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Study of Fly Ash as a Partial replacement of Cement in Concrete

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Abstract

For a variety of reasons, the concrete construction industry is not sustainable. First, it consumes huge quantities of virgin materials. Second, the principal binder in concrete is portland cement, the production of which is a major contributor to greenhouse gas emissions that are implicated in global warming and climate change. Third, many concrete structures suffer from lack of durability which has an adverse effect on the resource productivity of the industry. Because fly ash concrete addresses all three sustainability issues, its adoption will enable the concrete construction industry to become more sustainable.

To study the effect of partial replacement of cement by fly ash, laboratory studies was done and tests conducted on concrete that was incorporated with varying percentage of fly ash. These percentages were 0%-40% in the interval of every 10%. The concrete samples were cured for a period of 7days, 14days, 21days, 28days and 56 days. Three main tests were conducted namely:- compression test, flexural test and slump test. Based on the results of the tests, graphs were drawn and analyzed.

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Chapter 1 : Introduction

1.1 General Introduction

Concrete is an extraordinary and essential structural material in the human history. As written by Brunauer and Copeland (1964), “Man consumes no material except water in such tremendous quantities”. It is no doubt that with the development of human civilization, concrete will continue to be a dominant construction material in the future. However, the development of modern concrete industry also introduces many environmental problems such as pollution, waste dumping, emission of dangerous gases, depletion of natural resources etc.

Presently Portland cement and supplementary cementitious materials are cheapest binders which maintain/ enhance the performance of concrete. However, out of these binders, production of Portland cement is very energy exhaustive along with CO_2 production. About 1 tonne of CO_2 is produced in manufacturing of each tonne of Portland cement (PC). Thus, cement production accounts for about 5% of total global CO_2 emissions (Nixon, 2002). On the other side of the spectrum, in order to reduce the rate of climate change, a global resolution to an 8% reduction in greenhouse gas emissions by 2010 was set in the Kyoto Protocol in 1997. Developed countries are much aware for its need and a climate change tax was introduced by them. In this connection UK Government also introduced same kind of tax on 1st April 2001, in order to achieve its target of a 12.5% reduction in greenhouse gas emissions which is the government’s domestic goal of a 20% reduction in CO_2 emissions by 2010. Therefore, it is clear that, in order to keep its position as a dominant material in the future, the model of concrete industry needs to be shifted towards “sustainability”.

In order to fulfill its commitment to the sustainable development of the whole society, the concrete of tomorrow will not only be more durable, but also should be developed to satisfy socioeconomic needs at the lowest environmental impact (Aïtcin, 2000). In his prediction for the 21st century concrete construction, Swamy (2001) stated “bearing in mind the technical advantages of incorporating PFA, slag, SF and other industrial pozzolanic by-products in concrete, and the fact that concrete with these materials provides the best economic and technological solution to waste handling and disposal in a way to cause the least harm to the environment, PFA, slag, SF and similar materials thus need to be recognized not merely as partial replacements for PC, but as vital and essential constituent of concrete". Thus, using various wastes or by-products in concrete is a major contribution of the 21st century concrete industry to the sustainable development of human society.

1.2 Background Information

Fly ash also known as flue-ash, is one of the residues generated in combustion of coal. It simply refers to the ash that is produced during combustion of coal.

Until recently, fly ash has been considered as an industrial waste material. Currently it is the most widely used pozzolanic material all over the world. As a construction material, it is used in many other ways such as pozzolana cement, precast building blocks, light weight aggregate, fly ash cellular concrete, fly ash building bricks, partial replacement of fine aggregate in concrete and mortar, and high strength concrete.

Currently a lot of advancement is going on in the research of fly ash. A lot of books are written, thesis work and conferences are being conducted. According to **ecoba** (2014), the Eurocoalash 2014 conference will be held in 13 Oct 2014 in Munich. The programme will cover the most update information on ongoing research work on reactivity and activation of fly ash for use in cement, concrete, ceramics and special binders as well as processing option.

A lot of research has been done previously regarding fly ash as a resource material in concrete technology. This has led to the advancement of its use in most parts of the world.

1.3 Problem Statement

Although there are clearly economic and environmental benefits associated with the use of high level fly ash in concrete, the research is more focused on the mechanical properties of concrete with fly ash as a partial replacement of portland cement.

1.4 Goals and Objectives

The goal of the project was to determine the factors that influence the properties of concrete with high levels of fly ash and to produce guidelines to ensure the safe and appropriate use of high-volume fly ash concrete.

The objectives of the project were as follows:

1. To determine how fly ash as a resource material is used in concrete technology.
2. To determine and analyze the effect of fly ash replacement level on compressive strength, tensile strength, permeability, workability, durability etc.
3. To determine the amount of fly ash of total cementitious content provides the best yield in terms of compressive strength, durability, workability etc
4. To find out whether there is any limitations on the amount of fly ash to be used in replacing portland cement

1.5 Scope

This research although done in Malaysia, will be mainly focused with fly ash used in India, USA and China. How this aforementioned countries have implemented the use of fly ash in concrete technology and to what extent. The reason behind focusing on this three countries is because according to Heidrich and Weir (2013) the largest producers of fly ash are China, USA and India.

