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Performance Evaluation of High Performance Concrete Incorporating Silica Fume, Bottom Ash, and Steel Slag Aggregate

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Abstract

As micro-fillers, leading to a denser cementitious matrix. Their incorporation reduces the porosity of the mortar, enhances the interfacial transition zone between the cement paste and aggregates, and consequently improves the overall mechanical and durability performance of concrete. Silica fume is commonly used as a partial replacement for cement, bottom ash as a substitute for fine aggregate, and steel slag aggregate as a replacement for coarse aggregate. Their utilization not only promotes the recycling of industrial waste but also enhances the strength, durability, and long-term performance of HPC. Based on the experimental and analytical investigations, it can be concluded that the incorporation of industrial by-products plays a significant role in enhancing the strength and durability of structural concrete members.

Keywords: Silica fume, Bottom Ash, Aggregate, Strength, Mortar

1. Introduction

It is an undeniable truth that concrete is the most extensively used construction material for all types of activities in building industry world over and will remain so for the next few decades. The popularity of concrete is due to the raw material, excellence in strength and durability, low manufacturing and maintenance costs, versatility in moulding various shapes and its unlimited structural applications in combination with steel structures [1-5]. Aggregates are considered one of the important constituents of concrete since they occupy more than 70% of the concrete mix. Generally, the river sand is used as fine aggregate in concrete and it is obtained by mining the sand from river bed.

The mineral admixtures in optimum proportion improve the quality of concrete by

a) Lowering the heat of hydration and thermal shrinkage
b) Increasing the water tightness

c) Reducing the alkali-aggregate reaction
d) Improving the chemical resistance
e) Improving the corrosion resistance
f) Improving the early strength, workability and extensibility
g) Improving the rate of strength development

Depending on the type of boiler, dust collection system, burning temperature, and coal type, bottom ash, which makes up around 20% by volume of the total ash, is the companion to fly ash during the coal-burning process. Although its particles are coarser, more irregular, and porous than fly ash, their chemical makeup is essentially the same. Because bottom ash's particle size is similar to that of regular sand, some research on its use in concrete has concentrated on its potential to completely or partially replace fly ash. Steel slag aggregate is an industrial product that is produced under strict quality control and is free of clay, shells, organic contaminants, and similar materials. Reactive silica, which can react chemically with alkali aggregates, is absent from this aggregate. It lessens the effects on the environment, protects valuable natural resources required to sustain ecosystems, and can lower the amount of energy used in mining, stone crushing, and other operations. Steel slag is highly regarded as a recycled material that can lessen environmental impacts due to its resource-conserving and energy-saving qualities as a result of increased environmental consciousness.

2. Literature Review

According to Gupta et al. (2020), through pozzolanic reactions and pore refinement, industrial by-products including silica fume, fly ash, and slag greatly increase the compressive strength and durability of concrete. According to their review, using mineral admixtures in combination improves long-term performance and encourages sustainable building methods. Vinod et al. (2013) investigated a streamlined mix proportioning technique for high-performance concrete using experimental research on the durability, hardness, and rheological properties of HPC mixes.

Cement content, micro-silica addition, superplasticizer dose, and water powder ratio were shown to have an impact. The impact of silica fume on the microstructure of high-performance concrete was investigated by Muller et al. (2015). 10% silica fume was added to the concrete mixture. They came to the conclusion that, although the presence of silica fume had no effect on C-S-H densities, the chemical composition was affected and that, in comparison to standard concrete, there were no significant changes in capillary, C-S-H gel, or interlayer pore sizes.

Yoo et al. (2012) reported autogenous shrinkage in high-performance concrete with a w/c ratio of 0.3 and mineral admixtures fly ash (0%, 10%, 15%, 20%, & 30%) and silica fume (0%, 5%, 7.5%, 10%, & 15%) as well as chemical admixtures that reduced shrinkage and promoted expansion.

According to Kadam and Patil (2013), the properties of concrete with varying w/c ratios were affected when coal bottom ash was substituted for sand by 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% by weight because bottom ash absorbed more water when the amount of water was increased to achieve a 100 mm slump. In comparison to controlled concrete, the results demonstrated that as the amount of replacement coal bottom ash rose, the compressive strength, split tensile strength, and flexural strength declined.

Cement, fine aggregates, coarse aggregates, and water are the basic elements that make up conventional concrete. This study focuses on using industrial byproducts to substitute cement, fine aggregate, and coarse aggregate in concrete. Cement is a binding material that can hold other materials together and sets and hardens on its own. Cement is the primary binding material in contemporary civilization, whereas traditional binding materials like jaggery, lead, jute, rice husk, etc. were used in ancient civilization. Aggregates are made up of both fine and coarse aggregate. Although they usually make up 70% to 80% of the volume of concrete, they are often thought of as inert filler that has no bearing on the final concrete's characteristics. [21-25].

3. Materials and Method

A substance is crucial to the creation of high-performance concrete. When creating the HPC concrete mix, it's critical to choose the right elements, assess their qualities, and comprehend how various materials interact for best results. Cement, fine and coarse aggregate, water, a chemical additive (superplasticizer), and industrial byproducts such silica fume, bottom ash, and steel slag were the components employed in this study.

3.1 Ordinary Portland Cement

For the current experimental study, ordinary Portland cement of grade 43 that complies with IS: 8112-2013 was utilized. The provider provided Ordinary Portland Cement, also known as Chettinad Cement, and it met codal guidelines. Cement has a specific gravity of 3.10.

3.2 River Sand

Natural river sand conforming to Zone II grading as specified in IS 383:2016 was used as the conventional fine aggregate.

