Review

Agricultural wastes as aggregate in concrete mixtures – A review

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HIGHLIGHTS

• Potential uses of agricultural solid wastes in the construction industry.
• Some agricultural solid wastes can be used as aggregate for making concrete.
• Oil palm shell can be used to make a high strength lightweight concrete.

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ABSTRACT

Concrete is the most widely used construction material. With the ever-increasing industrialization and urbanization, huge amounts of natural resources are required to make concrete. This, in turn, means that large volumes of natural resources and raw materials are being used for concrete production around the world. To eliminate or minimize the negative environmental impact of the concrete industry and promote environmental sustainability of the industry, the use of wastes from industry as materials for concrete making is considered as an alternative solution for preventing the excessive usage of raw materials. The wide availability of agricultural wastes make them a suitable and dependable alternative for aggregate in concrete, wherever available. This paper reviews the possible use of agricultural wastes as aggregate in the concrete industry. It aims to promote the idea of using these wastes by elaborating upon their engineering properties. This summary of existing knowledge about the successful use of agricultural wastes in the concrete industry helps to identify other existing waste products for use in concrete making. From this identification by agricultural and civil engineers, significant achievements can be attained.

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1. Introduction

Cement and concrete buildings date back several centuries and the patent for Portland cement itself dates back over a century [1]. The great advantage of concrete is that it is possible to choose its constituents, and then it is up to the user to exploit and optimize the unique properties of each of the components to develop a high quality, durable construction material of high impermeability [2]. With more than 10 billion tons of concrete produced annually, it is considered to be the most important building material [3]. It has been predicted that the world’s population will increase from the present-day 6–9 billion by the year 2050 and to 11 billion by the end of the century, which will result in a considerable increase in the demand for water, energy, food, river sources, common goods and services [4]. Also, the demand for concrete is expected to grow to approximately 18 billion tons a year by 2050 [5]. Consequently, the concrete industry is going to use a considerable amount of natural resources to produce cement and concrete.

The green rating for infrastructure and buildings has become increasingly widespread in the last decade. Generally, the current Green Building Rating (GBR) systems evaluate the sustainability of buildings according to various categories, of which the construction material is one such category in most of the systems. Issues like CO₂ emissions during the production of Portland cement, along with a significant amount of energy, water, aggregate and fillers used for production of concrete as well as construction waste from the demolition of concrete structures, makes this important construction material look less compatible with the environmental requirements of a modern sustainable construction industry.

Ramezanianpour et al. [6] demonstrated that the current state of the concrete industry is not sustainable. However, the utilization of industrial and agricultural waste components can be a breakthrough to make the industry more environmentally friendly and sustainable. Waste materials, such as fly ash, silica fume, ground granulated blast furnace slag (GGBFS), recycled concrete, post-consumer glass, recycled tyres, and recycled plastics, have been successfully used in concrete for decades [3,7]. Also, recent studies have shown the successful use of agricultural solid waste as aggregate in structural and non-structural concrete. Oil palm shell (or palm kernel shell), coconut shell, rice husk, corn cob, pistachio shell, spent mushroom substrate and tobacco wastes are among the wastes used for this purpose. Since aggregate (sand as fine and gravel as coarse) makes up about 60–80% of the volume of concrete [8], the successful use of such agricultural solid wastes, as whole or partial replacement of conventional aggregates, contributes to energy saving, conservation of natural resources, and a reduction in the cost of construction materials. It also solves the disposal problem of the wastes, and, hence, helps environmental protection [6,9].

Research on the use of agricultural waste as aggregate in concrete production, is relatively new. More research on long term durability of this kind of concrete would give more confidence to the construction industry in using them for their more sensitive projects. The aim of this paper is to introduce some of the agricultural solid wastes that have been successfully used as aggregate for making concrete in experimental and practical environments. The relationships among concrete made using this type of aggregate, environmentally friendly concrete, and green building rating systems are also discussed. Mutual recognition of these materials, and their usage in concrete by both civil engineers and agricultural engineers, would pave the way for other potential uses of agricultural wastes in the construction industry, as well as certain other industries. It will also lead to a more environmentally sustainable concrete industry.

