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Use of Ground Granulated Blast Furnace Slag as a Partial Replacement of Cement in Concrete

Agrawal Sangeeta D[1], Dr. Pawar S. B.[2], Dr. Shirule Pravin A.[3], Dr. Husain Mujahid[4]
[1]Research Scholar, SSBT's College of Engineering & Technology, Jalgaon. Maharashtra, India
[2]Professor, SSBT's College of Engineering & Technology,Jalgaon,Maharashtra, India
[3]Head and Professor, SSBT's College of Engineering & Technology, Jalgaon, Maharashtra, India
[4]Professor, SSBT's College of Engineering & Technology, Jalgaon, Maharashtra, India

Abstract— In modern infrastructures all over the world, concrete is the most used construction material and plays an important role in shaping civilization. It is used for various types of structures due to its structural stability and strength. Its consumption is second to water with about 25 billion tons produced every year as per the World Business Council for Sustainable Development (WBCSD). It has emerged as the dominant construction material for the infrastructure needs of the 21st century. The challenge for civil engineers within the future is to style the project using high-performance materials within reasonable cost and lower impact on the environment. Large quantities of waste materials are produced from the manufacturing industry, service industry, and municipal solid waste incinerators. The waste materials are gaining attention as substitute materials to cement and natural aggregates in concrete and it has become a key aspect in society, economics, and development. Sustainable development will meet the requirements of this without compromising the ability of future generations to satisfy their own needs. In the present work, an attempt has been made to use a GGBS as a partial replacement of cement. The main aim of this work is to study the fresh and hardened concrete with partial replacement of GGBS with various percentages. To study the fresh properties workability, hardened properties compressive, splitting tensile strength and flexural tensile strength tests were conducted and comparison study is done.
Keywords—Cement, Ground Granulated Blast Furnace Slag, Concrete.

Introduction

Concrete serves as the fundamental material in civil engineering, utilized extensively in various structures. The primary components of concrete include cement, fine and coarse aggregates, admixtures, and water. Among these, cement is the most crucial element, as it acts as the binding agent for the aggregates. In constructional practices cement in concrete proves to be a promising agent but its extensive use leads to the depletion of natural resources. Cement is its major ingredient which acts as a binding material. The production of cement is responsible for a large amount of CO_2 emission inthe atmosphere. According to CEMBEURO (The European Cement Association), 5% of the world's total CO_2 is released from cement manufacturing plants. Due to the high strength and durability of steel slag, its suitability as construction material in many cases is superior to rock material, and the use of slag in construction also assist to decrease the quantity of landfilled. It has been reported that iron and steel slag have high pozzolanic potential and can be utilized as raw material or blending constituent in cement manufacturing and constructional activities. Ground granulated blast furnace slag (GGBS), a significant by product of the iron and steel industry, is produced in substantial quantities. This material is created by rapidly cooling molten iron slag from the blast furnace using water or steam, which enhances its cementitious properties and results in a glassy, granular substance akin to coarse sand. The cooled product is subsequently dried and finely ground to produce GGBS. Both diatomite and GGBS are utilized together as substitute materials for cement, serving as filler and binder components in concrete.

Ground Granulated Blast Furnace Slag

Ground-granulated blast-furnace slag (GGBS) is produced by rapidly cooling liquid iron slag from an impact heater with water, resulting in a fine powder. Its chemical composition is similar to that of cement, containing approximately 30% to 50% CaO, 28% to 38% SiO2, 8% to 24% Al2O3, and 1% to 18% MgO. As natural resources for cement, such as lime and silica, are depleting, GGBS serves as a viable alternative, allowing for partial substitution in cement formulations. The production of concrete contributes significantly to CO2 emissions; therefore, various materials can replace traditional cement, with GGBS being a notable option as it is a byproduct of the steel industry. GGBS enhances the mechanical properties of concrete, particularly when combined with glass fiber, positively influencing its performance. Utilizing waste from iron production in cement contributes to environmental sustainability. GGBS improves bond characteristics, resulting in increased compressive strength, elasticity, and enhanced crack resistance. The particle size of GGBS ranges from 0.1 to 40 microns, with a relative density of 2.85 to 2.95. When incorporated into concrete, GGBS requires a longer setting time to achieve strength, which may pose challenges for projects requiring rapid construction. Additionally, GGBS offers high resistance to sulfate and chemical attacks, enhancing the durability of concrete. It also provides a smoother finish and a more aesthetically pleasing color compared to traditional Portland cement. Furthermore, GGBS is easy to compact, pump, and place, reducing the likelihood of segregation during transportation and handling.

