iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 **Issue:** II **Month of publication:** February 2024

DOI: https://doi.org/10.22214/ijraset.2024.58560

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue II Feb 2024- Available at www.ijraset.com

Optimum Mix Design of GPC using Taguchi method

Dilip Srinivas[1], Dr. N Suresh[2]
[1]Research Scholar, NIE, Mysuru, India
[2]Professor, Civil Engineering Department, NIE, Mysuru, India

***Abstract:** The goal of the current study is to identify geopolymer concrete as an alternative to cement-free concrete. Although there have been numerous attempts to comprehend the necessity of carbon-free concrete, cement-free concrete needs to be replaced. Bagasse ash and GGBS were utilized as the binders in the current study. Various molar concentrations of GPC concrete, including 4M, 8M, and 12M, have been cast, with boric acid being used as an admixture. The objective of the study is to identify the optimal mix design, which has been aided by the well-known Taguchi analysis method. The findings show the ideal mixture of components needed to satisfy the fresh and hardened qualities of GPC at ambient and elevated temperature. Mix design is arranged as per the L18 orthogonal array of Taguchi method. After the completion of casting of concrete specimens, it has been cured for 3days,7days ,28days. At certain days of age, the specimens gain strength. The curing has been done by the sunlight. After that specimens are subjected to elevated temperature of 200C, 400C 600C ,800C up to the duration of 2 hours then cooling the specimens. The residual strength is tabulated.*
***Keywords:** Geopolymer concrete, Binder content, Alkaline liquid, Boric acid, Taguchi method, Orthogonal array, Ambient temperature, Elevated temperature, Compressive strength, Slump test, Compaction factor.*

I. INTRODUCTION

The word "geopolymer" was first used by Prof. T. Davidovits to refer to mineral polymers that have an interconnected network of inorganic molecules [16]. Alkaline liquids like NaOH and Na2SiO3 are combined with a silica and alumina-rich source material to create geopolymer[17]. The usage of concrete worldwide is the second most significant reason. When making concrete, ordinary Portland cement is frequently utilized as the main binder.

Some authors claim that the polymeric reaction of alkaline liquids with sodium silicate and sodium hydroxide can create additional binder material. It is a new building material that will be produced through chemical reactions between inorganic molecules. It can be manufactured without the need for Portland cement. By reacting aluminate and silicate-bearing minerals with bagasse ash and GGBS, geopolymer concrete is produced. Ash and slag, waste products from the processing of iron and metal, are frequently employed, which helps to maintain a better atmosphere

A. Taguchi Method

Taguchi may be a contemporary approach to experimental design that follows precise rules. An array subset known as orthogonal arrays is used in this method. These reference arrays show how to perform the minimum amount of experiments required to fully understand every element affecting the output parameter. The optimal geopolymer concrete mix style is ascertained using the Taguchi method.
With a small number of experiments, it will offer comprehensive information regarding the intensity of the variation parameter of the geopolymer concrete.

The process of choosing the most comprehensive combinations of the input design variables for an experiment is guided by the orthogon al arrays approach. A common table is utilized to arrange the control factors in this orthogonal series. Using a robust design of trials to lower variation during a phase is the Taguchi method's approach. This method minimizes the experiment's cost by lowering the number of tests. Japan's Dr. Genichi Taguchi created this method. The Taguchi approach facilitates the creation of experiments and the study of how different parameters and control factors affect the mix design., Olivia Monita et al. This study compares the effects of fly ash-based GPC and OPC on the mechanical properties and durability of concrete using the Taguchi method. This instance considers L9 OA. Aggregate content, the ratio of alkaline solution to fly ash, the ratio of sodium silicate to sodium hydroxide, and the curing technique are the experiment's parameters. It was determined that compared to OPC, fly ash GPC had a higher modulus of elasticity, drying shrinkage, water absorption, and sorptivity, as well as higher compressive, tensile, and flexural strengths.

