A Review of Agro-waste Materials as Partial Replacement of Fine Aggregate in Concrete.

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Abstract. An immense amount of agricultural waste is produced while growing, harvesting and processing goods; which should be treated as a resource for its prevalence and renewability. While developed countries are concerned with utilization and environmental issues, developing countries are focusing on the economic factors of social housing, especially in rural areas. Fortunately, environmental awareness has been raised in the construction industry by using agricultural waste as partial replacement for fine aggregate, coarse aggregate, reinforcing materials, cement and binders. This review is an attempt to collect world-wide data with references for future estimation possibilities of agro waste application focused on fine aggregate replacement in concrete.

1. Introduction
The use of vegetable fibers and other agricultural by-products materials such as sugarcane bagasse ash (SCBA), groundnut shell (GNS), oyster shell (OS), saw dust (SDA), oil palm shell (OPS), rice husk ash (RHA), cork waste ash (CPA) and coconut shell (CNS) in concrete leads to significant changes in the construction industry for house building and enriches the country's infrastructure with rapid development. This tendency in upper middle and high income countries is mainly viewed as an ecological disposal alternative; however, in the developing countries it is viewed as a cost reducing alternative. Additionally, in developing countries the safety issue is also a problem; properties are built without proper calculations, design and materials in earthquake-prone areas causing enormous human losses. For instance, as it happened in Haiti (2010) and Ecuador (2016). Consequently, the combination of local building materials with traditional building methods is rapidly gaining momentum worldwide which leads to an increase of research and experiments in countries as Brazil [1], Malaysia [2], India [3], as well as in Russia [4] and Belarus [5]. Currently, agricultural wastes are primarily used in concrete as a partial replacement for coarse and fine aggregates [6], admixtures [3], cement replacement [7] and even in ultra–high–strength concrete [8] and lightweight concrete [9]. Other uses encompass roof tile production [10,1], asphalt [11] and fibers for concrete reinforcement [12]. The most informative review was found by authors in [13], but as it is shown in the paper, this information is not enough. In this review paper, the data from various sources is gained for further possibilities examination of agro-waste materials as a replacement for fine aggregate; additionally, negative consequences are also taken into account.

2. Agricultural wastes production worldwide
Undoubtedly, biomass is an important and abundant resource, which can be utilized in different approaches. According to the information about the biomass and waste production of some countries annually, waste after biomass processing was approximately calculated in percentages.

![Figure 1. Annual waste balance per country](image)

The information given in figure 1 on the basis of Faostat (2016), Unimore (2017), Ricegrowers' Association, Indian production and trade statistics (2011) shows the need of recycling and biomass utilization; countries as India display an effective use of biomass with only 6% walnut shell waste, contrasting alongside China with an inefficient use of 40% walnut waste.

3. Physical and chemical properties of some agricultural wastes

In practice sand is usually used as a natural fine aggregate, but the necessity for alternative materials and need of sustainability has led to the use of agricultural waste as its replacement.

3.1 Physical properties

The physical properties of biomasses are highly diverse as a consequence of moisture and size variations, ash yield and different genetic types of inorganic matter [8]. Due to this statement it is substantive to assemble agricultural wastes in order to comprehend their feasibility.

In Table 1 the physical properties of agro-waste aggregates compared to sand are given. Bold figures were added by authors from various sources.

As it is seen in Table 1 OPS and CNS have the highest fitness modulus making it challenging to use them as fine aggregate. These agro-wastes are used as rather coarse aggregate in experiments [21, 22]. OPS and CNS can also be used as aggregates when creating sidewalks in urban parks.

| Properties         | Sand [7,14] | SCBA [13] | GNS [15,16] | OS [17] | SDA [18] | OPS [19,2] | RHA [20] | CPA [8] | CNS [21] |
|--------------------|-------------|-----------|-------------|---------|----------|-----------|---------|-------|---------|
| Specific gravity   | 2.38−       | 1.25−     | **1.54**    | 2.1−    | **2.15−**| **1.17−** | 2.03    | 1.5   | 1.05−1.20 |
2.64 2.54 2.48 2.5 1.37

