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Experimental Study on Properties of High volume GGBFS and High Volume Flyash Concrete

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Abstract: ***Construction industry consumes a huge volume of concrete every year and the demand for concrete as a construction material is on the increase. The main ingredient of concrete is cement and India is the second largest producer of cement in the world. The attention to environmental impacts of cement production has grown faster in recent decades. The cement industry is a significant greenhouse gases emitter mainly due to the calcinations of raw materials and the combustions of fuels. Portland cement production is increasing globally and contributes to greenhouse gas emissions. The current contribution of greenhouse gas emission from Portland cement production is about 1.5 billion tons annually or about 7% of the total greenhouse gas emissions[11].This leads to the utilization of wastes and industrial by-products in order to minimize the Portland cement consumption and also focuses on using eco-friendly concrete. In this experimental study There are 13 trials have been conducted on M40 Concrete in this study. out of 13trials , one trial is with control mix, 6 trials with Flyash at 60,70&75% of OPC replacement and the remaining 6 trials with GGBS at 60,70&75% OPC replacement.***
The investigations are being conducted for the fresh concrete properties like Workability of concrete, Temperature of concrete, Yield of concrete and Air percentage in concrete.
In hardened concrete the compressive strength and various durability tests were conducted like Rapid chloride permeability test, Initial surface water absorption test, water permeability test, 30 min water absorption test and Drying shrinkage test etc.
Keywords: Concrete, High volume, GGBFS, Flyash, Durability

I. INTRODUCTION

The production of cement contributes 5% of the global greenhouse gas emissions[6].Recent concrete construction environment focuses more on using environmentally friendly concrete to build taller structures. [19] Ground Granulated Blast-furnace Slag (GGBS) is a green mineral admixture that improves the rheology of fresh concrete, and its ultimate mechanical and durability properties. [19]The use of slag (GGBFS), an industrial by- product which otherwise would contribute to land pollution, as a replacement for Portland cement in concrete will result in less energy for the manufacture of cement and reduce the green gas emissions due to concrete construction [9] In India, the annual production of GGBS is 15 million tons in which only 55% of GGBS is utilized by the construction industry[10]Therefore, it is essential to increase the usage of industrial waste to the larger extent for the environmental benefits in the concrete industry.[15]Among these SCMs, numerous studies have been performed to evaluate fresh and hardened state properties of concrete Ground-granulated blast-furnace slag (GGBFS) is an industrial by-product of iron production used in steel making, with 50 million tons generated worldwide every year[8] Fly ash has been used for a long time in the concrete production; however usually the proportions is only limited to 15 to 25% [4] The HVFA term was introduced in CANMET in the 1980s, where the cement was replaced by at least 50% of fly ash. [4]

II. CASE STUDIES

Various national and international studies conducted on the High volume concrete using GGBFS and Flyash concrete.

1) Aliakbar Gholampour and Togay Ozbakkaloglu(2017) [1] Studied different properties of concretes To find out properties tests conducted such as workability, compressive strength, Elastic modulus Flexural and splitting tensile strength and Water absorption. It has been observed that when cement is replaced 90% with FA 58%Slump increases and in GGBS 51% slump decreases. It is observed larger decrease in the elastic modulus of FA mixes compare to control mixes. At the other end GGBS mixes shows higher elastic modulus than that of conventional concrete It has seen both the flexural and splitting tensile strength of ternary mixes were lower than that of the control mix. FA mixes develop a higher water absorption and GGBS mixes develop lower water absorption compared to that of conventional concrete The flexural and splitting tensile strength of ternary mixes are less than conventional concrete.

2) Ali Abdul Hussein Shubbar (2019) [2] Studied that when curing period is extended then compressive strength enhanced for all GGBS and PFA mixes. It is happened due to slow pozzolanic reaction. As percentage of GGBS and Flyash increases 7 days strength decreases compare to control mix. But at 14th day strength improved compare to 7days strength in both GGBS and Flyash. At the age of 28days compressive strength increase with 80 %GGBS and PFA.OPC is replaced with 80% GGBS and Flyash then it is improved compressive strength. If GGBS and Flyash used with high percentage that will help to reduced cement percentage, it helps to reduce CO2 emissions.

3) Ashish Kumer Saha (2018) [3]. Studied effect of partial replacement of Class F Flyash. Here Flyash replacement done with percentage 0,10,20,30,40.Except proportions of cement and Flyash other all raw material proportions were same. considering development of compressive strength Flyash mixes strength is seen incremental order as percentage is lower. when compared the drying shrinkage it has studied as percentage of Flyash increases drying shrinkage gradually reduces. Water permeability reduces as percentage of Flyash increases. For Flyash mixes as longer duration it has seen permeability reduces. Sorptivity is found less due to a longer period of curing. Effect of chloride permeability is found less as percentage of Flyash increase in mix. Due to pozzolanic reaction it continuously fills the void and create concrete denser. It has studied that concrete containing Flyash is more denser binder matrix compared to the control concrete mix.

4) B. Balakrishnan and A.S.M. Abdul Awal (2014) [4]. Studied the effect of high volume Flyash on mechanical and durability properties of concrete. Flyash were replaced with OPC 0, 40, 50 and 60%.Raw material selected were fulfilling the codal requirement. It has studied that as percentage of Flyash increase the strength decreases. Considering workability as percentage of Flyash increases the slump also increase as less percentage of Flyash the slump is less compare to control mix. Chloride penetration is high in control mix but in Flyash mix as percentage of Flyash percentage increases chloride penetration decreases. The specimens with high volume fly ash had experienced some weight and strength loss, the values were much lower as compared to 0% fly ash concrete. Specimen is dipped in chloride, sulphate and acid solution and effect of it measured. It has observed that due to pozzolanic reaction of Flyash received good compressive strength over the longer duration.

5) B K Varun & Harish B A.(2018) [5]. Studied partial replacement of cement by fly ash and ground granulated blast furnace slag for fresh properties, slump cone test, compaction factor test and vee-bee consistometer test. Very good result found in Fresh properties and Harden properties of Fly ash and GGBS as a partial replacement of cement in concrete. Amongst all mixes low volume of Fly ash and GGBS mixes is giving good result than high volume replacement. Slump and Compaction factor values are higher in high volume Fly ash and GGBS concrete. Vee bee value was found increased in minimum percentage of Flyash and maximum percentage of GGBS mix concrete. Maximum compressive strength and Split tensile strength found in 50% replaced OPC with Flyash and GGBS concrete. If used Incremental percentage of Flyash and GGBS in concrete that will save environment from generation Co2 from cement production.

