Blended portland cements and bottom ash engineering essay

Engineering

CHAPTER 2

Cement is a substance which has adhesive and cohesive properties with the ability of bonding mineral fragments into a compact whole. For construction purposes, the cements of interest in making of concrete have the ability of setting and hardening under water by virtue of a chemical reaction with it. (Properties of Concrete) The chemical composition of these cements can be quite diverse, but by the far the greatest amount of concrete used today is made with portland cements. (Concrete – Sidney Mindess)Portland cement is a hydraulic binder which retains strength and stability by time and has the ability of bonding of other materials together, is produced from ground portland cement clinker and calcium sulfate. The term hydraulic cement refers to a powdery material that reacts with water and, as a result, produces a strong as well as water-insoluable solid.(Concrete materials-S. Popovics) Portland cement clinker is made from a mixture of raw materials consisting lime, silica and small amounts of alumina and iron which are treated in hot temperature.

2. 2 Blended Portland Cements

Cement production is an energy intensive industry. There are also environmental concerns like greenhouse gas emissions, fuel consumptions and mining activities related to extract raw materials. It is reported that one ton of cement production gives rise to one ton of CO2 emission and minor amounts of NOx and CH4 into the atmosphere. Nearly half of the CO2 emissions derived from production of cement stem from calcination of the limestone and other half stems from burning of fossil fuels. Clinker production is nearly responsible for total CO2 emissions. Furthermore, earth has limited amounts of natural resources. Therefore, a cement substitute, typically from 20% to 60% cement replacement by mass, the use of by-products from thermal power production and metallurgical operations in the cement and concrete industry can result in substantial energy savings. (Malhotra-Pozzolanic and Cementitious Materials-googlebooks). The manufacturing of blended cements has an increasing trend due to rising environmental awareness and economical concerns.(http://www. fhwa. dot. gov/infrastructure/materialsgrp/cement. html)Blended cements are hydraulic binders consisting essentially of an intimate and uniform blend of at least two inorganic constituents including portland cement or portland cement clinker as one of the ingredients. They are used in same manner as portland cements (Concrete Construction Engineering Handbook - Edward G. Nawy) or designed for an specific purpose and may improve some mechanical or physical specifications of the ordinary portland cement. Blended cements are made either by intergrinding portland cement clinker and the supplementary cementitious materials such as natural pozzolan, fly ash, slag, etc. by blending portland cement and finely divided replacement materials, or a combination intergrinding and blending.(Concrete Materials-Popovics). A number of latently hydraulic, pozzolanic or inert fillers can be used as additions to blended cements or as mineral admixtures in concrete, with granulated blast furnace slag and fly ash leading the way. (International Symposium on Mineral Admixtures in Cement-Blended Cement in India, Manufacture and Use)The total volume of pozzolanic and cementitious materials generated every year by thermal power plants and metallurgical furnaces exceeds 500 million tons. Many of these by-products can contain toxic elements which can be hazardous to human health if not disposed in a safe manner. Their usage in cement and concrete industry makes harmful metals to safely incorporate into the hydration products of cement. (Malhotra-Pozzolanic and Cementitious Materials-googlebooks)Mineral admixtures help to form new hydration products reducing structural pores in the system. Furthermore, blended cements help reducing heat of hydration, mixing water amount and bleeding, enhancing sulfate resistance and hindering alkali-aggregate reaction. Blended cements usually have low strength values at early days, in time durability and strength values usually exceed the ordinary portland cement. For specification purposes, portland and blended cements are designated by type, depending on their chemical composition and/or performance requirements.(Supplementary cementing materials for use in blended cements, Rachel J. Detwiler). The European standard EN 197-1 specifies 27 different types of cement which are grouped into 5 main categories. Main types are called as CEM cements. Except from CEM I, other types describes blended cement types. CEM cement consists of at least half percent of total reactif CaO and reactif SiO2. It may consist of portland cement clinker, calcium sulfate and different types of mineral admixtures. CEM I is which is also known as portland cement produced by intergrinding the portland cement clinker and calcium sulfate and also at most 0-5 percent mineral additives together. CEM II known as Portland Composite Cement includes 6-35 percent supplementary material. Cement is labeled as either Portland slag cement or Portland Pozzalan cement depending on the additive type. CEM III known as blastfurnace cement contains granulated blast furnace slag cement that has 36-95 percent additives. CEM IV is known as Pozzolanic Cement. This type of cement contains 11-55 percent puzzolans and fly ash as additives. Granulated blast furnace slag and limestone is not added as supplemantry materials into this kind of cement type. CEM V includes Portland Composite cements which slag (18-50 percent) and both pozzolans and fly ash (18-50 percent) is added in changing amounts. Also, this type of cement comprises 20-64 percent of portland cement clinker. ASTM C 595, Standard Specifications for Blended Portland Cements talks about two primary classes of blended cements: portland blast-furnace slag cement (Type IS), and portland pozzolan cement (Type IP). Type IS is an intimate and uniform blend of portland cement and fine granulated blast furnace slag in which slag costituent is up to 95% of the weight of portland blast-furnace slag cement. Type IP is an intimate and uniform blend of portland or portland blast-furnace slag cement and fine pozzolan in which the pozzolan constituent is up to 40% of the weight of the portland pozzolan cement. There is also ternary blended cement (Type IP). It is an intimate and uniform blend of portland cement and either a combination of two different pozzolan or slag cement and a pozzolan. These blended cements may also come in the form of carrying features such as air-entraining, moderate sulfate resistant, or with moderate or low heat of hydration.

