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Research Article

Fly Ash as an Alternative Energy Efficient Building Material for Cement

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Abstract

Cement is a conventional building material for construction industry. Emissions from cement manufacturing are one of the major contributors in global warming and climate change. It is estimated that 5-6% of all carbon dioxide greenhouse gases generated by human activities originates from cement production. This paper focuses to cover the environmental issues and problems with the cement as a building material in the construction industry at present and also studies the choice of fly ash, which is a waste material from coal industry and has a problem of disposal. As the flyash has the low embodied energy it can be used as an alternative energy efficient building material.

Keywords: *Flyash, energy efficient, embodied energy, cement, environmental hazards.*

1. Introduction

India is witnessing a new phase in development with rapid economic growth and high rate of urbanization. Construction provides the direct means for the development, expansion, improvement and maintenance of human settlements is particular and economic growth in general. It also needs to be recognized that the construction industry adversely affects the environment, through physical disruption, the depletion of key renewable resources like fertile topsoil, forest cover and excessive consumption of energy. Therefore, there Is a strong need to adopt environmentally appropriate materials by upgradation of the conventional materials(Suresh 2010)

Climate change is considered as major environmental challenge for the world. Buildings have a significant and continuously increasing impact on the environment since they are responsible for a large portion of carbon emissions and also uses considerable number of resources. Buildings account for one-sixth of the world's fresh water withdrawals, one quarter of its wood harvest, and two-fifths of its material and energy flows. The construction sector consumes considerable amount of energy from the production of basic building materials, its transportation and assembling called embodied energy. (Deshmukh & More 2014)

Cement and concrete are key components of construction industry. Emissions from cement manufacturing are one of the major contributors in global warming and climate change. Cement manufacturing is a highly energy intensive process, which involves intensive fuel consumption for clinker making and resulting in emissions. Cement is an extremely important construction material used for housing and infrastructure development and a key to economic growth. Despite its popularity and profitability, the cement industry faces many challenges due to environmental concerns and sustainability issues. The major environment health and safety issues associated with cement production are emissions to air and energy use. Cement manufacturing requires huge amount of non renewable resources like raw material and fossil fuels. It is estimated that 5-6% of all carbon dioxide greenhouse gases generated by human activities originates from cement production.(Mishra & Siddiqui 2014) Low embodied energy materials conserve energy and limit Green House Gases (GHG) emissions thus limiting the impact on the environment.(Deshmukh & More 2014)

2. Environmental threats of Cement

Air is the basic necessity of human life but the quality of air is deteriorating continuously and it is being constantly polluted from different sources. One of the major sources of air pollution are automobiles and industries, as per estimates vehicular pollution is the primary cause of air pollution in urban areas (60%), followed by industries (20-30%). Cement industry is one of the most important industries involved in air pollution. The aerial discharge of cement factories consist of Particulate matter, Sulphur dioxide and Nitrogen oxides producing continuous visible clouds which ultimately settle on the vegetation, soil and effects whole biotic life around, as a result the whole ecosystem around the cement factory is subjected to extraordinary stress and abuse.

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Cement industry is one of the most basic industries involved in the development of a country. Cement is the most widely used building material throughout the world. With the increase in demand for cement in India too the numbers of factories are increasing each year and both consumption and production of cement has increased greatly in recent years. The cement industry has been recognized to be playing a vital role in the imbalances of the environment and producing air pollution hazards. The industry releases huge amounts of cement dust into the atmosphere, which settle on the surrounding areas forming a hard crust and causes various adverse impacts.

Three criteria air pollutants are released to the air during cement manufacturing which includes particulate matter (PM), nitrogen oxides (NOX) and sulfur dioxide (SO2) which can be categorised into two headings:

1) Particulates
2) Gaseous pollutants

Particulates

The health effects of particulates are strongly linked to particle size. Small particles, such as those from fossil fuel combustion, are likely to be most dangerous, because they can be inhaled deeply into the lungs, settling in areas where the body's natural clearance mechanisms can't remove them.