6) Cahit Bilim, et, al(2009) [7]. Studied the prediction of compressive strength of ground granulated blast furnace slag concrete. Three different water–cement ratios (0.3, 0.4, and 0.5), three different cement dosages (350, 400, and 450 kg/m3. partial slag replacement ratios considered (20%, 40%, 60%, and 80%). Slag replacement is shows loss in early strength compare to control mix but later on slag mix is gaining higher strength than control mix. The results showed that can be an alternative approach for the predicting the compressive strength of ground granulated blast furnace slag concrete using concrete ingredients as input parameters.

7) Dongjin Kim (2019) [8]. Studied durability and rheological characteristics of concrete mixtures incorporating high volume ground-granulated blast-furnace slag (GGBFS). durability characteristics of high-volume ground-granulated blast-furnace slag (GGBFS) mixtures were tested such as shrinkage induced cracking, freeze-thaw resistance, carbonation resistance, and chloride ingress resistance. The shrinkage of GGBFS blended concrete reportedly remains low at early ages due to very slow latent hydration process of GGBFS and low cement content. The improved is seen in carbonation resistance of high-volume GGBFS mixtures. from the results it has been observed that coefficient of chloride diffusion was remarkably reduced with high-volume GGBFS replacements.

8) Gupta S (2016) [11] Studied Effect of cement is replaced by slag at 20% and 60% by weight. Studied compressive and flexural strength were measured for mechanical performance while water penetration test and chloride migration test. Superplasticizer dosage can be reduced with increased cement replacement. As fineness of slag increases compressive strength also increase. Mechanical and durability properties also found very less when slag fineness is more. Depth of water penetration is significantly reduced with increase in slag fineness. As slag replacement is higher resistance to water penetration found higher.

9) Jaehyun Lee (2020) [12] This study sought to assess the durability and technical performance of concrete blended with locally produced ground granulated blast-furnace slag (GGBS).to determine the ideal CaO content range that can guarantee durability. Thus, tests were carried out by increasing the GGBS replacement ratio by 10% between 0% and 70%, while the unit The weight of the binder was set at 330 kg/m3. According to the results, compressive strength tended to rise when CaO content and basicity rose within 28 days of age, while identical characteristics of compressive strength were seen at 56 days of age, regardless of CaO content and basicity. In terms of determining durability, evaluations of four test, carbonation depth, chloride penetration depth, relative dynamic elastic modulus, and weight reducing ratio—were recorded. The best CaO level was found to be between 53 and 56 percent (GGBS replacement ratio: 27.5 percent to 47.1 percent), satisfying all requirements.

10) Jianda Xin (2022) [13] Studied that effect of high volume fly ash (HVFA) on mechanical properties and thermal cracking resistance of concrete with a high w/b of 0.45 using temperature stress testing machine (TSTM).The replacement of cement to Flyash is (0%, 20%, 50% and 80%).Results showed that the mechanical properties of concrete mixture decreased with the increasing FA replacement level; the ratio of creep-to-free strain (i.e., relaxation behavior) of concrete mixture decreased when the FA replacement level reached 20%, and converted to increase for the FA replacement level ranging from 50% to 80%; FA replacement level with 50% showed a desirable effect on the thermal cracking resistance enhancement of high w/b concrete mixture regarding restrained cracking control.

11) Mohamed Elchalakani,et,al(2014) [14] Studied fresh properties setting times, and workability requirements also harden properties like strength and durability. Concrete mixes made with OPC replacement with GGBS with 50%, 60%S, 70% and 80% replacement. A fly ash-blended mix made with 30% fly ash was also tested. Water absorption and Rapid chloride permeability test was done to find out durability. 50% GGBFS and 30% FA achieved good durability. Most economical mix found 80% GGBFS and 20% OPC.

12) Raghavendra Y B ,et,al.(2021) [16] Studied partial replacement of GGBS helps to improve workability of concrete. It Also enhance retention of slump. Initial compressive strength observed low but incremental strength is observed at 28days test. In GGBS mixes better durability properties observed reduced water absorption and permeability is seen in these mixes compare to control mix. Due to slag pozzolanic reaction, concrete pores gets filled and concrete become dense. Replacement OPC with GGBS reduces cost of concrete.50% OPC replacement with GGBS gives best result in terms of workability, strength, durability, and economy.

13) S. Arivalagan. (2014) [17] Studied the strength of ground granulated blast furnace slag (GGBS) at various replacement levels and its efficiencies in concrete. OPC Replacement done 20, 40 and 60 percent on two grades of concrete are investigated. In GGBFS mixes setting time found increased by 30min.As replacement percentage increases setting time also increases. Compressive strength significantly can increase when OPC replaced with GGBFS .Initial compressive strength found less compare to 28days compressive strength. Split tensile value found slightly decreased with compare to control sample. Use of industrial waste products saves the environment and conserves natural resources.

14) Santosh Kumar Karri, et al. (2015) [18] Studied Effect of partial replacement of cement with ground granulated blast furnace slag (GGBS) by replacing cement via 30%, 40%, 50%. Different test conducted on sample specimen such as compressive strength, split tensile strength, flexural strength. Durability studies with sulphuric acid and hydrochloric acid were also conducted. As GGBS replacement increases in mixes workability of concrete also increases. As OPC replaced with GGBS up to 40% compressive strength found increased for all mixes. Excellent result found in Split tensile strength and flexural strength of concrete as OPC replacement is done with GGBS up to 40%.Compressive strength values of GGBS concrete effected to HCl and H2SO4

15) Seung-Yup Jang (2017) [20] Studied Lower the water binder ratioand combination of GGBS and FA high compressive stregth will achieve.If used GGBS and FA combination 50% and 30% respecively then excellent chloride diffusion resistance properties achieved.combination of GGBS and FA gives very good durability values.Higest porosity found in control mix compare to GGBS and FA mixes. As w/b ratio is varies it impact on compressive strength. Combination of OPC and GGBS 50% each is tested and found highest compressive strength amongst all other combination. Chloride penetration found very less in mix which has 50GGBS and 50%OPC combination