GPC concrete had a flexural strength that was 1.4 times greater than OPC concrete, The findings showed that adding ferro sand aggregate to concrete enhances its strength whereas adding fly ash decreased it. Erdogan Ozbay This study uses the Taguchi technique to investigate the mix proportional parameter of high strength self-compacting concrete; the L18 orthogonal array is used in this instance. however GPC concrete was more prone to corrosion. Ali Nazari and Shadi Riahi etal, studied the Taguchi method to examine the compressive strength of GPC through testing in an oven and with water. Water use for two and seven days is adopted. Oven curing required three different temperatures—25, 70, and 90 degrees Celsius—as well as three different times and concentrations of NaoH molarity. ANOVA software is used to analyse the outcome and identify the optimal amount. The outcome demonstrates that a seven-day water curing period has a high compressive strength

More compressive strength is obtained via oven curing at 90 degrees Celsius than from water curing. Specimens with higher temperatures showed the highest strength growth. Khairun Azizi Azizli and Ahmer Ali Siyal ,This work uses the Taguchi method to study GPC setup times. Additionally, the effect of temperature, water to solid (W/S) ratio, parameter ratio (Si/Al), and Na/Al ratio on fly ash setting is determined in this research. The setting time is ascertained using the GPC vicat needle device. Two sets of temperature and ratio are taken into consideration for comparison. Thus, the outcome demonstrates that the W/S ratio has a good setting. Pathil Prashant V. et al. Using a L9 orthogonal array, the paper assesses the mechanical and physical characteristics of concrete that contains fly ash and ferro sand. Fly ash (10%,20%, and 30%) and fine aggregate (15%, 30%, and 50%) are the parameters. The split tensile, compressive, and flexural strengths of these specimens were measured. The W/C ratio, fly ash content, air entraining agent (AE) content, super plasticizer content, and fine aggregate to total aggregate (s/a) were the six parameters. The mechanical strength of these specimens was examined; the best mix design is employed to measure the mechanical strength.

II. EXPERIMENTAL DETAILS

A. Constituents of Materials

The properties of the following materials are listed below:

1) GGBS (Ground Granulated Blast Furnace Slag): It's made by cooling molten iron slag. It is a byproduct of the iron and steel industry. It is nonmetallic product which act as a good resistance to chloride attack in concrete. GGBS contains calcium silicates that forms in a liquid condition with steel or iron in a blast furnace. The incremental hydration of GGBS cement produces less peak and total heat than OPC.
2) Bagasse ash: The burning of sugar cane from the sugar cane industries the residue obtained is called sugar cane bagasse as. Generally, this material is rich in silica content and in some cases used to fill the land fill as a disposal material. Replacement of 30% of bagasse ash is used as binder content in concrete for structural purpose.
3) Sodium hydroxide: It is the in- organic chemical which is also known as lye and caustic soda. It consists of alumino silicates which leads to increase of hydroxide concentration. Increase in sodium hydroxide concentration gives higher compressive strength in GPC.
4) Sodium silicate: It is the alkaline solution, which is white soluble solids when it is placed in water to form alkaline solution. It is glass, color less and soluble in water.
5) Manufactures sand (fine aggregate): It is the artificial sand which is produced from crushing hard stones to small powdered particles, it is finely graded which can be used as construction aggregate. It shows superiority to river sand for the construction.
   Bulk density of fine aggregate (M sand)

- The density of loose sand = 1528.3 kg/m3
- The density of compacted sand = 1691.82 kg/m3

6) Coarse aggregate: It is made from the rock quarries from the ground deposits which are used for the construction components. These includes crushed stone which are used for the concrete. The coarse aggregate which is used in GPC is 20mm nominal size.
7) Boric acid: Boric acid used in concrete to get the workability of the concrete.

B. Specific gravity of the material Table 2.1

Sl.NO	Material	Specific Gravity
1.	GGBS	2.92
2.	SCBA	1.6
3.	Fine aggregate (M sand)	2.61
4.	Coarse aggregate	2.7

C. Fineness of material Table 2.2

Sl.NO	Material	Fineness
1.	GGBS	3.1
2.	SCBA	64

D. Mix design

A sample calculation of the mix design as shown in the below.

