Application of Industrial Waste as an Alternative for Ordinary Portland Cement as a Sustainable binding material: A Review

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Abstract - This paper examines he use of sustainable materials to replace cement in concrete. A comprehensive review of industrial waste with pozzolanic properties is, conducted to act as a complete or partial replacement of concrete binder. Fly Ash, Ground Granulated blast furnace Slag and Rice Husk Ash, respectively, industrial waste from thermal powerplants, iron plants, and rice processing plants, are recognized for their various applications in agriculture and industry. Fly Ash can be used for the production of durable geo-polymer cement through the geo-polymerization process, while GGBS and Rice Husk Ash are flexible materials that can be used in addition to cement and fly ash to produce concrete. These concretes have a wide range of applications, including, but not limited to, ready-mix concrete, pre-cast concrete products, road construction, bridges, dam construction, building construction, mass concreting. The best replacement ratios for FA, GGBS and RHA as cements are characterized by high compressive strength, low hydration heat, chemical resistance, improved functionality, good durability and cost-effectiveness. These can be used effectively as a replacement for OPCs in the production of sustainable concrete.

Index Terms - Industrial Wastes, Fly Ash, GGBS, Rice Husk Ash, Geopolymer Concrete

I. INTRODUCTION

Sustainable infrastructure development is essential for addressing the pressing challenges of our time, including climate change, resource scarcity, and the need for resilient and equitable societies. It provides a pathway to creating a better future for both current and future generations by balancing economic growth with environmental responsibility and societal well-being. Environmental Stewardship, where sustainable infrastructure is designed and built with a focus on minimizing its environmental impact. This includes reducing carbon emissions, conserving natural resources, and protecting ecosystems. By doing so, sustainable infrastructure helps mitigate the negative effects of climate change, preserve biodiversity, and promote responsible land and resource management.

Optimizing the use of materials and resources which leads to reduced waste generation, lower energy consumption, and less resource depletion. Long-term economic benefits of practicing energy-efficient buildings, renewable energy projects, and eco-friendly transportation systems can lead to cost savings over their lifespan. Intern it improves quality of life, this can include better access to public transportation, green spaces, cleaner air and water, and improved public health outcomes. While sustainable infrastructure may have higher initial costs, it often leads to significant long-term savings. For example, energy-efficient buildings reduce operational costs over time, and investments in flood-resistant infrastructure can save on disaster recovery expenses. Sustainable infrastructure incorporates energy-efficient technologies and practices, leading to lower energy consumption. This reduces greenhouse gas emissions and contributes to global efforts to combat climate change. Sustainable infrastructure development is achieved by using sustainable construction practices and materials of construction.

In this paper focus of research is given on sustainable construction materials in concrete. Cement is major producer of CO2, therefore using waste materials from industry like thermal power plant (fly ash), steel manufacturing plant (ground granulated blast furnace ash), Rice cleaning industry (rice husk ash) and silica fume etc., industry waste which has pozzolanic properties can reduce consumption of cement. There has been a constant effort in exploring these materials in concrete as replacement of cement completely or partially and research has shown tremendous potential of these materials even better performance than cement.

II. LITERATURE SURVEY

Three major industrial wastes, Fly Ash, Ground Granulated Blast Furnace Slag and Rice Husk Ash, where research has proven that these materials can be replaced completely or partially to replace conventional ordinary Portland cement are reviewed below:

Fly Ash (Low carbon Fly ash)

Fly ash is a fine, powdery material that is a byproduct of burning pulverized coal in electric power plants. It is composed of tiny, solid particles that are driven out of the boiler with the flue gases. In the past, this ash was often released into the atmosphere, causing environmental concerns due to its potential for air pollution. However, in modern power plants, fly ash is usually collected and stored for various beneficial uses. Fly ash primarily consists of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), iron oxide (Fe_2O_3), and calcium oxide (CaO), along with smaller amounts of other compounds. Its composition can vary depending on the source of the coal and the combustion process.

The composition of fly ash makes it good pozzolanic material hence when combined with alkali activators, it produces 3D structures of Aluminosilicates[1], which acts as binder in concrete. This concrete is referred as Geopolymer concrete. It can improve concrete's workability, reduce heat of hydration, and enhance durability. Fly ash has been the subject of extensive research and development to optimize its use in various applications. It is considered an important resource for the construction and environmental industries due to its versatility and sustainability benefits.

Fly ash can be completely or partially can be used in replacement of cement. In an research J. Guru Jawahar et al,[2] combination of Fly ash with GGBS enhances concrete properties, combination of 50% of Fly ash and 50% of GGBS yielded better performance in terms of compressive strength of concrete. There is no standard mix design procedure for Geopolymer concrete because of nonstandard chemical nature of fly ash, in on of the studies Pavithra, P. et al, [3] studied the concrete with fly ash by varying the proportions of Alkali activators/ binder ratio, and varied between 0.4 to 0.8, the compressive strength achieved by concrete is 54Mpa. M. Albitar et al.,[4] created an analytical model to compare the strengths of Geopolymer concrete and key element which affects the compressive strength, tensile strength and flexural strength, in analytical model it was found that naphthalene sulphonate polymer-based superplasticiser has little to no influence on workability and a detrimental effect on strength. When compared to OPC the results were conservative. M J Almufarji et al,[5] did experimental study on geopolymer mortar with blend of fly ash and GGBS with sand and found that incorporating GGBS in concrete has increased overall performance of concrete and a good alternative to the regular cement mortar. Asmara, Y. P. et al.,[6], worked on effect of flyash on steel reinforcement, and from research it was concluded that

