Journal of Civil Engineering and Construction Technology Vol. 3(2), pp. 42-48, February 2012
Available online at http://www.academicjournals.org/JCECT
DOI: 10.5897/JCECT11.088
ISSN 2141-2634 ©2012 Academic Journals

Review

Pelletized fly ash lightweight aggregate concrete: A promising material

A. Sivakumar* and P. Gomathi

VIT University, India.

Accepted 28 December, 2011

The production of concrete requires aggregate as an inert filler to provide bulk volume as well as stiffness to concrete. Crushed aggregates are commonly used in concrete which can be depleting the natural resources and necessitates an alternative building material. This led to the widespread research on using a viable waste material as aggregates. Fly ash is one promising material which can be used as both supplementary cementitious materials as well as to produce light weight aggregate. Artificial manufactured lightweight aggregates can be produced from industrial by-products such as fly ash, bottom ash, silica fume, blast furnace slag, rice husk, slag or sludge waste or palm oil shell, shale, slate, clay. The use of cost effective construction materials has accelerated in recent times due to the increase in the demand of light weight concrete for mass applications. This necessitates the complete replacement or partial replacement of concrete constituents to bring down the escalating construction costs. In recent times, the addition of artificial aggregates has shown a reasonable cut down in the construction costs and had gained good attention due to quality on par with conventional aggregates.

Key words: Fly ash, aggregate, pelletizer, lightweight concrete.

INTRODUCTION

Presently in India the power sector depends on coal based thermal power stations which produces a huge amount of fly ash and estimated to be around 110 million tonnes annually. The utilization of fly ash is about 30% as various engineering properties requirements that is for low technical applications such as in construction of fills and embankments, backfills, pavement base and sub base course; intermediate technical application such as in producing blended cement, concrete pipes, precast/ prestressed products materials, lightweight concrete bricks/blocks, autoclaved aerated concrete and lightweight aggregate (Baykal and Doven, 2000). Lightweight concrete is produced in different categories based on the no-fines concrete, aerated cellular concrete and lightweight aggregate concrete. With increasing concern over the excessive exploitation of natural aggregates, synthetic lightweight aggregate produced from environmental waste is a viable new source of structural aggregate material. The uses of structural grade lightweight concrete reduce considerably the self-load of a structure and permit larger precast units to be handled. For example the Autoclaved cellular concrete (ACC), is a lightweight concrete material, which can be manufactured using 60 to 75% fly ash by weight (Ahmaruzzaman, 2010).

One of the common techniques while producing the lightweight aggregate is by agglomeration technique. In agglomeration technique the pellet is formed in two ways either by agitation granulation and compaction. The agitation method is not taking any external force rather than rotating force. With increase in the dosage of water in the binder the cohesive force of the particles increase. Sintering, auto claving and cold bonding are three different processes to harden the green pellet (Bijen, 1986). The partial replacement of normal weight aggregate is 20 to 40% by the volume of lightweight aggregate with difference of the compressive strength as 1% only (Behera et al., 2004). This paper is to review on the application of using fly ash lightweight aggregate based on the cost, which method to fallow for manufacturing

---

*Corresponding author. E-mail: sivakumara@vit.ac.in.

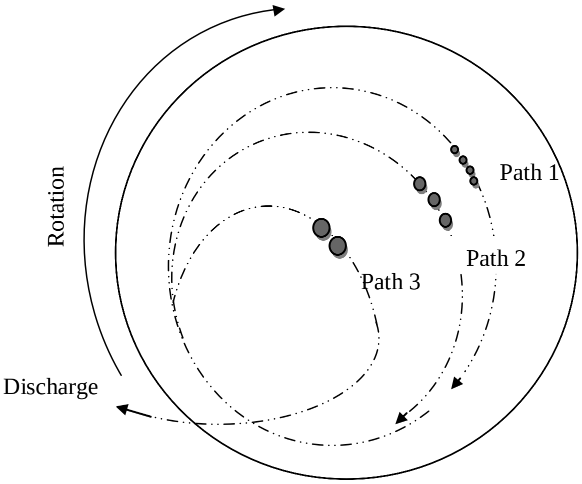

Figure 1. Growing path of pellets (Bijen, 1986).

Figure 2. Disc pelletizer machine.

LWA, mix proportions, strength improving physical and mechanical properties of lightweight aggregate concrete. Lightweight aggregate concrete is used for structurally lightweight structure, it reducing the density of concrete also over all weight of the structure.