Table 2.3: GPC on-meter cube proportional mix

Binder content	500 kg/m3
GGBS	350 kg/m3
Bagasse ash	150 kg /m3
Sodium hydroxide	12.8 kg/m3
Sodium silicate	120 kg/m3
Distilled water	67.2 kg/m3
Fine aggregate(M sand)	740.6 kg/m3
Coarse aggregate	1162.78 kg/m3
Boric acid	271.6kg/m3

E. Optimization of trial mix by taguchi's principal

It is listed what factors have been considered for mix design below the Table 2.4

Materials	Level 1	Level 2	Level3
GGBS + SCBA	(70% + 30%)	(80% + 20%)	-
NaoH+NasiO$_3$ ratio	1:2.5	1:2	1:1.5
Molarity	4M	8M	12M
Admixture	1%	2%	3%
AAC/BC	0.5	0.4	0.6
Curing days	3 days	7 days	28 days

Table of control factors with factor levels Table 2.5

Code	Parameter/Control factors	Unit
A	Alkaline liquid	Kg/m^3
B	Binder content	Kg/m^3
c	Coarse aggregate	Kg/m^3
d	Manufacture sand	Kg/m^3
e	water	Kg/m^3

The orthogonal array of taguchi method is selected for the experiment is (2^1x 3^6).

The value of these three levels is calculated by varying the positive and negative values for the obtained mix design. This experiment's orthogonal array is L18 = (2^1x 3^2) as it is mixed level.

III. RESULTS AND DISCUSSION

Identifying the optimal mix's power characteristics. Cubes were used to cast the GPC of 150 * 150 mm. Slump test was done for each experiment mix.

Geopolymer specimens are tested after the 28 days of casting, these specimens are tested for both ambient and elevated temperature of the casted specimens. All these specimens are tested to find the compressive strength of the geopolymer concrete and also to find the slump of the concrete.

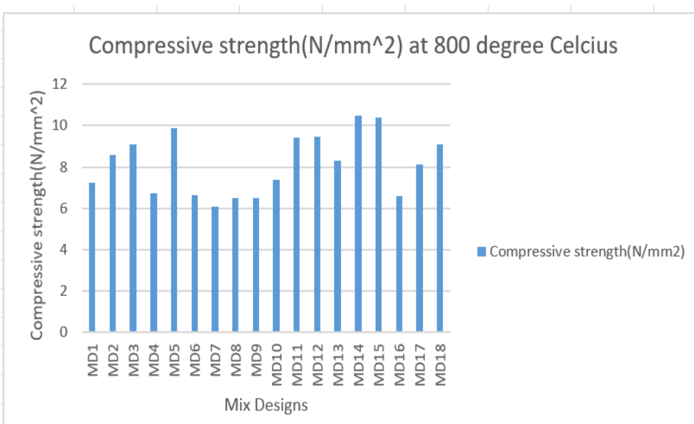
International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue II Feb 2024- Available at www.ijraset.com

A. Slump Test

As the attempts has been done by using the different percentage of boric acid like 1% ,2%,3% in the trail mix. It has been observed that as the percentage of the boric acid increases for the trail mixes the workability has been decreased. The optimum percentage of boric acid can be restricted to 1% only. The slump results of the attempted trail mixes has shown in the below table with the graphical representation.

Table 3.1 slump values.

