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Replacement of Natural Sand with Efficient Alternatives: Recent Advances in Concrete Technology

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ABSTRACT
Concrete is the most undisputable material being used in infrastructure development throughout the world. It is a globally accepted construction material in all types of Civil Engineering structures. Natural sand is a prime material used for the preparation of concrete and also plays an important role in Mix Design. Now a day's river erosion and other environmental issues have led to the scarcity of river sand. The reduction in the sources of natural sand and the requirement for reduction in the cost of concrete production has resulted in the increased need to find new alternative materials to replace river sand so that excess river erosion is prevented and high strength concrete is obtained at lower cost. Partial or full replacement of natural sand by the other alternative materials like quarry dust, foundry sand and others are being researched from past two decades, in view of conserving the ecological balance. This paper summarizes conclusions of experiments conducted for the properties like strength, durability etc. It was observed the results have shown positive changes and improvement in mechanical properties of the conventional concrete due to the addition or replacement of fine sand with efficient alternatives.

KEYWORDS: Concrete, Natural sand, Alternative materials, Quarry dust, Foundry sand, Mechanical properties.

I. I.INTRODUCTION

Concrete is that pourable mix of cement, water, sand, and gravel that hardens into a super-strong building material. Aggregates are the important constituents in the concrete composite that help in reducing shrinkage and impart economy to concrete production. River Sand used as fine aggregate in concrete is derived from river banks. River sand has been the most popular choice for the fine aggregate component of concrete in the past, but overuse of the material has led to environmental concerns, the depleting of river sand deposits and an increase in the price of the material. The developing country like India(Authors native land) facing shortage of good quality natural sand and particularly in India, natural sand deposits are being used up and causing serious threat to environment as well as the society. The rapid extraction of sand from the river bed causes problems like deepening of the river beds, loss of vegetation on the bank of rivers, disturbance to the aquatic life as well as agriculture due to lowering the water table in the well etc. Therefore, construction industries of developing countries are in stress to identify alternative materials to replace the demand for river sand. Hence, partial or full replacement of river sand by the other compatible materials like crushed rock dust, quarry dust, glass powder, recycled concrete dust, and others are being researched from past two decades, in view of conserving the ecological balance. The reuse of this waste will help to save cost, conserve limited resources and ultimately protect the environment.

Due to shortage of river sand as well as its high the Madras High Court restrictions on sand mining in rivers Cauvery and Thamirabarani. The facts like in India is almost same in others countries also. So therefore the need to find an alternative concrete and mortar aggregate material to river sand in construction works has assumed greater importance now a days. Researcher and Engineers have come out with their own ideas to decrease or fully replace the use of river sand and use recent innovations such as M-Sand (manufactured sand), robot silica or sand, stone crusher dust, filtered sand, treated and sieved silt removed from reservoirs as well as dams besides sand from other water bodies [16].

II. EFFICIENT ALTERNATIVE MATERIALS TO RIVER SAND

Concrete is the second largest consumable material after water, with nearly three tonnes used annually for each person on the earth. India consumes an estimated 450 million cubic meter of concrete annually and which approximately comes to 1 tonne per Indian. Bureau of Indian Standards, the National Standards Body of the country, considering the scarcity of sand from natural sources, has evolved number of alternatives which are ultimately aimed at conservation of natural resources apart from promoting use of various waste materials without compromising in quality. use of these alternative materials such as fly ash, slag, not only help in conserving our precious natural resources but also improve the durability of structures made using these.

2.1 COPPER SLAG

Copper slag is an abrasive blasting grit made of granulated slag from metal smelting processes (also called iron silicate). During the past two decades, attempts have been made by several researchers all over the world to explore the possible utilization of copper slag in concrete. At present about 33 million tonnes of copper slag is generating annually worldwide among that India contributing 6 to 6.5 million tonnes. 50 % copper slag can be used as replacement of natural sand in to obtain mortar and concrete with required performance, strength and durability. (Khalifa S. Al-Jabri et al 2011)

Fig 1: Copper slag[17]

2.2 GRANULATED BLAST FURNACE SLAG

Granulated blast-furnace slag (GBFS) is obtained by quenching molten iron slag (a by-product of Iron and steel-making) from a blast furnace in Water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. GBFS has been adopted for its superiority in concrete durability, extending the lifespan of buildings from fifty years to a hundred years.