2. Environmental sustainability

Sustainable infrastructure and green building rating systems, by establishing a grading system, independently assess several different aspects of an infrastructure or building design, construction and/or maintenance. All considered aspects are directly or indirectly relevant to the efficiency and environmental performance of buildings. Environmental consciousness in selecting the materials used in every step of the construction process can have an effect on the sustainability level of the outcome. These effects can be direct (like using an asbestos-free material) or indirect (like using recycled material and diverting them from landfill).

Assuming agricultural wastes are going to end up being destroyed or disposed of in the environment, salvaging them in the form of aggregate for concrete production, can be considered one of the environmental benefits of this technique that will be recognized by most of the sustainability rating systems. For instance, the United States Green Building Council’s (USGBC) Leadership in Energy and Environmental Design (LEED) [10], which is one of the most globally recognized rating systems, gives points to this concrete for using pre-consumer recycled material. Other categories and advantages in using these agricultural waste aggregates in concrete can result in points for the construction work, which include: rapidly renewable material, recycled content, regional materials (locally available material).

Concrete made using agricultural wastes has shown better thermal properties in research, which can result in sustainability points in the energy and atmosphere category of the LEED rating system, among them: “Optimize Energy Performance” credit. Hence, agricultural waste used as aggregate in concrete production can contribute in making the material, and, consequently, the structure more environmentally friendly.

3. Agricultural solid waste in concrete

3.1. Oil palm shell

The oil palm industry is one of the most important agro-industries in certain countries, such as Malaysia, Indonesia, Thailand and Nigeria. Malaysia and Indonesia are, respectively, the world’s largest and next largest palm oil producing countries. Malaysia alone produces more than 7 million tons of crude palm oil, each year.

![Fig. 1. World palm oil production 1996–2000](Image)
Fig. 1 shows the global scale of world palm oil production between 1996 and 2000 [12]. One of the significant problems in the palm fruit processing plants is that the process produces a large amount of solid waste. For instance, in Malaysia, Indonesia and Thailand, the annual production of solid waste from the palm oil industry is 47, 40 and 3.5 million tons, respectively. The solid wastes include oil palm bunches, palm fibre and fruit shells. In addition, over 8 million tons of oil palm shell is produced by these countries, annually [13].

3.1.1. Properties of oil palm shell (OPS)

The colour of oil palm shell (OPS) ranges from dark grey to black. Depending on the breaking pattern of the nut, the shape of the shells differs in a range from angular to polygonal [14]. Table 1 shows the characteristics of OPS. As can be seen in this table, OPS is approximately 60% lighter than conventional coarse aggregates. The density of OPS is within the range of most typical lightweight aggregates [16,17]. One of the attractive characteristics of oil palm shells is its significant low Los Angeles abrasion value, which is approximately 80% lower than conventional coarse aggregates [18]. This characteristic shows that OPS aggregates have good resistance to wear. In addition, because of the much lower impact and crushing values of OPS aggregates, these aggregates have good absorbance to shock [19]. The surfaces of the shells for both concave and convex faces are fairly smooth, while the broken edge is rough and spiky. Fig. 2 shows scanning electron microscopy (SEM) images of an OPS grain conducted by the SEM instrument (Fig. 3). Fig. 2a clearly shows the smooth surface of the shell while from the larger scale of this picture (Fig. 2b), it is clear that the edge of the shell is rough.

Table 1

<table>
<thead>
<tr>
<th>Properties</th>
<th>Oil Palm Shell</th>
<th>Coconut shell</th>
<th>Crushed granite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity (uncompacted) (kg/m³)</td>
<td>1.17–1.37</td>
<td>1.05–1.2</td>
<td>2.60–2.70</td>
</tr>
<tr>
<td>Bulk density (uncompacted) (kg/m³)</td>
<td>510–550</td>
<td>–</td>
<td>1300</td>
</tr>
<tr>
<td>Void ratio (uncompacted) (%)</td>
<td>63</td>
<td>–</td>
<td>52</td>
</tr>
<tr>
<td>24 h water absorption (%)</td>
<td>21–33</td>
<td>24</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Aggregate impact value (%)</td>
<td>4–8</td>
<td>8.15</td>
<td>13–17</td>
</tr>
<tr>
<td>Aggregate crushing value (%)</td>
<td>5–10</td>
<td>2.58</td>
<td>20</td>
</tr>
<tr>
<td>Los Angeles abrasion value (%)</td>
<td>3–5</td>
<td>1.63</td>
<td>24</td>
</tr>
<tr>
<td>Flakiness index (%)</td>
<td>65</td>
<td>–</td>
<td>25</td>
</tr>
<tr>
<td>Shell thickness (mm)</td>
<td>2–8</td>
<td>0.15–8 mm</td>
<td>–</td>
</tr>
<tr>
<td>Thermal conductivity (W/mK)</td>
<td>0.19</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Loss on ignition (%)</td>
<td>98–100</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Fig. 2. Microscopic images of the surface of an OPS grain in two scales.