Mix design	Slump in mm
MD1	90
MD2	130
MD3	100
MD4	80
MD5	100
MD6	120
MD7	90
MD8	100
MD9	90
MD10	120
MD11	110
MD12	100
MD13	90
MD14	110
MD15	120
MD16	80
MD17	80
MD18	100



Graph 3.1: Variations of slump values

B. Test On Hardened Property Of Concrete

COMPRESSIVE STRENGTH AT AMBIENT AND AT ELEVATED TEMPERATURE

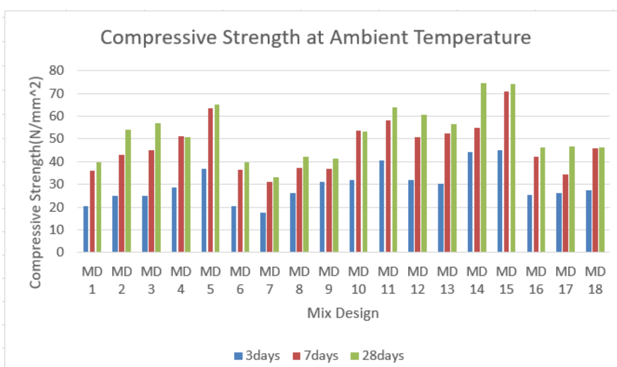
1) Compressive strength of GPC at Ambient temperature

The attempt has been done by conducting the GPC by using the tool of taguchi method L18 of orthogonal array, 18 mix design of GPC cubes has been casted. After 3 days, 7days ,28 days of curing. The compressive strength of all the 18 mix designs of GPC results has been shown in below table with the graph

Table 3.2: Results of Compressive strength of GPC at Ambient temperature

Strength at Ambient temperature			
MIX DESIGN	3days	7days	28days
MD 1	20.4	36.07	39.79
MD 2	25.1	43	54
MD 3	25.02	44.85	56.76
MD 4	28.74	51.3	50.8
MD 5	36.7	63.45	65.15
MD 6	20.6	36.3	39.5
MD 7	17.7	31.2	33.2
MD 8	26.3	37.3	42.18
MD 9	31.2	36.7	41.19
MD 10	32	53.7	53.3
MD 11	40.4	58.17	63.8
MD 12	32.1	50.89	60.5
MD 13	30.4	52.5	56.49
MD 14	44.3	54.7	74.7
MD 15	44.96	70.74	74.11
MD 16	25.29	42.3	46.23
MD 17	26.1	34.18	46.75
MD 18	27.3	45.9	46.08

Results of Compressive strength of GPC at Ambient temperature.



Graph 3.2: Variations of compressive strength at ambient temperature.

As per mix design the compressive strength is 33 N/mm2(Target strength) for grade M30 after 28 days. The graph depicts the test results strength of all 18 mix designs using the Taguchi approach. Taguchi analysis indicated that the optimum parameters for compressive strength of concrete at ambient temperature were obtained MD7= 33.2 N/mm2, MD6= 39.5 N/mm2, MD1=39.79 N/mm2, and MD8 =42.18 N/mm2 which were close to the target strength. These Mix designs 7,2,1,8 are sufficient for the manufacturing of geopolymer concrete. Mix design 7 of 4M having 34.6 N/mm^2 which is close to the target strength that shows the variables of the MD7 is best combination for the optimal condition of geopolymer concrete.

Rest of others mix design has been observed that having the strength higher than the target strength which are not necessity for the manufacture of geopolymer concrete.

2) Compressive strength (N/mm2) of GPC at Elevated temperature

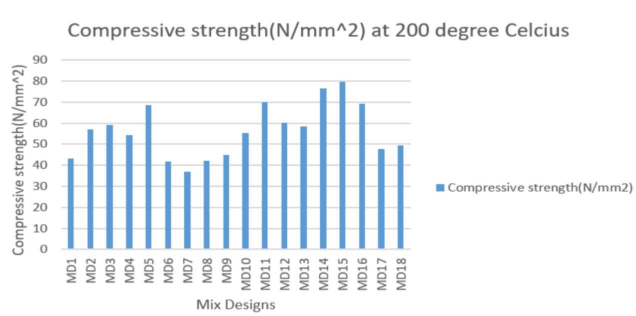
The changes in the mechanical property of concrete when subjected to elevated temperature is depending on the type of materials and also the effect of environmental conditions like moisture content high temperature, initial strength of concrete before exposure to high temperature [15].