3.3 Silica Fume

A by-product substance utilized as a pozzolana is silica fume, sometimes known as micro silica or condensed silica fume. This by-product is produced when silicon or ferrosilicon alloy is made by reducing high-purity quartz with coal in an electric arc furnace. At 20000 C (36300F), silica fume comes from the furnaces as an oxidized vapor.

3.4 Water

Clean potable water free from harmful impurities was used for mixing and curing all mortar specimens. Water satisfied the requirements of relevant Indian Standards to ensure proper cement hydration and consistent strength development.

3.7 Bottom Ash

The non-combustible waste left over after combustion in a furnace or incinerator includes bottom ash. In an industrial setting, it often refers to the combustion of coal and includes remnants of combustibles that are lodged in clinkers and adhere to the hot side walls of a coal-burning furnace while it is operating.

3.8 Steel Slag

The slag resulting from the steelmaking process are separated into blast furnace and metallurgical slag and then recycled. The steel slag aggregate material was obtained from Local industries at Chh. Sambhajinagar in India.

The IS 10262-1982 absolute volume technique principles served as the foundation for the mix design. In order to investigate the compressive strength at various w/c ratios of 0.4 and 0.45, concrete mixes were created to achieve M30 grade of concrete. The process of designing concrete mixes include figuring out how much of each component to use in order to create a mixture that will have certain qualities both when it is fresh and when it has solidified. A near-optimal mix fraction of HPC is crucial to achieving the unique mixes of performance and uniformity needs. Nevertheless, there are no established guidelines for the mix percentage of HPC.

The most popular test is the compressive strength test, which was performed on cube specimens of 150 x 150 x 150 mm in an AIMIL digital compression testing equipment with a 3000 kN capacity. For every combination of mixes, three

4. Result

Four mixes of silica fume concrete (SFC), five mixes of bottom ash concrete (BAC), and five mixes of steel slag aggregate concrete (SSAC) were created by substituting cement, fine aggregate, and coarse aggregate with replacement levels of 5%, 10%, 15%, and 20% for SF and 10%, 20%, 30%, 40%, and 50% by volume for BA and SSA. SFC1, SFC2, SFC3, and SFC4, BAC1, BAC2, BAC3, BAC4, and BAC5, and SSAC1, SSAC2, SSAC3, SSAC4, and SSAC5 were the names given to these concrete mixtures. After 28 days, the compressive strengths of CC, SFC, BAC, and SSAC were measured.

The strength considerably enhanced at 10% replacement when fine aggregate was substituted for BA compared to ordinary concrete. The compressive strength of SSAC was found to be between 39.55 MPa, 36.55 MPa, 35.86 MPa, 32.95 MPa, and 31.39 MPa. The improvement in compressive strength was equivalent to a 10% replacement when compared to CC. The results showed that 5% SFC, 10% BAC, and 10% SSAC had the highest percentage of compressive strength.

After 28 days of curing, the tensile strengths of SFC, BAC, and SSAC were measured. Tensile strength tests were performed on the cylinders, and average results were found. SFC1, SFC2, SFC3, and SFC4 produced cylinders with tensile strengths of around 3.64 MPa, 3.35 MPa, 3.01 MPa, and 2.89 MPa, respectively, compared to 2.77 MPa for standard concrete.

After 28 days of curing, the flexural strength of concrete mixes such SFC, BAC, and SSAC was measured. SFC1, SFC2, SFC3, and SFC4 produced prisms with flexural strengths of around 9.05 MPa, 8.62 MPa, 7.11 MPa, and 6.68 MPa, respectively, in comparison to 7.11 MPa for ordinary concrete. The strength was noticeably higher at 5% and 10% than that of the traditional concrete when SF was swapped out for cement.

5. Conclusion

It includes compressive strength, split tensile strength of cubes and cylinders, and flexural strength of prisms for all the specimens. For single combination of materials, four combinations of silica fume concrete (SFC) mixes, five combinations of bottom ash concrete (BAC) and steel slag aggregate (SSAC) concrete were made by

replacing cement, fine aggregate and coarse aggregate with the replacement level of 5%, 10%, 15% and 20%, for BAC and SSAC 10%, 20%, 30%, 40% and 50% by volume. From the optimum percentage of replacement on the basic of 28 days compressive strength of concrete, to obtain the binary and ternary combination mix.

For binary and ternary mixes, the optimum replacement percentage level was found from single combination results of the concrete mix of SFBAC, SFSSAC, BASSAC and SFBASSAC for finding compressive strength at different ages of 28, 56, 90 and 180 days curing, split tensile strength and flexural strength at 28 days curing. After 28 days of curing, the flexural strength of concrete mixes such SFC, BAC, and SSAC was measured. SFC1, SFC2, SFC3, and SFC4 produced prisms with flexural strengths of around 9.05 MPa, 8.62 MPa, 7.11 MPa, and 6.68 MPa, respectively, in comparison to 7.11 MPa for ordinary concrete. The strength was noticeably higher at 5% and 10% than that of the traditional concrete when SF was swapped out for cement.

At 28 curing days, the average compressive strength of concrete with 5% silica fume substitution of cement was 38.4 MPa, which was over 4.4% higher than CC. After 28 curing days, concrete with 10% bottom ash substitution of fine aggregate had an average compressive strength of 36.32 MPa, which was over 1.4% greater than that of CC. In a similar vein, concrete that substituted 10% steel slag aggregate for coarse aggregate had an average compressive strength value of 39.75 MPa after 28 curing days, which was over 12.92% greater than CC.

Declaration of Conflicting Interests

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