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APPLICATION OF AGRICULTURAL - WASTE MATERIALS IN CONSTRUCTION APPLICATIONS: A REVIEW

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Abstract: High demand of natural resources and the disposal problem of agricultural wastes are two main challenges faced by construction and agriculture sectors. Therefore, the use of agro-waste in the construction industry can be an optimum solution. In response to the increased interest in sustainable construction materials, many agricultural waste materials are already used in concrete as alternative replacements for cement, fine aggregate, coarse aggregate and reinforcing materials. This paper provides an overview for the successful implementations of different agricultural waste materials to produce green concrete for different construction applications. It highlights the quantitative benefits of sustainable construction using agricultural waste materials and benefits of green materials in construction applications. This would allow engineers and policymakers to consider designing for sustainability as a new requirement in the design for publicly funded structures.

Keywords: Agricultural waste materials, Agro-waste Concrete, Coconut shell, , Environmental impact, Green concrete, Oil palm shell, .

1 INTRODUCTION

Concrete is the major construction material and plays a vital role in the development of civilization. It is the most widely used man-made material in the world. The consumption of concrete as construction material in the world is over twice the total consumption of all other building materials including wood, steel, plastic and aluminium. It is reported that the total annual concrete production worldwide is more than 10 billion tonnes (Meyer 2009). More than 0.9, 0.6 and 5 billion tonnes of portland cement, potable water and aggregate respectively, are necessary to produce such an amount of concrete (Jorge de Brito . Nabajyoti Saikia 2013). The massive use of concrete as a construction material is due to its versatile properties. Properties such as strength, durability, affordability and abundance of raw materials make concrete the first choice for most construction purposes. However, concrete production has several negative impacts on the environment, such as the emission of CO_2 and other greenhouse gases and the use of non-renewable natural resources like natural aggregate and water. Therefore, natural resource consumption sustainability of concrete has gained a lot of attention (Jorge de Brito. Nabajyoti Saikia 2013).

The growing demand of natural aggregate results in reduction in the inventory of high quality aggregate especially in the developed countries (Tam 2009). The extraction of naturel aggregate (sand, gravel) from the waterway and gravel quarry enhances the cost of aggregate and has severely affected the financial viability of the construction industry. As such finding an alternate material to natural aggregate has got to be imperative.

Green Building Rating (GBR) systems (certification systems) facilitate the sustainable design processes by providing independent assessment tools, in which strategies used to improve sustainability of buildings can be evaluated according to common sets of rules that cover categories from energy efficiency to water resource (Lee et al 2011).

Construction materials has recently attracted the attention as one of the main factors affecting GBR for any structure. This can be ascribed to the high carbon foot print of cement and significant amount of energy, water, aggregate and fillers used for concrete production. Moreover, at the end of its life cycle, construction waste from the demolition of concrete structures is another environmental impact. Hence, there is a need to make this important construction material compatible with environmental requirements of the modern sustainable construction industry.

Research on the use of agricultural waste as course and fine aggregate in concrete production is relatively new. The use of industrial and agricultural waste is a possible way to increase concrete industry sustainability. Industrial waste materials such as fly ash, silica fume, Metakaolin, ground granulated blast furnace slag (GGBFS) and others have been successfully used in concrete for long time (Meyer 2009), (Federico & Chidiac 2009). Recently, agricultural solid wastes such as oil palm shell, coconut shell, corn cob, wood ash, pistachio shell have attracted researchers as replacements for natural aggregate in structural and non-structural concrete (Shafigh, P et al. 2014). The use of these agricultural solid wastes as total or partial replacements of natural aggregates; which makes up about 60–80% of the volume of concrete (Badur & Chaudhary 2008), represent substantial energy saving, conservation of natural resources, and a reduction in the cost of construction materials. In addition, it solves the disposal problem of the agricultural solid wastes helping in environmental protection (Ramezanianpour et al. 2009, Kurian 2005).

Due to variations in their properties, research on the use of agricultural waste materials is relatively new. More research on mechanical properties development and long term durability of concrete incorporating such waste is still needed. The aim of this paper is to introduce an overview of some of the agricultural wastes that have been successfully used as aggregate for concrete production. Recognition of these materials, and implementing in concrete would pave the way for other potential uses of agricultural wastes in the construction industry, as well as certain other industries leading to a more environmentally sustainable concrete industry.

2 ENVIRONMENTAL SUSTAINABILITY

To evaluate the environmental impact of construction materials, several issues need to be considered, namely collection, treatment and production of raw materials, construction, service life and demolition and disposal (Jorge de Brito et al. 2013). The development of sustainable construction materials should include many factors as energy saving methodologies and techniques, improved use of materials, increasing service life of products, further reuse/recycle of materials, eco-designing and emission control. In addition, another important factor should be considered which the durability of construction material is. A durable building material technically has a better and longer service life and therefore reduces the cost, and amount of materials used in repair and in new constructions in a particular time period.

