The Usage of Agricultural Waste Products for The Production of Composite Materials

Mehmet Serkan Yatağan

Abstract

The importance of the sustainability increases in the modern architectural designs. Especially, within the usage of sustainable materials or waste products, the sustainable architectural projects are designed and constructed. Different waste products of industrial and agricultural products are considered as the new alternative materials. Nowadays, the potential usage of the agricultural waste products increases for the sustainability. After the harvest of the agricultural products, the agricultural waste products are not considered for the alternative production. Each day, the need of the agricultural products increases, that's why the amount of waste products increase. As a regard of the increase in the amount of agricultural waste products, the materials are taken into account for the production of new composite materials. The paper reviews the usage of agricultural waste products as the building materials. It gives information about the different agricultural waste products and where they are used as the building material. The properties and benefits of these waste products are evaluated and explained in this paper. The paper should be a guide for the usage of agricultural waste products as the building materials. As a result of the study, the potential usage of the agricultural waste products for the composite materials are determined and evaluated.

Keywords: Agricultural, waste, composite, sustainability, alternative

INTRODUCTION

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.

For the sustainable projects, the usage of waste products in the production of the building materials become popular for the architectural design. Especially, disposals of solid wastes generated from agricultural production activities is a major serious problem in developing countries.

Agriculture production leaves behind it a considerable amount of waste. Some of these are reused as fertilizer, but most of it is burned. Uncontrolled burning is a solution with a negative impact on the environment and energy waste (Cantor and Manea 2015).

While prices of construction materials have increased in recent years, agricultural waste recycling presents a challenge for the fields of engineering, attention is directed to materials made from agricultural waste showing characteristic similar to the traditional production to a considerably low price (Bynum Jr 2000).

A prerequisite to examining the different applications of agro-waste in the development of construction materials is briefly reviewing the construction industry and its impact on environmental sustainability.

The benefits of agricultural wastes are counted as;

- Reduce indiscriminate disposal or burning of waste products which cause both soil, water and air pollution.
- Maintain the fertility of the soil
- Conversion of all forms of vegetable and animal waste into organic matter suitable for the needs of the growing crop.
- To reduce the dependence on chemicals and to move towards more natural and healthier methods of food production
- Help the farmer to increase their socio-economic and also country income
- Able to reduce the cost of animal feeding
- For productive use

- To ensure the success of the project, environmental and economic gain for the country

For sustainable construction and to reduce the usage of raw material, agricultural waste materials are used. Wide availability of agricultural waste makes them suitable. There is great potential for crops and by-products of animal husbandry to reduce the environmental impact of construction. At the same time construction can help to improve the economic viability of agriculture through adding value to existing crops, using waste agricultural materials or developing new crops. In addition to environmental benefits in production, many of these products bring environmental benefits in use. This relates to better air quality, natural management of moisture levels and reductions in allergic reactions (Kumar et al. 2020).

In this paper, the use of agricultural waste products as the different building materials, are investigated and evaluated by the material properties and sustainability relationship.

PROPERTIES OF AGRO-WASTE BIOCOMPOSITES

Agricultural waste-based bio-composites exhibit a wide range of properties, making them versatile and eco-friendly materials suitable for diverse applications. These properties include physical, mechanical, thermal, acoustic, chemical, and biological characteristics, which collectively determine their functionality and sustainability. With densities ranging from 0.7 to 1.4 g/cm^3, they show moderate water absorption (6%–20%) and porosity levels between 3% and 15%, impacting insulation and mechanical performance. Their tensile strengths range from 15 to 70 MPa, flexural strengths vary from 20 to 90 MPa, and impact resistance values range from 4 to 15 kJ/m^2, ensuring durability under dynamic loads. Thermal conductivity values fall between 0.18 and 0.4 W/mK, with heat deflection temperatures ranging from 70°C to 130°C, making them effective insulators for construction and automotive applications. Acoustic properties include sound absorption coefficients from 0.5 to 0.9 and noise reduction coefficients from 0.35 to 0.75, making them ideal for soundproofing. Chemically, they exhibit moderate resistance with pH values of 6.0–7.5, while biological properties include high biodegradability (55%–95%) and moderate to high resistance to fungal and bacterial attacks. Combining lightweight, moderate strength, thermal insulation, acoustic absorption, chemical stability, and biodegradability, these composites are promising alternatives to synthetic materials in various industrial applications. The properties of the agro-wastes of some bio-composites are given in Table 1 (Selveraj et.al 2018, Ogah et.al 2014).

