Light Weight Aggregate Concrete using Bottom Ash and Fly Ash

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Abstract - *The use of industrial wastes as a development material is a major jump in the sustainable construction. Bottom ash is waste material from power plants as a non flammable form. Light weight aggregate concrete uses the aggregates having low specific gravity when contrasted with the normal aggregates. Bottom ash is utilized to produce the light weight aggregates. The raw material first crushed, mixed with cement and lime and afterward pelletized with water followed by solidifying by sintering or cold bond technique. This paper summarizes about the preparation of the light weight aggregates and its properties and also discuss about the properties of concrete incorporated with light weight aggregate.*

Key Words: **Light weight aggregate, Bottom ash, Fly ash, Light weight aggregate concrete**

1. INTRODUCTION

Light weight concrete has a wide range of application in the modern construction industry. It reduces the overall weight of the structure. According to methods of production , light weight concrete divided into different sorts they are (a) Light weight aggregate concrete, which can be produced by using light weight aggregate having lower value of specific gravity instead of typical aggregates, (b) Aerated, cellular, foamed or gas concrete which can be produced by creating air voids in mortar mix by suitable air entraining agents, and gives more homogeneity and distribution of the voids within the concrete,(c) No fines concrete, which can be produced by eliminating the fine aggregates from the mix and this gives no segregation between the ingredients.

The utilization of bottom ash as the construction material is a viable technique for its waste management. Bottom ash contains Si-Al compounds. So bottom ash can effectively utilized to prepare light weight aggregates. Bottom ash is mixed with cement and lime, and then pelletized with water. These aggregates can be hardened by two processes as sintering and cold bonded. Sintering of aggregates can be done at a temperature of 800-1100ºC. In cold bonded aggregates prepared from ordinary Portland cement and lime can be hardened by water curing for twenty eight days.

2. LIGHT WEIGHT AGGREGATE CONCRETE

Presently there are such a significant number of innovations engaged with the on-going improvement of concrete. In that Cellular Lightweight Concrete (CLC) is one of the on-going developing advancements in making light weight concrete. By utilizing this sort of solid, found such huge numbers of benefits when contrasted with the typical regular concrete. This paper essentially cantered around making light weight concrete by incorporating aggregates produced with flyash and bottom ash.

Bottom ash is manufactured in a bottom coal boiler frequently found in coal-fired electric plants. Pulverisation of coal into powder form results in the formation of mainly 2 by products when it subjected to the boiler. The by-product of very fine size particle due to its lower weight rises with flue gas which is then collected with the help of electrostatic precipitator. This fine particle as the by product from boilers having cementicious property is generally called as flyash. Whereas the heavy particle fell down to the floor which is generally known by the name bottom ash. Quality of both bottom ash as well as flyash depends on source of coal used. In this review mainly emphasises on the properties of lightweight aggregate produced with lime and bottom ash and its further incorporation with concrete is discussed [1].

Fly ash is considered as one of the waste industrial product that cannot be easily disposed. It takes care of the issue of removal of flyash and simultaneously it bring down the expense of the construction. Thusly, flyash based CLC is considered as environment cordial feasible material created with least energy request. The density is impressively decreased by utilizing fly debris based cellular lightweight concrete than typical concrete and simultaneously, the quality isn't influenced with design mix. Also when we utilize this sort of blocks we will accomplish huge volume of construction by less measure of concrete. The manufacturing procedure of this sort of concrete doesn't include any significant expensive technology. [2].

Concrete is the most important mouldable construction material. It consists of binding material, fine and coarse aggregate mixed with water, having density range of 2240 to 2400 kg/m^3. In building construction, dead weight involves the majority of the total load on the structure, therefore it is significant to brings down the density by adopting Light

Weight Concrete (LWC). Reduction of self load, increased building charges and lower haulage and handling costs is another advantage. Low thermal conductivity[3]. One of the main properties that are associated with light weight is its low density in a construction perspective, buildings made with lighter material will indirectly reduce the overall size in the foundations and structural elements, an important factor especially in the construction of high rise buildings, and therefore reduce construction cost as a whole. With light weight features, the utilization of light weight blocks will likewise bring about higher structure rates due to lesser haulage rate and easy handling. It also possesses lesser value for thermal conductivity, which improves with a decrease in density[4].Also characterized as a kind of concrete which incorporates an expanding agent which expands the volume of blend while decreasing the dead weight[5].Structural LWC have density (unit weight) range of 1440 to 1840 kg/m^3.

