

An Experimental Study on Durability Attributes of Concrete by Partially Superseding Cement with GGBS and Fine Aggregates with Copper Slag

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ABSTRACT: This paper presents studies on durability idiosyncrasies of concrete by partial replacement of cement with GGBS and fine aggregates with copper slag. The study on type of materials incorporated in project was done so as to comprehend its effect in mix design. Slag which is an industrial by product had major problem affecting environment so this solid waste can be disposed off. These by products are employed in concrete as partial replacement for cement or aggregates which can pass through 4.76mm sieve size. Initially preliminary test was conducted by only supplanting cement with GGBS by 10%, 20% and 30%. The optimum result obtained that is compressive strength for one sort of proportion (10% GGBS) is kept constant throughout the project. In other words copper slag is the parameter which is varied in multiples of 10 from 10% to 40%. Durability tests were performed on these specimens prepared of various proportions and analogized to normal concrete which doesn't contain any slag. The results obtained from these are tabulated and plotted in the form of graph.

KEYWORDS: Durability, Strength, Copper slag, GGBS.

I. INTRODUCTION

Introduction

A conventional concrete is a coalescence of cement, fine aggregates, coarse aggregates and water. Aggregates give the target strength to the matrix after 28 days of curing. Whilst, Cement being hydrophilic in nature acts as a binding material when mixed with water. So as not to have honey combing, sand plays its role. Sand used should be free from impurities otherwise the concrete won't be strong enough due to organic matter or silt present in it. There are two aspects as far as concrete checks are concerned:

- 1) Strength of Concrete
- 2) Durability of Concrete

Mechanical failure differs from durability failure in the sense the former incorporates loss of carrying capacity due to service loads or ultimate loads applied which is determined by performing strength tests. Durability failure requires probabilistic approach unlike the former one. It may fail due various attacks. Strength tests have been conducted mandatorily over the period of time but recently durability has also been given equal importance and taken up earnestly due to series of failure in structures. The proficiency of concrete to countenance environmental, chemical attacks over its entire lifespan for which it is designed without dilapidation is known as Durability.

Production of GGBS

A white amorphous fine powder which is procured by quenching molten iron slag from blast furnace is called GGBS. The chemical composition chiefly alters with the composition of raw materials in iron production unit. In blast furnaces, having temperature about 1500 degrees centigrade that is 1773.15 Kelvin, a combination of suitable mixture of Iron ore,

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coke and limestone is catered. When the above mixtures are thawed in the process two products are yielded molten iron and molten slag. Molten slag being heavier remains below molten iron. Silica and alumina impurities from iron ore are combined with oxides of limestone. In order to splinter slag, the granulation process can be applied wherein squirt of stream is forced through molten slag. Fineness of GGBS is relatively the same as that of Portland cement.

Production of Copper Slag

Copper slag is a waste product from industries which can replace either cement or fine aggregates. The density of copper slag is more analogized to other materials due to towering configuration of Fe_2O_3 . The slag used for this project is obtained from Lakshmi Ganesh and co based in Tuticorin, Tamil Nadu. It is a slag extracted from copper in the process of heating and melting. Sulphides, oxides of ferric and copper are chief modules of smelting charge. It also envisages Silicon Oxide (SiO_2), Aluminum Oxide (Al_2O_3), Calcium Oxide (CaO) and Magnesium Oxide (MgO) which are, if absent in former concentration, added as flux. Oxides of Iron, Sulphur, Copper command over the physical and chemical configurations of smelting system. The impurities formed due to the above action start floating on this liquefied metal. This slag hovers in water and forms angular granules which are called a copper slag. Usage of this material helps in abridging dumping problems and concrete as far as cost is concerned.

Objectives

- 1) Mix design for M25 grade concrete for conventional concrete and blended concrete.
- 2) Scrutinize the durability properties of M25 grade concrete by partially supplanting cement and fine aggregates with GGBS and copper slag respectively.

II. LITERATURE REVIEW

Al-Amoudi, Al-Kutti, Ahmed, Maslehuddin focused on durability indices of plain and blended cement concretes. In this concrete specimens were prepared by replacing with silica fume and fly ash apart from normal concrete and water cement ratio was also changed for the specimens. Compressive Strength, Chloride Permeability, Water Penetration and Coefficient of chloride diffusion were obtained at the end of 28 days of water curing. Correlations between compressive strength and other durability parameters were achieved and analyzed by plotting a graph. These correlation values help learner deduce the durability characteristics of specimen using a formula which involves regression value but this factor can be found out from the analysis table. An excellent correlation was penned down between compressive strength and durability configuration. These correlations pave way for determining durability idiosyncrasies.

Brindha and Nagan presented the importance of copper slag in concrete. Copper slag was partial replacement for sand and results were obtained. The proportion in which the substitution was done was 0%, 5%, 10%, 20%, 30%, 40% and 50%. Leaching studies were also envisaged since harmful elements such as copper and iron are majorly there in it. The result of leaching showed that it doesn't make an easy way for these harmful constituents into concrete thereby reducing the strength and other idiosyncrasies. The compressive strength of concrete was ascended by about 40% and split tensile strength escalated around 30-35%. The optimum dosage of copper slag as a replacement for sand was 40%.

Swaroop, Venkateswararao and Kodandaramarao highlighted the importance of slag in concrete. Fly Ash and GGBS are two industrial slags produced which are nowadays utilized in civil engineering which solves the major problem of disposal. They evaluated the strength and weight loss in five mixes of M30 grade concrete. The first mix consisted of normal concrete so that it forms the base for comparison. The second mix was prepared by supplanting cement with 20% Fly Ash. The third trial mix incorporated 40% Fly Ash in place of full cement. Whereas, the fourth mix coalesced 20% GGBS and fifth mix amalgamated 40% GGBS. The impact of these mixes was determined by immersing in 1% of sulphuric acid for 7 days, 28 days and 60 days. The verdict of this was that blended concrete having 20% replacement of slag have satisfactorily gained strength as well as had excellent durability properties compared to normal concrete

Patil, Dwivedi and Patil consolidated on partial replacement of cement with GGBS. In this, ordinary portland cement was replaced by certain proportions of GGBS that varies between 10% and 40% in multiples of 10. This study revealed the fact that there is an inverse relation between compressive strength and percentage of replacement by

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GGBS. More the replacement lesser is the strength of concrete mix. Although, water cement ratio for blended concrete can be reduced since GGBS yields better workability for the same control mix. As mentioned above the relationship between variation of GGBS and strength, upto 20% replacement gives satisfactory results. If the replacement level advances beyond it then strength decreases. GGBS not only serves the purpose of maintaining economy in construction but also dissolves the problem of waste slag which is highly generated in abundance from steel industries.

III. EXPERIMENTAL INVESTIGATION

Prior to conducting preliminary test materials were collected and Mix Design for M25 grade concrete was done. Mix proportion for M25 grade concrete is shown in table 1.

Table 1. Mix proportion for M25 grade concrete

Mix Proportion for M25 Grade Concrete
Cement- 426 Kg/m ³
Water- 192 Kg/m ³
Fine Aggregate- 650 Kg/m ³
Coarse Aggregate- 1148 Kg/m ³
Mix Ratio- w/c:C:FA:CA
Mix Ratio- 0.45:1:1.53:2.69

This project so far has two varying parameters, one is GGBS and other is Copper Slag. From most of the journals referred, the optimum dosage of supplanting material could be decided but to check if it really holds true, a preliminary test was conducted before heading towards durability tests for actual project.

In this preliminary experiment only cement was replaced with GGBS in proportion of 10%, 20% and 30%. In addition to the specimens of size 150x150x150mm of above combinations, conventional concrete incorporating cement, sand, coarse aggregate and water was cast. The results by replacing cementitious material was compared to the conventional concrete and thus the value of compressive strength obtained at the end of 7 days of water curing was taken as fixed parameter throughout the project. The value of compressive strength (7 days) is 2/3rd of strength at the end of 28 days. Hence the results could be extrapolated.

Acid Resistance Test

Acid resistance test was carried out on cubes of standard size 150x150x150mm. The specimens were water cured for 28 days and then they were immersed in chemical having concentration of 2 Normal, 10% by weight of hydrochloric acid for about 4 weeks. The cubes were subjected to alternate wetting and drying conditions for every 2 days. The compressive strength and weight loss of the cubes were noted down at the end of 7 days and 28 days of chemical curing.

Chloride Resistance Test

This test was carried out on cubes of standard size 150x150x150mm specimens. After the period of 28days of water curing the specimens were immersed in a chemical solution having diluted 5% by weight of NaCl with water for around 4 weeks. The cubes were exposed to alternate wetting and drying conditions for 2 days. The weight loss and compressive strength of cubes were penned down at the end of 7 days and 28 days of chemical curing.

Sulphate Resistance Test

This test was carried out on cubes of standard size 150x150x150mm specimens. After the period of 28days of water curing the specimens were immersed in a chemical solution having diluted 5% by weight of MgSO₄ in water for around 4 weeks. The cubes were exposed to alternate wetting and drying conditions for 2 days. The weight loss and compressive strength of cubes were obtained at the end of 7 days and 28 days of chemical curing.

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Abrasion Test

Specimens of size 70x70x35mm were cast and water cured for 28 days. Five points were marked (4-corner and 1-centre). Prior to testing the weight of each specimen and the thicknesses at every marked points were noted down. The testing machine for this experiment is known as abrasion testing machine which is an assemblage of grinding disc, funnel, surcharge weight, socket and sensor. Before inserting specimen into the socket revolutions were set (22). Abrasive powder was fed into the funnel (Al_2O_3) and after the completion of first round the specimen about its vertical axis was maneuvered orthogonally. This was done until ten rounds that is 220 revolutions for one specimen. Loss in weight and thicknesses were penned down.

Water Absorption Test

The size of specimens was in the shape of a cube sizing 100x100x100mm. Cubes were sculpted and cured for 28 days by immersing in water. Lesser the absorption better is the concrete. No value of individual absorption should exceed 7% and average must not cross 5% as per guidelines. The values of sorptivity obtained were 1.27, 1.29, 1.16, 1.25 and 1.09 for NC, 10%, 20%, 30% and 40% respectively. Hence, the optimum percentage for replacement is 40%.

Corrosion Test

Corrosion test is a non standard test which was conducted on a specimen, cylindrical in shape, having diameter of 100mm and altitude 200mm with a 10mm steel rod insinuated inside the specimen at the centre maintaining cover of 45mm from sideways and 7mm to 10mm approximately from bottom. These specimens were cast and water cured for 28 days. Prior to casting, every steel rod was weighed. The apparatus required for this test are steel plates, regulated DC power supply unit, crocodile clips and bucket. A solution called brine was prepared to aid the process. Brine is a solution in which water is impregnated with salt, here it was sodium chloride ($NaCl$). Brine was concocted by adding 5% of $NaCl$ in 1litre of water. The testing begins with a specimen being placed in bucket containing brine upto a brim of cylinder. Steel plates were aligned with an inclination externally in the bucket. The concept of this is that steel plates act as cathode and embedded steel rod acts as anode. A potential of 30V was eternally supplied and the value of current at an interval of 30 minutes was observed in Amperes. A sharp rise in current connotes cracking of specimen. Generally, 3 hours observation is necessary for this test. The specimen was then opened and corroded steel rod embedded inside it was taken out for inspection. It was dipped in Clark's solution for 25minutes. Clark's solution is prepared by integrating 1 litre Hydrochloric Acid (HCl), 50gms Stannous Chloride ($SnCl_2$) and 20gms Antimony Trioxide (Sb_2O_3) then these corroded bars were weighed to deduce the loss of weight due to rusting or corrosion experiment.



Figure 1. Corrosion test (a) Experimental setup (b) Specimens for the test

Rapid Chloride Penetration Test

Chloride diffusion into concrete is one of the major causes of deterioration hence it is important to comprehend its effect. Diffusion of chloride ions assists depassivate the protective layer around steel which in turn affects the durability

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leading to failure. This test is accomplished in accordance with ASTM C 1202 to resolve the electrical conductivity and its resistance towards permeability of chloride ions in concrete. The specimens were water cured for a period of 28 days. The current was passed through cylindrical block of 50mm altitude and 100mm diameter by eternally supplying a potential of 60 volts for 360 minutes. This test is an assembly of various instruments such as regulated DC power supply, two reservoirs, crocodile clips. The role of crocodile clips was to make connections to a desired terminal while reservoirs (which are empty initially and then for this test were filled with chemical solutions) were prerequisite to keep the specimen intact between them. Regulated DC power supply provided the steady voltage. The chemical solutions driving the process were 0.3M Sodium Hydroxide (NaOH) and 3% Sodium Chloride (NaCl). The reservoir connected to a positive terminal was filled up with 0.3 Molar Sodium Hydroxide and the one connected to negative terminal of DC source was filled with 3% Sodium Chloride. A constant potential of 60 volts was supplied throughout the experiment for long and continuous 6 hours. The current across the specimens was penned down in milliamps (mA). This value of current, after the completion of test, was converted into Coulombs (C) using a formula which is deduced from trapezoidal rule. Quality of concrete can be gauged based on the unit formulated in ASTM C 1202. To convert into coulombs the following formula shall be used

$$Q=900[I_0+2(I_{30}+I_{60}+\dots+I_{360})]$$



Figure 2. Experimental setup of rapid chloride penetration test

Elevated Temperature Test

The cubes of 100x100x100mm were sculpted and cured for 28 days. After this duration, one or two cubes were tested in CTM and compressive strengths were noted down. The remaining specimens were incubated at 500oC in muffle furnace for 4 hours. Care should be taken while taking out the cubes from the chamber. After heating, with this intensity, some cubes were instantly immersed in water and some were exposed to room temperature as a process of curing for 1 day. On the next day, these water and air cured specimens were tested and the compressive strength ratio was observed that should marginally be close to 1.