Fig 2: Granulated blast-furnace slag[17]

According to the report of the Working Group on Cement Industry for the 12th five year plan, around 10 million tonnes blast furnace slag is currently being generated in the country from iron and steel industry. The compressive strength of cement mortar increases as the replacement level of granulated blast furnace slag (GBFS) increases. He further concludes that from the test results it is clear that GBFS sand can be used as an alternative to natural sand from the point of view of strength. Use of GBFS up to 75 per cent can be recommended [2].

2.3WASHED BOTTOM ASH (WBA)

The **WBA** is a waste material that is taken from electric power plant and the source material is called as bottom ash. Figure 3 show the typical steam generating system that illustrated the bottom ash dispose at the bottom furnace and fly ash is dispose to atmosphere by very tall chimney.

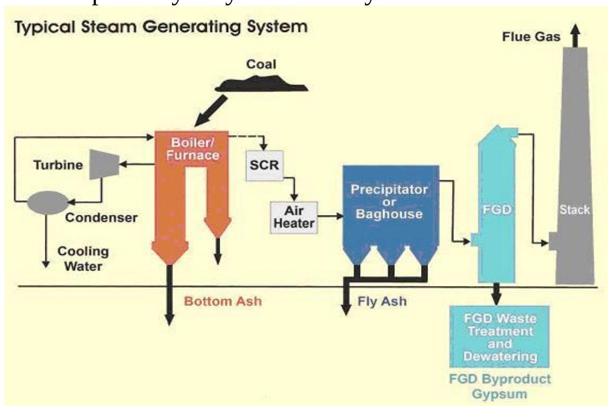

Fig 3: The production of coal combustion by-products in steam generating system. (NETL,2006).

2.4 QUARRY DUST (QD)

Quarry dust is fine rock particles. When boulders are broken into small pieces quarry dust is formed. It is grey in colour and it is like fine aggregate. In concrete production it could be used as a partial or full replacement of natural sand. Besides, the utilization of quarry waste, which itself is a waste material, will reduce the cost of concrete production.

2.4.1 ORIGIN OF QUARRY DUST

The quarry dust is the by-product which is formed in the processing of the granite stones which broken downs into the coarse aggregates of different sizes.

FIG 4: Quarry Dust[17]

2.5 FOUNDRY SAND

Foundry sand is sand which when moistened & compressed or oiled or heated tends to pack well and hold its shape. It is used in the process of sand casting. India ranks fourth in terms of total foundry production (7.8 million tonnes) according to the 42nd Census of World Casting Production of 2007. Foundry sand which is very high in silica is regularly discarded by the metal industry. Currently, there is no mechanism for its disposal, but international studies say that up to 50 per cent foundry sand can be utilized for economical and sustainable development of concrete (Vipul D. Prajapati 2013)[8].

Fig 5: Foundry sand[17]

2.6 SHEET GLASS POWDER (SGP)

Glass is amorphous material with high silica content, thus making it potentially pozzolanic when particle size is less than 75µm(Federio.L.M and Chidiac S.E,2001, Jin.W, Meyer.C, and Baxter.S,2000). The use of recycled glass as aggregate greatly enhances the aesthetic appeal of the concrete. Natural sand was partially replaced (10%, 20%, 30%, 40% and 50%) with SGP. Compressive strength, Tensile strength (cubes and cylinders) and Flexural strength up to 180 days of age were compared with those of concrete made with natural fine aggregates Attempts have been made for a long time to use waste glasses as an aggregate in concrete, but it seems that the concrete with waste glasses always cracks .Very limited work has been conducted for the use of ground glass as a concrete replacement. (M. Mageswari and Dr. B.Vidivelli 2010) [9].

