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CHARACTERIZATION AND DEVELOPMENT OF ECO-FRIENDLY CONCRETE USING INDUSTRIAL WASTE – A REVIEW

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Abstract: At present in India, about 960 million metric tons of solid waste is being generated annually as byproducts during industrial, mining, municipal, agricultural and other processes. Advances in solid waste management resulted in alternative construction materials as a substitute to traditional materials like bricks, blocks, tiles, aggregates, ceramics, cement, lime, soil, timber and paint. To safeguard the environment, efforts are being made for recycling different wastes and to utilize them in value added applications. The cement industries have been making significant progress in reducing carbon dioxide (CO_2) emissions through improvements in process technology and enhancements in process efficiency, but further improvements are limited because CO_2 production is inherent to the basic process of calcinations of limestone. In the past two decades, various investigations have been conducted on industrial wastes like flyash, blast furnace slag, Silica fume, rice husks and other industrial waste materials to act as cement replacements .This paper consist of a review extensively conducted on publications related to utilization of waste materials as cement replacement with an intention to develop a process so as to produce an eco-friendly concrete having similar or higher strength and thus simultaneously providing a remedy to environmental hazards resulting from waste material disposal.

Keywords: Blast furnace Slag, Silica fume, eco-friendly concrete

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INTRODUCTION

Concrete is the most commonly and widely used building material applied in all forms of construction, since the advancement of concrete technology – its evolution of methodology and mixing, various waste materials are being introduced partially as replacement to the cement. Of all construction materials, concrete is one of the most resistant materials to heat and fire. Experience has shown that concrete structures are more likely to remain standing through a fire than the structures made of other materials. Unlike wood, concrete does not burn and unlike steel, it does not lose a substantial degree of its rigidity at moderately high temperatures (Muszynski & Gulas, 2001).

Ground granulated blast furnace slag

When iron-ore, coke and limestone melt in the blast furnace, two products are formed; one is molten iron, and other molten slag. The molten slag is lighter and floats on the top of the molten iron. The molten slag comprises mostly silicates and alumina from the original iron ore, combined with some oxides from the limestone.

The process of granulating the slag involves cooling of molten slag through high-pressure water jets. This rapidly quenches the slag and forms granular particles generally not bigger than 5 mm. The rapid cooling prevents the formation of larger crystals, and the resulting granular material comprises around 95% non-crystalline calcium-alumino silicates. The granulated slag is further processed by drying and then grinding in a rotating ball mill to a very fine powder, which is Ground Granulated Blast Furnace Slag (GGBFS/GGBS).

According to ISA (Indian Slag Association Report) "We have a slag production capacity of about 41 million tonnes per annum and this is projected to reach 90 million tonnes by 2020. It can be used in various ways like making cement or sand". L.H. Rao, former Director of the National Council for Cement and Building Material said "About 30 per cent of the raw material used in steel production turns to slag and this can be used to meet the present sand shortage,"

Ground Granulated Blast furnace Slag (GGBS) is a byproduct from the blast-furnaces used to make iron. Blast-furnaces are fed with controlled mixture of iron-ore, coke and limestone, and operated at a temperature of about 1500°C.

GGBS Properties and applications

The granulated material, which is ground to less than 45 microns, has a surface area fineness of about 400 to 600 m^2/kg when measured with Blaine's apparatus. The relative density (specific gravity) for ground granulated blast furnace slag is in the range of 2.85 to 2.95. The bulk density varies from 1050 to 1375 kg/m^3 (66 to 86 lb/ft^3). The rough and angular-shaped ground slag in the presence of water and an activator, NaOH or CaOH, supplied by Portland cement, hydrates and sets in a manner similar to Portland cement. However, air-cooled slag does not have the hydraulic properties of water cooled slag. Granulated blast furnace slag was first developed in Germany in 1853 (Malhotra, 1996). Ground slag has been used as a cementitious material in concrete since the beginning of the 1900s (Abrams, 1925). Ground granulated blast furnace slag, when used in general purpose concrete in North America, commonly constitutes between 30 and 45% of the cementing material in the mix (PCA 2000). Some slag concretes have a slag component of 70% or more of the cementitious material. ASTM C 989 (AASHTO M 302) classifies slag by its increasing level of reactivity as Grade 80, 100, or 120. ASTM C 1073 covers a rapid determination of hydraulic activity of GGBS.

Silica fume

Silicon metal and alloys are produced in electric furnaces. The raw materials are quartz, coal, and woodchips. The smoke that results from furnace operation is collected and sold as silica fume, rather than using as landfill. The most important use of this material is as a mineral admixture in concrete. Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO_2). The individual particles are extremely small, approximately 1/100th the size of an average cement particle. Because of its fineness in fine particle sizes, large surface area, and the high Silicon dioxide (SiO_2) content, silica fume is a very reactive pozzolan when used in concrete.