Table 1. Properties of agro-waste biocomposites

Property	Rice husk	Coconut shell	Sugarcane bagasse	Corn stover	Wheat straw	Bamboo
Physical properties						
Density (g/cm3)	0.8–1.2	0.9–1.3	0.7–1.1	0.8–1.2	0.9–1.2	1.0–1.4
Water absorption (%)	10–15	8–12	12–18	15–20	14–19	6–10
Porosity (%)	5–10	4–9	6–12	8–15	7–13	3–8
Mechanical properties						
Tensile strength (MPa)	20–40	25–45	15–35	18–38	15–30	50–70
Flexural strength (MPa)	30–50	35–55	20–40	25–50	20–45	60–90
Impact strength (kJ/m2)	5–10	6–12	4–8	5–10	4–9	8–15
Thermal properties						
Thermal conductivity (W/mK)	0.2–0.4	0.25–0.35	0.18–0.3	0.2–0.35	0.22–0.37	0.25–0.4
Heat deflection temp. (°C)	90–120	80–110	70–100	80–110	85–115	100–130
Acoustic properties						
Sound absorption coefficient	0.6–0.8	0.5–0.7	0.65–0.85	0.6–0.75	0.55–0.8	0.7–0.9
Noise reduction coefficient	0.4–0.6	0.35–0.55	0.5–0.7	0.45–0.6	0.4–0.65	0.55–0.75
Chemical properties						
pH value	6.5–7.5	6.0–7.0	6.5–7.0	6.5–7.5	6.0–7.0	6.5–7.5
Chemical resistance	Moderate	High	Moderate	Moderate	Moderate	High
Biological properties						
Biodegradability (%)	70–90	60–80	75–95	70–90	65–85	55–75
Fungal resistance	Moderate	High	Moderate	Moderate	Moderate	High
Bacterial resistance	Moderate	High	Moderate	Moderate	Moderate	High

THE USE OF AGRICULTURAL WASTES AS BUILDING MATERIALS

1. The Usage of Agricultural Wastes in Concrete

Recently, like all other industries, the construction industry also focuses on developing sustainable, recyclable, and environmentally friendly building materials. Due to the limited natural resources, rapid urbanization will cause the demand for traditional building materials not to be met. On the other hand, the production of traditional building materials such as cement, brick, and steel causes harm to the nature due to the consumption of a lot of thermal and electrical energy. In order to meet the rapidly increasing demand for energy-saving and environmental-friendly building materials, cost-effective, environmentally friendly technologies should be adopted and traditional building materials should be improved with local waste materials (Madurwar, Ralegaonkar, and Mandavgane 2013).

Especially in developing countries, disposal of solid wastes from agricultural and industrial production activities is a serious problem. Wastes produced from agricultural sources include sugarcane bagasse, cellulose, jute fiber, bamboo, hemp, coconut husk, etc. It is very important to reuse it as a sustainable construction material. Because the recycling of agricultural wastes and using them as construction materials will be a suitable solution not only for the pollution problem but also for the high cost of landfill and construction materials.

Burning of agro-wastes such as RH and sugarcane bagasse under the controlled temperature produces an ash which contains mainly of pozzolanic elements such as silica and alumina, which have received the attention of the researchers of lower emission binders' alternatives such as alkali-activated materials (AAMs), geopolymer and various other industries such as plastic, steel production, semiconductors, glass making, ceramics, and many more.

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 and 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 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 and 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 (Ramezanjanpour, Khnai, and Ahmadibeni 2009).

