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Use of Waste Industrial Pozzolanic Materials in Conventional Concrete: A State of Art Review

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Abstract: *This state of art review represents the development in the field of utilization of waste industrial by-products in cementitious concrete. The paper reviews the utilization of various waste materials as the cement replacement having pozzolanic characteristics and the noticeable and important findings from the experimental works of various researchers. The various types of waste materials used and its types are discussed as a part of introduction in the review. After a careful study of large number of research papers on the topic it was felt by the authors to integrate all the important results for streamlining the potential of this area of research. The paper summarizes conclusions of experiments conducted for the properties like strength and durability. It was observed that the results have shown positive changes and improvement in strength and durability properties of the conventional cementitious concrete due to the addition or replacement of cement with silica fume and Fly ash in different proportions. From the review of past research works it could be concluded that utilizing the waste industrial by-products holds a great potential towards the development of environment friendly and sustainable cementitious concrete.*

Key Words: *Fly Ash, Silica Fume, concrete, strength, durability, utilization*

I. INTRODUCTION

The waste generated from the industries cause environmental problems. Hence the reuse of this waste materials and its utilization in construction industry reduces the technical and environmental problems of plants and decreases electric costs besides reducing the amount of solid waste, greenhouse gas emissions associated with Portland cement clinker production and conserves existing natural resources.

Fly Ash is widely used in blended cements and is by-product of coal-fired electric power plants. Two general classes of fly ash can be defined: low calcium fly ash, that is Class F fly ash produced by burning anthracite or bituminous coal and high calcium fly ash that is class C fly ash produced by burning lignite or sub-bituminous coal.

Silica fume is also a pozzolanic material and is by-product of silicon smelting process. It is used to produce silicon metal and ferrosilicon alloys which have a high content of glassy phase silicon dioxide and consist of very small particles. Silica fume is used in two different ways; as a cement replacement, in order to reduce the cement content (for economic reasons) and as an additive to improve concrete properties.

Over the last decades, much research has been conducted on compressive strength and durability aspects of binary mixes using pozzolanic material and Portland cement. But inadequate research focus is given to the ternary mixes using Portland cement and a combination of any two pozzolanic materials specially Class C fly ash and silica fume from the strength and durability point of view.

II. LITERATURE REVIEW

A R Hariharan [1] investigated the compressive strength of ternary blended concrete samples containing silica fume (SF), fly ash (FA) and cement. Class C fly ash was used in various proportions as 30%, 40% and 50% and silica fume as 6% and 10% by weight of cement. The compressive strength was determined at various ages up to 90 days. Based on the results it was concluded that (i) fly ash increases the long term strength development of silica fume concrete. (ii) The addition of 6% silica fume to different fly ash replacements had a high compressive strength greater than 10% silica fume. Ternary system (54% cement, 40% FA and 6% SF) had high compressive strength. (58.7 Mpa) (iii) The optimum and high strength concrete can be obtained with 6% silica fume and 40% fly ash.

Peng Zhang [2] investigated the workability and durability properties of concrete mixtures, in which content of silica fume varies from 3% to 12% by weight of cement and the fly ash content was fixed at 15% by weight of cement. The total cementitious content remained constant. Workability test, water permeability test, dry shrinkage, carbonation and freezing test were carried out. Based on the results obtained it was concluded that (i) With the increase in silica fume content, both the slump and slump flow decreased gradually. (ii) Compared with mix without silica fume, the decrease was determined as 62% for 12% silica fume content. (iii) The increase in maximum dry shrinkage strain at 90 days was determined for 12% silica fume content which was 28% higher than concrete without silica fume. (iv) Compared with the mix without silica fume, the decrease in carbonation depth was determined as 27.3% for 12% silica fume content. (v) Compared with the mix without silica fume, the increase in freeze thaw resistance was determined as 7.3% for 12% silica fume content.

