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Partial Replacement of Cement with Waste Materials – A Review

Aditya Kumar Saini[1], Abhinav Singh[2], Abhishek Tiwari[3]

[1]M.Tech Scholar, Dept of Civil Engineering, Swami Vivekanand Subharti University, Meerut, U.P. India
[2]Assistant Professor, Dept of Civil Engineering, Swami Vivekanand Subharti University, Meerut, U.P. India
[3]Assistant Professor, Dept of Civil Engineering, Swami Vivekanand Subharti University, Meerut, U.P. India

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Abstract - *Concrete is an important building material that has become an integral component of our daily life. Due to the scarcity of natural materials, today's construction costs are quite high when using conventional materials. The utilization of concrete and construction costs are rapidly growing with each passing day. Cement has great binding characteristics and is ideal for use in concrete. Cement production, on the other hand, consumes a significant amount of energy and emits a huge amount of greenhouse gases (CO_2). As a result, experts have been looking for cost-effective and environmentally benign alternatives to cement. This research aims at the use of various waste materials as a substitute for cement. The overall aim of this research is to find a waste material that has desired qualities when mixed with concrete. Industrial by-products such as Ground granulated blast furnace slag, Silica Fume, glass powder, rice husk ash, Meta-kaolin, and fly-ash provide excellent binding characteristics to concrete that can be used in place of cement. The use of these materials not only helps to reduce cement usage but also helps to ensure that it is properly disposed of. This study explores the effects of various alternatives to cement that can be used in partial substitutes. If the strength of the newly created eco-friendly cement is higher than that of conventional concrete, it is suitable for future construction.*

***Key Words*: Egg shell powder, rice husk ash, Glass powder, Fly-ash, GGBS, Industrial by-products, Meta-kaolin, Silica Fume.**

1. INTRODUCTION

Cement is a binder, a compound that sets and hardens and can bind together various materials. Cement is one of the key elements of concrete, and it is wreaking havoc on the environment at an alarming rate. For every tonne of cement produced, approximately 0.9 tonnes of CO_2 is discharged into the atmosphere. CO_2 is a greenhouse gas that is responsible for much of the world's warming. As a result, we can conclude that concrete is the backbone of infrastructural development and is the building block of any country's progress. For several reasons, the construction industry is today unsustainable. Concrete is used extensively in the construction industry. Because this material is in such great demand right now, there is a need to discover substitutes for it in concrete. Cement is an essential component in the manufacturing of concrete. Due to environmental concerns, efforts to limit the usage of Portland cement in concrete are gaining a lot of attention. As industrial waste accumulates daily, industries are under pressure to find a solution for its disposal, and utilization of waste material in concrete can also help to reduce natural resource usage. Glass powder, silica fume, fly-ash, rice husk ash, Eggshell powder, Meta-kaolin, and Ground granulated blast furnace slag are among the waste products investigated in this study.

2. LITERATURE REVIEW

2.1 Silica-Fume

Silica fume is the amorphous polymorph of silicon dioxide, silica. It's collected as a by-product of manufacturing silicon metal or ferrosilicon alloys. Silica fume is either grey or white, and its particles are much smaller than the usual size of cement particles. The goal of utilizing silica fume as a partial cement replacement is to increase the concrete's strength. The high surface area of silica fume is one of its distinguishing characteristics. It's a great pozzolanic material, hence it's used in high-performance concrete. Silica fume concrete can be extremely strong and long-lasting. Silica fume is commonly used as an additive or as a partial substitute for cement in concrete.

Malviya et al (2020) [1] investigated the strength characteristics of concrete using silica fume as a partial substitute. Different cubes, cylinders, and beams were made for the study by substituting cement with 0%, 5%, 10%, and 15% silica fume. The results reveal that substituting silica fume with cement had a significant impact on compressive, flexural, and split-tensile strength. The compressive-strength of concrete increases rapidly as the silica fume content increased, and the optimal value attains at 10% replacement. After 10 %, it begins to decline.

Srivastava et al (2014) [2] studied the effects of silica-fume in concrete and concluded that adding silica fume to concrete improves its compressive and bond strength. Silica fume concrete has equivalent tensile strength, flexural strength, and modulus of elasticity to conventional concrete.