The residual strength of geopolymer concrete at elevated temperature The compressive strength diminishes as the temperature rises, Specimens are tested at elevated temperature of 200 ^{0}C, 400 ^{0}C, 600 ^{0}C, 800 ^{0}C. The test results are tabulated below the table.

3) Compressive strength of GPC at elevated temperature of 200 ^{0}C.

Table 3.3: Results of Compressive strength of GPC at temperature 200 ^{0}C

Compressive strength at (N/mm^2) 200^{0}C	
Mix design	Compressive strength(N/mm^2)
MD1	43.3
MD2	57.2
MD3	59.2
MD4	54.3
MD5	68.4
MD6	41.8
MD7	36.8
MD8	42.3
MD9	44.9
MD10	55.2
MD11	69.8
MD12	60.3
MD13	58.4
MD14	76.6
MD15	79.8
MD16	69.2
MD17	47.7
MD18	49.3



Graph 3.3: Variations of compressive strength at temperature 200 ^{0}C.

As per mix design the compressive strength is 33 N/mm2 (Target strength) for grade M30 after 28 days. The graph depicts the test results strength of all 18 mix designs using the Taguchi approach.

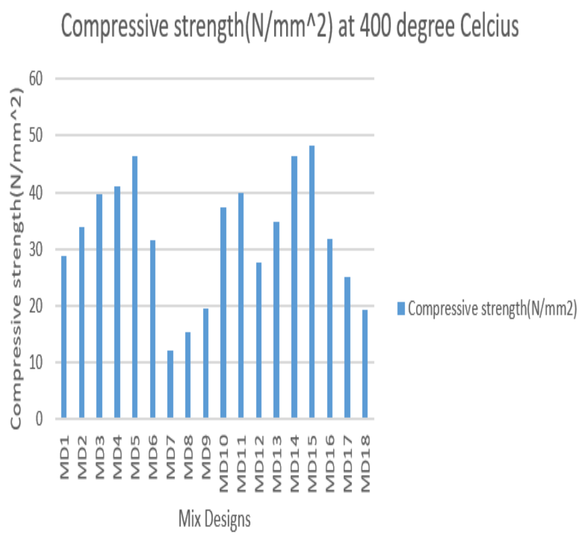
The specimens of geopolymer concrete has been subjected to elevated temperature of 200 ^{0}C for the duration of 2 hours. The test results has been observed that MD 7 = 36.8 N/mm^2, MD 6= 41.8 N/mm^2, having best combination of variables to get near the targeted strength. All other mix designs of test results have been observed the increase in strength when subjected to elevated temperature of 200 ^{0}C. Hence MD 7 shows the best optimal result to the target strength at 200 ^{0}C

4) Compressive strength of GPC at elevated temperature of 400 ^{0}C

Table 3.4: Results of Compressive strength of GPC at temperature 400 ^{0}C

Compressive strength at (N/mm^2) 400^{0}C	
Mix design	Compressive strength(N/mm^2)
MD1	28.9
MD2	33.85
MD3	39.65
MD4	41.15
MD5	46.3
MD6	31.5
MD7	12.1
MD8	15.4
MD9	19.45
MD10	37.3
MD11	39.9
MD12	27.6
MD13	34.8
MD14	46.4
MD15	48.15
MD16	31.8
MD17	25.1
MD18	19.3

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue II Feb 2024- Available at www.ijraset.com