The aggregates generally making up 70 to 80% of the volume of concrete and play a significant role in different concrete properties such as workability, strength, durability, stability and dimensional. There is a growing interest in using the agricultural wastes materials as alternative aggregate materials and significant research has been made on the use of many different types of agricultural materials as aggregate substitutes (Matalkah et al.2016, Khitab et al.2016)

Concrete made using agricultural waste has shown good performance (Wang et al. 2017,Wang et al. 2018), which can result in higher sustainability from the energy and environmental aspects. Hence, agricultural wastes used as aggregate in concrete production can help save the natural resources and result in environmentally friendly materials, and structures.

2.1 Agricultural waste used in the concrete

Oil palm shell (OPS) is a solid waste originating from the palm oil industry and is available in large quantities in the tropical regions (India, Malaysia) and has been found that OPS can be used as coarse aggregate for the manufacture of structural lightweight concrete (TEO et al. 2006). Abdullah (AA. 1984) used OPS as a lightweight aggregate for producing lightweight concrete.

Coconut shell (CS) is an agricultural waste and is available in plentiful quantities throughout tropical countries worldwide. In many countries, coconut shell is subjected to open burning which contributes significantly to CO2 and methane emissions. Besides that, coconut shell are potential candidates for the development of new composite material in concrete mix design because of their high strength and modulus properties (Gunasekaran et al 2012). Giant reed is a perennial grass that can grow up to 10 m tall and produce more than 20 tonnes above-ground dry matter per hectare. Aquaculture is one of the key businesses in island nations. The southwestern seaside territory of Taiwan primarily develops oysters. The oyster shell yield was 300,000 tons over the last five years, which would initiate environmental pollution concerns (Kuo et al., 2013).

Different types of agricultural waste materials such as oil palm shell (Okafor 1988) , periwinkle shell (Adewuyi & Adegoke 2008) (Ettu et al. 2013), Coconut shell (Olanipekun et al. 2006), date seed (Adefemi et al. 2013) ,corn cob (Pinto et al. 2012), pistachio shell, giant reed fibres (GRF) and giant reed ash (Ismail & Jaeel 2014), have been used as partial or full replacement for natural aggregate (fine or coarse) concrete and their properties have compared with naturel concrete.

2.2 Physical proprieties of agricultural wastes

This section highlights the main properties for agricultural wastes that make it a potential alternative for natural aggregate.

2.2.1 Specific gravity and water absorption

Various researchers have reported specific gravity values shown in Table 1.To prepare a light weight concrete, the specific gravity of light coarse aggregates is about 1/3- 2/3 of that of the natural weight aggregates according to ACI 213-R (Ries et al. 2010). The specific gravity of oil palm shell (OPS) normal ranges between 1.17-1.37 (Muthusamy & Zamri 2016).Reddy et al (2014) found the same specific gravity of 1.33 for coconut shell. Both agro-waste materials OPS and the CS acquired a specific gravity of normal weight aggregate (Olanipekun et al. 2006). Water absorption of oil palm shell OPS ranges between (9.03-33%) which is higher than natural aggregate as well as the other agro-wastes materials. However, water absorption of coconut shell is around (8-25%) which is comparable to water absorption of OPS.

2.2.2 Particle shape, texture, size and color

The proprieties of some agricultural wastes which are used as fully or partially replacement of coarse aggregate are shows in Table 1 and Figure 1. The color of OPS range between dark grey to black, depending on the sources and the quality of OPS. The maximum size of OPS is reported as 30mm. Teo et al. (2007) reported that the highly irregular shapes and the high absorption of OPS results in high air content of OPS concrete. The waste oyster shell (WOS) grows over the years and it is found in many sizes (Prusty et al.2016) . Oyster shell is found in several colors such as green, dark and light brown. Fineness module of WOS ranges between 2 – 2.5. Oyster shells characterised by the rough surface texture and a spiral in structure. On the other hand; crushed coconut shell are restricted to 12mm.

Figure 1 Some agricultural wastes, **(a)** Oil palm shell (Shafigh, Jumaat & Mahmud 2011), **(b)**Oyster shell (Prusty et al. 2016), **(c)** coconut shell (Gunasekaran et al. 2012) and **(d)** giant reed (Ismail & Jaeel 2014).