3. LIGHT WEIGHT AGGREGATE

Mainly now a days light weight aggregate are widely applied in construction industries due to its various advantages.

This paper focuses on LWA made from bottom ash and also discusses about the Fly ash LWA. Dust collectors collect the fly ash, from the combustion gases before it released to the environment. Class F fly ash was used for cement replacement. The major constituents of fly ash are SiO_2, Al_2O_3, and CaO[8]. The molecule sizes in fly ash change from under 1μm (micrometer) to higher than 100 μm with average particle size estimating under 20μm. Fly ash chosen for this examination is low calcium fly ash (ASTM Class F)with specific gravity by provider is 2.2[9]
Bottom ash (BA) gathered from coal-based power station, having chemical property like class-F fly ash was used[10].It is bigger particles ,with porous structure ,coarse, angular shaped material of permeable surface and size varying from gravel to sand, transcendently sand-sized. This material is made out of silica, alumina, and iron with modest quantities of calcium, magnesium, and sulfate [1]. Light weight aggregate (LWA) is mainly categorized into two, one is the naturally occurring one ,called as natural LWA and the other which is made from naturally occurring sources or from the by products of industries known as artificial LWA. Natural LWA are commonly found around the world, for example most common type is pumice stone. For artificial LWA the industrial wastes like fly ash, bottom ash, slag etc. are used. The artificial aggregates are manufactured and are hardened using different techniques like sintering, cold bonding and autoclaving.

The production process of Structural Light weight aggregate is called as pelletization which is done with a pelletizer. The pelletizer is of different types, mainly drum type, disc type and cone type. Disc palletizer has simple operation technique and also less space compared to others. The waste materials like fly ash or bottom ash are first inputed into the pelletizer along with binders like cement and lime, a definite amount of water is also added.. Water is sprayed using sprayer and is sprayed uniformly to all parts of the mix at the pellitisation process. Initially it is properly mixed at dry stage for some duration and then water is sprayed consistently. Likewise a small amount of superplasticizer is additionally added to the blend. Blending of the ingredients is a significant step considered during the production of LWA. In pelletization process, the particles consist of thin film and these combines together and make a shape when the palletizer is rotated .Green pallets are formed, mainly consist of nucleation and ball growth stages. Either Binders or alkali activators are added, if alkali activators are used, along with the optimization of water added, the optimization of alkali activators should also be done. Otherwise it will lead improper pellets formation. After the pellets are formed, then it should be cured either by sintering, cold bonding or autoclaving process. Sintering is the heating of pellets at a temperature of 1100-1200°C for certain duration, around 60 minutes. Cold bonded is the curing of aggregates for 28 days and autoclave consist of 5-10 hours heating at a pressure of 1 Mpa [11].

3.1 Sintered Light Weight Aggregates

Mainly the light weight aggregates are obtained from pelletizer undergoes hardening process. The aggregates are hardened either by sintering cold bonding or autoclave process. In 1917, lightweight aggregates were first obtained from clay and shale by using rotary kill. Here, high temperature is given hence the elements in raw materials expands and forms a vitrified layer on surface [12]. The process is called as sintering and it is mainly uses a temperature of 1040 – 1100 °C. These sintered low weight aggregates has a bulk density of 0.8 to1.4 g/cm^3 in large quantity at low cost. Properties of sintered aggregate differ depending on the type of binders and dosage utilized and there is a huge improvement in quality and decrease in water retention when bentonite is added to sintered aggregate [13]. When the sintering is below 1000°C, pellets contain loosely bound particles. Hence the range of optimum sintering temperature should be kept in between 1000°C – 1200 °C. Generally the fly-ash particles fuse at 1150°C, which then reduces to 1100°C with the help of addition of binders [14].