Graph 3.4: Variations of compressive strength at temperature 400 ^{0}C

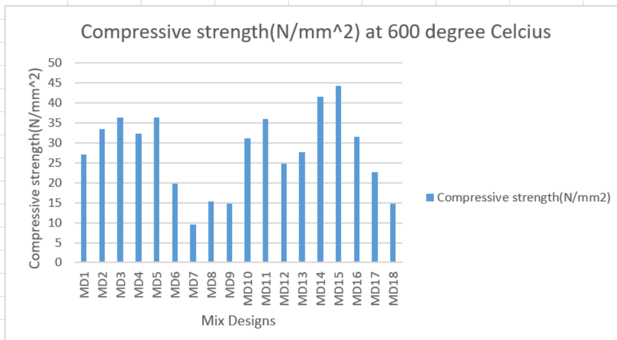
As per mix design the compressive strength is 33 N/mm2 (Target strength) for grade M30 after 28 days. The graph depicts the test results strength of all 18 mix designs using the Taguchi approach. The specimens of geopolymer concrete has been subjected to elevated temperature of 4000 c for the duration of 2 hours. The test results have been observed that MD2 = 33.8 N/mm^2, MD 3=39.65 N/^{mm2}, MD13 =34.8 N/mm^2 , MD10 = 37.3 N/mm^2, MD11= 39.9N/mm^2 having best combination of variables to get near the targeted strength. Since these mix design of GPC have capacity to withstand with the temperature of 400 ^{0}C.

5) Compressive strength of GPC at elevated temperature of 600 ^{0}C

Table 3.5: Results of Compressive strength of GPC at temperature 600 ^{0}C

Compressive strength at (N/mm^2) 600^{0}C	
Mix design	Compressive strength(N/mm^2)
MD1	27.15
MD2	33.5
MD3	36.4
MD4	32.3
MD5	36.4
MD6	19.85
MD7	9.6
MD8	15.42
MD9	14.75
MD10	31.05
MD11	36

MD12	24.75
MD13	27.6
MD14	41.6
MD15	44.3
MD16	31.6
MD17	22.7
MD18	14.75



Graph 3.5: Variations of compressive strength at temperature 600 ^{0}C.

As per mix design the compressive strength is 33 N/mm2 for grade M30 after 28 days. The graph depicts the test results strength of all 18 mix designs using the Taguchi approach. The specimens of geopolymer concrete has been subjected to elevated temperature of 6000 c for the duration of 2 hours. The test results has been observed that MD 3 = 36.4 N/mm2 , MD 5= 36.4 N/mm2 , having best combination of variables to get near the targeted strength .These two Mix designs (MD 3, MD5) has restrained to the temperature of 600 ^{0}C. since these combination of mix design having the capacity to with stand for the elevated temperature up to 600 ^{0}C. These Mix designs (3,5) are sufficient for the manufacturing of geopolymer concrete

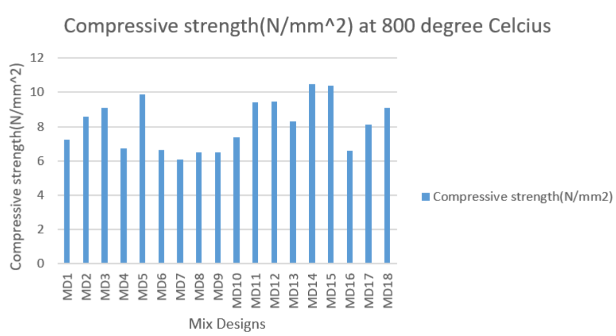
6) Compressive strength of GPC at elevated temperature of 800 ^{0}C

Table 3.6: Results of Compressive strength of GPC at temperature 800 ^{0}C

Compressive strength at (N/mm^2) 800^{0}C	
Mix design	Compressive strength(N/mm^2)
MD1	7.25
MD2	8.6
MD3	9.1
MD4	6.75
MD5	9.9
MD6	6.65
MD7	6.1

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue II Feb 2024- Available at www.ijraset.com

MD8	6.5
MD9	6.5
MD10	7.4
MD11	9.4
MD12	9.44
MD13	8.3
MD14	10.5
MD15	10.4
MD16	6.6
MD17	8.1
MD18	9.1



Graph 3.6: Variations of compressive strength at temperature 800 ^{0}C

As per mix design the compressive strength is 33 N/mm2 for grade M30 after 28 days. The graph depicts the test results strength of all 18 mix designs using the Taguchi approach. The specimens of geopolymer concrete has been subjected to elevated temperature of 800 ^{0}C for the duration of 2 hours. The variations of graph shows the test results of all 18 mix designs it has been observed that none of these 18 mix designs have restrained at the temperature of 800 ^{0}C. hence above mentioned are not adequate for use of geopolymer concrete at 800 ^{0}C.

