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To Evaluate Performance of Ternary Blended Concrete with Fly Ash and Silica Fume

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Abstract:

The use of fly ash (FA) and silica fume (SF) as replacements to ordinary Portland cement (OPC) with Superplasticizer (SP) makes the Ternary blended concrete less permeable to harmful ions due to its finer particle size distribution and pozzolanic reaction. Concrete is a unique construction material possessing superior strength and durability characteristics. A large number of structures have come up in the past few decades. Approximately a ton of CO2 is released into the atmosphere during the production of 1 ton of cement. Substantial energy and cost savings can result when industrial byproducts are used as a partial replacement of cement. Such as fly ash, rice husk ash, high-reactive metakaolin, and silica fume are some of the pozzolanic materials that can be used in concrete as a partial replacement of cement. Hence it is required to study the performance of Ternary blended concrete with fly ash and silica fume with durability aspect and reduction in cement production.

Keywords: Silica fume, Fly ash, Ternary blended concrete.

Introduction:

In the building sector, concrete is arguably the most widely utilized product. Constructions including airport terminals, highway bridges, and schools frequently employ concrete. In contemporary buildings, the mechanical and durability features of concrete are synonymous. The most frequent ingredient in concrete is cement. As a result, cement use rises. This requires a substantial amount of energy to build cement, which releases emissions into the environment in the form of carbon dioxide. As a result, the way to solve this issue is to prepare concrete using Pozzalanic goods instead of as much cement. According to earlier research, using Fly Ash (FA), Micro Silica (MS), and Ground Granulated Blast Furnace Slag (GGBS) in place of certain cement can decrease cement usage while simultaneously enhancing the strength and longevity of concrete. To further enhance the qualities of concrete Currently, silica fume materials are employed as extra materials. The utilization of silica and recent developments in nanotechnology have made concrete materials possible. Use of silica fume in conjunction with any kind of mineral additive is possible in concrete. In civil engineering construction, Portland cement concrete is and will continue to be a popular choice for building materials. The most vital component of concrete is Portland cement. Regretfully, the production of cement requires a significant amount of energy—roughly 7.36*106 kJ per ton of cement. Additionally, the manufacture of one tone of cement releases about one tone of CO2 into the environment. Therefore, CO2 emissions can be greatly decreased by partially substituting mineral wastes like fly ash and GGBS for Portland cement. Concrete containing fly ash has technical, ecological, financial, and energy-saving advantages. It is added to concrete as a pozzolanic mineral additive. According to ASTM C125, pozzolan is a siliceous or siliceous and aluminous material that has little to no cementitious value on its own. However, when combined with calcium hydroxide at room temperature and in finely divided form, it will chemically react to form compounds with cementitious qualities. Many research works have focused on the application of pozzolana materials. These days, creating and utilizing blended cements is standard procedure for the building sector. Pozzolana derived from industrial leftovers, like fly ash and SF, is gaining more attention these days because its applications usually enhance blended cement concrete's qualities, lower its cost, and lessen its adverse environmental consequences. Because fly ash and silica fume function as micro fillers and cause a pozzolanic reaction, they enhance the qualities of concrete. It's common knowledge that the pozzolanic reaction, the first function, is the most crucial. It is noted in many specifications that Fly Ash cement concrete requires a longer curing period than conventional concrete because the hydration reaction is dependent on the curing period. A large number of the investigated mineral admixtures cover cement pores and have a size of microns. The purpose of this experimental study is to determine how the combined application of fly ash (FA) and silica fume (SF) affects the characteristics of concrete. Partially in place of cement are fly ash and silica fume. In this experimental study, fly ash and silica fume at weight percentages of 1%, 2%, 3%, and 4% replace cement to some extent.