16) Syed Asif Ali & Professor Shaik Abdullah (2014) [21] Studied effect of replacement GGBS with 0 to 9% and Flyash 0 to 60%.As GGBS content increases workability reduces. Split tensile strength and High flexural strength is found high in 40% Flyash and 10% GGBS replacement concrete. Compressive strength found increased as GGBS and Flyash replacement increases. To make economic concrete OPC can be replace with GGBS and Flyash. Considering compressive strength and durability properties GGBS concrete can preferred

17) Tarun R Naik.(2003) [22] Studied long-term performance of concrete pavements made with high volumes of Class F and Class C fly ash (FA). It is studied that greater pozzolanic strength contribution of Class F fly ash relative to Class C Flyash. The concrete mixtures containing Class F fly ash exhibited higher resistance to chloride-ion penetration relative to mixtures containing Class C fly ash. The highest long-term compressive strength was achieved for the high-volume fly ash mixture. Chloride penetration is very low as percentage of Flyash both class C and Class F are increased in replacement percentage

18) XiangMing Zhou (2012) [23] Studied that effect of pulverized fly ash (PFA) and ground granulated blast furnace slag (GGBS) when mixed with different proportions. Flyash replaced with OPC done 30,50&70%.GGBS replaced with OPC done 30,50&70%.Studied workability of fresh concrete with different proportions of PFA and GGBS. Studied compression, split tensile test and Drying shrinkage test. Initial and final setting time is increases as percentage of PFA and GGBS increases. short discrete Fibers effects on workability of concrete in spite of proportions concreter has lower compressive and splitting tensile strengths compare to GGBS and control mix. Due to addition of fiber, it has seen continual increment in splitting tensile strength.30% GGBS replacement has seen more splitting tensile strength than control mix. It has studied Partially replacing PFA or GGBS reduced drying shrinkage of concrete.

III. MATERIALS

The raw material which used in study are given below:

1) *Cement:* The cement used in this study is Ordinary Portland Cement (OPC) 53 Grade cement brand is being used Ambuja Cement, manufactured according to ASTM C150.
2) *GGBS:* GGBFS was used which confirms to Requirement as per IS 16714:2018
3) *Flyash:* Class-F FA used in this study was sourced from the Thermal power plant Nashik, Maharashtra.
4) *Coarse and Fine Aggregate:* Dry and clean Crushed aggregate was used in concrete mixture. The aggregate used for the concrete mixtures consists of fine and coarse types. All aggregate source is Uran, Raigad, Maharashtra.
5) *Admixture:* A high range water-reducing superplasticizer was used in the concrete preparation. Polycarboxylate ether based superplasticizer manufactured used for all trial purposes.

A. Experimental Investigation

There are 13 trials have been conducted on M40 Concrete in this study. out of 13trials , one trial is with control mix, 6 trials with Flyash at 60,70&75% of OPC replacement and the remaining 6 trials with GGBS at 60,70&75% OPC replacement.

TM01 is the control mix trial TM02 &TM08 trials are done with 60% GGBS, TM04&TM10 trials are done with 70% GGBS, TM06 &TM12 trials with 75% GGBS; TM03 &TM09 trials with 60% Flyash; TM05 &TM11 trials with 70%Flyash; and TM07 &TM13 trials with 75% Flyash.

The investigations are being conducted for the fresh concrete properties like Workability of concrete, Temperature of concrete, Yield of concrete and Air percentage in concrete.In hardened concrete the compressive strength of each trial mix is tested at 7,28,56 and 90 days.

Besides, various durability tests were conducted like Rapid chloride permeability test, Initial surface water absorption test, water permeability test, 30 min water absorption test and Drying shrinkage test etc. All the durability tests were conducted on 56th day from casting date.

IV. RESULTS

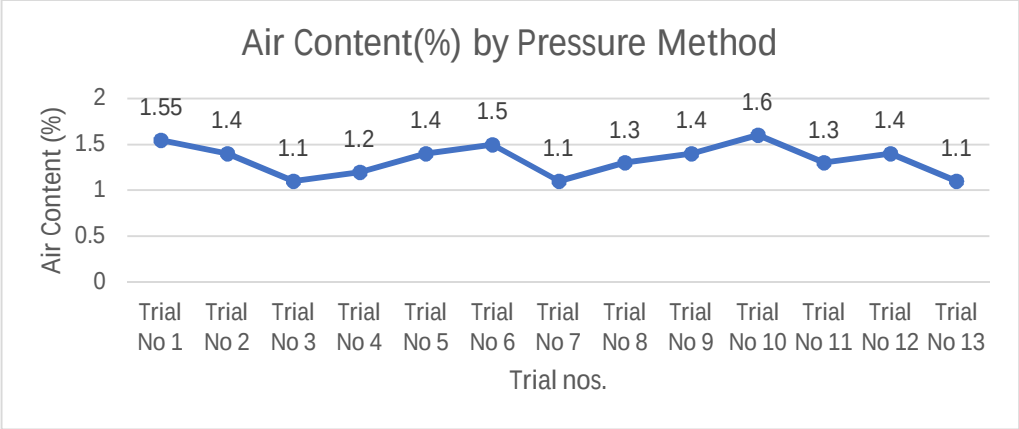
In this experimental study, various tests were conducted on concrete at fresh and hardened stage.In fresh concrete the tests conducted are like Air Content(%) by Pressure Method, Yield of concrete, workability and Temperature of concrete.

In hardened stage tests conducted are Compressive strength test and Durability test. In order to check durability of concrete various types of tests conducted in this study were Rapid chloride permeability test, Initial surface absorption test, Water permeability, 30min water absorption and Drying shrinkage.