Ground Granulated Blast Furnace Slag

Ground Granulated Blast Furnace Slag (GGBS) is a byproduct of the iron and steel industry. It is a type of hydraulic cementitious material that is obtained by finely grinding granulated blast furnace slag, a byproduct of the steel production process when iron ore is smelted in a blast furnace. GGBS is used as a supplementary cementitious material and is often mixed with Portland cement to improve the performance and properties of concrete.[7] GGBS is typically a fine powder with a particle size similar to that of cement. It contains mainly silicate and aluminate compounds and is high in calcium oxide (CaO) content. GGBS is highly reactive and pozzolanic, meaning it can react with calcium hydroxide to form additional cementitious compounds in the presence of water. GGBS is known for enhancing the durability of concrete by reducing the permeability of the material and improving resistance to chemical attack, especially in aggressive environments like marine structures and wastewater treatment facilities. The inclusion of GGBS in concrete reduces the heat generated during the cement hydration process, making it suitable for mass concrete pours. Over time, GGBS can contribute to increased compressive strength in concrete.

GGBS is typically used as a replacement for a portion of the Portland cement in concrete mixtures. The specific mix proportions depend on the desired performance characteristics and local standards. Applications: GGBS is commonly used in a wide range of concrete applications, including but not limited to, Ready-mix concrete, Precast concrete products, Road construction, Bridges, Dam construction, building construction, Mass concrete pours GGBS is an environmentally friendly material that not only improves the performance of concrete but also reduces the energy consumption and greenhouse gas emissions associated with cement production. It is a valuable ingredient in sustainable construction and infrastructure projects.[8]. In Research by Jayalakshmi Sasidharan Nair Basil Johny [9] shows that replacing cement with GGBS in high proportion as 50% will produce with high strength concrete, with adequate strength. Santosh Kumar Karri et al, [10], worked on concrete with replacing cement with GGBS with 30%, 20%, 50% , and tested for serviceability tests like acid attack and sulphur attack. Research proved that concrete with 50% replacement with OPC has outperformed concrete with 100% OPC. Shreyas K [11], has also worked on reducing the use of OPC in concrete and replacing with GGBS and found that 50% replacement yields better performance. The optimum GGBS replacement as cementation material is characterized by high compressive strength, low heat of hydration, resistance to chemical attack, better workability, good durability and cost- effectiveness.

Rice Husk Ash

Rice husk ash (RHA) is a byproduct of rice milling and a material that is increasingly being recognized for its various applications in agriculture and industry. It is produced when rice husks, the outer layer of rice grains, are burned or incinerated under controlled conditions. Rice husk ash contains high levels of amorphous silica and has several useful properties, making it valuable in various application Rice husk ash is primarily composed of silica (silicon dioxide, SiO2), which makes up a significant portion of its composition. The amorphous nature of the silica in RHA is one of its notable [12]characteristics. Rice husk ash is a byproduct of rice milling and is typically obtained from rice husks, which are the outer protective layer of rice grains. These husks are often discarded or used as low-value biomass fuel.

Rice husk ash is used as a supplementary cementitious material in concrete. When used as a partial replacement for cement, it can enhance the strength and durability of concrete, reduce permeability, and decrease the heat of hydration. [13]. Rice husk ash is a versatile material with a range of applications, particularly in construction and agriculture. Its use can contribute to sustainable practices and improve the performance of various products and processes. Amin, Mohamed Abdelsalam, Bassam Abdelsalam [12] has worked on using rice husk ash alternative and sustainable replacement for cement. The compressive strength was monitored at different ages: 3, 7, 28, 60 and 90 d. The water permeability test of hardened concrete as physical properties was conducted. Test results showed that the RHA and FA enhanced the mechanical and physical properties compared with the control mixture. The cementitious content of 450 kgm−3 exhibited better results than other utilized contents. In particular, the replacement ratios of 10 and 30% of RHA presented higher mechanical properties than those of FA for each group. The water permeability decreased as the cementitious content increased due to the decrease in air content for all mixtures. The water permeability loss ratios increased as the cementitious content decreased. In another research by Gautam et al., [14] ordinary Portland cement is replaced in different proportion with RHA to obtain concrete with comparable and satisfactory strength and properties to that of normal concrete. The proportions of replacement chosen are at 2.5% interval starting from 5 % to 15 % and the casted concrete were tested under compression at different ages and results obtained are compared with normal concrete of same grade and it is concluded that the results are comparable. Jalgan, Rahul, Mahajan, Ankit [15] studied the unfired compressed dirt block stabilized by solid waste as the test subject. 2 types of samples were prepared one with regulated Rice husk Ash which was burnt at a temperature of (500-650 c) & another one is unregulated rice husk temperature burnt. The sample is prepared of different amounts of R-h replacement 10percent, 15 percent, 20 percent & 30 percent; R-H Ash with 20 percent replacement of regulated one have better mechanical properties overall. These investigation results revealed that blocks and the right proportion of waste products might be made. The mechanical properties of a block containing R-h ash are also increased.

III. CONCLUSIONS

i. Using Industry waste in replacement to the cement is sustainable solution to reduce carbon emission and reducing landfills.
ii. All the materials are promising in replacement to cement with at least 50% of ordinary Portland cement.
iii. With the use of alkali activators these materials can be used to produce geo-polymer concrete with 100% replacement to cement.
iv. Fly ash has limitation of heat curing but has very fine structure and can be used in concrete to reduce pores and make concrete denser.
v. Fly ash can be used in precast construction where heat curing can be easily employed.
vi. GGBS is an extra ordinary material which is better performing than cement. It's used in high strength and high-performance concrete. This can be replaced to an extent of 50% with Ordinary Portland cement in concrete.
vii. Rice husk ash is effective replacement to cement, and about a 50% can be replaced in concrete.

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