Literature Review

Jagannadha Rao, Mohammed Abdul Mujeeb.(2014): The cement industry is a significant contributor to environmental pollution due to its high energy consumption and massive CO2 emissions during manufacture. Furthermore, the overproduction of solid waste products like fly ash and silica fume is creating an increasing environmental problem, which has led several researchers to experiment with using these materials as constituents in concrete. Therefore, the purpose of this paper is to investigate the strength characteristics of Ternary Blended Concrete for M40 grade and to determine the optimal Ternary Blended Concrete mix. It is observed that all mechanical properties increase when pozzolans are added to concrete at varying percentages. When different combinations of FA and SF are used to replace 30% of the cement, the strength is found to be optimal at 20% FA and 10% SF.

Anjaneya Babu Padavala.(2021): it requires a significant amount of energy to produce and emits a large amount of CO2, which contributes to global warming, the cement industry is the main source of environmental pollution. In order to mitigate these impacts, ternary blended mix concrete is created by partially substituting cement with a mixture of fly ash (FA) and silica fume (SF). The behavior of ternary blended concrete mix of M30 grade with corresponding mechanical qualities is the main topic of this investigation. To examine the qualities To create the blended concrete mix, various percentage substitutions of cement by SF (5%, 7.5%, 10%) and FA (20%, 30%, 40%) were used. The best compressive, split tensile, and flexural strengths were shown by a ternary mix that contained 62.5% cement, 30% FA, and 7.5% SF.

T. Nochaiya (2010): The usual consistency, setting time, workability, and compressive strength of Portland cement, fly ash, and silica fume systems are reported in this research. The findings indicate that while the initial setting time was found to reduce, the amount of water needed for normal consistency was found to increase with increasing SF content. When compared to blends lacking silica fume, workability measured in terms of slump was found to decrease with silica fume level. It is important to remember that even though the slump values decreased, the Portland cement-fly ash-silica fume concrete's workability was typically still higher than that of the Portland cement control concrete. Additionally, it was shown that adding silica fume to fly ash increased the concrete's compressive strength by up to 145% at early ages (less than 28 days), with the highest strength being attained when the silica fume was added at a weight percentage of 10%. Furthermore, using fly ash with silica fume produced a much denser microstructure, which increased compressive strength, according to scanning electron micrographs.

Mohammed K. H. Radwan, Chiu Chuen Onn, Kim Hung Mo.(2021): Granulated ground blast furnace slag (GGBS) and coal fly ash are more frequently utilized as supplemental cementitious ingredients in the manufacture of cement. This study examines the effects of replacing high-volume ordinary Portland cement (OPC) with fly ash and/or GGBS on the resulting binary and ternary blends' flow, compressive strength, and environmental effects. The use of ternary mixes, particularly those containing 20% to 30% fly ash, improved the flow properties, according to the results of the experiments. Overall, the early-age compressive strength was decreased by partially substituting OPC in the ternary and binary blends, but the later-age strength showed improvement. However, after

28 days, the ternary blends with fly ash at 20% and 30% showed the maximum compressive strength. Life cycle assessment (LCA) studies showed that, independent of blending system, OPC is the main source of environmental effect, with 50% and 70% OPC replacement reducing overall impacts by an average of 44% and 61%, respectively. As a result, blends' eco-mechanical performance was significantly enhanced. In the presence of 10% and 20% fly ash, the 70% ternary mixes had excellent eco-mechanical performance (lowest GWP/strength ratio). This study also demonstrated that the qualities of the OPC blends (i.e., eco-mechanical performance) may be properly predicted by an artificial neural network model that can be created.

S.K. Antiohos(2007): Different ash intermixtures comprising of two types of fly ashes were developed in order to overcome some of the limitations that are characteristic of both fundamental fly ash types (high and low calcium content). The main premise underlying this attempt is that the advantageous qualities of one kind of ash could make up for the drawbacks of the other. All ternary cements' compressive strength development, pozzolanic activity potential, and hydration product nature were carefully observed and compared to the corresponding characteristics of the original binary blends. Moreover, efficiency factors were determined for all new systems and were further used to confirm previously reported expressions characterizing Binary Fly ash-Cement (BFC) systems. The ternary fly ash systems that were studied here performed better than the corresponding binary systems during the majority of the curing period, in line with other research. The superior effectiveness of the ternary mixtures was thought to be mostly due to the synergy between the various fly ash kinds. The results show that the previously created analytical formulas that relate the k-values to the active silica of SCMs may also be used in the case of multicomponent ash systems.