Silica Fume Properties and applications

Silica fume, also referred to as micro-silica or condensed silica fume, is a byproduct material that is used as a Pozzolan. This byproduct is a result of the reduction of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as an oxidized vapor from the 2000°C (3632°F) furnaces. When it cools it condenses and is collected in huge cloth bags. The condensed silica fume is then processed to remove impurities and to control particle size. Condensed silica fume is essentially silicon dioxide (usually more than 85%) in non-crystalline (amorphous) form. Since it is an airborne material like fly ash, it has a spherical shape. It is extremely fine with particles less than 1 μm in diameter and with an average diameter of about 0.1 μm, about 100 times smaller than average cement particles. Condensed silica fume has a surface area of about 20 000 m^2/kg (nitrogen adsorption method). For comparison, tobacco smoke's surface area is about 10 000 m^2/ kg; Type I and Type III cements were used-(Type I is ordinary Portland cement, and it is available in white or gray and Type III is high early strength cement. It is ground finer and reacts faster than Type I, so the early strength gains are greater. However the ultimate strength is not higher than Type I) have surface areas of about 300 to 400 m^2/kg and 500 to 600 m^2/kg (Blaine), respectively.

The specific gravity (relative density) of silica fume is generally in the range of 2.20 to 2.5. Portland cement has a specific gravity (relative density) of about 3.15. The bulk density of silica fume varies from 130 to 430 kg/m^3 (8 to 27 lb/ft^3). Silica fume is sold in powder form but is more commonly available in a liquid form (Malhotra, 1982)

Silica fume is used in amounts between 5 and 10% by mass of the total cementitious material. It is used in applications where a high degree of impermeability is needed and in high strength concrete.

DRAWBACKS OR DISADVANTAGES OF USING GGBS

The use of ground granulated blast-furnace slag (GGBFS) will generally retard the setting time of concrete. The degree of set retardation depends on factors such as the amount of Portland cement, water requirement, the type and reactivity of the slag or pozzolan dosage, and the temperature of the concrete. Set retardation is an advantage during hot weather, allowing more time to place and finish the concrete. However, during cold weather, pronounced retardation can occur with some materials, significantly delaying finishing operations. Accelerating admixtures can be used to decrease the setting time. Proper curing of all concrete, especially concrete containing supplementary cementing materials should commence immediately after finishing. A seven-day moist cure or membrane cure should be adequate for concretes with normal dosages of most supplementary cementitious materials. As with Portland cement concrete, low curing temperatures can reduce early-strength gain. (Gebler, 1986)

DRAWBACKS OR DISADVANTAGES OF USING SILICA FUME

Silica fume can be used as a partial replacement for cement. The percentage replacement may vary from 0 to 30 percent. Though this does not change the weight of the cementitious materials, there is an increase in the water demand because of the extreme fineness of silica fume. In order to maintain the same water- (cement plus silica fume) ratios, superplasticizers are used to maintain the required slump. This approach also results in an increase in compressive strength at the age of 3 days and thereafter. Because of its extreme fineness, silica fume is very light (about 850 kg per cubic meter) and does present handling problems.

PREVIOUS RESEARCH WORK ON GGBS & SILICA FUME STRENGTHENED CONCRETE

Several works on the effect of GGBS and silica fume on concrete by replacing cement have been carried out and it was reported that when GGBS is used in concrete, it improves workability, increases strength and durability.

Wang (2008) investigated the effects of elevated temperature on cement pastes by conducting experimental test on concrete by replacing cement with GGBS in percentages of 5, 10, 20, 50, 80 and 100%. The test specimens were heated to temperatures of 25, 105, 200, 440, 580, 800 and 1050ºC with a temperature increase from 25 to 105ºC in the first two hours, the heating duration at 200ºC level was 6 hours and the duration for 580, 800 and 1050ºC was 4 hours. Once the desired temperature was reached, temperature was maintained until the specimen was removed. Weight loss resulting from heat induced cracking and spalling was recorded. After exposure to a temperature of 580ºC, the compressive strength of a paste containing 20% replacement was found to be three times than that of the control specimen. An effort was made to find the optimal GGBFS content at different W/B (Water/Binder) ratios and at W/B ratio of 0.23, the optimum GGBFS content is between 50% and 80%. However, there were no clear trends for W/B ratios of 0.47 and 0.71. For years, engineers have recognized that the performance of concrete can be optimized by adding GGBFS. Thus, most of the GGBFS has been recycled even though GGBFS is a byproduct from the iron and steel industry. The Federal Highway Administration (FHWA) reported that 90% GGBFS has been recycled in the US (S.C. Maiti) and similarly, in European countries (*e.g.* Netherlands, Denmark) also. In producing cement, about 45% of the cost is consumed for electricity requirements whereas the rest is the material cost. It is estimated that the cement industry consumes about 8% of the electricity of a city (A.K.Mullick). With the addition of GGBFS, electricity consumption can be reduced. Based on the above mentioned point, there are clear benefits to partially replacing cement with GGBFS, such as improvements in compressive strength and reduction of cracking at elevated temperature. At a W/B ratio of 0.23, the optimum GGBFS content was found to be 80%. With 80% addition of GGBFS, the material cost can be reduced by 40%. In Germany 100% GGBFS has been recycled. In Taiwan, it was estimated that 100% GGBFS, 4 million tons annually, is recycled. Based on the current unit price in Taiwan, the costs for cement and GGBFS are $71 and $34.8 per ton, respectively. It is found that 10% of the concrete cost can be reduced through 20% replacement with GGBFS, based on 300 kg of cement per cubic meter of concrete. Similarly, 40% of costs can be saved with an 80% addition of GGBFS. This indicates that the 28-day compressive strength was compatible to the control concrete that contained no GGBFS.

