INTEGRATIVE REINFORCEMENT OF NATURAL FIBER: FABRICATION OF PEANUT SHELL TILES IN BUILDING CONSTRUCTION

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ABSTRACT
Alternative recycling materials are one of the most promising strategies in the construction sector for reducing global warming, high energy demand, and carbon emission release. Several studies oriented their research toward encouraging the concept of recycling, reusing, and reducing agriculture plant waste to be integrated into material construction. With a focus on "peanut shell waste", the paper aims to highlight the possibility of generating lightweight and sturdy units/tiles in building construction. The method first started with evaluating the energy parameters effect of peanut shells in building construction, followed by the experimental test. This test was done by examining a mix of peanut shells with sand and corn starch to generate tiles/brick units. Different form-generation were explored to fabricate the casting mould of the unit. With the use of bio-resin, the mix was cast in the mould and then assembled after drying. The resulting tile's prototype showed the possibility of using them as 3D units that can be assembled to generate a self-structured element, or as tiles to be used indoors or outdoors. Different architecture applications can be generated from these tiles/units as an alternative to industrial building materials which can decrease the environmental impact of natural waste storage. In addition, these tiles will enhance the thermal performance of the space if it is used as insulation in the walls, which in parallel will reduce carbon emission. Further research is to generate 3D printing filament from peanut shell waste as bio-based material. Another study can assess the difference between peanut shells mixed with clay bricks with traditional fired bricks from a mechanical behaviour and thermal performance point of view for humidity and temperature monitoring.
Keywords: peanut shell, recycle, casting, form-finding, digital fabrication.

1 INTRODUCTION

The massive increase in population growth increases the demand for new buildings and more agricultural industries. The increase of both industries resulted in generating a huge amount of abundant materials and agricultural waste that affect the environment if burnt or left to dispose of the land. However, both processes release huge amounts of greenhouse gases into the environment. Therefore, it is imperative to find ways to reuse and recycle this crop waste. Industrial materials in construction sectors are responsible for the climate change crisis resulting in high energy demand and carbon emission release which affect human thermal comfort. Several studies have shown the possible application of agricultural wastes in building materials enhancing their mechanical properties and reducing the cost of materials production, pollution, and gas emissions [1]. However, a lack of studies on durability and thermal properties is observed. Providing alternative waste management through reusing it can help in reducing environmental impacts worldwide [2].

The research question highlight how crop waste can be recycled into building materials, thereby minimizing waste and improving sustainability within the construction industry. As a way of exploring the possibility of using peanut-shell waste as a raw material without burning, the paper studied the generation of lightweight units/tiles in building construction. The method first started with reviewing previous studies that highlighted the peanut shells

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properties, energy effect and carbon emission released from, followed by an experimental test. Two tests were done; first to examine the behaviour of peanut shell when it mixed with sand and corn starch, second, using bio-resin without any heat or pressure. Form-generation test was explored to fabricate a mould to cast the mixture in then assemble the units after drying. The research develops a vision of global challenge translated in an architectural application in form of tiles extracted from agricultural waste as an alternative in today's construction material industry. The prototype obtained renewability, sustainability, and innovation character.

2 RELATED WORK

2.1 Groundnut/peanut shell production worldwide

The continuous global population growth resulted in the increase demand in agriculture and construction that provide both food and shelters, which in parallel increased more waste and pollution to the environment [3]. To get rid of the agriculture plant waste, many countries used to burn them which harms the environment by polluting the air through the gas emission produced from this process. Groundnut shells waste for instance are burnt or buried resulting in environmental pollution [4]. In 1997, Egypt witnessed one of the biggest black cloud phenomena that cover the Delta and Cairo resulting from burning the of rice straw. After the great toxic emission resulting from this phenomenon, the ministry of agriculture with the ministry of environment banned burning the rice straw in the open-air and put a protocol that encourage reusing and recycling the rice straw for many organic products and fuels which provide more jobs. Agricultural waste provides more than 33% of total biofuels usage in the world [5]. This waste includes fibres and bio-composite that can be used as an alternative for architectural construction materials [6]. Generally, with the shortage in the resources resulting from the climate change problems, searching for clean ways to recycle the plant waste has been received increasing attention in several fields. Regardless of the high energy consumption resulting from the building sectors, especially in cement production, which is the main binder used in concrete, mortar, and fired bricks, had led to search for an alternative sustainable construction materials for reducing/replacing cement [7]. This can lead to more sustainable industry, not only as a way to reduce the high cost but to reduce the high energy demand and the CO_2 emission released from cement production which reaches 5% [8].

