IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

GEO-TECHNICAL CHARACTERIZATION OF SEVENTEEN WASTE MATERIALS EQUIVALENT TO INGREDIENTS OF CONVENTIONAL CONCRETE WITH IMPROVED QUALITY & REDUCED COST FACTOR

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Abstract

Conventional concrete [ordinary & standard] has basic ingredients: Cement, Aggregate [Coarse and Fine grained] as non-renewable category and Water-as renewable category. The ingredients of non-renewable category have depletion trend and adverse impact on sustainable environment at fast rate along-with huge cost factor. The water though belongs to renewable category, but in limited nature of good quality. The major civil engineering structures, constructed through concrete presently are associated with certain defects like: deformation, crack formation, seepage & leakage, non-durable and less stable within the designed time period.

The eco-friendly, economically viable of improved strength and reduced cost based, **Waste Materials** are available in prevailing Indian socio-environmental set-up as well as in Agricultural & Industrial sectors. Seventeen such waste materials [six of renewable category and eleven of non-renewable category] have been investigated, whose properties are equivalent to ingredients of conventional concrete as Cement, Coarse Aggregate [stone chips] and Fine Aggregate [sand]. The geo-technical characterization of such relevant waste materials have been studied under their physical and strength parameters [index and engineering properities] namely: density, specific gravity, water absorption [%], fineness of modulus, workability, w/c ratio, CBR, compressive strength, split tensile strength, flexural strength, along-with application as improved quality of conventional concrete. The proper utilization of these waste materials under 'recycle' is the future of Indian concrete, along-with national mission of **Clean Environment & Green Environment.**

Introduction

The preparation of conventional concrete presently requires basic ingredients namely: Cement, Coarse Aggregate [stone chips], Fine Aggregate [sand] and Water. Except, water, all ingredients belong to non-renewable category, with bearing major cost factor and may not sustain for longer time period. It is to be looked virtually, for eco-friendly, economically viable construction material, as replacement of conventional concrete, based upon concept, 'conversion of waste material into national wealth through recycling' for longer time period. The scrutiny of available BIS code provision for cement, aggregate to the equivalent of Seventeen [six renewable and eleven non-renewable] waste material has been carried out through evaluation of their index and engineering properties.

Methodology & Objectives

The evolved methodology is based upon conventional approach as relevant literature review cum personal discussion with IIT- ians of Roorkee, Kanpur, Dhanbad & Bombay in and off campus with following objectives:-

- Evaluation of four index properties of Fine Aggregate equivalent to relevant waste materials pertaining to physical parameters.
- Evaluation of four index properties of Coarse Aggregate equivalent to relevant waste materials pertaining to physical parameters.
- Evaluation of six engineering properties of Cement equivalent to relevant waste materials pertaining to strength and physical parameters.
- Binding characteristics of Fly-ash.

Literature Review

The first cement plant in India was commissioned at birth place of Mahatma Gandhi- Porbander [Gujarat] in 1913 with production [1,000 tons] in 1914. The first Indian Cement- Concrete [CC] road was constructed in the same year [1914] at Madras [Chennai] by India Cement Limited, who has sponsored to Chennai Super King [CSK] cricket team in IPL during 2015 session, and still is active [13].

Seventeen different types of waste materials, equivalent to ingredients of conventional concrete have been documentated as Table1.

The more stress for different types of waste material towards alternative of cement has been observed, due to its cost and carbon dioxide emission in atmosphere during preparation stage at cement plant, than other ingredients like coarse aggregate & fine aggregate. The first partial replacement of cement through fly-ash was introduced in 1955 at Central Building Research institute [CBRI] Roorkee and successfully applied at Obra Dam [district Sonebhadra, UP] in 1962 [3]. The metallurgical slag from Iron & Steel Industry has been used successfully at Jojobera [near Tatanagar, Jharkhand by TISCO in 1988 [22], as Portland Slag cement, widely used for reinforced concrete. The silica fume- as waste from Ferro-Alloy Industry has been successfully used for High Performance Concrete. The metallurgical slag from Copper Industry has been used for Geo-polymer Concrete, without any portion of Portland cement at Congo in 2019 [10]. The renewable waste materials for partial replacement of cement like Rice husk Ash from Rice milling plant, Sugarcane Bagasse Ash from Sugar factory, Bacteria concrete for self healing of cracks and Bamboo for support to concrete have been successfully investigated at various Geotechnical Labs in India.