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Karla Hornbostel , Claus K. Larsen(2013) : The movement of ions through the microstructure of concrete controls the process of reinforcing corrosion in part. Ions carry charges, and a material's electrical resistivity determines its capacity to tolerate the transfer of charge. Therefore, a relationship between the electrical resistivity of concrete and the corrosion process of steel implanted in concrete may be anticipated. This study examines the literature on the connection between concrete resistivity and corrosion rate. All in all, the parameters have an inverse portional correlation. Nevertheless, the dependence differs between research and corrosion rate and resistivity cannot be found to be correlated in a single way. The paper analyzes and assesses the impact of several aspects, such as the experimental setting, the design of the concrete mix, and the corrosion cause, in order to address the variation.

Manikanta Damma (2021): Researchers have been forced to hunt for alternative binder materials or mineral admixtures due to the essential demand to minimize the carbon footprint by reducing the usage of cement in the construction industry. The effectiveness of using mineral admixtures in concrete to partially replace cement has been demonstrated by improved performance characteristics. The utilization of blended cements, both ternary and quaternary, in concrete has grown recently because of the synergistic effect that comes from using numerous mineral admixtures at the same time. The current work uses fly ash (FA), silica fume (SF), and graphene oxide (GO) to explore the attributes of high performance self-compacting concretes that incorporate ternary and quaternary blended cements. By analyzing compressive strength, split tensile strength, resistivity, absorption characteristics, and fast chloride penetrability, the mechanical and durability properties were evaluated.

Muhammad Nasir Amin, Afaq Ahmad(2022): This study looked at what happened when silica fume (SF) and sugarcane bagasse ash (BA) were used in place of a large amount of cement. To ascertain the various mechanical and microstructural qualities of concrete, three binary and three ternary blends with varying ratios of cement/BA and cement/BA/SF were evaluated in addition to the control. The compressive and tensile strengths of three identical specimens at 7, 28, and 91 days were tested by casting eighteen cylindrical concrete specimens for each mix and curing them according to usual procedure (wet at 20 °C). The test results showed that compared to all other mixtures, including the control, the binary mix with 20% BA and the ternary mix with 33% BA and 7% SF had higher strengths. These mixtures' decreased water absorption and apparent porosity compared to the other mixes verify their greater strengths.

Kaffayatullah Khan, Muhammad Nasir Amin (2017): The present investigation examined the impact of the fineness of locally accessible basaltic volcanic ash (VA) and its combination with other cementitious materials (SCMs) on the compressive strength of mortar. Tons of garbage are produced by nearby steel and quarry businesses in the eastern province of Saudi Arabia. These wastes are typically referred to as electric arc furnace slag (EAFS) and quarry dust (QD), respectively. A total of nineteen mortar combinations, including the CM, were made by replacing cement with different SCMs (VA, FA, QD, and EAFS), varying the amount of each SCM in binary mixes, varying the fineness of VA, and blending ultra-fine VA with other SCMs (ternary and quaternary). Specimens were cured at varying temperatures (20, 40, and 60 °C) and moisture levels (continuous and partially moist) after casting. At 7, 28, and 91 days of age, compressive strength was tested in accordance with ASTM C 109, and the average value of three identical 50-mm3 specimens was reported. The test findings showed that at all ages, especially at high curing temperatures, enhanced VA fineness up to 30% mass replacement of cement demonstrated compressive strength comparable to control and reference FA mortars. Furthermore, at all ages, the strength of a quaternary blend of ultra-fine VA (20%), EAFS (10%), and QD (10%) was superior to all other ternary and quaternary blends, and it was similar to control mortar after 91 days.

