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Investigative Study of GGBS, Fly Ash and Steel Slag on Compressive Strength of Concrete

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Abstract- Concrete is world's most used material after water for urban development. Concrete is made up of naturally occurring material such as Cement, Aggregate and Water. Global warming gas is released when the raw material of cement, limestone and clay is crushed and heated in a furnace at high temperature of about 1500'C. To promote sustainable development, it is promising to utilize by-products in the making of new CAM instead of using only cement. In this research, the cement content was partly replaced by fly ash or ground-granulated blast furnace (GGBS) slag to achieve this objective. The objectives of this study are to use industrial by-products such as fly ash, GGBS, and steel slag with the traditional concrete ingredients without impairing the performance characteristics. In order to assess the comparative performance of the improvised concrete obtained from the partial substitution of similar ingredient materials, the strength of concrete was analyzed from the viewpoints of indicators mainly the compressive strength and flexural strength. Industrial wastes like Ground Granulated Blast Furnace Slag (GGBS) show chemical properties similar to cement. Use of GGBS as cement replacement will simultaneously reduce cost of concrete and help to reduce rate of cement consumption.
Keywords- Fly ash, aggregates, Ground Granulated Blast-furnace Slag, Steel slag

I. INTRODUCTION

Concrete is the most preferred and the single largest building material used by the construction industry. Concrete is basically made of aggregates, both fine and coarse, glued by a cement paste which is made of cement and water. Each one of these constituents of concrete has a negative environmental impact and gives rise to different sustainability issues. The current concrete construction practice is unsustainable because, not only it consumes enormous quantities of stones, sand, and drinking water, but also one billion tons a year of cement, which is not an environment friendly material. For production of cement huge amount of energy is needed and about 8 % of CO2 is released to atmosphere during cement production. In fact, many byproducts and solid wastes can be used in concrete mixes as aggregates or cement replacement, depending on their chemical and physical characterization, if adequately treated. The incorporation of GGBS, fly ash and blast furnace slag in concrete leads to many technical advantages. When two mineral admixtures are used together, better results can always achieve. The use of such industrial by-product or waste material having desirable qualities can result in saving of energy and conventional materials.

With increase in population, the demand for construction of residential and public buildings is also increasing. The iron and steel industry produces extremely large amounts of slag as by-product of the iron making and steelmaking processes. As useful recycled materials, iron and steel making slag are mainly used in fields related to civil engineering, for example, in cement, roadbed material, and concrete aggregate. However, the requirements for potable water or cement or aggregates will be escalating on a futuristic prediction leading to a demand- supply gap. In such cases, the requirements of the original concrete ingredients can be significantly reduced without affecting the concrete quality by way of using the otherwise branded as wasted materials such as fly ash, Ground Granulated Blast-furnace Slag (GGBS), foundry sand and steel slag with particular reference to making improvised concrete.

II. LITERATURE REVIEW

(Le et al. 2019) The application of cement asphalt mortar (CAM) in modern high-speed railways has been gaining attention due to its combined merits between asphalt and cement hydration product characteristics. To promote sustainable development, it is promising to utilize by-products in the making of new CAM instead of using only cement. In this research, the cement content was partly replaced by fly ash or ground-granulated blast furnace (GGBS) slag to achieve this objective. Then, laboratory experiments were conducted to determine the effect of these admixtures on the fresh and hardened characteristics of CAM. The test results revealed that the CAM mixture with slag received better fresh properties compared to the controlled mixture. However, the poor pozzolanic property of these by-product materials may lead to the low strength development. Meanwhile, although the mixture with fly ash suffered from slow strength establishment compared to the control mix at an early age, the strength of this condition increases dramatically after 28 days.

Based on the findings, the application of appropriate fly ash content in the CAM mixture will not only provide ideal workable time and mixing stability but also ensure the required strength for the design target. This combination also serves as a cost-effective and environmental solution.