Shanmugapriya and Uma (2013) [3] conducted tests on concrete with a mean strength of 60 MPa, a w/c ratio of 0.32, and a CONPLAST SP-430 super-plasticizer. The optimum dosage for maximum concrete performance was calculated to be 7.5 percent silica fume by weight. The tensile strength, compressive-strength, and flexural strength of the material increased by 20%, 15%, and 23% respectively.

Amudhavalli and Mathew (2012) [4] examined M35 concrete with partial substitution of cement by silica fume ranging from 0% to 20%. Because silica fume has a larger surface area than cement, they found that consistency improves as the amount of silica fume increases. In the range of 10-15 % silica fume replacement level, the optimum 7 and 28 days compressive and flexural strength was attained. The flexural strength appears to be more affected by silica fume than the split tensile strength. When the cement was replaced with 10% Silica fume, the weight loss and compressive-strength percentage were lowered by 2.23 and 7.69, respectively, when compared to other mixes.

Dilip Kumar et al (2012) [5] investigated the qualities of low/medium strength concrete. They discovered that silica fume provides strong particle bonding. When 10% of the cement was replaced with silica fume, the compressive-strength was higher than conventional concrete. At 10% cement replacement with silica fume, split tensile strength and flexural strength were also improved. Silica fume concrete can be utilized in regions where there is a risk of chemical attack, frost action, and other factors.

2.2 Eggshell Powder

Eggshells are agricultural wastes released by chick hatcheries, fast-food restaurants, and bakeries, etc which can contaminate the environment and requires proper treatment. The innermost layer, the maxillary third layer, grows on the egg's outermost membrane and acts as a base for the palisade layer, which is the egg shell's thickest section. The vertical layer's top layer is wrap up in an organic cuticle. The egg shell's primary components are magnesium carbonate (lime), calcium, and protein. Dried eggshells served as a calcium source in animal nutrition. It's a fine-grained powder with the right proportions that sieved to the appropriate size before being mixed into concrete or mortar.

Humdullah et al (2020) [6] studied the effect of eggshell powder as a partial replacement of cement on fresh and hardened properties of concrete. At the percentages of 0%, 2.5%, 5%, 7.5%, and 10%, the cement was partially substituted with eggshell powder (by weight of cement). The impact resistance, energy absorption, load-slip parameters, and ultimate bond strength of the resultant concrete were all studied. The initial and final setting times, slump, density, and compressive-strength are measured. The obtained findings demonstrated the benefit of using eggshell powder in concrete. The eggshell powder content had no measurable impact on the concrete unit weight. When compared to the reference mix, the 2.5 % eggshell powder produces the best results.

Bysani Mythili et al (2017) [7] investigated on Limited Substitution of Egg Shell Powder with Cement in Concrete. Cement is partially replaced with eggshell powder in the proportions of 5 %, 10 %, 15 %, 20 %, 25 %, and 30 % by weight of cement in 1:3 cement mortar. There was a small drop in compressive-strength on eggshell powder replacement at day 28 when admixtures used were Saw dirt ash, ash, and small oxide to reinforce the strength of the concrete combined with 5% eggshell powder as a substitute of cement, and it was discovered that replacement of 5% eggshell powder + 22% Micro silica are often superimposed with no reduction.

Mohamed Ansari M et al (2016) [8] investigated the egg shell as a possible replacement for cement. The effect and experimental results of replacing the egg shell powder in cement are described in this paper. The compression test was performed on a cube specimen that had substituted with 10%, 15%, and 20% eggshell powder in Portland Pozzolana cement (PPC) accordingly. On day 7, a compression test was performed on 150mm cube specimens, which was repeated on day 28. The results, which were achieved after the project was completed successfully, show that eggshell powder can be used as a cement substitute. The findings show that using 10-15% eggshell powder as a substitute is advantageous, and after that increasing the percentage of eggshell powder reduces compressive-strength.

Doh Shu Ing et al (2014) [9] studied the ESP as potential filler in Concrete. In this experiment, 5 distinct eggshell powder percentages were added to the M25 concrete mix concerning cement. The most commonly used materials were a super plasticizing agent, portland cement, river sand, broken sandstone, and eggshell powder. The eggshell concrete slump findings in the experiment all ranged from 65 to 75 mm, indicating a medium degree of workability. 10 % eggshell concrete had a compressive-strength of 42.82 N/mm2, which is 57 % higher than the standard specimen. As the eggshell powder concentration rises from 0% to 10%, the flexural strength increased.