As for the research focus, peanut, which is also known as groundnut, is used mainly in food production that contains many nutritional minerals and is imported in three different forms; in-shell, shelled, and peanut oil [9]. Based on Atlasbig, the largest countries of peanut production are China in the first place with a total of 17.5 million tonnes per year, followed by India, and Nigeria with 6.7 and 4.5 million tonnes per year respectively [10]. Together they are responsible for more than 50% of the world's total peanut production globally as shown in Fig. 1. Egypt ranked at 22 with a total of 231,223 tonnes per year where 30%–35% of the total production is exported globally. While the largest countries for importing peanuts are Italy, Germany, Greece, and the Netherlands. With all these amount of peanut production, tons of peanut shells are discarded to be a huge waste, where different solutions need to be done to reuse these waste [11].

As a way of reusing raw crop waste, particleboard is one of the most famous applications that generates panel under pressure and heat from wood or lignocellulosic fibres combined with resins and bonded together. This process is considered economic and low-cost where the furniture industry benefits from these boards. Other applications of these particleboards

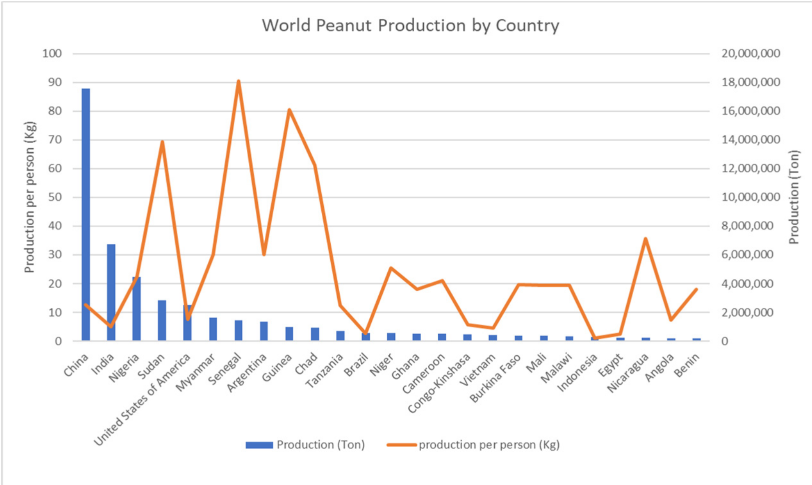


Figure 1: The world peanut production.

can be seen in walls, partitions, tiles, roof top, etc. [12]. Several types of resins are used in manufacturing these boards for instance, phenol formaldehyde (PF) which is known with its high strength, thermal and moisture resistance, excellent temperature stability, less toxic, and high compaction of the fibres [12].

2.2 Architecture applications of peanut shell and their mechanical properties

Many studies have been focusing on integrating agriculture crop waste among the natural fibres into traditional building materials and structural composites because their higher strength and stiffness with the availability considering a waste [13]–[15]. Natural fibres advantages can be seen in their lower pollutant and greenhouse emissions, lower thermal expansion, lightweight, less cost, less energy demand and more recovery, eco-friendly, and biodegradable components at the end of the building life-cycle [16], [17]. These wastes are used as an alternative to reduce the amount of the cement and clay used in concrete and bricks manufacturing reaching more strength and lightness. Crop wastes capture CO_2 during growth, and their harvesting does not use large amounts of fuel energy [15]. Their growth absorb CO_2 with less amount of energy needed during harvesting, and an average of 5–10 times less non-renewable energy than glass fibres [16], [18] and 30–70 times less than carbon fibres [19] during production.

Both biomaterials extracted from plant waste and carbon fibres became the leading materials used especially in structure. At Stuttgart University at ITKE/ICD, a team led by Achim Menges and Jan Knippers and their team constructed two pavilions at Stuttgart University based on biomimicry principles. They used woven-resin-impregnated glass and carbon fibre. These materials allow generating lightweight composite that reached a large-span structure to reach the aim of reducing the formwork as shown in Fig. 2 [20]. The woven technique by the robot arm allowed seamless and joint less interaction for the whole structure. Dahy and her team [21] at BioMat/ITKE based in Stuttgart university generated the BioMat pavilion, where they used modular bio composite sandwich panels combined with the structural beams. Also, she generated the Polyclad Acoustic Panel out of bio composite and thermoplastic as a way of recycling agricultural waste.

Figure 2: Carbon-fibre pavilion, ITKE/ICD, Stuttgart university, 2017.