2. 2. 1Hydration of Portland Blended Cements

The addition of supplementary cementitious materials to portland cement make hydration process more complex. When mineral admixtures such as fly ash or slag is added to portland cement, the alumino silicates compounds in these react with Ca(OH)2, the hydration product of portland cement, to produce new calcium silicate hydrates. (Quantification of hydrated cement products of blended cements in low and medium strength concrete using TG and DTA technique R. Vedalakshmi). Yet, these reactions usually do not commence before 7 days. Mineral admixtures have pozzolanic, self-cementitious properties and also both of them. If mineral admixture is a pozzolanic material, the term pozzolanic reaction is used to describe the chemical interaction between a pozzolan and calcium hydroxide (lime) to form calcium silicate hydrates. The reaction between any pozzolan and lime mixes produces the same compounds as those generated during hydration of portland cement since the overall chemical composition of the two mixes fall into same field. (Mazzassa – Lea’s chemistry). Calcium silicate hydrate is the main product of lime-pozzolan reaction. Calcium alumino hydrate, hydrated gehlenite, calcium carboaluminate, ettringite and calcium alumino monosulfate are some of the other products that result from the lime-pozzolana reaction in addition to calcium silicate hydrate. (Admixtures for concrete-T. erdogan). The hydration between slica of pozzolans and calcium hydroxide are given by equation ?. The reaction is very slow; therefore the rates of heat liberated and strength development will be accordingly slow. (concrete Mehta) Slow rate of the reaction should be supported by long period of moist curing. The C/S ratio of C-H-S is variable and depends to the type of pozzolana, the time and the temperature of curing, the lime/pozzolana ratio as well as the analytical method used. (Mazzassa – Lea’s chemistry). The increased fraction of C-S-H leads to a more homogenous microstructure, particularly when highly reative, finely divided pozzolans are used. Admixtures reactions will reduce the overall porosity (the specific gravity of C-S-H is lower than calcium hydroxide) and pore size. (Concrete-Mindness). Cementitous metarials such as ground granulated furnace slag also produce C-S-H and CH as hydration products like portland cement. In slag- cement blends, the slag has also pozzolanic behaviour. (Concrete, Mindness). That is, in a finely divided form, they react with calcium hydroxide in the presence of moisture and join to formation of additional calcium-silicate-hydrate (C-S-H).(Admixtures for concrete). Experimental studies have shown that the main hydration product of slag is an amorphous gel C-S-H, hydrotalcite, tetracalcium aluminate hydrate, strätlingite, ettringite, and hydrogarnet. (http://www. cme. ctw. utwente. nl/en/Research/Research%20Projects/Finished%20Projects/Project%20Wei/index. html). Due to the precence of impervious coatings of amorphous silica and alumina that form around slag particles early in the hydration process, slag needs to be activated by alkaline compunds, which can be either soluable sodium salts, such as NaOH, Na2CO3, or NaSiO3, or calcium hydroxide. (Concrete, Mindness).

2. 3. Pozzolans

A pozzolan is defined as a siliceous or siliceous and aluminous material, which in itself possesses little or no cementing property but will, in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. (Concrete – Mehta). Siliceous and aluminous minerals don’t always carry pozzolanic properties. Some crystalline minerals, for instance silica as quartz, alumina as corundum and aluminosilicate as mullite do not react with lime solution at ordinary temperature. To show pozzolanic properties, siliceous and aluminous materials should be present in noncrystalline form. (Correlation of fly ash characteristics with pozzolanic behavior-Chen)The term " pozzolan" comes from the town of Pozzouli where the Romans make a hydraulic binder by mixing lime and pozzolana, a fine volcanic soil, to built structures more than 2000 years ago. (http://www. rmajko. com/pozzolan. htm). The name is now applied to any reactive aluminosilicate material, of either natural or industrial origin that must either occur in finely divided state or be ground to cement fineness. A good pozzolan should have a high fraction reactive glassy or amorphous material. (Concrete- Mindness). Pozzolans are mineral admixtures or supplementary cementing materials known by their environmentally friendly manner, chemically react with portlandite (CaOH2) producing new hydration products. The CaOH2 produced from the hydration of portland cement is often desirable, as it helps preventing the corrosion of reinforcing steel strengthening elements in concrete structures by offering passive film protection. (Pozzolanıc reactıvıty of the supplementary cementıtıous materıal pıtchstone fınes by thermogravımetrıc analysıs – Vesselas-fulltext). But, in acidic environmental, it can cause some durability problems. Pozzolans are generally grouped as natural pozzolans and artificial pozzolans concerning the origin of the material.