3.2 Cold bonded Light Weight Aggregate

In cold bonding method the pelletized aggregates are subjected to water curing at an optimum temperature or it is stored at an enclosed area with normal water curing until the required strength is obtained which suits for concrete [11]. Mainly 7, 14, 28 days of water curing is done. This procedure is viewed as more efficient in terms of cost than sintering process because of the lower energy utilization. Various types of binders like lime, cement, kaolinite etc. can be used along with bottom ash or fly-ash. Instead of binders, alkali activators are also sprayed which is a mix of sodium silicate and sodium hydroxide. The Cold bonded Light Weight Aggregate has a crushing strength of 15.7 MPa and the density of LWA ranges from 709 – 1060 kg/m^3. It has an excellent flowability and the 28 day strength should be in between 14.8 – 38.1. Cold bonded fly –ash aggregate concrete with flyash as binder or flyash facilitates high amount of fly-ash used in concrete with a very few amount of energy requirement [15].

3.3 Binders

A significant constituent in the production of green pellets is cementicious material. It helps to keep the size as well as shape till it's harden [2]. It improves plasticity and different properties. Likewise it uncertainly affects shrinkage and colour shading variation. Clay binders like kaolinite, metakaoline, clay with plasticity index with the value of 78 are used and also low, medium and highly expanding bentonites are used for the pelletization process. The fresh as well as dried strength of the balls will be affected by the influence of binders [10]. Lime, cement, Sulphate liquor waste, bitumen and alkali materials are the conventional binders[16]. Among these, bentonite is widely used binding material for manufacture of binding material. The dose of the binders ought to be constrained else it will prompt to produce muddy balls [17]. S.MU et al confirmed that shale is a decent binder to create sintered fly-ash aggregates. The sort of binder is irrelevant while considering the sp gravity and water absorption of the aggregates. Likewise the utilization of low binders and high temperature builds the pellet's Sp gravity. Properties of aggregate are upgraded at high binder content, sintering temperature and time. Proposed that utilization of calcium hydroxide as a pelletization enhancer and the measurements is suggested at 2%[18].The utilizing of borax as flex upgrades mechanical properties and decreases the terminating temperature bringing about energy savings[19].

3.4 Alkaline Activators

Rather than binders alongside fly ash or bottom ash, alkali activators are utilized. Primarily mixes of sodium silicate and sodium hydroxide are utilized. The alkaline liquid was set up by combining both the solutions for 24 hours before using. Sodium silicate arrangement with SiO_2 to Na_2O proportion by mass of around 2. [10].

Sodium silicate is utilized as a consolidating agent and NaOH is utilized as an oxidizing specialist to improve the joining reactivity of fly ash. The silica modulus is in the range of 1.5 (Ms = molar SiO_2/Na_2O). 10M NaOH is utilized [11].

3.5 Moisture Content

Water is showered in consistent way and furthermore the water should arrive at all the outside of the blend consistently all together for the compelling development of the pellets. The measure of moisture content gives the optimised state. Capillary state is the most reasonable state for the development of pellets where the inter granular spaces is totally loaded up with water and there is no water film exist on the surface of pellet, it empowers most elevated tension force between the particles. A slight variation in the moisture content may prompt the pulverization of capillary force which causes the variation in size and engineering performance of the pellets formed[20]. The moisture content that can be utilized for the creation of fly ash LWA lays in the scope of 15% to 35%. The moisture content beyond this limit prompts development of muddy balls instead of pellets [13].

3.6 Superplastisizer

Superplastisizer varaplast PC 432 is a chloride free superplastisizing admixture. It is as brown coloured arrangement which is immediately dispersible in water and gives a significant level of water reduction and subsequently expands the strength and furthermore improves workability [21].

4. LIGHT WEIGHT AGGREGATE FROM BOTTOM ASH AND FLY ASH

K Ramamoorthy et al factors affecting the pelletization and properties of lightweight aggregate using bottom ash through alkali initiation and curing at ambient temperature. They show that pelletization effeciency increments at high molarity of soluble alkali activator[22].

O. Arioz disussed about bottom ash got from thermal power plant was utilized and different LECA granules were produced. According to test outcomes, the water absorption estimations of the aggregate created from clay and bottom ash were found between right around 47 and 60 [1].