The test results are discussed as follows:

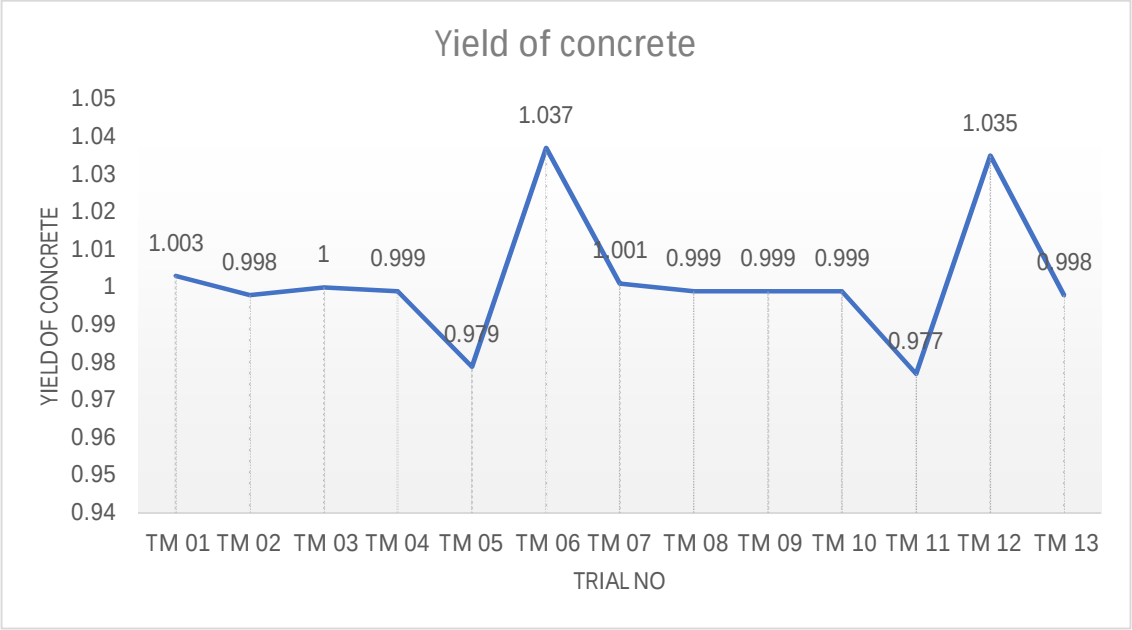
A. Fresh Concrete properties

1) Air Content(%) by Pressure Method



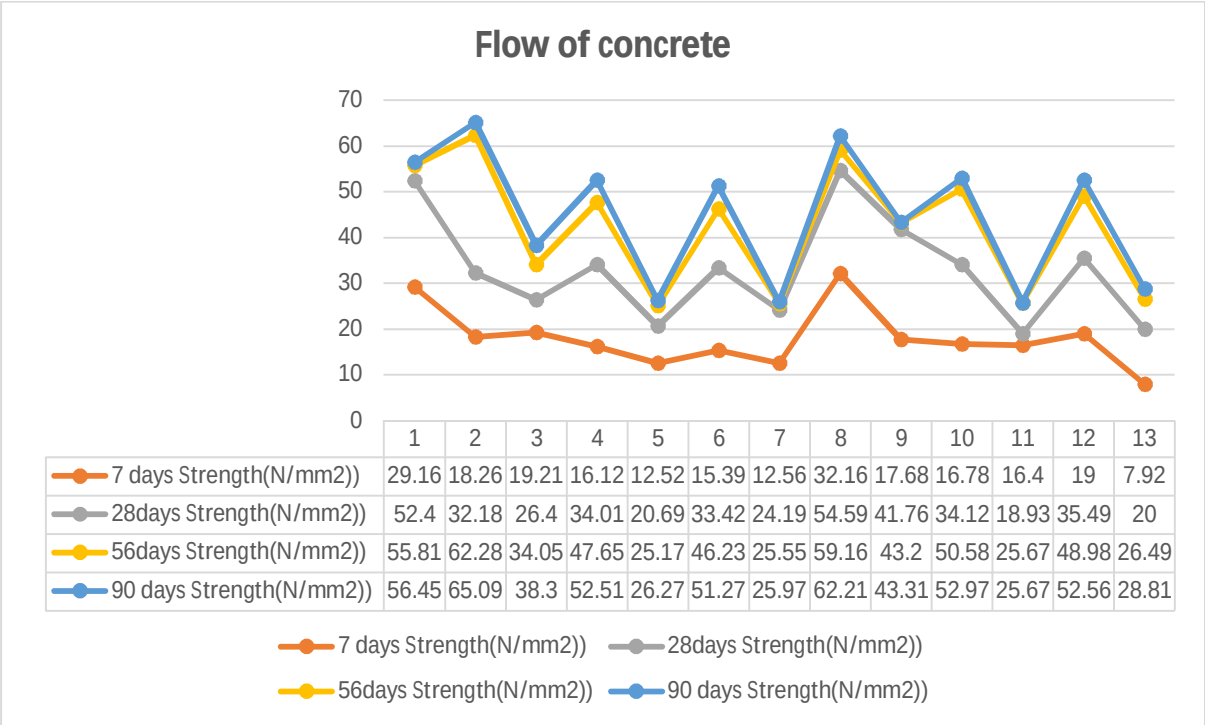
Referring to the above test results it has been found that in GGBFS mix air content vary from 1.2% to 1.6% and maximum air content found is 1.6%.In Flyash concrete the air content varies from 1.1% to 1.4%.It shows that maximum air content found is 1.4%. Air content present in fresh concrete with respect to trial numbers. It has observed from above graph air content is lies between 1.1% to 1.6%.

2) Yield of Concrete



The below graph shown in Fig.No3 illustrates yield of fresh concrete of each trial mix. It has observed that yield of concrete is varies in between 0.977 to 1.037. It shows that in spite of replacing cementitious in various percentage in concrete it is not making drastic change in yield of concrete.