Fitness modulus 2.21–3.44 1.42–2.12 2–2.8 1.78 6.08 6.26

Bulk density (kg/m^3) 1428–1744 837–2040 254.55 1250 590–600

Water absorption (%) 0.74–2.9 0.88 1.61 2.9–7.66 14–24

Moisture content (%) 0.94–0.97 0.42 19.80 8-15 4.2

1SCBA-Sugarcane bagasse ash 2GNS- Groundnut shell 3OS- Oyster shell 4SDA-Saw dust 5OPS- Oil palm shell 6RHA- Rice husk ash 7CPA Cork waste ash 8CNS- Coconut shell

### 3.2 Chemical properties

In the construction industry ash yield from agricultural wastes is used as an acidic additive in concrete mixtures but is not widely applied primarily due to a high degree of heterogeneity in the chemical composition. The chemical compound also varies according to specific species of each agro-waste [23]. Additionally, chemical properties are able to play a key factor in workability and overall performance of concrete. Bold figures were found in various sources pointed in Table 2.

**Table 2. Some chemical properties of agro-wastes.**

| Chemical compounds(%) | SCBA [13,24] | GNS [25,26,4] | OS [6,27] | SDA [28] | OPS [19,29] | RHA [30] | CPA [8] | WNS [31] |
|-----------------------|--------------|---------------|-----------|----------|-------------|---------|--------|--------|
| SiO₂                  | 62.43–90     | **16.21**     | 2–20.06  | 65.3-87 | 62.5-97.6   | 38.15   |        |        |
| Al₂O₃                 | 2.85–4.28    | **5.93**      | **0.5-5.85** | 2.5-4   | 0.14        | **3.65** |        |        |
| Fe₂O₃                 | 4.76–6.98    | **1.80**      | 0.2-3.05 | 2.0-2.23 | **0.54-0.94** | **1.95** |        |        |
| CaO                   | 1–11.8       | **8.69**      | 51.06–98.2 | **3.50-9.6** | **0.1 - 1.31** | **35.88** | **0.89** |        |
| MgO                   | 0.07–3.61    | **6.74**      | 0.51-0.93 | **0.24-5.8** | **0.01 - 1.96** | **1.41** |        |        |
| SO₃                   | 1.48         | **6.21**      | 0.06–2.71 |          |              |        |        |        |
| K₂O                   | 3.19–3.53    | **15.73**     | 0.06–0.97 | 0.11    | **0.1-2.54** | **2.13** |        |        |
SCBA, SDA, RHA have the highest Silica content, while OS has mostly CaO. CPA has both SiO₂ and CaO as predominants.

4. **Fresh properties of concrete**

Fresh properties are used to determine the workability which by definition is a full compaction achievement in concrete mixtures that depends on several factors like chemical composition, slump test values, etc. But the main factor that affects workability is water. Unfortunately, there is no acceptable test which will measure directly this characteristic [23].

| Agro-waste | Slump test | Compaction factor | Air content | Flow table test |
|------------|------------|-------------------|-------------|-----------------|
| SCBA [17,7] | + | + | - | - |
| GNS [16] | + | + | - | - |
| OS [6] | + | - | - | - |
| SDA [32] | + | - | + | - |
| OPS [33,14] | + | - | + | + |
| RHA [34] | + | - | - | - |

The most conducted test is the slump test due to the fact that it measures consistency of mixed proportions (see Table 3). Another test that helps us understand workability is the compacting factor which as we may see is not so widely used. CPA, WNS and CNS are not included since the information about the tests of these agro wastes as fine aggregate replacement has not been found.