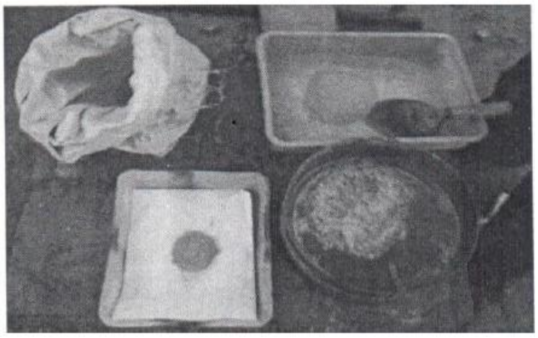

Fig 6: Glass powder[17]

2.7 CONSTRUCTION AND DEMOLITION WASTE:

Construction and demolition waste is generated whenever any construction/demolition activity takes place, such as, building roads, bridges, fly over, subway, remodelling etc. It consists mostly of inert and non-biodegradable material such as concrete, plaster, metal, wood, plastics etc. A part of this waste comes to the municipal stream.

These wastes are heavy, having high density, often bulky and occupy considerable storage space either on the road or communal waste bin/container. It is not uncommon to see huge piles of such waste, which is heavy as well, stacked on roads especially in large projects, resulting in traffic congestion and disruption. Waste from small generators like individual house construction or demolition, find its way into the nearby municipal bin/vat/waste storage depots, making the municipal waste heavy and degrading its quality for further treatment like composting or energy recovery. Often it finds its way into surface drains, choking them. It constitutes about 10-20 % of the municipal solid waste (excluding large construction projects).

Fig 7: Construction and demolition waste[17]

2.8 CRUSHED SPENT FIRE BRICKS (CSFB)

Fire bricks are the products manufactured (as per IS: 6 and IS: 8 specifications) from refractory grog, plastic, and non plastic clays of high purity. The different raw materials are properly homogenized and pressed in high capacity presses to get the desired shape and size. Later, these are fired in oil-fired kiln at a temperature of 1,300°C.

Fig 8: Fire brick samples

III. PHYSICAL AND MECHANICAL PROPERTIES DIFFERENT ALTERNATIVES

3.1 COPPER SLAG:

The sieve analysis for copper slag infers that the gradation properties of fine aggregates at all the replacement levels are similar to the specification for sand zone II as per IS: 383.

The sieve analysis report is shown in Table 1

Table 1[1] Fineness test on copper slag

Sieve size In (mm)	Weight retained(b)g	Cumulative weight retained (g)	Slag retained(n)g	Slag passing % of soil
4.75mm	4	0.4	0.4	99.6
2.36mm	17	1.7	2.1	97.9
1.18mm	225	22.5	24.6	75.4
600micron	433	43.3	67.9	32.1
300micron	281	28.1	96	4
150micron	37	3.7	99.7	0.3
75micron	3	0.3	100	0
Pan	0	0	100	0

The test results of concrete were obtained by adding copper slag to sand in various percentages ranging from 0%, 20%, 40%, 60%, 80% and 100%. All specimens were cured for 28 days before compression strength test, splitting tensile test and flexural strength. The highest compressive strength obtained was 35.11MPa (for 40% replacement) and the corresponding strength for control mix was 30MPa. This results of the research paper showed that the possibility of using copper slag as fine aggregate in concrete. The results showed the effect of copper slag on RCC concrete elements has a considerable amount of increase in the compressive, split tensile, flexural strength characteristics and energy absorption characteristics [1].

3.2 GRANULATED BLAST FURNACE SLAG

The granulated blast furnace slag (GBFS) is glassy particle and granular materials in nature and has a similar particle size range like sand. The specific gravity of the slag is 2.63. The bulk density of granulated slag varies from 1430 kg/m3 which were almost similar to bulk density of convectional fine aggregate.

FIG 9 shows the gradation curve for both natural sand and GBFS.

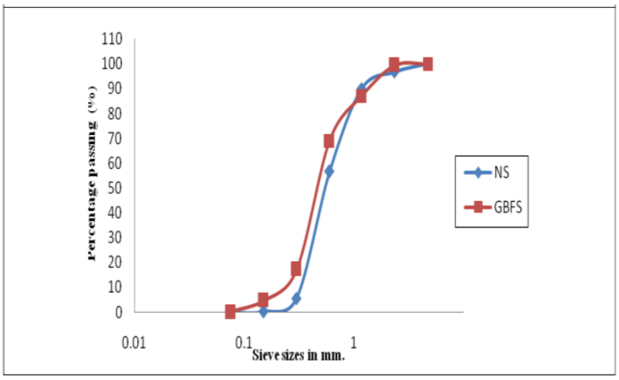

Fig 9

Investigation was carried out on cement mortar mix 1:3 and GBFS at 0, 25, 50, 75 and 100% replacement to natural sand for constant w/c ratio of 0.5 is considered (Table 2). The flow characteristics of the mix and compressive strengths at various ages are studied. From this study it is observed that there is a considerable increase in compressive strength evident from Table 2 thus GBFS could be utilized partially as alternative construction material for natural sand in concrete but there is reduction in workability for all replacement levels. The workability can be increased by adding suitable dosage of chemical admixture such as super plasticizer

Table 2

Combination	Compressive Strength, N/mm²		
	3 days	7 days	28 days
25%GBFS+75%NS	27.73	35.6	49.07
50%GBFS+50%NS	27.47	33.11	48.41
75%GBFS+25%NS	26.01	31.87	48.11
100%GBFS+0%NS	21.73	25.61	44.81
0%GBFS+100%NS	23.94	34.91	48.02

3.3 WASHED BOTTOM ASH

The physical properties of washed bottom ash are tabulated below in Table 3

Table 3: The physical properties of bottom ash

Property	Bottom Ash
Specific Gravity	2.1 -2.7
Dry Unit Weight	7.07 - 15.72 kN/m^3 (45 - 100 lb/ft^3)
Plasticity	None
Absorption	0.8 - 2.0%

The fineness modulus is the summation of the cumulative percentage retained on the sieve standard series of 150, 300 and 600µm, 1.18, 2.36, 5.0 mm up to the larger sieve size used. The calculated fineness modulus of bottom ash was 3.65 which is more than 3.5 and is considered to be very coarse. For categorization given in BS 822:1992 based on percentage passing the 600µm sieve between 55% to100% would defined it as fine sand. While WBA has percentage passing 600µm of 58.99%. Therefore, the WBA is considered as fine sand (Alexander & Mindess, 2005)[3].

Generally, all concrete with WBA replacement has increment in strength until long term duration i.e. at 60 days. Different concrete mixes with constant water to cement ratio of 0.55 were prepared with WBA in different proportions as well as one control mixed proportion. The mechanical properties of special concrete with 30% WBA replacement by weight of natural sand is found to be an optimum usage in concrete in order to get a favourable strength and good strength development pattern over the increment ages [4].

3.4 QUARRY DUST: The physical properties of quarry dust obtained by testing the sample as per the Indian Standards are listed in the below table. Table 4: Showing the Physical properties of quarry dust and natural sand

Property	Quarry Dust	Natural Sand	Test method
Specific gravity	2.54 -2.60	2.60	IS2386(Part III)- 1963
Bulk density (kg/m3)	1720- 1810	1460	IS2386(Part III)- 1963
Absorption (%)	1.20- 1.50	Nil	IS2386(Part III)- 1963
Moisture Content (%)	Nil	1.50	IS2386(Part III)- 1963
Fine particles less than 0.075 mm (%)	12-15	6	IS2386(Part III)- 1963
Sieve analysis	Zone-II	Zone-II	IS 383- 1970

Quarry dust is poorly graded as compared to sand. The particle size distribution of QD is shown in Fig 10

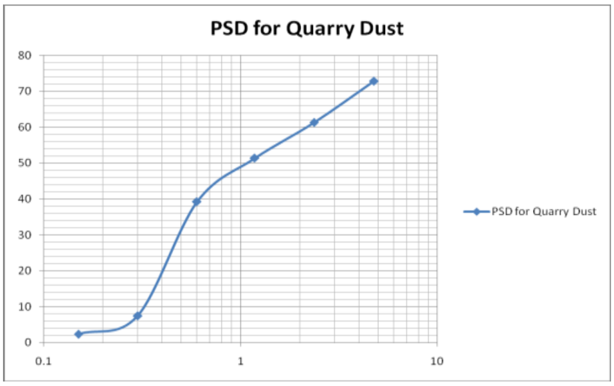

Fig 10

The results of the compression test are tabulated below.

Table 5

Compressive strength in N/ mm^2			
Days	Ordinary mix	10%	20%
7 days	23.12	22.86	22.65
14 days	24.45	23.87	23.50
21 days	30.52	31.45	31.69
27 days	33.00	34.46	35.21

The results show that there is an increase in the compressive strength of the concrete [5,6] which the increment is about 55% to 75% depending on the replacement if the sand with the quarry dust, for the 100% replacement of the sand the compressive strength is depending on the quarry dust location from where the quarry dust was taken. The workability of the concrete is decreasing when the replacement percentage of the quarry dust is increasing gradually; so as to increase the workability small quantity of the fly-ash is replaced in place of cement to increase the workability [7].

3.5 FOUNDRY SAND:

Table 6: Physical properties of foundry sand

Property	ASTM Standard	Foundry Sand with Clay (5%)	Foundry Sand without Clay
Bulk density (pcf)	C29	60-70	80-90
Moisture content (%)	D2216	3-5	0.5-2%
Specific gravity	D854	2.5-2.7	2.6-2.8
Dry density (pcf)	D698 Standard Proctor	110-115	100-110
Optimum moisture content (%)	D69	8-12	8-10
Permeability coefficient (cm/s)	D2434	10^{-3} -10^{-7}	10^{-2} - 10^{-6}

The fine aggregate has been replaced by used foundry sand accordingly in the range of 0%, 10%, 30% & 50% by weight for M-20 grade concrete. Concrete mixtures were produced, tested and compared in terms of compressive and flexural strength with the conventional concrete. These tests were carried out to evaluate the mechanical properties for 7, 14 and 28 days. This research work is to investigate the behaviour of concrete while replacing used foundry sand in different proportion in concrete. This low cost concrete with good strength is used in rigid pavement for 3000 commercial vehicles per day and Dry Lean Concrete (DLC) 100mm thick for national highway to make it eco-friendly [8]. The maximum compressive strength was achieved with 50% replacement of fine aggregate with waste foundry sand and it was found that there is overall increase in the split tensile strength and flexural strength of plain concrete.

3.6 SHEET GLASS POWDER

Table 7: Physical properties of Sheet Glass powder

S.No	Physical Properties of Glass Powder	
1	Specific gravity	2.6
2	Fineness Passing 150μm	99.5
3	Fineness Passing 90μm	98

The compressive strength of cubes and cylinders of the concrete for all mix increases as the % of SGP increases but decreases as the age of curing increases due to alkali silica reaction. The Tensile strength of cubes and cylinders of the concrete for all mix increases than that of conventional concrete age of curing and decreases as the SGP content increases. The Flexural strength of the beam of concrete for all mix increases with age of curing and decreases as the SGP content increases. 100% replacement of SGP in concrete showed better results than that of conventional concrete at 28 days and 45 days curing but later it started to decrease its strength because of its alkali silica reactions. The density of SGP concrete is more that of conventional concrete. SGP is available in significant quantities as a waste and can be utilized for making concrete. This will go a long way to reduce the quantity of waste in our environment. The optimum replacement level in fine aggregate with SGP is 10% [9].

3.7 CONSTRUCTION AND DEMOLISHION WASTE

The fine aggregate was replaced with crushed waste sandcrete block (CWSB) in various percentages in the steps of 10 starting from 10% to a maximum of 100%, while 0% represents the control. The properties of the concrete were evaluated at 7, 14 and 28 days curing periods. Results showed (Table 3) that replacing 50% of CWSB aggregate after 28 days curing attained the designed compressive strength as the conventional concrete (i.e., the control). Thus it is concluded that CWSB can be used as a supplementary aggregate material in concrete [10].