Gaseous pollutants

Gaseous pollutants have major negative impacts on health. They also play an important role in environmental changes in atmospheric chemistry. SO2 and NO2 form acids through different chemical reactions in the atmosphere, and these acids are subsequently deposited on land and ocean surfaces as acid rain. It is anticipated that the increasing load of atmosphere sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon dioxide (CO2), carbon monoxide (CO), and ozone (O3) will contribute to global climate change, consequently, it is necessary to quantify the emission in the very near future. Cement manufacturing releases carbon dioxide (green house gas) in the atmosphere both directly when calcium carbonate is heated, producing lime and carbon dioxide, and also indirectly through the use of energy if its production involves the emission of carbon dioxide. The cement industry is the second largest CO2 emitting industry behind power generation(Mehraj .d.).

3. Carbon dioxide emissions and cement industry

The cement industry is one of the primary producers of carbon dioxide (a major greenhouse gas) creating up to 5% of worldwide man-made emissions of this gas, of which 50% is from the chemical process and 40% from burning fuel(Anon .d.) This industry's heavy reliance on coal leads to especially high emission levels of CO2, nitrous oxide, and sulphur, among other pollutants.

The CO_2 emission from the concrete production is directly proportional to the cement content used in the concrete mix; 900 kg of CO_2 are emitted for the fabrication of every ton of cement. Cement manufacture contributes greenhouse gases both directly through the production of carbon dioxide when calcium carbonate is thermally decomposed, producing lime and carbon dioxide,[4] and also through the use of energy, particularly from the combustion of fossil fuels.

The carbon dioxide CO_2 produced for the manufacture of one ton of structural concrete (using ~14% cement) is estimated at 410 kg/m^3 (~180 kg/tonne @ density of 2.3 g/cm^3) (reduced to 290 kg/m^3 with 30% fly ash replacement of cement)(Anon .d.)

4. Flyash

In India, coal will continue to remain a major source of fuel for power generation. At present, about 60% power is produced by using coal as fuel, which results in the production of about 112 million tons of flyash per annum. Considering the tremendous growth required in the power sector for the development of Indian economy, it is expected that ash generation will reach 225 million tons by 2017.(Kavilkar & Patil 2014). Fly ash is a byproduct from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber with the exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles called fly ash. The fine powder does resemble portland cement but it is chemically different. Fly ash chemically reacts with the byproduct calcium hydroxide released by the chemical reaction between cement and water to form additional cementitious products that improve many desirable properties of concrete. All fly ashes exhibit cementitious properties to varying degrees depending on the chemical and physical properties of both the fly ash and cement.

4.1 Utilization of Flyash

Ash is good resource material for utilization in various areas such as manufacture of cement, cement concrete, embankment construction, low lying area filling etc.

The major utilization areas of flyash are as under:

- Manufacture of Portland Pozzolana Cement & Performance improver in Ordinary Portland Cement (OPC).
- Part replacement of OPC in cementconcrete.
- High volume fly ash concrete.

- Roller Compacted Concrete used fordam& pavement construction. Use of ash in road embankmen
- Manufacture of ash bricks and other building products.
- Construction of road embankments, structural fills, low lying area development.
- As a soil amender in agriculture and wasteland development(Kavilkar & Patil 2014)

4.2 Why use fly ash in concrete?

First of all, the spherical shape of fly ash creates a ball bearing effect in the mix, improving workability without increasing water requirements. Fly ash also improves the pump-ability of concrete by making it more cohesive and less prone to segregation. The spherical shape improves the pump-ability by decreasing the friction between the concrete and the pump line. In addition, some fly ashes have been shown to significantly decrease heat generation as the concrete hardens and strengthens. Fly ash, as do all pozzolanic materials, generally provide increased concrete strength gain for much longer periods than mixes with portland cement only.(Anon .d.)