Experimental Programme

In the current study, cement is replaced with Ground Granulated Blast Furnace Slag (GGBS) in Concrete. The purpose is to find out the optimum replacement proportion of cement in a concrete. The physical, chemical and mechanical properties were determined by some tests during the experimental work. Different mix proportions have been taken for the laboratory experiment to verify its suitability and compared with the traditional concrete. Experimental analysis based on mechanical properties of concrete such as compressive strength, split tensile strength, flexural strength, workability, setting time, by partial replacement of cement with GGBS in the concrete was conducted. Optimization of cement replacement ratio in cement (0–50% by weight of cement) for evaluating the enhanced performance for M30 grade of concrete. Mechanical and physical properties were correlated to assess the enhanced performance of the cement concrete comprising cement.

Literature review

By the various study of research paper some of them are explained below in summary.

1. V.R. Prasath Kumar∗ , K. Gunasekaran, T. Shyamala (2019). Characterization study on coconut shell concrete with partial replacement ofcement by GGBS.

The rising demand for construction materials and the depletion of natural resources have necessitated the search for alternatives to traditional concrete. This research focuses on the complete substitution of coarse aggregate with coconut shell (CS), an agricultural byproduct. While this approach meets the required strength, the quality of coconut shell concrete (CSC) can be further enhanced by the addition of Ground Granulated Blast-furnace Slag (GGBS), a pozzolanic material. The optimal replacement percentage of GGBS with cement was determined to be 10% through compressive strength tests conducted at various replacement levels of 0%, 5%, 10%, 15%, and 20%. For the optimal mix, a comprehensive durability assessment and microstructural analysis were performed using techniques such as SEM, XRD, EDX, FTIR, and IMM. The findings indicated that the inclusion of GGBS can enhance the concrete's strength by approximately 15%. The microstructural analysis demonstrated that the hydration process is significantly improved, leading to a more effective formation of Calcium Silicate Hydrate (C–S–H) and Calcium Aluminium Silicate Hydrate (C-A-S-H) when GGBS is utilized.

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2. MohanKumar R, R. Srinivas Raju, Dr. V Ramesh (2017).Strength and durability studies on concrete with partial replacement of cement by GGBS.

Concrete is arguably the most widely utilized construction material globally, with an annual production of approximately six billion tons. It ranks second only to water in terms of per capita consumption. Nevertheless, the issue of environmental sustainability is compromised due to the detrimental effects associated with the extraction of raw materials and the carbon dioxide emissions generated during cement production. This situation has prompted researchers to seek methods for reducing cement usage by partially substituting it with supplementary materials. These materials can be naturally sourced, industrial byproducts, or waste products that require less energy for processing. Known as pozzolanas, these substances, when mixed with calcium hydroxide, demonstrate cementitious properties. The most frequently utilized pozzolanas include fly ash, silica fume, metakaolin, and ground granulated blast furnace slag (GGBS). It is essential to evaluate the performance of these admixtures when blended with concrete to ensure a lower life cycle cost. This paper aims to investigate the properties of M40 grade concrete with varying levels of cement replacement using GGBS at 20%, 35%, and 50%. The study involves testing cubes, cylinders, and prisms for compressive strength, split tensile strength, and flexural strength, along with durability assessments using sodium hydroxide and hydrochloric acid.

3.Santosh Kumar Karri, G.V.Rama Rao, P.Markandeya Raju (2015).Strength and Durability Studies on GGBS Concrete.

Concrete is arguably the most widely utilized construction material globally, with an annual production of approximately six billion tons. It ranks second only to water in terms of per capita consumption. Nevertheless, the issue of environmental sustainability is increasingly critical, particularly concerning the ecological damage associated with raw material extraction and the carbon dioxide emissions generated during cement production. This situation has prompted researchers to seek methods for reducing cement usage by partially substituting it with supplementary materials. These materials can be naturally sourced, industrial by-products, or waste products that require less energy for processing. Known as pozzolanas, these substances, when mixed with calcium hydroxide, demonstrate cementitious properties. The most frequently employed pozzolanas include fly ash, silica fume, metakaolin, and ground granulated blast furnace slag (GGBS). It is essential to evaluate the performance of these admixtures when blended with concrete to ensure a lower life cycle cost. This study specifically examines the properties of M20 and M40 grade concrete with varying levels of GGBS as a partial replacement for cement, at rates of 30%, 40%, and 50%. The investigation includes testing cubes, cylinders, and prisms for compressive strength, split tensile strength, and flexural strength, as well as conducting durability assessments using sulfuric acid and hydrochloric acid.