2. 3. 1Classification of Pozzolans

Natural pozzolans which are naturally occurring materials such as tuff, volcanic ashes, pumicite, diatomaceous earths, opaline cherts and shales should be ground in order to use in cement. Natural pozzolans include for the most part volcanic ashes which have undergone chemical alteration but, all natural pozzolans don’t possess pozzolanic activity.(Leonard, Roy Junior, Ph. D., Iowa State University, 1958). Some of them require calcining to improve their pozzolanicity. These type of pozzolan is classified as Class N type according to ASTM C 618. There is no classification of natural pozzolans in the national specifications. However, particular classifications were arranged by some researhes. One of these researchers-Massazza- classified the natural pozzolans as pyroclastic rocks, altered materials of mixed origin, and clastic rocks, where pyroclactic rocks have been further classified as incoherent rocks and altered coherent rocks.(Admixtures for concrete, T. erdoğan)Artificial pozzolans are the industrial by-products such as fly ashes (finely divided residue resulting from the combustion of powdered coal), granulated blast furnace slag (by-product cooled and solidified by rapid water quenching to a glassy state generated during iron production), silica fume (finely divided by-products obtained in manufacturing of silicon metal or silicon alloys). Fly ash will be explained in detail in section 4.

2. 4. Fly Ash

2. 4. 1Definition and Classification of Fly Ash

Fly ash is the fine solid residue generated from combustion of ground or powdered coal to produce electricity, which can be easily transported by flue gases and collected with the help of electrofilters or cyclones. During coal combustion, carbon particles are burned, volatile matter evaporates and most of the remainder mineral part disintegrates. (Concrete admixture handbook) The disintegrated particles turning out to molten state due to high burning temperature of coal later become mostly spherical due to cooling rates the droplets of that of molten state ash. Most of the fly ash from the precitators and bottom ash from the boilers are mixed together and send into the ash ponds in the form of slurry (Pozzolanic properties of pulverized coal combustion bottom ash) or dumped to landfills. (Strength characteristics of Illinois coal combustion by product: pcc dry bottom ash)Fly ash has pozzolanic properties as the natural pozzolans do. (Use of fly ash in concrete, ACI Committee) Therefore, it is a good cement replacement material to attain economic, environmental and technical benefits. American standard ASTM C 618 talks about two types of fly ash considering the type of coal burned. First type, Class F fly ash is generally produced from burning anthracite or bituminous coal. Second type, Class C fly ash is produced from lignite or subbituminous coal. Class F fly ash include more than 70 % of $SiO_2+Al_2O+Fe_2O_3$. Besides, this type of ash is diagnosised by low lime property which does not pass 10 %. F type fly ash possesses pozzolanic property. Class C fly ash contains more than total 50 % of $SiO_2+Al_2O_3+Fe_2O_3$ and more than 10 % of CaO. Class C type fly ash has self binding property in addition to pozzolanic property. In EN 197-1, fly ashes are classified as siliceous (V) and calcerous (W) fly ashes. V type fly ash is a kind of ash which reactive lime content should be less than 10 % and reactive silica content should be more than 25 %. V class fly ash has pozzolanic property. W class fly ash comprises more than 10% of reactive lime and more than 25 % of reactive silica. This type of fly ash posseses self binding and pozzolanic property.

2. 4. 2Physical Properties of Fly Ash

Physical properties like the shape, particle-size distribution, density have great importance on the properties of freshly mixed, unhardened concrete and strength development of hardened concrete. (Use of fly ash in concrete)The properties of particle size and shape of fly ashes are designated from the origin and uniformity of coal, the grade of pulverization, the combustion conditions (temperature and oxygen levels), uniformity of combustion, the type of collection system used and the cooling rate. (Use of fly ash) (Concrete admixtures handbook)Fly ash particles range in size from 0. 5 µm to over 100 µm in diameter. Fly ash particles mostly consists of glassy spherical solid and hollow forms which are either completely empty (cenospheres) or spheres involving conglomeration of smaller particles existing in the bigger spheres (plerospheres). Specific gravity of fly ash shows great difference from average of 1, 9 to 3, 02. Wesche states that the maximum specific gravity value (2, 98kg/dm3) for fly ashes corresponds to the maximum Fe_2O_3 content. (Fly ash in concrete: properties and performance, K. Wesche) Likewise, high carbon content drops the specific gravity. Some hollow particles can float on water.

2. 4. 3Chemical Composition of Fly Ash

Chemical properties of fly ashes are depended to several factors including origin and geology of coal used, combustion process and techniques applying handling of coal (coal preparation, dust collection, desulfirization etc.). (Türkiye'deki uçucu küllerin sınıflandırılması ve özellikleri)Fly ashes consist mostly of oxides including silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), iron oxide (Fe_2O_3). Besides, Class C fly ashes include considerable amounts of calcium oxide (CaO). Fly ashes particles show a generally highly heterogeneous formation consisting of a combination of glassy particles with various identifiable crystalline phases such as quartz, mullite, and various iron oxides.(Use of fly ash in concrete and http://en. wikipedia. org/wiki/Fly_ash)Minor elements arised from the ash source coal encompass titanium, iron, magnesium, phosphorus, sulfur, oxygen, potasium, sodium, carbon and others as traces. (Use of fly ash in concrete)Loss on ignition rate derived from unburned carbon content, combined water and carbon dioxide may arise up to 10% or more for Class F fly ashes and drop uo to 1% for Class C fly ashes; indeed loss on ignition rate is mostly considered to equal unburned carbon content due to trace existance of other constituents.