S N	Name of Alternative Waste Material	Involved Organization	Equivalent To Ingredients of Conventional Concrete	Category
1	Crushing Stone Dust	ASR Institute of Engineering & Technology [Chittor]	Sand	Non-renewable
2	Fine Grinded Glass Powder	Bagdad University [Iraq]	Sand	Non-renewable
3	Demolished Building Waste	Buldana [Maharashtra]	Stone Chips	Non-renewable
4	Coconut shell	Sri Venkateshewer College of Engineering, Tirupati	Stone Chips	Renewable
5	Electronic [e] Waste	SRM University-Chennai, Periyar M University, Thanjavur	Stone Chips	Non-renewable
6	Rice Husk Ash	R I T, Roorkee	Cement	Renewable
7	Sugar Cane Bagasse Ash	Gujarat & Tamilnadu	Cement	Renewable
8	Bamboo	Nagpur [Maharashtra] & Gujarat	Cement	Renewable
9	Bacteria	Nasik [Maharashtra] & Sharda University NOIDA [NCR]	Cement	Renewable
10	Iron & Steel Industry Slag	Tata-nagar [Jharkhand]	Cement	Non-renewable
11	Ferro-Alloy Industry-Silica Fume	Gujarat & Odisa	Cement	Non-renewable
12	Copper Smelter Slag	Congo [West Africa]	Cement	Non-renewable
13	Ceramic Waste	Gujarat	Cement	Non-renewable
14	Marble Dust &Slurry Waste Marble water	SATI, Vidisha [MP], NMAMIT, Karkala [Karnataka] & RNGPIT College [Gujarat]	Cement	Non-renewable
15	Phosphate-Gypsum Waste	Gujarat	Cement	Non-renewable
16	Fly-Ash	NTPC Units	Cement	Non-renewable
17	Human Hair Fabric	Jaipur Engg. College & Research Center, Jaipur	Fly Ash	Non-renewable & renewable

Table 1: Alternative waste material equivalent to ingredients of conventional concrete

The U S Naval Facilities And Engineering Command [NAVFAC] has developed High Volume Fly Ash, in which 50% [by weight] Portland cement has been replaced by in 2012 Fly Ash [4].

The soil stabilization in clayey formation has good scope for application of Fly Ash, as it reduces shrinkage factor due attributing cementitious material. The use of 25% Fly ash [by weight] to red soil for pavement design has reduced shrinkage factor by 20% at Trichur in 2012 [9]. The soil stabilization in clay-loamy soil along-with Fly Ash with application of Human Hair Fabric [HHF] as 1.6 % [by weight], enhances CBR up-to 16.98 %, observed at Jaipur in 2020 [6].

Marble dust, 40 % [by weight] from Marble Industry, as partial replacement of cement has been studied for getting M 30 grade concrete at Karnataka in 2015[20]. Stone waste Slurry Marble Water form Marble Industry up-to 50 % [by weight], as partial replacement of potable good quality water, with meeting BIS Code provision has been proved for M 25 grade Concrete, WITH INCREASING Compressive Strength =13.63 % & Split Tensile Strength =8.03% at Gujarat in 2020 [17].

Fly ash in association with Ceramic waste has been studied for partial replacement of cement to get M30 & M35 grade concrete at Rajkot in 2016 [16].

Fly ash in association with local stone quarry waste has been studied for preparation of Geo Polymer Concrete with total replacement of Portland cement at Vidisha [MP] in 2020 [7].

Rice Husk Ash [RHA] as 15% [by weight] replacement to ordinary Portland cement has been studied for preparation of 25.82 M Pa strength concrete at Roorkee in 2016 [8].

Sugar Cane Bagasse Ash [SCBA] as 20% [by weight] has been studied for replacement of ordinary Portland cement for preparation of M20 grade concrete at Srikalashasti [AP] in 2015 [25].

