without binder exhibited a 7.8 MPa strength which was greater than the strength of flyash aggregate with 8M of NaOH (NF1) as well as 10M of NaOH (NF2). It can be concluded that the ternary blends of flyash -cement and lime has yielded higher crushing strength with higher concentration (12M) of NaOH. Also, compared to normal hydration of cement, the rate of hardening by means of geo-polymerisation had resulted in higher strength (9.49 MPa) for the mix containing fly ash with alkali (NC3) at early age of oven curing (1 day). In addition to this, effective geo-polymerisation occurs under hot air oven curing at 100^{o}C. However a maximum strength was reported for fly ash aggregate containing cement binder kept under normal water curing (Figure-10). It can be concluded that the strength gain as a result of geo-polymerization by adding sodium hydroxide in flyash aggregates was faster than the setting due to cement hydration. Also, compared to the normal curing method (water and air drying) the strength gain in hot air oven curing was much effective.

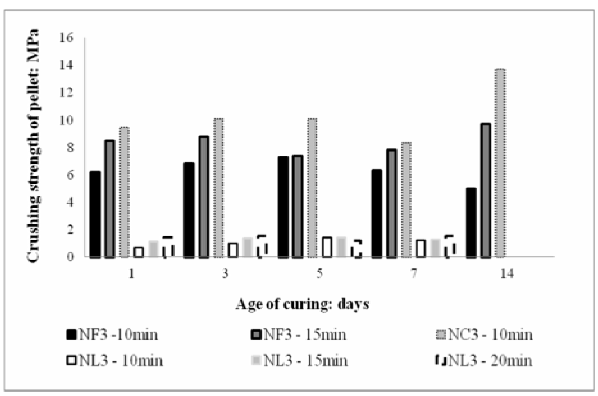

Figure-8. Crushing strength of various type of fly ash aggregate at 12M of NaOH for different curing days.

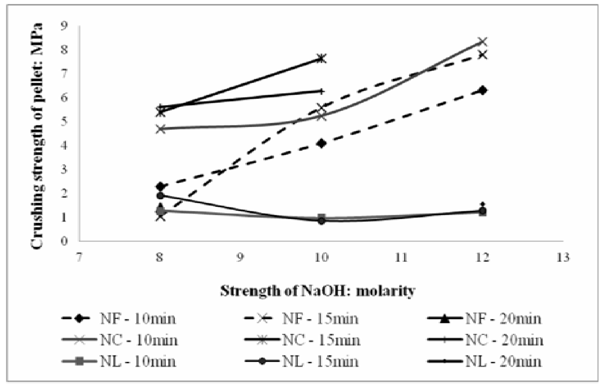

Figure-9. Variation of crushing strength of various type of fly ash aggregate at 8M, 10M and 12M of NaOH at 7 days curing.

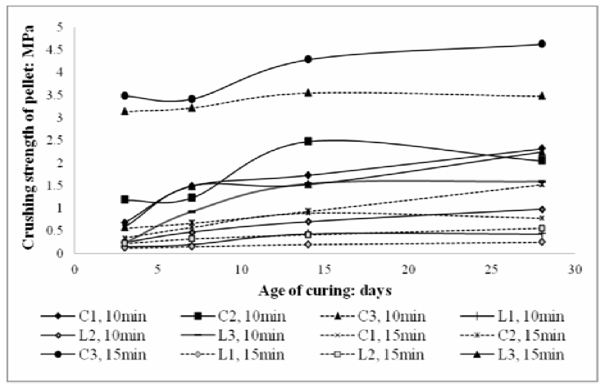

Figure-10. Crushing strength of fly ash aggregate without alkali activator at normal water curing.

4. CONCLUSIONS

The following conclusions are made from the experimental study on the different types of fly ash aggregate:

a) Aggregate production efficiency increases with the duration of pelletization process; due to increased agglomeration mechanism which leads to more uniform shape and size of aggregates.
b) Compared to flyash aggregates with cement binder, the ternary blends of flyash - cement-lime exhibited higher production efficiency as well as higher strength.
c) The addition of NaOH in flyash aggregates provided higher strength at shorter curing time with reduced water absorption.
d) The strength of flyash aggregates (NC3) were found to be higher (13.72 MPa) when the mean size of aggregates is 13.53 mm and lower (0.8 MPa) when the size of aggregates is maximum 26.68 mm.
e) The crushing strength of the pellets was improved with the addition of cement binder as compared to lime binder and further increase was observed with the addition of NaOH at higher concentration (12M).

f) The strength of aggregates containing flyash and cement binder at 12M of NaOH recorded a maximum strength of 13.72 MPa at 14 days oven curing with minimum water absorption of 13.33%.
g) An optimum size and shape of aggregates were formed between 10 to 15 minutes pelletization duration and showed the maximum bulk density (942.68 kg/m^3) in the case of flyash aggregates with cement binder (NC3).
h) It can be concluded that for all flyash aggregates with binder, the addition of NaOH at higher concentration (12M) exhibited higher strength gain due to geopolymerisation reaction and rate of hardening was effective when the specimens were cured at higher temperature (hot air oven at 100^{o}C).

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