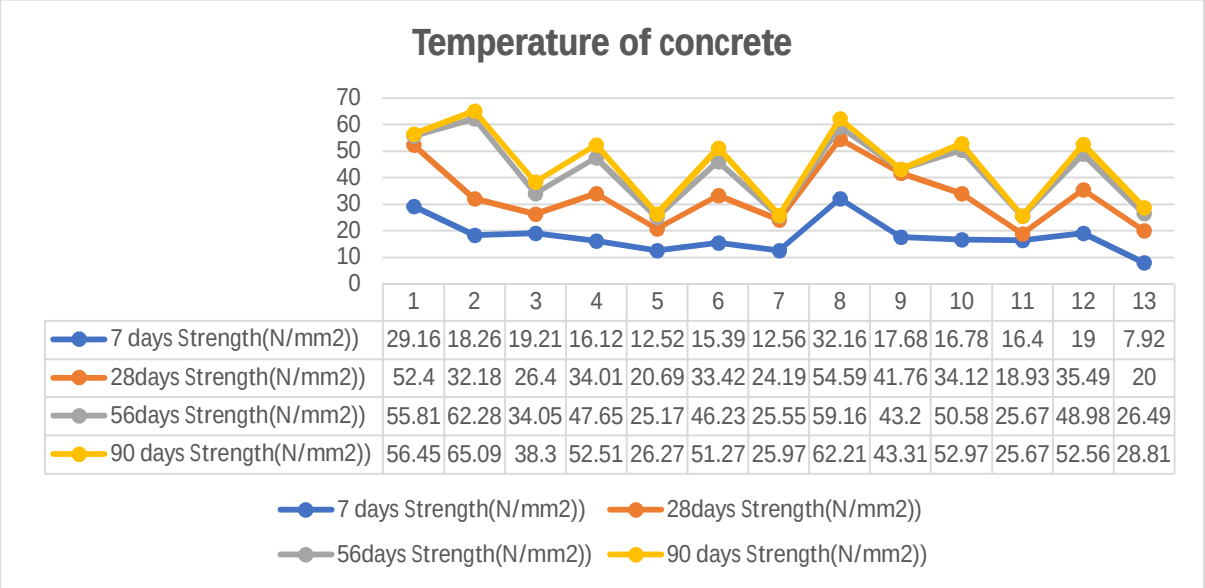
3) Flow of Concrete



	1	2	3	4	5	6	7	8	9	10	11	12	13
7 days Strength(N/mm2))	29.16	18.26	19.21	16.12	12.52	15.39	12.56	32.16	17.68	16.78	16.4	19	7.92
28days Strength(N/mm2))	52.4	32.18	26.4	34.01	20.69	33.42	24.19	54.59	41.76	34.12	18.93	35.49	20
56days Strength(N/mm2))	55.81	62.28	34.05	47.65	25.17	46.23	25.55	59.16	43.2	50.58	25.67	48.98	26.49
90 days Strength(N/mm2))	56.45	65.09	38.3	52.51	26.27	51.27	25.97	62.21	43.31	52.97	25.67	52.56	28.81

Workability test done for longer period also that is depend on the concrete mixes. Here in experimental study flow test conducted with the help of flow table. Time interval for test is initial,1hour,2hourand 3hour from batching time. At every interval flow is recorded it is seen that there is very less difference amongst all mixes

4) Temperature of Fresh Concrete

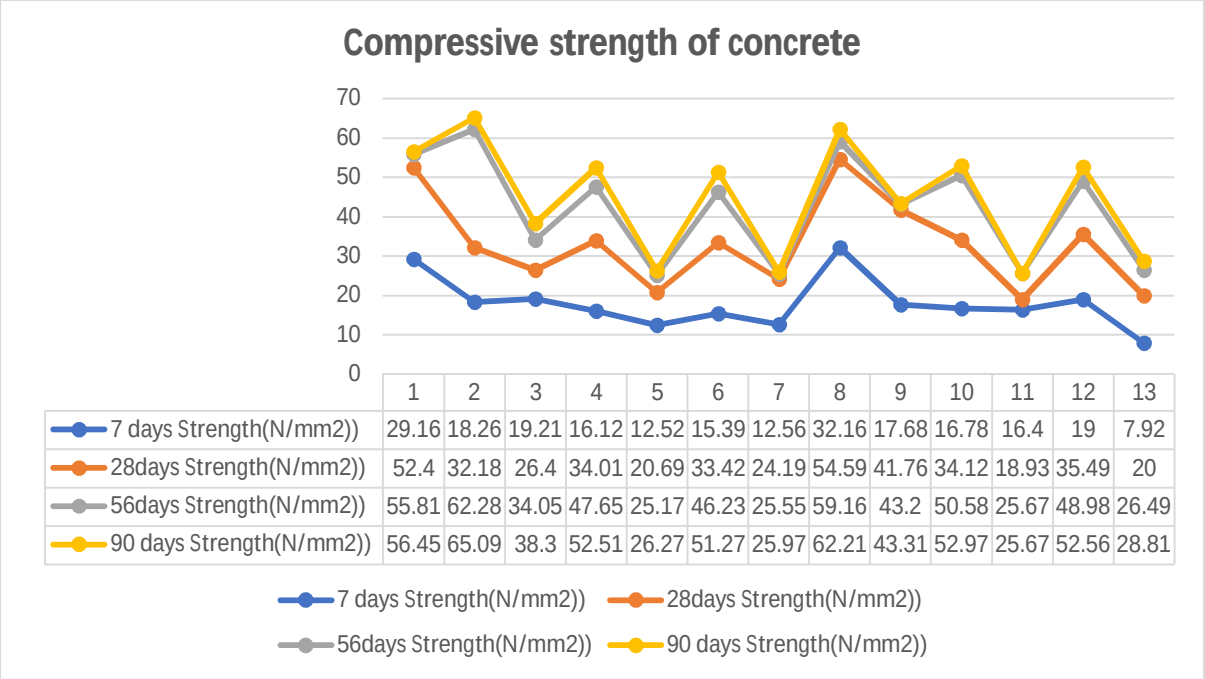


	1	2	3	4	5	6	7	8	9	10	11	12	13
7 days Strength(N/mm2))	29.16	18.26	19.21	16.12	12.52	15.39	12.56	32.16	17.68	16.78	16.4	19	7.92
28days Strength(N/mm2))	52.4	32.18	26.4	34.01	20.69	33.42	24.19	54.59	41.76	34.12	18.93	35.49	20
56days Strength(N/mm2))	55.81	62.28	34.05	47.65	25.17	46.23	25.55	59.16	43.2	50.58	25.67	48.98	26.49
90 days Strength(N/mm2))	56.45	65.09	38.3	52.51	26.27	51.27	25.97	62.21	43.31	52.97	25.67	52.56	28.81

In study experiment normal water being used for concrete mix but temperature of concrete is also recorded to see the effect of OPC replacement. Temperature recorded at Initial,1hr.,2hr and 3hr. There are many factors may affect on temperature of concrete. For e.g. Temperature of aggregate, water, cementitious percentage used in mixes, atmospheric temperature etc. These all may result in increasing temperature of fresh concrete.

