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A Brief Study on Partial Replacement of Cement with Metakaolin

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ABSTRACT: This experimental study aims to investigate the suitability of Metakaolin and Blast Furnace Slag as partial replacement for Coarse aggregate in the production of low-cost and light weight concrete. In this experimental study is an attempt to find the optimum usage of Metakaolin and Blast Furnace Slag in normal concrete various proportions. Tests is conducted on concrete cubes, cylinders to study compressive strength, split tensile strength. Tests are conducted for finding the strength of the concrete in 7 days, 28 days, 56days, 90days strength. Finally the results are compared with the normal conventional concrete. The weight reduction is also calculated. The effect of the Metakaolin and blast Furnace Slag on concrete is evaluated.

KEYWORDS: Blast Furnace Slag, Metakaolin, Compressive strength, Split Tensile strength

I.INTRODUCTION

Concrete is prepared by mixing various constituents like cement, aggregates, water, etc. which are economically available. Concrete is a composite material composed of granular materials like coarse aggregates embedded in a matrix and bound together with cement or binder which fills the space between the particles and glues them together. Almost three quarters of the volume of concrete is composed of aggregates. To meet the global demand of concrete in the future, it is becoming a more challenging task to find suitable alternatives to natural aggregates for preparing concrete. Therefore the use of alternative sources for natural aggregates is becoming increasingly important. Slag is a co-product of the iron making process. Iron cannot be prepared in the blast furnace without the production of its co-product i.e. blast furnace slag. The use of blast furnace slag aggregates in concrete by replacing natural aggregates is a most promising concept because its impact strength is more than the natural aggregate. Steel slag aggregates are already being used as aggregates in asphalt paving road mixes due to their mechanical strength, stiffness, porosity, wear resistance and water absorption capacity.

Steel slag is an industrial byproduct obtained from the steel manufacturing industry. It is produced in large quantities during the steel-making operations which utilize Electric Arc Furnaces (EAF). Steel slag can also be produced by smelting iron ore in the Basic Oxygen Furnace (BOF). Steel slag can be used in the construction industry as aggregates in concrete by replacing natural aggregates. Natural aggregates are becoming increasingly scarce and their production and shipment is becoming more difficult. Steel slag is currently used as aggregate in hot mix asphalt surface applications, but there is a need for some additional work to determine the feasibility of utilizing this industrial by-product more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture. Most of the volume of concrete is aggregates. Replacing all or some portion of natural aggregates with steel slag would lead to considerable environmental benefits.

The raw material in the manufacture of Metakaolin is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. Kaolins are classifications of clay minerals, which like all clays, are phyllosilicates, i.e. a layer silicate mineral. The Meta prefix in the term is used to denote change. In case of Metakaolin, the change that is taking place is Dehydroxylization, brought on by the application of heat over a defined period of time. Dehydroxylation is a reaction of decomposition of kaolinite crystals to a partially disordered structure.

The results of isothermal firing shows that the dehydroxylation begins at 4200C.[3] At about 100- 2000C clay minerals lose most of their adsorbed water. The temperature at which kaolite loses water by dehydroxilization is in the range 500-800 0C. This thermal activation of a mineral is also referred to as calcining. Beyond the temperature of dehydroxylization, kaolinite retains two dimensional order in the crystal structure and the product is termed Metakaolin. Metakaolin is neither the by-product of an industrial process nor is it entirely natural. It is derived from naturally occurring mineral and is manufactured specially for cementing applications.

Metakaolin is produced under carefully controlled conditions to refine its colour, remove inert impurities, and tailor particle size such, a much high degree of purity and pozzolanic reactivity can be obtained. Metakaolin is white, amorphous, highly reactive aluminiumsilicate pozzolan forming stabile hydrates after mixing with lime stone in water and providing mortar with hydraulic properties.

Slag is a by-product generated during manufacturing of pig iron and steel. It is produced by action of various fluxes upon gangue materials within the iron ore during the process of pig iron making in blast furnace and steel manufacturing in steel melting shop. Primarily, the slag consists of calcium, magnesium, manganese and aluminum silicates in various combinations. The cooling process of slag is responsible mainly for generating different types of slags required for various end-use consumers. Although, the chemical composition of slag may remain unchanged, physical properties vary widely with the changing process of cooling.

