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Experimental Evaluation on Compressive and Tensile Behavior of Concrete utilising GGBS, Fly Ash and Recycled Aggregates

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Abstract: ***Today, with the increasing rate of construction, concrete is being manufactured in the world on a large scale. It is important for the growth of infrastructure for many decades. But concrete consumes a lot of natural resources due to which it is not considered as an environment-friendly material. Portland cement is a major constituent of concrete which generates carbon dioxide gas during its production which in turn adversely affects the environment. Also, the other ingredients such as sand and coarse aggregates are depleting at a faster rate thereby increasing the cost of construction. Due to this, there is a need to identify alternate materials for cement, sand and coarse aggregates. In this study, GGBS, fly ash and recycled aggregates addresses this issue. The main objective of this research is to analyse and identify the effects of recycled waste materials in different proportions on Compressive and Split tensile strength of concrete. Ground Granulated Blast Furnace Slag (GGBS) (as a partial replacement of cement), Fly Ash (as a partial replacement of sand) and Recycled Aggregates (as a partial replacement of coarse aggregates) were the different recycled materials used. Taguchi's Approach is being used in this study to obtain different combinations of percentage replacement. It was observed that when cement, sand, and coarse aggregates are being replaced by 30% GGBS, 30% Fly ash and 20% Recycled Aggregates respectively, the compressive strength and split tensile strength test values show better results than conventional mix concrete.***

Index Terms: ***Fly Ash, GGBS, Recycled Materials, Recycled Aggregates, Sustainable Concrete***

I. INTRODUCTION

Concrete is considered to be the most widely used manufactured construction material in the world. It is generally obtained by mixing the cementing materials, fine aggregates, coarse aggregates, water and sometimes admixtures, in the desired proportion. After the mixture is formed, it is placed in the required forms and then, allowed to cure so that the mixture will harden and turned into a solid mass material known as Concrete. This solidification of the material is due to the effect of the chemical reaction occurring between cement and water. This reaction goes for a longer duration and consequently, the concrete mix gain strength with age. In another way, this concrete mass can be considered as a composite in which smaller material fills the voids of larger material to gain strength. Also, within the concrete, a paste is formed by the cementing material and water called Cement-water paste. This paste has several functions including filling of the pores of fine aggregates, helps in coating the fine aggregates and coarse aggregates, helps in binding the fine aggregates and coarse aggregates just after the curing and thus, fix the aggregates together in a dense, compact mass. Therefore, one can easily conclude that the strength of the concrete depends upon its ingredients, their proportions, and their mechanical, chemical and physical properties. As the world advances, it had been observed that the concrete properties are majorly affected when it is incorporated with some other materials. But, the strength of the concrete can also be increased by partially changing its constituents with some other strength giving materials. Thus, we can produce a concrete which is utilizing the strength of some industrial waste or by-products, as a partial replacement of its major ingredients i.e. cement, sand (fine aggregates) and coarse aggregates. Such a concrete may be defined as a Sustainable or Green Concrete. The advantages of sustainable concrete include the production of a durable structure, structures which are having a low maintenance requirement, utilisation of large proportions of recycled materials which may be harmful to the environment if not used properly. Carbon-dioxide emission is reduced with the reduced use of Portland cement, energy consumption is also reduced and wholly there is a reduction in the global warming rate. Also, by using recycled materials we can have reduced cost of construction. On considering the partial replacement of the main ingredients of the concrete, several useful materials are present in the market through which the strength of the concrete can be increased. The alternatives available for cement have a special property that they can supplement the cement clinker without reducing the role of cement as a construction material. Also, such alternatives reduce the amount of the production of clinker, ensuring savings in fuel, raw materials, and emission. Some of the major alternatives available to the cement are Rice Husk Ash (RHA), Fly ash (which is obtained from the coal), Ground Granulated Blast Furnace Slag (which can be obtained from steel industry), silica fume, etc. The alternatives that are available for the partial replacement of sand are majorly industrial waste and by-products. These industrial waste and by-products are of great concern as these materials are hazardous for both environment and human health.