(Shah 2019) This paper investigates the compressive strength properties of concrete with Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash in concrete by partial replacement of cement. The incremental demand of cement in the construction field is a concern for environmental degradation, in this regard; replacement of cement is carried out with waste materials by using GGBS and Fly Ash. On optimum level of GGBS and Fly Ash was assessed with varied percentage from 0 to 30% for different curing days. Replaced concrete were tested with the slump, compaction factor, Vee-bee and compressive strength. Cement to water ratio was maintained at 0.47 for all mixes. The compressive strength tests were conducted for 3, 7, 14 and 28 days of curing on a M25 grade concrete. The results obtained from the slump, compaction factor, Vee-bee and compressive strength of concrete containing GGBS and Fly Ash was increased as the curing time increases. The workability of replaced concrete improved when slump value achieved 30% as compared to controlled one SF0 and the compressive strength obtained 26.30% improvement at SF9 as compared to SF0. The outcomes indicated that the addition of GGBS and Fly Ash enhances the workability and compressive strength which eventually improved the mechanical properties of concrete.

(Pradesh et al. 2017) In the study, Concrete is the most extensively used construction material in the world with about six billion tones being produced every year. Geopolymer concrete has the potential to substantially control CO2 emission. To produce more durable infra -structure capable of design life measured in hundreds of years. GPC is a hardened cementation paste made from GGBS and alkaline solution. The objective of the present study is to observe the effect of GGBS based on GPC and by replacing of 100% GGBS with OPC. The molarity of sodium hydroxide is 6molar, 8molar, and 10molar. The proportion of soluble activators is 1:2. Calcium silicate is framed when GGBS gets responded with sodium hydroxide and sodium silicate. A mix proportion for Geopolymer concrete was designed by assuming the unit weight of geopolymer concrete as 2400 kg/m3. The study is performed to conduct the GPC with GGBS to analyse the progressions of properties like strength and durability.

(Maske 2016) A utilization of supplementary cementitious materials is well accepted because of the several improvements possible in the concrete composites and due to the overall economy. The present paper is an effort to quantify the 28-day cementitious efficiency of Ground Granulated Blast Furnace Slag (GGBS) in concrete at the various replacement levels with the help of literature review found and studied. 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.

(Karri, Rao, and Raju 2015) Concrete is probably the most extensively used construction material in the world with about six billion tones being produced every year. It is only next to water in terms of per-capita consumption. However, environmental sustainability is at stake both in terms of damage caused by the extraction of raw material and CO2 emission during cement manufacture. This brought pressures on researchers for the reduction of cement consumption by partial replacement of cement by supplementary materials. These materials may be naturally occurring, industrial wastes or by- products that are less energy intensive. These materials (called pozzalonas) when combined with calcium hydroxide, exhibits cementitious properties. Most commonly used pozzalonas are fly ash, silica fume, metakaolin, ground granulated blast furnace slag (GGBS). This needs to examine the admixtures performance when blended with concrete so as to ensure a reduced life cycle cost. The present paper focuses on investigating characteristics of M20 and M40 grade concrete with partial replacement of cement with ground granulated blast furnace slag (GGBS) by replacing cement via 30%, 40%, 50%. The cubes, cylinders and prisms are tested for compressive strength, split tensile strength, flexural strength. Durability studies with sulphuric acid and hydrochloric acid were also conducted.

Nishant Raj Kapor et al. (2016) studied the performance of fly ash on the behavior of compressive strength of concrete with 25% of replacement level. Fly ash replaced with the equal interval of 5% of cement content. Test results revealed that when the prolonged, the replacement level beyond 25% the strength value gets decreased and thereby the optimum replacement level is up to 25%. It can be concluded by saying fly ash will be effectively used as a cement admixture and replacement of cement with limited percentage level.