PELLETIZING PROCESS

The desired grain size distribution of an artificial lightweight aggregate is either crushed or by means of agglomeration process. The pelletization process is used to manufacture lightweight coarse aggregate; some of the parameters need to be considered for the efficiency of the production of pellet such as speed of revolution of pelletizer disc, moisture content, angle of pelletizer disc and duration of pelletization (Harikrishnan and Ramamurthy, 2006). The different types of pelletizer machine were used to make the pellet such as disc or pan type, drum type, cone type and mixer type. With disc type pelletizer the pellet size distribution is easier to control than drum type pelletizer. With mixer type pelletizer, the small grains are formed initially and are subsequently increased in particle size by disc type pelletization (shown in Figure 1, Bijen, 1986). The disc pelletizer size is 570 mm diameter and side depth of the disc as 250 mm, it is fixed in a flexible frame with adjusting the angle of the disc as 35 to 55° and to control for the rotate disc in vertically manner should varying speed as 35 to 55 rpm shown in Figure 2 (Manikandan and Ramamurthy, 2007). In a cold bonded method is to made the increase the strength of the pellet as to increase the fly ash/cement ratio as 0.2 and above (by weight) (Yang, 1997). Moisture content and angle of the disc parameter influence the size growth of pellets (Harikrishnan and Ramamurthy, 2006). The dosage of binding agent is more important for making flyash balls and the optimum range was found to be around 20% to 25% by the total weight of binders (Bijen, 1986). Initially some percentage of water is added in the binder and then poured in a disc; remaining water is sprayed during the rotating period because while rotating without water in the disc the fly ash powder tends to form lumps and does not increase the distribution of particle size. The pellets are formed approximately in duration of 20 min.

HARDENING PROCESS IN LWA

The two major classes of fly ash are specified in ASTM C 618, namely class-C and class-F classified based on the chemical composition resulting from the different types of coal burning. Class-C fly ash is normally produced from the burning of sub-bituminous coal and lignite and class-C fly ash. The flyash aggregates are porous material and to improve the strength of the pellet the binder material like cement, lime, bentonite, metakaolin, kaolinite, glass powder and ceramic powders are added. The clay binders like metakaolin and kaolinite gives higher fines value (Geetha and Ramamurthy, 2011). The percentage of binder content is taken by the weight of fly ash. Hardening the pellets is done by various process namely cold bonding, sintering and autoclaving. Cold-bonded fly ash aggregates are hardened by different curing process namely normal water curing, steam curing and autoclaving. Autoclave and steam curing method is less effective to improve the properties of aggregate as compare to normal water curing method. Among accelerated cured class c fly ash aggregate, autoclaved aggregates has properties closer to the normal water cured aggregate due to the dense microstructure formation. The curing method is more important to enhance the aggregate strength. Hence, a normal water curing method can be adopted and autoclaving may be adopted for high-early strength (Manikandan and Ramamurthy, 2008). A higher strength of the aggregate can be obtained at 8 to 10 h in autoclave curing (Bekir and Tayfun, 2007).

Sintering process can be defined as burning the cold bonded pellet in a muffle furnace at temperature range of 800 to 1200°C. The mineral particles in the binder fuse together to form the crystalline structure (CSH) and results in higher strength of the aggregate. Therefore sintered fly ash lightweight aggregate production is more convenient while replacing the normal weight aggregate to lightweight aggregate (Verma et al., 1998).

MIX DESIGN OF LWAC

The mix design of lightweight aggregate concrete is not same as the conventional concrete mix design. Since the aggregates are porous and results in compensation of extra water for obtaining more workability. The mix design concepts are usually based on the production of higher strength matrix to low water cement ratio for the weaker aggregate. Therefore in ordinary concrete, the number of batches that are necessary to determine the best composition can be reduced to a minimum. But in a Lightweight aggregate concrete mix design more complicated for adding of water, LWA is a porous aggregate so we need extra water in the concrete (Grubl, 1979). The gradation of aggregate with different aggregate grading size distributions are required to improve the engineering properties in the concrete mix (Sari and Pasamehmetoglu, 2005).

