Application of Solid Wastes for the Production of Sustainable Concrete

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Abstract. The production of concrete results in emissions of about 0.13 t of CO_2 per ton of concrete, equal to 1/9th the emissions of cement. The tremendous usage of conventional raw material creates a negative impact on the concrete industry which can be minimized by the application of solid wastes as a raw material. The present paper reviews various solid wastes in different compositions to develop sustainable concrete. In view of the utilization of agro-industrial wastes as a pozzolanic material, their physical and chemical characterizations were reviewed. The crushing strength of high strength concrete incorporated with various agro-industrial wastes as a pozzolanic material was studied. This paper also proposes a procedure for producing manufactured coarse aggregates made of solid waste (i.e. sediment dredged from dam reservoir). The crushing strength of concrete incorporating the manufactured coarse aggregates was experimentally measured. Along with it, the physico-mechanical properties of the artificial sand, produced using the industrial solid wastes (i.e. fly ash) were analyzed. Reusing of solid waste as a substitute raw material will not only solve its disposal problems but also serves as an economical option to develop the sustainable concrete. The present paper is useful for various researchers involved in using solid wastes to develop the sustainable concrete.

Keywords: Solid waste · Sustainable concrete · Reservoir sediment
Agro-industrial waste

1 Introduction

The continuous increase in demands of residential apartments and infrastructural facilities is because of the higher rate of increase in population as well as an improvement in living standards. This needs concrete for their construction. After water, concrete is the most consumed material in India, which ultimately requires large quantities of cement, sand, and aggregates for its production. The entire world is currently facing the most serious environmental issue of rapid depletion of natural resources due to their enormous increase in consumption rates. Cement production requires a tremendous amount of energy for its production and can generate nearly one ton of CO_2 for every ton of processed cement. Stringent new laws prohibit blasting of hills for obtaining aggregates. There is also ban on removal of natural sand from rivers. These are the crucially important materials for every new construction. These resources

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are exhausting very rapidly because of their tremendous usage. So it is a need of the time to find some substitute to these natural resources.

Disposal of a considerable quantity of agro-industrial wastes is currently one of the serious environmental issues. Utilization of such solid waste for the production of cement, sand, and aggregates will not only answer the disposal problem of solid wastes but also gives the sustainable solution to the depletion of natural resources. Another severe problem the world is facing is a water shortage. Dams built all over the world are filled with a large volume of sediment, which occupies from around 10% to more than 70% of reservoir volume. The only way out is the removal of this sediment and use it in the making of artificial aggregates. Finding an alternative raw material is a dire need of the time before it is too late.

2 Cementitious Materials

Figure 1 indicates the information on the status of waste produced from different agro-industrial sources in India [1]. A lot of waste produced from agro-industrial sources is wheat straw husk, sugarcane bagasse, paddy, groundnut shell, cotton stalk, coconut shell, jute fiber, wooden industry waste etc. [2]. Akram et al. [3] reported that the India is the second largest country in producing sugarcane i.e. 290 million tons yearly. Prasad et al. [4] reported that India alone annually generates 30 million tons of rice husk. Singh et al. [1] reported that the annual production of maize across India is about 18.5 and 5.55 million tons of maize residue i.e. corn cob is generated.

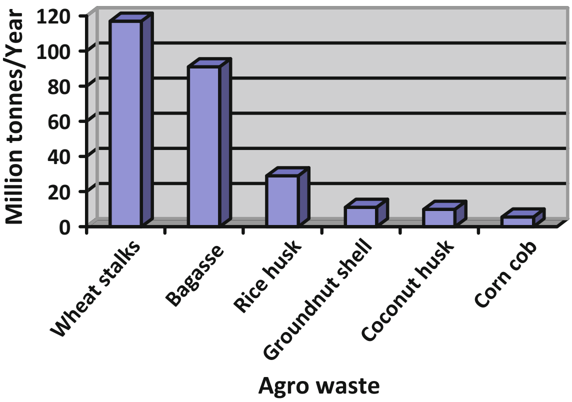

Fig. 1. Status of agro-industrial wastes produced in India (million tonnes/year) [1]

2.1 Physical Properties of Agro-Industrial Waste Ashes

From Table 1, it is seen that the particle size, specific gravity, and the density of all the agro-industrial waste ashes are lower than that of cement except for corn cob ash. The