C. Compaction Factor

It is the weight of partially compacted concrete divided by the weight of completely compacted concrete.
Compaction factor = wt. of partially compacted concrete / wt. of fully compacted concrete
The results are shown in the below Table 3.7 compaction factor values

Mix design	Compaction Factor
MD1	0.66
MD2	0.69
MD3	0.66

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue II Feb 2024- Available at www.ijraset.com

MD4	0.68
MD5	0.63
MD6	0.61
MD7	0.62
MD8	0.66
MD9	0.68
MD10	0.64
MD11	0.69
MD12	0.68
MD13	0.62
MD14	0.73
MD15	0.75
MD16	0.63
MD17	0.65
MD18	0.60

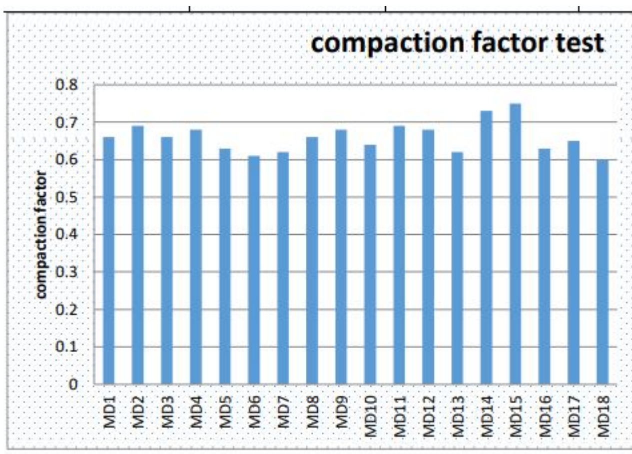


Table 3.7 Graphical representation of compaction factor

IV. CONCLUSION

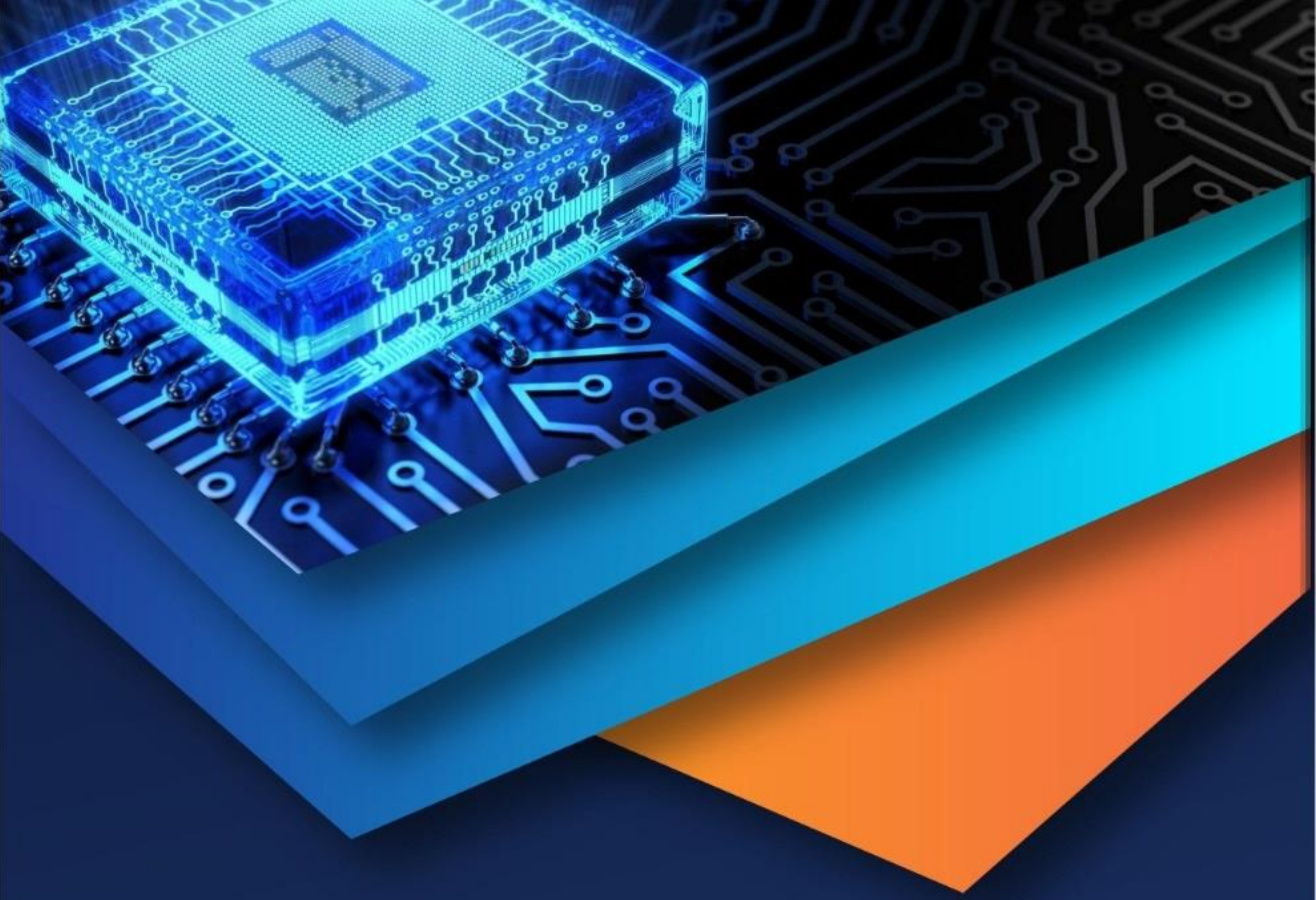
A GGBS and Bagasse ash based geopolymer was optimized by using a dynamic approach of the Taguchi method. The output results of slump, compaction factor, compresssive strength of the geopolymer concrete is shown by the graphical representation under optimized conditions were obtained. It was confirmed that the geopolymer manufactured with the optimized conditions exhibits good compressive strength at ambient temperature. As the compressive strength is reduced when it is exposed to elevated temperature. Geopolymer concrete shows the good workability with long term strength.

From on the experimental observation, the following conclusion are made.

1) GPC has been achieved by the mixes which are designed by Taguchi method.