The self-consolidating properties of lightweight aggregate concrete can be obtained by means of densified mixture design algorithm (DMDA) which gives higher strength, flow-ability and excellent durability as compared to the ACI 211.11 method (Chao-Lung and Meng-Feng, 2005). The design of lightweight aggregate are followed in two methods; loose volume calculation and absolute solid volume calculation (Wang et al., 2005). In mix proportion the LWA are mixed in different status while fully saturated condition, partially saturation condition and dry condition. The lightweight aggregate is pre-wetting before addition of concrete mix. The Polyurethane (PUR) foam waste as a lightweight aggregate were prepare before mixing in a concrete mix while LWA were immersed in water of 24 h to improve the workability of concrete (Amor et al., 2010). The selection of sand-aggregate ratio is 28 to 42% in the mix proportion, which can influence the compressive strength and regulate the workability of concreter (Wang et al., 2005).

The strength of concrete is equal to the effective water to binder ratio which is chosen as 0.26. The quantity of the ingredients can be selected the volume of coarse aggregate to total volume of aggregate ratio as 0.6; based on the cold-bonded fly ash aggregate the quantity of cement content as 551 kg/m^3 greater than sintered fly ash aggregate as around 548 kg/m^3. Both type of lightweight aggregate concrete had shown the higher compressive strength (Niyazi and Turan, 2011). Lightweight concrete incorporating the bottom ash and the sintered fly ash in the concrete should increase the permeability; by replacing 30% of OPC with fly ash, to improve the permeability of LWC (Yun Bai et al., 2004). Addition of admixture in the lightweight concrete is to increase the strength and elastic modulus. The addition of silica fume at 5 to 15% in the LWC can improve the strength properties while, replacements of 10% fly ash instead of cement in concrete can decrease strength as compared to without fly ash (Shannag, 2011). A detailed mix proportion of light weight aggregate concrete adopted in different studies are given in Table 1.

PHYSICAL PROPERTIES OF LWAC

The physical characteristics of the lightweight aggregate produced by pelletization are given in Table 2 (Bijen, 1986). The moisture content and amount of binder can affect the size of fly ash aggregates thus formed. The fineness of the fly ash (414 m^2/kg) gives the better pelletization efficiency compared to the coarser fly ash (257 m^2/kg). Therefore finer fly ash needs the addition of the binder material and the addition of clay binder in the coarser fly ash will increase the pelletizing efficiency (Manikandan and Ramamurthy, 2007). The specific gravity of fly ash lightweight aggregate is increase without adding binder and it's a denser structure. The addition of bentonite and glass powder in fly ash is to reducing the specific gravity as compare to lime and cement binder in fly ash (Ramamurthy and Harikrishnan, 2006).

Density of LWAC

The properties of lightweight aggregate can be improved with the addition of different binder at various percentage. Therefore, the percentage of binder increased vice versa density increase. Density of sintered fly ash aggregate with binder is decreased while increased the temperature range between 1150 to 1200°C. The bentonite and glass powder binder is melted and bloating firmly for rising temperature and the glassy particle filled the voids in a crystal form to improve the strength (Niyazi and Turan, 2011). The difference between the density of the pre-wetting and without pre-wetting PUR lightweight aggregate concrete is lower than 12 Kg/m^3 (Amor et al., 2010). The density of shell aggregate is 28% lower than the normal aggregate (Okafor, 1988)

POZZOLANIC REACTIVITY OF LWA MADE WITH FLY ASH

A pozzolanic reaction occurs between dissolved minerals

Table 1. Mix proportion of LWAC ingredients studied from various literatures.

Author	Concrete type	W/b ratio	Cement content (kg/m^3)	Fine aggregate content (kg/m^3)		V_{CA}/V_{TA} ratio	Light weight aggregate content (kg/m^3)	AEA (%)	Admixtures (%)	
				Natural sand	Crushed sand				FA-F	SP
Yannick et al., 2006	LWAC	0.27	475.6	674.4	-	0.6	546.6	-	158.7	-
		0.34	335.3	728.9	-		612.4		110.6	
		0.28	391.2	734.0	-		540		107.0	
Niyazi, 2011 (Niyazi and Turan, 2011)	CLWC	0.26	551	318	318	0.6	592	0.2	-	1.1
	LWBC		548	316	317		567			
	LWGC		549	317	317		580			
Wasserman and Bentur, 1997	SLWAC	0.4	440	49%		0.51	51%	-	-	-

from glass and calcium from portlandite. Hydroxyl ions break down the silica in the glass, which in turn react with the calcium in the portlandite to form CSH paste. This reaction increases the bond strength between the aggregate and the cement matrix. Since an artificial fly ash lightweight aggregate are porous structure and it composed of glass phase, pozzolanic reaction expected on the surrounding of this aggregate. Commonly in fly ash two type of carbonaceous fragment matter (Nambu et al., 2007). The reduction of CH occurs during the sintering process of flyash aggregate at higher temperature (900°C) (Weasserman and Bentur, 1997).