K. Uma Shankar J et al (2014) [10] researched the efficiency of using eggshell powder, GGBS, and sawdust ash as industrial waste materials. The purpose of this study is to see if eggshell powder, crushed granulated blast furnace slag, and sawdust ash may use as cement substitutes in some applications. The research outcomes were promising as a result of the testing. The cement sample is made up of 50 % GGBS, 20 % eggshell powder, and 10 % sawdust ash.

2.3 Glass-Powder

Glass is a non-crystalline amorphous material that is mainly a super-cooled liquid. Glass can be manufactured in different shapes and sizes, from microscopic fibers to large size pieces, with great uniformity. Glass is mainly composed of limestone, soda ash, sand, and other chemicals (Alumina, Iron, Chromium, Cobalt, and Lead. Glass has been utilized as an aggregate in the roads, buildings, and masonry construction for a long time. The locally accessible waste glass was collected and ground into glass powder. Glass trash is a very tough substance. Glass powder must be grounded into the correct size before being added to the concrete.

Amurutha et al (2021) [11] investigated the compressive-strength and flow tests on mortar and concrete that were carried out by adding 0 to 25 % ground glass to the mix, with the water to binder ratio remaining constant throughout all replacement levels. Increased glass addition resulted in a slight increase in mortar flow, as well as a minor effect on concrete workability. Concrete cube samples were prepared and tested for strength in the same way that mortar samples were. When compared to control samples, the compressive-strength of recycled glass mortar and concrete was found to be higher. In terms of cost and environmental impact, a 10% cement replacement with waste glass was found to be convincing.

Kalakada and Doh (2018) [12] focus on the experimental investigation of recycled waste Glass Powder (GP) as a pozzolanic cement. For the ongoing investigation, 75 m and 150 m particle sizes were chosen. Workability, density, compressive, and tensile strengths were tested at glass-powder replacement levels of 0 %, 20 %, 40 %, 60 %, and 80 % by weight of cement. Test results demonstrate that using GP as a partial cement replacement for low strength and lightweight applications is viable. Furthermore, GP could be used in workplaces where high workability is required.

Rakesh Sakale et al (2016) [13] studied the experimental effects of glass powder replacement by cement in concrete with different dosages of 10%, 20%, 30%, and 40% by volume of cement on compressive-strength, split tensile strength, workability, and flexural strength are investigated. The compressive, flexural, and split tensile strengths of concrete are shown to increase initially as the fraction of cement replaced by glass powder increases, peaking at around 20% and then declining.

Mirzahosseini et al (2015) [14] investigated how the performance and microstructure parameters of cementitious systems including glass cullet as an SCM are affected by the mix of glass kinds and particle sizes. At a curing temperature of 50°C, the findings shows that mixed glasses can boost reaction rate and shows pozzolanic capabilities, especially when particles of green and clear glass with a diameter of fewer than 25 m were utilized. A linear addition can account for the simultaneous influence of sizes and types of glass cullet (surface area) on the reaction rate of glass powder, indicating that surface area has a substantial impact on glass-cullet reactivity. Cementitious systems with mixed glass types and sizes, on the other hand, exhibited different performance characteristics.

Raghavendra et al (2015) [15] investigated compressive-strength, split-tensile strength, and water absorption of M40 concrete grade mix with 20% waste glass powder replacement in cement and partial waste foundry sand replacement in fine aggregate. According to the test findings, strength was at a lower level on day 7 and day 14 but increased on day 28th. High strength values were discovered at a 40 % replacement level in strength parameters, with the proportion attaining its maximum at M40.

2.4 Fly-Ash

Fly-ash is a category of materials with a wide range of compositions. It's the leftover residue after coal is burned, and it's collected on an electrostatic precipitator or in a baghouse. When powdered coal is was used to generate electricity, it combines with flue gases. Fly-ash is a by-product of coal combustion that is made up of fine particles that are carried out of the boiler with the flue gases. In Portland cement concrete, fly-ash is utilized to increase the concrete's performance. The free-state calcium oxide generated during cement hydration combines with fly-ash silicates to form strong and durable cementing compounds, which improves concrete characteristics.