3.8 CRUSHED SPENT FIRE BRICKS

Table 8: Physical properties of Spent fire bricks [11]

Sl. No.	Physical Properties	Values
01	Bulk density, [kg/m3]	2,000
02	Porosity, [%]	25 to 30
03	Size tolerance, [%]	±2
04	Working temperature, [°C]	1,300 to 1,400
05	Crushing strength (cold), [N/mm2]	24.5 to 27

An experimental investigation of strength and durability was undertaken to use "Spent Fire Bricks" (SFB) (*i.e.* waste material from foundry bed and walls; and lining of chimney which is adopted in many industries) for partial replacement of fine aggregate in concrete. The compressive strength of partial replacement of Crushed Spent Fire Bricks (CSFB) aggregate concrete is marginally higher than that of the river sand aggregate concrete at age of 7 days, 14 days, and 28 days, respectively. The split tensile strength of partial replacement of CSFB aggregate concrete is higher than that of the river sand aggregate at all ages. The modulus of elasticity of partial replacement of CSFB aggregate concrete is marginally higher than that of the river sand aggregate concrete. The partial replacement of GGBS can be used effectively as fine aggregate in place of conventional river sand concrete production [11].

IV. CONCLUSION

COPPER SLAG: The results of compression & split-tensile test indicated that the strength of concrete increases with respect to the percentage of copper slag added by weight of fine aggregate. Addition of slag in concrete increases the density thereby the self weight of the concrete.

GRANULATED BLAST FURNACE SLAG: There is a considerable increase in compressive strength thus GBFS could be utilized partially as alternative construction material for natural sand in concrete but there is reduction in workability for all replacement levels. The workability can be increased by adding suitable dosage of chemical admixture such as super plasticizer.

WASHED BOTTOM ASH: 30% WBA replacement is found to be the optimum amount in order to get a favourable strength and good strength development pattern over the increment ages. The cost of concrete is less than conventional concrete and the concrete becomes environment friendly.

QUARRY DUST: The study suggests that stone dust is quite appropriate to be selected as the substitution of fine aggregate. Quarry dust has a potential to provide alternative to fine aggregate thus minimizing waste products and disposal problems associated with it. The only major limitation is the decrease in workability which can be overcome by the use of fly ash or chemical admixtures such as super plasticizers which give high workability at the same water contents.

FOUNDRY SAND: Waste foundry sand can be effectively used as fine aggregate in place of conventional river sand, in concrete. The maximum compressive strength was achieved with 50% replacement of fine aggregate with waste foundry sand. Replacement of fine aggregate with waste foundry sand showed increase in the split tensile strength and flexural strength of plain concrete.

SHEET GLASS POWDER: It is observed that the compressive strength of concrete for all mix increases as the percentage of SGP increases, but decreases with the age of curing increases because of alkali silica reaction. The Tensile strength of the concrete for all mix increases than that of conventional concrete of same age of curing and decreases with increase in SGP content. Similarly the Flexural strength of the beam of concrete for all mix increases with age of curing and decreases with increase in SGP content.

CONSTRUCTION AND DEMOLITION WASTE: The density of the concrete decreases as the percentage of the CWSB content increases. Concrete containing up to 50% CWSB as fine aggregate compared favourably with normal concrete mixture and therefore 50% CWSB content is taken as the optimum for 30N/mm2 design characteristic strength.

CRUSHED SPENT FIRE BRICKS: The SFB is a locally available, low cost, and inert industrial solid waste whose disposal is a matter of concern likes construction waste. On an overall, the CSFB can be comparable to the natural river sand.

This paper shows that no material in the world is waste and if utilized properly such materials will improve sustainability by reducing the human consumption of natural resources. The use of these materials should be in such a way that the locally available alternative materials should be selected so as to achieve economy and required design strength.

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