STRENGTH PROPERTIES

The cement, lime and bentonite are used as a binder in 10, 20 and 30% by weight of fly ash for pelletization. It is also observed that the improvement in the 10% fines value and reduction in water absorption of sintered fly ash aggregate. For 10% fineness is used to test strength of lightweight aggregate. The addition of bentonite is to enhance the aggregate strength, cement is to give minimum strength and the lime is for improving the ballability. Therefore, the addition of 20% bentonite gives an optimal strength (Ramamurthy and Harikrishnan, 2006)

The strength of the LWAC with various binder content improves the strength properties of aggregate and given in Table 3. The compressive strength of polypropylene fiber reinforced SLWC is higher than the steel fiber reinforced by 7 Mpa (Kayali et al., 2003). Fiber reinforced concrete increase the tensile strength with low modulus of elasticity as well as reducing the shrinkage cracking in LWAC (Kayali et al., 1999). The lightweight aggregate manufactured using pelletizing process gives a smooth surface after sintering process. The sintered fly ash aggregate (FAA) were crushed that is not invove pelletizing, the structure gives a rough surface and enhancing the compressive strength as 66.76 Mpa (Kayali, 2008).

Expanded clay lightweight aggregate has higher porosity in the transition zone which may show significant effect on the permeability of lightweight concrete. The pre-wetting time of expanded clay lightweight aggregate were critically affected the strength and slump of the concrete (Lo et al., 1999). The pore structure of the sintered pulverized fuel ash lightweight aggregate is approximate range of the pore size from 200 µm down to less than 1µm with all the size had been evenly distributed throughout the pellet and gives the better bond between the pellets and cement matrix (Swamy and Lambert, 1981)

The high resolution optical microscope and image analysis software were used to find out the pore area percentage and pore size distribution in the cement paste and the interfacial zone of concrete cured at 28 days. The transition zone is a weak zone of more porous in nature between the aggregate and cement matrix. The experimental results of lightweight aggregate show large water absorption range from 8.9 to 11% which produce greater pore percentage as 14.4 and 21.7% at the interfacial zone (Lo et al., 2006).

Therefore, lightweight aggregate is more porous from the outer layer and it present dense interfacial zone for the aggregate without any outer layer. So that the aggregate gives better bond appeared due to the mechanical interlocking

Table 2. Physical characteristics of pelletized aggregates from various literatures.

Authors	Type of LWA used	Specific gravity of LWA		BD (Kg/m^3)		Voids (%)		Water absorption (%)		Crushed strength of pellet (Mpa)
		SSD	OD	LBD	RBD	LV	RV	24	48	
Niyazi and Turan, 2011	CLWA	1.63	1.3	789	842	39.2	35.1	-	25.5	3.7
	SFA+1200+10B	1.57	1.56	933	993	40.1	36.2	-	0.7	12
	SFA+1200+10G	1.6	1.59	936	936	41	37	-	0.7	9.6
Ramamurthy, 2006	SFA+20B	-	1.83	850	-	-		15.8	-	-
Amor et al., 2010	Polyurethane foam waste LWA	45		21		13.9		-		-
Chi et al., 2003	CLWA	1.76	1.44	972		-		20.8		8.57

Table 3. Mechanical properties of lightweight aggregate concrete from various literatures.

Author	Concrete type	Comp strength (Mpa)		Split tensile strength (Mpa)		Modulus of elasticity (Gpa)	
		28 d	56 d	28 d	56 d	28 d	56 d
Byung-Wan et al., 2007 (Chi et al., 2003)	AFLAC	26.7	-	-	-	-	-
Kayali et al., 2003 (Behera, 2004)	SFAC	68.0	-	6.6	-	25	-
Santish and Leif, 1983 (Chao-Lung and Meng-Feng, 2005)	LWAC	20.4	-	-	-	-	-
Niyazi and Turan, 2011	SFA+1200+10G	55.8	60.4	4.9	5.1	25.7	25.9
	SFA+1200+10B	53.5	59.5	4.8	5.1	26.0	26.3
	LWCC	42.3	44.6	3.7	3.9	19.6	19.7
Kayali, 2008 (Grubl, 1979)	FAA	66.75	-	3.75	-	25.5	-