Girish et al. (2015) studied and presented the result of experimental investigations carried out to analyse the effects of replacing aggregate (coarse and fine) with that of slag on various concrete properties. From these results of the study, we can say that as the percentage of steel slag as a replacement is increased (0% to 55%) the strength of concrete increases. After 55% replacement of coarse aggregate as steel slag slight decrease in strength is observed, but still, it is higher than 0% substitution without any adverse effect on the strength of concrete.

III. METHODOLOGY

The materials used in the present investigation are ordinary Portland cement, natural river sand, coarse aggregates, steel slag, fly ash, ground granulated blast furnace slag, and ordinary potable water.

Mix Proportion

The M30 conventional concrete mix in accordance with IS code comparison was taken up as control mix for the comparison. The modified mix included the combinations of fly ash and GGBS in partial replacement of cement without detrimental to the quality criteria on par with or above those of the conventional concrete mix. The trials also included the combination of steel slag as partial replacement of coarse aggregate.

Mix Proportion with GGBS

Control Mix CC - Conventional concrete of grade M30
MG1: 10% replacement of cement with GGBS
MG2: 15% replacement of cement with GGBS
MG3: 20% replacement of cement with GGBS
MG5: 25% replacement of cement with GGBS

Mix Proportion of GGBS with Fly ash

CC - Conventional concrete on grade M30
MGF1: 20% GGBS+ 5% Fly ash
MGF2: 20% GGBS+ 10% Fly ash
MGF3: 20% GGBS+ 15% Fly ash
MGF4: 20% GGBS+ 20% Fly ash

Mix Proportion of GGBS, Fly ash and steel slag

MGFS1 - 20% GGBS + 15% Fly ash + 15% Steel Slag + 85 % of Coarse Aggregate
MGFS2- 20% GGBS + 15% Fly ash + 30% Steel Slag + 70 % of Coarse Aggregate
MGFS3- 20% GGBS + 15% Fly ash + 45% Steel Slag + 55 % of Coarse Aggregate
MGFS4- 20% GGBS + 15% Fly ash + 60% Steel Slag + 40 % of Coarse Aggregate

Slum Cone Test

Slump cone test has been performed on the slump cone of top diameter 10 cm and bottom diameter 20 cm with a height of 30 cm. The slump cone is well lubricated with the oil and the green concrete which has been mixed manually has been placed inside the cone at three levels and compacted well with a tamping rod for 10 blows.
Soon after placing the third level of concrete the cone is removed from upside and the height of the fall in concrete is noted and measured using a ruler directed as slump value of the concrete. There are three types of slump such as true slump, shear slump and failure slump for which concrete has been involved. The slump cone test has been performed in the laboratory.

Compressive Strength Test

The compressive strength test was carried out on 150 mm x 150mm x 150 mm cubes as specified by IS 516-1959. This test was carried by using the compression testing machine of 2000kN capacity at uniform stress after the specimen had been centered in the test machine. The ultimate load (P) was noted down. The compressive strength was calculated by using the relationship
Compressive Strength in MPa = P/A
where,
P is ultimate load in Newton
A is area of cube in mm2

Flexural Strength Test

The extreme stress calculated at the failure of the specimen is called modulus of rupture. It is also called as an indirect measure of predicting the tensile strength of concrete. A specimen of size 100 x100 x 500 mm were cast and tested as per IS 516:1959 to determine the modulus of rupture or the flexural strength mainly to determine the bending ability of concrete, and the test has been performed on the prism size of 100 x 500 mm with a thickness of 100 mm. A prism of the above-said dimension has been cast and tested on the compression-testing machine and many times at universal testing machine based on the length of the prism. Compression Testing Machine (CTM) is preferred when the size of the beam is extended and to determine the structural properties of a concrete specimen. The load is applied on the prism, and the failure load has been noted very similar to that of compressive and split tensile strength. The flexural strength is obtained by using the formula and expressed in N/mm2 or MPa.
Flexural Strength in MPa = FL / bd2

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IV. RESULT AND DISCUSSION

This section presents the effect of various industrial by products which are included in the study, based on the results of the various tests conducted on the modified concrete mixes.