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IV. EXPERIMENTAL RESULTS

Experimental results for preliminary and durability tests are presented in tables and figures shown below.

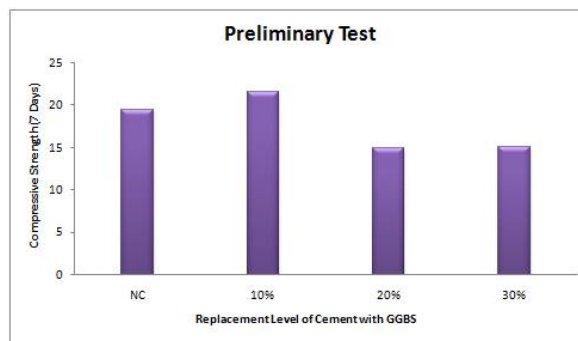


Figure 3. Strength parameter between various combinations of blended concrete and normal concrete

The above result shows that cement replaced with 10% GGBS produced better results than other set of combinations as far as strength parameter is concerned.

Acid resistance test

It depicts that the strength parameter after 7 and 28 days of chemical curing is more for 40% replacement of sand with copper slag and weight loss is less for 30% replacement as shown in table 2.

Table 2. Results of cubes immersed in HCl solution

Specimens	Compressive Strength (MPa)		Change in Weight (%)	
	7 Days	28 Days	7 Days (Loss)	28 Days (Loss)
NC	30.10	28.40	1.15	1.84
10%	36.15	30.00	1.53	1.92
20%	38.75	25.50	0.64	1.05
30%	34.15	31.40	0.63	0.87
40%	40.15	37.15	0.87	0.92

Chloride resistance test

It depicts that the strength parameter after 7 and 28 days of chemical curing is more for 30% replacement of sand with copper slag whereas there was increase in weight at the end of 7 days of chemical curing and 10% showed more increase than other variations but the results at the end 28 days displayed loss in weight parameter. The increase in weight is mainly due to crystal formation around the specimens. Amongst all, 40% replacement of sand with copper slag has clearly indicated the same weight before immersing in chemical solution which is 0% as long as weight criterion is concerned. Results are shown in table 3.

Table 3. Results of cubes immersed in NaCl solution

Specimens	Compressive Strength (MPa)		Change in Weight (%)	
	7 Days	28 Days	7 Days (Gain)	28 Days (Loss)
NC	41.40	38.80	0.25	0.24
10%	38.30	37.20	0.32	0.25
20%	29.90	25.90	0.25	0.12
30%	42.95	39.20	0.25	0.13
40%	39.90	39.10	0.19	0

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Sulphate resistance test

The test results are accentuated below in table 4 and hence the graphs are plotted. It depicts that the strength parameter after 7 days of chemical curing is more for 30% replacement of sand with copper slag but after the complete period strength observed was more for 40% replaced sand. There was increase in weight at the end of 7 days of chemical curing and 30% showed more increase than other variations but the results at the end 28days displayed loss in weight parameter. The increase in weight is mainly due to crystal formation around the specimens.

Table 4. Results of cubes immersed in MgSO₄ solution

Specimens	Compressive Strength (MPa)		Change in Weight (%)	
	7 Days	28 Days	7 Days (Gain)	28 Days (Loss)
NC	37.65	36.40	0.07	0.60
10%	36.85	32.80	0.06	0.39
20%	31.95	25.90	0	0.26
30%	39.50	35.50	0.19	0.27
40%	37.50	36.80	0.07	0.12

Abrasion test

The results tabulated below (table 5) accentuates that, 40% replaced material yielded better resistance to abrasion in both parameters which are loss in thickness and weight. The loss in thickness and weight for 40% substituted fine particle was 0.09mm and 1.33gms respectively.