Alireza Bagheri [3] investigated the properties of concrete of ternary mix with Portland cement, Fly ash, Fine fly ash and silica fume. The replacement levels ranged from 2.5%-10% for silica fume, 15%-30% for Fly ash and 7.5%-15% for fine fly ash. Various combinations were made with total cementitious material remaining constant at 420kg/m^3. Tests conducted were compressive strength, the electrical resistance and rapid chloride permeability test. Tests results showed that the combination of 5% silica fume and 15% fly ash has resulted in considerable strength improvement at all ages over the control. The addition of silica fume has substantially increased the electrical resistance, especially at ages of 28 days and higher. The same combination also performed well for electrical resistance for all ages. The results for Rapid Chloride Permeability test showed substantial reduction in the passed charge at all ages due to incorporation of silica fume.

Mansur Sumer [4] investigated the compressive strength and sulphate resistance properties of concrete mixtures in which Turkish Class C and Class F fly ashes were partially replaced with cement. Compression test were carried out at 28 days and 90 days. Based on the results it was concluded that (i) The use of Class C type fly ash instead of Class F type fly ash with the same cement dosage and fly ash percentage generally increased compressive strength. (ii) Higher the level of addition of Class C and Class F fly ashes mixtures, less linear expansion occurred in magnesium sulphate solution for each series.

Mucteba Uysal [5] investigated the durability properties of concrete containing Turkish Class C and Class F fly ashes where a total of 39 mixtures with different mix designs were prepared. Compression test, chloride ion permeability test, Sorptivity test and Freezing-thawing resistance test were carried out. Compression test were carried out at 28 and 90 days. Based on the results they concluded that (i) As class C fly ash contained higher calcium amount, the compressive strength resulted higher in early ages compared to class F fly ash (ii) The chloride ion permeability of concretes containing fly ash decreased when the fly ash content regardless of fly ash type was increased. (iii) The sorptivity of the concretes decreased with an increase in the cement dosage and binder content. The reason of lower sorptivity of the concretes containing Class C and Class F fly ashes compared to control concretes was consisted in the pozzolanic action. (iv) The rate of reduction in the UPV of specimens had not changed significantly when replacement levels of Class C and Class F fly ashes were increased. (v) Dramatic reduction in weight was not shown by the specimens after freezing thawing cycles. (vi) The incorporation of Class C and Class F fly ashes also improved durability performance.

Michelle R. Nokken [6] investigated the strength and durability properties of concrete using two types of fly ash in conjunction with four cements. The cements were both high and low alkali, with and without blended silica fume. Standardized tests were performed for compressive strength as well as sulphate, chloride and alkali resistance. Based on the results obtained they concluded that (i) Silica fume alone was insufficient to reduce expansions to acceptable levels with highly reactive aggregate. Fly Ash was more effective in reducing expansion mainly due to lower CaO content. (ii) It was found that use of Silica Fume at low percentages (up to 6%) improved the performance of high calcium Fly Ash in terms of sulphate resistance. (iii) As Fly Ash percentage increase, the compressive strength is relatively constant until 40% replacement, after which it drops drastically at higher percentages. (iv) For this study Fly Ash replacement level of 40% was considered the optimum replacement level for durability.

Vikas Srivastava [7] investigated the effects of silica fume on fresh and hardened concrete. Materials used were Ordinary Portland cement and Silica fume. Tests conducted were workability, Compressive Strength, Tensile Strength, Bond Strength and Modulus of Elasticity. Based on the results obtained it was concluded that (i) Workability reduced with the addition of silica fume. However workability improved in some cases. (ii) Compressive strength of concrete was significantly increased (6-57%) with inclusion of silica fume. The increase depended upon the replacement level. (iii) Flexural and tensile strength of silica fume concrete was almost similar to the referral concrete. (iv) Bond strength was improved with the addition of silica fume (v) Modulus of elasticity of silica fume concrete was almost similar to the referral concrete.