W. Wongkeo et al(2014): This study examined the effects of silica fume and high-calcium fly ash as binary and ternary blended cements on the chloride resistance and compressive strength of self-compacting concrete (SCC). A portion of the cement at 50, 60, and 70 weight percent was substituted with high-calcium fly ash (40–70%) and silica fume (0–10%). Investigations were conducted on the compressive strength, density, volume of permeable pore space (voids), and water absorption of SCC. The chloride resistance of SCC was determined by measuring the total charge passed in coulombs. The findings indicate that at all test ages—3, 7, 28, and 90 days—binary mixed cement with high level fly ash generally decreased the compressive strength of SCC. When ternary blended fly ash cement with silica fume and fly ash was compared to binary blended fly ash cement at the same replacement level, the ternary blended cement showed greater compressive strength after 7 days. When silica fume and high-calcium fly ash are used as ternary mixed cement, a compressive strength of more than 60 MPa (high strength concrete) can be achieved. Although the volume of permeable pore space (voids) and water absorption of SCC were enhanced, fly ash decreased the charge passed of SCC and tends to decrease with increasing fly ash content. Furthermore, the charge passing of SCC with ternary blended cement was lower than binary blended cement with fly ash alone at the same replacement level when compared to binary blended cement. This suggested that at large volume contents of Portland cement replacement, fly ash and silica fume can enhance the chloride resistance of SCC.

H. Yazici (2008): In this investigation, Class C fly ash (FA) has been substituted for cement in varying amounts, ranging from 30% to 60%. Within the context of this study, durability qualities of several self-compacting concrete (SCC) combinations, such as freezing and thawing resistance and resistance to chloride penetration, have been examined in addition to mechanical capabilities. The addition of 10% silica fume (SF) to the identical mixes was tested in a similar manner. The test findings suggest that a high-volume FA could produce SCC. Additions of 10% SF to the system had a positive effect on the fresh and hardened characteristics of high-volume, high-performance FA SCC. These combinations offer strong mechanical qualities, resistance to freeze-thaw, and resistance to chloride penetration while having a little amount of cement.

A.C.A. Muller(2015) : Utilizing 10% weight of silica fume, white Portland cement paste has been characterized using 1H NMR. Samples were not allowed to dry out during the hydration process; they were measured sealed. 1H NMR signal intensities and relaxation analysis are used to compute paste compositions and C-S-H properties. The outcomes are contrasted with a related investigation of standard white cement paste. When comparing the paste containing silica fume to the plain white cement paste, there are no significant differences in the diameters of the capillaries, C-S-H gel, and interlayer pores. But in the silica fume blend, the gel/interlayer water ratio rises.

M.S. Ahmed (2008): In this work, concrete specimens cast with an effective weight-to-bulk ratio of 0.48 and subjected to seven days of curing were used to employ and compare the two fast chloride permeability tests: the University of Cape Town's (UCT) chloride conduction test and the AASHTO's rapid chloride permeability test (RCPT). Cement was gradually replaced by fly ash and blast furnace slag at 25%, 50%, and 70% levels. Additionally, 10% of the cement replacement was supplemented using silica fume. As a result, the cementitious material matrix was either binary or ternary in nature. Standard statistical techniques were employed to assess the significance of the experimental data. The findings show that, in comparison to 25% fly ash, ternary blends containing 10% silica fume and 25% fly ash significantly reduced charge passed. In a similar vein, ternary blends of 25% BFS and 50% BFS with 10% silica fume added demonstrated reduced charge as compared to the corresponding binary blends. Compared to the RCPT, the UCT test has proven to be quicker and easier to administer. When comparing binary and ternary blends, however, the RCPT demonstrated a greater degree of sensitivity in identifying notable variations in the derived values, whereas the UCT test yielded negligible changes in this regard.