Lim *et al*. (2012) also studied the effect of Ground Granulated Blast Furnace Slag on the mechanical behavior of engineering cement composites (ECC) in which he used slag as replacements of 20 and 40%, Specimens were casted for testing compression, tensile and flexure strengths for 7 days, 28 days and 90 days. The author's study reported that the use of ground granulated blast furnace slag as a replacement not only increased the strength but also created a better bridging property that resulted in better ductility.

Kamran *et al.* (2004) studied the effect of GGBS on four different mix ratio's (1:2:4, 1:5:3, 1:1.25:2.50, 1:1:2). The water cement ratio for the first two mixes was kept as 0.65 and the remaining two mixes as 0.45. Cement was replaced by GGBS in percentages of 0%, 25% and 50%. It was concluded that the price of GGBS was up-to 25% less than that of Ordinary Portland Cement. Tests on workability, compressive strength, tensile strength and modulus of rupture were carried out. Increase in the percentage of slag, increased workability, improved finishing. The compressive strength of GGBS based concrete was less in the early stages, 3 days and 7 days but the 28 days strength was similar to that of plain cement (control) concrete. The split tensile strength was similar to that of plain cement concrete, even up-to replacement levels of 50 % GGBS.

Latha *et al.* (2012) conducted an experimental program on GGBS and high volume flyash for M20, M40 and M60 at different ages of 28, 90 and 120 days with GGBS replacements from 0 to 70% in increments of 10%. It was found that in case of GGBS concrete with 40% being the optimum percentage of replacement and 50% in case of higher grade concrete (M60). They concluded that the partial replacement of cement with GGBS and high volume flyash (HVFA) in concrete has shown enhanced strength and durability properties which offer good compatibility.

Dubey *et al.* (2012) studied the effect of blast furnace slag on concrete by replacing cement from 5% to 30%; from the experimental studies it was observed that the optimum replacement of ground granulated blast furnace slag was 15 % without much reduction in the compressive strength. Only a reduction of 5 % in strength was observed .Concrete cubes were cast of size 150 × 150 × 150 mm and cured for 7, 14 and 28 days. It was concluded that increasing the percentage of blast furnace slag resulted in decrease in compressive strength.

Tamilarasan & Perumal (2012) conducted an experimental study for the effects of replacing cement with ground granulated blast furnace slag on the compressive, split tensile and flexural strengths of concrete. In this study GGBS was used to replace cement from 0 to 100% in 5% increments, for this study M20 and M25 grades of concrete were used and it was concluded that tensile, compressive and flexure strength increased in all levels of replacements adopted. compression tests were carried out at 3, 7 and 28 days curing, split tensile and flexure were carried out at the end of 28 days. The results obtained for M20 grade concrete were all above 20 MPa. The compressive strength increased up to 30% (optimum mixes) thereafter there was a decrement observed till 60% replacement level. Tensile and flexural strength increased with an in replacement of GGBS up-to 60% level.

Vijaya *et al.* (2012) undertook a study on supplementary cement materials like flyash, blast furnace slag and silica fume on durability properties of high strength concrete (M80 and M90 grade). The durability was checked using Rapid Chloride permeability tests. Concrete mix design as per IS:10262 (2009) was made and test on standard cylindrical disc specimens of size 100 mm diameter and 50 mm thick after a curing period of 90 days in water was carried out. The author concluded that the addition of SCM's (Supplementary cement materials) caused pozzolanic reaction thus resulting in improvement of pore structure of concrete leading to lower permeability, causing higher resistance to chloride ion penetration at the higher percentage replacement compared to conventional concrete..