2. 4. 4Use Fly Ash in the Cement Industry

First appearance of fly ash in concrete goes back to 1935 to reduce the heat of hydration in mass concrete. Since then fly ash has been utilized to improve durability of concrete. Fly ash can be used either as additive in blended cement or admixtures in concrete. It can also be used as a raw material alternative to clay, shale etc of portland cement clinker (low quality fly ash) and a fuel in the kiln (high-carbon fly ash) in cement industry. (Fly ash in concrete, properties and performance, K. Wesche). Portland fly ash cement is a homogeneous mixture of portland cement clinker, fly ash and gypsum. In general, the fly ash content is 30%. (Fly ash in concrete, properties and performance, K. Wesche). According to EN 197-1 portland fly ash cement may consist up to 35% of fly ash. There are applications where fly ash are used as a replacement of lightweight aggregate.

2. 4. 4. 1Effects of Fly Ash on Cement or Concrete Properties

Fly ashes incorporating cementitious systems are generally known as their low heat of hydration natures. Besides, it is used in concrete for reasons including economics, improvements in workability, and contribution to durability and strength in hardened concrete.(Use of fly ash in concrete reported by aci committee 226). Since there are a great deal of investigations about fly ash incorporating cementitious systems, only general information will be given about the subject.

2. 4. 4. 2Effects on Fresh Cement or Concrete

There is a general agreement that the use of fly ash as a partial replacement of cement increases both initial and final setting time of the concrete. The effect of fly ash on the time of setting depends on the characteristics of the fly ash and the amount used. All Class F fly ashes generally increase the time of setting as most Class C fly ashes do. However, some Class C fly ashes containing high amounts of calcium oxide may have no significant effect to retard the setting time of concrete. (T. Erdoğan, Admixtures for concrete). Although it is known that the use of fly ash reduces the water requirements at equal consistencies and increases the fluidity of cementitious systems. The effect of fly ash on the water requirement of the concrete mixture depends on the fineness of the fly ash particles and shape of the particles. The spherical particle shape provides lower internal friction and lowers the amounts of water. (T. Erdoğan Admixtures for concrete)Fly ash usage can reduce the rate and amount of heat evolution. Hydration processes of fly ash incorporating cementitious systems are mush slower than the hydration of cement itself. This results in slower heat generation. Rapid heat generation can cause high internal concrete stresses and higher shrinkage. (T. Erdoğan). Replacing large percentages of cement with fly ash (fly ash generates only 15 to 35 percent as much heat as compared to cement at early ages) can reduce the damaging effects of thermal cracking. (http://www. flyash. com/data/upimages/press/HWR_brochure_flyash. pdf). Fly ash may influence the air content and the stability of entrained air voids. (Use of fly ash in concrete ACI committee). The reason fly ash has a such critical role regarding air entrainment is related to unburned residual carbon. Fly ash carbon has a strong tendency to interact with the surfactants used as air-entraining admixtures. (http://www. nrmca. org/research/CIF 06-4 Tech Talk. pdf). If constant air content is required, admixture dosage can be increased depending on the carbon content, loss on ignition, fineness and other organic material. (Use of fly ash in concrete). The amount of increase depends on the type of fly ash used. A fly ash with a low loss on ignition (low carbon content) will results in lower increase in the amount of air-entraining admixtures than fly ash with a high loss on ignition. (T. Erdoğan). Workability of concrete mix containing fly ash is enhanced due to the fine particle size and spherical shape of fly ash particles. (Concrete admixtures handbook). When fly ash is added to concrete, paste volume increases. Increase in paste volume produces a concrete with improved plasticity and better cohesiveness. (Use of fly and in concrete-Lane 1983). Furthermore, when paste volume is increased, the workability and pumpability of a concrete mixture are enhanced by decreasing the friction between aggregate particles. (Fly ash silica fume slag and natural pozzolans in concrete). The effect of addition fly ash as aggregate supplement in workability and pumpability is significant when sand content decreased and coarse aggregate content increased. The use of fly ash in concrete reduces the bleeding by hindering the channels of bleed-water flow and increasing the ratio of surface area of solids to the volume of water with the use of very fine ash particles. (Fly ash silica fume slag and natural pozzolans in concrete, Admixtures for concrete). Because setting time of concretes containing fly ash is usually longer, such concretes should be finished at a later time to prevent sealing the bleed water under the top surface creating a plane of weakness.

