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Experimental Investigation of Granulated Blast Furnace Slag as Fine Aggregate in Concrete

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ABSTRACT: Sustainable materials are currently widely considered and investigated in construction engineering research. There are some examples of sustainable research which are being worldwide used as recycled concrete aggregates, coal fly ash, ground clay brick and pervious paver block system. Also the research work has been conducted on fibre-reinforced concrete, a concrete made of a mix of hydraulic cement, aggregates, water and reinforcing fibres. The increasing demand for concrete in the construction has drastically led to reduction of natural river sand which has led to environment damage thereby causing ecological imbalance. The experimental investigation includes the replacement of fine aggregate i.e. natural river sand. This fine aggregate is replaced by granulated blast furnace slag (GBFS). GBFS is a by-product of iron and steel which is produced in a blast furnace while producing iron and steel. It is a solid waste product which is gets dumped. As it is a waste product, instead of getting dumped GBFS can be used as a fine aggregate which will give the environment a great advantage as solid waste management is a main concern all over the world. This experiment includes the use of GBFS partially replacing fine aggregate in a cement concrete. The variation of replacement of natural river sand with GBFS is of 0%, 30%, 40% and 50% for the compression test. For this test 12 cubes were casted using this variation to check the compression strength of concrete. Further natural river sand was replaced by GBFS in a variation of 25%, 30% and 35%. This variation was carried out for testing of concrete properties i.e. compression, tension and flexure. For compression test, 9 cubes were casted. 12 cylinders were prepared for 0%, 25%, 30% and 35% to conduct split tensile test. For flexure test, 12 beam specimens were casted for 0%, 25%, 30% and 35%. The maximum compression stress, tensile strength and flexure strength this obtained at 30% replacement. The results are presented in the form of Table and Charts.

KEYWORDS: Granulated blast furnace slag, Blast furnace slag, Plain cement concrete, Fly ash, Basic oxygen slag, Target compressive strength

I. INTRODUCTION

1.1 General

Concrete is a mixture of cement, aggregates and water which are economically available. Sand is a most important material used for preparation of mortar as well as concrete. In India, natural river sand (fine aggregate) is commonly used in mortar and concrete. Manufactured sand is somewhat different from natural river sand. The difference is that its surface characteristics are different from that of natural sand. Generally artificial sand is irregular and also it is more porous. Grading varies over a wide range which results in the internal porosity and reduction in workability of concrete. Nowadays there is a scarcity on the availability of river sand due to various reasons such as erosion of rivers and other environmental issues. Now a day's construction is increasing day by day which leads to increase in the demand of the

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river sand which leads to the scarcity of the sand. Hence to meet the demand of concrete, it has become an important job to find an alternative solution for the replacement of sand with another product. Also while finding an alternative solution; it has become an important job not to harm the environment generated by construction industry.

Over a period of time, waste management is becoming the most important task in the world. The rapid growth of industrialization leads to the various kinds of wastes generation which is very harmful to the environment. In present days due to the increasing population leads to increasing demand, due to the increasing demand a high volume of production has also been generated which creates a considerable amount of waste materials which have adverse impact on the environment. During the production of iron and steel, a waste product is generated generally known as blast furnace slag. Without blast furnace slags iron and steel cannot be prepared in blast furnace. The use of granulated blast furnace slag (GBFS) aggregates in the production of concrete by replacing natural aggregates has become very helpful in the construction industry according to environmental as well as economical considerations. The researchers also said that this slag can be used in the construction industry and can be used as a fine aggregate in concrete. Instead of getting dumped as it is a waste product, using it as a construction material will cause less harm to the environment.

1.2 Granulated blast furnace slag

Granulated blast furnace slag is a by-product of iron and steel which is produced in a blast furnace to produce a granular product. It can also be defined as blast-furnace slag is a non-metallic product, which consists of silicates and alumina-silicates of calcium and other bases which can be developed in a molten condition with iron or steel in a blast furnace. Blast furnace slag as an aggregate in concrete provides environmental as well as economical benefits. Many steel industries in India are supplying GBFS as an alternative to sand.

1.3 Types of blast furnace slag

There are many types of blast furnace slag. First type of slag includes blast furnace rock slag which can be used as a coarse aggregate for the construction of buildings but mainly for road construction. It is well known as blast furnace rock slag. Molten slag after leaving the blast furnace is directed towards the ground bays where it air-cools the slag to form a rock-like material. BFS is used for the building construction in the production of concrete used as an aggregate. It is also used in the road construction for the preparation of base and sub-base coarse. It can also be mixed with other materials for mechanically stabilizing as a cementitious material. When compacted, BFS develops a high degree of mechanical particle interlock which results in high shear strength partly due to its rough texture.

Another type of blast furnace slag is granulated blast furnace slag which is made fine like sand of blast furnace rock slag by crushing it with jaw crusher. It is well known as granulated blast furnace slag. Molten slag, after leaving the blast furnace is directed towards a specialised plant which is known as a granulator in which high pressure, high volume and cold water sprays lead to cool the molten slag resulting in the formation of an amorphous, coarse sand sized material. Although the main use of GBFS is in the manufacture of slag blended cement and Ground Granulated Blast Furnace Slag, it can also be used as a fine aggregate where its high strength and hardened properties make it an excellent fine aggregate for concrete and masonry construction units where high strength is required. It can also be used in geo-polymer concrete, as an additive for glass manufacture.

1.4 Important considerations for choosing GBFS

1.4.1 Durability

GBFS can be used in concrete for providing protection against both sulphate attack as well as chloride attack. GBFS can be used in a replacement of 30% to 50% in concrete to protect against chloride attack. In the case of marine environments wherever the concrete is exposed to the environment a large amount of chloride attack occurs, which can be reduced by adding GBFS in concrete as a fine aggregate. Also the bridges, abutments and piers suffer chloride attack due to its surroundings which can be prohibited by using GBFS. Also the corrosion in reinforcements can be reduced by introducing GBFS in the concrete.

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1.4.2 Appearance

GGBS aftermixing with cement gives a very nice lighter white colour which gives a great advantage for the architectural view with low cost. To acquire such type of colour in concrete, GGBS content in cement should be from 50% to 70%. Adding GGBS in cement also produce a smooth surface due to which dirt does not adhere to the surface which reduces maintenance cost.

1.4.3 Strength

Introducing GBFS in a concrete gives a higher amount of strength at a certain replacement amount. The compressive strength of concrete is increased at a certain optimum amount of replacement. Early and later age flexural strength is also slightly increases. It also improves abrasion resistance.

1.5 Applications of GBFS

1. Better workability, making, placing and compaction easier.
2. Lower early age temperature rise, reducing the risk of thermal cracking.
3. Elimination of the risk of damaging internal reactions such as alkali-sulphate reaction.
4. High resistance to chloride, reducing the risk of reinforcement corrosion.
5. High resistance to attack by sulphate and other chemicals.
6. It gives a considerable sustainability benefits.