AFLAC – Alkali-activated fly ash lightweight aggregate concrete; SFAC – Sintered fly ash aggregate concrete; SFA+1200+10G – Sintered fly ash aggregate with 10% glass powder at 1200°C temperature; SFA+1200+10B - Sintered fly ash aggregate with 10% bentonite at 1200°C temperature; LWCC – Cold-bonded fly ash lightweight aggregate concrete; FAA - Fly ash aggregate manufacture by using sintering without pelletizing aggregate and the procedure is same. That aggregate are crushed in briquette and fired in a kiln.

between aggregate and the cement paste (Min-Hong and Gjorv, 1990). The use of silica fume for adding in LWC is to improve the mechanical properties, but disadvantage of shrinkage performance is less compared to normal weight concrete (Mehmet et al., 2004).

MICROSTRUCTURAL CHARACTERISTICS OF FLYASH AGGREGATE CONCRETE

The mechanical behavior and durability aspects of concrete affected by its aggregate and cement paste as well as the interfacial zone between them. Normal weight concrete the aggregate-cement paste interface is the weakest part of the micro-structural system and the place where cracks begins, strongest component that is normal aggregate (Min-Hong and Gjorv, 1990). But, the lightweight aggregate concrete is different to the

Table 4. Durability properties of different lightweight aggregate concrete.

Authors	Concrete type	Chloride penetration test (coulombs)		Water permeability test (mm)		Accelerated Corrosion test (days)		Freezing and thawing resistance	
								Air entrainment	
		28 d	56 d	28 d	56 d	28 d	56 d	4%	6%
(Niyazi and Turan, 2011)	LWCC	1464	748	36	79	28	49	-	-
	LWBC	586	264	19	39	123	-	-	-
	LWGC			23	41	106	-	-	-
Byung-Wan et al., 2007	ALWA	-		-	-	-	-	78	92

interaction between the cement paste-aggregate is complex and it's vary to the normal aggregate concrete. This type of aggregate are porous in nature, the grains are capable of absorbing water which yielded to the surrounding matrix. The porosity of Lytag aggregate can vary between 25 to 75% depending on the manufacturing process used (Swamy and Lambert, 1981). Many more research work to indentify the internal and external structure of lightweight aggregate, particularly cement matrix- aggregate interface carried out (Shondeep et al., 1992). For applied micromechanical method considered the perfect bonding between the aggregate and mortar (Chung-Chia and Ran, 1998).

Normally sintered fly ash lightweight aggregate were produced by heat and polymer treatment so that to improve their strength, absorption and pozzolanic activity according to their properties of aggregate by change to the microstructure. SEM analysis to observe the higher magnification to see more uniform distribution of small pore size in the sintered fly ash aggregate at the temperature treated aggregate as 1200 to 1300°C (Weasserman and Bentur, 1997). Mechanical interlocking plays an important role for strengthening the interface (Shondeep et al., 1992). The effect of aggregate using is dry and prewetting lightweight aggregates on the ITZ microstructure. The thickness of ITZ around the dry aggregate is 10 µ less than the other prewetted and normal aggregate as 15 µ and beyond 35 µ respectively (Amir Elsharief et al., 2005).

DURABILITY PROPERTIES OF HARDENED CONCRETE

Durability of concrete essentially dictates the permeability resistance of concrete and needs to be assessed for long time sustainability. The durability properties of lightweight aggregate concrete is given in Table 4. Permeable concrete is significantly attack the concrete ingredients and accumulate water inside of concrete it caused deterioration of concrete and reinforcement. Normally permeable of water and chloride will be decrease when increase the age of concrete but in lightweight aggregate concrete will be more permeable than normal concrete. To carry out the chloride penetration test for LWBC gives the best performances compare to other type of lightweight aggregate concrete. Sintering lightweight aggregate concrete showed the low permeablity except cold-bonded lightweight aggregate at 28days. Sintering and cold-bonded aggregate has highest chloride permeability with total charge passed values of 1464 and 586 coulombs at 28 days and 748 and 264 coulombs at 56 days (Niyazi Ugur Kockal and Turan Ozturan, 2011). A sintered lightweight aggregate with bentonite is less water permeable compare to normal aggregate concrete. Almost glass powder, bentonite binder adding in the sintering aggregate which gives the best performance of water permeability test. In a cold-bonded process the water permeability is more than sintered process (Niyazi Ugur Kockal and Turan Ozturan, 2010; Niyazi Ugur Kockal and Turan Ozturan, 2011). The durability factor of the 4% air entrainment specimen gives the marginal freezing and thawing was 78 with compare to the 6% air entrainment specimen gives the good freeze-thaw resistance was 92 (Byung-Wan Jo et al., 2007).