2. 4. 4. 3 Effects on Hardened Cement or Concrete

The use of fly ash as cement replacement material is generally resulted in low early compressive strength. The early strength reductions can be coped with lowering the w/c ratio, with the concomitant use of a water reducing admixture. (Concrete-Mindness). However, at later ages concretes with fly ash usually develop higher compressive strengths than concretes without fly ash. Concrete made with fly ash generally gains equal strength at 28 days and higher strength values within 1 year than that of regular concretes made without fly ash. Strengths at any age and rate of strength gain of concrete are affected by the characteristics of the particular fly ash, the cement with which it is used, and the proportions of each used in concrete. (Use of fly ash in concrete)

High lime Class C fly ash shows higher rate of strength gain than Class F fly ash. The self hardening properties of the Class C fly ashes make the concrete gain equal or sometimes greater strengths since hardening reactions may occur at the same time frame as the normal portland cement reactions. (Fly ash in concrete: production, properties and uses - Ramesh C. Joshi, R . P. Lohtia).

Fly ash concrete has lower permeability than that of a concrete made with plain cement. Permeability of concrete depends upon the proportion of CSH to Ca(OH)2 in the cement paste. Calcium hydroxide is a water soluble substance and can leave voids for the ingress of water after leaching out of hardened concrete.(use of fly ash in concrete). When the proportion of CSH to Ca(OH)2 is higher, the permeability of the concrete will be lower. Since fly ash concrete is used Ca(OH)2 which is liberated by the hydration reactions of cement to form new CSH, permeability of the concrete decreases. Fly ash also improves the sulfate resistance of concrete. Fly ash in concrete reduces sulfate attack by reacting with calcium hydroxides to form new calcium silicate hydrates. Additional calcium silicate hydrates fills the capillary pores in the cement paste reducing permeability of concrete. Since sulfate attack occurs when water containing sulfates and tricalcium aluminate or calcium hydroxide in cement comes in contact producing calcium sulfoaluminate hydrates which can expand excessively and thus forms cracks on the concrete. When fly ash is used in concrete, the amount of tricalcium aluminate will be reduced and thus the potential of this type of expansion is also reduced.(http://www. flyash. com/data/upimages/press/HWR_brochure_flyash. pdf)Class F fly ash is known to be more effective in improving sulfate resistance of concrete than class C fly ashes. Class C fly ashes should be used at higher proportions of the total cementitious material to get better resistance.(http://www. flyash. com/data/upimages/press/HWR_brochure_flyash. pdf). Aggregates containing certain forms of silicate react with high soluable alkalies in concreteto form a reaction product that expands in the presence of moisture and results in deleterious cracking of concrete.(Alkali Silica Reactions - By Karthik Obla, Ph. D., P. E. Director of Research and Materials Engineering, NRMCA). The reaction between the siliceous glass in fly ash and the alkali hydroxides in the portland cement paste consumes alkalies, which reduces their availability for expansion reactions with reactive silica aggregates. When the amount of fly ash in concrete is properly adjusted, detrimental effects of alkali silica reaction can be eliminated.(Use of fly ash in concrete). Often the amount of fly ash necessary to prevent damage due to alkali-aggregate reaction is more than the optimum amount necessary for improvement of workability and strength properties of concrete.(Admixtures for concrete, Use of fly ash in concrete). To improve freeze-thaw resistance of concrete in cold weather conditions, air entraining admixtures are introduced. Freezing and thawing resistance of concrete with fly ash or without fly ash depends on the adequacy of the air void system, the soundness of coarse aggregate, age, the strength of concrete, and its moisture condition at the time of exposure. (Admixtures for concrete, Use of fly ash in concrete). The addition of fly ash does not affect the frost resistance of concrete significantly if the strength and air content are maintained constant.(Concrete admixtures handbook). Besides, proper amount of entrained air and air void distribution should be adjusted. When high amount of carbon containing fly ash is used (carbon content > 6%), the dosage of air entraining admixtures are increased to gain equal resistance like concrete without fly ash. Drying shrinkage of concrete is mostly influenced by the fractional volume of the paste, the water and cement content, the cement type, and the type of aggregate. (Admixtures for concrete, use of fly ash in concrete, fly ash, silica fume, and slag and natural pozzolans in concrete). Since water content is one of the factors of drying shrinkage and the usage of fly ash in concrete generally reduces the water requirement of the paste, drying shrinkage may be reduced or retain in same level as the concrete without fly ash. . Yet, fly ash incorporation in concrete may increase paste volume. In that case, drying shrinkage may also be increased slightly if the water content remains constant. (Use of fly ash in concrete.). It has been reported that the addition of fly ash up to 25% does not significantly affect the drying shrinkage of the concrete. (Fly ash, silica fume, and slag and natural pozzolans in concrete). The bond of concrete to steel aims to be affected by the surface area of steel in contact with the concrete, the depth of reinforcement, and the density of the concrete. The bleeding water accumulates at the lower interfaces of the reinforcing bars decreasing adhesion between the concrete and steel. The incorporation of fly ash in concrete increases the paste volume and decreases bleeding. (Use of fly ash in concrete – ACI Committee). Since fly ash reduces the bleeding of concrete, the bond of the concrete to steel may enhance. ACI committee 226 reported that development length of reinforcement in concrete is primarily a function of concrete strength. With proper consolidation and equivalent strength, the development length of reinforcement in concrete with fly ash should be at least equal to that in concrete without fly ash. The bonding of new concrete to old is little affected by the use of fly ash. (Use of fly ash in concrete). Corrosion indicators of reinforcing steel in concrete are by pH, electrical resistivity, soluable chloride content, and soluble sulfate content. (Fiber Reinforced Coal Combustion Products Concrete. May, 2007, bottomash file). High amount of unburned carbon content of the fly ash can also worsen the corrosion of reinforcing steel. Corrosion of steel is an electrochemical process. Unburned carbon content increases the electrical conductivity of the concrete. Yet, fly ash concrete with up to 6% unburned carbon content does not show any difference in reinforcing steel corrosion than concrete without fly ash. (Effect of unburnt carbon on the corrosion performance of fly ash cement mortar, flyash file). Likewise, sulfur compounds in fly ash are usually within the limits determined by the specifications and they are not materially different in the concrete whether fly ash is used or not. (Admixtures for concrete). Although the CH which contrubites to the alkalinity of concrete is utilized by the pozzolanic reaction of fly ash, similar pH degree to that in concrete without fly ash remains to provide a passive film protection. (Use of fly ash in concrete). Fly ash reduces the chance of intrusion of water, corrosive chemicals and oxygen by reducing permeability of concrete.