Based on the objectives stated in clause 1.3, lab experiments will be conducted to get the data required for the research. Based on the data that will be attained, conclusions will be made to satisfy the project undertaken.

1.6 Significance and Contribution of the research

The use of materials such as fly ash as a supplementary cementing material in concrete has become commonplace in most parts of the world especially in the developed countries. Properly used, fly ash can significantly enhance the properties of concrete. There is increasing pressure to replace higher levels of Portland cement with fly ash to help reduce the CO_2 emissions associated with the manufacturing of Portland cement. Essentially, for every tonne of Portland cement manufactured, one tonne of CO_2 is released into the atmosphere. Therefore, replacing Portland cement with fly ash could reduce cement production and hence reduce CO_2 emissions. The demand and consumption of Portland cement is increasing, therefore it is important for the cement and concrete industry to start utilizing more fly ash to meet these demands rather then increase Portland cement production (Malhotra and Mehta, 2002).

In Western Canada, EcoSmart (an industry-government partnership) is aggressively promoting the use of high-volume fly ash in concrete construction. Many architects are embracing "Green Building" strategies, part of which involves maximizing the use of recycled materials in construction.

Chapter 2 : Literature Review

2.1 History of Fly ash

Fly ash in concrete is nothing new. According to Burt Lockwood (2005), the technology for using pozzolan could be said to go thousands of years, far predating the invention of portland cement in the early 1800's or the coal-fired power plants that generate fly ash.. Lime plasters- the precursors to both Roman and modern concrete-date as far back as 2500BC in India, Mesopotamia, China and the Mediterranean. No one knows for certain who things started, but probably a large bonfire encircled by limestone rocks reached a high enough temperature to calcine the limestone turning it unexpectedly into quick-lime. Soon enough, rain falling on the quick lime would cause it to hiss, spit, and heat up. Someone eventually discovered that the resulting material could be ground up, mixed with more water and applied to earthen walls in a paste that hardened to a much greater density and durability than any manmade thing previously known. Lime plaster was born, eventually concrete followed.

The next step in the development of concrete was to improve the lime by adding reactive silica. The ancients found that calcined clay, when mixed with lime created a much harder plaster that would even cure under water. Later the Romans were able to produce the same effect by using certain type of volcanic soils from the region of Pozzuoli, Italy- hence the term pozzolans. The famous Roman concrete which survives to this day is a mixture of lime plaster and pozzolanic soil. Nowadays, we explain Roman concrete by saying that hydrated lime reacted with silica in the pozzolanic soil to provide the "glue" for the concrete. We describe the effect of adding fly ash to portland cement in a similar way since hydrated lime in the portland cement reacts with a reactive silica in fly ash to better hold the concrete together (Shaw, 2009).

According to the Roman history, the fly ash story started 2000 years ago when the Romans built the Colosseum in the year 100 A.D. It is interesting to note that the building still stands to date. The Romans in the construction of the Colosseum they used the ash generated from the volcanoes. This is a classic example of a building which has proved durability by using fly ash. Volcanic ash is just like fly ash. The only difference between the two is that volcanic ash is produced naturally from volcanic eruptions while fly ash is obtained from burning coal.

Together with the Colosseum is the Pantheon. The Pantheon is a circular concrete temple built in Rome in 128 A.D. It has walls 6.1 meters thick and a dome measuring 43.3 meters in diameter. The building still stands strong due to the excellent quality of the mixture which contained volcanic ash.

In the history of U.S.A, the first concrete project to utilize fly ash was in the construction of Hoover dam in 1929. According to L&M Construction Chemicals (2014), in the construction of the Hoover dam alot of volume of concrete was needed. Due to the massive volume necessary for the dam's construction, the exothermic heat generated by hydrating portland cement was anticipated to be a problem on the project. A large amount of internal heat in concrete was predicted to have a detrimental effect on the concrete strengths. It was found out that by reducing the amount of portland cement in the concrete mix and replacing it with fly ash, the same strength could be achieved while the internal temperature of the concrete could be greatly reduced. It is believed that if only portland cement was used in the project, the Hoover Dam would have needed approximately 150 years to cool to ambient temperature.

In 1983, the U.S. Environmental Protection Agency issued "Cement and Concrete Containing Fly Ash Guidelines for Federal Procurement", which encouraged increased use of concrete containing coal fly ash in federally-funded projects. The Washington, D.C. Area Metro subway system, built during the 1980's, used more than 200,000 cubic yards of concrete containing coal fly ash. The massive 85,000 stadium built in 1996 for the Summer Olympics in Atlanta is another example of HVFA (High Volume Fly Ash) construction. As stated above, the use of fly ash in concrete started long time ago, but it was not widely used. In the past, fly ash was generally released into the atmosphere, but pollution control equipment mandated in recent decades now requires that the fly ash is captured before being released to the atmosphere. For instance, in the USA the fly ash is either stored at coal power plant or placed in landfills. It is approximated that about 43% is recycled and often used to supplement Portland cement in concrete production.