Fig. 3. Scanning electron microscopy instrument.

3.1.2. Oil palm shell lightweight concrete

The use of OPS as a lightweight aggregate for producing lightweight concrete was explored as early as 1984 by Abdullah [20] in Malaysia and by Okafor [16] in Nigeria. In most cases, it has been shown that the compressive strength of OPS lightweight concrete, with and without cementitious materials, is within the typical compressive strength for structural lightweight concrete (20–35 MPa) with a density of about 20–25% lower than normal weight concrete (NWC) [17,18,21–24]. However, recent studies have shown the possibility of producing high strength OPS lightweight concrete of up to about 53 and 56 MPa for 28 and 56 days compressive strength [25,26]. Promoting the compressive strength of concrete and the ability to produce high strength concrete with aggregate, such as OPS, is very important because the compressive strength of concrete plays a fundamental role in the design and construction of concrete structures [27], and, also, such potential application of a waste material will encourage the construction
industry to use this type of environmentally friendly concrete in actual projects. The techniques for producing high strength OPS concrete have been explained in various published papers [25,26,28]. In summary, these techniques include the use of old OPS, crushed OPS and OPS with smaller maximum coarse aggregate. Old OPS does not have any fibre on their surface, which results in a better bond between the cement matrix and the OPS, and, consequently, higher compressive strength. Another technique is based on crushing large old OPS and reducing the maximum size of coarse OPS aggregate. Crushed OPS is hard and has a strong physical bond with hydrated cement paste. This stronger bond is due to a reduction in the total smooth surface of OPS and the increased total surface of the broken edges because of the crushing of large sizes of OPS aggregate. In addition, the use of a smaller size of OPS aggregate causes an increase in the bond between the aggregate and the paste, which results in a higher compressive strength. Fig. 4 shows OPS aggregate in several different states. Table 2 shows some selected mix proportions of OPS concrete with normal and high strength concrete. For all the OPS lightweight concrete mixtures with normal strength, the maximum size of OPS (as coarse aggregate) is 9.5 mm or more while for making high strength OPS concrete this maximum size reduces to 8 mm.

From the test results of previous studies it was concluded [14] that the mechanical properties of OPS concrete, such as splitting tensile strength, flexural strength and modulus of elasticity at the same compressive strength, are lower than other types of lightweight aggregate concretes made from artificial or natural lightweight aggregates. However, a recently published study [28] has shown that incorporating steel fibre into OPS concrete improves the compressive strength, and, furthermore, the splitting tensile and flexural strength improve significantly. The splitting tensile/compressive strength ratio of steel fibre OPS concrete is in the range of normal weight concrete and the flexural strength of such concrete is comparable to artificial lightweight aggregate concrete. In respect of the modulus of elasticity of OPS concrete, although it has been reported that this property of OPS concrete is significantly lower than normal weight concrete, similar to many other types of lightweight aggregate concrete, recent studies [28,29] have shown that by following certain methods the modulus of elasticity of OPS concrete significantly improves to the range of normal weight concrete. These methods, which significantly promote the compressive strength of OPS concrete, are based on

![Fig. 4. Oil palm shell grains in different conditions. (a): old, (b): fresh, and (c): crushed from large size old OPS.](image)