Results of GGBS modified mix

The trial on GGBS incorporation is designated as MG ranging from MG1 to MG4 in accordance with increasing percentage proportioning 10 to 25% in increments of 5%.

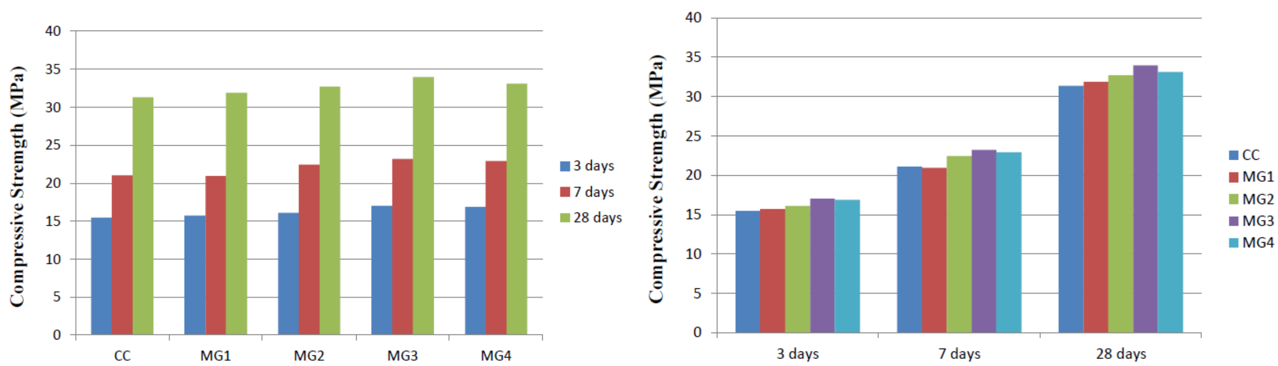

Figure 1: (a) Variation of compressive strength; (b) Comparison of Compressive strength

Based on above observations 20% replacement of cement with GGBS in concrete is chosen as optimum dose for producing concrete with further modifications.

Results of GGBS and Fly ash modified mix

The aim of this experiment is to find the most optimal proportions of GGBS and fly ash as replacement of cement without detrimental to the conventional concrete mix.

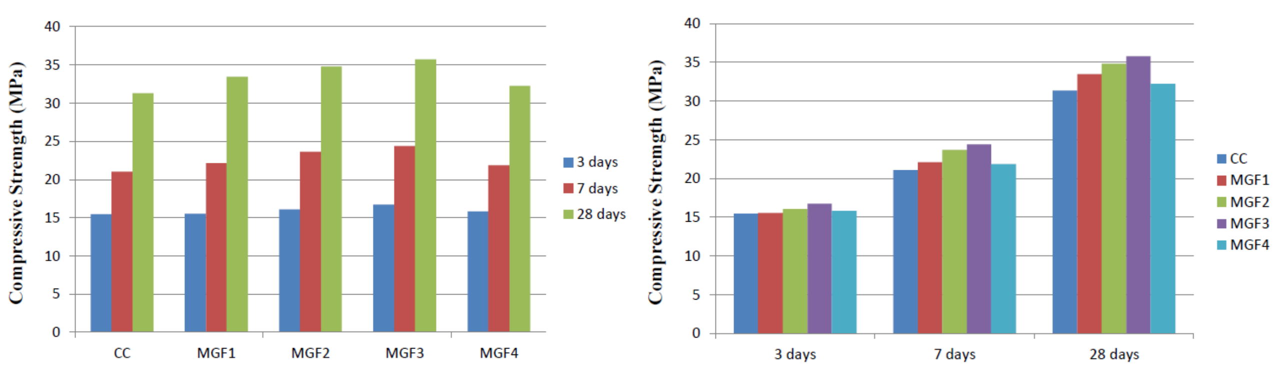

Figure 2: (a) Variation of compressive strength; (b) Comparison of Compressive strength

The maximum value of compressive strength (35.76 MPa at 28 days) was observed at addition of 20% GGBS and 15% fly ash which is 14.14% more than the control mix (31.33 MPa). Based on above observations proportion of GGBS and fly ash as replacement of cement in concrete is chosen as 20% and 15% respectively. This replacement (20% GGBS + 15% Fly ash with cement) is used as optimum dose for producing concrete with further modifications.