Saini and Soni (2014) [16] determined the compressive-strength, split-tensile strength, and elastic modulus of fly-ash concrete at 80˚C, 100˚C, and 120˚C. The percentage ratio of fly-ash in the cement was calculated as 30%, 40%, and 50% by weight. The compressive-strength, split tensile strength, and modulus of elasticity of concrete with a cement replacement of up to 30% was comparable to those of concrete without fly-ash, whereas those of concrete with a cement replacement of more than 30% were lower than those of concrete with no cement replacement. When compared to room temperature, the compressive-strength of fly-ash concrete reduced to 120°C.

Wankhede and Fulari (2014) [17] investigated the impact of fly-ash on concrete qualities and found that when 10% and 20% of cement was replaced with fly-ash, the compressive-strength increased, however when 30% of cement was replaced, compressive-strength declines. It was also noted that if the excess amount of fly-ash was added to the concrete, the slump loss increased.

Patil et al (2012) [18] explore the compressive strengths of concrete with fly-ash as a partial replacement for cement. From 5% to 25% of the cement is substituted by fly-ash, with each percent rising by 5%. For concrete with no replacement of cement with fly-ash, the rate of compressive-strength development peaks at 60 days. Up to the age of 21 days, concrete with 5% fly-ash has the fastest rate of compressive-strength development, after which it slows down. The maximum strength is obtained after 90 days with a 10% fly-ash injection. Thus, the initial strength development rate is slower in concrete with partial substitution of cement with fly-ash, but the needed maximum strength is eventually attained.

Sigrun Kjær Bremseth (2010) [19] discussed the pros and cons of utilizing fly-ash in concrete. The capacity to resist alkali-aggregate reaction is one of the most significant benefit of fly-ash concrete, while air-entraining and a slower rate of strength growth are the most significant disadvantages.

Bargaheiser and Butalia (2007) [20] reviews the advantage of using high-volume fly-ash concrete to resist the damage caused due to corrosion in structures. Corrosion in concrete was caused by carbon dioxide and chloride entering the concrete. Fly-ash in concrete reduces carbon dioxide emissions, gives a more sustainable design and longer service life for infrastructure, slows the intrusion of moisture, oxygen, chlorides, carbon dioxide, and aggressive chemicals into concrete, and inhibits corrosion in reinforced concrete structures.

2.5 Ground Granulated Blast Furnace Slag

GGBS, or ground granulated blast furnace slag, is made from molten iron slag, which is a by-product of steel and iron production. Iron slag from a blast furnace is quenched in water steams to form a granular, glassy product, which is then dried and crushed into a fine powder. Ground-granulated blast furnace slag is the name given to this fine powder.

S. Arivalagan (2014) [21] determined the strength efficiency factor of M35 hardened concrete with GGBS as a partial cement replacement. For various ratios of GGBS substitution of cement, the slump, compressive-strength, flexural-strength, and split-tensile strength of concrete are experimentally determined. The concrete strength at 28 days increases when 20 % of the cement is replaced with GGBS. In comparison to OPC concrete, adding GGBS approximately 40% cement by weight resulted in normal workability.

Awasare and Nagendra (2014) [22] investigated the strength characteristics of M20 grade concrete with GGBS replacement at 20%, 30%, 40%, and 50%. The outcomes of natural sand and crushed sand are also compared. Concrete with both natural and crushed sand has the best strength when 30% of the cement is replaced with GGBS. It is also assumed that integrating GGBS into the concrete improves flexural and tensile strengths.

Ramezanianpour et al (2013) [23] studied the effects of replacing cement with GGBS on compressive-strength and sulphate resistance of concrete. Percentages of cement replacement of 35%, 42.5%, and 50% were considered. The concrete was immersed in a 5% sodium sulphate solution for 180 days and 270 days, and compressive-strengths were measured. After 270 days of exposure, concrete with 50% replacement of cement by GGBS exhibited an increase in resistance to sodium sulphate solution, but concrete with 35% replacement levels showed a drop in resistance. A lower w/c ratio is also associated with higher compressive resistance.