Konstantin (2005) investigated on the mechanic-chemical floatation of cement with high volumes of blast furnace slag and studied the effect of grinding on the strength of modified cement containing granulated blast furnace slag in high volumes. Three additional components were used in his experimentation: ground granulated blast furnace slag (GGBFS), silica fume (SF), and a reactive silica-based complex admixture (RSA). According to him test results showed an increase of 62% increase in strength when compared to the reference mix. Silica fume of 10% by weight of cement was used and a constant 45% of GGBS was used in all cements mixes. The water cement ratio was adjusted to have a constant flow with a sand to cement ratio of 2.75. The experimental tests included the effect of mineral additives and duration on fineness of cement, normal consistence, setting time and compressive strength. Specimens were tested after moist curing period of 2, 7, and 28 days. The setting time of the results obtained using silica fume and high performance cements increased significantly because of the incorporation of large volumes of mineral additives. It was recognized that the setting time was further extended with the inter-grinding of SF and cement, due to the RSA–cement interaction and mechano-chemical changes in the system.

Sarat *et al.* (2012) used Ground granulated blast furnace slag in various cement replacements of 10 to 80% and cement kiln dust for replacements ranges from 0 to 40% with 10% increments and tests were conducted to determine the compressive strength of concrete at the ages of 1, 3 and 6 months. The results showed that the 28 day compressive strength of concrete containing GGBS up to 30% replacement were all slightly above than that of normal concretes and when compared with all other percentages of replacement levels.

Maiti & Raj (2010) did an experimental study on concrete mix design on Portland cement replacements by GGBS from 50 to 65% for M20 grade concrete. Tests were conducted to determine the compressive strength of concrete after moist curing of 28 and 90 days. The test results led to the conclusion that with the increase of percentage of GGBS in concrete, the chloride ion permeability decreases. It was recommended to increase more than 50% GGBS in concrete to reduce harmful alkali-silica reaction. The heat of hydration of concrete using flyash and GGBS was less than that of concrete with only ordinary Portland cement. Ground granulated blast furnace slag is the safest option to mitigate alkali – silica reaction in concrete.

Mullick (2012) conducted experiments on binary and ternary cement blends with Ordinary Portland Cement (OPC) being replaced by flyash, silica fume, ground granulated blast furnace slag and the specimens were cured for 1, 3, 7 and 28 days. The results showed improvements in compressive strength and durability and he concluded that the use of ternary blends should be encouraged for ensuring greater durability in constructions.

Susan *et al.* (2010) studied the effect of alkali slag concrete reinforced with steel fibers. The compressive, splitting tensile and flexural strengths, flexural notch sensitivity, pull-out and water absorption properties were evaluated on concrete specimens cured for 28 days and the test results showed a reduction in compressive strength with fiber addition but an increase in split tensile and flexural strengths with increasing fiber volume from 3.75 to 4.64 MPa and from 6.40 to 8.86 MPa respectively at 28 days of curing. The final conclusion was that the alkali-activated slag concretes reinforced with fibers exhibit a mechanical performance better than control mixes of ordinary Portland cement concrete.

Ramesh *et al.* (2013) conducted an experimental investigation on durability characteristics of high performance concrete using mineral admixtures on M75 grade concrete with replacement levels of 0, 5%, 7.5% and 10% of silica fume and ground granulated blast furnace slag with a constant cement binder ration of 0.26 and 0.3% fiber glass was added with superplasticizer CONPLAST- SP-430. Investigations were carried out on durability properties such as saturated water absorption, porosity and alkalinity measurements. For all the mixes specimens were cured for 28 and 56 days, Thus, from the results, it was observed that the maximum compressive strength were obtained for mixes with 10 percent replacement of cement by silica fume and at age of 28 and 56 days respectively. The compressive strengths at the age of 28 days for M75 grade of HPC trial mixes containing 0, 5, 7.5 and 10 percent cement replacement of ground granulated blast furnace slag were 69.5, 73.2, 79.3 and 85 MPa respectively; and at the age of 56 days 72.1, 76.4, 82 and 88.5 MPa respectively That is, the silica fume content in concrete increased the strength when compared to the ground granulated blast furnace slag content at the age of 28 and 56 days respectively. This was due to the fact that the increase in compressive strength was due to the pozzolanic reaction and filler effects of ground granulated blast furnace slag. Hence, the optimum percentage of cement replacement by silica fume and ground granulated blast furnace slag for achieving maximum compressive strength was found to be 10 percent for M75 grades of HPC.