<table>
<thead>
<tr>
<th>Mix no.</th>
<th>Mix proportion (kg/m³)</th>
<th>Fresh property (slump, mm)</th>
<th>Density (kg/m³)</th>
<th>28-Day cube compressive strength (MPa)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>480 0 0 1 0.41 370 0</td>
<td>820 7</td>
<td>1900</td>
<td>29</td>
<td>Mannan and Ganapathy [15]</td>
</tr>
<tr>
<td>2</td>
<td>510 0 0 1.4 310 0</td>
<td>850 60</td>
<td>1960</td>
<td>28</td>
<td>Teo et al. [38]</td>
</tr>
<tr>
<td>3</td>
<td>360 0 0 1.8 45 380 210</td>
<td>830 33</td>
<td>1910</td>
<td>34</td>
<td>Shafigh et al. [14]</td>
</tr>
<tr>
<td>4</td>
<td>480 48 24 1</td>
<td>580 105</td>
<td>1690</td>
<td>37</td>
<td>Alengaram et al. [23]</td>
</tr>
<tr>
<td>5</td>
<td>480 0 0 1.5 38 380 0</td>
<td>1050 50</td>
<td>1990</td>
<td>47</td>
<td>Shafigh et al. [26]</td>
</tr>
<tr>
<td>6</td>
<td>550 0 0 1.1 23 330 180</td>
<td>710 205</td>
<td>1580</td>
<td>53</td>
<td>Shafigh et al. [25]</td>
</tr>
</tbody>
</table>

*a* Demolded density.

*b* Air dry density.

*c* Oven dry density.

![Fig. 5. OPS grains (darker) in a lightweight concrete.](image)
the use of old OPS and old crushed OPS. Fig. 5 shows a cross section of a lightweight concrete specimen containing OPS grains. The durability properties of OPS structural lightweight concrete under different curing conditions were investigated by Teo et al. [30]. They reported that the durability properties of this concrete were comparable to that of other conventional lightweight concretes. The research concluded that proper curing is required for OPS concrete to achieve better durability. They recommended that the minimum duration of moist curing should be carried out continuously for at least 7 days.

A comparative study [31] of the bond properties of OPS concrete with normal weight concrete revealed that although the bond stress of the OPS concrete was about 86% of the corresponding normal weight concrete, the ultimate bond stress of OPS concrete was 2.5 times higher than the theoretical values calculated based on BS 8110 [32]. In addition, the flexural and shear behaviour of reinforced and un-reinforced concrete beams made with oil palm shell structural lightweight concrete was experimentally investigated. Teo et al. [33] reported that reinforced concrete beams made of oil palm shell lightweight concrete with low reinforcement ratio gave satisfactory performance in all the serviceability requirements of the BS 8110 [32] code. They reported that OPS reinforced concrete beams with reinforcement ratios up to 3.14% showed 4–35% ultimate moments compared to the predicted moments. However, for a beam with higher reinforcement ratio (i.e. 3.90%), BS 8110 underestimates the ultimate moment capacity by about 6%. Therefore, they recommended larger depths for OPS concrete beams when the reinforcement ratio is greater than 3.14%.

Ahmed and Sobuz [34] reported that the flexural behaviour of beams made of oil palm shell shows very close agreement with the theoretical results. Furthermore, the satisfactory shear behaviour of oil palm shell concrete beams has also been reported [35,36]. Alengaram et al. [37] reported that the overall flexural behaviour of reinforced OPS concrete beams closely resembled that of equivalent beams made with normal weight concrete.

For showing the potential use of oil palm shell (OPS) as aggregate for producing lightweight concrete in practice, two small structures were built at University Malaysia Sabah (UMS) [38]. These structures comprised a small footbridge with a span of about 2 m (Fig. 6a) and a low-cost house with a floor area of about 59 m² (Fig. 6b). These structures are located near the coastal area, which has an annual rainfall of about 2500 mm, air temperature in the range of 23–32 °C and relative humidity of 72–91%.

### 3.2. Coconut shell

Coconut cultivation is predominant in the tropical regimes of Asia and East Africa [39]. Table 3 shows the main countries in the global market together with their production and land area in 2005 [40]. As can be seen in this table, the main producers are Indonesia, the Philippines and India with 75% of the world production. Coconuts vary considerably in size, shape, weight and colour [41]. Annually, 40–50 million tones of coconuts are grown worldwide. A mature coconut comprises 28 wt% of the white meat, which is surrounded by 12 wt% hard protective shell, which, in turn, is covered by a thick husk of 35 wt%. Annually, 15–20 million tones of husk are produced, which constitute about 30 wt% fibre and 70 wt% pith [42]. Coconut shells, like oil palm shells are available in large quantities in the tropical regions of the world [43]. It has been reported [44] that coconut shells are one of the most promising agro wastes with possible uses as coarse aggregate in the production of concrete. A comparative study of concrete properties using coconut shell and oil palm shell shows that concrete containing coconut shells exhibit a higher compressive strength than oil palm shell [43]. Gunasekaran et al. [40] investigated various mechanical properties – compressive strength, flexural and splitting tensile strengths, and impact resistance – of concrete with coconut shell as the coarse aggregate. They concluded that coconut shell can be used as a lightweight aggregate for producing lightweight concrete. This lightweight concrete can be classified under structural lightweight concrete. The mechanical properties of coconut shell, as well as conventional coarse aggregate (crushed granite) are provided in Table 1. Fig. 7 shows microscopic images of coconut shell grains. A comparison between this figure and Fig. 2a reveals that the surface of a coconut shell is rougher than OPS. This may be one of the reasons for the better compressive of coconut shell concrete compared to oil palm shell concrete [43].