2.2.3 Bulk density

Bulk density for different agro-waste materials are mentioned in Table 1. The loose for agro materials varies from 510 to 592 kg/m^3 whereas the compacted bulk density can reach up to 1190 kg/m^3. (Mannan & Ganapathy 2001b) had observe loose bulk density for oil palm is 510 kg/m^3, and the compacted density of 596 kg/m^3. Hence, the density of OPS is within the range of typical lightweight aggregate (Okafor 1988)(Okpala 1990). Several experimental research observed that the size and shape of the aggregate greatly affected the closeness of packing which may cause a variation of bulk density with a given specific gravity (Alengaram et al. 2010).The bulk density of agro-wastes materials like wild giant reed (535kg/m^3) is significantly smaller than that of the sand (1428-1744) kb/m^3. Consequently agro-waste materials contain more void in comparison to the naturel fine aggregate and it can adversely affect the workability, strength and durability of light concrete produced by agro-waste aggregate.

Table 1 proprieties of agricultural wastes materials as conventional aggregate

Proprieties	Oil palm shell (Muthusamy & Zamri 2016)	Coconut shell (Olanipekun et al. 2006)(Reddy et al. 2014)	Oyster shell (Kuo et al. 2013)(Yang et al. 2005)(Yang et al. 2010)	Giant reed fibres *(Ismail & Jaeel 2014).*
Size (mm)	30	5-20	-	2.5-10
bulk density(compacted) kg/m^3	590-740	650-1900	-	535
bulk density(loose) kg/m^3	510-550	550-592	-	-
Water absorption (%)	9.03-33	8-25	2.9-7.66	-
Specific gravity	1.17-1.37	1.05-1.2	2.1-2.48	-
Fineness modulus	-	-	2-2.8	-
Moisture content (%)	8-15	4.2	-	-
Shell thickness (mm)	2-8	0.15-8	-	-

2.3 Fresh propriety

2.3.1 Workability

The workability of fresh concrete is a crucial property; it controls other fresh and hardened proprieties of concrete such as air content, density and strength. Workability of concrete is depend on various properties of its constituents. Workability performance of concrete containing agro-wastes aggregates was studied extensively since various properties of agro- aggregate, do not match those of natural aggregate (NA). Concrete workability can be determined by various methods; the slump test is one most used in all over the world.

Yang et al. (2005) reported that the slump value decreased by increasing OS content in the mixture. Ismail & Jaeel (2014)also observed that the slump value decreased when the substitution of giant reed fibres and giant reed ashes increased in the mixture. . The reduction of slump value was attributed to the angularity of particles and the higher water absorption of such waste used.

. On the other hand , (Gunasekaran et al. 2012) reported that the cocrete produced with coconut shell has bertter workability than the control concrete in same mix ratio of 1,1.47 and 0.65 and a w/c ratio of 0.42. The increased slump was attributed to the smooth surface on one side of the used sizes. The reduced workability was the reason that Sada et al. (2013) suggested the use of agro- waste aggregates for the prodcution of lightweight concrete and road construction.

2.3.2 Air content

The presence of a certain amount of air bubbles trapped during concrete mixing have several beneficial effects for fresh and hardened concrete properties. The addition of OPS aggregate to concrete resulted in an increase in the air – content (Alengaram et al. 2013). Yang et al (2005) observed an increase in the air–content of concrete with an increase in oyster shell (OS) content, with was visible for a replacement percentage10 till 20%

2.4 Hardened concrete properties

2.4.1 Compressive strength

Previous researches showed that the compressive strength of naturel lightweight concrete produced with OPS with or without cementitious materials is comparable to the compressive strength for structural lightweight concrete (20-35 MPa). Shafigh, Jumaat, Mahmud, et al. (2011) observed that the 28 and 56 days compressive strength of lightweight concrete made with OPS reached up to about 53 and 56 MPa successfully. Mannan & Ganapathy (2001a) studied the Long-term strengths of concrete with OPS as coarse aggregate by using 480 kg/m^3 ordinary Portland cement and free w/c ratio of 0.41, the 28 day compressive strength of the OPS concrete was between 20 and 24 MPa, depending on the curing conditions. Moreover, they observed that the use of an accelerator such as calcium chloride ($CaCl_2$) results in a strength of up to 29 MPa (Mannan & Ganapathy 2001b). On the other hand, (Yang et al. 2010) tested the compressive strength of OS concrete over a period of 1 year.. They noted that the substitution of OS as a fine aggregate showed an insignificant effect on the 28 day concrete compressive strength. The strength development of CS concrete was faster that the conventional concrete due to the water absorbed by the coconut shell during the course of soaking and the pore structure the coconut shell behaved like a reservoir. Consequently, this special property of CS helps the continuous hydration process of CS concrete. The lubrication between the CS and cement past was developed accordingly, the compressive strength of OS concrete continues to increase with age (Gunasekaran et al. 2012).

2.5 Durability of agro-waste concrete

The durability of concrete is defined its ability to withstand chemical attack and external aggressive environmental and the physical actions. Many researchers conducted durability tests such as chemical attack, freezing and thawing, and carbonation. Etc. of concrete containing agricultural wastes as fine and coarse aggregate replacement the following is an overview of the major findings.