2) Among the 7 control factors AAC/BC and the ratio of $NaOH+NaSiO_3$ andmolarity of NaOH having significant effects on the strength of the GPC.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue II Feb 2024- Available at www.ijraset.com

3) Boric acid has no significant effect on the strength of GPC.
4) Taguchi analysis indicated that the optimum parameters for compressive strength of concrete at ambient temperature were obtained from MD 734.6 N/mm2, MD6= 39.5 N/mm2, MD 1=40.79 N/mm2, and MD 8 =40.84 N/mm2 which were close to the target strength.
5) In the present investigation it shows that MD6, MD7 has adequate strength for use of geopolymer concrete at 200^0c.
6) In the present investigation it shows that MD2, MD3, MD13, MD10, MD11 has adequate strength for use of geopolymer concrete at 400^0c.
7) In the present investigation it shows that, MD3, MD 5 has adequate strength for use of geopolymer concrete at 600^0c.
8) Based on present investigation it shows that results of all 18 mix designs it has been observed that none of these 18 mix designs have restrained at the temperature of 800^0C.
9) As the percentage of the GGBS increases the strength increases.
10) It has observed as the molarity increases the compressive strength also increases.
11) Spalling, cracks or any other physical changes are not found till the temperaturereaches 600^0C.
12) The residual strength of GPC at elevated temperature gives less compressivestrength.



10.22214/IJRASET

INDEX COPERNICUS 45.98

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY