SOME PHYSICAL AND MECHANICAL PROPERTIES OF CONCRETE MADE FROM PARTIAL REPLACEMENT OF NATURAL AGGREGATES WITH ARTIFICIALLY MANUFACTURED AGGREGATES USING GROUND GRANULATED BLAST FURNACE SLAG (GGBS)

Prasanna Kumar .P[1], S Suhas [2],Ravikumar D[3],Roopa S[4], Keshavmurthy M S[5], Shivam Agarwal[6]

[1]*Professor, Department of Civil Engineering, BMS College of Engineering, Bangalore, India*
[2]*Student, Department of Civil Engineering, BMS College of Engineering, Bangalore, India*
[3]*Student, Department of Civil Engineering, BMS College of Engineering, Bangalore, India*
[4]*Student, Department of Civil Engineering, BMS College of Engineering, Bangalore, India*
[5]*Student, Department of Civil Engineering, BMS College of Engineering, Bangalore, India*
[6]*Student, Department of Civil Engineering, BMS College of Engineering, Bangalore, India*

Abstract

The potential use of Ground Granulated Blast Furnace Slag (GGBS) obtained from iron ore plant while producing artificial aggregate has been systematically investigated in this study. GGBS has been used in concrete either as a supplementary cementitious material or as a replacement for fine aggregate. This study deals with the use of GGBS as coarse aggregate by means of its artificial production through the process of aggregation or granulation. Some important mechanical properties of GGBS aggregate was evaluated for its crushing and impact strength and compared with natural aggregates. The resulting aggregates were used as replacement for natural aggregate in concrete. The investigation results suggested that the GGBS aggregate showed a highest aggregate crushing value of 24% and aggregate impact value of 31%. The values obtained are well within the IS code provisions for crushing and impact values for use in structural concrete. The scope of the investigation is limited to generate some mechanical and physical properties for concrete of M20 grade made with various percentages of replacement of natural aggregate by GGBS aggregate up to 40%. The experimental program consisted of casting and testing sixteen concrete mixes for their strength in (i) compression and (ii) pull out strength (Bond strength) and compared with that of concrete made with natural aggregates. The test results confirmed that the partial replacement of GGBS aggregates in concrete reduces the properties such as compressive strength and pull out strength marginally but meets the required strength as per IS 456-2000 to be used as a structural concrete.

Keywords: *Granulation, aggregation, GGBS, crushing, impact, pull out.*

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1. INTRODUCTION

The increase in production of steel due to rise in demand has led to the increase in production of a supplementary product “slag” which is a waste by product. The environmental dreads from these plants include air, water and land pollution. Slag when ground becomes ground gets converted to granules and is termed as Ground Granulated Blast furnace Slag (GGBS). It is widely used as supplementary cementious material in manufacture of cement and also used in making concrete blocks. Though the artificial aggregate production attained attention in research field, in India it is not implemented widely. This may be due to the availability of natural resources, relatively higher initial cost for manufacturing ,time and energy required for curing etc.,. Extensive use of natural aggregates causes scarcity and also disposing of slag which is a waste product produced while producing steel is a problem. Then there lies the challenge of using this slag effectively. One of the options may be to convert it to artificial aggregates and to use as an artificial aggregates in construction.The advantages of producing artificial aggregate is that it does not deplete the natural resources and also prevents the damages done by aggregate mining. In this investigation, GGBS aggregates are produced through a process of artificial granulation. The properties of GGBS aggregates produced is discussed and compared with natural aggregates for its feasibility in concrete. Concrete made by replacing natural aggregate with artificial aggregate with variable percentages from 20%, 30% and 40% were studied with normal concrete to know mechanical property - compressive strength and physical properties - pull out strength to assess the use in reinforced concrete.

2. LITERATURE REVIEW

V.Strokova,I. Zhernovsky,et. Al "Artificial aggregates based on granulated reactive silica powders" Journal on Advanced Powder Technology, Elsevier published .Vol. 25, Issue 3, May 2014. Have conducted test on artificial aggregates from reactive silica powder (AAGS). They have reported that optimum alkali content in aggregate core can vary from 10 to 30%. The effect of RS (reactive silica) and AAGS (Artificial aggregate granulated silica) composition on the structure of hardened cement composite was investigated.

AnjaTerzic, Latopezo et al "Artificial Fly ash based aggregate properties influence on light weight concrete performances", Ceramic international, Elsevier pub. 2014. Have studied the effect of application of fly ash based aggregates obtained through different processing techniques on the behaviour of lightweight concretes was analysed. The lightweight concrete behaviour was compared to that of normal-weight concrete through compressive strength, flexural strength, porosity, shrinkage, and modulus of elasticity investigation. Finally, the ideal combinations of ash pellets production parameters and properties that gave the lightweight concrete with behaviour matching to that of standard concrete were established

R. Cioffi, F. Colangelo, F. Montagnaro, and L. Santoro "Manufacture of artificial aggregate using MSWI bottom ash". This paper reports the results of an investigation on stabilization/solidification of bottom ash coming from a municipal solid waste incineration plant. Stabilization/solidification was carried out to produce artificial aggregate in a rotary plate granulator by adding hydraulic binders based on cement, lime and coal fly ash. The granules were tested to assess their suitability to be used as artificial aggregate through the measurement of the following properties: density, water absorption capacity, compressive strength and heavy metals release upon leaching. Concrete mixes were prepared with the granulated artificial aggregate and tested for in-service performance, proving to be suitable for the manufacture of standard concrete blocks in all the cases investigated.

3. MATERIALS AND METHODS

3.1 Experimental Program

In this program, an attempt was made to use GGBS to produce artificial aggregates by granulation process. Artificial aggregates were produced with varying cement content in percentages of 6, 8, 10 and 14 to the weight of the GGBS. Three methods, steam curing, oven drying, and normal curing by exposing them to sunlight were adopted to evaluate the strength gain process. Properties of artificial aggregates and natural aggregates were compared, with tests such as aggregate crushing value, aggregate impact value and water absorption. GGBS aggregate produced were typically rounded in shape since they were firmed in a rotating the mixer. Normal curing of aggregates under sunlight for 3 days gave better results and are found to be economical when compared with oven and steam curing processes. The water absorption of GGBS aggregate is higher than that of natural aggregate which is the major disadvantage. GGBS aggregate with 8% cement content of the weight of GGBS under normal curing for 3 days showed a good aggregate crushing value and aggregate impact value which are well within the limits prescribed by IS code provisions. The following assumptions are made in the design of reinforced cement concrete,(i) material is homogeneous and isotropic and (ii) perfect bond between steel and concrete. However the above assumptions are valid only when one type of material with uniform physical and engineering properties are used. When alternative materials are used in partial replacement of natural materials with inert component, we need to verify the above mentioned assumptions for their validity through laboratory experiments such as compressive strength and pull out strength etc. Concrete mix design is carried out according to IS 10262:2009. Concrete is made with natural aggregate and GGBS aggregate with varying super plasticizer dosages is tested for its compressive strength for 1day, 7day and 28 day of curing and Pull out test carried out to find out the bond strength between concrete and steel.

3.2 Concrete Materials

3.2.1 Cement

Ordinary Portland 43 grade cement with specific gravity 3.15 was used as the binder.

Physical properties of GGBS

Material	Specific gravity	Specific surface area	lime reactivity
GGBS	2.76	477 m^2/kg	43.2 kg/cm^2
IS 1727 provisions for Pozzolanic material	Allowable limits 2.70 to 2.95	>400m^2/kg.	>40kg/cm^2

3.2.2 Natural Aggregate

12.5 mm graded crushed gravel was used as coarse aggregate having specific gravity of 2.7 and river sand of specific gravity 2.6 used as fine aggregates.

3.3 Manufacture Of GGBS Aggregate

The process adopted to produce artificial aggregate is granulation. It is the process of compressing or moulding a material into the shape of an aggregate. Cement of 43 grade and GGBS was taken in different ratios like 1:6, 1:8, 1:10 and 1:14. Initially material is mixed with trowel till a see uniform colour is obtained. Then the resulting dry mixed powder is poured to the concrete mixer of 50 litre capacity. The mixer is rotated at 45rpm for 2 minutes. Then water is sprayed through sprayer so as to spread water to larger area and to avoid slurry formation. During this process, small granules grow in size gradually in about 6- 8 minutes. Aggregates grow in size with increase in moisture. Fresh aggregates formed are kept in an open room for a day for natural curing. Aggregates from 12.5mm to 4.75 mm size are used for testing and for preparation of concrete. Different methods of strength gain were adopted such as : Steam curing: After one day of air curing, the aggregates were transferred to steam curing chamber where the temperature was raised gradually from 250 Celsius to 1000 Celsius in a span of 6 hours. The temperature of 1000C was maintained for the next 18 hours. Then the hardened aggregates were then removed from the chamber which was ready for use. Oven curing: The air cured aggregates are placed in an oven where the temperature was maintained at 1000 Celsius for 24 hours. Later the hardened aggregates were removed from the oven and allowed to cool to room temperature. The hardened aggregates were then removed from the chamber and were ready for use. Normal air curing: The prepared aggregates were kept in open air for 3 days and 7 days for hardening. The hardened aggregates are then ready for use. Comparison between the above three methods of strength gain is carried out.

3.4 Studies on Properties of Artificial GGBS Aggregates

Properties of GGBS aggregates and natural Aggregates passing through 12.5 mm and retained in 10 mm sieve were used for mechanical tests such as aggregate crushing value and aggregate impact value. Physical tests such as specific gravity and water absorption were carried out. Most of the strength gain of GGBS aggregate was acquired in one day in oven and steam curing whereas, in normal curing 3 days is required to gain strength. GGBS aggregate with 8% cement content under normal air curing for 3days showed a good aggregate crushing value and aggregate impact value when compared with the other two methods of curing. Therefore, GGBS aggregate with 8% cement content under normal air curing conditions was used for the preparation of concrete.

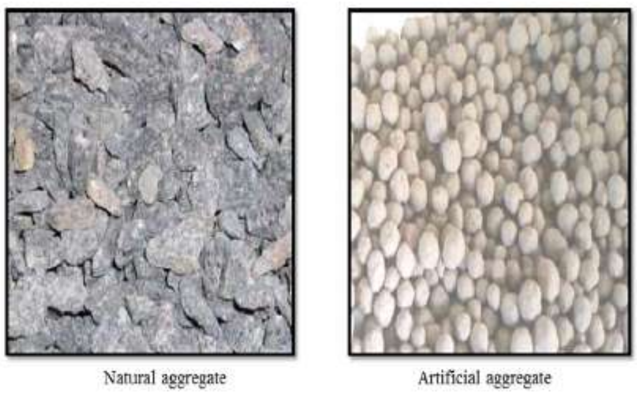
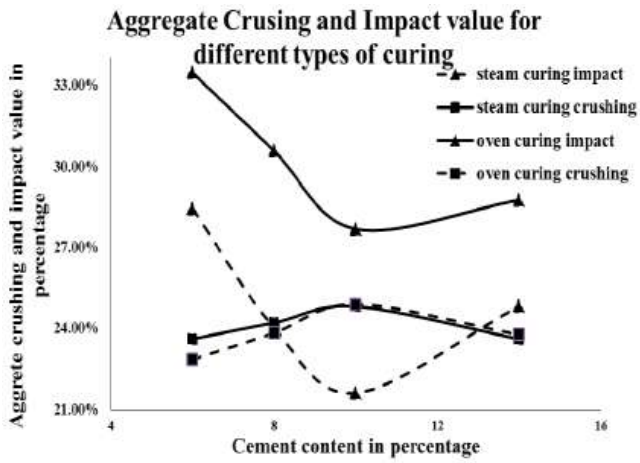


Fig 1. Comparision of natural aggregate with artificial aggregate



3.5 Studies on GGBS Aggregate Concrete

3.5.1 Mix Proportion

Mix designed was carried out as per IS 10262:2009. Water reducing admixture with a base chemical poly carboxylic ether was used as super plasticizer in this study. Percentage of super plasticiser used was 0, 0.2% 0.3% and 0.4%.

3.5.2 Preparation of Test Samples

Cube moulds of 100x100x100 mm were used for compressive strength study as the size of the aggregates was less than 10mm. Moulds were properly maintained by cleaning and oiling before each casting. The mix was compacted using a tamping rod in three layers as per code provisions.

3.5.3 Procedure of Casting and Curing of Concrete Mix

The dry mix of sand and cement was poured into the concrete mixer and run for a for duration of 1 minute till a uniform colour was obtained. Then, coarse aggregate with or without artificial aggregate was added and mixed for another 1 minute till uniform colour is achieved. Water with or without super plasticizer was added and mixed well. A slump of 75mm to 100mm was achieved for the concrete while the cubes were cast. The concrete cubes were cured for 28days by submerging them in a water bath at ambient temperature. Each value is the average of three samples.

3.5.4 Pull Out Test Procedure

Ribbed reinforcing bars of 12 mm diameter were used for measuring the pull out strength. The bars were cleaned in order to make them free from grease, paint, or other coatings and were made perfectly straight in order to avoid the introduction of lateral thrust pulling the bars. Plain Concrete of M20 grade having a slump of 75mm to 100mm was used for the test. Reinforcement was inserted into the fresh concrete while casting using a proper setup so that the insertion was not disturbed till the concrete completely hardened. All the specimen was cured uniformly for 28day.Each value is the average of three specimens for each type of mix. Samples were tested in a universal testing machine (UTM). The test specimen was mounted in UTM in such a manner that one end was firmly gripped and the other was pulled such that the bar could be pulled axially from the cube. Dial gauge was fixed at the end where the bar was pulled to measure displacement. The movement between the reinforcing bar and the concrete cube, as indicated by the dial gauge was read and noted manually at regular load intervals. The process was continued till the bond between the bar and the concrete was lost indicated by the decrement in the tensile force applied. The maximum load at which the specimen failed was recorded and the graph of displacement (mm) versus axial pull out load (kN) was plotted for each specimen and the resulting slope is called as slip modulus.

4. RESULTS

4.1 Properties of GGBS Aggregates

The shape and texture of aggregate affects the fresh property of the concrete. GGBS aggregate is rounded in shape while natural gravel is angular in shape. Rounded aggregates promotes workability of concrete while the angular nature of natural gravel gives a better bonding property but requires more cement mortar for better workability.

Table 1: Table indicating optimum curing age for artificial aggregates for a cement: GGBS ratio of 1:10

Sl. no.	Days	Steam curing		Oven curing	
		Crushing value	Impact value	Crushing value	Impact value
1	1	25%	22%	25%	28%
2	3	26%	27%		
3	7	28%	24%	23%	33%

Table 2: Table indicating crushing and impact values for different ratios of cement content for steam and oven curing at one day for artificial aggregates

Sl.no.	Cement content (%)	Water absorbed by aggregates while production	Steam curing		Oven curing	
			Crushing value	Impact value	Crushing value	Impact value
1	6	18.8%	23%	28%	22%	33%
2	8	18.8%	24%	24%	23%	30%
3	10	18.8%	25%	22%	25%	28%
4	14	18.8%	25%	22%	24%	29%

Table 3: Table indicating crushing and impact values for 8%cement content under normal air curing

Sl.no.	Days	Crushing value	Impact value
1	3	25%	30%
2	7	25%	31%

The strength of aggregates is compared from crushing and impact values. One day natural curing was found out to be sufficient as 3 day and 7 day curing did not show much improvement Optimum cement content was found to be 8% for artificial aggregate made with GGBS since it exhibited better crushing and impact resistance than other ratios tried. Normal curing of aggregates under sun for 3 days gave better results and also was found to be economical when compared with oven and steam curing process. Though GGBS aggregate showed better result for crushing value which involves application of load gradually, it showed lower resistance to impact which involved sudden application of load. Comparatively, both the natural and artificially manufactured aggregates show values within the permissible limit. Water absorption of GGBS aggregates was 14% which is very high when compared with natural aggregates.