II. LITERATURE REVIEW

Sabir.B.B et al (2001) carried out a study on the utilization of Metakaolin as pozzolanic material for mortar and concrete and mentioned about the wide range application of Metakaolin in construction industry .They reported that the usage of Metakaolin as a pozzolana will help in the development of early strength and some improvement in long term strength. They mentioned that Metakaolin alters the pore structure in cement paste mortar and concrete and greatly improves its resistance to transportation of water and diffusion of harmful ions which lead to the degradation of the matrix.

Jian-Tong Ding et al (2002) experimentally found out the effects of Metakaolin and Silica Fume on the properties of Concrete. Experimental investigation with seven concrete mixtures of 0, 5, 10, and 15% by mass replacement of cement with high- reactivity Metakaolin or Silica fume, at a water cement ratio of 0.35 and a sand-to-aggregate ratio of 40% was carried out. The effect of Metakaolin or Silica fume on the workability, strength, shrinkage, and resistance to chloride penetration of concrete was investigated. The incorporation of both Metakaolin and Silica fume in concrete was found to reduce the free drying shrinkage and restrained shrinkage cracking width. It is also reported that the incorporation of Metakaolin or Silica fume in concrete can reduce the chloride diffusion rate significantly. The performance of Silica fume was found to be better than Metakaolin.

Badogiannis.E et al (2004) evaluated the effect of Metakaolin on concrete. Eight mix proportions were used to produce high-performance concrete, where Metakaolin replaced either cement or sand of 10% or 20% by weight of the control cement content. The strength development of Metakaolin concrete was evaluated using the efficiency factor (k value). With regard to strength development the poor Greek Metakaolin and commercilly obtained Metakaolin yielded the same results. The replacement with cement gave better results than
that of sand. When Metakaolin replaced cement, its positive effect on concrete strength generally started after 2 days where as in case of sand it started only after 90 days. Both Metakaolin exhibited very high k-values (close to 3.0 at 28 days) and are characterized as highly reactive pozzolanic materials that can lead to concrete production with excellent performance.

Justice.J.M et al (2005) made a comparative study by replacing 8% by weight of cement with Metakaolin and Silica fume. Metakaolin addition proved to be beneficial, resulting in concrete with Metakaolin was more effective in improving concrete properties than the coarser Metakaolin. Addition of Metakaolin increased the use of super plasticizers. Addition of Metakaolin exhibited improvements in shrinkage, durability and other strength aspects.

Nabil M. Al-Akhras (2005) carried out an investigation by replacing cement with Metakaolin to find out the durability of concrete against sulphate attack. Three replacements of cement with Metakaolin (5, 10 and 15% by weight) were done with water cement ratio of 0.5 and 0.6. After the specified days, the samples were immersed in 5% sodium sulphate solution for 18 months. The effect of metakaolin addition proved to be beneficial in improving the resistance of concrete to sulphate attack. Metakaolin with water cement ratio of 0.5 exhibited better results in sulphate resistance than 0.6. Autoclaved cured specimens had better resistance against sulphate than moist cured specimens.

Abid Nadeem et al (2008) made an investigation on the chloride permeability of high strength concrete and mortar specimens containing varying proportions of Metakaolin (MK) and Fly ash at elevated temperatures. A total of seven concrete and three mortar mixes were tested after exposing each mix to 200, 400, 600 and 800°C. In concrete, the dosage levels of MK were 5, 10 and 20% and for Fly ash the dosage levels were 20, 40 and 60%. In mortar, the dosage level of Metakaolin and Fly ash was 20%. All concrete specimens investigated in this study had a minimum compressive strength of 85 MPa. At normal temperatures, concrete and mortar specimens had very low chloride ion Penetrability. At normal temperature, metakaolin mixes had lower chloride permeability than Fly ash and Portland cement mixes. At normal temperatures, mortar specimens were more chloride permeable than concrete specimens. At 200°C and 400°C, mortar was still more chloride permeable than concrete but the ratio of mortar to concrete chloride permeability considerably was less than that at normal temperature.

III. MATERIALS AND PROPERTIES

CEMENT:
Ordinary Portland Cement of 43 Grade of brand name Bharati company, available in the local market was used for the investigation. Care has been taken to see that the procurement was made from single batching in air tight containers to prevent it from being effected by atmospheric conditions. The cement thus procured was tested for physical requirements in accordance with IS: 169-1989 and for chemical requirement in accordance IS: 4032-1988.The size of cement varies from 1µ-45µ.The colour of the cement grey in colour. Cement is used to bind the materials of aggregates.

FINE AGGREGATES:
River sand locally available in the market was used in the investigation. The aggregate was tested for its physical requirements such as gradation, fineness modulus, specific gravity and bulk density in accordance with IS: 2386-1963.The sand was surface dried before use.