Results of GGBS, Fly ash and Steel slag modified mix

The present investigation has been contemplated as a stepping stone only to explore the plausibility of concrete ingredients substitution with prominent and promising industrial waste by-products such as fly ash and GGBS as an equivalent cement replacement material. The present experimentation includes the technical feasibility of replacing the coarse aggregate of a conventional concrete mix with equivalent fractional sizes of steel slag available abundantly as industrial by-products simply getting dumped onto the roadsides, inducing atmosphere pollution and water resources contamination besides paving for land degradation.

The replacement of coarse aggregate with steel slag is done in variable percentages (15%, 30%, 45% and 60%) to investigate its effect on the properties of concrete. The compressive strength test was conducted for 3 different time lapses namely 3 days, 7 days and 28 days.

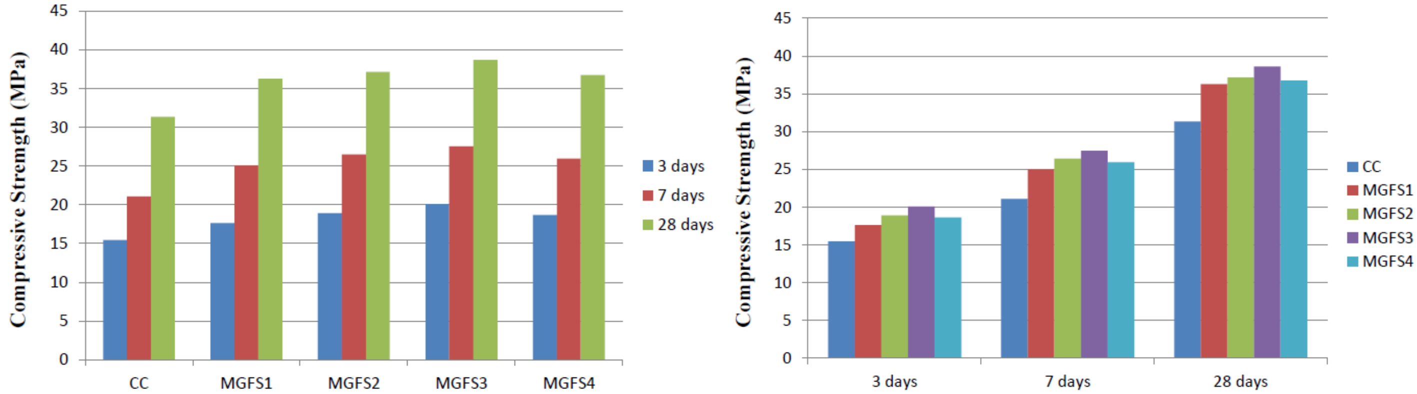

Figure 3: (a) Variation of compressive strength; (b) Comparison of Compressive strength

From the analysis of results it has been found that the addition of steel slag as replacement of coarse aggregate improves the compressive strength of concrete. The comparative analysis shows that compressive strength of steel slag modified concrete (38.64 MPa at 45% replacement) along with 20% GGBS and 15% fly ash as replacement of cement, improves by 23.33% in comparison of conventional control mix (31.33 MPa).