Today growing numbers of major concrete structure projects are being built by using high volume of fly ash in Europe and the U.S.A to improve and increase durability, workability, strength of the concrete.

2.2 Replacing Portland Cement with Fly ash

2.2.1 Why so?

It is important to note that Portland cement cannot be completely replaced with Fly ash. They need to be added together for it to work out in the concrete mix. A team work between Portland cement and fly ash makes a “dream team”. The chemistry provided by the fly ash compliments with that of portland cement. Moreover the physical properties of fly ash improve the rheology and microstructure of concrete to a greater extent. It is important to note that fly ash by itself cannot react with water. It needs free lime produced on hydration of portland cement, to trigger its pozzolanic effect. Once triggered then the fly ash can play a very big role in improving the quality of the concrete.

As McCraven (2013) states , “The no.1 source of electrical generation has always been, is today, and likely will continue to be coal”. Due to the relatively low cost, the use of coal as the primary source of energy will continue to grow for the foreseeable future. Hence, if the production of coal will continue to grow due to the demand, as the population also is growing, then it is natural that the amount of fly ash will increase.

Increase in the amount of fly ash would mean a lot of waste production that would end up in landfills taking significance amount of land size with no benefit. Already the world is facing challenges with land availability due to the increased in the world population. So out of the option of either recycling or disposing, recycling is chosen. Due to the effect of global warming and other current environmental related issues, there is also great need of creating a greener environment. One of the ways of achieving a greener environment is to re-use or recycle waste materials to the maximum way possible.

Another possible problem with the ash waste remaining in the land fills is that it might lead to groundwater contamination which can adversely affect humans and animals alike. This is due to the fact that coal contains traces of arsenic, barium, beryllium, boron, cadmium, mercury etc. Its ash will eventually continue to contain these traces and therefore cannot be dumped or stored in a place where rainwater can leach the metals and penetrate to the aquifers below the ground. But not all the fly ash is recycled. Research shows that in U.S.A 2008, the amount of fly ash utilized was 30.1 million tonnes (42%) and the amount disposed was 42.3 million tonnes (58%).

Another reason of replacing Portland cement with fly ash is because of the amount of CO_2 emitted to the atmosphere when using Portland cement. For every single ton of cement we replace with fly ash, we are not only eliminating waste material but also we are reducing the emission of 0.85 tons of CO_2 into the atmosphere. Hence substituting percentage of Portland cement with fly ash will lead to a reduction in the production of Portland cement thereby reducing the amount of CO_2 emissions to the atmosphere. This is the reason why leading organizations all over the world are now adopting this so as to achieve a green environment.

Do we only substitute Portland cement with fly ash only because of environmental concerns? The answer is "No". The extensive research done on properties of concrete with fly ash as a material shows that fly ash adds so much to the concrete.

Some of the many benefits of it are:-

i) It improves workability of concrete

ii) It delays the heat of hydration hence reduces the thermal cracking in concrete

iii) It increases the ultimate concrete strength

iv) It increases the concrete durability

v) Reduces concrete shrinkage during curing

These aforementioned benefits are just a few of the many advantages of adding fly ash in concrete mix. More detail of each of the benefit will be discussed under clause 2.3.2

When choosing materials in concrete three main criteria are analyzed, and that is durability, cost and strength.

In most of the cases the cost of fly ash is generally less when its compared to Portland cement depending on the transportation (Ash Grove Resources, 2014). The price of fly ash depends on its availability. Engineers are always working on trying to economize a construction project as much as possible and the addition of fly ash in the concrete can greatly reduce the total cost of the project.

2.2.2 Efforts in implementing clause 2.2.1

2.2.2.1 Incentive

The use of low levels of fly ash in concrete technology is something like a norm in the current construction industry. It is something that has been accepted and implemented in a lot of projects throughout the world. The projects range from dams, buildings, bridges, roads etc. The current trend now is to shift from low levels of fly ash to higher levels of fly ash to replace Portland cement. This is so because of sustainability factor. Sustainability is one of world's most discussed topic. Its meaning is broad and encompasses the aspects of preservation of the environment as well as essential construction related issues such as efficiently utilization of resources, stable economic growth etc.

A lot of efforts is made to replace Portland cement with high level of fly ash as a way to achieve sustainability. Both Canada Green Building Council (CaGBC) and U.S. Green Building Council (USGBC) are promoting the development of LEED (Leadership in Energy and Environmental Design). Both CaGBC and USGBC are membership-based non-profit organizations that promotes sustainability in how buildings are designed, built and operated.