1.6 Advantages and disadvantages

GBFS has a certain advantages over the construction of building structure. As it is a waste product it has a high environmental benefit by using it in a construction process instead of getting dumped which is much needed in our current situation. The advantages and disadvantages of using GBFS can be stated as below.

1.6.1 Advantages of GBFS

Environmentally friendly: GBFS is considered as an environmentally friendly steel by-product as it reduces solid waste from the environment.

Available free of cost: GBFS can be acquired free of cost from the steel industries or can be getting at a very low cost.

Enhances more durability: Introducing GBFS in a cement concrete gives protection against both sulphate attack and chloride attack which increases durability of structure.

Continued strength gain: Compressive strength increases by increasing GBFS content up to a certain amount. Flexure strength also slightly increases. It also improves abrasion resistance.

Increase life span of building structure: Life span of the structure increases by 50 to 100 years.

Reduces heat in mortar and concrete: During mixing of concrete a large amount of CO₂ is generated which is the cause of heat generation of concrete. Introducing GBFS in concrete reduces this CO₂ generation which reduces heat in mortar as well as in concrete.

Plastic and hardened property: GBFS increases early age plastic and hardened properties in the mortar and concrete. It helps in plastering over the surfaces which require early age hardened property.

Fire resistant: It has a property of fire resistance. It can resist temperature up to 600°C.

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1.6.2 Disadvantages of GBFS

Difficult to crush: Blast furnace slag is so tough to break it into smaller pieces. Hence it is difficult to crush it in fine particles. BFS is crushed by using jaw crusher into fine particles to use it as a fine aggregate.

Available only near industrial area: The main disadvantage of getting GBFS is that it does not locally available in the market. As the steel manufacturing industries mainly situated outside the cities, it is available there only.

1.7 Aim and objective

The aim of the experimental study is to analyse the properties of cement concrete by using the most suitable combination with replacement of natural river sand by using additive like GBFS and its comparative study with conventional concrete.

1. To determine the optimum content of GBFS for the replacement of natural river sand.
2. To check the behaviour of concrete in compression, tension and flexure strength.
3. To study the effect of concrete using GBFS over conventional concrete.

II. LITERATURE REVIEW

2.1 General

The use of sand from Natural River needs to search for an alternative solution due to depletion of sand because of increasing demand in the larger construction industries. Hence the construction industry has to look for an alternate construction material without losing the strength of concrete. To meet the global demand of concrete in the future, it has become a most important job to find sustainable ways of construction. Sustainable construction means to reduce the negative environmental impacts generated by construction industry. The rapid growth of industrialization leads to various kinds of wastes generation which are very dangerous to our environment. Granulated blast furnace slags are one of the best sustainable solutions as they are obtained as solid wastes generated by industry. Hence it reduces the solid waste disposal problem and other environmental issues.

2.2 Review of literature

A. S. Al-Gahtani et al. (1994) studied a design for the evaluation of the relative corrosion of concrete produced by using Portland cements containing 2% to 14% C_3A cement with and without 50%, 60%, 70%, and 80% cement replacement by blast-furnace slag (BFS). The results show that BFS blended-cement concretes had a slightly high corrosion resistance performance. The best protection for corrosion was found to be at 50% BFS cement. Replacement level of 50% shows better results as compared to plain cement concrete. The optimum percentage of replacement of cement is 50% blast furnace slag. After that the corrosion protection seems to be decrease for further replacements [1]. K. Ganesh Babu and V. Sree Rama Kumar (2000), makes an effort to check the efficiency of concrete at the age of 28 days using GGBS at various replacement levels. The GBFS cement is replaced in concrete in the percentage of 10% to 80%. For 28 days evaluation, the overall strength efficiency factor 'k' varies from 1.29 to 0.70 for the replacement of 10% to 80%. The overall strength of concrete varies in from of 20MPa to 100MPa by replacing GGBS 10 to 80% [2]. Gengying Li and Xiaohua Zhao (2003) presents a laboratory investigation by using the combination of fly ash (FA) and ground granulated blast furnace slag (GGBS) over the properties of high strength concrete. A study was carried out using FA and GGBS on the concrete, control Portland cement concrete and high volume FA high strength concrete. Tests were carried out for the testing of compression strength of concrete and H_2SO_4 attack. After testing it was observed that GGHFC has achieved an early age compressive strength, while maintaining long term strength more than PCC. GGHFC is more durable than that of HFAC as well as PCC for H_2SO_4 attack. GGHFC weight change is 8% after 50 weeks exposure to 2% H_2SO_4 solution. The relative strengths of GGHFC, HFAC and PCC decreases because of the absence of calcium and the extensive corrosion of hardened cement in H_2SO_4 solution while, the decreasing rate of GGFAC is the lowest [3].

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Cengiz Duran Atis and Cahit Bilim (2007) reports a laboratory investigating the compressive strength of ground granulated blast furnace slag (GGBFS) of concrete carried under wet and dry curing conditions. In this study, a total number of 45 concretes which includes control specimen of normal Portland cement (NPC) concrete and GGBFS concrete were casted with different water-cement ratios of 0.3, 0.4 and 0.5. Four partial GGBFS replacement percentages of 20%, 40%, 60% and 80% were applied. A typical plasticizer that is hyper plasticizer is used in concrete at various quantities to keep a constant workability. Twelve cube specimens were produced, then six cubic samples were cured at temperature of $22 \pm 2^\circ\text{C}$ with 65% relative humidity (RH), and other six cube specimens were cured at temperature of $22 \pm 2^\circ\text{C}$ with 100% RH for 112 days for compression test. On the basis of compressive strength the comparison is made between GGBFS concrete and NPC concrete. GGBFS concretes were also compared between themselves. After analysing the results it is observed that compressive strength of GGBFS concrete cured at temperature 65% RH was more than that of NPC concrete [4].

Isa Yuksel et al. (2007) presents an investigation over affecting the concrete durability by using bottom ash (BA), granulated blast furnace slag (GBFS), and combination of both of these materials as fine aggregate in cement concrete. Test on durability property of concrete was conducted and the results were evaluated comparing with conventional concrete. Three types of concrete were produced by replacing GBFS, BA and GBFS + BA were replaced with fine aggregate. The replacement percentages were of 10%, 20%, 30%, 40% and 50%. Five test groups were created for each of percentage replacements. The results concluded that GBFS and BA affect some of the durability properties of concrete which were used as a fine aggregate. Surface abrasion due to high temperature is affected positively. The most optimum content of was found out to be 20%. Hence it is possible to produce durable concrete by using GBFS and BA as fine aggregate [5].