Ch.W. Chung(2010) : This study looks into how long-lasting concretes with fly ash and silica fume that are subjected to a combined mode of deterioration are. Concrete's chloride ion diffusivity was assessed for this reason both before and after 300 freeze-thaw (F-T) cycles. It was discovered that as air content and the water to cementitious material ratio (w/cm) increased, so did the coefficient of chloride ion diffusivity (CCID). Test findings unequivocally demonstrated that following F–T cycles, CCID rose for all concretes. In addition, regardless of the curing schedule, air content, or w/cm, concrete containing silica fume had the lowest CCID and the highest durability factor (DF). On the other hand, when low w/cm and appropriate curing and air content were given, fly ash concrete demonstrated good resistance to chloride ion diffusivity both before and after F-T cycles.

Malhotra, V.M(1997): We looked into how three ASTM Class F fly ashes and a Portland cement clinker's physical characteristics were affected by grinding. As the grinding time rose, so did the fly ashes' specific gravity and fineness. After two hours, though, this growth became less noticeable. By grinding, the fly ashes' morphology was altered. After two hours of grinding, the majority of the plerospheres and large, irregular-shaped particles were crushed. However, when grinding intensity increased, the quantity of spherical particles decreased. For the fly ashes, there seems to be an ideal grinding period of about 4 hours, after which the water need went up and the strength activity indices either declined or did not appreciably rise.

Roy, D. K.(2012) : The industry's capacity to regularly and commercially produce SF-modified concrete that is flowable but still cohesive was significantly impacted by the use of silica fume (SF) in a short amount of time. This allowed the industry to develop high early and high later-age strengths, including resistance to harsh environments. An experimental investigation of the nature of SF and how it affects the characteristics of both fresh and cured concrete is presented in this work. An attempt has been made to look into the strength parameters of concrete that has had some of the cement replaced with SF in the current study. Very little, if any, research has been done on substituting silica fume for cement. Furthermore, no attempt has been made to replace silica fume in low- and medium-grade concretes (i.e., M20, M25) with cement. The ultimate compressive strength, flexural strength, splitting tensile strength, and tensile strength of hardened concrete have been measured for various material mix combinations, and these results are contrasted with those of standard concrete. The goal of the current study is to raise awareness among practicing civil engineers about the benefits of these novel concrete mixes.

Kumar, R.(2016): The purpose of this study is to assess the efficacy of an industrial byproduct called silica fume as an admixture in concrete, taking into account the growing market demand for cement, which forces large-scale cement production, leading to problems with the environment and the depletion of natural resources on the one hand, and rising prices on the other. In order to address these issues, research into the utilization of industrial waste and products was established. An appealing cementation material was discovered to be the byproduct of the silicon and ferrosilicon industries' smelting process, silica fume. This dissertation investigates the impacts of partially replacing silica fume and how it affects the characteristics of concrete using the M-35 concrete mix. This study's primary parameter was the M-35 concrete mix, which had silica fume substituted in varied amounts (0, 5, 9, 12, and 15% by cement weight). A thorough experimental investigation on split tensile strength, flexural strength, and compressive strength over seven and twenty-eight days, respectively, is presented in this research. When compared to regular concrete, the use of silica fume in concrete has enhanced its strength and durability across all age groups, according to the results of an experimental inquiry. Because of this, using silica fume reduces the amount of cement needed for building, and its use should be encouraged for both improved performance and environmental sustainability.

Harish B. A.(2015): The most crucial material in engineering is concrete, and adding additional materials can alter its characteristics. The demand for concrete with a higher compressive strength is rising due to the trend towards using concrete more widely for high-rise constructions and prestressed concrete. For a long time, cement has been used with mineral additions, also referred to as mineral admixtures. Particles of silica fume are 100 times smaller than typical cement particles. Because of environmental problems, management and disposal of it are a concern. Typically, silica fume is classified as an additional cementitious material. These substances show cementitious, pozzolanic, and/or a combination of the two types of characteristics. These characteristics allow for a variety of effects on the behavior of the concrete. In this work, an attempt has been made to assess the limit of cement substitution for M20 grade concrete, as well as to use silica fume as a supplemental material. This work's primary goal is to compare the mechanical characteristics of silica fume concrete with varying percentages of silica fume (5, 10, 15, and 20%) replacing some of the cement in the concrete with M20 grade control concrete.