Various researchers tested different applications of using peanut shell, include its uses as building material insulation mixed with plaster evaluating its thermal properties [7], [14]. achieved good compression strength through using groundnut shell ash as a partial replacement of cement in sand Crete blocks with an average of 10% to 20% percentage with compression strength average of 3.8 N/mm2. Quaranta et al. [22] used peanut shell for ceramic manufacture with percentage of 5%, 10% and 15%, where it shows the more percentage of the biomass, the higher energy needed to get good strength and high compressive strength. Adeosun et al. [23] used groundnut shells in nanofiber preparation which were used in packing and tissue engineering applications [12] generated medium-density panel from peanut shell after testing different fibres percentage of 50%, 60%, 70% and 80% through compaction. Tensile strength showed higher value of 11.4 MPa in the ratio of 50%. For achieving light weight concrete. Sada et al. [24] used efficiently groundnut shell to reduce the amount of the cement used in concrete production. Also, Mahmoud et al. [7] used the shells for replacement of the fine aggregates in the concrete with reaching percentage of 75%. Escalera et al. [25] produced lightweight porous fired bricks using nut shells where a decreasing shrinkage were observed from 11.60% to 6.80% with an increase in the thermal conductivity from 0.20 W/mK to 0.76 W/mK [2].

2.3 Energy and recyclability

Perea-Moreno et al. [26] reports in their study that the energy properties of the peanut shells contribute for environmental conservation because of their lower emission comparing to biomass, with the low content of sulphur 0.54%, nitrogen 0.50% and the chlorine 0.07%. This make the peanut shell ideal for biofuel that would decrease the CO_2 emission to be used in production either for heating or cooling. The same study recorded very low value of moisture content in the peanut shell with a value of 5.79%, which make an advantages that no drying treatment is needed using any energy purposes [26]. A study done by Perea-Moreno et al. shows that biofuel is the highest production extracted from the peanut shells globally, where China is the greatest to extract the energy from it follow by India, Nigeria, the US, and Sudan with average of 25,579.75, 11,440.42, 5253.69, 3637.60 and 2891.79 MWh respectively.

3 METHODOLOGY

3.1 Materials and tools

The material used in with the peanut shells are sand, corn-starch, and bio resin. Based on a study done by Kulshreshtha et al. [27], when corn starch is mixed with water and sand, they forms a non-Newtonian fluid state where the starch granules in cold water. When this mixture is heated in oven or microwave for 3 min, it generates a hardened mix called CoRncrete [27]. This composition has a compressive strength similar to the fired clay bricks. In addition to this mix, this research integrated the peanut shells as recycled materials that act as fibres by grinding them into two different sizes: coarse and fine grains of 6–8 mm and 2–4 mm respectively as shown in Fig. 3. The sand and corn starch particles varied between 0.5 and 1 mm, which act as binder to bond the peanut shells with the mix in form of 2 cubes.

Figure 3: Different size of grinded peanut shells.

Bio-resin was added to the mixture instead of corn starch and water where no heating, which acts as a binder and gives more strength to the tiles. The mix was cast in a mould and assembled after drying in room temperature. Scale, grinder machine, and microwave were used. The resin used in the research is a bio-based epoxy that has a density of 1.09 g/cm3, tensile strength of 67.5 MPa, energy intensity of 49 MJ/kg, and global warming potential of 4.08 kg CO_2-eg/kg [15].

3.2 Method

In order to generate peanut shell tiles, the literature review aimed to evaluate the energy effect resulted from the peanut shells in building construction, followed by the experimentation test. This test is divided into three main phases: (1) material characterization, (2) form-finding, (3) fabrication of mould, and (4) the casting and assembly process as shown in Fig. 4. The peanut shells were collected and grained into coarse and fine particles and sieved as powder. Two different of binders were tested; cornstarch that need heating, and bio-resin the does not need any heating process.

3.2.1 Material characterisation test

To study the microstructure of the powder shells, SEM images were taken using Olympus microscope model no. BX41 showing both the outer skin protection layer and the fibres inside. Two cubic moulds were made to test the homogeneous of the mixture with a ratio of sand, cornstarch, and shell (1:2:2) for both fine and coarse shells. The samples were heated in a microwave with temperature of 200°C to bond the cornstarch which acts as a binder. Bio resin was replaced by the cornstarch to remove the heating process with a ratio to the sand and shells of (0.5:1:2). Compression test was done for the samples.