5. **Hardened properties of concrete**

Studying hardened properties is the most important and necessary process in all experiments related to concrete. Researchers need to know how different aggregates in concrete significantly affect the compressive, flexural, tensile strength, etc. Table 4 demonstrates the amount of researched hardened properties which were found for agro-wastes.
Table 4. Researched hard properties of agro-waste as partial fine aggregate replacement.

| Agro-waste | Compressive strength | Tensile strength | Flexural strength | Elastic modulus | Ultrasonic pulse velocity |
|------------|----------------------|------------------|-------------------|----------------|--------------------------|
| SCBA [30]  | +                    | +                | +                 | -              | -                        |
| GNS [26]   | +                    | -                | -                 | -              | -                        |
| OS [28]    | +                    | +                | +                 | -              | -                        |
| SDA [25]   | +                    | +                | +                 | +              | -                        |
| OPS [33]   | +                    | +                | -                 | -              | -                        |
| RHA [20]   | +                    | +                | -                 | -              | -                        |
| CPA [11]   | +                    | -                | -                 | -              | -                        |
| CNS [35]   | +                    | +                | -                 | -              | +                        |
| WNS [31]   | +                    | -                | -                 | -              | -                        |

According to Table 4 the compressive strength test is the most common test, partly because of its simplicity and importance in structural engineering. However, the results for strength are not only affected by the aggregate, it has to be remarked that other factors as type of mould, curing, specimen size, rigidity of the testing machine and the likewise play an important role in the experiment; a thorough description should always be given. Tensile strength is of importance when estimating the load under which cracking will develop. This information is of vital importance since it helps maintain the continuity of concrete structures, and ever prevention of corrosion reinforcement. For unreinforced concrete beams flexural strength tests should be carried out and especially if the material is planned to be used in developing countries (see Table 5).

Table 5. Types of replacement researched in concrete.

| Type of replacement in concrete | SCBA [24;17;7;36;37] | GNS [15;38;39;26] | OS [28;30] | SDA [32;41] | OPS [22;14;42;43] | RHA [47;5;3] | CPA [49;8] | CNS [11;21;50] | WNS [3;51;3] |
|--------------------------------|-----------------------|-------------------|------------|-------------|-------------------|-------------|-----------|-------------|------------|
| Fine aggregate                 | +                     | +                 | +          | +           | +                 | +           | +         | +           | +          |
| Coarse aggregate               | -                     | -                 | -          | -           | +                 | -           | +         | -           | -          |
| Cement                         | +                     | +                 | +          | -           | +                 | -           | -         | -           | -          |
| Admixture                      | +                     | -                 | -          | +           | +                 | -           | -         | -           | -          |

RHA had the lowest successful percentage replacement of sand with only 5% [47] followed by CNS and SCBA with 10% [35,17]. WNS was reported to have a 20% [51] replacement value along SDA with 25%. It was reported that the partial replacement of sand with SDA did not affect the overall
strength results of the specimen [42]. The most noticeable result was 80% with OS where the overall strength properties increased compared with the 0% OS specimen [28]. However, some tests showed how strength properties decreased as the amount of aggregate increased in the concrete mixture [11, 47, 15, 51]. Thus, as stated in [37] the overall improvement depends on the durability of aggregates in the cementious medium. Most of the aggregates are described as being suitable for the addition in conventional concrete to reduce the density of concrete which is useful to reduce weight of concrete and achieve light weight concrete [35,42,5,37,51] except for OS which according to [28] can be used as a structural element material in a single floor building.

6. Technological treatment processes
The described above aggregates are organic wastes, and therefore, are subject to varying degrees of biological decomposition in contact with an aggressive environment. A possible solution to this problem is the application of technological treatment processes. In [37] SCBA was dried at a temperature of 105-110C for 24 hours since not all the ash particles were equally burnt and mixed with water; this procedure was also applied to CPA [8]. On the other hand [52] GNS was only sun dried. In [44] OPS was washed with detergent in order to remove excess oil and dirt from the surface and then dried. But in [21] it is not indicated whether such procedures were carried out with CNS. Afterward, all the subjects were submitted to grinding with different types of machinery as rice milling machine [52] with GNS and planetary mill RETCSH PM 100 machine [8] with CPA. It is also required a more accurate description of the technological processes, since doubts arise in if it is possible to compare the obtained results or not. Moreover, the processing necessity has to be verified, since it is not stated whether it is absolutely necessary. No accounts on how labor-consuming or complex the technological processes were held.