4. RafatSiddiquea,RachidBennacerb (2012). Use of iron and steel industry by-product (GGBS) in cement paste and mortar.

The rise in industrialization has led to a substantial increase in the production of industrial by-products. Various industries generate different types of by-products, and effectively utilizing these materials pose a significant challenge. One notable by-product is ground granulated blast furnace slag (GGBS), which is derived from the blast furnaces used in the iron and steel sectors. GGBS plays a crucial role in the formulation and enhancement of high-quality cement paste, mortar, and concrete. This paper provides an in-depth examination of the physical and chemical properties of GGBS, along with its hydration reactions. Additionally, it addresses the workability, setting times, compressive strength, and resistance to chloride and sulfate in cement paste and mortar.

5. J.M. Gao, C.X. Qian, H.F. Liu, B. Wang, L. Li (2005). ITZ microstructure of concrete containing GGBS.

The interfacial transition zone (ITZ) between aggregate and cement paste, as well as the morphology of hydrates in concrete incorporating ground granulated blast-furnace slag (GGBS), has been examined through X-ray diffraction (XRD), scanning electron microscopy (SEM), and micro hardness assessments. The findings indicate that the inclusion of GGBS markedly reduces both the quantity and the orientation of calcium hydroxide (CH) crystals within the ITZ. Additionally, the size of CH crystals diminishes with the incorporation of GGBS. The previously weak ITZ between the aggregate and cement paste is enhanced due to the pozzolanic activity of GGBS. These enhancements become increasingly pronounced as the particle size of GGBS decreases.

6. K. Ganesh Babu, V. Sree Rama Kumar (2000).Efficiency of GGBS in concrete.

The use of supplementary cementitious materials is widely recognized due to the numerous enhancements they offer in concrete composites and their contribution to cost-effectiveness. This paper aims to quantify the 28-day cementitious performance of ground granulated blast furnace slag (GGBS) in concrete across various replacement levels. It was noted that the overall strength efficiency of GGBS concrete can also be characterized using a methodology previously applied to other cementitious materials, such as fly ash and silica fume. The overall strength efficiency was determined to be a function of a general efficiency factor, which varies with age, and a percentage efficiency factor that correlates with the level of replacement, similar to findings for other materials like fly ash and silica fume documented in prior studies. This assessment facilitates the design of GGBS concrete to achieve a specified strength at any chosen replacement percentage.

7. M.V.MohammedHaneef, R.Sivasankar, A.LillyJoice, S.Sebastin, S.Jansisheela (2017) Mathematical model approach for suitability of GGBS as a replacement material for cement and pond ash as a replacement material for fine aggregate in Concrete.

The document examines the mathematical evaluation of Ground Granulated Blast Furnace Slag (GGBS) as a substitute for cement and pond ash as a fine aggregate in concrete. The production of Portland cement is a significant contributor to carbon emissions, releasing substantial amounts of CO2 into the atmosphere during both manufacturing and subsequent use in micro and mass concrete applications. In response to the pressing need for sustainable construction practices, there is a shift towards green concrete solutions aimed at reducing CO2 emissions. Therefore, it is essential to find effective alternatives to cement that do not compromise the essential properties of concrete. Additionally, coal-fired power plants produce considerable quantities of fly ash, which significantly impacts air quality due to particulate matter. This fly ash is collected via electrostatic precipitators, while bottom ash is often disposed of in large ponds and dykes in slurry form. The disposal of pond ash requires extensive land, water, and energy resources, highlighting the necessity for its recycling. The initial phase of this study focused on evaluating the mechanical behavior of concrete with these replacements, leading to the development of a mathematical framework to assess the results.