Mohamed *et al.* (2012) conducted an investigation on the locally available ground granulated blast furnace slag to protect the environment against waste dumping and to promote local products. The slag content such (20, 30, 40, 50, 60 and 80%) was used. Blast furnace slag had shown a positive effect on both the flexural and compressive strength of concrete after 28 days. The real gain in strength was noticed after the 28 day mark especially when 120 grade GGBFS was used. The long term strength of slag cement depended on many factors such as the amount of slag and Portland cement, and water to cement ratio. Clinkers have well reacted with slag, but a slight difference in the resulting resistance was observed mainly at medium and long term. The best resistance at 28 days was obtained with higher C_3S and the C_3A content. It was also noted that the minor elements played an important role in the slag reaction. The results of the long-term mechanical tests have shown that regardless the type of clinker used, the performance in compressive strength was very significant. An average of 30% increase in resistance with regards to the findings recorded at 28 days was also noted. The major reasons of such increase were higher C_3S content and its quick reaction with water which provided an important degree of resistance.

Deepa (2012) conducted a comparative study on mechanical properties of different ternary blended concrete by incorporating ground granulated blast furnace slag, silica fume and flyash. The properties investigated included workability, compressive strength and flexural strength. Mix design for M30 grade concrete was carried out, the dosage of superplasticizer used was 0.78% of cement weight.

The specimens were prepared by using both hand compaction and using vibrating table; curing of the specimens was done for 28 days and 90 days. The ternary blends replacements were done from 0 to 30% in 5% increments. Silica fume replacement gave the highest strength in flexure after 28 and 90 days. Silica fume also gave the highest compressive strength after 90 days. The author also concluded that by using industrial waste materials environment can be made more sustainable.

Comments on the present review

Literature review on earlier research works in the field of replacing cement with industrial waste materials have shown that the investigators have tried to use flyash, Ground Granulated Blast Furnace Slag, Silica fume, metakaolin in different mix proportions and percentages. All the authors have concluded that the addition of industrial waste materials have showed a positive response in terms of compressive strength, tensile strength and in terms of durability . Most of them have expressed a concern that these studies should be further carried out and applied to construction industries.

The test results showed that an increase in GGBS percentage led to a decrease in chloride ion permeability, thus making concrete more impermeable. The economic feasibility of recycling depends largely on the application. Concrete and cement industry can contribute to sustainable development by adopting supplementary cementitious materials, recycled aggregate to save natural resources, energy, reducing CO_2 emissions, and protect the environment and can improve its record with an increased reliance on recycled materials and in particular by replacing larges percentages of Portland cement by byproducts of industrial processes. This will help our sustainable and green environment.

Proposed method to produce eco-friendly concrete using industrial waste materials

To overcome these problems discussed above, in this research work the potential tools and strategies to meet the environmental challenges can be summarized as follows:

To replace as much Portland cement as possible by supplementary cementitious materials, especially those that are byproducts of industrial processes, such as ground granulated blast furnace slag, and silica fume. To use recycled materials in place of natural resources. To improve durability the literature review has also shown that the usage of industrial waste materials have helped in many durability properties such as reducing shrinkage which is a long term effect, reducing chloride permeability and service life of structures, thereby reducing or increasing the amount of materials needed for their replacement; to improve mechanical properties such as compressive strength, tensile and flexural strength as it is evident from the conclusion from all the research work conducted by other authors as reviewed in literature and other properties of concrete, which can also reduce the amount of materials needed.

The proposed Project aimed at to find an alternate way of reducing the carbon dioxide emission from the production of cement manufacture which would help in reducing global warming. To find a way of recycling industrial waste materials like Ground Granulated Blast Furnace Slag and& Silica fume. To compare the strength benefits of GGBS and Silica fume.

CONCLUDING REMARKS

The extensive literature survey has given an insight to the authors and supported to gain in depth knowledge and understanding on cement replacements that may be adopted in practice with different industrial waste materials. This work has given information about previous studies and that information helped the authors to undertake systematic experimental investigation for revisiting the issues in hand, such as the pollution in land and air that had been caused by the industrial wastes as there were no method of disposing these wastes but dumping them as land fill which led to serious health hazards. It was only after research, it was found that these industrial wastes had some good properties such as binding of aggregates and enhanced strength and durability of concrete, so these industrial waste materials could be used as a cement replacement in construction industry thereby reducing the cost of cement which in turn reduced the construction cost and at the same time an effective way was found to dispose of industrial waste materials there by reducing environmental health hazards and reducing pollution. Keeping these facts in mind a study needs to be conducted which would help to select the characterization and development of eco-friendly concrete using optimum quantity of industrial waste.

This paper reviewed on existing research works on cement replacements done by adding different industrial waste materials. This paper mainly focused on different percentages of replacement by waste material. The importance of this review paper is that it has opened up the field of recycled waste material concrete field to study the strength and durability of concrete in compression and tension and also to study the durability aspects of such concrete.