7. Future recommendations
Concerning future recommendations, it would be useful to have some structural recommendations on agro-waste application possibilities for different conditions and climatic zones. For instance, which types of agro-waste should be used in earthquake-prone areas or areas with different moisture contents.
It considered that concrete based on natural aggregates or admixtures can only be used in economically underdeveloped areas as means to reduce costs, but it can also be used in upper middle or high income areas, if necessary, for the erection of temporary structures as pavilions, shelters, etc. The conclusion about expediency of application should be made not only based on economic issues, but also taking into account social factors as demands and environmental factors.

8. Conclusions
1. Not enough information was found about the tensile and bending tests, and an exact definition of workability was not given in research. Tensile and flexural tests are of importance due to the fact that some structures are designed to be used as structural elements in rural areas.
2. No information about the chemical composition of OPS, CNS and WNL was found. In addition, it is necessary to take into account the chemical heterogeneous properties mentioned before and their impact in the mixture. Furthermore, experiments are needed in order to bring the chemical composition of agro-wastes into homogeneity.
3. There were not found any specifications on how the technological processing of agro-wastes affects the overall mixture outcome or detailed information of costs, machinery, time and overall feasibility.
4. It is not widely observed how a final construction element has to be processed in order to improve its fire resistance, wear resistance, etc. For instance, the resistance to the elution of agro-waste particles, upon contact of the structure with water is of importance in tropical conditions with long rainy seasons.
5. There is a need on durability studies since most tests of hard properties were conducted on the 3rd, 7th, 14th and 28th day of concrete curing. Thus, there is an assumption that the strength properties may
decrease [11, 31, 27, 1], which is reassured by [37]; it is shown that on the samples tested on the 360 and 540 days how the strength was reduced with time.

9. References
[1] Jose A R, Sergio F S, Gustavo H D and Holmer S Jr Agricultural Wastes as Building Materials: Properties, Performance and Applications Build. Mat.: Prop., Perf. and App. 9 1–44
[2] Alengaram U J et al Malaysia 2013 Utilization of oil palm kernel shell as lightweight aggregate in concrete—A review Construction and Building Materials 38 161–172
[3] Akulova M V, Isakulov B R, Dzhumabaev M D, Imanbekova A M 2016 Getting binder of cement, fly ash and sludge, activated by the method of complex electromechanical activation for use in light arbolit concrete Naykovedenie 3 1–9
[4] Asasutjarit C, Hirunlabh J, Khedari J, Charoenval S and Zeghmati B 2007 Development of coconut coir–based lightweight cement board Construction Buildings Materials 21 277–288
[5] Obilade I O 2014 Experimental Study On Rice Husk As Fine Aggregate In Concrete Int. J. of Eng. and Sci. 3 9–14
[6] Li G, Xu X, Chen E, Fan J and Xiong G 2015 Properties of cement–based bricks with oyster–shells ash Journal of Cleaner Production 91 279–287
[7] Ramesh K V, Goutham R and Siva Kishore I 2017 An experimental study on partial replacement of bagasse ash in basalt concrete Int. J. of Civ. Eng. and Techn. 8 335–341
[8] Ramos T, Matos A M and Sousa–Coutinho J 2014 Strength and Durability of Mortar using Cork waste Ash as Cement Replacement Materials Research 17 893–907
[9] Anbazhagan A and Gopinath L 2017 Light Weight Concrete Using Coconut Shell SSRG International Journal of Civil Engineering 6 73–75
[10] Saravanan J, ImthiayasAhamed S, Muniyasamy X, Muthu Ganesh P and Rawther Ibrahim Ali Sait Low Cost Roofing Tiles using Agricultural Wastes International Journal of Civil Engineering 4 71–75
[11] Ramadhansyah P J, Nurfatin A M, Siti N A J, Norhafizah M, Norhidayah A H and Dewi S J 2016 Use of coconut shell from agriculture waste as fine aggregate in asphaltic concrete Journal of Engineering and Applied Sciences 11 7457–462
[12] Sethunarayanan R, Chockalingam S and Ramanathan R 1989 Natural Fiber Reinforced Concrete Transportation Research Record 1226 57–60
[13] Jnyanehdra K P, Sanjaya K P and Basarker S S 2016 Concrete using agro–waste as fine aggregate for sustainable built environment Int. J. of Sustainable Built Environment 5 312–333
[14] Shafigh P, Mahmoud H B, Jumaat M Z and Zargar M 2014 Agricultural wastes as aggregate in concrete mixtures- A review Construction and Building Materials 53 110-117
[15] Sada B H, Amartey Y D and Bako S Nigeria 2013 An investigation into the use of groundnut shell as fine aggregate replacement Nigerian Journal of Technology 32 54–60
[16] Arshad H H and Kumar R D South India 2017 Performance of concrete properties by groundnut shell ash as a partial replacement of cement with sisal fiber Int. J. of Civ. Eng. 17 23–28
[17] Prashant O M and Vyawahare M R 2013 Utilization of Bagasse Ash as a Partial Replacement of Fine Aggregate in Concrete Procedia Engineering 51 25–29
[18] Kumar D, Singh S, Kumar N and Gupta A 2014 Low Cost Construction Material for Concrete as Sawdust Int. J. of Current Engineering and Technology 4 3428–3430
[19] Teo D C L, Mannan Md A and Kurian J V 2006 Flexural Behaviour of reinforced lightweight concrete beams made with oil palm shell (OPS) J. of Advanced Concrete Technology 4 1–10
[20] Padma Rao P, Pradhan Kumar A and Bhaskar Singh B 2014 A Study on Use of Rice Husk Ash in Concrete International journal of education and applied research 4 75–81
[21] Gunasekaran K, Kumar P S and Lakshmipathy M 2011 Mechanical and bond properties of coconut shell concrete Construcrion and Building Materials 25 92–98
[22] Khanhaja E, Salim M R, Mirza J, Hussin M W and Rafieizonooz M 2016 Properties of sustainable lightweight previous concrete containing oil palm kernel shell as coarse aggregate Construction and Building Materials 126 1054-1065
[23] Neville A M 2011 Properties of concrete (London: Pearson) pp 1–2866
[24] Shafana T and Venkatasubramani R 2014 A study on the Mechanical Properties of Concrete with partial replacement of Fine aggregate with Sugarcane bagasse ash International Journal of Advanced Structures and Geotechnical Engineering 3 34–39
[25] Olutoge F A 2010 Investigations on sawdust and palm kernel shells as aggregate replacement Journal of Engineering and Applied Sciences 5 7–13
[26] Nwofor T C and Sule S 2012 Stability of groundnut shell ash (GSA)/ordinary portland cement (OPC) concrete in Nigeria Adv. Appl. Sci. Res 3 2283–2287
[27] Hameester M R, Balzer P S and Becker D 2012 Characterization of Calcium Carbonate Obtained from Oyster and Mussel Shells and Incorporation in Polypropylene Mater. Research 15 204–208
[28] Mohanalakshmi V, Indhu S, Hema P and Prabha V C 2017 Developing Concrete using Sea Shell as a Fine Aggregate International J. for Innovative Research in Science & Techn. 3 282–286