Bacteria concrete has been studied on the basis of microbial induced calcite precipitation through bacteria reproduction. It has property of crack repairing performance in concrete through self healing mechanism [biologically]. It has been studied at Sharda university, NOIDA & Nasik in 2020 [12].

Bamboo reinforced slab panel has been studied as low cost reinforcing material for reinforced concrete, on account of light weight at Nagpur in 2020 [2].

The Coarse Aggregate [stone chips] has been replaced up-to 30 % [by weight] through coconut shell for preparation of M20 grade concrete at Tirupati & Chittur in 2017 [24]. The Coarse Aggregate has been replaced up-to 30 % [by weight] also by another waster material belongs to Demolished building-as recycled coarse aggregate for preparation of M50 grade Concrete , having self compacting property at Buldana [Maharashtra] in 2017 [13].The Coarse Aggregate has been replaced up-to 15 % [by weight] through crushed e-waste for preparation of M25 grade Concrete at SRM University & Periyar Mamanai University in 2017 [14].

The Fine Aggregate [sand] has been partially replaced by 30 % [by weight] through crushing plant dust for preparation of M20 grade concrete at Tamilnadu in 2017 [22]. The Fine Aggregate [sand] gas been partially replaced by 25 % fine powdered and grinded glass waste for preparation of 70 MPa strength concrete in2015 at Bagdad [19]. The Fine Aggregate has been replaced up-to 8 % [by weight] through crushed e-waste for preparation of M 25 grade Concrete at PSR Engineering College, Sivakashi in 2016 [1].

The water is required in huge quantity for concrete formulation during mixing [paste preparation], placing and finishing [curing] for the desired durability, strength and maintenance of concrete structure. The quantity of water during paste preparation is governed by w/c ratio in the range of 0.35 to 0.50 [11]. The quality of water must be clean and free from sewer with following BIS IS 426-2000. The desired water quality parameters for concrete are summarized as Table 2.

S N	Parameter [unit]	Limit range
1	Ph	6.5-8.5
2	Chloride [mg/Liter]	2000 [PCC], 4000 [RCC]
3	Alkalinity [mg/Liter]	< 25
4	Sulphate [mg/Liter]	400
5	Fluoride [mg/Liter]	1.5
6	Organic Solid [mg/Liter]	200
7	In-organic Solid [mg/Liter]	3000

Table: 2 Water Quality parameters for utilization in concrete at different stages

Result & Discussion

The growth of urban India and related infra-structural setup, developmental activities require cost effective, eco-friendly and economically viable concrete. The sustainability and long term performance of concrete structure with minimum defects depend upon two major parameters namely: Favorable to prevailing environmental condition and Strength, besides cost factor. The minimum use of non-renewable resource materials like- Limestone, Sand and Hard rock and recycling of waste material-disposed off through Industrial, Agricultural and Social sectors are the basic key elements for sustainable development.

The future of Indian concrete by large is likely to be depend upon-commercial utilization of waste material, as partial to fully replacement of aggregate and cement, without losing quality criteria. The evaluation of geotechnical characterization of Seventeen identified waste material towards the partial replacement of ingredients of conventional concrete has been carried out for achieving the desired objectives:-

✓ Evaluation of four index properties of Fine Aggregate equivalent to relevant waste materials pertaining to physical parameters.

The four index properties namely: Density/Bulk density, Specific Gravity, Fineness of Modulus and Water absorption [%] have been evaluated of waste materials equivalent to Sand as Fine Aggregate. The major physical properties and strength parameters of two waste materials are summarized as follows:-

[1] Crushing Stone Dust, has been studied for it's index properties at ASR Institute of Engineering & Technology [Chittor], with following BIS code provision [24]. The Specific Gravity and Fineness of Modulus are obtained 2.57 and 1.8 gm/cc respectively. The 30 % [by weight] of Crushing Stone Dust has been replaced to sand for obtained concrete of good workability and compressive strength of 24.32 N /Sq. mm.