Table 1. Physical properties of agro-industrial waste ashes

Property	Particle size (μm)	Particle size (%)	Specific gravity	Specific gravity (%)	Density (kg/cum)	Density (%)	Source
Cement	25	100	3.12	100	3140	100	[5–7]
Bagasse ash	5.4	21.60	1.85	57.81	90–140	2.87–4.46	[8, 9]
Rice husk ash	12.3	49.60	2.16	67.50	150–175	4.78–5.57	[8, 9]
Corn cob ash	29–45	116–180	2.5–3.6	78.13–112.50	300–330	9.55–10.51	[8, 10]

corn cob ash blended concrete doesn't show much improvement in the compressive strength of concrete compared to other agro-industrial waste ashes at early ages. So, larger particle size may be one of the reasons for not having any significant strength improvement. As the specific gravity and density of the agro-industrial waste ashes are lower than the cement, the concrete produced will be lighter in weight compared to the control concrete produced without agro-industrial waste ashes. It is examined that the variation in the results of the each property of different agro-industrial waste ashes is because of the disparity in the selection of suitable of incinerator/furnace, grinding method, burning time, burning temperature, and cooling time etc. of agro-industrial wastes.

2.2 Chemical Characterization of Agro-Industrial Waste Ashes

Table 2 shows that the residue after combustion of agro-industrial waste ashes gives the chemical characterization dominated by SiO_2 (silicon dioxide). More the percentage of amorphous silica in a material better is the pozzolanic activity. The review also shows that the agro-industrial waste ashes contain all the elemental oxides, which are present in cement. Nair et al. [11] analyzed that the large quantity of amorphous silica found in ashes burnt at the temperature of 500–700 °C. Habeeb et al. [12] examined that the rice husk ash is effective as a supplementary cementitious material i.e. it is dominated by amorphous silica content (88.32%). Jauberthie et al. [13] identified the origin of the amorphous silica in rice husk ash. The rice husk ash contains a strong concentration of silica occurring in an amorphous and crystalline (quartz) forms. The amorphous silica occurs mainly on the external face of the husk and to a lesser concentration on the inner surface. This amorphous silica explains the pozzolanic role. Adesanya et al. [14] investigated that, as the corncob ash percentage increases, additional silicate and alumina were available to react with the lime produced during hydration of cement to produce further cementitious products. The silica and alumina content are responsible for the development of cementitious compounds. Aprianti et al. [5] explained that when pozzolanic materials are combined with Portland cement, they react to form cementing particles whereas, by themselves, these ashes do not possess any cementitious properties. Thus, a cementitious material can exhibit a

Table 2. Chemical composition of agro-industrial waste ashes

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	SO_3	LOI	Source
OPC	25.1	5.5	5.9	55	3.4	0.5	2.7	0.9	[7]
Bagasse ash	65	4.8	0.9	3.9	–	2	0.9	10.5	[7]
Rice husk ash	86.81	0.5	0.87	1.04	0.85	3.16	–	4.6	[15]
Corn cob ash	67.33	7.34	3.74	10.29	1.82	4.2	1.11	–	[16]

self-cementitious i.e. a hydraulic activity and contains quantities of CaO while a pozzolanic material requires $Ca(OH)_2$ to form strength.

2.3 Compressive Strength of Agro-Industrial Waste Ash Blended Concrete

Table 3 shows that researchers were utilized various agro-industrial wastes ashes in varied proportions blended with cement and also adopted various methodologies to produce ordinary, standard, and high strength concrete (As per IS 456 clause no. 6.1, 9.2.2, 15.1.1, and 36.1) of various grades. From the reviewed results of Table 3, it is observed that as the cement replacement (%) increases the (28 days) compressive strength decreases except for the rice husk ash blended high strength concrete. But still,

Table 3. Cement replacement and respective compressive strength of agro-industrial waste ash blended concrete

Agro waste	Cement replacement (%)	Comp strength 28 days (Mpa)	Control concrete strength (Mpa)	Source	Remarks as per IS 456 (clause 6.1, 9.2.2, 15.1.1 and 36.1) [17]
Bagasse ash	2	59.75	50.10	[18]	Standard/high-strength concrete
	6	57.25			
	10	56.20			
Bagasse ash	10	43	36	[19]	Standard concrete
	20	40			
	30	32			
Bagasse ash	5	29.50	13.80	[20]	Ordinary concrete
	15	19.32			
	25	17.73			
Rice husk ash	10	40.6	36.8	[21]	Standard concrete
	15	37.9			
	20	36.7			
Rice husk ash	10	81	76	[22]	High strength concrete
	20	86			
	30	80			
Corn cob ash	10	23	24	[23]	Ordinary concrete
	20	19			

the compressive strength values are more than the control concrete strength. Agro-industrial waste ashes when blended with cement, silica of the ashes react with $Ca(OH)_2$ and produces an additional calcium-silicate-hydrate gel. This gel greatly contributes towards the compressive strength of concrete. So, blending of cement with the pozzolana in concrete reduces the quantity of $Ca(OH)_2$ and increases the strength.