Similar to the compressive strength of GGBS Fly Ash and Steel Slag proportioned concrete the flexural strength has also been tested for various proportions as shown below:

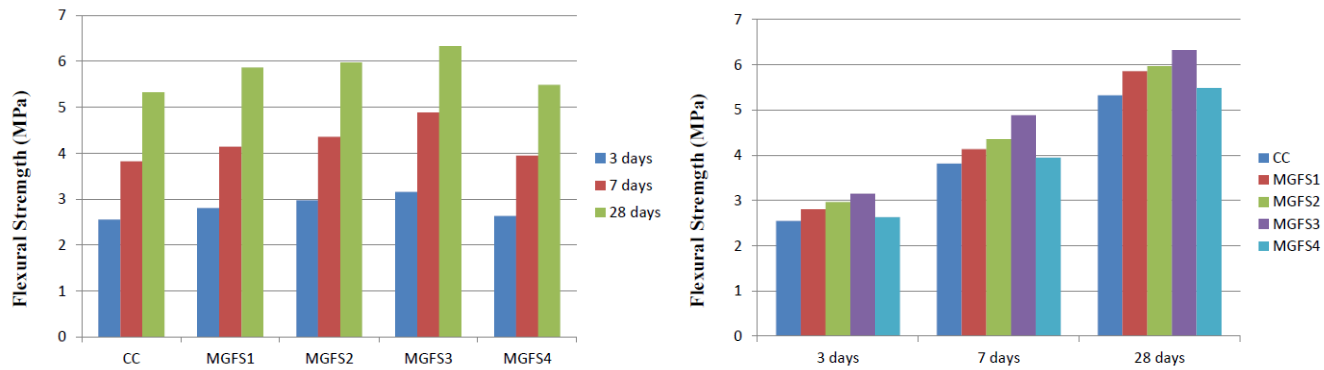

Figure 4: (a) Variation of Flexural strength; (b) Comparison of Flexural strength

The flexural strength test was conducted for 3 different time lapses namely 3 days, 7 days, and 28 days, after the preparation of fresh concrete mix. Even as the range of flexural strength for the control as well as the modified mix ranged from a minimum of 2.55 Mpa after 3 days to a maximum 6.33 MPa after 28 days, the individual modified mix, as well as the control mix, showed the marked difference between the values with respect to the times elapsed. Similar to the compressive strength, the flexural strength also improves with the increased percentages of steel slag up to 45% replacement and then decreases. The maximum value of flexural strength of modified mix (6.33 MPa after 28 days) was observed at 45% replacement which is about 19% higher than the conventional mix (5.32 MPa).

V. CONCLUSION

In order to assess the comparative performance of the improvised concrete obtained from the partial substitution of similar ingredient materials, the strength of concrete was analyzed from the viewpoints of indicators mainly the compressive strength and flexural strength. Following conclusions have been drawn, from the analysis of the experimental results

- The optimal proportioning percentage of GGBS with cement was found to be 20% at which maximum compressive strength of 33.96MPa over a nominal curing spell of 28 days, as against 31.33MPa gained with the conventional concrete mix.
- For the frozen proportion of 20% GGBS further on trial, the substitution of fly ash was found to be 15 % among the various trials of 5 to 20%
- The compressive strength of an optimal combination proportioning of GGBS (20%) with fly ash (15%) yields the highest strength of 35.76MPa which is 14.14% more than the control mix (31.33 MPa)

- The proportioning of steel slag at 45% corresponding to the point of inflection with GGBS (20%) and fly ash (15%) addition within the cement mantle, the maximum compressive strength was found to be 38.64MPa against 31.33MPa with the conventional concrete mix.
- When the experimentation was extended to assess the flexural strength, the maximum strength values obtained was 6.33 MPa after 28 days which is about 19% higher than the conventional mix (5.32 MPa).
- The Slump value observed with the convention concrete mix samples, as well as the improvised concrete mix at w/c ratio of 0.5 %, found to lies in the range of 74 to 97 mm which is very well contained within the prescribed ranger 50 to 100mm.
- The ultimate improvised concrete for this investigation was obtained for 35% partial substitution of the cementitious fractions whereas 45% replacement by steel slag for aggregate.

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