V. PROPERTIES OF HARDENED CONCRETE

A. Compressive Strength Test

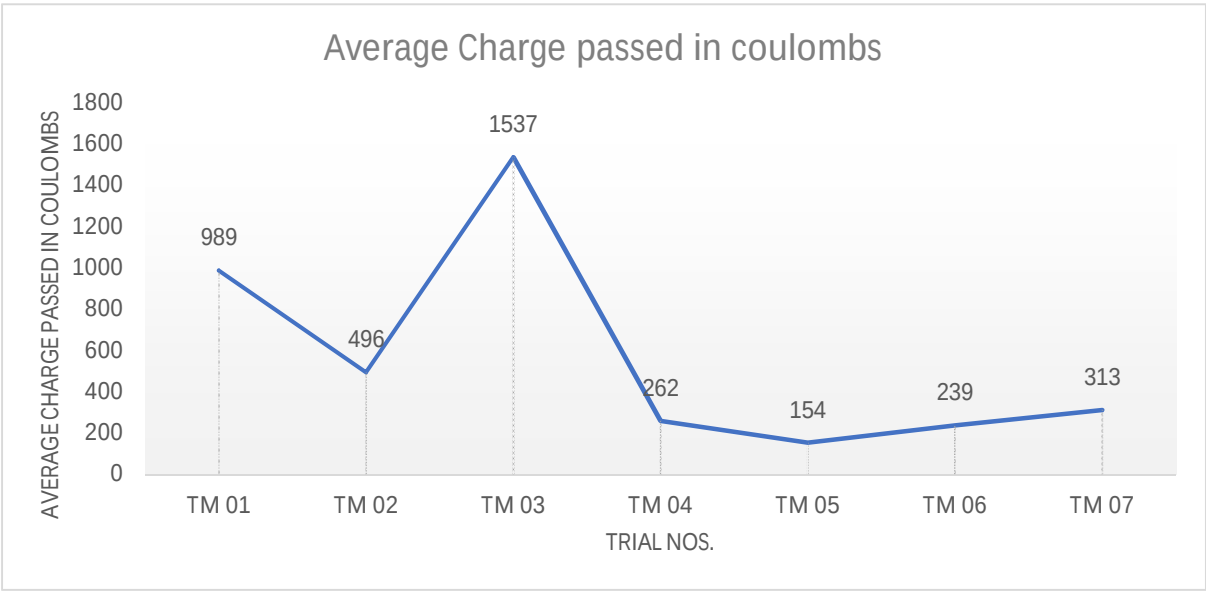


	1	2	3	4	5	6	7	8	9	10	11	12	13
7 days Strength(N/mm2))	29.16	18.26	19.21	16.12	12.52	15.39	12.56	32.16	17.68	16.78	16.4	19	7.92
28days Strength(N/mm2))	52.4	32.18	26.4	34.01	20.69	33.42	24.19	54.59	41.76	34.12	18.93	35.49	20
56days Strength(N/mm2))	55.81	62.28	34.05	47.65	25.17	46.23	25.55	59.16	43.2	50.58	25.67	48.98	26.49
90 days Strength(N/mm2))	56.45	65.09	38.3	52.51	26.27	51.27	25.97	62.21	43.31	52.97	25.67	52.56	28.81

Here in study experiment compressive strength conducted on 7,28,56 and 90 days. All test result have recorded and analyzed. Details are as follows. It has been observed that early strength of both GGBS and Flyash concrete is less or equal to control mix concrete. As percentage of GGBS increases strength of concrete also increase. It has been seen that stable and incremental strength is achieved by 60 and 70% GGBS replacement mix. After that there is slight decrease in strength observed in 75%GGBS replacement mix. Considering Flyash replacement 60,70 and 75% in all mixes strength decrease In comparison with control and GGBS mixes. Even Flyash mixed not achieved grade strength that is 40N/mm2.