R. Cioffi et al reports the results of an examination on material recovery by hardening of bottom ash originating from a muncipal solid waste burning plant. Different blends were tried in which the bottom ash content somewhere in the range of 60% and 90%.The density lies somewhere in the range of 500 and 2000 kg/m^3.The density measurements also show that the effects of type of binder. Bottom ash from solid waste incinerator can be effectively utilized for the creation of artificial low weight aggregates. Various binders can be utilized for the creation of the granules, yet cement give palatable mechanical properties in the field of structural LWA [23].

Khairul Nizar Ismail et al studied about Properties of cold-bonded lightweight artificial aggregate containing bottom Curing of aggregate is as significant as the curing procedure of concrete. It will fundamentally impact the quality of structural component that utilized these total pellets. Traditional curing method is the most favored approach to fix tests whereby they were cured in water for 28 days. Also the presence of temperature and dampness are additionally significant. Higher water absorption will adversely influence the concrete strength produced using LWA. It can be concluded that, the higher the amount of bottom ash utilized in LWA production, the higher value of water absorption of LWA and reduced the strength of LWA. Bottom ash in aggregate mixture tends to absorb more water and imparts aggregate strength. The existence of internal pores created by foams was also contributed to higher value of water absorption[24].

Theradej Litsomboon Et al studied about Workability of LWAC. In all-lightweight concrete where the dosage of superplasticizer was kept constant, the water requirement had increased just to maintain the desired workability. This examination inspects the feasibility of utilizing diverse lightweight aggregate (LA) and bottom ash as coarse and fine aggregate in concrete with fly ash [25].

K Muthusamy et al The experiments shows that utilization of appropriate measure of coal bottom ash ready to create oil palm shell lightweight aggregate concrete reasonable for basic structural application. Coordination of 15% of CBA produces concrete displaying the most elevated compressive quality when contrasted with different blends. This finding is required to support the utilization of this waste material in lightweight concrete creation and simultaneously decrease the utilization of natural sand [26].

S. Bethanis et al discussed from the current study show that it is conceivable to successfully manufacture lightweight aggregates from mixes of wastes, such as incinerator bottom ash and pulverized fuel ash. The aggregate production process have wet milling process of the IBA/PFA Clay may also be added to aid pelletisation. IBA may also be mechanical ground to a suitable size that allows pelletisation. Lightweight aggregates with relatively high particle and bulk densities (in the range of 1.5-1.8 g/cm^3 and 0.8-0.9 g/cm^3 respectively) and water absorption values between 16-19% by dry weight can be manufactured. Although the IBA-derived aggregates show higher densities and water absorptions than Lytag, when used in concrete they developed comparable compressive strengths to Lytag concrete; the IBA-derived aggregates achieved 28-day strengths of about 57-59 N/mm2 and Lytag achieved a 28-day strength of 58 N/mm^2[27]

Joung-Soo Sun et al Dry bottom ash of the size of 0.6 mm or larger shows at least 50 % of the total pore rate and 30 % of the closed pore rate. These results are explained by the fact that the closed pores, most of which are larger, tend to be destroyed when the particle size decreases, consequently becoming open pores. The same reason explains why the absorption rate increases when the particle size becomes smaller[28].

Su-Chen Huang et al. discusses the light weight aggregates manufactured from recycled resources. The methodology includes preparation of raw material, drying, pulverizing, blending, pelletization, sintering and cooling. The LWA obtained in this study has bulk density between 0.2 and 0.8 g/cm^3 and cylindrical compressive strength ranging from 4.3 to 7.5MPa. The LWA fabricated in this study has a unit weight of 0.5–1.6 g/cm^3 and specific gravity of 0.5, which meet the requirements for use in making lightweight partition walls [12].

Niyazi Ugur Kockal et. al researched attributes of lightweight fly ash aggregates with different binders created by various temperature treatments. They studied by changing the binder ratio with fly ash. Irregular particles were obtained when 15% bentonite was added to fly ash. An increment in measurements of bentonite beyond the level brought about adhering of pellets to one another prompting production of muddy balls. Addition of binders brings up the specific gravity at low sintering temperatures (1100 and 11500C) because of higher specific gravity of the binders compared to fly ash Bentonite was more effective in increasing the strength than glass powder especially at 1150^{0}C [29].