It is known that processed/incinerated waste can be used as (partial) cement replacement if its composition is such that it contains sufficient quantities and ratio of CaO and SiO_2. Therefore, this review provides state of art literature on the use of different agricultural solid waste such as palm oil fuel ash (POFA), rice husk ash (RHA), sugarcane bagasse ash (SCBA), and bamboo leaf ash (BLA) in concrete production. It provides a systematic evaluation of the properties of selected agricultural wastes with regards to their intended use as cement replacement or aggregate replacement and general production processes to make them ideal for use and some challenges towards promotion of their use in concrete production. It also provides possible solutions that can be implemented after further studies/research is undertaken.

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 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 CO_2 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, Annadurai, and Kumar 2013). Giant reed is a perennial grass that can grow up to 10 m tall and produce more than 20 tones 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, periwinkle shell Coconut shell (date seed, corn cob pistachio shell, giant reed fibers (GRF) and giant reed ash, have been used as partial or full replacement for natural aggregate (fine or coarse) concrete and their properties have compared with naturel concrete.

Utilization of different agricultural wastes as a fine and coarse aggregate replacement was reviewed. 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.
- 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, develops higher compressive strength when compared to concrete control.
- Utilizing OS substituted for fine aggregate did not show negative influences on freezing and thawing, carbonation, and chemical attack resistance was improved.
- 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 (Figure 1).

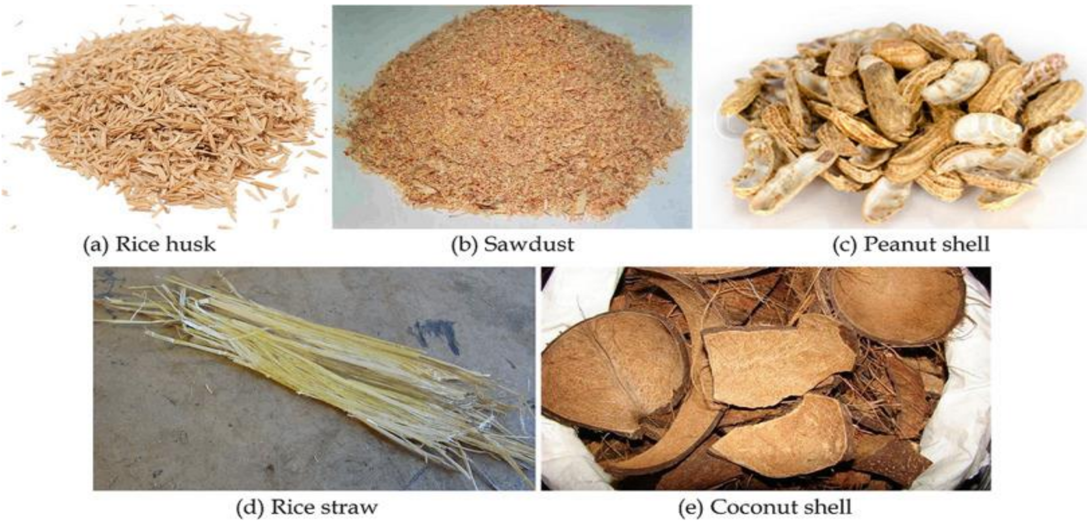

Figure 1. Different types of agro-waste products

2. The Usage of Agricultural Wastes in Bricks

The excessive usage of the earth materials that are utilized for production of fired bricks results in massive depletion of the natural resources and also high energy consumption. These bricks are also responsible for serious environmental degradation due to the high greenhouse gas emissions.

The utilization of waste materials as an additive in brick production is not only helpful to improve the properties of bricks but also overcomes the scarcity of natural resources and controls the associated environmental problems (Kazmi et al. 2017). Different waste materials like waste glass powder, marble powder, paper production residue, municipal solid waste incinerator slag, petroleum effluent treatment plant sludge, fly ash, rice husk ash and sugarcane bagasse ash were used to improve the performance of clay bricks. Lighter bricks can be produced using agricultural wastes in burnt clay bricks (Kazmi et al. 2017). Light weight bricks can be helpful in reducing the structural load of buildings and are considered desirable for construction purposes in earthquake affected areas in Figure 2.