Miguel Angel Sanjuan [8] studied the effect of silica fume fineness on the pozzolanicity of blended cement. 25% Silica Fume and 75% Portland cement was used as mixtures. Several methods like pozzolanicity test, chemical analysis and strength activity index techniques were used. Results showed that (i) Silica Fume with higher surface area led to higher reactivity. (ii) Mechanical and durability properties are improved when the Silica Fume is sufficiently fine. (iii) Highest compressive strength was given by 25% Silica Fume with 45 um sieve residue between 0.98% and 4.13% Silica Fume. (iv) Coarser Silica Fume does not exhibit a good performance when added in high amounts than 25 %

(45 um sieve residue of 32.11%). (v) Thus they advised a fineness between 0.98% and 4.13%. (vi) Addition of silica fume to Portland cement led to higher strength and lower permeability.

Mahmoud Nili [9] investigated the effects of Silica fume and Nano Silica on the strength properties and corresponding cement paste at early and older ages.

Silica fume as well as Nano Silica both were replaced by weight of cement at the most by 7.5%. A microstructure study was performed by SEM (Scanning Electron Microscopy) and XRD (X-ray Diffraction). Results obtained from their investigations concluded that (i) Introducing both silica fume and Nano silica in concrete increased their compressive strength. (ii) The simultaneous presence of Nano silica and silica fume provided the greatest effect on strength development on both cement pastes and concrete samples with 5% silica fume and 5% Nano silica by weight of cement. (iii) Microstructure modifications which were studied using SEM and XRD showed that both Nano silica and silica fume had effects on reducing pore spaces.

A. Ferhat Bingol [10] investigated the effects of different curing regimes on compressive strength of Self Compacting Concrete which was produced using silica fume (up to 15%) and fly ash (up to 55%). Different curing regimes were air curing, water curing and steam curing. Based on the results obtained they concluded that (i) Fly ash additive showed better results in workability compared to silica fume. (ii) 15% silica fume replacement of cement content provided the highest compressive strength. (iii) Air curing resulted in reductions (lowest strength values) in compressive strength for all groups. (up to 37% reductions). (iv) The highest compressive strength values were obtained from standard cured specimens (cured in water for 28 days).

I. B. Muhit [11] investigated the individual effects of silica fume and fly ash as a partial replacement of Ordinary Portland cement on water permeability, compressive strength, split tensile strength and flexural tensile strength of concrete. Replacement levels of silica fume by weight of cement was up to 20% whereas for fly ash it was 30%. Based on the investigations it was concluded that (i) 10% by weight silica fume exhibited lowest penetration of water (11 mm), whereas lowest water permeability (15 mm) for fly ash was obtained at 20% by weight. (ii) 65 N/mm^2 was the maximum compressive strength which was obtained for 7.5% by weight silica fume. (iii) 10% by weight fly ash showed maximum compressive strength and it was 66 N/mm^2. (iv) 5.2 N/mm^2 was the maximum split tensile strength which was obtained for 7.5% by weight silica fume. (v) 10% by weight fly ash showed maximum split tensile strength and it was 5 N/mm^2. (vi) Overall 7.5% silica fume and 10% fly ash were found to be optimum for maximum compressive strength, maximum split tensile strength as well as maximum flexural strength.

Fereshteh Alsadat Sabet [12] investigated the effects of natural zeolite, silica fume and fly ash on the properties of fresh and hardened concrete. Slump Flow, compressive strength, electrical resistivity, water absorption and chloride permeability were measured for all mixes. Based on the results obtained they concluded that (i) Silica fume was found to be the most effective material in increasing the compressive strength. (About 80MPa) (ii) Concrete mixes containing 20% silica fume had considerably higher records of electrical resistivity almost 4.5 times the resistivity of 20% natural zeolite and 20% fly ash. (iii) Silica fume was the most effective one in reduction of final absorption at almost 2.57% at 20% silica fume replacement. Hence 39% reduction in final absorption. (iv) Silica fume was most effective in controlling chloride penetration. (0.07% weight of concrete). (v) Hence overall silica fume was found to be the most effective material.