A. Sivakumar et.al. shows that moisture content and amount of binder have a influence on the size of aggregates made by fly ash. The fineness of the fly ash gives the better pelletization efficiency compared to the coarser fly ash. Density of fly ash aggregate made by sintering process with binder is decreased while increased the temperature range between 1150 to 1200°C. The cement as binder, lime powder and bentonite powder are used as a binder in 10, 20 and 30% by weight of fly ash for pelletization. It is likewise seen that there is an increase in the 10% fine value and decrease in water assimilation of sintered fly ash aggregate. This investigation shows that the productivity of pelletization relies upon the pelletizer speed, pelletizer angle and the kind of binder included alongside the fly ash[30].

Manu S et.al. studied the different parameters in the production of low dense aggregates concrete.Physical properties produced by these aggregate were influenced by the fineness of flyash. Bentonite as a binder is widely adopted. The spherically shaped aggregates are with specific gravity ranges from1.33-2.35 are mostly produced. Concrete with compressive strength 23 Mpa to 74 MPa can be designed with the utilization of light weight concrete with less denser aggregate. Sintered flyash aggregate possess a lower results on the permeability values as well as chloride permeability value when compared with the normal concrete mix. Because of superior ITZ it exhibits greater resistivity and corrosion resistance within these concretes [31].

K.I. Harikrishnan et al. talks about binder impact on sinterd fly ash aggregate. Discusses Specific gravity increases when binders are used. Among the binders, aggregate with bentonite has a lower specific gravity compared to lime and cement. Aggregate crushing value test cannot be used for light weight aggregates. Absorption capacity of sintered fly ash aggregate without binders lies in 21–22%. Addition of lime reduces the water absorption marginally. Their research work shows that the light weight aggregate features depend upon the binder dosage. The binders used did not alter the chemical composition, while they influenced the microstructure of the aggregate, which results in enhancement in the properties of aggregates [13].

5 PROPERTIES OF LIGHT WEIGHT AGGREGATE

5.1 Physical Properties

The relation between properties of aggregates and performance in concrete are not well explained in several aspects. Aggregate properties have greater influence on concrete properties and hence the manufacturing of high-quality concrete. The main features of the aggregates are density, strength and water absorption .The physical properties mainly include water absorption, bulk density, and specific gravity.

5.2 Shape and texture

Shape of the aggregate has significant role on orientation of particle and interlocking of aggregate within the matrix [32]. The sintered flyash aggregate possess a spherical shape with earthy colored in shading with an inside dark center. The microstructure is smooth at the same time, for the micro smaller scale [33]. Engineering properties of the LWAC depends on the aggregate 'Shape Index'. Shape Index of spherical aggregates generally possesses a lower value in contrast with angular aggregate. Despite the fact that the aggregate qualities are comparable, at that point aggregate having higher shape index may display higher strength in concrete [34].It is additionally accepted that for permeable aggregates or aggregates with a harsh surface, paste of cement or cement hydration items may infiltrate into pore pockets or large pores on the surface of aggregate.. It acts like a multiple ''hooks" binding the phase of aggregate as well as phase of paste simultaneously [35].

5.3 Specific gravity

It is observed that specific gravity of the sintered aggregates ranges from 1.3 to 2.3.. The specific gravity is 13–46% lower when compared with the usual aggregates. Lightweight concrete. Low specific gravity aggregates like porous lightweight aggregate, which have lower than 2.6.[4].

5.4 Water Absorption

It is seen that the assimilation of the flyash aggregate differed from 0.7% to 34%.The flyash aggregates available has a water absorption cabability of 10–25%[36]. Noteworthy decrease in water retention capability of the aggregate was likewise seen in the binder material during the production of aggregate. Ramamurthy and Hari Krishnan[8]reported that utilization of bentonite up to 20% as binder material will brings down the water assimilation by around 30%. LWA posess low water absorption rate. The water absorption recommended for LWA made with bottom ash is 20%.

