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Effect of Pozzolanic Material on the Strength of ConcreteA Comprehensive Review Paper

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Abstract—*Concrete is the material of choice where strength, performance, durability, impermeability, fire resistance and abrasion resistance are required. The hunger for the higher strength leads to other materials to achieve the desired results and thus emerged the contribution of cementitious material for the strength of concrete In present day constructions, concrete is chosen as one of the best choices by civil engineers in construction materials. The concept of sustainability is touching new heights and many pozzolonic materials are tried and tested as partial replacement for the cement.*
In this paper , comprehensive review of available literatures are studied to evaluate the performance of pozzolonic materials such as ceramic waste powder , copper slag , silica fume on the strength of concrete by the partial replacement of ordinary materials such as cement , fine aggregate and coarse aggregate at different percentage of composition .
From the study, we conclude that ceramic wastes are suitable to be used in the construction industry, and more significantly on the making of concrete. Ceramic wastes are found to be suitable for usage as substitution for fine and coarse aggregates and partial substitution in cement production. They were found to be performing better than normal concrete, in properties such as density, durability, permeability and compressive strength.
Silica fume, also known as micro silica or condensed silica fume, is a relatively new material compared to fly ash, It is another material that is used as an artificial pozzolonic admixture. High strength concrete made with silica fume provides high abrasion/corrosion resistance.
Copper slag is the waste material of matte smelting and refining of copper such that each ton of copper generates approximately 2.5 tons of copper slag. Copper slag is one of the materials that is considered as a waste which could have a promising future in construction Industry as partial or full substitute of aggregates.

Keywords*: Concrete, pozzolonic materials, Ceramic Waste powder*

1. INTRODUCTION

The advancement of concrete technology can reduce the consumption of natural resources and reduce the burden of pollutants on the environment. The cost of natural resources is increased day by day. They have forced to focus on recovery, reuse of natural resources and find other alternatives. As the world population grows, so do the amount and type of wastes being generated. Many wastes produced today will remain in the environment for hundreds and perhaps thousands of ye The traditional construction materials such as concrete , ceramic waste powder, copper slag, silica fume are being produced

1.1 Ceramic waste

Ceramic waste is one of the most active research areas that encompass a number of disciplines including civil engineering and construction materials. Ceramic waste powder is settled by sedimentation and then dumped away which results in environmental pollution, in addition to forming dust in summer and threatening both agriculture and public health.

Therefore, utilization of the ceramic waste powder in various industrial sectors especially the construction, agriculture, glass and paper industries would help to protect the environment. It is most essential to develop eco-friendly concrete from ceramic waste. They are generated in ceramic industries with an important impact on environment and humans. The use of the replacement materials offer cost reduction, energy savings, arguably superior products, and fewer hazards in the environment. Indian ceramic production is 100 Million ton per year. In ceramic industry, about 15%-30% waste material generated from the total production. This waste is not recycled in any form at present. However, the ceramic waste is durable, hard and highly resistant to biological, chemical, and physical degradation forces. The Ceramic industries are dumping the powder in any nearby pit or vacant spaces, near their unit although notified areas have been marked for dumping. This leads to serious environmental and dust pollution and occupation of a vast area of land, especially after the powder dries up so it is necessary to dispose the Ceramic waste quickly and use in the construction industry. As the ceramic waste is piling up every day, there is a pressure on ceramic industries to find a solution for its disposal.

Concrete with partial cement which is replaced by ceramic powder although it has minor strength loss possess increase durability performance. Ceramic waste partially replaced in the form of aggregate, sand and cement.

Ceramic waste powder

Ceramic waste is produced from ceramic industry at the end process of polishing and finishing. This ceramic slurry waste is collected from Morbi ceramic area Rajkot, Gujarat. This waste is collected in the form of pest and after drying and hand crushing it passing through 90 microns and replaced by cement. Its physical and chemical investigation is done by Geo- test house Baroda. Specific gravity of ceramic waste powder is 2.33, water absorption is 2.