Figure 2. Agro-waste bricks

Therefore, there is utmost need to develop energy efficient buildings. One of the best ways to make a building energy efficient is by improving the thermal performance of walls. Generally, bricks are commonly used as a construction material in walls. Therefore, generation of micro-pores in bricks can be helpful to improve the thermal performance of walls leading towards energy efficient buildings (Kazmi et al. 2017). Micro pores can be generated by utilizing waste materials in brick manufacturing. These waste materials burn during firing of bricks and result into micro pores leading to improve the thermal conductivity of bricks Different waste materials like waste marble powder , recycled paper waste olive stone flour , olive pomace bottom ash, spent mushroom compost expanded vermiculite and pumice have been widely used to generate pores and improve the thermal performance of bricks. Bricks incorporating 20% olive pomace bottom ash showed improved thermal conductivity by 17%.

Sugarcane bagasse ash (SBA) and rice husk ash (RHA) are the agricultural wastes generated in many parts of the world like Brazil, South Africa, India, China, Cambodia, Philippines, Indonesia, Thailand and Pakistan (Kazmi et al. 2017). Sugarcane is processed in the sugar mills to extract juice leaving the bagasse as waste. Bagasse is then burnt as a fuel source and results into the generation of SBA. Similarly, Pakistan being agricultural country produces 2 million tons of rice husk each year. Rice husk is also used as fuel in brick and paper industry and after combustion RHA is produced. Therefore, utilization of agricultural wastes in production of burnt clay bricks can be helpful to overcome related environmental and landfilling issues leading towards sustainable and economical solution (Figure 3).

Figure 3. Sugarcane bagasse ash bricks

3. The Usage of Agricultural Wastes as Biomaterials

A precursory study clearly suggested that the manufacturing technology of so-called 'hempcrete' can be modified best to suit the agro-waste generated in India. Hempcrete which is manufactured primarily from the residue of Hemp plant. Hempcrete is one of the most explored Bio-Crete which is a composed by mixing lime binder, water and the non-fibrous part of hemp, called 'shiv'. With passage of time the composition hardens and can be used as bricks (Figure 4).

Bio-based plastics are made from renewable sources like corn, potatoes, wheat and vegetable oil through chemical or biological process which include hydrolysis, acidification, microbial fermentation, etc.

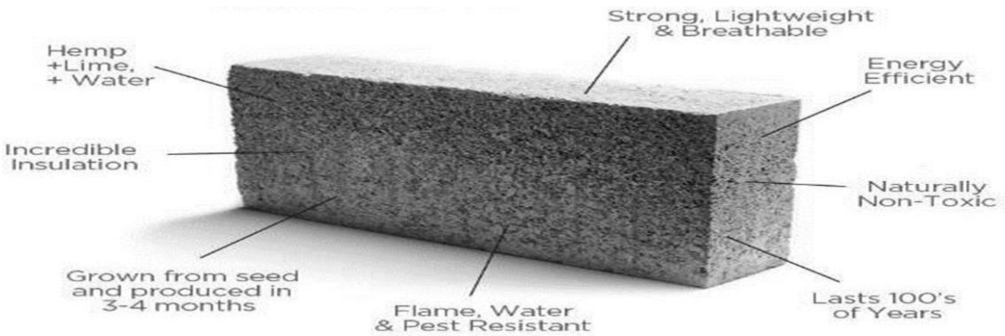

Figure 4. Hempcrete

In general, starch-based plastics are more cost competitive than alternative bioplastics. They can accommodate a wide range of physical properties that alternative bioplastics lack, such as tensile strength and heat tolerance. Starch composites can also incorporate recycled plastics. Starch can be used to reduce the carbon footprint of traditional resins because they can replace petroleum-based polymers with natural ones. It is also highly degradable, meaning it can be used alongside a compostable polymer without interfering with the degradation process. Starch-based plastics have increased in relevance with the introduction of improved resin grades, their ability to blend with other biopolymers and an increasing number of suppliers. In fact, starch-based bioplastics are widely rising-application-in- medical-field-to-burgeon-the-growth-of-starch-based-bioplastics-market because of their biocompatibility, low toxicity, degradation properties and mechanical properties.

Cellulose plastics are bioplastics manufactured using cellulose or derivatives of cellulose. Cellulose plastics are manufactured using softwood trees as the basic raw material. Barks of the tree are separated and can be used as an energy source in the production. The properties and chemical composition of cellulose esters is dependent on the acids and anhydrides used in the production process. Major applications for cellulose plastics include thermoplastics, extruded films, eyeglass frames, electronics, sheets, rods, etc. Molding materials is the most dominant application segment for cellulose plastics and the trend is expected to continue for a foreseeable future. Softwood is the dominant raw material used in the production of cellulose plastics and increasing number of deforestation regulations is a major restraint for the market. Easy availability and low cost of conventional plastics is also among major restraint for cellulose plastics market growth. Moreover, high efficiency and comparative cost benefit of conventional plastics over cellulose plastics has restrained market growth for cellulose plastics.

Corn and soy-based protein plastics are being developed as an alternative to petroleum-based plastics. They are bio renewable, biodegradable, and naturally release fertilizers during degradation. These plastics can be molded into any shape and used with existing equipment. Mechanical properties are similar to petroleum-based plastics. Possible applications include home and garden supplies, toys, building materials, and industrial packaging. Wheat gluten is among the proteins that forms the most cohesive material. Wheat gluten plastics can be made into many different types of products, including flexible films, foams and rigid solid 3D items. It can be colored in all kinds of colors and made opaque or translucent. Protein's plastics are stiff and to obtain flexible products, these have to be plasticized with e.g. a natural sugar (keeping the whole product bio based). There are many possible applications for protein-based plastics and even though they are moisture sensitive, for more demanding environments (high moist conditions), they can be prepared with antimicrobial agents (in the same way as wood is for certain applications).

4. The Usage of Agricultural Wastes as Thermal Insulators

The low density, foam-like core of the corn cob makes this by- product a good alternative for insulation. The thermal conductivity of corn cob particle sheets formed by wood glue is comparable with XPS (Paiva 2012). Corn microstructure, elementary chemical composition, and superficial temperature made it applicable as building thermal insulation (Pinto 2011).

Coir or coconut fiber is a brown natural fiber extracted from the husk of coconut, found between the hard, internal shell and the outer coat of a coconut. But pith is the powdery material resulting from the processing of the coir fiber. Ropes and cordage are among the ancient uses of coir. Coconut pith and fiberboards also were found as good thermal insulation materials because of low thermal conductivity and acceptable physical values in similar studies (Manohar 2012; Sampathrajan, Vijayaraghavan, and Swaminathan 1992).

Natural cellulose fibers which can usually be found in agricultural waste such coconut husk has proven in previous studies to have the capability to absorb sound. Not only this could mitigate the noise issue, it might also overcome the waste problem. When a sound wave hits a surface, those are not reflected is absorbed. According to Salter (2002) all materials have some sound-absorbing properties. The more fibrous a material is the better its absorption capability; and denser materials on the other hand are less absorptive. For this reason, the recycling of the agricultural waste has become more popular that can replace the traditional one. There is many research initiated to study the potential of waste especially the agricultural waste as an acoustic panel. Yang, Kim, and Kim (2003) study the acoustic properties of rice straw-wood particle composite boards and found that the sound absorption coefficient in the frequency range of 500 to 8000 Hz is higher than other wood-based materials which are due to the low specific gravity of the composite boards. Banzo and Valesco (1982), Van Dam (2003) and Tejano (1984) all agreed that at some level the coconut coir can be made an acoustic panel for its sound absorption character such as spongy and fibrous. Current traditional sound absorption panels using synthetic materials such as glass, mineral wool, felts or polyester fibers are not sustainable and can be hazardous to human's health and occupancy of the building. At the same time, more sustainable and green approach solution is craved around the world to solve such issues. Looking at this, attention is moved to waste for the possible solution. For instance, agricultural waste such as coconut husks and other waste such as papers are left abandoned in dumping areas. These wastes could be used as an alternative material for sound absorption panel.

Composite panels made from agricultural materials are in the same product category as wood-based composite panels and include low-density insulating board, medium-density fiberboard, hardboard, and particleboard. More so, composite panel binders may be synthetic thermosetting resins or modified naturally-occurring resins like tannin or lignin, starches, thermoplastics, and inorganics (Rowell, and Rowell 1996).