V.S.Tamilarasan et al (2012) [24] reviewed the workability of M20 and M25 grade concrete with partial substitution of cement by GGBS. Replacing levels were established in 5 percent increments from 0 to 100%. Various tests, such as the flow test, slump test, compaction-factor test, and Vee-Bee consistometer test, were used to examine the qualities of concrete. The workability of concrete improved up to 45% replacement level in M20 concrete grade and around 50% replacement level in M25 concrete grade, according to the findings. The workability of M25 grade concrete was also shown to be superior to M20 grade concrete.

Pavia and Condren (2008) [25] investigated the durability of GGBS concrete when prone to magnesium sulphate solution and silage effluent solution. For different values of GGBS incorporated in the concrete, properties such as porosity, permeability, capillary suction, mass loss, water absorption, and compressive-strength were studied. When concrete is subjected to silage effluent cycles and salt crystallization, the durability parameter of the concrete increases as the GGBS content rises. As a result, a concrete mix using GGBS as a partial replacement for cement can be used effectively in agricultural silos.

2.6 Meta-kaolin

Meta-kaolin is a dehydroxylated version of kaolinite (clay-mineral). It's a non-crystallized amorphous material made up of lamellar particles. Meta-kaolin is an outstanding pozzolanic element that can ameliorate the durability, strength, and other mechanical characteristics of concrete.

Suryawanshi et al (2015) [26] studied the effects of Meta-kaolin and super-plasticizer on M35 concrete grade. Meta-kaolin was used to substitute cement in 4%, 8%, 12%, and 20%. The w/c ratio was 0.43 in all cases, and compressive-strength was measured at day 3, day 7, and day 28. The compressive-strength improved until 12 % of the cement was replaced, at which point it began to decline. When the cement was substituted with meta-kaolin, the compressive-strength improved by more than 10%. Although the use of meta-kaolin affects the workability, it can be balanced by the use of super-plasticizers.

Devi (2015) [27] used meta-kaolin as a partial replacement of cement to evaluate the compressive, tensile and flexural-strength and durability parameter of concrete having quarry dust as fine aggregate. Meta-kaolin has been used to substitute cement in concrete at various amounts ranging from 5% to 20%. Meta-kaolin was added to quarry dust concrete to improve rheological qualities such as workability, segregation, compaction, and bleeding. The best percentage replacement of cement with meta-kaolin was found to be 15%, which improved the corrosion resistance and strength of concrete at all ages. Meta-kaolin also reacts with calcium hydroxide, which enhances the pore structure of concrete.

Nikhila and Chaitanya Kumar (2015) [28] investigated the partial replacement of cement with MK in M70 grade of concrete at 0%, 10%, 15%, 20%, 25%, and 30%. The Erntroy empirical Shacklock method was used to create the mixed design. Specimens are evaluated for durability studies with 0.5% and 1% concentrations of H_2SO_4 and HCL, respectively. At 15% replacement, cubes, cylinders, and prisms are examined for temperature investigation. The specimens were heated to temperatures of 100°C, 200°C, 300°C, 400°C, and 500°C for 3 hours at each temperature. The usage of Meta-kaolin Concrete (MKC) has increased concrete's performance in a variety of situations.

Patil and Kumbhar (2012) [29] studied the properties like workability, compressive-strength, and durability of M60 grade high-performance concrete consisting of Meta-kaolin. Different quantities of meta-kaolin, as well as a relevant superplasticizer, were mixed into the concrete. The best workability and compressive-strength were found when meta-kaolin was added up to 7.5 % by the weight of cement. When 7.5 % meta-kaolin was applied, the compressive-strength increased by 7.73 % after 28 days. The concrete was attacked by chloride and sulphate, and it was concluded that adding meta-kaolin to the mix improves the chemical resistance of the concrete.

Badogiannis et al (2002) [30] used a high purity commercial meta-kaolin and a produced meta-kaolin to replace fix amount of cement in the concrete. For both forms of meta-kaolin, concrete attributes such as air permeability, sorptivity, durability, strength development, chloride permeability, and porosity are evaluated and compared. It was discovered that the commercial meta-kaolin and the meta-kaolin produced gave identical results in terms of concrete strength and durability. When compared to regular Portland cement concrete, meta-kaolin had stronger 28-day and 90-day strength, as well as pore size, lower chloride permeability, sorptivity, and gas permeability.