2. 5Bottom Ash

2. 5. 1Definition and Classification of Bottom Ash

Bottom ash, the solid residue from electric power generation process, represents the coarser size fraction which falls to the bottom of the combustion boiler. The combustion technologies and furnace type determines the characteristics of the material generated. In dry pulverized bottom furnaces, ashes are collected as dry solids before complete melting occurs. These solid particles are collected in a collection hopper and removed by high- pressure water jets and conveyed to a disposal pond or a decant basin for dewatering, crushing, and stockpiling for disposal or use. (http://www. tfhrc. gov/hnr20/recycle/waste/cbabs1. htm). This type of bottom ash is known as " dry bottom ash". Material is dark gray in color and has porous, granular sand like appearance. On the other hand, boiler slag is derived from wet boilers. During coal combustion, bottom ash is kept in molten state and tapped off as liquid. Molten material flows into the hopper where quenching water is held. When the molten slag comes in contact with quenching water, it crystallizes and forms pellets. Boiler slag consists of hard, black, angular and having glassy-like appearance materials. There are some selected standards depending on the usage of bottom ash. AASHTO Standard T 99 and ASTM Standard D 698 contain specific requirements for moisture-density relationships that may influence the use of boiler slag in structural fills or embankments. Industry or design specifications may further determine the suitability of boiler slag in roofing shingles and blasting grit. Because of the salt content and, in some cases, low pH, boiler slag may exhibit corrosive properties. The potential for corrosion of metal components that would come in contact with boiler slag could be a concern and should be tested. Information pertinent to this issue can be found in ACAA Technical Bulletin TB 51 " Underground Corrosion of Metals in Bottom Ash Backfills." Testing to indicate potential corrosivity of boiler slag (or bottom ash) should evaluate pH, electrical resistivity and soluble chlorides and sulfates. (http://www. tfhrc. gov/hnr20/recycle/waste/cbabs1. htm)

2. 5. 2Physical Properties of Bottom Ash

Like fly ash, physical properties of bottom ash depend on the coal type, preparation before combustion and temperature of combustion. (Utilization of industrial coal ash). Most scientists and researches have come to the conclusion that bottom ash displays physical properties similar to the that of natural sands.(Strength characteris. Of Illinois coal com. by-product: pcc dry bottom ash, S. Kumar). Bottom ash has a high porous surface, large particle size, angular shape and glassy texture. Bottom ash particles range in size from a fine gravel to a fine sand.(S. Kumar). The ash is usually a well-graded material, although variations in particle size distribution may be encountered in ash samples taken from the same power plant at different times.(S. Kumar). Bottom ash particles tend to range in size between 50. 8 mm and 0. 075 mm (No. 200) standard sieve. (Coal ash utilization in asphalt concrete mixtures). When examined the literature, specific gravity of ash particles range in between 2. 20 to 2. 70. (Bottom ash: an engineering material).

2. 5. 3Chemical Composition of Bottom Ash

Chemically, CBA (coal bottom ash) has similar properties to fly ash and composition of bottom ash particles is controlled by the source of coal. Three predominant oxides are silicon dioxide(SiO_2), aluminum oxide(Al_2O_3) and feride oxide (Fe_2O_3). Minor quantities of calcium oxide (CaO), magnesium oxide (MgO), sodium oxide(Na_2O_3), potassium oxide (K_2O), sulfur trioxide (SO_3) and other minor oxides such as P_2O_5, TO_2. Bottom ash originally which comes from lignite or sub-bituminous coals has a higher percentage of calcium than that of derived from anthracite or bituminous coals. There can be some percentage of carbon particulate resulting from incomplete combustion, but percentage is low. Due to the salt content and, in some cases, the low pH of bottom ash and boiler slag, these materials could exhibit corrosive properties. When using bottom ash or boiler slag in an embankment, backfill, subbase, or even possibly in a base course, the potential for corrosion of metal structures that may come in contact with the material is of concern and should be investigated prior to use. Corrosivity indicator tests normally used to evaluate bottom ash or boiler slag are pH, electrical resistivity, soluble chloride content, and soluble sulfate content. Materials are judged to be noncorrosive if the pH exceeds 5. 5, the electrical resistivity is greater than 1, 500 ohm-centimeters, the soluble chloride content is less than 200 parts per million (ppm), or the soluble sulfate content is less than 1, 000 parts per million (ppm). (http://www. tfhrc. gov/hnr20/recycle/waste/cbabs1. htm)