5.5 Bulk density

Bulk density of the aggregates determines the paste volume required for a concrete matrix and thus richness and economy of the mix[32]. European Standard specifies that oven-dry density of aggregate should not exceed more than 2000 kg/m^3 or loose dry bulk density above 1200 kg/m^3 [37]. Depending upon the size of the aggregates loose dry bulk density of 880–1120 kg/m^3 is permissible for the production of structural concrete according to ASTM C 330. The loose bulk density of the Light weight aggregates varied from 760 to 950 kg/m^3. As the size of the pellet is inversely proportional to the bulk density, subsequently density decreases and it causes reduction in strength of the aggregates.

5.6 Mechanical properties of aggregates

For aggregates having crushing value less than 30, 'ten percentage fineness values' is preferred [38]. The individual crushing strength of aggregates having little size are higher than large sized ones [39]. The crushing value and ten percentage fineness value of the aggregates was found to be around 23.5 and 0.5 to 4.25, respectively. Guneiysis determined crushing strength of sintered flyash aggregate is 3–4 times greater than the cold bonded aggregates manufactured from the same flyash [40]. Soundness tests led on flyash aggregates by utilization of sodium sulphate indicates the loss of weights is well beneath 12% [20].

6 PROPERTIES OF LWA CONCRETE

6.1 Fresh properties

Le Anh-tuan Bui et.al obtained excellent flow-ability. High-slump flowing concrete was obtained without bleeding or segregation. Slump, slump flow and flowing time of fresh HPLWC are excellent. Initial slump obtained was in the range of 260 mm and 270 mm. Slump flow ran from 575 mm to 720 mm. For the most part, the propensity to form bleeding capacity of aggregate is higher in elongated and flat particles than in rounded ones; and to create a similar workability, the lengthened as well as angular particles require more cement paste than rounded particles [11]. Results show that there was a considerable reduction in the unit weight of fresh concrete, when natural aggregate replaced completely with LWA .It relies upon the unit weight of LWA utilized.

The unit weight of new HPLWC went from 1836 kg/m³ to 2056 kg/m³.

6.2 Compressive strength

Compressive strength depends on both intrinsic and extrinsic factors. Water content, type of cement and aggregates, content of cement and aggregates are intrinsic ones. While extrinsic factors include curing and testing conditions. Porosity of the concrete affects the compressive strength.Compressive strength is the primary design parameter for the structural engineers. As per CEB/RILEM concrete having densities somewhere in the range of 1600 and 2000 kg/m³ and compressive strength more than 15 MPa can be considered as structural concrete [31]. For structural HPLWC requiring a base 28-day compressive strength of 17.2 MPa [11].

6.3 Split tensile strength

Least split tensile strength requirement for structural-grade lightweight aggregates concrete conforming to ASTM C 330 [21] is 2 MPa

7. CONCLUSION

Fineness of fly ash and bottom ash impacts the physical properties of the produced aggregates. Among various binders, bentonite is the normally utilized one. Its best dose is between 15 to 35% of the powder content. The angle and the speed of pelletization circle can be fluctuated between 35º to 70°and 20–50 rpm, respectively. The sintering temperature generally differed from 1000 to 1200ºC. Aggregates is spherical in shape and specific gravity of aggregate ranges from 1.33 to 2.35. The free bulk density varied somewhere in the range of 765 and 936 kg/m³. Economically accessible aggregates have water absorption limit around 10–25%.It is conceivable to deliver concrete having compressive strength between 23.12 to 74 MPa and density 1651 to 2017 kg/m³. Likewise, the tensile strength and e-modulus ranges from 2 to 4.9 MPa and 16.7 to 30.65 GPa, respectively. Every one of these reaches are positive for the advancement of structural concretes. When compared to the conventional normal density concretes, the structural efficiencies of these concretes are much higher. HPLWC with incredible flow capacity is easily produced. High slump flowing concrete was acquired without bleeding or segregation. The unit weight of new HPLWC ran from 1836 kg/m³ to 2056 kg/m³. The strength of concrete should be higher than 17.0 MPa used for structural purposes. The 28-day compressive strength of all HPLWCs ranged from 14.8 to 38.1 MPa.