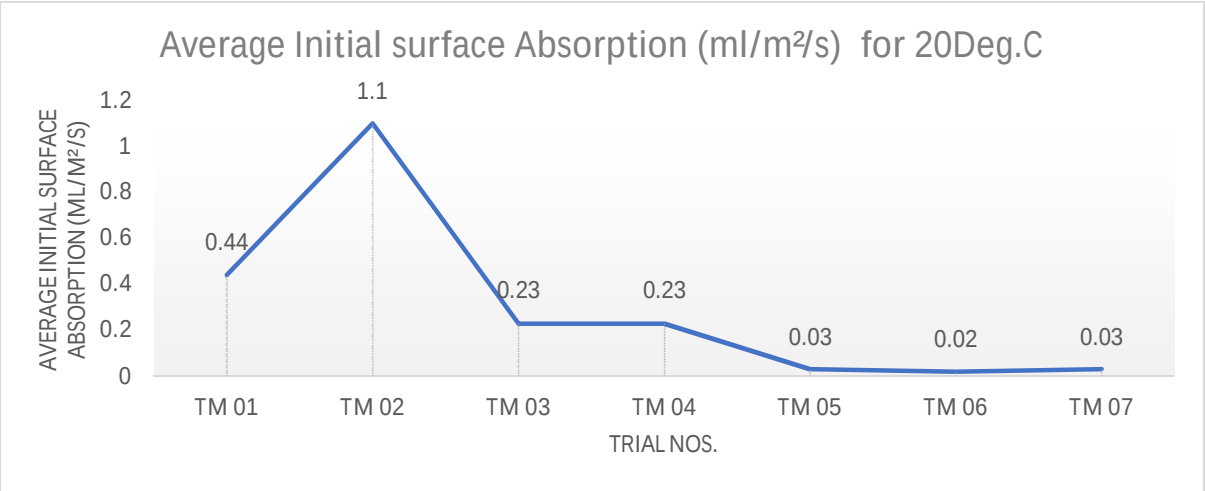
B. Durability Tests

1) Rapid Chloride Permeability Test



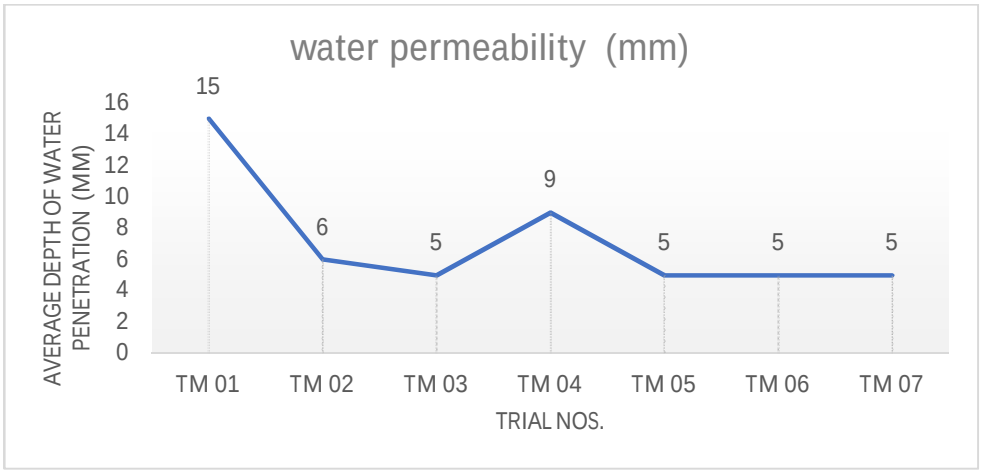
Durability tests conducts on harden concrete after 56 days of casting samples until that cured in water in laboratory temperature 27deg.c (+- 2deg.c).It has been observed that maximum RCPT average value 1537C achieved by TM 03 mix that is OPC replacement 60% Flyash.
Minimum RCPT average value observed is 154C in TM 05 which is 70%OPC replacement with Flyash.

2) Initial Surface Absorption Test



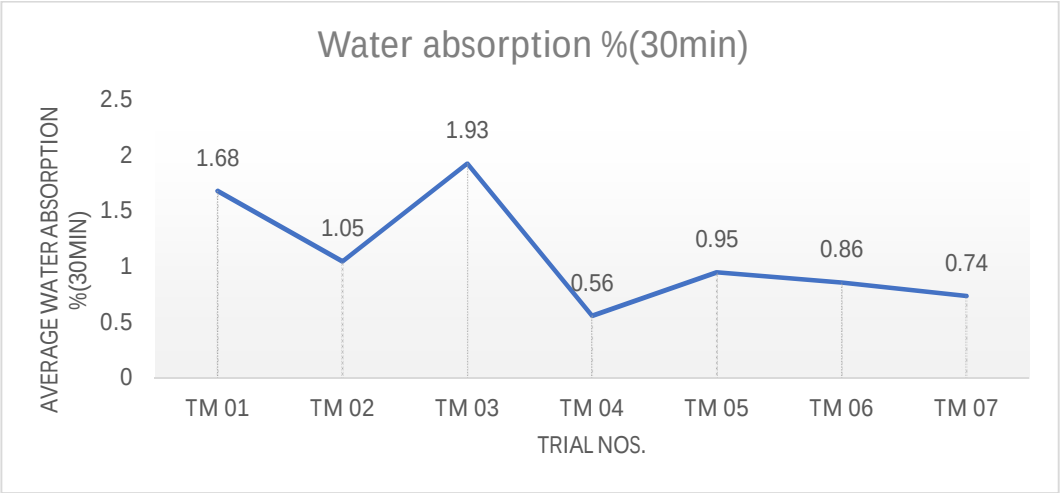
The above graph represents average value of Initial surface absorption at 56th day Highest ISAT observed in TM02 that is 1.1ml/m2/sec. and lowest ISAT observed in TM 06 that is 0.02ml/m2/sec. That mean trial no 06 has less absorption compare to all other result. ISAT value may increases due to porous concrete surface or high water absorption of raw material used in concrete mixes.

3) Water Permeability



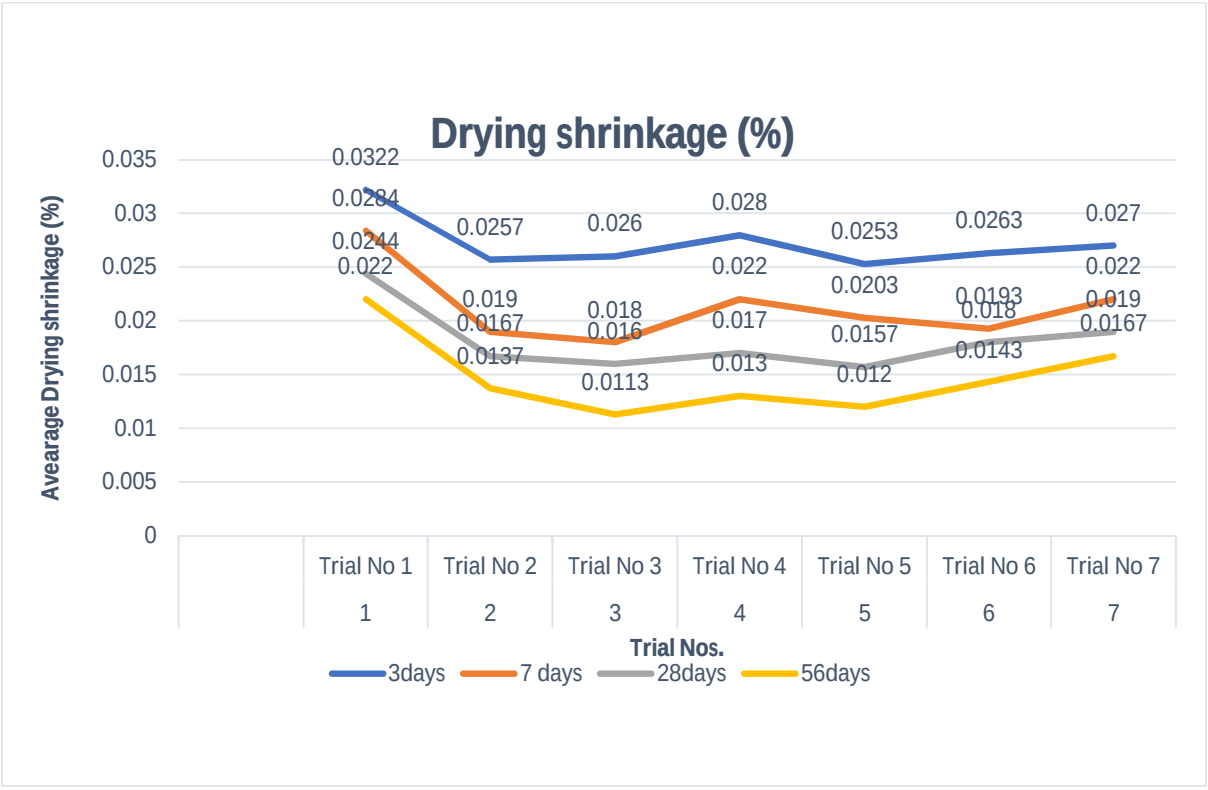
Water permeability test result found more in control mix that is Average Depth of water penetration is 15mm.altough as per DIN 1048 it is less than maximum allowable limit that is 20mm, but it is highest amongst all mixes. Considering other mixes TM03,TM05,TM06 and TM07 Average Depth of water penetration found 5 mm. that is less compare to all other mixes. OPC replacement with GGBS and Flyash both shown exceptionally good resistance to Water permeability.