The 28 days compressive strength behavior of concrete is shown in Fig. 2. It explains that compressive strength decreases with the increase in percentage agro-industrial waste ashes at short term ages (28 days). Insignificant improvement in compressive strength of blended concrete is observed at lower ages (28 days). This can be attributed to the fact that the low rate of pozzolanic reaction at early ages. While Fig. 3 shows the increase in 90 days compressive strength of blended concrete as the percentage of agro-industrial waste ashes increases up to the certain limit. This is because the silica from pozzolan reacts with lime produced as the by-product of

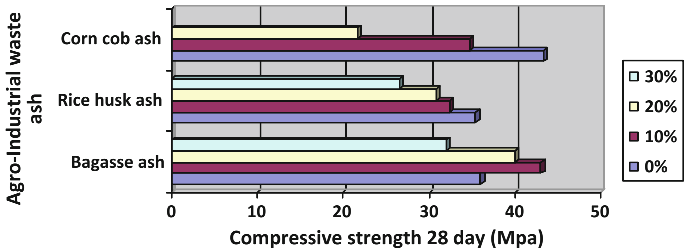

Fig. 2. Comparison of 28 days compressive strength of standard concrete with 10, 20, and 30% cement replacement [16, 24, 25]

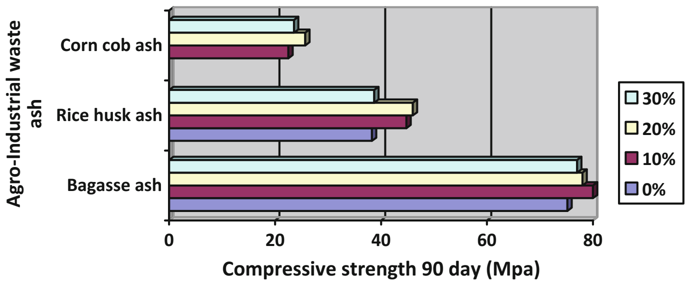

Fig. 3. Comparison of 90 days compressive strength of standard and high strength concrete with 10, 20, and 30% cement replacement [7, 26, 27]

hydration of ordinary Portland cement to form additional calcium-silicate-hydrate that increases the binder efficiency and corresponding strength values at later days of curing (90 days).

3 Manufactured Aggregates

The consumption of the concrete has been increasing in recent years in developing countries like India at a rate far exceeding that suggested by the economy growth rate of the construction industries. Concrete is an important part of society's infrastructure. Everyday life is greatly affected by concrete in numerous ways. The aggregates occupy 70–80% of the volume of concrete; their impact on various characteristics and properties of concrete is undoubtedly considerable. Blasting of hills and quarry mining for crushed aggregates will automatically come to a stop by using the manufactured aggregates instead of natural and crushed aggregates for making concrete, and all the subsequent adverse impacts on the environment will be avoided. The methodology for producing the manufactured aggregates out of reservoir sediment is proposed here.

3.1 Methodology Adopted

The fine sediment was collected from the Khadakwasla Dam Reservoir, Pune, Maharashtra, India. It was manually segregated to remove all unwanted materials such as shells, organic matter, and plastic bags. The fine sediment was then sun and air dried in order to reduce the moisture content from sediments. The sundried material was crushed into sufficiently fine size, nearly to a powder form. After crushing into a fine powder, the material was sieved manually through a 300µ sieve. The physical characteristic of the sediment is reported in Table 4. More than 50% particles were of clayey nature. It indicates that it was a highly organic clayey soil. Also, it was of highly plastic nature according to plasticity index value.

Table 4. Physical test results of the fine sediments

Soil classification	Specific gravity	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Ingredients (%)			
					Gravel (%)	Sand (%)	Silt (%)	Clay (%)
Highly organic	2.65	74.3	47.17	27.13	0	21.6	22.13	56.22

Trial mixes of dredged fine sediment and admixtures (Sodium hydroxide [NaOH], sodium silicate [Na_2SiO_3], Bottom ash and Cement) were prepared. Trial mix details are given in Table 5. Sieved dredged sediments and admixtures thoroughly mixed with optimum water content. Then the mixture was filled and compacted into the cylindrical molds. Then the molds were cut into angular shapes and random sizes by using trimming knife. These raw aggregate samples were sundried for 10 days. The dried aggregates were baked at the temperature of 1100 °C in a scientific oven by using Ramp and hold arrangement. All the six types of baked aggregates are as shown in Table 5. The manufactured aggregates were tested for determining the various engineering properties (crushing value, abrasion value, impact value, soundness, and water absorption) and to check whether they meet Indian Standards for aggregates to be used in construction. The results of engineering properties of the manufactured aggregates

Table 5. Trial mixes of fine sediment and admixture for manufacturing aggregates

Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Trial mix field sediment + 0% admixture	Field sediment + 2.5% NaOH	Field sediment + 2.5% Na_2SiO_3	Field Sediment 2.5% + bottom ash	Manufactured aggregates + coating of 10% Na_2SiO_3	Manufactured aggregates + coating of 10% cement
					

Table 6. Mechanical properties of manufactured aggregates

Sr. no	Experiment	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Permissible limit (%)	IS 2386: 1963
1.	Crushing value (%)	29.19	25.2	20.3	27.5	21.8	19.0	<30	Part 4
2.	Impact value (dry) (%)	28.9	21.4	15.2	28.8	21.7	26.8	<30	Part 4
3.	Impact value (wet) (%)	31.9	23.4	19.7	30.0	22.0	27.0	<39	Part 4
4.	Water absorption (%)	11.3	5.0	3.1	11.3	6.3	6.7	<2	Part 3
5.	Abrasion value (%)	31.3	27.7	23.1	28.5	26.8	29.4	<30	Part 4
6.	Specific gravity (−)	1.4	1.3	1.2	1.4	1.4	1.7	–	Part 3
7.	Soundness value (%)	9.8	8.4	8.2	9.7	8.6	9.5	<18	Part 5

are shown in Table 6. All the six types of manufactured aggregates were tested for Crushing value, Impact value (Dry), Impact value (Wet), Water absorption, Abrasion value, Specific gravity, Soundness value in accordance with IS 2386 (Part 3)-1963, IS 2386 (Part 4)-1963, and IS 2386 (Part 5)-1963 Codes. The test results of manufactured aggregates were compared with the permissible limits given in respective IS code. The specific gravity of the produced aggregates ranging from 1.76 to 1.28 is significantly lower than the specific gravity of commercially available natural aggregates. By studying the test results it can be concluded that the produced aggregates can be used as Light Weight Aggregates (LWA) for structural concrete. Type 4 aggregate was found to have better strength amongst all six types, which confirms that manufactured aggregates are able to serve as structural aggregates.

4 Artificial Sand

One of the major challenges with the environmental awareness and scarcity of space for land-filling is the wastes/by-products utilization as an alternative to disposal. Throughout the industrial sector, including the concrete industry, the cost of environmental compliance is high. Use of industrial by-products such as foundry sand, fly ash, bottom ash, and slag as a substitute material for the natural river sand can result in significant improvements in overall industry energy efficiency and environmental performance. Use of natural river sand in concrete has a number of constraints pertaining to its availability, quality, cost, and environmental impacts. Waste foundry sand, bottom ash, and copper slag are reviewed in the present paper.

Table 7. Physical properties of artificial sand

Fine aggregates	Specific gravity	Unit weight (kg/cum)	Fineness modulus	Source
Sand	2.63	1890	3.03	[31]
Waste foundry sand	2.61	1638	1.78	[31]
Bottom ash	1.93	948	1.60	[31]
Copper slag	3.40–3.91	2080	3.47	[32, 33]

4.1 Physical Properties of Artificial Sand

Kim et al. [28] experimentally evaluated that the density of hardened concrete linearly decreases as the replacement ratio of bottom ash increases. As the bottom ash is having lowest specific gravity and the unit weight shown in Table 7. Kou [29] found that a slump value of fresh concrete gets affected by the fineness modulus of artificial sands. Substitution of artificial sands in concrete increases its slump value. Siddique et al. [30] reviewed that the water absorption capacity of the concrete decreases with increase in waste foundry sand content and so adversely affect the slump of the concrete. The effect of particle size of artificial sand on the strength properties of the concrete was also studied. Using waste foundry sand having the particle size in the range of clay and silt results in the decrease in the porosity of the concrete. Possibly, it can be the favorable effect on the strength properties of the concrete.