Isa Yuksel et al. (2007) discuss about the research which is aimed at studying the use of bottom ash (BA) and granulated blast-furnace slag (GBFS) in producing cement concrete elements. Concrete element includes briquettes; paving blocks and kerbs specimens containing GBFS and BA replacing fine aggregate were allowed to cast in the laboratory. Tests conducted for these specimens include durability and mechanical properties of concrete. For briquette specimens, tests conducted were of unit weight, compression strength and freeze-thaw test. For paving blocks, compression strength, freeze-thaw, water absorption and surface abrasion tests were conducted. And for kerb specimens surface abrasion and flexural tensile strength tests were conducted. According to test results, compression strength decreases slightly. Improvement was found out over durability characteristics such as resistance of freeze-thaw and abrasion. As the replacement of BA for briquettes increases, resistance against freeze-thaw decreases. The optimum replacement percentage for BA is 30%. In case of paving blocks, as GBFS ratio increases, water absorption increases however compression strength and freeze-thaw resistance decreases. The flexural strength of kerb specimens increases at a certain limit. The optimum percentage for GBFS replacement is 25%. The results showed that usage of partially fine aggregate of these industrial by-products has more beneficial effects on durability characteristics of plain concrete elements [6].

Okzan Sengul and Mehmet Ali Tasdemir (2009) investigate the compressive strength of concrete. Ordinary Portland cement is replaced partially by using finely ground granulated blast furnace slag and finely ground fly ash. Two types of concrete were prepared having water/cement ratios of 0.60 and 0.38. Portland cement was replaced in the manner of 50% fly ash, 50% blast furnace slag and combined replacement of 25% fly ash + 25% blast furnace slag for both water/cement ratios. Compressive strength of concrete by adding pazzolans was less at a water/cement ratio of 0.60 as compared to Portland cement. At the water/cement ratio of 0.38, the compressive strength of concrete reduction was less as compared to the water/cement ratio of 0.60. Compressive strength of concrete produced with 50% slag shows better results than that of Portland cement concrete [7].

Juan Lizarazo Marriaga et al. (2011) presents an investigation on the compressive strength of concrete with the influence of steel basic oxygen slag (BOS) and ordinary Portland cement; along with that the hydration mechanism of ground granulated blast furnace slag (GGBS) pastes is also evaluated. Properties to be observed in this experiment were

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compressive strength, mineralogical changes because of hydration, initial and final setting times, alkalinity of the raw materials were measured on binary and ternary mixes. On the replacement level of steel slag and OPC on the GGBS binder, the influence of compressive strength has been studied in detail. It was observed that up to 60% there was a slight reduction in strength. Further replacement has a great reduction in strength of 20%. The optimum replacement of GGBS is of 40%. After that a slight reduction of strength is about 6%. The steel slag used in this experiment can be used as an activator for GGBS. No expansion was found out in the concrete mixes observed after test. It gives encouraging results for the use of combined mixture of steel and blast furnace slag in construction process [8].

RafatSiddique and DeepinderKaur (2012) deal with the mechanical properties of concrete produced by using ground granulated blast furnace slag (GGBFS) which was subjected to temperatures up to 350°C. For this purpose, concrete was designed for the compressive strength of 34 MPa using GGBFS as a partial replacement of cement. Cylindrical specimens of size 150 x 300 mm were casted and then they were subjected to elevated temperatures of 100°C, 200°C and 350°C. The tests were performed for mass loss, compressive strength, splitting tensile strength, and modulus of elasticity. This experiment on the concrete which is exposed to temperature up to 350°C gives some important data on the properties of concrete. This paper concludes that in areas of elevated temperatures, concrete containing GGBFS can possibly be used in such cases. There was no very significant deterioration of the mechanical properties of the concrete between temperature of 27°C and 100°C. Even after the applied temperature of 350°, reduction in the values of compressive strength, splitting tensile strength and modulus of elasticity were remained lower than 40% than that of initial value. The mass loss is not very significant at temperatures between 200°C and 350°C. From the results it can be easily concluded that up to 20% GGBFS could be suitably used in concrete designed for structures [9].

OthmaneBoukendakdji et al. (2012) carried an experimental investigation on the granulated blast furnace slag along with two types of superplasticizers over the properties of self-compacting concrete (SCC). Blast furnace slag was replaced in the percentage of 10%, 15%, 20% and 25% with cement in a controlled SCC. Poly-carboxylate based superplasticizer and naphthalene sulphate based superplasticizers were used in this experiment. The tests to be carried out for the modified slump test, and compressive strength. After analysing the results it was observed that the poly-carboxylate based superplasticizer concrete give more workability and higher compressive strength, at all ages, than that of naphthalene sulphate based superplasticizer. By introducing blast furnace slag as a replacement to cement was found to be very beneficial to fresh self-compacting concrete. It was observed that there is an improvement of workability for up to 20% of slag content. The optimum content was found to be 15%. With 15% and 20% of slag content, workability retention of 45 min was obtained using a poly-carboxylate based superplasticizer. With an increase in the slag content, compressive strength was found to be decreased [10].

MuctebaUysal et al. (2012) presents an experimental investigation over the performance of self-compacting concrete (SCC) subjected to high temperatures. In this experiment, Portland cement is replaced by fly ash (FA) and granulated blast furnace slag (GBFS) in various proportions with and without polypropylene (PP) fibres and the PP fibre content was 2 kg/m³. Specimens at the age of 56 days old, they were subjected to elevated temperatures of 200, 400, 600 and 800°C. Afterwards to determine the weight loss and compression strength, tests were conducted. After the specimens were exposed to elevated temperatures, observations for surface crack were made and also the change in the ultrasonic pulse velocity was determined. After the specimens were heated up to 600°C, strength loss was observed for all the concrete specimens especially for concretes that contained PP fibres. In case of SCC mixtures at a temperature greater than 400°C, the compressive strength is lost in a significant amount. Based on the test results, it can be concluded that the performance of FA concrete is better than the GBFS concrete [11].

XiaoluGuo and Huisheng Shi (2013), conducted an experiment over the feasibility of glass powder as an admixture along with GGBFS in the mortar. Study takes place on the effects of glass powder with the requirement of water for the normal consistency, compressive strength, setting times and hydration products of cement paste. It is observed that the glass powder decreases the normal consistency water requirement. Also the setting time of cement paste is decreased. As the age of curing increases, the compressive strength of mortar increases with the addition of combined admixture [12].

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T. Raghavendra and B. C. Udayashankar (2014) conducts an experimental study by using an industrial by-product i.e. ground granulated blast furnace slag in CLSM. CLSM (Controlled Low Strength Material) is defined by American Concrete Institute is a typically self-flowing material which consists of Portland cement, fine aggregates, supplementary cementing materials and water. Mix proportions were made for CLSM and GGBS and were allowed to test for the flow and compressive strength. The compressive strength increases as the water cement ratio decreases. It is possible at the specific water content to gain a required specified flow as well as strength [13].

MeriemSenani et al. (2014) conduct an experiment by using the crystallized blast furnace sand slag in the production of concrete. The natural sand was replaced partially and completely by the crystallized sand slag in the production of concrete. The concrete was prepared on the basis of mechanical properties, compressive strength, tensile strength as well as durability. The experimental results of concrete by replacing natural sand with crystallized sand slag were compared with experimental results of conventional concrete. By analysing the results, they conclude that the high compactness in concrete can be achieved by replacing sand slag in a suitable proportions which increases compressive and tensile strength with 42% and 35% respectively. The use of sand slag in the production of concrete helps in minimizing the amount of cement in the concrete production and increase in the mechanical characteristic of concrete. The use of sand slag also gives an economical benefit in reducing the cost of concrete as well as environmental benefit in reducing the waste. The study in this work shows the benefit of use of crystallized sand slag in the production of concrete compared to the ordinary concrete. So this slag can be used in the production of concrete [14].

Gaurav Singh et al. (2015) conducts an experimental work on the possibility of using GBFS by replacing natural sand as a fine aggregate in concrete. In this paper an experiment is done to check the variation in compressive strength of concrete by replacing GBFS in different contents. Cost analysis is also done to suggest the optimum content of GBFS. During this experiment, sand is replaced by GBFS in variations of 10% to 100% and its effect on compressive strength is also studied. Economic study is also done along with that to suggest the most optimum percentage of GBFS for the replacement of sand. After analysing the results he concludes that the compressive strength of concrete increases with increase in GBFS content up to a certain percentage and after that it decreases. The most optimum GBFS percentage to be used in normal conditions is from 40% to 50% and for marine conditions it is from 50% to 60% considering both strength and economy factor [15].

Rakesh Kumar Patra and BibhutiBhusanMukharjee (2015) explores an alternative solution for fine aggregate by investigating the effect of granulated blast furnace slag (GBFS) as a fine aggregate by replacing natural fine aggregate on the properties of concrete. The water/cement ratio selected for the preparation of concrete is 0.45 and 0.5. In this experiment, GBFS replacing natural sand by 20%, 40%, and 60%. Various properties of concrete such as compressive strength, splitting tensile and flexural strength were tested for the age of 7, 28 and 90 days. According to results, the compressive strength of concrete at later stage increases with an increasing amount of GBFS content. The optimum content for the replacement of GBFS for compressive strength is found to be of 60%. The improvement in tensile strength of concrete is resulted due to GBFS as replacement of fine aggregate. Both the split tensile as well as flexural strength values show an increasing value up to 60% replacement [16].

ErdogenEzboyand Mustafa Erdemir(2016) review a literature on the efficiency of GGBFS on the properties of concrete and mortar. Tests conducted on workability, setting time, bleeding, slump loss, segregation over the fresh concrete. Strength gain, modulus of elasticity, creep, shrinkage, alkali-silica reaction and sulphate attack are tested on hardened concrete. Results state the improvement in workability, modified segregation and positive slump loss. Compressive strength increases drastically after 40 days. Increase in early and later age flexure strength. Improvement in abrasion resistance. Increases sulphate as well as alkali-silica reaction [17].

K Ramakrishnan et al. (2016)presents an investigation on the use of crushed waste glass powder (GP) and granulated blast furnace slag (GBFS)combined by partiallyreplacingcement. The mechanical properties observed were compressive strength, flexural strength and split tensile strength. Replacement of cement by GP was from 5% to 45%

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with an increase rate of 5% as well as GBFS was from 45% to 5% with an increase rate of 5%. 10 different combinations were studied in total at three different ages of 3, 7 and 28 days. The optimum mix was selected from compressive strength of different ages of concrete. The combined mix was (sand + GP + GBFS) 50:15:35 and 50:20:30. The test results conclude that the compressive strength was increased by 44.20% with 50:15:35 and 43.08% with 50:20:30. Similarly the split tensile strength of the combined mix with 50:15:35 and 50:20:30 increased the strength value by 9% and 7.6% respectively. The flexure test for concrete shows increase in strength by 6.3% and 1.6% with 50:15:35 and 50:20:30 respectively. The optimum percentage of replacement of GP and GBFS was found out to be 15% and 35% respectively [18].

Aliakbar Gholampour and Togay Ozbakkaloglu (2016) presents an experimental investigation over the properties of concrete which have ternary binders containing high volume Class-F FA and GGBS by replacing cement up to 90%. 15 numbers of batches in total of concrete were prepared based on FA, GGBS, and cement. Experimental tests were conducted on the properties of concrete such as density, workability, compressive strength, elastic modulus, splitting tensile strength and flexural strength. After analysing the results it was concluded that the compressive strength decreases with an increase in the FA content from 50% to 90% of concrete containing FA. The compressive strength of conventional concrete shows same results as concrete containing GGBS up to 90% at age of 28 days. It was observed that ternary mixes having 70% replacement ratio with relative FA to GGBS ratio of 1:2 and 50% replacement ratio with FA to GGBS ratio of 1:1 shows a similar 28 and 90 days compressive strength than that of conventional concrete. A further increase in the replacement ratio and ternary mixes results in a decrease in the compressive strength. The results also show that GGBS mixes develop a slightly higher 28 day elastic modulus than that of conventional concrete mix. The flexural and splitting tensile strength of ternary mixes are lower than that of conventional concrete. Ternary mixes of 90% and FA to GGBS ratio of 1:1 develop 25% lower flexural strength and 24% lower splitting tensile strength compared to those of conventional concrete [19].

III. PROBLEM STATEMENT AND METHODOLOGY

3.1 General

Now a day's construction has been increased so fast that it needs a lot of resources for its execution. A lot of construction needs a lot of concrete. Fine aggregate i.e. natural river sand is an important ingredient of concrete. Hence there is so much demand for the natural river sand for the process of construction. As the demand increases, depletion of natural river sand has been occurred. Due to this there is an environmental restriction has been conducted on the use of natural river sand. Hence to meet the demand of construction, an alternative solution of river sand needs to be finding out.

3.2 Problem statement

Most of the work takes place on replacement of cement in the preparation of concrete. Also Natural River sand is decreasing day by day. Due to this artificial sand is getting used now a day for the construction process in the preparation of concrete. Artificial sand is used as an alternative to Natural River sand. But using GBFS instead of artificial sand will require less energy as it is a waste product. Hence this will also help in reducing solid waste. Also it is cheaper than artificial sand. In this experiment, Natural River sand is replaced by using GBFS as a fine aggregate in a specific content to reduce the use of Natural River sand.

3.3 Significance of choosing the problem

Granulated blast furnace slag (GBFS), is a by-product of the steel industry, has been widely used as a fine aggregate that is specified as a promoting green environment for the global environment. Hence it reduces the solid waste disposal problem and other environmental issues. Granulated blast furnace slag (GBFS) has been the best solution for the replacement of fine aggregate as they are obtained as solid wastes generated by industry. GBFS has been used extensively as a replacement of fine aggregate in concrete to improve durability, strength and high performance

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concrete which brings environmental as well as economic benefits together. The use of alternative aggregate is considered as an important step for solving the problem of the depletion of the natural sand.

It is well known that the large production of Portland cement consumes a huge amount of energy and is hence a primary source of CO² and atmospheric pollution. Thus, the use of GBFS can be a less expensive and eco-friendly solution to the problem of emissions of concrete production.

3.4 Relevance to Construction Industries

Recent concrete construction industries focuses more on using environmentally friendly concrete to build taller structures and with smaller structural elements. The concrete needs to achieve both high early strength and ultimate strength capacity to improve the construction process. Other than the mechanical properties of the concrete, the durability properties of the concrete also should have been high for the longer life span of the building. Introducing solid waste such as Granulated Blast furnace Slag (GBFS) has been considered to improve certain concrete properties. In comparison to manufacturing sand, the production of GBFS requires less energy. Thus concrete with GBFS is a more environmentally friendly concrete compared to manufacturing sand.

3.5 Methodology

The experimental study was carried out in three phases. The first phase of the experiment was to check the compression strength on the cubes of the trial concrete mix which was necessary to adopt for mix design. The second phase includes preparing a concrete replacing natural river sand with different GBFS percentage to check on which GBFS percentage the maximum compression strength will achieve. The third phase includes adopting the proper variation to further split tensile test and flexure test.

1. A mix design for M25 grade of concrete is adopted for trial. Cubes were casted for curing period of 28 days. These cubes were tested for compression strength. By analysing the results the final mix design was adopted.
2. A total 9 number of cubes were casted replacing natural river sand by using GBFS by 30%, 40% and 50% in order to test the cube specimens for the maximum compression strength. By analysing results further replacements were done.
3. Further 9 cubes were casted by replacing Natural River sand using GBFS by using variations of 25%, 30% and 35% for the compression test. After the results these variations were adopted.
4. Further cylinder and beam were allowed to cast for the variation of 25%, 30% and 35. A total number of 12 cylinders and 12 beams were casted for split tensile test and flexure test respectively. After the test an optimum amount of GBFS as a fine aggregate was concluded.

IV. CONCRETE MIX DESIGN

4.1 Introduction

Concrete mix design can be defined as the process of selecting ingredients suitable enough for the production of concrete and also to determine their relative amounts with an aim of producing concrete of the required strength, durability as well as workability as economical as possible. Mainly the concrete mix design is done to check the compressive strength of the concrete. Generally, the compressive strength of concrete is considered as an index of other properties which depends upon factors such as quality of cement, quantity of cement, aggregates (coarse and fine aggregates), water to be added, batching and mixing, placing, compaction and curing. The cost of concrete is totally dependent over the cost of materials which we are going to add in it. Also it depends on the plant and labour charges. The variation in the cost of concrete mainly comes from the fact is that the cement is much costlier than that of aggregates. Thus the main motive of the mix design is to produce a concrete with not more than required the quantity of cement. Also higher quantity of cement causes shrinkage and cracking in the structure.

Concrete mix design is basically done by suitable proportioning the various ingredients required for the concrete production. Requirement of concrete mix design basically includes the minimum compressive strength required for the structure to stand. Maximum water-cement ratio, maximum cement content for obtaining the durability of the structure. Proper cement content to avoid shrinkage and cracking in the structure. Factors to be considered while calculating mix design includes the grade required for the characteristic strength of the concrete. Type of cement influencing the

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compressive strength of concrete. Maximum nominal size of aggregates to be used in concrete as specified by IS 456:2000.

The Bureau of Indian Standards (BIS) has given us a recommended guideline specified for concrete mix design which was published in IS 10262:1982 for the proportioning of concrete mixes. It is then revised in the year 2009. During the experimental study of this project, the concrete mix design is adopted from Indian Standards of concrete mix proportioning - guidelines first revision (IS 10262:2009) for the M25 grade of concrete.

4.2 Concrete mix design

The concrete mix design is done according to IS 10262:2009 for the mix proportion of the ingredients in the concrete.

4.2.1 Data required

Data required for the concrete mix design is as follows:

Table 4.1 Data required

SN	Description	Values
1	Grade designation	M25
2	Type of Cement	OPC (53 grade)
3	Max nominal size of aggregates	20 mm
4	Water-cement ratio	0.45
5	Workability	75mm (slump)
6	Exposure condition	Mild
7	Type of aggregates	Crushed angular aggregates
8	Sp. Gravity of cement	3.15
9	Sp. Gravity of C.A.	2.79
10	Sp. Gravity of F.A.	2.65
11	Fine aggregate	Grade zone II

4.2.2 Target strength of mix proportioning

The target compressive strength of the mix design can be calculated by using following formula:

$$f_{ck}' = f_{ck} + 1.65 s \quad (4.1)$$

From **Table 1** of IS 10262:2009, Standard deviation, $s = 4 \text{ N/mm}^2$

Therefore,

$$\begin{aligned} \text{Target compressive strength} &= 25 + 1.65 \times 4 \\ &= 31.6 \text{ N/mm}^2 \end{aligned}$$

4.2.3 Selection of water cement ratio

According to IS 10262:2009 from **Table 5**

The maximum water cement ratio for mild exposure RCC = 0.55

For trials, take water cement ratio as 0.45

4.2.4 Selection of water content

From IS 10262:2009, **Table 2**, the water content for 20mm size of aggregate is 186kg for 25 to 50mm slump.

Water content for 75 mm slump is,

$$\begin{aligned} &= 186 + \frac{6}{100} \times 186 \\ &= 197 \text{ kg.} \end{aligned}$$

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4.2.5 Calculation of cement content

Cement can be calculated by:

$$\begin{aligned}\text{Cement content} &= \frac{\text{Water content}}{\frac{\text{w/c ratio}}{197}} \\ &= \frac{197}{0.45} \\ &= 438 \text{ kg/m}^3\end{aligned}$$

4.2.6 Volume of C.A. and F.A.

According to IS 10262:2009, from **Table 3** volume of coarse aggregate per unit volume of total aggregate for 20mm aggregate and grade zone II is given by:

Volume proportion of C.A. = 0.62

Volume proportion of F.A. = 1 – 0.62

$$= 0.38$$

4.2.7 Mix calculation per m³ of concrete

a. Volume of concrete = 1

$$\begin{aligned}\text{b. Volume of cement} &= \frac{\text{Mass of cement}}{\text{Sp. gravity of cement}} \times \frac{1}{1000} \quad (4.2) \\ &= \frac{438}{3.15} \\ &= 0.139 \text{ m}^3\end{aligned}$$

$$\begin{aligned}\text{c. Volume of water} &= \frac{\text{Mass of water}}{\text{Sp. gravity of water}} \times \frac{1}{1000} \quad (4.3) \\ &= \frac{197}{1} \times \frac{1}{1000} \\ &= 0.197 \text{ m}^3\end{aligned}$$

$$\begin{aligned}\text{d. Volume of aggregates} &= [a - (b + c)] \\ &= [1 - (0.139 + 0.197)] \\ &= 0.664\end{aligned}$$

$$\begin{aligned}\text{e. Mass of C.A.} &= e \times \text{Volume of C.A.} \times \text{Sp. Gravity of C.A.} \times 1000 \\ &= 0.664 \times 0.62 \times 2.79 \times 1000 \\ &= 1111.54 \text{ kg/m}^3\end{aligned}$$

$$\begin{aligned}\text{f. Mass of F.A.} &= e \times \text{Volume of F.A.} \times \text{Sp. Gravity of C.A.} \times 1000 \\ &= 0.664 \times 0.38 \times 2.65 \times 1000 \\ &= 703.84 \text{ kg/m}^3\end{aligned}$$

4.2.8 Final mix proportion for M 25 grade of concrete

The mix proportion calculated above can be stated as **Table 5.2**

Table 4.2 Mix proportion

Description	Cement	Fine Aggregate	Coarse Aggregate	Water
Mix proportion (by weight)	1	1.60	2.53	0.45
Quantities of materials (in kg/m ³)	438	703.84	1111.54	197

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4.3 Cube compressive strength

The concrete mix design is checked for the compression strength. For this purpose cubes were casted in order to test them for the compression strength. A total number of 6 cubes were casted. Three cubes were casted for 7 days of curing test and three cubes were casted for 28 days curing test. Average of three cubes will be considered for the compression strength of these cubes. The test was carried out in an UTM machine of 1000 KN capacity. The test results are shown in Table 5.3

Table 4.3 Compression test results

Sr. No.	Days	Load (KN)	Compressive stress (MPa)	Average Compressive stress (MPa)
1	7	420.0	18.63	19.35
2		454.7	20.21	
3		432.6	19.23	
4	28	747.2	33.21	33.09
5		731.7	32.52	
6		754.6	33.54	

4.4 Casting of Specimens

Cubes of size 150mm x 150mm x 150mm had to be casted as available standard mould sizes. At a time 3 cubes were casted in the laboratory itself. First of all the moulds used for casting were oiled from inside so that the concrete will not stick to the surface. Then nuts and bolts were checked, whether well tightened or not. Immediately after mixing, the concrete filled in mould in three layers. Each layer was tamped 25 numbers of time for proper compaction of concrete. A total number of 18 cubes were casted.



Fig 4.2 Compaction of concrete

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Fig 4.3 Concrete in moulds

Cylinders casted are of size 150mm x 300mm. Moulds of size 150mm x 300mm were available at the laboratory. At a time 3 cylinders were casted in the laboratory. Moulds used for casting purpose were oiled from inside so that the concrete will not stick. Then nuts and bolts were checked, whether well tightened or not. Immediately after mixing, the concrete filled in the mould in three layers. Each layer was tamped 25 numbers of time with 16mm diameter and 0.6m long tamping rod. A total number of 12 cylinders were casted.



Fig 4.4 Casting of cylinder

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Fig 4.5 Finished cylinders

Beams of size 150mm x 150mm x 700mm had to be casted. A standard size mould of beam was available in the laboratory. At a time 3 beams were casted. At first all the moulds used for casting purpose were oiled from inside so that the concrete will not stick to the surface. Then nuts and bolts were checked if well tightened or not in case the concrete will not come out. Immediately after mixing the concrete, the moulds were filled in three layers. Each layer was tamped 25 times with tamping rod. A total number of 12 beams were casted.

V. RESULTS AND DISCUSSIONS

Results and discussions include the test results which were carried out during the experiment. In this experiment cube specimen, cylinder specimen and beam specimen were prepared for the testing of compression, split tensile and flexure test respectively. In this chapter, test results were shown in Table as well as in Graphical format.

5.1 Test Results

5.1.1 Compression test

At first compression test was conducted on the cubes of GBFS replacement 30%, 40%, and 50% with sand. The compression tests on cubes carried out at age of 28 days for the conventional as well as for different replacement percentages as shown in **Table 5.1**. For each variation three specimens were prepared and the average of three test results is stated as below. The maximum compressive stress is for the replacement of 30% slag. Hence to check further, cubes were casted for 25%, 30% and 35% replacement of GBFS with sand. The test results were obtained is shown in **Table 5.1**

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Fig 5.1 Testing of cube

The test results show that the maximum compressive stress obtained is for 30% replacement of GBFS with natural sand. A bar chart is stated below to show the test results in **Figure 5.2**. The Figure shows the different compressive stresses for different variations in concrete along with conventional concrete. For each variation, an average of three test results is shown below.

Table 5.1: Test results of compression test

SN	Cube Specification	Load (KN)	Compressive stress (MPa)	Average Compressive stress (MPa)
1	CC-1	747	33.2	33.63
2	CC-2	756	33.6	
3	CC-3	767.25	34.1	
4	C25-1	552.82	24.57	27.36
5	C25-2	612.45	27.22	
6	C25-3	681.97	30.31	
7	C30-1	823.5	36.6	37.60
8	C30-2	865.8	38.48	
9	C30-3	848.92	37.73	
10	C35-1	766.8	34.93	34.44
11	C35-2	751.95	34.1	
12	C35-3	771.97	34.31	
13	C40-1	766.8	34.08	33.87
14	C40-2	767.25	33.42	
15	C40-3	771.97	34.13	
16	C50-1	684.22	30.41	30.28
17	C50-2	672.1	29.87	
18	C50-3	688.2	30.58	

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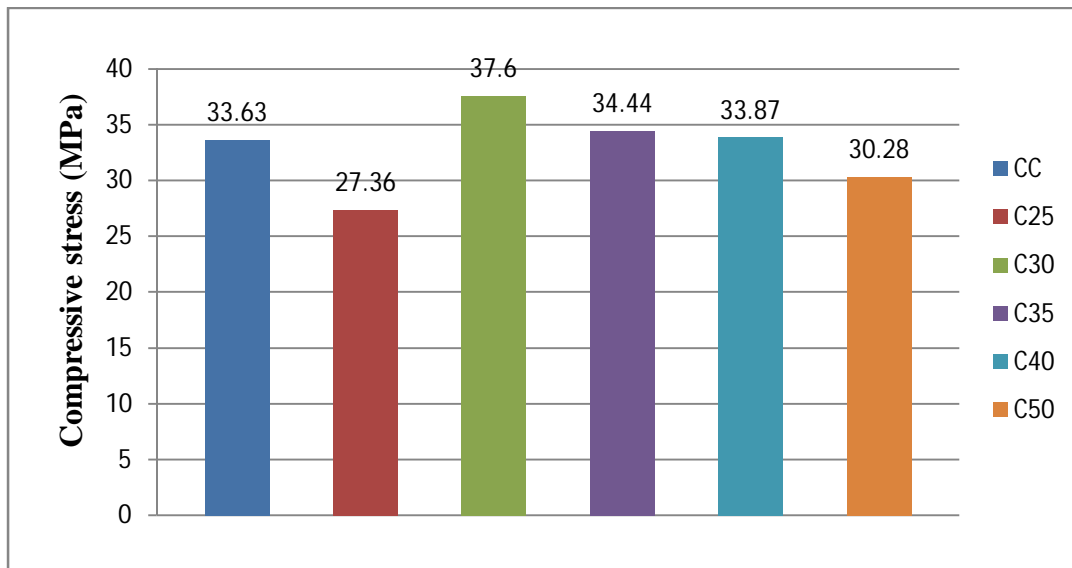