CONCLUSION

The potential applications of light weight aggregate are more phenomenal in terms of the usage as new construction materials. Cost effective construction practices with alternate construction materials are most desired in terms of huge savings in construction cost. Fly ash is not a waste and can be effectively used in concrete either as aggregate fillers, replacement for fine aggregates or as a fly ash brick material. The overall studies conducted by various researches shown that the fly ash aggregate produced by pelletization can be an effective aggregate in concrete production. Also, the efficiency of pelletization depends on the speed of the pelletizer, angle of the pelletizer and the type of binder added along with the fly ash. The cost effective and simplified production techniques for manufacturing fly ash aggregate can lead to mass production and can be an ideal substitute for the utilization in many infrastructural projects. In the near future the depletion of the nature resources for aggregate can be suitably compensated from the fly ash aggregate.

REFERENCES

Ahmaruzzaman M (2010). A review on the utilization of fly ash. Prog. Energy Combustion Sci., 36: 327-363.

Amir Elsharief, Menashi D Cohen, Jan Olek (2005). Influence of Lightweight Aggregate on the Microstructure and Durability of Mortar. Cement Concrete Res., 35: 1368-1376.

Amor Ben Fraj, Mohamed Kismi, Pierre Mounanga (2010). Valorization of coarse Rigid Polyurthane Foam Waste in Lightweight Aggregate Concrete. Constr. Build. Mater., 24: 1069-1077.

Behera JP, Nayak BD, Ray HS, Sarangi B (2004). Lightweight Weight Concrete with Sintered Fly ash Aggregate: A Study on Partial Replacement to Normal Granite Aggregate. IE (I) Journal-CV., 85: 84-87.

Bekir Ilker Topcu, Tayfun Uygunoglu (2007). Properties of Autoclaved Lightweight Aggregate Concrete. Build. Environ., 42: 4108-4116.

Bijen JMJM (1986). Manufacturing processes of artificial lightweight aggregates from fly ash. Int. J. Cement Composit. Lightweight concrete. 8(3): 191-9.

Byung-Wan Jo, Seung-Kook park, Jong-bin Park (2007). Properties of concrete made with alkali-activated fly ash lightweight aggregate (AFLA). Cement Concrete Composit., 29: 128-135.

Chao-Lung Hwang, Meng-Feng Hung (2005). Durability design and performance of self-consolidating lightweight concrete. Constr. Build. Mater., 19: 619-626.

Chi JM, Huang R, Yang CC, Chang JJ (2003). Effect of Aggregate Properties on the Strength and Stiffness of Lightweight Concrete. Cement Concrete Composit., 25: 197-205.

Chung-Chia Yang, Ran Huang (1998). Approximate Strength of Lightweight Aggregate using Micromechanics Method. Adv. Cement Based Mater., 7; 133-138.

Geetha S, Ramamurthy K (2011). Properties of Sintered Low Calcium Bottom Ash Aggregate with Clay Binders. Constr. Build. Mater., 25: 2002-2013.

Grubl P (1979). Mix Design of Lightweight Aggregate Concrete for Structural Purposes. Int. J. Lightweight Concrete, 1(2): 63-69.

Harikrishnan KI, Ramamurthy (2006). Influence of Pelletization Process on the Properties of Fly Ash Aggregates. Waste Manag., 26: 846-852.

Kayali O (2008). Fly ash lightweight aggregates in high performance concrete. Constr. Building Mater., 22: 2393-2399.

Kayali O, Haque MN, Zhu B (1999). Drying shrinkage of Fibre reinforced lightweight aggregate concrete containing fl ash. Cement Concrete Res., 29: 1835-1840.

Kayali O, Haque MN, Zhu B (2003). Some characteristics of high strength fiber reinforced lightweight aggregate concrete. Cement Concrete Composit., 25: 207-213.