[2] Fine Powdered & well Grinded Glass Waste has been studied for Bulk density as 24.4 Kg/cubic meter, Fineness of Modulus =1.67 and Water Absorption Ratio [%] = 1.4 at Bagdad University, Iraq [19]. The 25 % of Fine powdered & well Grinded Glass waste has been replaced to local river sand for obtained compressive strength of 70 M pa and Flexural Strength of 4, the better quality concrete. The glass waste has been collected through broken residential building, demolished in a terrorist activity, firstly fine powdered and later, well grinded in Loss -angles abrasion machine.

✓ Evaluation of four index properties of Coarse Aggregate equivalent to relevant waste materials pertaining to physical parameters.

The four index properties namely: Density/Bulk density, Specific Gravity, Fineness of Modulus and Water absorption [%] have been evaluated of waste materials equivalent to Stone Chips as Coarse Aggregate. The major physical properties and strength parameters of two waste materials are summarized as follows:-

[3] Demolished Building Waste as Recycled Coarse Aggregate [RCA] has been studied at PLIT, Buldana [Maharashtra] with following BIS code provision [14]. The index properties like- Bulk Density = 1356 Kg/cubic meter, Fineness of Modulus =6.96 and Water Absorption [%] =5.64 has been obtained. The 20 % of Demolished Building waste [standard grain size] has been replaced to conventional Broken Stone Chips for obtained concrete of strength characteristics like- Compressive strength =35 M Pa, Split Tensile strength = 5 M Pa, Flexural Strength = 8 M Pa, Workability = 65-80 mm [slump height] with self compaction performance.

[4] Coconut Shell Waste has been studied for partial replacement of Broken Stone chips at ASR Institute of Engineering & Technology, Chittor and Sri Venkateshewer College of Engineering, Tirupati [5]. It has been observed that Coconut shell-Cement ratio satisfies the criteria of structural Light Weight Concrete. The Coconuts have been broken manually to drain out water. The coconut half shells have been sun dried for three days for obtaining index properties like- Bulk density = 800 kg/cubic meter, Specific Gravity = 1.3, Water absorption [%] =24, Shell Thickness = 2-7 mm, Specific Gravity =2.57, Fineness of Modulus = 2.12 The 10 % of Coconut Shell Waste [standard grain size] has been replaced to conventional Broken Stone Chips for M30 grade concrete of Strength characteristics like- Compressive Strength = 24.35 N/Sq.mm, Split Tensile Strength = 3.34 n/Sq.mm, Workability – slump =66 mm, with reduced cost factor =16.6 %.

The Coconut shell as 10 % - replacement to Coarse Aggregate [conventional stone chips] + Quarry Dust as 30 %- replacement to Fine Aggregate [conventional sand] has provided M20 grade concrete of same Strength characteristic like- Compressive Strength = 24.35 N/Sq.mm, Split Tensile Strength = 3.34 N/Sq.mm, Workability – slump =66 mm, w/c =0.5 [24].

The Coconut shell based concrete is suitable as filler material in Framed Structure, Flooring Tile and Thermal Insulating Concrete.

[5] Electronic [e] Waste has been studied for partial replacement of coarse Aggregate at SRM University, Chennai & Periyar Mamanai University, Thanjavur [14]. Experimental study on e Waste and comparing with conventional concrete has provided Non-corroded Concrete with improved strength. The physical properties of used e Waste are as follows:

Optimum size of crushed Electronic Waste = 20 mm, Specific Gravity =2.71, Fineness of Modulus =2.50, Water Absorption [%] =0.20.

The partial replacement of Coarse Aggregate up-to 15 % [by weight] of e waste for preparation of M25 grade Concrete of following strength parameters:

Compressive Strength =40 N/Sq. mm, Flexural Strength [a] In Hydro-chloride acid =3.81 N/Sq. mm, [b] In Sulfuric acid =3.88 N/Sq. mm, towards corrosive reaction purpose.