2. 5. 4Use Bottom Ash in the Cement Industry

Although the utilization of bottom ash either as a cement replacement material or a concrete mineral additive is not practiced due to high unburned carbon content as well as large particles size and a high porous surface, it possess limited pozzolanic properties. Researches showed that when it is ground, the pozzolanic properties will be enhanced. There are not any practical or industrial usages of bottom ash as a cement additive. Likewise there are not any standard that explains its usage in cement works. Nevertheless, EN 450 and ASTM 618 can be used as guides since chemical properties and mechanical properties are similar to that of fly ash. The previous studies conducted showed that bottom ash could be a natural sand replacement material in concrete. (Strength and drying shrinkage properties of concrete containing furnace bottom ash as fine aggregate, Y. Bai). Combustion process in power plants makes them a convenient alternative to lightweight aggregate with their well graded nature. When Ghafoori and Bucholc searched the literature about the use of bottom ash in concrete, they did not find any research investigations focused on the subject. (Properties of high calcium dry bottom ash concrete, Ghafoori and Bucholc). Then, they use a lignite based bottom ash from a power plant in Indiana as a fine aggregate in production of structural normal weight concretes. They observed that porous surface and angular shape of bottom ash particles increased quantity of mixing water causing the concrete mixture with bottom ash and combined bottom ash and natural sand mixture showed higher degree of bleeding than the reference concrete. Higher water requirement of bottom ash was also resulted in lower compressive strengths of concretes with bottom ash and combined bottom ash and natural sand mix. Yet, at later ages, the compressive strength of the bottom ash incorporation specimens reached to similar values to the reference samples. Bottom ash incorporation systems had a lower modulus of elasticity than the reference sample. Concrete containing bottom ash as fine aggregate showed similar resistance to sulfate environment. Also, their resistances to abrasion were as 40% worse as the reference concrete whereas the resistance of concrete containing both natural sand and bottom ash was about 13% better than the reference concrete. Detrimental effects of porous structure of bottom ash particles on permeation process beyond 30% replacement of natural sand was reported by Bai et all. Collins et all and Kohno et all also indicated the improving effects of porous structure on shrinkage of concrete due to its " internal curing effect" through slow release of moisture from the saturated porous particle. (Strength and drying shrinkage properties of concrete containing furnace bottom ash as fine aggregate, Y., Bai).

2. 5. 4. 1Effects of Ground Bottom Ash on Mortar and Concrete Properties

There are very limited amounts of studies about the usage of bottom ash in mortar and concrete bodies as cement replacement or concrete admixtures. Hopkins et al. state that if particle size distribution of bottom ash is reduced under 45µm, the cementitious properties enhance. Lower limit of the particle size after reduction might not be less than 1-2µm due to higher grinding costs.

Water Requirement

Jaturapitakkul and Cheerarot stated that original bottom ash mortars needs more water than that of cement mortar due to porous and rounded nature of particles. The water requirement increased when replacement rate increased while the water requirements of ground bottom ash mortars were less than those of the cement and original bottom ash mortars.

Workability

Jaturapitakkul and Cheerarot investigated in detail the normal consistency of bottom ash incorporating mortars. They concluded that ground bottom ash doesn’t enhance the normal consistency dramatically. There is seen a slight improvement in normal consistency up to 20 % ground bottom ash replacement of cement amount. Yet, normal bottom ash containing mortars show a decrease in normal consistency. Kohno and Komatsu showed that flows of mortars containing 5 to 15% ground bottom ash as a percentage substitution were lower than that of reference mortar after 5% replacement. On the other hand, the flow values of mortars containing 5 to 15% ground bottom ash as a percentage addition are observed to somewhat higher than that of concrete without ground bottom ash. They also indicated that the water content of the ground bottom ash concrete decreased slightly to have the same slump (10 cm) for each fresh concrete.

Setting time

When bottom ash is used in cementitious systems as a substitution material of portland cement; due to diminution in the amount of C3S, setting times of the mortars or concretes increases. Jaturapitakkul and Cheerarot revealed that the initial setting times of original and ground bottom ash cement paste retarded about 9-23 minutes compared to cement paste. Final setting times of original bottom ash cement pastes lasted 15-30 minutes longer than that of the cement paste.