Lo Tommy Y, Cui HZ, Tang WC, Leung WM (2006). The effect of aggregate absorption on pore area at interfacial zone of lightweight concrete. Constr. Build. Mater., 22: 623-628.

Lo Y, Gao XF, Jeary AP (1999). Microstructure of pre-wetted aggregate on lightweight concrete. Build. Environ., 34: 759-764.

Manikandan R, Ramamurthy K (2007). Influence of fineness of fly ash on the aggregate pelletization process. Cement Concrete Composites, 29: 456-464.

Manikandan R, Ramamurthy K (2008). Effect of Curing Method on Characteristics of Cold Bonded Fly Ash Aggregate. Cement Concrete Composites, 30: 848-853.

Mehmet Gesoglu, Turan Ozturan, Erhan Huneyisi (2004). Shinkage Cracking of Lightweight Concrete made with Cold-bonded Fly ash Aggregates. Cement Concrete Res., 34: 1121-1130.

Min-Hong Zhang, Gjorv Odd E (1990). Microstructure of the interfacial zone between lightweight aggregate and cement paste. Cement Concrete Res., 20: 610-618.

Nambu Masateru, Kato Masahiro, Anosaki Takao, Nozaki Kenji, Ishikawa Yoshitaka (2007). Pozzolanic Reactions between natural and Artificial Aggregate and the Concrete matrix. World of Coal ash.

Niyazi Ugur Kockal, Turan Ozturan (2010). Effects of lightweight fly ash aggregate properties on the behavior of lightweight concretes. J. Hazard. Mater., 179: 954-965.

Niyazi Ugur Kockal, Turan Ozturan (2011). Charecteristics of lightweight fly ash aggregates produced with different binders and heat treatments. Cement Concrete Composites, 33: 61-67.

Niyazi Ugur Kockal, Turan Ozturan (2011). Durability of lightweight concretes with lightweight fly ash aggregates. Constr. Build. Mater., 25: 1430-1438.

Niyazi Ugur Kockal, Turan Ozturan (2011). Optimization of Properties of Fly ash Aggregates for High-strength Lightweight Concrete Production. Mater. Des., 32: 3586 - 3593.

Niyazi Ugur Kockal, Turan Ozturan (2011). Strength and Elastic Properties of Structural Lightweight Concretes. Mater. Des., 32: 2396-2403.

Okafor OF (1988). Palm Kernel Shell as a Lightweight Aggregate for Concrete. Cement Concrete Res., 18: 901-910.

Ramamurthy K, Harikrishnan KI (2006). Influence of binders on properties of sintered fly ash aggregate. Cement Concrete Composit., 28: 33-38.

Santish Chandra, Leif Berntsson (1983). Technical notes: Influence of polymer microparticles on acid resistance of structural lightweight aggregate concrete. Inter. J. Cement Composit. Lightweight Concrete, 5(2): 127-131.

Sari D, Pasamehmetoglu AG (2005). The effects of gradation and admixture on the pumice lightweight aggregate concrete. Cement Concrete Res., 35: 936-942.

Shannag MJ (2011). Characteristics of Lightweight Concrete Containing Mineral Admixtures. Constr. Build. Mater., 25: 658-662.

Shondeep L Sakar, Satish Chandra, Leif Berntsson (1992). Interdepence of Microstructure and strength of Structural Lightweight Aggregate Concrete. Cement Concrete Composites, 14: 239-248.

Swamy RN, Lambert GH (1981). The microstructure of Lytag aggregate. Int. J. Cement Composit. Lightweight Concrete, 3(4): 273-282.

Verma CL, Handa SK, Jain SK, Yadaw RK (1998). Techno-commercial perspective study for sintered fly ash light-weight aggregates in india. Constr. Build. Mater., 12: 341-346.

Wang Lijiu, Zhang Shuzhong, Zhao Guofan (2005). Investigation of the Mix Ratio Design of Lightweight Aggregate Concrete. Cement Concrete Res., 35: 931-935.

Wasserman R, Bentur A (1997). Effect of Lightweight Fly ash Aggregate Microstructure on the Strength of Concretes. Cement Concrete Res., 27(4): 525-537.

Yun Bai, Ratiyah Ibrahim, Muhammed Basheer PA(2004). Properties of Lightweight Concrete Manufactured with Fly ash, Furnace Bottom ash and Lytag. International Workshop on Sustainable Development and Concrete Technology. pp. 77-87.