✓ Evaluation of six engineering properties of cement equivalent to relevant waste materials pertaining to strength and physical parameters

The six engineering properties namely: Workability, W/C Ratio, CBR, Compressive Strength, Split Tensile Strength and Flexural Strength have been studied to eleven waste materials equivalent to conventional Cement. The details of strength and physical properties of each relevant waste material are summarized as follows:

[6] Rice Husk Ash [RHA] has been considered as "green construction material" with eco-friendly and pozzalanic character, based upon natural fiber with high porosity. The RHA with varying 5-15 % [by weight] for replacement of cement has provided concrete of following strength characteristics [8].-

5 % RHA replacement to cement [by weight] has improved w/c ratio, workability and compact factor.

9 % RHA replacement to cement [by weight] has sustained Split Tensile Strength of 172 M Pa.

12 % RHA replacement to cement [by weight] has sustained Compressive Strength of 500 M Pa.

15 % RHA replacement to cement [by weight] has obtained concrete of same Strength parameters, but drastic reduction in cost factor.

[7] Sugar Cane Bagasse Ash [SCBA] is eco-friendly material with cellulose as natural fiber and water absorption [%] up-to 70-75. The SCBA with varying 3-12 % [by weight] for replacement of cement has provided concrete of following strength characteristics [25].-

3 % SCBA replacement to cement [by weight] has obtained 5% increment of Compressive Strength for M30 grade concrete.

10 % SCBA replacement to cement [by weight] has obtained 10 % increment of Split tensile Strength and workability.

12 % SCBA replacement to cement [by weight] has obtained w/c ratio =0.48 for M20 grade concrete.

[8] Bamboo has indirect assistance to concrete on account of natural fiber for reinforced concrete with reduction in cost factor. The Tensile Strength of Bamboo is 20 times more than steel [2].

[9] Bio-concrete is also known as Bacteria concrete. The bacterial carbonate precipitation has shown positive influence on Compressive Strength, Durability and reducing hydraulic property. It is associated with self healing phenomena for repair of crack in concrete [12].

[10] Ceramic waste is produced through ceramic industry in various processes about 10 % of final product. The powder of ceramic waste up-to 5-30 % [by weight] replacement to cement has provided Self Compacting property to M30 & M35 grade concrete on account of enhancing fresh and harden property and Workability of concrete [16].

[11] Marble dust waste- The Marble Stone industry produces 40 % solid waste. The marble dust up-to 5-20 % [by weight] replacement to cement has provided improved Compressive Strength as35.46 N/Sq.mm, Split tensile Strength =2.83 M Pa, Flexural Strength =4.5 M Pa of M 30 grade concrete.

8-16 % Marble dust [by weight] + 8% Silica Flume [by weight], replacement to Ordinary Portland Cement has provided M30 grade concrete with 8% increment of Compressive Strength and w/c ratio =0.26 -0.42 [23].

[12] Phosphate-Gypsum waste- It is generated from Chemical & Fertilizer Industry. The adequate replacement of Phosphate-Gypsum to cement for concrete pavement decreases alkali-aggregate reactivity, increases resistance to Sulfate on account of less W/C ratio [13].

[13] Silica Flume- It is generated from Ferro-Alloy Industry. It has two grade of Bulk Density, as [i] un-densifed-having value of 200-350 kg/cubic meter, occurring in filter as very light powder. It has good application in concrete for mortar and grouting purpose. [ii] Densifed- having value of 500-700 Kg/cubic meter. It is used for precast concrete preparation [13].

[14] Iron & Steel Industry Slag- Granulated Blast Furnace Slag [GBFS] is replaced by Portland Cement for enhancing reinforcement in concrete as per BIS Code [IS 455-1989] by either inter-grinding or blending after grinding. It is under production near Tata-nagar since 1990 [3.13]

[15] Copper Slag- It is generated from Copper Smelter Plant and well studied at Congo [West Africa]. It is used for preparation Geo Polymer Concrete [GPC], total replacement of Portland cement. The combination of activated clay 25 % [by weight] and copper slag 75% [by weight] with silica oxide/aluminum trioxide ratio =2.23 has been observed as most suitable proportion, for concrete of Compressive Strength =64.48 M Pa [10].

[16] Fly Ash – It is generated from Thermal Power Station through combustion of Bituminous Coal in India and follows BIS Code [IS 3812-2003]. The Fly Ash with 40-60 % [by weight] replacement to cement gas been attempted, with findings are as follows:

40 % Fly Ash [by weight] replacement to cement has been obtained compressive Strength = 40 M Pa in 2012.