The aim of this research is to evaluate the effectiveness of GGBS as a partial replacement for cement and pond ash as a substitute for fine aggregate, ensuring that the strength and durability of conventional concrete are maintained. By partially substituting cement with GGBS, the demand for cement can be alleviated, potentially leading to a reduction in CO2 emissions. The study investigates the physical and chemical characteristics of both GGBS and pond ash, utilizing these industrial by-products to replace up to 40% of cement and 20% of fine aggregate in concrete. The mechanical properties of the resulting specimens, including compressive strength, split tensile strength, and flexural strength, were assessed at 7, 28, and 56 days, along with durability characteristics such as water permeability.

8. Vishal Sodhi, SandeepSalhotra (2017) .Utilizing wastes as partial replacement in concrete – A review.

Concrete is widely utilized in contemporary infrastructure across the globe, necessitating significant quantities of natural resources for its production. The primary ingredient, cement, plays a crucial role in the depletion of these resources due to its manufacturing process. The production of cement contributes to environmental degradation and the exhaustion of natural resources. To mitigate waste disposal issues, particularly concerning plastic bottles, it is essential to implement measures that minimize landfill and waterway contamination. One effective strategy is to reduce waste by substituting cement with fine mineral residues such as fly ash, which not only lowers production costs but also decreases energy consumption and the depletion of natural resources. Additionally, plastic waste can be repurposed as a reinforcing agent in concrete, rather than being discarded in landfills. Therefore, the partial replacement of cement with industrial by-products like fly ash and Ground Granulated Blast-furnace Slag (GGBS), along with the incorporation of plastic fibers, represents a more sustainable approach to concrete production.

9. Amir Moohmend, SandeepSalhotra (2017). Integration of GGBS and pet fiber in concrete – a review.

PET fiber is one of the most commonly utilized materials globally, yet it poses significant challenges in terms of disposal and contributes to environmental pollution when sent to landfills. Its bonding properties are advantageous in concrete applications, making it a valuable eco-friendly product. Cement factories are known to emit substantial amounts of carbon and other pollutants, adversely impacting the environment. This study explores the use of reduced cement content in concrete, substituting it with Ground Granulated Blast Furnace Slag (GGBS), which possesses similar properties to traditional cement. The review examines the incorporation of PET fiber into concrete at varying lengths and widths, with fiber content ranging from 0.5% to 3%. Additionally, GGBS is used to replace cement at ratios of 30%, 40%, and 50%. According to IS code, various mix designs were employed, primarily utilizing 43 and 53 grade cement, as seen in most research. The mechanical properties of the concrete were assessed through tests on cubes, beams, and cylinders at 7, 28, and 56 days, including compression, split tensile, and flexural tests for hardened concrete, while compaction was evaluated for fresh concrete. The literature indicates that the strength of concrete incorporating GGBS and PET fiber tends to decrease with increasing fiber length and percentage. However, while the combination of PET fiber and GGBS requires time to develop strength, it generally yields satisfactory results.

10. Pal Ghanshyam (2016).Impact of Strength Parameter of Concrete by using GGBS, FLY-ASH & SILIKA – FUME.

Ordinary Portland Cement (OPC) serves as a fundamental component in concrete production. However, the manufacturing process of cement results in significant carbon dioxide emissions, which are a primary factor in the greenhouse effect and global warming. The construction industry continues to experience a rapid increase in concrete usage. Cement, derived from natural raw materials such as lime and silica, is a key ingredient in concrete. A potential future scenario could arise where lime becomes scarce, posing a challenge for cement production. This situation necessitates that professionals in the construction sector engage in research to identify alternative materials for cement replacement. Consequently, it is essential to explore new materials or consider partial substitutions. Our research focuses on the partial replacement of cement through the combined use of Ground Granulated Blast Furnace Slag (GGBS), Fly Ash, and Silica Fume in varying proportions, while assessing the impact of these materials on concrete performance.

Methodology

The current study work is to analyses strength properties of partially replaced cement by GGBS in concrete. The tests of concretes are carried out as per IS code for this proposed investigation work. Materials used for present investigations are cement, sand, coarse aggregate, GGBS and water. Cement used in the experimental work is 53 grade Ordinary Portland Cement conforming to IS:12269-1987. The cement for the whole work was procured in a single consignment and properly stored. Sand was purchased which satisfies the required properties of fine aggregate required for experimental work and the sand confirms to zone III. Crushed stone of 20mm maximum size has been used as coarse aggregate. The sieve analysis of combined aggregates confirms to the specifications of IS 383:1970 for graded aggregates. Tap water was used in this experiment. The properties are assumed to be same as that of normal water.