Strength and Strength Gain

Researches have showed that substitution of bottom ash in cement and concrete either decreased or increased the compressive strength of the samples. Kurama and Kaya indicated that the compressive and flexural strengths of representative concrete specimens prepared by incorporation of bottom ash by 5-25% weight in place of portland cement increased with increasing amount of ash replacement up to 10%. Higher substitution rates were found to give decreased strength values where decrease was more significant for the lower curing times such as 7 and 28 days. The decrease in compressive and flexural strength was attributed to the different phase distributions and higher unburned carbon contents of CBA. In the study of Jaturapitakkul and Cheerarot, compressive strengths of mortar specimens with a replacement rate of 10-30% ground bottom ash by weight of cementitous material were observed to give higher strength values than that of portland cement after 28 days. Yet, the compressive strengths of original bottom ash mortars with same replacement ratios were concluded to be lower than the minimum value stated by EN 197-1. They attributed this to smaller surface area of large particle size of original bottom ash to react with lime. Jaturapitakkul and Cheerarot also have studied concrete samples incorporating 20% of ground bottom ash replacement which was designed to reach 25, 35 and 45 MPa at the age of 28 days. Concretes including bottom ash substitution designed to reach same strength to its ordinary portland cement equivalent in which both of them had same W/C. They have found that mixture with higher cement content had higher development rate of compressive strength. The strength of bottom ash concrete designed as 45 MPa got close to that of its portland cement counterparts as early as 14 days. Other bottom ash incorporating concretes showed to improve compressive strength values as high as ordinary portland cement at the age of 28 days or later. Finally, they stated that higher cement content presented higher hydration reaction and gave more Ca(OH)2, which was needed for pozzolanic reaction if ground bottom ash to be used as pozzolanic material have high fineness. Researches conducted by Kohno and Komatsu on mortar and concrete specimens concluded that ground bottom ash is a good mineral admixtures up to 15% with comparable strength values especially at later age (28 days and longer). Yet, when percentage of ground bottom ash substitution rose, strength values fell off. Strength increased as the curing period got longer. The strength of the mortar with bottom ash and without bottom ash became nearly same at 91 days. On the other hand, up to 15% addition to initial cement amount, the bottom ash mortars had higher strengths for all ages. Kohno and Komatsu also studied the ground bottom ash concrete which ground bottom ash used as a substitute of 5 and 10% of the initial cement amount. The concrete specimens were cured in three different ways. The strengths of concretes were slightly lower than concrete with ordinary portland cement at the end of the 28 days for standard curing. It was observed that strength development of ground bottom ash concretes were higher than that of reference concrete from 28 days to 91 days. In case of steam curing, ground bottom ash concretes have higher 7 and 28 days strength values than the reference concrete. They indicated that the addition of siliceous material was effective for steam curing. The strengths of concretes were higher than that of reference concrete when autoclave curing was applied for 3 day treatment. The 3 day strength of the specimens were almost 80% of the 28 days strength values of standard curing specimens since autoclave curing speeds up the hydration. As well as the tensile strength of ground bottom ash concretes showed higher results for all ages, the development of tensile strength of ground bottom ash concretes were higher, when compared with compressive strengths. The improvement in strength was also observed in the research by Hopkins et al. Cementitious composition consisted of approximately 80% by weight of cement and 20% by weight of the pozzolanic material which contained fly ash, silica fume and ground bottom ash mixture. When pozzolanic material comprised ground bottom ash and silica fume mixture, it included approximately 80% by weight of ground bottom ash and 20% by weight of silica fume. Cementitious material constituted 380 kg/m3 of the concrete samples. The concretes were prepared with a fixed water cementitious ratio of 0. 45. They found that replacement with ground bottom ash and dry silica fume mixture resulted in highest 28 day strength improvement with 22% increase over control. Concrete which comprised portland cement and ground bottom ash also showed good performance with a 9% increase over control at 28 days whereas fly ash replacement make a decrease of about 9% over control. Later, they conducted the same procedure with other cements (Bath T-10 and St. Constant T-10). Replacing cement with bottom ash and fly ash decreased 28 day compressive strength as compared with the control. Yet, blends of bottom ash and either dry or wet silica fume showed a slight increase in 28 days' compressive strengths as compared with the control. They contribute that to a remarkable increase in slump of bottom ash mixture. They stated that when high slump will be lowered by reducing water content, the compressive strength of bottom ash blend will increase.

Strength Activity of Bottom Ash

The strength activity index is the ratio of average compressive strength of test-mixture mortar cube or bar to the average compressive strength of control-mixture mortar cube or bar. ASTM C 311 describes strength activity test as " the test for strength activity index is used to determine whether fly ash or natural pozzolan results in an acceptable level of strength development when used with hydraulic cement in concrete". Strength activities of pozzolans are determined according to the European standard EN 450 and American standad ASTM C 311. Cherief et al studied the strength activity index of a Brazilian bottom ash and portland cement mixture mortar bars prepared according to EN 450. Results indicated that bottom ash was convenient for use in concrete. Strength activity index of bottom ash reached to 0. 88 at 28 days and 0. 97 at 90 days which were higher than those specified by the EN 450.

Drying Shrinkage

Kohno and Komatsu indicated that drying shrinkage of concretes containing ground bottom ash were about 6 % higher than that of concrete without them when ground bottom ash was used as 5 to 10% substitution.

Water Permeability

It is reported that the coefficient of water permeability of ground bottom ash concrete were lower than that of concrete without ground bottom ash by Kohno and Komatsu.