The silica and alumina are the most significant oxides present in the ceramic pastes. It should be noted that the red paste shows high proportion of iron oxide responsible for the red color of the products. For 20% cement replacement represents 3.75 of the cost of Portland cement. This indicates saving of around 17% in the cost of Portland cement in concrete. The cost of cement represents almost 45% of the concrete cost. Therefore, overall cost of concrete will be reduced by more than 7.5%.

1.2 GGBS

GGBS means the ground granulated blast furnace slag is a by-product of the manufacturing of pig iron. Iron ore, coke and Lime-stone are fed into the furnace and the resulting molten slag floats above the molten iron at a temperature of about 1500^{o}C to 1600^{o}C. The molten slag has a composition close to the chemical composition of Portland cement. This glassy granulate is dried and ground to the required size, which is known as ground granulated blast furnace slag (GGBS).

The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process. Silicate and aluminate impurities from the ore and coke are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the case of pig iron production the flux consists mostly of a mixture oflimestone and forsterite or in some cases dolomite. In the blast furnace the slag floats on top of the iron and is decanted for separation. Slow cooling of slag melts results in an unreactive crystalline material consisting of an assemblage of Ca-Al-Mg silicates. To obtain a good slag reactivity or hydraulicity, the slag melt needs to be rapidly cooled or quenched below 800°C in order to prevent the crystallization of merwinite and melilite. To cool and fragment the slag a granulation process can be applied in which molten slag is subjected to jet streams of water or air under pressure. Alternatively, in the pelletization process the liquid slag is partially cooled with water and subsequently projected into the air by a rotating drum. In order to obtain a suitable reactivity, the obtained fragments are ground to reach the same fineness as Portland cement.

The main components of blast furnace slag are CaO (30-50%), SiO2(28-38%), Al2O3(8-24%), and MgO (1-18%). In general increasing the CaO content of the slag results in raised slag basicity and an increase in compressive strength. The MgO and Al2O3 content show the same trend up to respectively 10-12% and 14%, beyond which no further improvement can be obtained. Several compositional ratios or so-called hydraulic indices have been used to correlate slag composition with hydraulic activity; the latter being mostly expressed as the binder compressive strength.

Materials	**Ceramic Powder %**
Silicon Dioxide(SiO2)%	78.20
Aluminium Oxide (Al2O3)%	0.820
Iron Oxide (Fe2O3)%	-
Calcium Oxide(CaO)%	1.510
Magnesium Oxide (MgO)%	3.580
Chloride (CL)%	0.302
Sulphur as Sulphur Trioxide (SO3)	0.064
Loss of Ignition %	3.590

1.3 SILICA FLUME

The terms of microsilica, condensed silica fume, and silica fume are often used to describe by-products extracted from the exhaust gases of ferrosilicon, silicon, and other metal alloy smelting furnaces. However, the terms of silica fume and micro silica are used for those condensed silica fumes that are of high quality for using in the cement and concrete industry. In the European standard, the term of silica fume has been used. Silica fume was first discovered in Norway in 1947 when the environmental controls started the filtering of the exhaust gases from furnaces. The main portion of these fumes was a finely composed of a high percentage of silicon dioxide. As the pozzolonic reactivity for silicon dioxide was well known, many studies have been done on it.

It is very fine no crystalline silica manufactured by electric arc furnaces as a by-product of the production of metallic silicon or ferrosilicon alloys. The raw materials are coal, quartz, and woodchips. The smoke that produced from furnace operation is stored and sold as silica fume rather than being land filled.

2. PAPER REVIEW

2.1 CERAMIC WASTE POWDER

Jay Patel et al., (April 2014) Ceramic products made up with different raw materials like china clay, ball clay ,potash feldspar, dolomite, talc and different chemicals for a glazing and finishing. Ceramic production conducts on temperature 200°C to 2000°C, So the possibility of pozzolonic reactivity in such products, which is responsible for long term strength and good durability. Ceramic powder as cementatious material will be good for economy and environment.

It can be reducing cost of cement 20% to 30% for M30 and above grade with 20% replacement.

Ceramic powder has very good pozzolonic reactivity due to their manufacturing process on temperature 200°C to 2000°C. Optimum percentage of ceramic powder for replacement is 20%-30% as cementations material. Compressive strength of concrete increases up to 30-40% of replacement based on pozzolonic activity. More than 30-40% replacement by weight of cement strength decreases. They tried to replace ceramic material with cement up to 50 % with M-20 to M-40 grade of concrete.

Fernando Pacheco-Torgal and Said Jalali (2010) done experiment named “The compressive strength and durability properties of ceramic wastes based concrete”. This paper presents an experimental study on the properties and on the durability of concrete containing ceramic wastes.. Results shows that concrete mixtures with ceramic aggregates perform better than the control concrete mixtures concerning compressive strength, capillarity water absorption, oxygen permeability and chloride diffusion. The replacement of cement and aggregates in concrete by ceramic wastes will have major environmental benefits

Siddesha H (2012) Had done experimental studies named “The effect of ceramic fine aggregate on the strength properties of concrete”. In this study an attempt has been made to find the suitability of ceramic fine aggregate as a possible substitute for conventional fine aggregate in concrete. Experiments were carried out to determine the compressive, split tensile and flexural strength of ceramic fine aggregate and comparison is made with conventional concrete. Test results indicate that, the properties of ceramic fine aggregate are well within the range of values of concrete making aggregates.

Amit kumar D. Raval et al., (2013) Done research named “The use of ceramic powder as a partial replacement of cement”. In this research study the (OPC) cement has been replaced by ceramic waste powder accordingly in the range of 0%, 10%, 20%, 30% 40%, & 50% by weight for M-25 grade concrete. The wastes employed came from ceramic industry which had been deemed unfit for sale due to a variety of reasons, including dimensional or mechanical defects, or defects in the firing process. The results demonstrate that the use ceramic masonry rubble as active addition endows cement with positive characteristics as major mechanical strength and the economic advantages. Reuse of this kind of waste has advantages economic and environmental, reduction in the number of natural spaces employed as refuse dumps. Indirectly, all the above contributes to a better quality of life for citizens and to introduce the concept of sustainability in the construction sector.

Jay Patel et all., (2014) ceramic powder in concrete by partial replacement of cement Ceramic products made up with different raw materials like china clay, ball clay ,potash feldspar, dolomite, talc and different chemicals for a glazing and finishing. Ceramic production conducts on temperature 200°C to 2000°C, So the possibility of pozzolanic reactivity in such products, Which is responsible for long term strength and good durability. Here some literature paper analysis done, which are base on ceramic material partially replaced by cement in concrete. In such paper authors conducted mechanical properties tests and durability tests. They tried to replace ceramic material with cement up to 50 % with M- 20 to M-40 grade of concrete.

O. Zimbili et al., (2014) Construction and Demolition (C&D) wastes contribute the highest percentage of wastes worldwide (75%).Furthermore, ceramic materials contribute the highest percentage of wastes within the C&D wastes (54%). The current option for disposal of ceramic wastes is landfill.

Lalji Prajapati et al., (March 2014) Ceramic waste is most commonly produce from ceramic industry, this waste is in the form of pest and hard form, pest waste is known as the filter waste or slurry waste, which is produced at the end of polishing and finishing of ceramic tiles. The paper discuss that ceramic slurry waste powder is replaced by cement in concrete. Concrete grade M25 was made by replacing by 0% to 30% of Ordinary Portland 53 grade cement with ceramic slurry waste powder passing through 90 microns. Compressive strength, flexural strength, water absorption and sorptivity are determined with water cement ratio 0.48. The result shows core compressive strength achieved up to 30% replacement of ceramic waste powder without affecting the characteristic strength of M25 and no significant change in flexural strength. Water absorption and sorptivity increased compare to conventional concrete and after 10% interval it’s increased very less.

2.2 GGBS

Shariq et al.(2008) studied the effect of curing procedure on the compressive strength development of cement mortar and concrete incorporating ground granulated blast furnace slag.The compressive strength development of cement mortar incorporating 20, 40 and 60 percent replacement of GGBFS for different types of sand and strength development of concrete with 20, 40 and 60 percent replacement of GGBFS on two grades of concrete are investigated. Tests results show that the incorporating 20% and 40% GGBFS is highly significant to increase the compressive strength of mortar after 28 days and 150 days, respectively.

Peter et al. (2010) studied the BS 15167-1 which requires that the minimum specific surface area of GGBS shall be 2750 cm2 /g (BS 15167-1:2006). In China, GGBS is classified into three grades; namely S75, S95 and S105. The GB/T18046 requires a minimum surface area of 3000 cm2 /g for grade S75 GGBS, 4000 cm2 /g for grade S95 and 5000 cm2 /g for grade S105, which are higher than the BS EN’s requirements (GB/T18046-2008). It was reported that slag with a specific surface area between 4000 cm2 /g and 6000 cm2 /g would significantly improve the performance of GGBS concretes. Mojtaba Valinejad *Shoubi et al. (2013)* reviewed in their research the specifications, production method and degree of effectiveness of some industrial byproducts such as GGBS, Silica Fume and PFA as cement replacement to achieve high performance and sustainable concrete which can lead not only to improving the performance of the concrete but also to the reduction of ECO2 by reducing the amount of PC showing how they affect economical, environmental and social aspects positively. Aveline Darquennes et al. (2011) determined the slag effect on cracking. Their study focuses on the autogenous deformation evolution of concretes characterized by different percentages of slag (0 and 42% of the binder mass) under free and restraint conditions by means of the TSTM device (Temperature Stress Testing Machine).

Elsayed (2011) investigated experimentally in his study the effects of mineral admixtures on water permeability and compressive strength of concretes containing silica fume (SF) and fly ash (FA). The results were compared to the control concrete, ordinary Portland cement concrete without admixtures. The optimum cement replacement by FA and SF in this experiment was 10%. The strength and permeability of concrete containing silica fume, fly ash and high slag cement could be beneficial in the utilization of these waste materials in concrete work, especially in terms of durability. *Reginald Kogbara et al. (2011)* investigated the potential of GGBS activated by cement and lime for stabilization/solidification (S/S) treatment of a mixed contaminated soil. The results showed that GGBS activated by cement and lime would be effective in reducing the leachability of contaminants in contaminated soils.

Martin et al. (2012) studied the influence of pH and acid type in the concrete. The conclusions were that concrete tested cannot adequately address the durability threat to all parts of wastewater infrastructure over a significant life span due to the extraordinarily harsh nature of this form of attack.

Wang Ling et al. (2004) analyzed the performance of GGBS and the effect of GGBS on fresh concrete and hardened concrete. GGBS concrete is characterized by high strength, lower heat of hydration and resistance to chemical corrosion.

2.3 SILICA FLUME

A compressive review of literature related to Silica Fume and Steel Fiber concrete was presented by ACI Committee 544 (ACI Committee, 544, 2006), Balaguru and Shah (Balaguru P. N et al., 1992) . It included guidelines for design, mixing, placing and finishing steel fiber reinforced concrete, reported that the addition of steel fibers in concrete matrix improves all mechanical properties of concrete.

Sakr (2006) reported that at 15% silica fume content gravel concrete, barite concrete and ilmenite concrete showed increased compressive strength by 23.33%, 23.07% and 23.52% respectively at 7 d, 21.34%, 20% and 22.58% respectively at 28 d, 16.5%, 18.7% and 22% respectively at 56 d and 18%, 7.14% and 22.80% respectively

Sengupta and Bhanja (2003) reported that inclusion of silica fume in the range of 5-25% increases compressive strength about 6-30% for water cement ratio in the range of 0.26-0.42.

Kadri and Dual (1998) reported that at 10% replacement level, compressive strength increased in the range about 10-17% at different water cement ratio (0.25-0.45)

Khayat et al. (1997) reported that at 7.5% replacement level, compressive strength increased in the range of about 10-17% at different water cement ratio (w/c)

Babu Ganesh and Suryaprakash (1995) reported that concrete with silica fume even up to 40% replacement showed strength higher than that of the control concrete. The improvements in strength at the different percentages of replacement at any water cement ratio were also varying over a wide range.

Khan and Ayers (1995) reported 67% increase in compressive strength at 10% replacement level and 0.38 w/c.

Cong et al. (1992) reported that concrete containing silica fume as a partial replacement of cement exhibits an increased compressive strength in large part because of the improved strength of its cement paste constituent.

Slaniska and Lamacska (1991) reported that at different replacement level of cement by silica fume (3.75-10.25%) increase in compressive strength in the range of about 12%-57% is observed.

Detwiler and Mehta (1989) reported that silica fume concrete showed improved compressive strength in the range of 11.56%-18.89% than the conventional concrete at different water cement ratio.

Yogendran et al. (1987) reported that at 0.34 w/c, the compressive strength of concrete at 7, 28 and 56 d with 5 and 10% replacement level are slightly higher than the control mix.

Ramakrishnan and Srinivasan (1982) reported that high strength fibre reinforced concretes can be produced by addition of silica fume. Compressive strength as high as 58 MPa have been obtained with locally available lime stone aggregate.

Gafoori and Diaware (2007) reported that at 28 d concrete with 5, 10, 15 and 20% silica fume (as partial replacement of fine aggregate) showed gain in compressive strength of concrete by 25, 64, 42 and 25% respectively when compared with referral.

Tensile strength: Splitting tensile strength of concrete and incorporating silica fume is similar to that observed in concretes without silica fume. As the compressive strength increases the tensile strength also increases, but at a gradually decreasing rate (Goldman, 1987). Several study showed that splitting tensile strength at various ages ranged between 5.8-15% of the compressive strength.

Paillere et al. (1989) reported that at 15% silica fume content and tensile strength of concrete found to be in the range of 4.79-5.34% of its compressive strength. *Sakr (2006)* reported that at 15% replacement level, tensile strength of silica fume concrete increased in the rang

Yogendran et al. (1987) reported that at 0.34 w/c, the flexural strength of concrete was at 7, 28 and 56 d with 5 and 10% replacement level which are slightly higher than the control mix. However at 15% replacement level, loss in strength is observed due to improper compaction since, the voids could not be removed even using vibrating table.

Ramakrishnan and Srinivasan (1982) reported that flexural strength of silica fume concrete was higher by 10-15% as compared that of ordinary fibre concrete. Sakr (2006) reported that at 15% replacement level, flexural strength of silica fume concrete found to be increase in the range of 52-65% as compared to concrete without silica fume.

Bond strength:

Using silica fume as a component of concrete has been shown to improve bond strength. Sakr (2006) reported that at 15% replacement level bond strength of silica fume concrete found to be increase in the range of 37-43% as compared to concrete without silica fume. Modulus of elasticity: The static modulus of elasticity of silica fume concrete is apparently similar to that of Portland cement concrete. Detwiler and Mehta (1989) reported that at 0.25 and 0.34 w/c, modulus of elasticity of silica fume concrete found to be decrease by 2.34 and 3.76% respectively, whereas at 0.50 w/c it was found to be increase by 3.59% as compared to conventional concrete.

3. RESULTS

3.1 Ceramic waste

Results show that concrete with ceramic waste powder although has minor strength loss possess increase durability performance. Results also show that replacement of traditional sand by ceramic sand is a good option because does not imply strength loss and has superior durability performance. As for the replacement of traditional coarse aggregates by ceramic coarse aggregates, the results are promising but require further investigations.

Sustainable development is a key towards improving living conditions of the future generations. Thus recycling wastes is only rational and logical step towards conservation of natural resources. The economic aspect of recycling is motivation to proceed in this direction. From the researches discussed, it is clear that ceramic wastes are suitable to be used in the construction industry, and more significantly on the making of concrete. Ceramic wastes are found to be suitable for usage as substitution for fine and coarse aggregates and partial substitution in cement production. Researchers have indicated their potential for usage in both structural and non-structural concrete and even for mortars. They were found to be performing better than normal concrete, in properties such as density, durability, permeability and compressive strength. Thus to continue with further research in this area is necessary to make available the information, which will inevitably come handy in the near future.