5. The Usage of Agricultural Wastes as Particleboards

Ecological insulation panels made of vegetable raw materials are increasingly used in the building sector; they have an interesting role because their use allows their revaluation as agricultural wastes, whose disposal is a serious issue (Gaspar 2020) allowing them to be converted from waste to secondary raw material. In the construction industry, the goals of these materials are obtained thanks to the easy usability of raw materials, simplicity, applicability, low cost, as well as thermal and acoustic characteristics (Islam, and Bhat 2019; Ricciardi, Belloni, and Cotana 2014).

Lignocellulosic composite panels are the matrix materials that form either inorganic or organic based binders with used wood and non-wood-based reinforcement elements in the system. In recent years, many new composite materials have been introduced to the market for different purposes. However, great demand on those products and technological developments it has started to study on the availability and suitability of new raw lignocellulosic sources which could be used in fiber board and chipboard manufacturing processes.

Several studies were conducted to find the suitable agro-fibers for composite manufacturing. Some of the agro-fibers studied so far are kenaf, wheat and cotton straws sunflower stalks, tea leaves], date palm leaves, and peanut shell. According to these studies, with the combination of wood chips, modification of agro-fibers, and the addition of some moisture repellant, it is feasible to produce particleboard from the wastes of agricultural crops having the physical and mechanical properties as required by related standards (Figure 5).

Figure 5. Agro-fibers board

The high rate of demand for forest wood consumption is considered as a main reason for the high rate of deforestation as well as grave impact on the environment which has resulted to global warming. The growing demand for wood-based particleboards have raised serious challenges on the issue regarding the sustained supply of raw materials to this sector for quite some time. However, the need to reduce the dependence on wood and forest resources has resulted in a great interest for alternative resources substitute wood raw material for agricultural residues and wastes for particleboard production.

The alternative fibers such as agricultural residues and non-wood plant fibers could serve as the balance between supply and demand for the manufacturing of composite panels such as particleboard. The need to reduce the dependence on wood and forest resources has gingered interest in the utilization of agricultural residues and wastes for particleboard production. Many researchers have conducted studies on a wide variety of agricultural wastes and residues from many different regions of the world: wheat straws, rice husks/straws, waste grass], kenaf, betel palm, rice bran, kiwi pruning, cotton carpel and bagasse.

Technological development has led to renewed interest in the utilization of industrial and agricultural wastes. It enhances total wastes utilization, reduces cost of production, promotes a cleaner environment and enhances the earning of the farmers. It also prevents burning of agricultural residues and wastes and thus mitigates climate change (Gunasekaran, Annadurai, and Kumar 2012). Different value-added products have been produced from agricultural and industrial wastes. These products have eliminated most of the negative implications posed by indecent disposal and management of wood residues as waste (Gunasekaran, Annadurai, and Kumar 2012). Cement-bonded particleboards have been subjected to different studies with the purpose of using other types of wood or vegetable biomass, as the chemical compounds from wood (extractives and sugars) tend to inhibit of cement hydration.

Many useful value-added products have been manufactured from industrial and agricultural wastes. These products have eliminated most of the adverse effects posed by improper disposal and management of wood residues as mere waste. The increasing in awareness in the possibility of utilization of raw materials in wood composite industries has led scientists to investigate non-wood lignocellulosic biomass utilization in composite production including particleboards in the recent time (Gunasekaran, Annadurai, and Kumar 2012; Karade 2010). In view of the huge quantities of plant fiber and agricultural waste materials annually have become alternative raw materials for particleboard production, and more than 30 plants have been reportedly utilized in their productions around the world (Colak et al. 2007; Alirez et al. 2011). Nemli et al. (2009) maintained those alternative raw materials such as agricultural residues will play a major role in the particleboard industry in the future. Studies on particleboards utilizing agricultural and wood residues include cotton stalks, hazelnut husk, betel palm and kenaf stalks, almond shells, kenaf core, sunflower stalks, eggplant stalks, waste grass clippings and bagasse].