2.7 Rise Husk Ash

Rice Husk Ash (RHA) was a term used to describe an agricultural by-product produced by burning of husk at temperatures below 800°C. The procedure yields around 25% ash with amorphous silica content of 85% to 90% and alumina content of about 5%, making it very pozzolanic. RHA is the outcome of rice husk combustion. The key deposits are the silicates, which are eventually lost when a substantial fraction of the evaporable components of rice husk are lost after consumption. The characteristics of the debris are affected by the configuration of the rice husks, the temperature at which it is consumed, and the amount of time it is consumed. For every 100 kilograms of husks consumed in a heater, approximately 25 kg of RHA is produced.

Sai Kumar and Raju (2017) [31] investigated the use of Rice Husk Ash in place of cement at various percentages (i.e. 0 percent, 5%, 10%, 15%, 20%, and 25%). The M25 grade is employed, and the strength at days 7 and 28 is determined according to code requirements. The basic idea for adopting RHA is that it is cost-effective and has pozzolanic properties. He stated that RHA can be replaced in a range of 0% to 15% and that utilizing it in concrete could help to fix the problem of RHA disposal.

Anil Kumar and Suraj Baraik (2016) [32] investigated the design mix of M20 concrete grade with quarry sand replacements of 0%, 15%, 30%, 45, and 60% for laboratory tests such as slump, flexural-strength, split-tensile strength, compressive-strength, permeability voids, and acid attack. The effect of partially replacing cement with Fly-Ash and Rice Husk Ash on concrete is a subject of detailed investigation. He also blended both types of ash as a partial replacement for cement and river sand with quarry sand and conducted studies. Maximum strength is achieved by combining 7.5% Rice Husk Ash + 22.5% Fly-ash with 60% quarry sand.

Kashyap et al (2015) [33] investigated the characteristics of concrete in which 5-20% of the cement was replaced with rose husk ash (RHA). M30 mix concrete was used in the research. The highest level of strength is achieved when 10% of OPC is replaced by RHA. The use of RHA instead of OPC leads to a 7% to 10% reduction in the cost of concrete manufacture.

Obilade (2014) [34] studied the usage of rice husk ash as a partial replacement for cement in range of 0% to 25%. They discovered that the ideal percentage of rice husk ash is between 0% and 20% based on their research. As the percentage of rice husk ash replacement rises, the compacting factor values, bulk densities, and compressive-strengths of concrete starts decreasing.

C. Marthong (2012) [35] investigated the impact on concrete characteristics when various grades of OPC were partially substituted by RHA. The percentages of OPC replaced with RHA were 0%, 10%, 20%, 30%, and 40%, respectively. Concrete's compressive-strength, water absorption, shrinkage, and durability were primarily investigated. The study reveals that replacing up to 20% of OPC with RHA could be used as a partial cement replacement with good durability and compressive-strength.

3. CONCLUSIONS

We live in a world that is constantly evolving and striving for more comfort and convenience. However, it has a detrimental impact on the ecosystem since resources are depleting and pollution occurs to many natural resources. Using waste materials as partial replacement in concrete production have a significant influence on the environment, leading to cleaner and more peaceful surroundings. As a result of the above literature survey, many kinds of research can be carried out on how waste material should partially replace cement up to a maximum level. Partial substitution of concrete materials with locally accessible waste could prove to be cheaper than regular concrete, as well as the method of reducing the problem of disposing of waste generated by diverse sectors. We're seeking to create cost-effective, environmentally friendly concrete that has all the desired qualities and strengths that can be achieved with conventional concrete materials. According to research conducted by numerous academics, there is a lot of room to improve the properties of concrete and reduce the amount of cement used. Concrete characteristics are affected uniquely by each of the seven replacement options discussed in this research. In order to boost concrete's strength, workability, and durability, it will be necessary to replace all of the cement in concrete with an appropriate combination of cement substitutes. In addition, fresh alternatives should be found that can overcome the disadvantages of the previously described options. By repurposing industrial waste as a valuable substance, we can reduce the amount of waste we produce. As a result, a pollution-free environment can be achieved.

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