The biggest reason to use fly ash in concrete is the increased life cycle expectancy and increase in durability associated with its use. During the hydration process, fly ash chemically reacts with the calcium hydroxide forming calcium silicate hydrate and calcium aluminate, which reduces the risk of leaching calcium hydroxide and concrete's permeability. Fly ash also improves the permeability of concrete by lowering the water-to-cement ratio, which reduces the volume of capillary pores remaining in the mass. The spherical shape of fly ash improves the consolidation of concrete, which also reduces permeability. Other benefits of fly ash in concrete include resistance to corrosion of concrete reinforcement, attack from Alkali-silica reaction, sulfate attack and acids and salt attack.(Anon.d.)

4.3 How much fly ash in concrete?

Typically, concrete designers use fly ash as a partial replacement for portland cement at values up to 30 percent of the total cementitious composition. The use of high volume fly ash concrete has gained increasing acceptance by structural engineers and architects from an environmental standpoint, as well as the life cycle cost approach. When designing and specifying concrete for strength and durability, the proper selection of constituent materials depends on the exposure conditions, type of structure and intended use. For applications such as footings, columns, walls and beams, where surface exposure is minimal, high volume fly ash concrete mixes may be used effectively. For mass concrete placements such as mat or raft foundations, the use of even higher quantities of fly ash is recommended(Anon d.)

5. Embodied Energy

In Building construction, the requirement of energy is large. It is in various forms. Materials which are required for construction, their manufacturing, transportation, actual use in construction and after construction, large amount of energy utilized. That form of energy is called, as Embodied Energy. Embodied Energy is the sum of all the energy required to produce any goods or services, considered as if that energy was incorporated or 'embodied' in the product itself. The concept can be useful in determining the effectiveness of energy-producing or energy-saving devices, or the "real" replacement cost of a building, and, because energy-inputs usually entail greenhouse gas emissions, in deciding whether a product contributes to or mitigates global warming. One fundamental purpose for measuring this quantity is to compare the amount of energy produced or saved by the product in question to the amount of energy consumed in producing it.

Embodied energy is an accounting method which aims to find the sum total of the energy necessary for an entire product life-cycle. Determining what constitutes this life-cycle includes assessing the relevance and extent of energy into raw material extraction, transport, manufacture, assembly, installation, disassembly, deconstruction and/or decomposition as well as human and secondary resources.

The energy in buildings may be looked from two different perspectives. Firstly the energy that goes into the construction of the building using a variety of materials. Secondly the energy that is required to create a comfortable environment within the building during its lifetime.(Deshmukh & More 2014)

5.1 Embodied Energy of Fly Ash

Fly ash is generated in large quantities especially by thermal power plants. A lot of research has been carried out for effective utilization of fly ash in building industry (Deshmukh & More 2014).

Table 1 Mix proportions of concrete and embodied energy

Sr. No	Mix No.	Cement*	Fly Ash*	Sand*	Stone*	Embodied Energy in MJ for 1 m^3 Concrete
1	A0	429	0	720	1079	2658.967
2	B0	362	79	677	1073	2447.02
3	C0	298	160	642	1069	2258.113
4	D0	234	240	607	1073	2067.54

*Quantities in kg/m^3

The use of fly ash from coal-fired power plants is beneficial in two ways: it can help with our solid waste problems, and it reduces overall energy use. While fly ash is sometimes used as a source of silica in cement production, a more common use is in concrete mixture as a substitute for some of the cement.

When fly ash replaces cement in certain percentage, the study shows that in calculation, as seen in Table 1, the embodied energy of fly ash is less as compare with cement. (Deshmukh & More 2014)

In the above background, Flyash, basically a waste material has a dear edge over the other construction material as it can be converted to a resource with minimum amount of investments. (Suresh 2010)

Conclusions

There is a need to produce more alternative building materials for various elements of construction, considering the short supply, increasing cost and energy and environment considerations for traditional and conventional materials. Cement is a conventional vital component in building construction today. It is among the most energy intensive materials used in the construction industry and a major contributor to CO2 in the atmosphere. Hence, replacing cement by flyash in concrete mix will minimize environmental impact. This recycling of waste material like flyash as replacement for cement, provides a large setting for the disposal of fly ash in a very efficient, useful and profitable way. So we can conclude that, if we increase use of fly ash in concrete in place of cement, we get lower embodied value for the construction making the whole structure energy efficient.

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