The utilization of industrial and agricultural wastes such as sawdust and palm wastes for production of particleboards could be the best method to encourage total wood utilization, reduce cost of production and enhanced cleaner environment. Enhanced value-added products can be made from agricultural and industrial wastes. Waste's utilization has reduced to the barest minimum the negative implications experienced by improper disposal and management of agricultural and wood wastes. Other industrial and agricultural wastes being investigated for their suitability in the production of particleboards include: eucalypt and poplar], rattan furniture waste], coconut coir, coconut husk, bagasse: wheat and eucalyptus. The utilization of agricultural and industrial wastes for production of particleboards has the potential to reduce the pressure on forest resources and at the same time provide solutions to the problems of agricultural and industrial wastes disposal.

CONCLUSION

The usage of agricultural waste as the building materials begins to grow all around the world. For the sustainability architectural designs, the waste products get more important to produce new sustainable materials. The agricultural wastes are suitable for the production of new building materials. At first, they are used in the biopolymers, but now they are used as particleboards, concrete, thermal and acoustical insulations, bricks and blocks. Moreover, they have better characteristic material properties. Also, they can supply environmental protection to decrease the carbon foot print and to supply waste management. In future, the agricultural waste products will be used every construction and architectural designs.

There is no conflict of interests, research involving human participants and/or animals and informed consent.

REFERENCES

Alirez, A., Taghi, T., KAzizic K., & M. Reza, M. 2011. "Wood–wool cement board using mixture of eucalypt and poplar", Industrial Crops and Products, vol. 34, pp. 1146– 1149, 2011.

Badur, S. and Chaudhary, R. 2008. "Utilization of Hazardous wastes and By- products as a Green Concrete material through S/S process: A Review. Rev. Advance Material Science.17 pp.42 – 61.

Banzon and Velasco. 1982. Coconut Production and Utilization, Philippines.

Bynum Jr. Richard T. 2000. Insulation Handbook, A.I.A McGraw-Hill Professional Publishing.

Cantor, D.M.& Manea, D.L. 2015." Innovative Building Materials Using Agricultural Waste Procedia Technology 19, 456 – 462.

Colak, S., Çolakoglu,G. Aydın,I. & Kalaycioglu,H. 2007. "Effects of steaming process on some properties of eucalyptus particleboard bonded with UF and MUF adhesives" Building Environment., vol. 42, no. 1, pp. 304–9.

Federico, L.M., Chidiac, & S.E. 2009. "Waste glass as a supplementary cementitious material in concrete – Critical review of treatment methods", Cement & Concrete Composites 31 606–610.

Gaspar, F., Bakatovich, A., Davydenko, N. & Joshi, A. 2020. "Building insulation materials based on agricultural wastes". Bio-Based Materials and Biotechnologies for Eco-Efficient Construction; Woodhead Publishing Series in Civil and Structural Engineering; Woodhead Publishing: Duxford, UK, pp. 149–170.

Gunasekaran K., R. Annadurai R. & Kumar,P.S. 2012. "Long term study on compressive and bond strength of coconut shell aggregate concrete", Construction and Building Materials, vol. 28, pp. 208–215.

Gunasekaran, K. & Annadurai, R. & Kumar, P. 2013. "A study on some durability properties of coconut shell aggregate concrete." Materials and Structures. 48. 10.1617/s11527-013-0230-2.

Islam, S., Bhat, G. 2019. "Environmentally-friendly thermal and acoustic insulation materials from recycled textiles". Journal of Environmental Management, 251, 109536.

Karade, S.R., 2010. "Cement-bonded composites from lignocellulosic wastes", Construction Building Materials, vol. 24, no. 8, pp. 1323–1330.

Kazmi, S, Munir, M., Patnaikuni, I. & Wu, Y. & Fawad, U. 2017. “Thermal performance enhancement of eco-friendly bricks incorporating agro-wastes”. Energy and Buildings. 158. 10.1016/j.enbuild.2017.10.056.

Kumar P R, Sreelekshmi K S, Anjana S Babu, Harikrishnan S, Santhanu G Nath, Leena V P. 2020. “Role of Agricultural Wastes in Construction Industry”, International Journal of Engineering Research & Technology (IJERT) Volume 09, Issue 03.