REFERENCES

[1] O. Arioz, G. Arslan et al, "Lightweight Expanded Aggregate Production from Bottom Ash"10th ECerS Conf., Göller Verlag, Baden-Baden, 2007, 2051-2053, ISBN: 3-87264-022-4
[2] Lina Chica, Albert Alzate, "Cellular concrete review: New trends for application in construction"Construction and Building Materials Vol. 200, 2019, pp 637–647
[3] Siveji J S, Dr. Elson John , "Aerated concrete incorporating quarry dust", International Research Journal of Engineering and Technology (IRJET), Volume: 05 Issue: 04 | Apr-2018
[4] Indu Susan Raj, Dr. Elson John, "Evaluation of properties of aerated Concrete partially replaced by cement with fly ash"International Journal of Advanced Research in Engineering and Technology (IJARET) Volume 10, Issue 1, January- February 2019, pp. 223-229
[5] Indu Susan Raj, Dr. Elson John, "A Study on the Properties of Air-Entrained Concrete for Masonry Block", International Journal of Scientific Engineering and Technology (ISSN : 2277-1581) Volume No.3 Issue No.11, pp : 1367-1370 01 Nov. 2014
[6] Sarika.R, Indu Susan Raj, Dr. Elson John, "Effect on the properties of aerated concrete developed by partially replacing cement with fly ash and fine aggregate with rubber powder",GRD Journels,Vol 2,Issue 12,November 2017
[7] K. Naveen Kumar, D.S. Vijayan,R. Divahar, R. Abirami, C. Nivetha,"An experimental investigation on light-weight concrete blocks using vermiculite", Materials Today: Proceedings, 2019
[8] Merin K Abraham, Elson John, Bybin Paul,"A Study on the Influence of Mineral Admixtures in Cementitious System Containing Chemical Admixtures", International Journal of Engineering Research and Development Volume 10, Issue 3 (March 2014), PP.76-82
[9] Sarika R, Prof.Sarah Anil, "Study on the Properties of Aerated Concrete Incorporating Fly Ash & Rubber Powder", IJSTE International Journal of Science Technology & Engineering | Volume 3 | Issue 11 | May 2017
[10] S. Geetha, K. Ramamurthy, "Properties of sintered low calcium bottom ash aggregate with clay binders" Construction,Vol.25,2011,2002–2013,
[11] Le Anh-tuan Bui, "Manufacture and performance of cold bonded lightweight aggregate using alkaline activators for high performance concrete", Construction and Building Materials Vol.35, 2012, pp 1056–1062
[12] S. Huang, F. Chang, S. Lo, M. Lee, C. Wang, J. Lin, "Production of lightweight aggregates from mining residues, heavy metal sludge, and incinerator fly ash",J. Hazard Mater. Vol.144 (1–2),2007, pp 52–58.
[13] K. Ramamurthy, K.I. Harikrishnan, "Influence of binders on properties of sintered fly ash aggregate", Cement Concrete Composites, Vol.28, 2006, pp 33–38.
[14] V. Adell, C.R. Cheeseman, M. Ferraris, M. Salvo, F. Smeacetto, A.R. Boccaccini, "Characterising the sintering behaviour of pulverised fuel ash using heating stage microscopy", Mater. Charact. Vol.58,2007, pp 980–988.