Table 5. Final results of abrasion test

Proportion	Average Loss in Thickness (mm)	Average Loss in Weight (gms)
NC Specimens	0.34	3.20
10% Specimens	0.33	3.50
20% Specimens	0.30	2.50
30% Specimens	0.19	2.17
40% Specimens	0.09	1.33

Corrosion test

The test results accentuated in table 6 depict that the value of current initially increases for first 90minutes and then gradually decreases until the completion of experiment. It was observed that the peak value of current was 1.84 Amperes for 40% which is lesser peak value contrasting other specimens of blended and normal concrete. The loss in weight of reinforcement after being submerged into Clark's solution was relatively less for 40%.

Table 6. Results of corrosion test

Time (min)	Current in Ampere				
	NC	10%	20%	30%	40%
30	1.24	1.43	1.68	1.54	1.57
60	1.83	1.53	1.76	1.85	1.71
90	2.02	1.87	1.97	1.90	1.84
120	1.85	1.48	1.56	1.31	1.60
150	1.63	1.35	1.24	1.15	1.13
180	1.57	1.28	1.01	0.99	0.80
Weight of Steel Bar (gms)	NC	10%	20%	30%	40%
Initial Weight	154.03	154.11	148.23	149.38	152.17
Final Weight	152.49	152.64	146.90	148.25	151.31
Weight Loss	1.54	1.47	1.33	1.13	0.86

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Rapid chloride penetration test

This connotes that the all the specimens posses good resistance to chloride diffusion into slices since the value of chloride permeability for all is ranging between 1000 and 2000 units that is low.

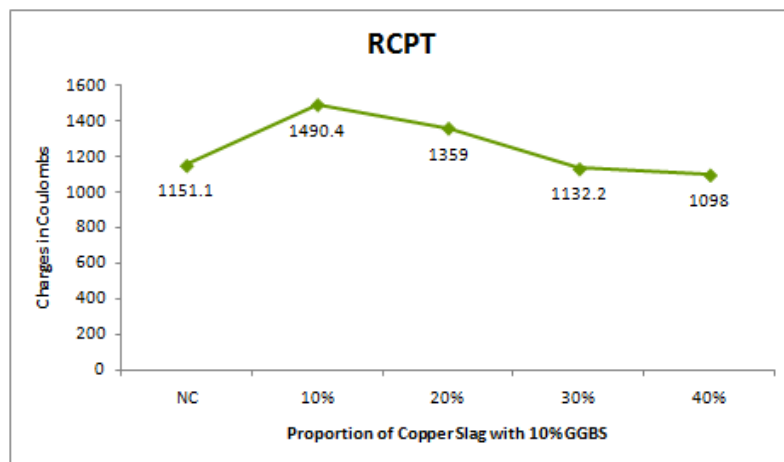


Figure 4. Results of rapid chloride penetration test

Elevated temperature test

The test results point out that specimen subjected to air cooling possesses better compressive strength than water cooled specimens. Although, the strength before incubating specimens was higher for 30% but 10% replaced quantity for sand has good compression strength ratio compared to others which is close to 1.

Table 7. Results of elevated temperature test

Type of Concrete	Type of Cooling	Compressive Strength		C S R
NC	Air Cooling	40.40	29.80	0.738
	Water Cooling	40.40	24.90	0.616
10%	Air Cooling	39.50	32.20	0.815
	Water Cooling	39.50	29.50	0.747
20%	Air Cooling	41.30	29.90	0.724
	Water Cooling	41.30	23.10	0.560
30%	Air Cooling	44.60	30.00	0.673
	Water Cooling	44.60	22.80	0.511
40%	Air Cooling	43.70	29.90	0.684
	Water Cooling	43.70	27.70	0.634

V. CONCLUSION

The better defiance against strength was procured from 40% superseded fine aggregates whereas 30% has offered better resistance against weight loss from acid resistance test. From the chloride resistance test, 30% replaced material presented better resistance against strength parameter however the weight before and after chemical curing remains unalterable for 40%. The results obtained from sulphate resistance test revealed that strength and weight loss were at its optimal value for 40% replaced fine aggregates. The results extracted from abrasion test connote that 40% of copper slag has yielded better weight loss and loss in thickness of cuboids under scrutinity. The inference from water absorption test clarifies that 40% exhibited a better resistance against sorpitivity. It is ascertained from corrosion test

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that 40% replaced material procured optimum value which is lesser, contrasting normal and other blended concrete, value of peak current and the weight loss of steel bar was observed to be less in 40%. It is crystal clear from RCPT that all the variations of blended concrete and conventional concrete have low chloride permeability and amongst these the optimum value has been possessed by 40%. Specimens subjected to high temperature abridged value of compressive strength due to disintegration of bond within concrete. It can be perceived from this test that air cooled specimens have relatively better value than water cooled specimens and 10% has gained good compressive strength ratio.

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