Kuo, W., Wang, H., Shu, C. & Su, D. 2013. “Engineering Properties of Controlled Low-Strength Materials Containing Waste Oyster Shells”. Construction and Building Materials. 46. 128–133. 10.1016/J.Conbuildmat.2013.04.020.

Madurwar M.V, Ralegaonkar R.V, Mandavgane S.A. 2013. “Application of agro-waste for sustainable construction materials: a – review”. Construction and Building Materiasl 38:872–878.

Manohar, K. 2012. Experimental Investigation of Building Thermal Insulation from Agricultural By-products. British Journal of Applied Science & Technology. 2. 227-239. 10.9734/BJAST/2012/1528.

Meyer, C. 2009. “The greening of the concrete industry.” Cement and Concrete Composites, 31(8), 601-605.

Nemli, G.S., Samet, Demirel, E., A. Gümüşkaya, A., Aslan,A. & Acar, C. 2009. “Feasibility of incorporating waste grass clippings (LoliumperenneL.)in particleboard composites”, Waste Management, vol. 29, no. 3, pp. 1129-1131, 2009.

Ogah, A.O., Afiukwa, J.,& Englund, K. 2014. “Characterization and Comparison of Thermal Stability of Agro Waste Fibers in Bio-Composites Application, Journal of Chemical Engineeering and Chemistry Research,1,84-93

Paiva, A., Pereira, S., Briga S.A., Cruz, D.J., Varum, H. & Pinto, J. 2012. “A contribution to the thermal insulation performance characterization of corn cob particleboards”. Energy and Buildings Journal, Elsevier. 45. 274-279. 10.1016/j.enbuild.2011.11.019.

Pinto, J. Paiva, A., Varum, H., Costa, A., Cruz, D., Pereira, S., Fernandes, L., Tavares, P. & Agarwal, J. 2011. Corn`s cob as a potential ecological thermal insulation material. Energy and Buildings Journal, Elsevier. 43. 1985-1990. 10.1016/j.enbuild.2011.04.004.

Ramezanjanpour, A., Khnai,M. & Ahmadibeni, G. 2009. “The Effect of Rice Husk Ash on Mechanical Properties and Durability of Sustainable Concretes”, Engineering International Journal of Civil Engineering.

Ricciardi, P., Belloni, E. & Cotana, F. 2014. “Innovative panels with recycled materials: Thermal and acoustic performance and life cycle assessment”. Applied Energy, 134, 150–162.

Rowell R.& Rowell J. 1996. Paper and Composites from Agro-Based Resources, CRC Press, USA.

Salter. 2002. Acoustic for Libraries, Institute of Museum and Library Design.

Sampathrajan A, Vijayaraghavan N, Swaminathan K. 1992. “Mechanical and thermal properties of particle boards made from farm residues”. Bioresource Technology 40(3):249–251.

Savastano, H., Warden P.G.& Coutts, R.S.P. 2003. “Potential of alternative fibrecements as building materials for developing areas”, Cement and Concrete Composites, vol. 25, pp. 585-592.

Selveraj, V., Jayanthi, K.P.& Alagar, M. 2018. “Development of Biocomposites From Agro Wastes for Low Dielectric Applications, Journal of Polymers and The Environment, 26, 3655-3669.

Shafigh, P., Mahmud, H.B., Jumaat, M.Z., & Zargar, M. 2014. “Agricultural wastes as aggregate in concrete mixtures-A review”, Construction and Building Materials, 53, 110-117.

Tejano E.A. 1984. “State of The Art of Coconut Coir Dust and Husk Utilization (General Overview)”, Philippine Journal of Coconut Studies, 10(2), pp. 36-41.

Van Dam, Jan E.G. 2003. “Production process for high density high performance binderless boards from whole coconut husk”, Industrial Crops and Products 20 97–101.

Yang, H.S., D.J. Kim and H.J. Kim, 2003. Rice straw-wood particle composite for sound absorbing wooden construction materials. Bioresource Technology., 86: 117-121.