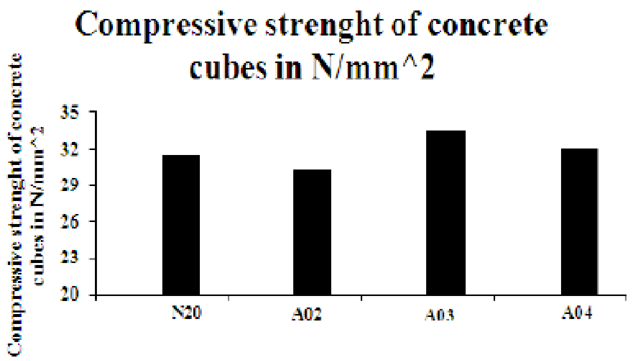
4.2 Concrete Properties

The compressive strength of concrete made with replacement of natural aggregate with artificial aggregate up to 40% exhibited same compressive strength as that of concrete without any replacement as evident in Table 4.

Table 4: Table showing compressive strength and pull out (slip modulus) strength of different concrete.

Concrete type	Compressive strength in N/mm^2	Pull out strength (Slip modulus) in N/mm
N00	30.6	5561
N20	31.5	6575
N30	27.3	3100
N40	30.3	5851
A02	33.5	3843
A22	30.3	2945
A32	24.3	2506
A42	31.7	4395
A03	33.5	4214
A23	30.6	3515
A33	23.1	5650
A43	24.3	2753
A04	32	3403
A24	30.3	3279
A34	24.3	3473
A44	30.2	4027

N – Normal Concrete, A –Concrete with Artificial aggregates, 1St digit after alphabet – super plasticizer dosages (0%, 0.2%, 0.3% and 0.4%), 2nd digit after alphabet – percentage replacement of natural aggregates with artificial aggregates (0 %, 20%, 30% and 40%)



Physical properties of concrete, the pull out strength of artificial concrete shows good strength and almost matches to that of natural concrete.