Table 1 Summary of materials used, tests conducted, and results

S .No	Title	Author	Name of Journal/ Year of Publication	Grade/ Materials used	Experiments Conducted	Curing days	Test Results	Conclusion
1	The effects of elevated temperature on cement pastes by conducting experimental test on concrete by replacing cement with GGBS	H. Y. Wang	Cement & Concrete Composites, Vol. 30, pp. 992-999, (2007)	GGBS percentages of 5%, 10%, 20%, 50%, 80% and 100%.	Specimens were heated to temperatures of 25, 105, 200, 440, 580, 800 and 1050 ^{o}C with a temperature increase from 25 to 105^{o}C in the first two hours, the heating duration at 200^{o}C level was 6 hours	28 days	At a W/B ratio of 0.23, the optimum GGBFS content was found to be 80%.	28-day compressive strength was compatible to the control concrete that contained no GGBFS.
2	Effect of ground granulated blast furnace slag on mechanical behavior of PVA-ECC	Ing Lim, Jenn-Chuan Chern, Tony Liu, and Yin-Wen Chan	Journal of Marine Science and Technology, Vol. 20, No. 3, pp. 319-324 (2012)	Short random fibers, GGBS	Compressive strength, flexural tests strength	28 days	Mixtures containing slag generally increase compressive strength of the specimen, but slag grade 100 needs time for strength development so that the strength at early age might be lower.	This study concluded that the effect of ground granulate blast furnace slag replacement not only increased the strength but also created a better fiber bridging property that resulted in better ductility of the ECC.
3	Effect of blending of portland cement with ground granulated blast furnace slag on the properties of concrete	Kamran Muzaffar Khan, UsmanGhani	Singapore Concrete Institute, Singapore, pp.329-334. (2004)	GGBS on mix ratio's (1:2:4, 1:5:3, 1:1.25:2.50, 1:1:2). The water cement ratio for the first two mixes was kept as 0.65 and the remaining two mixes as 0.45	Workability, compressive strength, tensile strength and modulus of rupture.	3,7,28 days	Increase in the percentage of slag, increased workability, improved finishing	Split tensile strength was similar to that of plain cement concrete, even up-to replacement levels of 50 % GGBS

S .No	Title	Author	Name of Journal/ Year of Publication	Grade/ Materials used	Experiments Conducted	Curing days	Test Results	Conclusion
4	Estimation of GGBS and HVFA Strength Efficiencies in Concrete with Ag	K. Suvarna Latha, M V Seshagiri Rao, Srinivasa Reddy. V	International Journal of Engineering and Advanced Technology (IJEAT) Vol. 2, No. 2, December 2012	Grade 53 Ordinary Portland Cement, ground granulated blast furnace slag (GGBS) and high volume fly ash HVFA	Replacement levels for GGBS and HVFA vary from 10% to 70% in an increment of 10%	28, 90 and 180 days	Usage of GGBS and HVFA significantly reduces the risk of damages caused by Alkali – Silica reaction (ASR) provides higher resistance to chloride ingress	GGBS hardens very slowly and for use in concrete, it needs to be activated by combining with OPC there is an increase in and HVFA
5	Effect of blast furnace slag powder on compressive strength of concrete	Atul Dubey, Dr. R. Chandak, Prof. R.K.Yadav	International Journal of Scientific & Engineering Research Volume 3, Issue 8, August-2012	GGBSSF (Silica fume)	Compressive strength, Sulphate resistance	7 days, 14 days and 28 days	The optimum replacement of ground granulated blast furnace slag was 15 % without much reduction in the compressive strength	Partial replacement of Portland cement with GGBF slag is found to improve the sulfate resistance of concrete.
6	Performance study of concrete using GGBS as a partial replacement material for cement	V.S. Tamilarasan & P. Perumal.	European Journal of Scientific Research Vol. 88, No 1 pp. 155-163. (2012)	In this study GGBS was used to replace cement from 0% to 100% in 5% increments	Tensile, compressive and flexure strength	3, 7 and 28 days	The results obtained for M20 grade concrete were all above 20 N/mm^2	The compressive strength increased up to 30 %(optimum mixes) thereafter there was a decrement observed till 60% replacement level.
7	Durability of high performance concrete containing supplementary cementing materials using rapid chloride permeability test	M Vijaya Sekhar Reddy, I V Ramana Reddy, K Madan Mohan Reddy and Abibasheer Basheerudeen	Journal. Structural. & Civil Engg. Res. 2012) Vol. 1, No. 1, November 2012	Flyash, Silica fume, Blast furnace slag and Metakaoline.	The rapid chloride permeability test for different concrete mixtures was carried out as per ASTM C1202 (1997).	28,90 days	Rapid Chloride Permeability test results reveals that the total charge passed in Coulomb's is very low for M90 HPC mix with replacement of 33%% Flyash and 15.13% of Metakaoline.	In high performance concrete mix design as water/cement ratio adopted is low, super plasticizers are necessary to maintain required workability