4) 30min Water Absorption



The above graph shown average of water absorption test result at 56th day. The maximum water absorption is observed in TM no 03 that is 1.93% and minimum water absorption observed in TM no 04.that is 0.56%.It shows that Tm no 03 has more water absorption and TM no 04 has less water absorption.

5) Drying Shrinkage



Shrinkage is the inherent properties of cement and concrete. As heat of hydration process takes place and same time concrete start to set. As initial setting time starts the shrinkage activity also starts.to stop shrinkage need to retain moisture on concrete surface.
The below graph Fig.No. 20illustrate average Drying shrinkage test result at 3,7,28& 56th day. More shrinkage observed 0.0322% in TM no 01 at 3rd day. And less shrinkage observed 0.0113% in TM no 3at 56th day.

VI. CONCLUSION

After analyzing all of the combinations, it was revealed that Flyash compositions have the least amount of air content, maximum RCPT values, more resistant to surface absorption. The influence on concrete yield is minor in all combinations. if the Fly ash content increases, the workability may decrease and vice versa. Because GGBS does not absorb water, the combination's workability increases as the amount of GGBS in the mixture increases. The GGBFS exothermic reaction rate is relatively slow, it will take more than 90 days or more to achieve the required strength for replacement levels more than 70%. The grade strength was not achieved even after adding flyash versus control mix. according to the initial surface absorption test results, and they are more consistent in ISAT. Results of the 30-minute water absorption reveal that GGBS mixtures are more robust than Flyash mixes.The results of concrete drying shrinkage are evident. According to the study's findings, GGBS mixes that were substituted up to 70% showed the best performance in terms of workability, strength, and durability.

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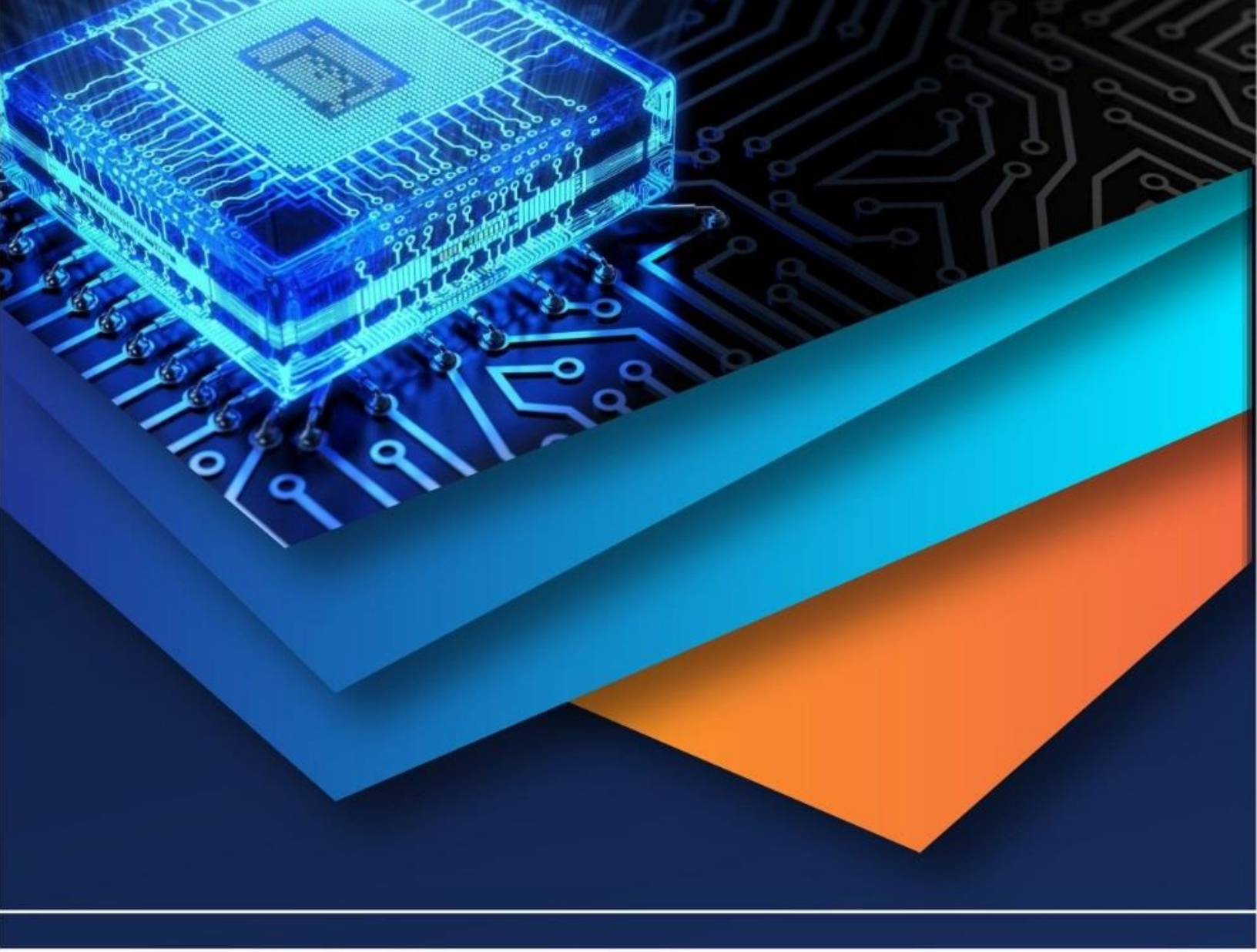

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