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Such materials are used in construction for their proper utilization and incorporating such dangerous materials can reduce their impact on human life and nearby environment. Some of the major alternatives which are available for sand are Fly ash, GGBS, Copper Slag, Bottom Ash, Quarry Dust, Foundry Sand, Crumb Rubber, etc. Also, some of the construction, as well as demolition waste, can also be used as a partial replacement of sand in the concrete mix so as to increase its strength and durability. In the present world, there is no material available which can be considered as a proper replacement for the conventional aggregates for concrete. But, some materials can affect the concrete properties by their partial replacement to coarse aggregates. Some of these materials are Recycled Aggregates, Glasscrete, Papercrete, Crushed Rubber, Plastic, and Coconut Shell. Also, polymers like High-Density Polyethene and Expanded Polystyrene can also be used as a partial replacement of Coarse Aggregates in the concrete mix. In this study, a sustainable concrete is being prepared by using Ground Granulated Blast Furnace Slag as a partial replacement for cement, Fly ash as a partial replacement for sand and Recycled aggregates obtained from broken tested cubes in the lab as a partial replacement for coarse aggregates. The main aim of this study is to find how effectively these materials can be mixed together and to identify the suitable percentage of replacement of GGBS to cement, Fly Ash to sand and Recycled aggregates to coarse aggregates. Design mix for M25 grade concrete is prepared and Taguchi's Approach is used to obtain different mix proportions. The cubes are then tested for Compressive strength and Split tensile strength at 7 and 28 days and the results obtained are then analysed and compared with the normal concrete mix.

II. LITERATURE REVIEW

Numerous research studies across the world have started to recognize the potential of recycled materials as a partial replacement to traditional materials in concrete. Table 1 discusses the research application of GGBS, Fly Ash and Recycled aggregates in concrete.

Table 1. Use of GGBS, Fly Ash and Recycled Aggregates as a partial replacement in concrete.

Researcher	Outcome/Result/Findings
M. L. Berndt (2009) [1]	The properties of sustainable concrete were evaluated by using a percentage of fly ash or slag in place of cement and using a percentage of recycled aggregates in place of natural aggregates. It was reported that the concrete mix with 50% slag gave the increased strength.
M. S. Ahmed & H. S. Vidyadhara (2013) [2]	In this study, recycled aggregates are used as a replacement for natural aggregates. The strength of concrete was examined for M20 grade. It was reported that when recycled coarse aggregates percentage increases, the strength of concrete decreases.
S. Arivalagan (2014) [3]	It was reported that due to less grain size of GGBS as compared to cement, the early strength of concrete is less. However, with time the strength increases. Also, after replacing the cement by GGBS up to 40%, normal workability conditions can be achieved for M35 grade concrete.
B. Johny, M. V. George, E. John (2014) [4]	In this study, different percentage replacement of cement and coarse aggregates was done and the optimum percentage was found out. It was reported that the strength criteria for M30 grade concrete can be achieved when 50% of cement and coarse aggregates were replaced with slag and recycled aggregates respectively.
P. Vignesh & K. Vivek (2015) [5]	Low calcium fly ash was replaced with slag in different proportions and strength properties of geopolymer concrete was investigated. It was concluded that geopolymer concrete absorbs less water than normal concrete. Also, geopolymer concrete achieves 70% strength in the first 4 hours after setting.
S. N. Manjunath, P. V. Sivapullaiah & M. P. Kumar (2015) [6]	In this study, cement is being replaced by fly ash and sand is being replaced by GGBS in different proportions. It was reported that as the percentage of fly ash increases normal consistency along with the initial and final setting time of mortar increases.
T. Li, C. Zhu, Z. Zhong, & J. Xiao (2016) [7]	Large size recycled coarse aggregates were used as a replacement of normal coarse aggregates. It was reported that the bond between mortar and large size recycled aggregates was good and there was a very nominal difference in the cube compressive strength and splitting tensile strength of concrete when tested for large size recycled aggregates and normal aggregates.
R. Kurda, J. D. Silvestre, & J. Brito (2017) [8]	It was reported that percentage limits mentioned in the previous literature for fly ash and recycled aggregates can be increased after the incorporation of both fly ash and recycled aggregates, especially after 90 days. For the incorporation of fly ash above 36%, recycled aggregate concrete with great ion penetration rate and low permeability is obtained. Shrinkage of concrete mix increases after the addition of recycled aggregates. The opposite occurs when the addition of fly ash is done.
R. A. Hawileh, F. Fardmanesh, A. Khalili, J. A. Abdalla, & P. Shahsana (2017) [9]	It has been observed that when cement is replaced by GGBS in the concrete mix, the load carrying capacity gets slightly affected. Also, the high amount of GGBS up to 90% can reduce the strength and flexural stiffness of reinforced concrete beams. However, this decrease can be compensated by an improved ductility.

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H. Guo, J. Zhu, T. C. Ling, C. Shi, Y. Wang, X. Guan, & Y. Ding (2018) [10]	It had been observed that the presence of a high quantity of mortar adhered to recycled aggregates will lead to high porosity and more water absorption, which in turn improves the durability of recycled aggregate concrete. When this recycled aggregate is used with fly ash or slag, the pore structure of the concrete improves. Also, when it reacts with existing CaOH, the production of additional C-S-H products further strengthens the layer.
A. K. Saha (2018) [11]	It had been observed that when class F fly ash was used as a replacement of cement, the strength reduced after 28 days of curing. Also, with more addition of fly ash, the strength further decreases sharply. The hydration rate decreases with the inclusion of fly ash resulting in drying shrinkage of concrete containing fly ash. However, the density of concrete improves with the addition of fly ash.
Y. Hefni, Y. A. El Zaher, & M. A. Wahab (2018) [12]	It was observed that when fly ash was used as a replacement of cement, the strength decreases at early ages. However, at the ages of 65 up to 170 days, there was a noticeable increment in the strength of concrete. When concrete is exposed at high temperatures, fly ash enhances the concrete strength.

III. MATERIALS AND THEIR PROPERTIES

A. *Cement*

The most widely used concrete making material is cement. The various ingredients present in this cementing material are expressed in Table 2. The oxide composition is obtained from the cement manufacturer.

Table 2. Oxide composition of OPC

Oxide	Formula	Percentage (%)	Average (%)
Lime	CaO	61-66	64
Silica	SiO_2	18-26	21
Alumina	Al_2O_3	3.7-9.2	6.5
Iron Oxide	Fe_2O_3	0.7-6.2	3.4
Magnesia	MgO	0.7-4.2	2.5
Sulphur Dioxide	SO_3	1.5-2.5	2.0
Alkalis	Na_2O+K_2O	0.7-1.5	1.3

The cement which is used in this study is OPC 43 Grade. The different experiments used to calculate the properties of ordinary Portland cement (OPC) such as specific gravity, initial and final setting time, standard consistency, fineness of cement was carried out as per IS 4031 [13]. The properties of cement obtained is shown in Table 3.

Table 3. Properties of OPC

S. No.	Characteristics	Cement
1	Specific Gravity	3.15
2	Initial Setting Time (min)	200
3	Final Setting Time (min)	395
4	Standard Consistency (%)	40
5	Fineness of cement	5%
6	Compressive Strength of Cement (N/mm^2)	50.42

B. Aggregates

These are the naturally occurring inert granular materials. They can be fine aggregates and coarse aggregates. The quantities of the fine aggregates and coarse aggregates are determined on the basis of the concrete mixes. The various tests and their respective results conducted on fine aggregates and coarse aggregates as per Indian Standard Code IS 2386 [14] are shown in Table 4.

Table 4. Properties of Fine and Coarse Aggregates.

Characteristics	Fine Aggregates	Coarse Aggregates
Specific Gravity	2.45	2.50
Fineness Modulus	2.11	7.65
Water Absorption (%)	1.37	3.24
Bulking (%)	24.4	-
Flakiness Index (%)	-	33.53
Elongation Index (%)	-	7.78
Grading	Zone II (IS 383)	-
Texture	-	Rough

C. Fly Ash

Fly ash is considered to be a waste product or by-product obtained from the generation of electricity which varies according to the source. It contains a good quantity of silicon dioxide, which is present in nature in both amorphous and crystalline form i.e. Aluminium oxide and Calcium Oxide (CaO) respectively. Fly ash can be of two types: Class C & Class F. In this Study, class F fly ash has been used. The utilization of fly ash has enormous environmental benefits when it is used to replace one or two main ingredients of the concrete. The chemical constituents of fly ash was obtained from the supplier whereas its specific gravity was determined from Le Chatelier's Flask and is shown in Table 5.

Table 5. Properties and Chemical Composition of Fly Ash.

Parameters	Formula	Fly Ash
Specific Gravity	-	2.24
Lime (%)	CaO	0.83
Iron Oxide (%)	Fe_2O_3	4.57
Silica (%)	SiO_2	62.1
Magnesia (%)	MgO	0.55
Alumina (%)	Al_2O_3	27.44
Sulphur Trioxide (%)	SO_3	0.4
Alkalies (Soda & Potash) (%)	Na_2O & K_2O	0.04 & 1.17

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D. Ground Granulated Blast Furnace Slag (GGBS)

GGBS can be produced by the process of quenching. It is a waste product or by-product obtained during the production of iron in a blast furnace. It is estimated that 1 ton of pig iron generation creates 300kg of slag. GGBS can be effectively used in place of cement which in turn reduces the cement consumption, energy consumption, and is cost-effective and environment-friendly. It is used to make concrete structures durable when used as a replacement to cement in partial amount. GGBS concrete develops lesser strength at early ages. It achieves 50-60% of its strength in 7 days whereas it achieves full strength at 28 days and continues to develop strength after 90 days. The chemical composition of GGBS was obtained from the supplier whereas its specific gravity was determined from Le Chatelier's Flask and is shown in Table 6.

Table 6. Properties and Chemical Constituents of GGBS.

Parameters	Formula	GGBS
Specific Gravity	-	2.93
Lime (%)	CaO	1.53
Silica (%)	SiO_2	43.5
Alumina (%)	Al_2O_3	12.5
Iron Oxide (%)	Fe_2O_3	1.3
Alkalies (Soda & Potash) (%)	Na_2O & K_2O	0.9 & 0.6
Sulphur Trioxide (%)	SO_3	-
Magnesia (%)	MgO	1.5

E. Recycled Aggregates

Recycled aggregates are composed of natural aggregates as well as cement paste which is hydrated. This hydrated cement paste lowers the specific gravity whereas the porosity gets increases which in turn leads to more absorption. Construction and demolition go in parallel to each other. Developing countries like India are struggling to find landfills to get rid of demolished waste. Recycling of these demolished waste can be done as there is a shortage of land for landfills, the location of landfills are at a remote location which is a costly affair to maintain. Also, the natural coarse aggregates are depleting at a faster rate. Therefore, recycled aggregates can be used as a replacement for natural aggregates to reduce their consumption. Recycled aggregates obtained by already demolished cubes in the concrete laboratory are used in this study. Some tests on recycled aggregates are performed in lab and their properties are obtained as shown in Table 7.

Table 7. Properties of Recycled Aggregates

S. No.	Characteristics	Recycled Aggregates
1	Specific Gravity	2.22
2	Water Absorption (%)	2.7
3	Percentage Voids (%)	42.93
4	Bulk Density (kg/l)	1.35
5	Texture	Rough

IV. CONCRETE MIX DESIGN

The Concrete Mix design is a procedure to determine the relative amount of various ingredients of the concrete mix. The main objective of making a concrete mix is to achieve required strength, workability, and durability. The concrete mix design of the concrete is carried out as per Indian Standards code IS 10262:2009 [15]. In this study, M25 concrete mix has been used.

Characteristic Compressive Strength at 28 days,

f_{ck} = 25 N/mm^2

Nominal maximum size of aggregate = 20mm

Cement (kg/m^3)	Sand (kg/m^3)	Coarse Aggregates (kg/m^3)	Water/Cement Ratio
350	750	1350	0.45

Actual material quantities for 1 cube of size 150 x 150 x 150 mm. Volume of concrete required for 1 cube (assuming 25% wastage) 0.153 x 1.25 = 0.004218m^3

Cement (kg)	Sand (kg)	Coarse Aggregates (kg)	Water (kg)
1.476	3.163	5.684	0.6642

Actual material quantities for 1 cylinder of size 300mm height and 150mm diameter.

Volume of concrete required for 1 cylinder (assuming 25% wastage) = 0.00529m^3

Cement (kg)	Sand (kg)	Coarse Aggregates (kg)	Water (kg)
1.851	3.967	7.141	0.833

Some tests have been performed on fresh concrete and hardened concrete prepared through the calculated design mix for M25 grade concrete. The results obtained are shown in Table 8.

Table 8. Tests performed on Fresh and Hardened Concrete.

Parameters	Result
Slump Value (mm)	162
Compaction Factor Value	0.94
Cube Compressive Strength (7 days) (N/mm^2)	18.51
Cube Compressive Strength (28 days) (N/mm^2)	27.846

V. EXPERIMENTAL SETUP

In this study, samples are being prepared for conventional concrete and geopolymer concrete in various mix proportions. In mix design of geopolymer concrete, Ground Granulated Blast furnace Slag (GGBS) is used partially in place of cement, Fly ash is used partially in place of sand and Recycled aggregate is used partially in place of coarse aggregates. Cube specimens of size 150mm x 150mm x 150mm are being casted for compressive strength test [16] whereas cylindrical specimens of size 300mm height and 150mm diameter are being prepared for Split tensile strength test [17]. The specimens were casted for 7 and 28 days and were being tested under Universal Testing Machine.

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VI. TAGUCHI'S APPROACH

Taguchi's Method was invented by Dr. Taguchi. He is currently working in Nippon Telephones and Telegraph Company, Japan. This method was considered to be the fresh method as it includes the solution of the given problem by using a set of arrays, called Orthogonal Arrays. These arrays give reduced experimental specimens for a particular problem under optimum settings and control parameters. Also, these arrays provide the best result due to the optimization of the given problem. [18,19] In accordance with this study, Taguchi's approach is used for determining the optimum combinations of the materials so that the strength parameters of the resultant mix may improve. In this study, the cement is replaced with GGBS, sand is replaced with Fly Ash and Coarse Aggregates are replaced with Recycled Aggregates. We are considering different proportions of the partially replacing materials as 10%, 20%, and 30%. Table 9 shows the various proportions taken for recycled materials.

Table 9. Different proportions of partially replacing materials.

Representation	Factors	Proportion 1	Proportion 2	Proportion 3
A	GGBS (%)	10	20	30
B	Fly Ash (%)	10	20	30
C	Recycled Aggregates (%)	10	20	30

Now, by using Taguchi's Approach, we can get different trial mixes so that we can compare the compression and tension strength of the conventional concrete and geopolymer concrete having different proportions of recycled materials.

VII. OBSERVATIONS

The compressive strength of concrete without partial replacement (T0) and with partial replacement (T1 – T9) of the main ingredients of the concrete at 7 days and 28 days is shown in Table 12.

Table 12. Compressive Strength of Concrete at 7 and 28 days

Experiment No.	Trial Mixes	Strength Observed at 7 days (N/mm^2)	Strength Observed at 28 days (N/mm^2)
T0	-	18.51	27.85
T1	A1B1C1	20.47	30.01
T2	A1B2C2	21.97	31.45
T3	A1B3C3	25.36	36.77
T4	A2B1C2	20.59	30.89
T5	A2B2C3	21.25	31.20
T6	A2B3C1	31.56	42.97
T7	A3B1C3	27.50	38.90
T8	A3B2C1	31.75	42.05
T9	A3B3C2	32.63	44.13

Similarly, the splitting tension strength of concrete without partial replacement (T0) and with partial replacement (T1 – T9) of the main ingredients of the concrete at 7 days and 28 days is shown in Table 13.

Table 13. Split Tensile Strength of Concrete at 7 and 28 days

Experiment No.	Trial Mixes	Strength Observed at 7 days (N/mm^2)	Strength Observed at 28 days (N/mm^2)
T0	-	1.91	2.85
T1	A1B1C1	2.11	2.01
T2	A1B2C2	2.26	2.31
T3	A1B3C3	2.61	2.86
T4	A2B1C2	2.12	3.25
T5	A2B2C3	2.18	3.45
T6	A2B3C1	3.25	4.87
T7	A3B1C3	2.83	3.98
T8	A3B2C1	3.27	4.92
T9	A3B3C2	3.36	5.03

VIII. RESULT AND DISCUSSION

After performing all the required experiments, it had been noted that the inclusion of the alternatives to cement, sand (fine aggregates) and coarse aggregates increases compressive strength as well as the tensile strength of concrete mix for M25 grade both at 7 and 28 days of curing. The observations also showed that it is not necessary that every sample shows a greater impact on the strength of the concrete in compression as well as in tension. Considering the compressive strength aspect first, it had been observed that minimum compressive strength was observed when cement, sand and coarse aggregates were partially replaced with 10% of GGBS, Fly Ash and Recycled Aggregates each respectively. The similar pattern was also observed when the cement and coarse aggregates were replaced with 20% of GGBS and 20% of Recycled Aggregates respectively, and sand with 10% of Fly Ash. Figure 1 shows the comparative analysis of the compressive strength of concrete for different combinations.

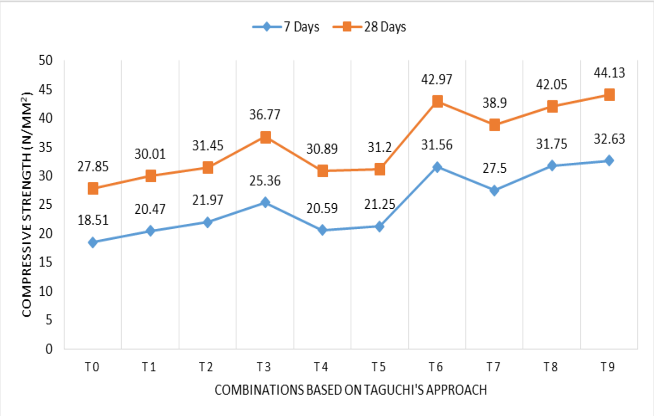

Fig 1. Comparative Analysis of Compressive Strength of Concrete for different combinations

The major change in compressive strength of the concrete was observed when the cement and sand were partially replaced with 30% GGBS and 30% Fly Ash respectively, and coarse aggregates with 20% Recycled Aggregates for both the duration of curing taken into consideration.

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It had been noted that the maximum compression strength of the geopolymer concrete mix was increased by 66.28 % and 58.43% after partially replacing of 30% of both GGBS and fly ash, and 20% of crushed aggregates at 7 days and 28 days respectively. Considering the strength of the concrete in tension, the comparative analysis has been done in Figure 2.

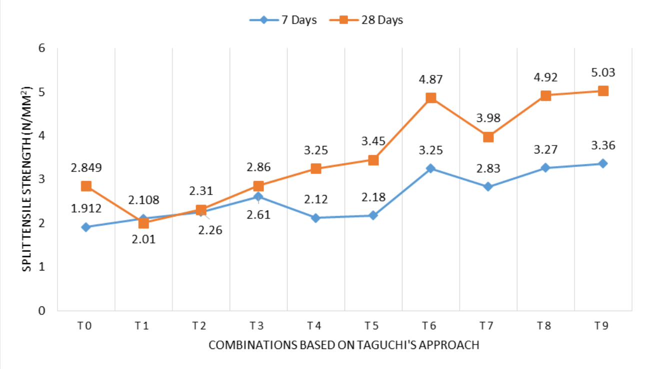

Fig 2. Comparative Analysis of Tensile Strength of Concrete for different combinations

The minimum strength is observed when the basic ingredients are replaced with 10% each of GGBS, Fly ash and Recycled aggregates, both in the 7 and 28 days. The maximum strength in tension is observed when the ingredients are replaced by the maximum proportion which is taken into consideration i.e. 30% GGBS, 30% Fly ash, and 20% Recycled aggregates. It had been noted that the maximum strength in tension of the concrete mix was increased by 75.7% and 76.55% after partially replacing of 30% of both GGBS and fly ash, and 20% of crushed aggregates at 7 and 28 days respectively.

IX. CONCLUSION

It can be concluded that the compressive strength and split tensile strength of the concrete mix can be improved when the core components of the concrete were partially replaced with recycled products. The result of this study revealed that the minimum compressive strength and tensile strength were observed when cement, sand and coarse aggregates were partly re-placed with 10% of GGBS, Fly Ash and Recycled Aggregates each respectively. Also, the major improvement in both compression and tensile strength of the concrete was observed when the cement and sand were partially replaced with 30% GGBS and 30% Fly ash respectively and Coarse aggregates with 20% Recycled Aggregates for both 7 days and 28 days. It was noted that the compressive strength of the geopolymer concrete mix increased by 66.28% and 58.43% at 7 and 28 days respectively as compared to normal concrete whereas strength in tension of the geopolymer concrete mix was increased by 75.7% and 76.55% after partial replacement of 30% of both GGBS and fly ash, and 20% of crushed aggregates at 7 days and 28 days respectively. Thus, it may be concluded that if the core ingredients of the concrete, i.e., cement, sand (fine aggregates) and coarse aggregates are partially replaced by some of the waste materials in optimum quantity, the strength of the concrete increases. Different proportion of these waste materials can be used to make a concrete structure a sustainable concrete structure as we are using the products which are already being used in the industry and not useful in any sense. Thus, minimizing the cost of the new structure as well as reducing the adverse impact on the environment.

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AUTHORS PROFILE

Abhishek Dixit – He did his Masters in Structural Engineering from Amity University, Noida (Silver Medalist). He had a good academic experience as an Assistant Professor in various colleges. His review paper on Bamboo Bonding in Concrete is selected in International conference, INFRACON 2019 and is published in SCOPUS Indexed Journal. His research area is Sustainable Infrastructure, recycled materials, Industrial by-products and Bamboo reinforcement in concrete.

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Yaman Hooda, He completed the degree of Masters in Technology in Structural Engineering (Gold Medalist) and the degree of Bachelors of Technology in Civil Engineering (Gold Medalist). He had a good working experience in different construction companies. He has a good knowledge of the software tools used in the same above stative fields, such as Autodesk AutoCAD 2D and 3D Modelling, STAAD Pro and ETABS. The area of research work will include the topics in the area of Structural Engineering, Earthquake Engineering and Concrete Technology.

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