S .No	Title	Author	Name of Journal/ Year of Publication	Grade/ Materials used	Experiments Conducted	Curing days	Test Results	Conclusion
8	Mechano-chemical modification of cement with high volumes of blast furnace slag	Konstantin Sobolev	Cement & Concrete Composites, Vol. 27, pp. 848–853. (2005)	Silica fume of 10% by weight of cement was used and a constant 45 % of GGBS was used in all cements mixes.	Compressive strength test, Split Tensile strength test	2, 7, and 28 days	Test results showed an increase of 62% increase in strength when compared to the reference mix.	The setting time of the results obtained using silica fume and high performance cements increased significantly
9	Sustainable Development Using Supplementary Cementitious Materials and Recycled aggregate	B Sarath Chandra Kumar, Vamsi Krishna Varanasi, Dr. P Saha	International Journal of Modern Engineering Research (IJMER) Vol.2, Issue.1, pp-165-171 .(2012)	GGBS in concrete at various replacement percentages (10–80%).Cement Kiln dust(CKD)	Compressive strength was determined at the age of 1, 3, and 6 months. Based on the test results, they reported .	1,3 and 6 months	The 28-day compressive strength of concretes containing GGBS up to 30% replacement were all slightly above that of normal concretes, and at all other percentages.	Portland cement by byproducts of industrial processes. This will help our sustainable and green environment.
10	Concrete and its quality	S.C. Maiti and Raj K. Agarwal)	Indian Concrete Journal, (2006)	Portland slag cement containing 50-65% ggbs. M20 grade	Compressive strength	28 and 90 days.	The percentage of ggbs increases in concrete, the chloride ion permeability decreases. To resist harmful alkali-silica reaction, use of more than 50% ggbs in concrete has been recommended	The heat of hydration of concrete using fly ash and ggbs is less than that of concrete with only opc. ground granulated blast furnace slag is the safest option to mitigate alkali – silica reaction in concrete.
11	Performance of concrete with binary and ternary cement blends	A.K. Mullick	Indian Concrete Journal, (2007)	OPC by fly ash, granulated slag and silica fume	Compressive strength and durability tests	1,3,7,28	Ternary blends with OPC containing silica fume and GGBS provide greater durability to concrete	The use of ternary blends should be encouraged for ensuring greater durability in constructions.

S .No	Title	Author	Name of Journal/ Year of Publication	Grade/ Materials used	Experiments Conducted	Curing days	Test Results	Conclusion
12	Performance of an alkali-activated slag concrete reinforced with steel fibers	Susan Bernal, Ruby De Gutierrez, Silvio Delvasto, Erich Rodriguez Escuela de Ingeniería de Materiales, Grupo de Materiales Compuestos	Science Direct Construction and Building Materials, (2010)	Alkali-activated slag concrete (AASC) reinforced with steel fibers.	Compressive, splitting tensile and flexural strengths, flexural notch sensitivity, pull-out and water absorption properties were evaluated	28 days	Results revealed a reduction of AASC compressive strengths with fiber, incorporations. However, splitting tensile and flex- ural strengths were largely improved with increasing fiber volume, varying from 3.75 to 4.64 MPa and from 6.40 to 8.86 MPa at 28 days of curing	The alkali-activated slag concretes reinforced with fibers exhibit a mechanical performance better than control mixes of OPCC.
13	Experimental Investigation on Durability Characteristics of High Performance Concrete Using Mineral admixtures	G.Ramesh kumar, P. Muthupriya, & R. Venkatasubramanil	International Journal of Advanced Scientific and Technical Research, Vol. 2, pp 239-251,(2013).	M75 grade concrete with replacement levels of 0, 5%, 7.5% and 10% of silica fume and ground granulated blast	Compressive strength test	28 and 56 days	Maximum compressive strength were obtained for mixes with 10 percent replacement of cement by silica fume and at age of 28 and 56 days	Optimum percentage of cement replacement by silica fume and ground granulated blast furnace slag for achieving maximum compressive strength was found to be 10 percent for M75 grades of HPC
14	Investigating the Local Granulated Blast Furnace Slag	Mohamed Nacer Guetteche, Abdesselam Zergua, Samia Hannachi	Journal of Civil Engineering-Scientific research, pp. 10- 15./2012	OPC–slag	Compressive and tensile strength by bending at 2, 28, and 90 days	28 days	The highest strength obtained is attributed to the first group of OPC–slag mortars as 80.1 MPa at 28 days for the optimum OPC–slag mortar	The major reason of increase in resistance was higher C_3S content and its quick reaction with water which provided an important degree of resistance.
15	Comparative mechanical properties of different ternary blended concrete	Deepa. A. Sinha	Indian Journal of Research, Vol. 1,No 10, pp. 65 – 69.(2012)	M30 grade	Workability, compressive strength and flexural strength.	28 days and 90 days	Silica fume replacement gave the highest strength in flexure and compressive strength after 28 and 90 days.	Using industrial waste materials, environment can be made more sustainable.