A long-term study on the compressive strength of coconut shell aggregate concrete [45] shows that this concrete, even at later ages (365 days), has good quality. In addition, Gunasekaran et al. [45] reported that the ultimate bond strength of this concrete was much higher compared to the theoretical bond strength as per BS 8110 [32]. Table 4 shows some selected mix proportions of coconut shell lightweight concrete and their fresh and hardened properties. Fig. 8 shows coconut shell grains in concrete.

A recent study conducted by Gunasekaran et al. [46] shows the satisfactory performance of coconut shell reinforced concrete beam in flexure. According to this publication, the flexural

### Table 3

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (nuts)</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(kt)</td>
<td>(ha)</td>
</tr>
<tr>
<td>Indonesia</td>
<td>16,300</td>
<td>2670</td>
</tr>
<tr>
<td>Philippines</td>
<td>14,797</td>
<td>3243</td>
</tr>
<tr>
<td>India</td>
<td>9500</td>
<td>1860</td>
</tr>
<tr>
<td>Brazil</td>
<td>3034</td>
<td>281</td>
</tr>
<tr>
<td>Thailand</td>
<td>1500</td>
<td>343</td>
</tr>
<tr>
<td>Vietnam</td>
<td>972</td>
<td>110</td>
</tr>
<tr>
<td>Mexico</td>
<td>950</td>
<td>150</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>890</td>
<td>395</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>650</td>
<td>180</td>
</tr>
<tr>
<td>Malaysia</td>
<td>642</td>
<td>179</td>
</tr>
</tbody>
</table>
behaviour of a coconut shell lightweight concrete beam is comparable to other types of lightweight concrete. However, similar to OPS concrete, the authors recommended that because the deflections under the design service load for reinforcement ratios is greater than 3.14%, which exceeds the allowable limit of BS 8110, larger beam depths should be used. Such a problem for both types of lightweight concrete beam in reinforcement ratios greater than 3.14% is probably due to the low modulus of elasticity of these concretes, which is about 5.1–5.3 GPa for a compressive strength of about 26–27 MPa. Although it is expected that in higher strength levels, and, consequently, greater modulus of elasticity, this limitation for these organic materials will be solved, further research is needed. It is worth noting that the chemical composition, consistency and structure of OPS have been reported as being very close to that of coconut shells [47].

3.3. Corn cob

Corn cob is an agricultural solid waste from maize and corn. The United States (the largest maize producer) and Africa produce 43% and 7% respectively of the world’s maize [48]. Previous studies [48–50] show that the ash of corn cob has SiO₂ of more than 65% and a combination of Al₂O₃ and SiO₂ of more than 70%. This means that corn cob ash can be used as a cementitious material in blended cement concrete. Although the use of the ash of this waste in concrete technology started more than a decade ago, the use of corn cob grains as aggregate is only recently developing. Faustino et al. [51] investigated the use of corn cob for sound insulation purposes in buildings. They tested a corn cob particleboard with a size of 3 cm (thickness) × 100 cm (width) × 50 cm (height) for impact sound insulation purposes. The sample was made of binding corn cob particles by wood glue with a ratio of 1(glue):4(corn cob particles). This corn cob particleboard had a density of about 334 kg/m³. This density is similar to a natural sound insulation material, namely, cork. They concluded that this product has an interesting acoustic behaviour for building purposes. In addition, as reported by Pinto et al. [52], the elementary chemical composition and the microstructure of the corn cob shows that this agricultural waste is similar to extruded polystyrene or corn. They reported that corn cob can be a suitable building material in terms of thermal insulation.