Detwiler, R.I. (1996): One of the natural disasters that might affect building construction is fire. The high temperatures cause damage to buildings that are constantly at risk of fire. Thus, research was done on how high temperatures affected the mechanical and physical characteristics of concrete. In this investigation, silica fume ratios have been used in place of some of the regular Portland cement. Without any load, the heat treatment temperature was adjusted every three hours between 100 and 600°C in steps of 100°C. Every temperature was applied to concrete sample. For every temperature level, the specimens were heated in the same way. Investigations were conducted into the comparison of mechanical and physical properties during heat treatment. After casting, each specimen underwent a 28-day moist-curation period. Specimens were heated, then carefully cooled to room temperature for testing. The investigation's findings showed that adding 10% silica fume by weight to regular Portland cement increased its compressive strength by roughly 64.6%. However, adding silica fume to regular Portland cement in ratios of 20 and 30% increased its compressive strength by only 28% at 600°C. This may be explained by the extra tobermorite gel (CSH phase) that resulted from the interaction of $Ca(OH)2$ with silica fume.

T.K. Erdem(2008) : Concrete may benefit more from combinations of cement additions than from any one of them alone. Eighty high-strength concretes with a variety of additives and quantities were made for this study. The initial step was determining the silica fume levels of binary mixes that yield the maximum strengths for varying binder contents. In the second stage, concretes that had already contained Portland cement and silica fume in the levels observed in the first stage were combined with a third binder, either Class F or Class C fly ash or powdered granulated blast furnace slag. The findings showed that, given appropriate replacement level selection of the additions, ternary blends nearly invariably allowed for higher strengths than Portland cement + silica fume binary combinations. Furthermore, slag performed worse in ternary blends than Class C fly ash but better than Class F fly ash.

Y. P. Pawar, C.P.Pise (2022): The current research analyzes Self-Compacting Concrete (SCC) in order to understand its behavior and uses in traditional construction procedures. This study aims to review the pertinent literature in order to comprehend the workability and compressive strength of SCC when fly ash and high-volume fly ash (HVFA) are utilized as a partial substitution for construction material in SCC. The study's other main focus is the advantages of using hybrid natural and artificial fibers in SCC. According to a review of the literature, adding fly ash to SCC in place of some of the cement can significantly increase the strength and workability of the concrete by 10% to 25% and 5% to 0.75 percent, respectively.

S. M. Shelake, S. S. Kadam, G. D. Lakade and Y. P. Pawar (2018): There has been a constant need for materials with ever-higher compressive strengths for commercial uses. Using silica fume, quartz sand, and super plasticizers, an attempt is made in this work to investigate the mechanical properties of reactive powder concrete. A broad range of mechanical properties were examined for each test item. At 0.25, the water cement ratio, or w/c ratio, remained unchanged. Three specimens have been cast and tested as a result of this.

Conclusion

These studies collectively highlight the benefits of using SCMs such as fly ash, silica fume, sugarcane bagasse ash, and volcanic ash in concrete:

Mechanical Properties: Enhancements in compressive and tensile strengths, often surpassing those of conventional concrete.

Durability: Improved resistance to water absorption, chloride penetration, and corrosion, attributed to denser microstructures and pozzolanic reactions.

Environmental Impact: Reduced carbon footprint due to lower cement content and utilization of industrial by-products.

These studies collectively underscore the advantages of using SCMs like FA and SF in concrete to enhance mechanical properties, durability, and sustainability by reducing cement consumption and environmental impact. The optimal combinations and percentages of these materials vary based on specific grades of concrete and intended performance criteria, such as strength, durability, and resistance to environmental factors. The research also highlights the complex interactions between different SCMs and their impact on concrete properties, which is crucial for optimizing concrete mix designs in various applications.

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