REFERENCES

Wang, H.Y. (2008) The effect of elevated temperature on cement pastes containing GGBFS. *Cement & Concrete Composites*, **30**, 992–999.

Muszynski, L.C., Gulas, S. (2001) Fire resistance and performance of alternative concrete wall systems. *J. Constr Educat* **6**(3),146–54.

Lim, I., Jenn, C.C., Tony, L. & Yin, W.C. (2012) Effect of Ground Granulated Blast furnace Slag on Mechanical behavior of PVA-ECC, *J. Marine Sci. and Technology*, **20**(3),319–324.

Kamran, M.K., Usman,G. (2004) Effect of blending of portland cement with ground granulated blast furnace slag on the properties of concrete, *Singapore Concrete Institute,* Singapore, 329–334.

Suvarna, K.L., Seshagiri, M.V.R. & Srinivasa, R.V. (2012) Estimation of GGBS and HVFA strength efficiencies in concrete with age, *Int. J. Engng and Advanced Tech.,* **2**(2),221–225. doi:10.1016/j.conbuildmat.2007.10.027

Atul, D., Chandak, R., Yadav, R.K. (2012) Effect of blast furnace slag powder on compressive strength of concrete, *International J. Sci. & Engng Research*, **3**(8).

V.S. Tamilarasan, V.S & Perumal, P (2012) Performance study of concrete using GGBS as a partial replacement material for cement, *European J. Sci. Research*, **88**(1) 155–163.

Vijaya, S.M.R., Ramana, R.I.V., Madan, M.R.K. & Abibasheer, B. (2012) Durability of high performance concrete containing supplementary cementing materials using rapid chloride permeability test, *Int. J. Structural & Civil Enginng Research*, **1**(1), 92–98.

Konstantin, S. (2005) Mechano-chemical modification of cement with high volumes of blast furnace slag, *Cement & Concrete Composites*, **27**(1), 848–853

Sarath, B.C.K., Vamsi, K. V., Saha, P. (2012) Sustainable Development Using Supplementary Cementitious Materials and Recycled Aggregate, *Int. J. Modern Engng Research (IJMER),* **2**(1) 165–171.

Maiti, S.C., Raj K.A. & Rajeeb, K. (2006) Concrete mix proportioning, *The Indian Concrete J.*, 23–26.

Mullick, A.K. (2007) Performance of concrete with binary and ternary cement blends, *The Indian Concrete J.*, 15–22.

Susan, B., Ruby D.G., Silvio, D., Erich, R. (2010) Performance of an alkali-activated slag concrete reinforced with steel fibers, *Construction and Building Materials*, **24**(1), 208–214.

Ramesh, K.G., Muthupriya, P.R.V. (2013) Experimental Investigation on Durability Characteristics of High Performance Concrete Using Mineral Admixtures, *Int. J. Advanced Scientific and Tech. Research*, **2**(1), 239–251.

Mohamed, N.G., Abdesselam Z., Samia, H. (2012) Investigating the Local Granulated Blast Furnace Slag, *J. Civil Engng - Scientific Research,* 10–15.

Deepa, A.S. (2012) Comparative mechanical properties of different ternary blended concrete. *Indian J. Research*, **1**(10), 65– 69.

Bhanja, S., Sengupta, B. (2005) Influence of silica fume on the tensile strength of concrete, *Cement and Concrete Research*, **35**(1), 743–747.

Barbara, P., Iwona, W. (2013) Hydration of Cement Composites Containing Large Amount of Waste Materials, *Procedia Engng*, **57**, 53–62.

Tarek, H. A & Yousef, A.A.S. (2001) Ultimate Strength prediction for RC beams externally strengthened by composite materials, *Composites: Part B,* **32**,609–619.

Gebler, S. H., & Klieger, P. (1986) Effect of Fly Ash on the Durability of Air-Entrained Concrete, *Research and Development Bulletin RD090, Portland Cement Association*,

Malhotra, V. M., Carette, G. G. (1982) Silica fume-A pozzolan of new interest for use in some concretes, *J. Concrete Constructions*, 443–446.

IS: 10262 (2009) Concrete Mix Proportioning-Guidelines, Bureau of Indian Standards, New Delhi.