Mix design is taken as the conventional mix M30 grade of concrete. The proportion of cement, fine aggregate and coarse aggregate are 1:1.48:3 with addition of GGBS at (0%, 10%, 20%, 30%, 40%, 50%) respectively. The cement, fine aggregates and coarse aggregates were mixed manually in a concrete mixer and then the GGBS was added to the concrete at respective % to prepare the concrete. This prepared concrete was placed in 150mm cube moulds, cylindrical moulds and prism mould in three layers and each layer was compacted by giving 25 blows with a 25mm tamping rod respectively.

TABLE I. MATERIAL QUANTITY

Material	***Mix I (Kg)***	***Mix II (Kg)***	***Mix III (Kg)***	***Mix IV (Kg)***	***Mix V (Kg)***	***Mix VI (Kg)***
	0%	***10 %***	***20 %***	***30 %***	***40 %***	***50%***
Cement	***22.45***	***20.20***	***17.19***	***15.71***	***13.47***	***11.22***
Fine Aggregate	***33.3***	***33.3***	***33.3***	***33.3***	***33.3***	***33.3***
Coarse Aggregate	***67.3***	***67.3***	***67.3***	***67.3***	***67.3***	***67.3***
GGBS	***--***	***2.245***	***4.49***	***6.735***	***8.98***	***11.25***
Water Cement Ratio (0.49%)	***11.0***	***11.0***	***11.0***	***11.0***	***11.0***	***11.0***

Result and discussion

This chapter deals with the results obtained from the various experiments conducted to access mechanical properties. The aim of the study is to determine the compressive strength, flexural strength and spilt tensile strength. The mechanical properties of concrete such as compressive strength, flexural strength and split tensile strength are determined from the standard experiments. They are as follows.

Compressive Strength

TABLE II. COMPRESSIVE STRENGTH FOR GGBS M30 GRADE OF CONCRETE

S.N	***% of GGBS in concrete***	***7 Days Compressive Strength***		***28 Days Compressive Strength***	
		Load(KN)	***CS(N/MM²)***	***Load(KN)***	***CS(N/MM²)***
1	***0%***	*810*	*36*	*900*	*40*
2	***10%***	*800*	*35.55*	*800*	*35.55*
3	***20%***	*530*	*23.55*	*550*	*24.44*
4	***30%***	*340*	*15.11*	*700*	*31.11*

5	40%	430	19.11	790	35.11
6	50%	360	16	560	24.89

TABLE III. FLEXURAL STRENGTH FOR GGBS M30 GRADE OF CONCRETE

S.N	% of GGBS in concrete	28 Days Flexural Strength	
		Load(KN)	FS(N/MM²)
1	0%	20.45	8.18
2	10%	20.0	8.00
3	20%	19.92	7.17
4	30%	15.15	6.06
5	40%	12.92	5.17
6	50%	11.55	4.62

TABLE IV. SPLIT TENSILE STRENGTH FOR GGBS M30 GRADE OF CONCRETE

S.N	% of GGBS in concrete	28 Days Split Tensile Strength	
		Load(KN)	FS(N/MM²)
1	0%	200	5.65
2	10%	190	5.37
3	20%	160	4.527
4	30%	170	4.81
5	40%	188	5.32
6	50%	140	3.96

Conclusion

This experimental study has proved to be better way in providing strong and durable concrete. It is also giving solution to disposal problem of ground granulate blast furnace slag. Due to the scarcity of building material we have to search for alternative materials. So by using these different kinds of materials we can make a great change in our construction field and we can environmental to the great extent. It's our responsibility to save our country from pollution and lots of money can be saved by using these materials and also by following these techniques.

1. Use of GGBS is effective, economical and eco-friendly.
2. It is visible that replacement of 10% of cement by GGBS results into highest compressive strength as compared to another proportion.
3. There is no considerable increase of flexural strength attained by this concrete but 10% replacement of cement by GGBS results into highest flexural strength as compared to another proportion.
4. Comparing the result of split tensile strength there

is no specific increase in the strength of the concrete but the highest strength was attained by the 10% addition of GGBS.

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