[29] Abbas A and Ansumali S 2010 Global Potential of Rice Husk as a Renewable Feedstock for Ethanol Biofuel Production BioEnergy Research 3 328–334
[30] Varshney H 2016 Utilisation of Rice Husk Ash in concrete as cement replacement Journal of Mechanical and Civil Engineering 16 28–31
[31] Kamal I, Sherwani A, Ali A, Khalid A, Saadi I, Harbi A 2017 Walnut Shell for Partial Replacement of Fine Aggregate in Concrete: Modeling and Optimization J. of Civ. Eng. Res. 4 109–119
[32] Oyedepo O J, Oluwajana S D and Akande S P 2014 Investigation of Properties of Concrete Using Sawdust as Partial Replacement for Sand Civil and Environmental Research 6 35–42
[33] Muthusamy K, Zamri N, Zubir M A, Kusbiantoro A and Ahmad S W 2015 Effect of mixing ingredient on compressive strength of oil palm shell lightweight aggregate concrete containing palm oil fuel ash Procedia Engineering 125 804–810
[34] Seyed A Z, Ameri F, Dorostkar F and Ahmadi M 2017 Rice husk ash as a partial replacement of cement in high strength concrete containing micro silica: Evaluating durability and mechanical properties Case Studies in Construction Materials 7 78–81
[35] Anbazhagan A and Gopinath L 2017 Light Weight Concrete Using Coconut Shell SSRG International Journal of Civil Engineering 6 73–75
[36] Dhegare S W, Dr Rauf S P, Bandwal N V and Khangan A 2015 Investigation into Utilization of Sugarcane Bagasse Ash as Supplementary Cementitious Material in Concrete Int. J. of Emerg. Eng. Research and Techn. 3 109–116
[37] Bahurudeen A, Kanraj D, Gokul Dev V and Santhanam M 2014 Performance evaluation of sugarcane bagasse ssh blended cement in concrete Cement and Concrete Research 56 32–45
[38] Arshad H H and Kumar R D South India 2017 Performance of concrete properties by groundnut shell ash as a partial replacement of cement with sisal fiber Int. J. of Civ. Eng. 17 23–28
[39] Olutoge F A, Bui A T A and Adeleke J S 2013 Characteristics Strength and Durability of Groundnut Shell Ash (GSA) Blended Cement Concrete in Sulphate Environment International Journal of Scientific & Engineering Research 4 2122–134
[40] Erni S, Gagoek H and Purwanto K 2016 Green Concrete made of Oyster Shell Waste to Support Green Building Material Jurnal Teknologi (Sciences & Engineering) 78 203–207
[41] Kumar D, Singh S, Kumar N and Gupta A 2014 Low Cost Construction Material for Concrete as Sawdust Int. J. of Current Engineering and Technology 4 3428–3430
[42] Bdeir L M H Iraq 2012 Study Some Mechanical Properties of Mortar with Sawdust as a Partially Replacement of Sand Anbar Journal for Engineering Sciences 5 22–30
[43] Auta S M et al 2016 Flexural strength of reinforced revibrated concrete beam with sawdust ash as a partial replacement for cement Constr. of Unique Build. and Struct. 5 31–45
[44] Aslam M, Shafigh P and Jumaat M Z 2016 Oil–palm by–products as lightweight aggregate in concrete mixture: a review Journal of cleaner production 126 56–73
[45] Mo K H 2015 Experimental investigation on the properties of lightweight concrete containing waste oil palm shell aggregate Procedia Engineering 125 587–593
[46] Muthusamy K, Zulkepli N A, Mat Yahaya F 2013 Exploratory Study of Oil Palm Shell as Partial Sand Replacement in Concrete Research J. of Applied Sc., Eng. and Techn. 5 2372–75
[47] Nithyambigai G 2015 Effect of Rice Husk Ash in Concrete as Cement and Fine Aggregate International Journal of Engineering Research & Technology 4 934–936
[48] Alireza N G, Suraya A R, Farah N A A and Salleh M A M 2010 Contribution of Rice Husk Ash to the Properties of Mortar and Concrete: A Review Journal of American Science 6 157–165
[49] Branco F G, Tadeu A and Reis M de L B G Can cork be used as a concrete aggregate? ResearchGate 1–8
[50] Yerramala A and Ramachandrudu C India 2012 Properties of concrete with Coconut Shells as Aggregate Replacement International Journal of Engineering Inventions 1 21–31
[51] Mirza S H, Anwar A, Samarul H and Mohd A 2017 Cost Optimization of concrete by replacing fine aggregate with walnut shell powder Int. J. of Civil Engineering and Technology 8 82–89
[52] Akeke G A, Ephrahim M E, Akobo, I Z C and Ukpata J O 2012 Structural properties of rice husk ash concrete International Journal of Engineering and Applied Sciences 3 57–62

Acknowledgments
This paper was financially supported by the Ministry of Education and Science of the Russian Federation on the program to improve the competitiveness of Peoples’ Friendship University of Russia (RUDN University) among the world's leading research and education centers in the 2016-2020. This publication was prepared with the support of the “RUDN University Program 5-100”.