3.2.2 Form generation

The unit's form was inspired by the outer shell of the peanut morphology. The form consists of two elliptical shapes from both sides. This elliptical shape was developed to give

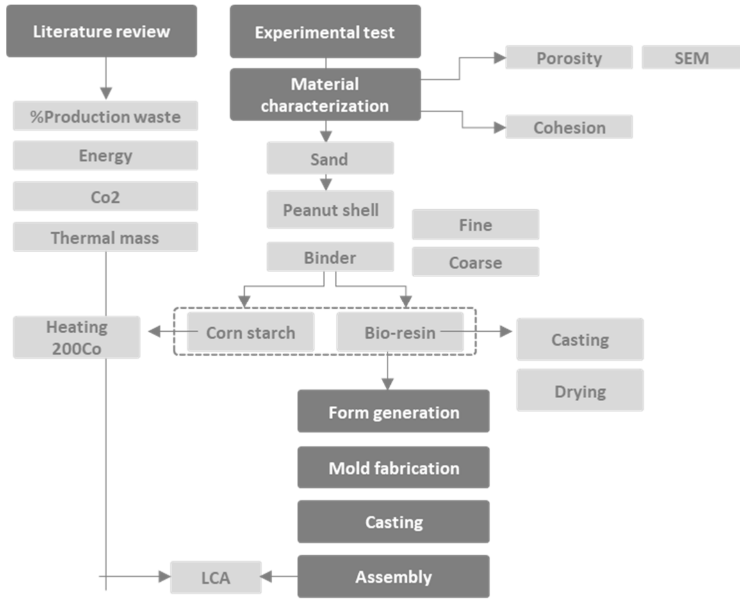


Figure 4: The method of the research.

alternative and multiple forms as shown in Fig. 5(a) to reach a unit that can be connected and attached to another either overlapped or side by side. The arrangement of the units were in two directions, where the small units are perpendicular and the bigger units are diagonal to assemble similar form of hexagon.

Two squared sizes were designed considering the connection between the units 12 cm and 8 sm. The bigger units are assembled diagonally, while smaller units are assembled perpendicular which acted as connectors as shown in Fig. 5(b).

(a) (b)

Figure 5: (a) The form finding of the unit; and (b) The arrangement and assembly of both units.

3.2.3 Mould fabrication and casting process

Two different sizes of mould were cut using acrylic sheet with thickness of 5 mm using laser cutter machine to cast the mixture in as shown in Fig. 6. Two mixtures were prepared one for the fine grains and the other for the coarse grains to generate different porosity which will affect the lightness of the tiles. The peanut shells are mixed with sand and resin as a binder.

Figure 6: Two units' sizes during casting process in the mould.

The mixture has filled the units after reaching a homogeneous state. The casted units are kept drying within few hours in room temperature 24°C.

4 RESULTS AND DISCUSSION

4.1 Material behaviour

SEM images in Fig. 7 shows the microstructure of the peanut shell for both pattern and porosity. While the fine particles have less spaces in between which make it denser. This concludes that the small particles of both sand and corn-starch can fill the space faster, which will need more materials in case the bigger particles as shown in Fig. 8. For the mechanical behaviour, the cubic samples for both fine and coarse grains recorded compressive strength of 28 to 22 MPa, respectively. It was noticed that the cohesion of the coarse sample was too lose.

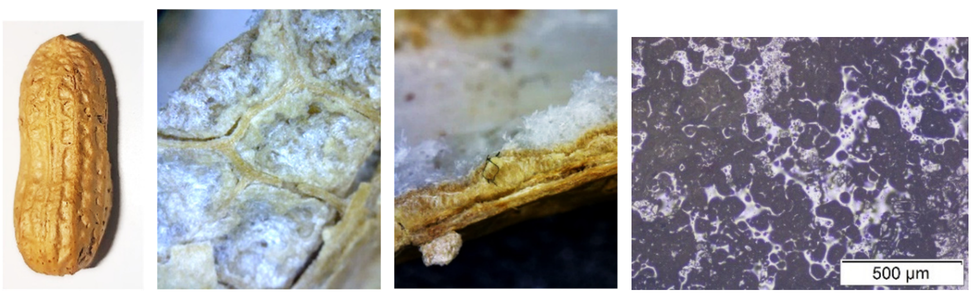


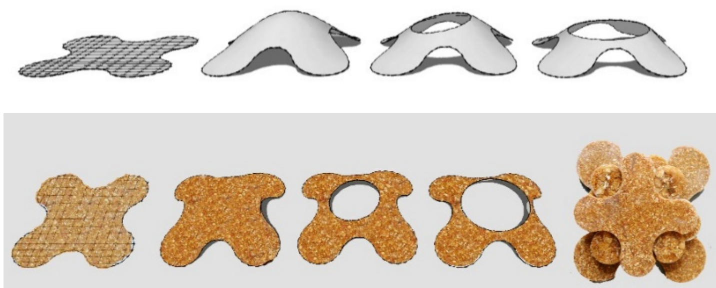
Figure 7: The external peanut shell and SEM images shows pattern of the shell and the microstructure of the peanut shell thickness.