COARSE AGGREGATES:
Crushed aggregates of less than 20mm size produced from local crushing plants were used. The aggregate exclusively passing through 20mm sieve size .The aggregates were tested for their physical requirements such as gradation, fineness modulus, specific gravity and bulk density in accordance with IS:2386-1963.

BLAST FURNACE SLAG
Slag is a waste produced during manufacturing of pig iron and steel. It consists of oxides of calcium, magnesium, manganese, aluminum, nickel and phosphorous. The physical properties of slag depends upon change in process of cooling, however the chemical composition remain unchanged. The slag produced in blast furnace during pig iron manufacturing is called blast furnace slag and slag produced at steel melting plant is known as steel slag. Large amount of industrial waste produced every year in developing countries.

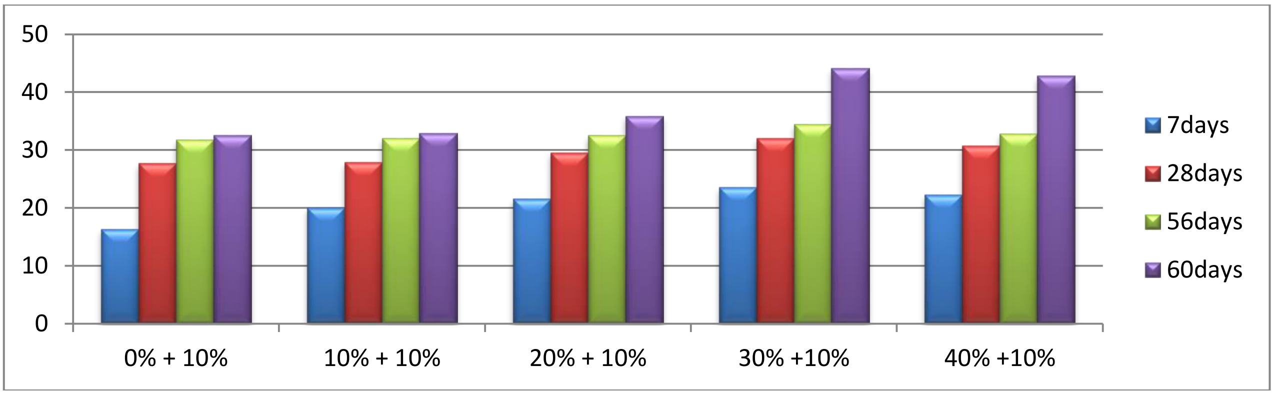
Total world steel production crossed 1200 million metric tons. In India, Slag output obtained during pig iron and steel production is variable and depends on composition of raw materials and type of furnace. For ore feed containing 60 to 65% irons, blast furnace slag production ranges from about 300 to 540 kg per ton of crude iron produced. Blast furnace slag is a nonmetallic co-product produced in the process. It consists primarily of silicates, alumina-silicates, and calcium-alumina-silicates. The molten slag, which absorbs much of the sulfur from the charge, comprises about 20 percent by mass of iron production. Figure presents a general schematic, which depicts the blast furnace feed-stocks and the production of blast furnace co-products (iron and slag).

METAKAOLIN
- Calcinations of clay mineral(kaolin) at moderately high-temperature (650^{oc}-800^{oc})
- Breaks down the crystal structure producing a transition phase (silica and amorphous alumina in reactive form) of high surface area
- Optimum burning temperature will depend on the base material used
- Burning at high temperature will cause recrystalization into quartz and mullite (Inert material).