45 % Fly Ash [by weight] replacement to cement has obtained 35 % decreased in Split Tensile Strength.

50 % Fly Ash [by weight] replacement to cement has obtained 23 % slump flow in 2007.

60 % Fly Ash [by weight] replacement to cement has obtained 12 % decreased in Flexural Strength.

The comprehensive application of Fly Ash for replacement of cement has been carried in 2015, at Egypt [15].

[17] Human Hair Fabric [HHF] Waste- It is renewable and non-biodegradable waste. It has property for improving of strength for clay loamy soil particularly CBR for stabilization in association with application of Fly Ash [as non-renewable]. The preliminary study carried at Jaipur Engineering College has provided encouraging findings [6].

✓ <u>Binding characteristics of Fly-ash.</u>

It has been studied on account of low content of calcium in Fly Ash, with observation that clayey soil stabilizes it in optimum amount due to cation exchange chemical property. It assists in pozzalanic reactivity for improving the self hardening property of Fly Ash [11].

Conclusion

Concrete is the major item of present day construction activity. The basic ingredients of concrete are: Cement, Aggregate [Coarse & Fine] & Water with prescribed proportion [as per BIS code] through mixing, preparation and processing stages for durability, stability, performance and serviceability of civil engineering structure for designed life period. The patience, pursuance, carefully following specifications are required for maintenance and functioning of civil engineering structure properly in all above mentioned stages, with involvement of huge cost under skilled and experienced engineer.

The constructed concrete based civil engineering structures presently do not sustain for designed life period. These are often associated with defects like: crack Formation, Seepage & Leakage, Weather's effect & Deformation. Such negative issues are to be handled through eco-friendly, low cost, economically viable measures pertaining to utilization of available waste materials in prevailing society, industrial and agricultural sectors.

Fifteen waste materials [five of renewable and ten of non-renewable category] have been identified and investigated, pertaining to the equivalent properties of the ingredients of conventional concrete with improved quality and at reduced cost. Six such new varieties of concrete have been studied experimentally with proven application capability. These are the **future concrete of India** under national mission-'Clean Environment & Green Environment' and as follows:-

- Geo-Polymer Concrete [GPC]:- It has the total replacement of Portland cement. It is obtained with varying Fly Ash of 30 % [by weight] for M30 & M50 grade concrete.
- Glass Fiber Reinforced Concrete [GFRC]:- It has partial replacement of cement by fine glass powder in 2%, 4%, 16%, 20% [by weight], as per BIS Code [10262-2009] for M30 grade concrete. It has high Flexural Strength, which decreases the load on super imposed structure with more stability & durability. It is used for light weight window, design component of balcony and exterior design of façade panel. It is also known as Architectural Precast Concrete.
- Reinforcement Improved Concrete: - It has partial replacement of cement through metallurgical slag from Iron& Steel Industry and Silica Flume from Ferro-Alloy Industry.
- Bacteria Concrete: - It is also known as Biological Concrete. It is based upon reproduction of bacteria through precipitation of calcium. It has self mechanism for repair of crack formation in concrete.
- Coconut shell based Concrete: - It is also known as Light Weight Aggregate concrete. It has partial replacement of Coarse aggregate [Stone Chips] as 50 % [by weight] with processed Coconut shell for getting M30 grade concrete, having strength parameters as compressive strength =20 M Pa and workability [slump=10mm]. It has been successfully utilized in Low Cost Housing Scheme at Tirupati.
- Pavement Concrete: - It is used for pavement improvement in Red soil & Clay soil by utilization of Fly Ash in the range of 3%. 5% & 9% at Trichur- coastal area [India] in 2013. It has been observed in the enhancement of CBR, Liquidity Index, Plasticity Index and Compressive Strength, which favored for construction of Cement –Concrete [CC] road, successfully.

Acknowledgement

The authors would like to express their gratitude to the authorities of Dr. C V Raman University, Kota, Bilaspur [CG] for rendering the necessary assistance. The views expressed in the paper are the views of the authors and do not of the organization, to whom they belong.

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