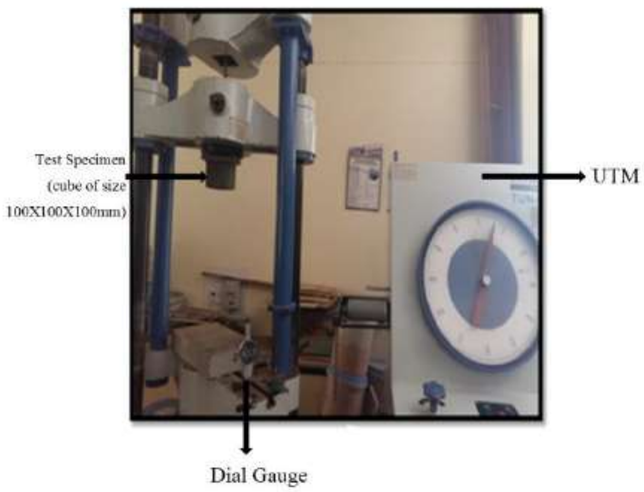


Fig2. Test set up for pull out test

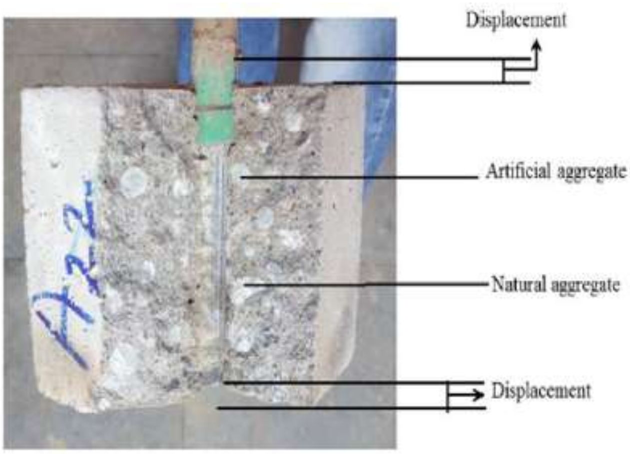
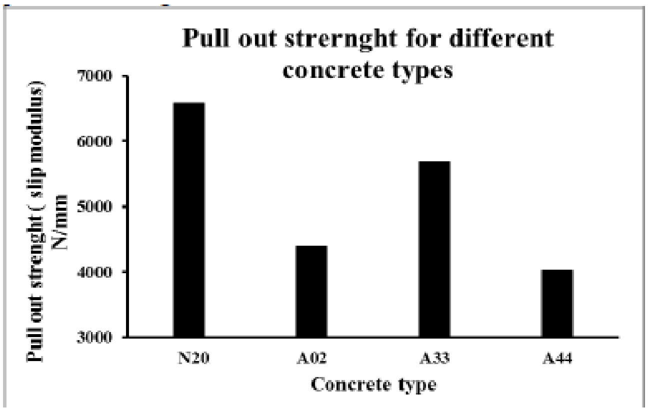
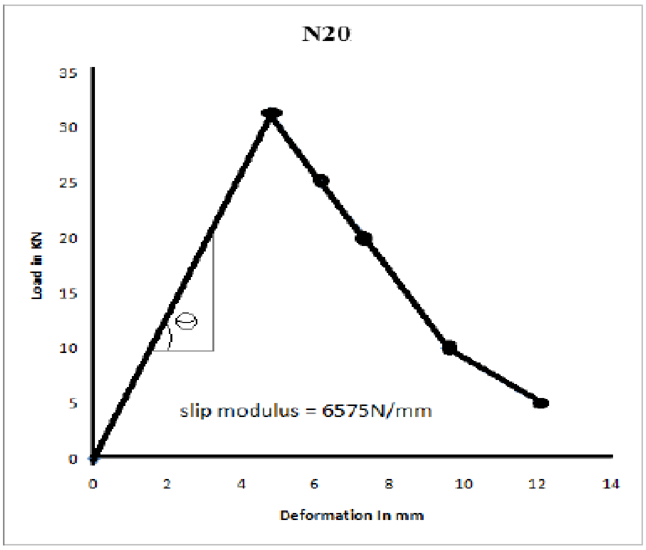


Fig3. Pull out test specimen after failure.

Variation of the Pull out strength of cubes for normal aggregates and with replacement of natural aggregates by20%, 30%, and 40% with artificial aggregate and with varying super plasticiser dosages of 0%, 0.2%, 0.3% and 0.4%.



Pull out strength measured as load verses deformation.



Slip modulus for Normal concrete with 0.2% super plasticizer

5. DISCUSSION

5.1 GGBS Aggregate

GGBS aggregate is rounded in nature which improves workability. Oven curing is found to be the best type of curing for faster production of artificial aggregates. However, natural curing was found to be economical but time consuming. The water absorption of GGBS aggregate is higher than that of natural aggregate which is a major di sadvantage. After casting 192 cubes from 16 mixes and the resulting test results we can say that the artificial aggregates are feasible when naturally cured and in places moisture absorption is not a criterion. It may not be usable in adverse environment conditions where performance of concrete is a major criterion of concern.

5.2 Compressive Strength when Compared with Normal Concrete

A02 concrete (replacement of natural aggregate by 20% artificial aggregate and without super plasticizer) had a compressive strength of 33.5 N/mm2 when compared with normal concrete (N20) with 0.2% super plasticizer has value of 31.54 N/mm2

5.3 Pull out Strength when Compared with Normal Concrete

N2 (normal concrete with no replacement of natural aggregate and with 0.2% super plasticizer) had a pull out (slip modulus) strength 6575N/mm. Concrete with artificial aggregate A33 (artificial concrete with 30% replacement of natural aggregate and with 0.3% super plasticizer) had a pull out (slip modulus) strength 5650 N/mm.

6. CONCLUSION

Oven curing was found to be better type of curing for faster production of artificial aggregate however it is not energy efficient.

Crushing and impact value of artificial aggregate was well within IS code limits.

Concrete with partial replacement of natural aggregate with artificial aggregate exhibited almost same compressive strength.

Concrete with partial replacement of natural aggregate with artificial aggregate exhibited almost same pull out (slip modulus) strength.

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