4.2 Chemical Characterization of Artificial Sand

The reviewed waste foundry sand exhibits pozzolanic properties since it contains low CaO content, highest silica content i.e. 83.8% and other oxides such as Al_2O_3, SiO_2, and Fe_2O_3 shown in Table 8. All other reviewed industrial wastes also have all the elements which are present in cement. Use of these wastes in the concrete industry can have the benefits of reducing the costs of disposal and helps to protect the environment.

4.3 Compressive Strength of Artificial Sand Blended Concrete

Aggarwal et al. [31] experimentally analyzed that the inclusion of waste foundry sand and bottom ash as fine aggregate does not affect the strength properties negatively as the strength remains within limits. The concrete was endowed with comparable mechanical properties and greater resistance to aggressive agents (chemical, physical and environmental). Table 9 shows the blending of artificial sands in the concrete in varied proportion. For every artificial sand different optimum percentage is obtained. The strength obtained by the replacement of industrial wastes is more than the control concrete strength except for the bottom ash blended concrete. Guney et al. [38] studied the reason for the decrease in strength property of concrete after excessive sand replacement. It is possibly due to the weakening in cement/aggregate adherence, an increase in the amount water required and retardation in cement hydration. In addition,

Table 8. Chemical composition of artificial sand (% by mass)

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	SO_3	LOI	Source
Waste foundry sand	83.8	0.81	5.39	1.42	0.86	1.14	0.21	–	[34]
Bottom ash	56.4–57.9	29.2–22.6	8.44	0.75–2	0.4–3.2	1.29	0.24	0.89–1.67	[35, 36]
Copper slag	25.8–31.9	0.22–2.52	68.29–59.11	0.15–1.25	1.65	0.23–0.81	0.11–1.34	6.59	[33, 37]

Table 9. Sand replacement and respective compressive strength of artificial sand blended concrete

Artificial sand	Sand replacement (%)	Comp. strength 28 days (Mpa)	Control concrete strength (Mpa)	Source
Waste foundry sand	10	33.24	33.14	[39]
	20	32.58		
	30	31.24		
	40	29.48		
	50	25.23		
Bottom ash	10	21.41	39.52	[40]
	20	23.78		
	30	24.65		
	40	19.99		
	50	21.20		
Copper slag	10	46.00	45	[41]
	20	47.00		
	40	47.10		
	50	47.00		
	60	46.00		
	80	34.80		
	100	35.10		

water absorption during cement hydration and, then, water loss in the hardened concrete may cause an increase in the voids and, later, the occurrence of cracks in the concrete. The strength and durability of concrete decrease significantly under these unfavorable conditions.

5 Conclusions

The review shows that many agro-industrial waste ashes such as bagasse ash, rice husk ash, and the corn cob ash have the potential to be used as a supplementary cementitious material for producing sustainable concrete. The quality of highly reactive ash depends on the controlled burning conditions of agro-industrial waste i.e. selection of suitable of incinerator/furnace, burning time, burning temperature, cooling time, and grinding method etc. of agro-industrial wastes. Application of agro-industrial waste ashes in concrete enhances the compressive strength with the age of concrete. Better results were observed for 90 days age than the 28 days age in the present study. The use of less expensive agro-industrial waste ash is more desirable to decrease the overall production cost of concrete and to reduce the cement requirement. Which leads to decrease the environmental pollution and energy by cement factories thus providing economic and environmental benefits along with providing a way of disposing of this agricultural waste product which otherwise has a little alternative use. Using agro-industrial waste ashes as a supplementary material in concrete will be a valuable contribution and viable solution for sustainable construction. So, it can be concluded that the agro-industrial waste ash mineral is a promising pozzolanic material and can be fruitfully used as a supplementary material in Portland cement.

The reservoir sediments can be used as primary resource material for manufacturing lightweight aggregates that can achieve not only technical benefits but also can result in good social and ecological benefits. The Specific gravities of the produced manufactured aggregates ranged from 1.28 to 1.76, as against 2.67 for the natural aggregates. They also meet the requirements of relevant IS codes. Type 4 i.e. Sodium silicate admixture aggregates are having better properties amongst all six types of aggregates. Making artificial aggregates by using dam reservoir sediment will solve two problems with one solution, namely (1) Emptying the dam reservoirs and increasing its water storage capacity and (2) Offering an eco-friendly solution, which will not only provide an essential product for human use but also it will not create any new environmental problems. It is feasible to use the reviewed industrial waste ashes as fine aggregate in preparing concrete mixes. Replacement of fine aggregates with bottom ash can easily be equated to the strength development of normal concrete.

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