[15] G. Joseph, K. Ramamurthy, “Workability and strength behaviour of concrete with cold bonded flyash aggregate”, Material and Structures, Vol. 42,2009, pp 151–160.
[16] J. Srb, Z. Ruzickova, “Pelletization of Fines”, Elsevier Science Publishing Company, NY, USA, 1988.
[17] R. Manikandan, K. Ramamurthy,“Swelling characteristic of bentonite on pelletization and properties of fly ash aggregates”, J. Mater. Civil Eng. ASCE (2009) 578–588.
[18] E.A. Uwe, A.R. Boccaccini, S.G. Cook, C.R. Cheeseman, “Effect of borate addition on the sintered properties of pulverised fuel ash”, Ceram. Int. Vol.33,2007, pp 993– 999,
[19] V. Vasugi, K. Ramamurthy, “Identification of admixture for pelletization and strength enhancement of sintered coal pond ash aggregate through statistically designed experiments”, Mater. Des. 60 (2014) 563–575,
20] G. Baykal, A.G. Doven, “Utilization of fly ash by pelletization process; theory, application areas and research results”, Resour. Conserv. Recycl. Vol.30,2000, pp 59–77.
[21] Reddy , “Performance of Light Weight Concrete using Fly Ash Pellets as Coarse Aggregate Replacement”, International Journal of Engineering Research and Technology,Vol 9, pp 95-104
[22] S. Geetha, K Ramamurthy, “Properties of geopolymerised low-calcium bottom ash aggregate cured at ambient temperature”, Cement & Concrete Composites 43 (2013) 20–30
[23] R. Cioffi , F. Colangelo F. Montagnaro , L. Santoro, “Manufacture of artificial aggregate using MSWI bottom ash”, Waste Management 31 (2011) 281–288
[24] Norlia Mohamad Ibrahim, Khairul Nizar Ismail ,”Properties of cold-bonded lightweight artificial aggregate containing bottom ash with different curing regime”, E3S Web of Conferences 34, 01038 (2018)
[25] Theradej Litsomboon, Pichai Nimityongskul and Naveed Anwar, “Development of Lightweight Aggregate Concrete Containing Pulverized Fly ash and Bottom Ash”, Key Engineering Materials Vols 400-402 (2009) pp 379-384
[26] K Muthusamy, R Mohamad Hafizuddin, “Compressive strength performance of OPS lightweight aggregate concrete containing coal bottom ash as partial fine aggregate replacement”, IOP Conf. Series: Materials Science and Engineering 342 (2018) 012099
[27] S. Bethanis, “Value-added utilisation of municipal waste incinerator bottom ash as lightweight aggregate in concrete”, WIT Transactions on Ecology and the Environment, Vol 102, © 2007
[28] Joung-Soo Sun et al , “Evaluation on the applicability of dry processed bottom ash as lightweight aggregate for construction fields”, Mater Cycles Waste Manag DOI 10.1007/s10163-015-0367-x Springer Japan 2015
[29] N.U. Kockal, T. Ozturan, “Effects of lightweight fly ash aggregate properties on the behavior of lightweight concretes”, J. Hazard. Mater, Vol.179,2010, pp 954–965,
[30] P. Gomathi, A. Sivakumar, “ A accelerated curing effects on the mechanical performance of cold bonded and sintered fly ash aggregate concrete”, Constr. Build. Mater. Vol.77 ,2015, pp 276–287
[31] Manu S. Nadesan, P. Dinakar , “Structural concrete using sintered flyash lightweight aggregate: A review” School of Infrastructure, Indian Institute of Technology Bhubaneswar, India, Construction and Building Materials 154 (2017) 928–944
[32] M.G. Alexander, S. Mindess,“Aggregates in Concrete” Taylor & Francis, 270 Madison Ave, New York, NY 10016, 2005.
[33] S. Chandra, L. Berntsson, “Lightweight Aggregate Concrete: Science, Technology”, and Applications, Noyes Publications, Norwich, New York USA, 2002.
[34] H.Z. Cui, T.Y. Lo, S.A. Memon, W. Xu, “Effect of lightweight aggregates on the mechanical properties and brittleness of lightweight aggregate concrete”, Constr. Build. Mater. Vol. 35,2012, pp 149–158,
[35] M.H. Zhang,“Microstructure of the interfacial zone between lightweight aggregate and cement paste”, Cem, Concr. Res.Vol.20,1990,pp 610–618.
[36] EuroLightCon. (2000) “Light Weight Aggregates” The European Union – Brite EuRam III. Document BE96-3942/R15
[37] prEN 13055-1. “Lightweight aggregate for concrete, mortar and grout - Part 1: Lightweight aggregates for concrete, mortar” European Committee for Standardization. Management Centre: rue de Stassart, 36 B-1050 Brussels 2002
[38] IS 2386 Indian Standard: “Methods of Test for Aggregates for Concrete (Part 4) Mechanical Properties”New Delhi: Bureau of Indian Standards.1963.
[39] P. Gomathi, A. Sivakumar, “An accelerated curing effects on the mechanical performance of cold bonded and sintered fly ash aggregate concrete”, Constr. Build. Mater. Vol.77, 2015, pp 276–287.
[40] E. Guneyisi, M. Gesoglu, O. Pursunlu, K. Mermerdas, “Durability aspect of concretes composed of cold bonded and sintered flyash lightweight aggregates”, Composites Part B 53 (2013) 258–266