Fig 5.2 Graphical representation of compression test results

5.1.2 Split Tensile test

Split tensile test was carried out for the variation of 25%, 30% and 35%. For each variation 3 cylindrical concrete specimens were casted. The test was carried out for the age of 28 days. The test was carried over UTM machine. The test is carried out by placing a cylindrical specimen horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder, along the vertical diameter. The maximum applied load indicated by the testing machine at failure was recorded and stated in **Table 5.2**



Fig 5.3 Testing of cylinder

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Table 5.2 Test results of tensile test

Sr. No.	Cylinder Specification	Tensile Strength (MPa)	Average Tensile Strength (MPa)
1	CCYL-1	1.59	1.59
2	CCYL-2	1.55	
3	CCYL-3	1.65	
4	CYL25-1	1.06	1.01
5	CYL25-2	1.01	
6	CYL25-3	0.96	
7	CYL30-1	1.97	1.95
8	CYL30-2	1.95	
9	CYL30-3	1.95	
10	CYL35-1	1.76	1.77
11	CYL35-2	1.77	
12	CYL35-3	1.80	

The test results show that the maximum stress obtained is for 30% replacement of GBFS with natural sand. Hence the optimum percentage of GBFS replacement for natural river sand is of 30%. A bar chart is shown to check the test results in **Figure 5.4**.

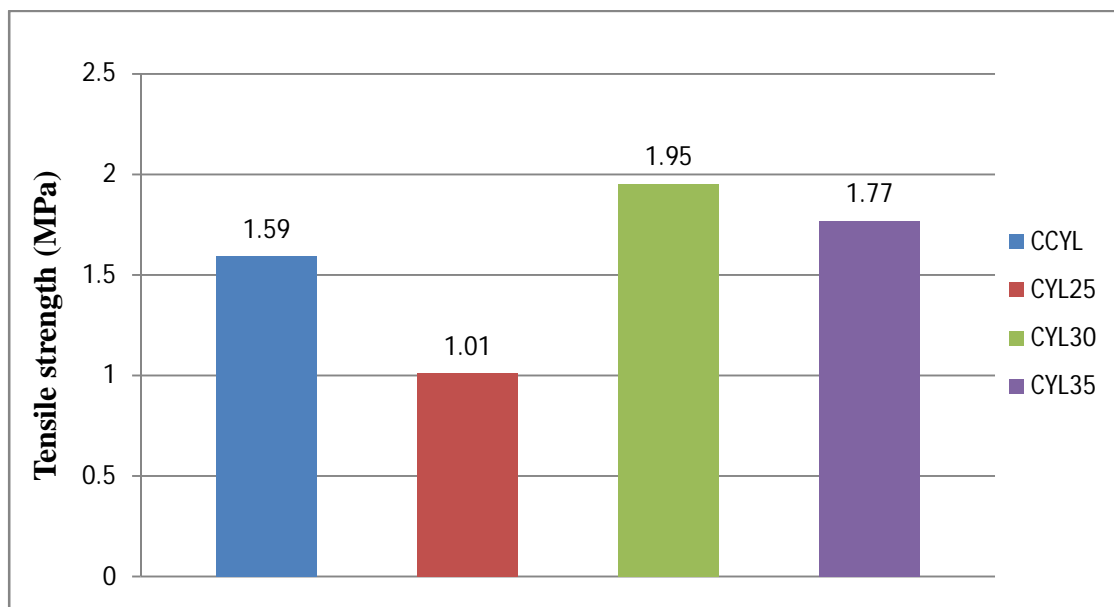


Fig5.4 Graphical representation of split tensile test results

5.1.3 Flexure test

The experimental setup is based on the four-points bending test on Universal testing machine. The specimen is then placed in the machine in such a manner that the load is applied to the uppermost surface as cast in the mould, along two lines spaced 20 cm apart. The axis of the specimen is carefully aligned with the axis of the loading device. The load is increased until the specimen fails, and the maximum load applied to the specimen during the test is recorded. The

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deflection at the centre of beam is measured by using dial gauge. The summary of results for flexure test on beams is provided in below **Table 5.3**

Table 5.3: Test results of flexure test

Sr. No	Beam specification	Ultimate load (KN)	Average deflection (mm)	Flexure Strength (MPa)	Avg. flexure strength (MPa)	Mode of Failure
1	CB-1	75.9	3.695	15.74	14.12	Flexure
2	CB-2	72.7	3.61	14.95		Shear + Flexure
3	CB-3	72.1	2.495	11.69		Flexure
4	B25-1	65.6	2.58	10.97	11.74	Shear + Flexure
5	B25-2	65	2.53	10.08		Shear + Flexure
6	B25-3	68.4	2.69	14.18		Flexure
7	B30-1	83.8	4.38	17.38	16.92	Flexure
8	B30-2	79.3	2.865	16.92		Flexure
9	B30-3	81.6	3.89	13.39		Flexure
10	B35-1	78.3	2.88	16.24	15.3	Flexure
11	B35-2	75.5	2.78	13.22		Shear + Flexure
12	B35-3	79.3	3.14	16.44		Flexure

From these results we can say that the maximum load is taken by the beam with 30% replacement of GBFS with natural sand. The graphical representation of test results is shown in **Figure 5.5**. The graph shows the average test results for each of the variations in concrete.