Effect of ceramic waste powder on compressive strength:

Compressive strength is determined at 7 and 28 days after successful curing period. Due to high percentage of silica oxide in ceramic waste its core compressive strength is achieve at 40 % replacement of ceramic waste concrete. By more than 30% of replacement, compressive strength is decreasing, so more research on it is preferred. Cylindrical compressive strength is achieved at 40% replacement of ceramic waste powder. Further replacement its compressive strength is decreased.

Effect of ceramic waste powder on flexural strength:

Flexural strength is determined at 28 days after curing period of 28 days. As per the result the flexural strength is near to convention concrete by addition of ceramic waste powder up to 30%. But flexural strength is significantly decreased at 10% replacement of ceramic waste powder. As per the result at 10% interval its flexural strength continuously decreased of 7.27% compare to conventional concrete.

Effect of ceramic waste powder water absorption and sorptivity:

Water absorption is measured at 28 days after curing period. Water absorption is increased at 10% of replacement of ceramic waste powder up to 30%. At 10% replacement water absorption is increased 10.98 % compare to conventional concrete grade of M25.then after 4.9% water absorption increased at 10% interval.

Sorptivity gives capillary action of concrete in M25 grade concrete sorptivity increased 33% compared to conventional concrete and then after 10% interval its sorptivity increases very less

Effect of ceramic waste powder on cost of concrete :

Concrete on 30% replacement of cement with ceramic waste, compressive strength obtained is 26.77 N/mm2and vice-versa the cost of the concrete is reduced up to 13.27% and hence it becomes more economical without compromising concrete strength than the standard concrete. It becomes technically and economically feasible and viable.

3.2 GGBS

Effect of GGBS on compressive strength :

Compressive strength is determined at 7 and 28 days after successful curing period. It is observed that GGBS-based concretes have achieved an increase in strength for 20% replacement of cement at the age of 28 days. Increasing strength is due to filler effect of GGBS. The degree of workability of concrete was normal

Effect of GGBS on flexural strength:

Flexural strength is determined at 28 days after curing period of 28 days. As per the result the flexural strength is near to convention concrete by addition of GGBS up to 20%. But flexural strength is significantly decreased at 30% replacement of GGBS. As per the result at 10% interval its flexural strength continuously decreased of 5.27% compare to conventional concrete.

3.3 Silica Flume

Concrete properties	Increase	decrease	enhancement
Tensile strength	×		
Compressive strength	×		
Compressive modulus	×		
Flexural modulus	×		
Tensile ductility	×		
Air void content	×		
Freeze-thaw durability			×
Vibration damping capacity			×
Abrasion resistance			×
Bond strength with steel bars			×
Chemical attack resistance			×
Corrosion resistance of reinforcement steel			×
Dispersion of micro fibres			×
Alkali-silica reactivity		×	
During shrinkage		×	
Permeability		×	
Creep rate		×	
Coefficient of thermal expansion		×	
Dielectric constant		×	
Thermal conductivity		×	
Density		×	
Workability		×	
Bleeding		×	

The addition of silica fume reduces workability. However, in some cases improved workability were also reported. Silica fume inclusion increases compressive strength significantly (6-57%) and increase in compressive strength depends upon replacement level. Tensile strength and flexural strength of silica fume concrete is similar to that of conventional concrete. Addition of silica fume improves bond strength of concrete. Modulus of elasticity of silica fume concrete is similar to that of conventional concrete.

4. DISCUSSION

Availability of raw material is very less due to higher use of concrete. Normal practice of concreting is batching of all raw materials, mixing (all raw materials), transporting, compaction at site, finishing and curing is followed by industry. In developed country like India use of concrete is higher quantity and availability of raw material is very less.

Total replacement of concrete is not possible due to no material plays the role of concrete in terms of strength, durability, and workability. We have to partial replace all the material to achieve desire properties of concrete in terms of workability, strength and durability. Utilization of such waste and its application for the sustainable development of the construction industry is the most efficient solution and also address the high value application of such waste.

Utilization of these materials in concrete leads to cheaper construction without compromising the strength of the concrete.

It's a waste minimization process to utilize in the construction industry.

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