2.5.1 Chemical attack

Kuo et al. (2013) and Yang et al. (2005) did not observe any effect for the substitution ratio of OS on the weight loss of concrete specimens. The deterioration of OS concrete continued with age. (Yang et al. 2010) found that the substitution of OS does not affect the performance of concrete specimens exposed to acid attack. It is concluded that the chemical attack resistance of agro-concrete is independent of their substitution ratio of OS.

2.5.2 Water absorption

Shafigh, Jumaat & Mahmud (2011) found that the replacement level of limestone powder of OPC (10,20 and 30%) by the fine OPS aggregate, the water absorption capacity of OPS high-strength concrete varies from 3.1% to 6.2% (Fig. 2) shows water absorption ratio of different mixtures of OPS concrete . The authors observed that use of giant reed fibres in the concrete increased the water absorption capacity compared to giant reed ash concrete and control concrete (Ismail & Jaeel 2014). The water absorption capacity increased by a replacement level of GRA up of 12.5% when used as fine aggregate. Kuo et al. (2013) reported that the replacement of oyster shell sand by fine aggregate, increased the water absorption capacity by 1.1-1.6% compared to the conventional concrete since waste shell sand has a higher absorption and porosity.

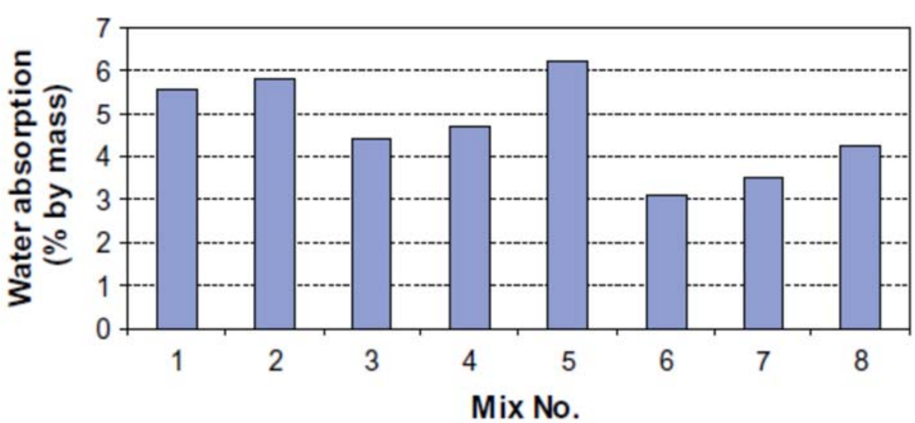

Figure 2 water absorption of different mixtures of OPS concrete (Shafigh, Jumaat & Mahmud 2011)

2.5.3 Depth of carbonation

(Yang et al. 2010) observed that the carbonation depth increased of OS concrete with increasing the carbonation age. Hence, the depth of carbonation was independently reduced with the replacement level of OS.

2.5.4 Freezing and thawing

The freeze – thaw phenomenon is an important issue for cold region concrete. The resistance of concrete containing agro – wastes aggregates against freeze – thaw cycles is reported by several researchers (Carrasco, B. et al. 2014, Yang et al. 2010).(Yang et al.2010) observed that the freezing and thawing resistance is significantly affected by increased OS substitution in the concrete mixture, particularly for long-term performance.

3 CONCLUSION

Utilisation of different agricultural wastes as a fine and coarse aggregate replacement was reviewed in this paper. Following important conclusions have been drawn from these studies:

- The angularity of particles and the higher water absorption of ash used for concrete containing oil palm shell (OPS) resulted in decreased slump when the replacement level increased. However, an increase in the waste oyster shells replacement results in an increased slump.
- The size and proportions palm kernel shells (PKS) have slight influence on the fresh and hardened densities of palm kernel shells concrete.
- Agro- waste concrete produced with oil palm shells, coconut shells, giant reed fibres and oyster shells develops higher compressive strength when compared to concrete control.
- Concrete containing OS, minimum strength achieved by addition of optimal 20 % of replacement level.
- Utilizing OS substituted for fine aggregate did not show negative influences on freezing and thawing, carbonation, and chemical attack resistance was improved.
- The use of giant reed ash as partial replacement of fine aggregate which provide additional pozzolanic property in concrete.
- The properties of concrete with agro waste aggregate as partial replacement of NA up to given replacement ratios (20% in most of the cases) are similar to the equivalent properties of lightweight conventional concrete.
- Utilizing the oyster shell (OS) substituted for fine aggregate did not shows negative signification on freezing and thawing, carbonation and chemical attack resistance was improved.
- The use of giant reed fibres as partial replacement of fine aggregate provides additional pozzolanic property in concrete.

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