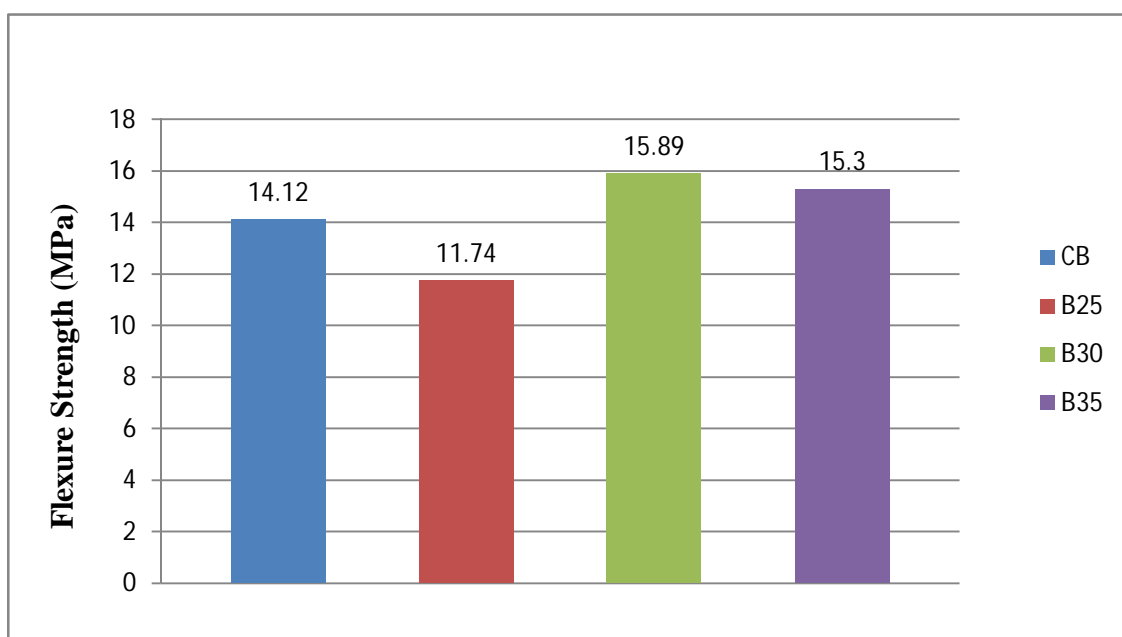


Fig 5.5: Graphical representation of flexure test results

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After the testing of beam specimens, the loads with their deflections were recorded. Using dial gauges on both sides of the beam, deflections were recorded. These deflections were recorded by an increasing load of 5KN. From these results, a graph of load-deflection curves was obtained. This graph is shown in **Figure 5.6** below.

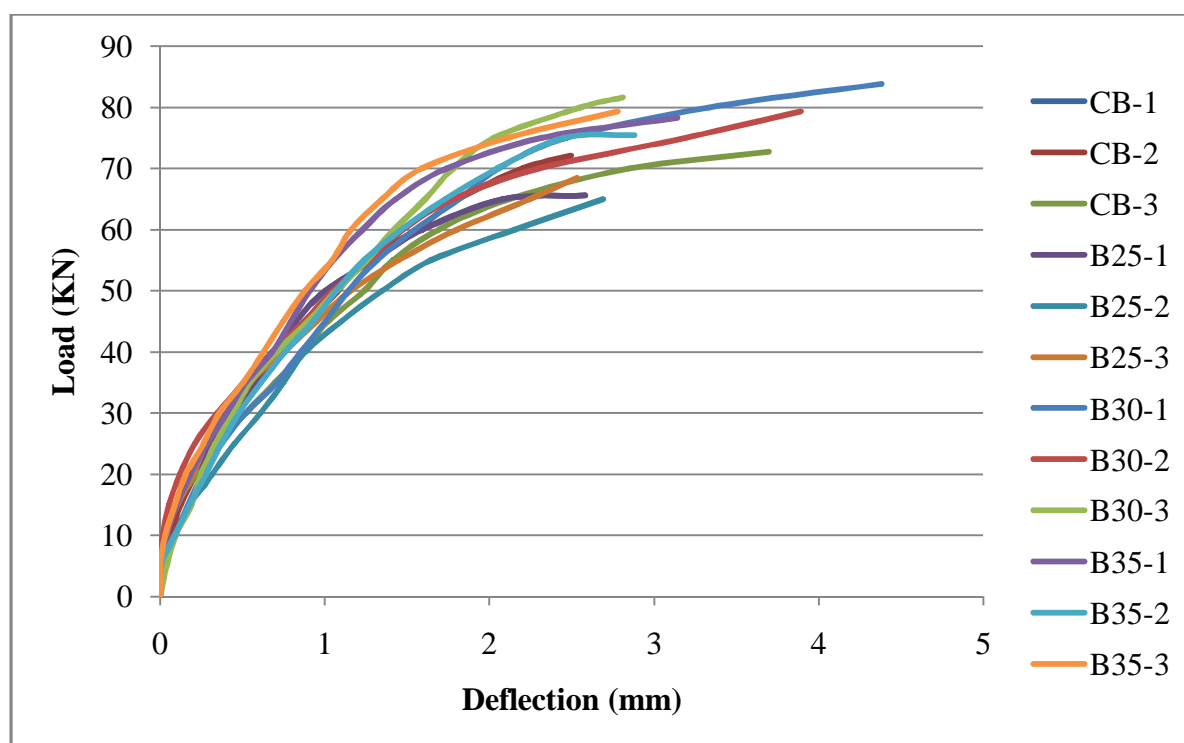


Fig 5.6: Load - deflection graph

5.2 Discussions

The variations in GBFS percentage replacements show different results for all tests. The increase and decrease in strength as well as the load carrying capacity for different beams and their deflections are stated below.

5.2.1 Strength

1. For the compression test, it has been observed that the maximum increase in the percentage of compressive stress with the control specimen is of 11.80% for 30% replacement of river sand. The decrease in the percentage of compressive stress with control specimen is found to be 18.64% for 25% replacement of river sand. Also there is a slight decrease in compressive stress of 9.96% for 50% replacement of river sand. Further increase in compressive stress for 35% and 40% replacement of sand is found to be 2.40% and 0.71%.
2. For split tensile test, the maximum increase in tensile strength was found out to be 22.64% for 30% replacement of river sand whereas decrease in tensile strength was of 36.47% for 25% replacement of river sand. Further increase in tensile strength for 35% replacement of sand was found to be of 11.32%.
3. In case of flexure test, the maximum increase in flexure strength with the control beam is 12.53% by replacement of 30% river sand, while decrease in the flexure strength with control beam was found out to be 16.85% by replacement of 25% river sand. Further increase in flexure strength for 35% replacement of river sand was found to be 8.35%.

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5.2.2 Deflection

The maximum deflection for control beam was found out to be 3.69 mm. The maximum deflection of beam for 25% replacing GBFS was 2.69mm. The maximum deflection for beam replacing 25% GBFS was 4.38 mm. The maximum deflection of beam for 25% replacing GBFS was 3.14 mm.

5.2.3 Failure mode

The failure mode found on control beam was flexure failure with major vertical cracks found on the mid span of the beam as well as shear + flexure failure combined was observed. Same thing happened with beams replacing 25% and 35% GBFS. But in case of beam replacing 30% GBFS, the failure mode was found to be flexure failure. The failure diagram of control beam is shown in **Figure 5.5**



Fig 5.7 Shear - Flexure failure of beam

Failure diagram of beam replacing 30% GBFS is shown in **Figure 5.6**

VII. CONCLUSIONS

1. The maximum strength is obtained at 30% GBFS for the replacement of natural river sand. Hence the optimum content for replacement of sand is 30%.
2. In compression test, the maximum percentage increase is 11.80% more than that of control specimen in 30% replacement of GBFS. In split tensile test, the maximum tensile strength is on 30% replacement of GBFS than that of control specimen. The percentage increase was 22.64%. In flexure test 12.53% increase flexure strength is for 30% GBFS than control beam.
3. At first, the strength in concrete was increased by increasing the GBFS content at a level of 30% replacement. Later it goes on decreasing.

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