Ali Mardani-Aghabaglou [13] investigated the effect of cement replacement with fly ash, silica fume and metakaolin on the compressive strength, dynamic elastic modulus, chloride ion penetration, water absorption, water sorptivity and freeze thaw and sulphate resistance of the mortar mixtures. From the various test results obtained, it was concluded that (i) Silica fume bearing mortars showed the highest compressive strength values compared to those of mortar mixtures. (ii) Silica fume had the highest specific surface activity and hence the highest Ultrasonic Pulse Velocity values belonged to silica fume mixtures at all ages. (iii) Fly Ash had the lowest unit weight of all the mixtures. (iv) Chloride ion penetration value of silica fume bearing mixture was lower than 1000 coulombs, the limit specifies for very good chloride ion penetration resistance. (v) The maximum and minimum absorption values were obtained in the control and silica fume mortar mixtures as 4.2% and 1.8% respectively. (vi) Sorptivity of silica fume was 2.9 mm which was the most superior result. (vii) The performance of the mixtures against the sulphate attack was arranged in descending order as silica fume, metakaolin, fly ash and control mortars. (viii) Test results demonstrated that the mixture containing silica fume had the best performance against the frost action.

David O. Koteng [14] investigated the development of compressive strength by varying the water-binder ratio, powder proportioning, and fineness of lime, silica fume content and curing conditions. Based on the results it was concluded that (i) When Fly Ash content was 30%, Silica Fume content 10% and Non Hydraulic Lime 60%, the compressive strength results were found to be the highest at 28 days. (ii) Silica Fume content contributed more to early strength than pozzolana content. (iii) Without Silica Fume, the strength development is very slow in the paste with 40%

Fly Ash but no Silica Fume. (iv) 28 day strength of the paste can be enhanced by water curing at 60 degree Celsius. (v) The main advantage over the Portland cement was the appreciable strength gain beyond 28 days.

Nihat Kabay [15] investigated the effects of partial replacement of Pumice Powder, Fly Ash and their blends by cement on physical, mechanical and durability properties of concrete. Various tests were conducted and based on the results it was concluded that (i) Addition of Fly Ash and Pumice Powder decreased the early compressive and split tensile strength. (ii) Addition of Fly Ash had no significant effect on slump. (iii) Replacement of Pumice Powder and Fly Ash with cement resulted in concrete with lower water absorption, sorptivity and void content values.

III. DISCUSSION

Based on various researchers, it is observed by using Silica fume and Class C Fly Ash that the overall compressive strength and tensile strength increased compared to control mixture. Most of the researchers noticed that by using Silica Fume and Class C Fly Ash as cement replacement, slump and slump flow decreased. Most of the researchers noticed positive changes in the concrete containing Silica Fume and Class C Fly Ash in terms of compressive strength and durability. Also, Water permeability decreases as replacement of silica fume and Class C Fly Ash increases to a certain value. Also it shows that silica fume with Class C fly ash reduces the carbonation depth considerably. Researchers also found that the freeze thaw resistance of concrete made with silica fume and class C Fly Ash was found to increase compared to normal concrete. However all researchers have noticed that concrete incorporated with Silica Fume and Class C Fly Ash can be suitably used in making structural or non-structural grade concrete. It should also be noted that the effects of concrete containing Silica Fume and Class C Fly Ash shall differ as the properties of Silica Fume and Class C Fly Ash may be different from source to source.

IV.CONCLUSION

Based upon above literature review it could be concluded that all researchers gave their findings with concrete up to 5-15% replacement of cement with Silica Fume and 15%-25% replacement of cement with Class C Fly Ash in which compressive and tensile strength is increased up to 40%. Also workability decreases with the increase of silica fume content because of very fine particles size. However the durability properties of the concrete incorporating Silica Fume and Class C Fly Ash were enhanced overall and it was also noted by researchers that concrete made with Silica Fume and Class C Fly Ash can be suitably used in making structural grade concrete. But, very few researchers have worked upon the durability properties of the ternary mixes containing Portland cement, Silica Fume and class C Fly Ash. Hence durability criteria and tests like XRD (X-ray Diffraction) and SEM (Scanning Electron Microscopy) is needed to be studied further effectively in future.

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