Corn cob as a lightweight aggregate for producing lightweight concrete for non-structural applications for the first time was researched by Pinto et al. [53]. In the study, they measured the density, compressive strength and thermal insulation properties of a corn cob lightweight concrete. The results were compared with a non-structural lightweight concrete made with an artificial lightweight aggregate, namely, expanded clay. The lightweight aggregate mix ratio (by mass) for both corn cob and expanded clay were 6(aggregate):1(Portland cement):1(water) and 3:1:1, respectively. The first mix ratio was reported to be a usual mix ratio for the regularization layer of expanded clay concrete in the Portuguese context. The average results of this study are shown in Table 5. As can be seen in the table, with a ratio of 6:1:1 the density of the corn cob concrete is about 34% lower than the expanded clay concrete, and, consequently, its thermal transmission coefficient is about 27% lower. In this respect, it can be seen that corn cob lightweight concrete has better performance than expanded clay lightweight concrete. As concluded by Pinto et al. [53], using corn cob as an alternative to artificial and natural materials, has economic and sustainable benefits.

3.4. Rice husk

Rice husk (RH), which is poor in nutrition, forms the outer covering of rice grain and is always removed during the milling process [54]. Rice husks constitute about 20% of the volume of rice produced annually in the world [55], which is approximately 80 million tones [56]. Although some rice husks are used for animal feed, fire making, litter material, marking concrete, board production, and as silicon carbide whiskers to reinforce ceramic cutting tools [54,57], most of this agricultural by-product is disposed of, and its accumulation is a serious environmental problem. After aluminium and steel, Portland cement is the most

---

**Table 4**

<table>
<thead>
<tr>
<th>Cement (kg/m³)</th>
<th>Water to cement ratio</th>
<th>Coconut shell (kg/m³)</th>
<th>Fine aggregate (kg/m³)</th>
<th>Slump (mm)</th>
<th>28-Day cube compressive strength (MPa)</th>
<th>Air dry density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>510</td>
<td>0.42</td>
<td>330</td>
<td>750</td>
<td>5</td>
<td>27</td>
<td>1970</td>
</tr>
</tbody>
</table>
energy-intensive material [55]. Therefore, finding a solution to substitute a practical recycled product for cement replacement is desirable for sustainability goals in the construction industry [6]. The use of rice husk ash is a possible solution, and the successful use of this material for making concrete has been researched for many years [58–61]. However, there is little information regarding the use of rice husks as aggregate for making concrete. Salas et al. [62] investigated the substitution of sand and gravel with rice husk in concrete. The used rice husk was in the natural state or treated with a 5% lime solution. They concluded that concrete containing rice husks have been used as aggregate for making concrete in which the concrete was used for insulating purposes [65].

3.5. Tobacco waste

Tobacco waste is toxic due to the presence of alkaloid nicotine. Large quantities of this waste are produced annually during processing and cigarette making [66]. Ozturk and Bayraktar [67] investigated the possibility of using tobacco waste in producing lightweight concrete. They used different percentages of tobacco waste in lightweight concrete containing pumice. Based on the characteristics, such as consistency, unit weight, porosity, compactness, compressive strength and thermal conductivity, they concluded that pumice lightweight concrete with tobacco waste additive can be used as a coating and dividing material in construction. They reported that lightweight concretes containing tobacco waste have low thermal conductivity in the range of 0.194–0.220 W/mk. These values are lower than most other masonry materials, such as brick (0.45–0.6 W/mk), briquette (0.7–1.0 W/mk), pumice concrete (0.29 W/mk) and Ytong (0.23 W/mk).

4. Conclusions

With the increase in the world’s population, sustainable development should be of particular importance and the concrete industry should contribute to this purpose. One approach can be through the use of by-products and agricultural wastes in concrete. Studies show the possibility of use and acceptable performance of certain agricultural solid wastes, e.g. oil palm shell, coconut shell, rice husks, and tobacco waste, as aggregate in making concrete. Since aggregate makes up about 60–80% of the volume of the concrete, the substitution of solid waste as full or partial replacement for conventional aggregate contributes significantly in cost effectiveness, energy saving and mitigation of the environmental impact of the construction industry. Considering the current criteria for a sustainable infrastructure, green building rating systems and related environmental benefits, making concrete using agricultural wastes as aggregate can help in making the concrete industry environmentally-friendly. Therefore, the development of existing knowledge and identification of other useful solid wastes to be used in making concrete will also provide a valuable contribution in the environmental sustainability of the industry.

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