IV. EXPERIMENTAL RESULTS

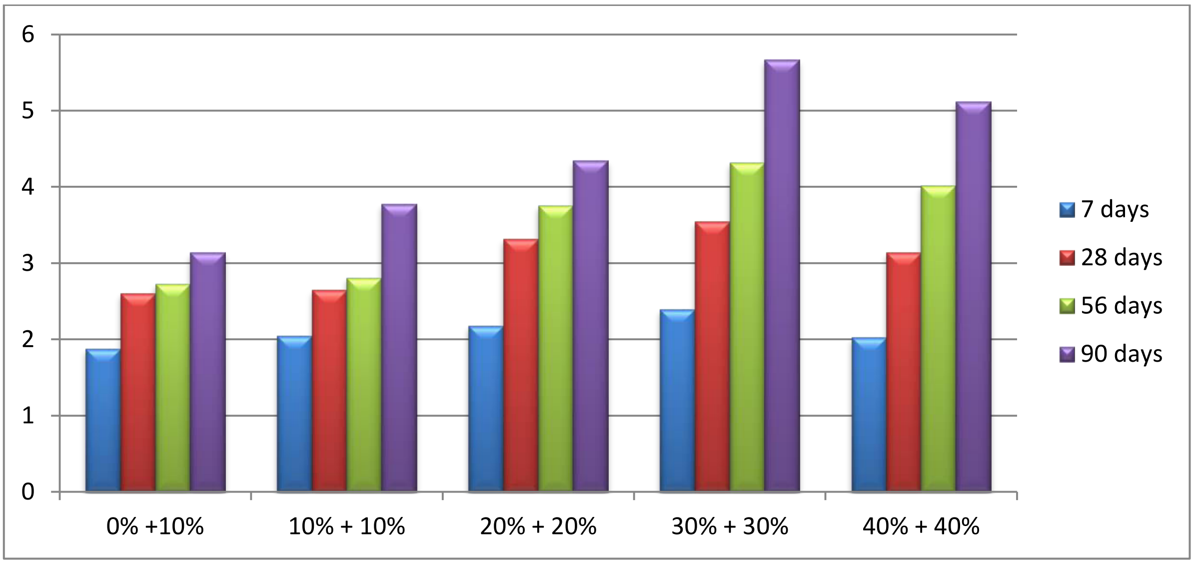
This chapter deals with the various mix proportions adopted in carrying out the experiments and experimental results obtained with respect to their Compressive strength and Split tensile strength.

% of slag replacement	%of metakaolin replacement	Compressive strength(N/mm^2)			
		7 days	28 days	56 days	90 days
O	10	16.4	27.8	31.8	32.56
10	10	20.1	27.9	32.09	32.89
20	10	21.6	29.6	32.56	35.90
30	10	23.6	32.1	34.5	44.18
40	10	22.3	30.8	32.85	42.86



Tensile strength of cylinders for each % replacement of slag and metakaolin for both 7 days, 28 days, 56days, 90days

% of slag replacement	% of metakaolin replacement	Tensile strength (N/mm^2)			
		7 days	28 days	56 days	90days
0	10	1.88	2.61	2.73	3.14
10	10	2.05	2.65	2. 81	3.78
20	20	2.18	3.32	3.76	4.35
30	30	2.4	3.55	4.32	5.67
40	40	2.03	3.14	4.02	5.12



V. CONCLUSION

In this investigation we are going to replace coarse aggregate with blast furnace slag and 10% of cement with metakaolin. Blast furnace slag is a by- product and using it as a aggregate in concrete will might prove an economical and environmentally friendly solution in local region. The strength of concrete increase gradually upto30% replacement of concrete and the decreases this is mainly due to arrangement and the increase of air voids beyond 30% replacement. This replacement leads to the reduction of cost of construction due to the use of industrial waste as ingredient of concrete. Metakaolin act as mineral admixture and converts calcium hydroxide in to cementicious compound so it leads to strength increment. The cost of slag is very less by usage of these materials in the concrete improve strength and durability of concrete with low cost.

- The physical and chemical properties of GBFS are suitable for the production of concrete mix.
- The compressive strength and split tensile strength are higher for replacement of 30% of GBFS and replacement of cement with 10% Meta Kaolin.
- The compressive strength and split tensile strength are lower for 0% replacement.
- The results showed that using Meta Kaolin and increasing % of flash with GIBFS an improvement in the impermeability of concrete.

VI. SCOPE FOR THE FUTURE RESEARCH

The availability of good quality aggregates is depleting day by day due to tremendous growth in Indian construction industry. Aggregates are the main constituents of concrete occupying approximately 75% of its volume and directly affecting the fresh and hardened properties. Concrete being the largest man made material used on earth is continuously requiring good qualities of aggregates in large volumes a need was felt to identify potential alternative source of aggregate to fulfil the future growth aspiration of Indian construction industry. Use of slag as aggregates provides opportunity to utilize this waste material as an alternative to normally available aggregates.
Based on the experience of work following future scopes are identified:

- Characterization of slag available from various steel manufacturing plants could be done for the comparison of performances of concretes obtained with these slag.
- Collection of data for characterization of such slag wastes generated from all the steel making plants is of extreme importance and could be taken up immediately.
- Study of environmental problems created by such wastes remaining without recycling and proper utilization.
- Development of mathematical model based on various parameters to ascertain its strength characteristics in respect of concrete