For the samples with bio-resin, the mixture does not need any heating or pressuring process, and the solidification hardened in less than two hours. Unlike the cubic samples, it was observed that the compressive strength of the fine grains to the coarse grains was 50 MPa and 62 MPa. Yet in case of using the powder as 3D printing material or turning it into filament, heat will be needed to melt the binder which will increase the compression strength when resin released to temperature between 500 and 1000°C.

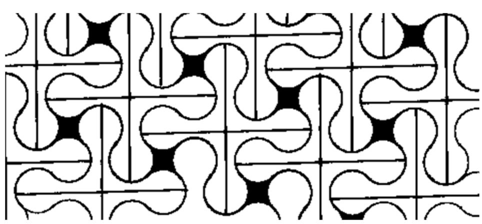
Figure 8: Two samples after heating using corn starch with fine and coarse shells.

4.2 Porosity of the tessellated unit

It is easy to control the openings' size in the block to give more variety depending on the function beneath. Fig. 9(a) shows the variation in the opening's size and how the unit be a 3D which will use differently. These openings in the case of wall partitions can be changed with different sizes depending on the function. The porosity will result more lightweight tiles. Connections between the tiles leave some voids in a form of square as shown in Fig. 9(b) which can be used as a ventilation system or light entry.



(a)



(b)

Figure 9: (a) The unit differentiation in the void's size; and (b) Tessellation of the proposed unit.

4.3 Connection and fabrication assembly

The unit can be connected in several ways giving different alternatives. The join can be through sticking the units together overlapped, or through steel rebar where the units can form the final panel. The overlapping forms when using in walls give the ability to reduce temperature inside the space, which act as an insulator.

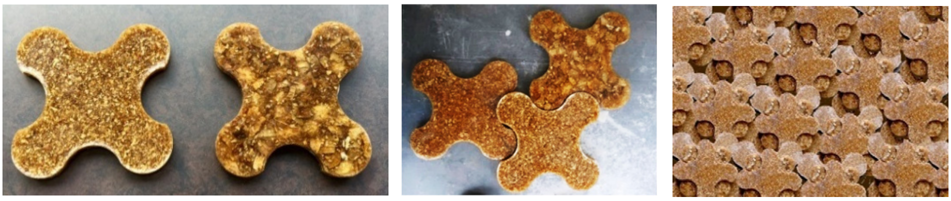


Figure 10: The generated units; fine and coarse shells, the connection, and the panel assembly.

4.4 Architecture application and life cycle assessment

Many architectural applications can integrate the peanut shells either in interiors as cladding and finishes, wall system or in outdoors such as in tiles, panels, and boards that can be reused in furniture design. For building materials, peanut shells can be used as insulation filler in air cavity to reduce the thermal resistance of the wall causing temperature heat reduction which is left for another research. Another application can be done as fibres in fired brick, sun dried bricks, mortar, or in concrete production as a replacement of the cement production. Additionaly, cellioluse extraction can be produced out for other bio-composite prodcution. For life cycle assessment, the bio-resin can be melter and reused again, yet, some carbon emession will release.

5 CONCLUSION

The paper presented the possibility of using agricultural waste as a base in building material. The resulted units could act as a friendly material that can be replaced with the non-efficient material that harms the environment. The literature presented some results of previous research how the shells out of crops assess in reducing the waste in the environment instead of burning them. After different form findings, the paper showed the possible alternatives that can be generated from one form. Porosity of the particles in the coarse or the fine state showed differentiation in the weight that respond back to the mixture cohesion. The arrangement and the connection of the units through using steel rebars can be done in further research testing the structural stability of panel application. As the paper presented an application of using the waste without any heating or pressure, further research could be implemented to turn this waste into filament material for 3D printer, which later can be a door for multiple applications through different additive manufacturing methods. The units can be applied in architecture as an alternative construction building material which could reduce the total carbon emission and energy needed for the building. Life cycle assessment will be done in another part as a continue of this paper.

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