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Development of Clay/Plastic Waste Building Block in a Circular Economy

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Abstract

This project is motivated by the desire to develop low-cost, high-quality building bricks that will compete favourably with existing conventional masonry units using plastic waste and clay in line with the call to transition to a circular economy. The study uses clay samples from Ngor-Okpala bonded by waste plastic bottles for building applications as a response to the call to mitigate the adverse effect of indiscriminate plastic waste disposal. The materials were collected from local sites and sorted and screened for this project. Clay was poured into molten plastic at 255 C and mixed until a supersaturated mixture was achieved. The mix was then compressed in a metallic mould to form bricks of predetermined shapes. Test specimens were subjected to crushing, water absorption and dry density to determine their suitability for use in the industry. The production process of the materials proved more eco-friendly and could help to convert waste to wealth in the long term while making the environment more habitable for human beings.

Keywords: Clay, Plastic, Waste Building, Block, Curricular Economy

Introduction

In the wake of the current global challenges in the supply of fossil fuels from which virgin plastics are made, Nigeria and the continent of Africa must take a more unassailable position on the recovery, re-use and re-manufacture of single-use plastics (Hossain et al., 2022). This is so important because only about 9% of the approximately 90 billion tonnes of petroleum-based plastic materials extracted annually end up being recycled. This pattern, according to the

Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2020), impacts negatively the natural environment and endangers human health. Tulashie et al. (2020) approximated global yearly plastic waste as 300 million tonnes, with 6.8 billion tonnes generated between 1950 and 2020. Again, less than 10% of this humongous waste was recycled and about 79% was landfilled and littered while 12% was incinerated (Geyer et al., 2017); further endangering human and aquatic lives. This imbalance between plastic waste generation and management as well as the sustained increase in the generation above recycling leaves an unsavoury taste in the mouth of relevant stakeholders, Nigeria inclusive. Hence, there is plenty of room for improvement as it relates to the recovery of reusable plastic wastes as against municipal landfilling. (Olatayo et al., 2022).

Plastics are extensively used in wide-ranging applications, thanks to their comparative mechanical, thermal and chemical advantages (Medupin et al., 2017). While policies have been advocated as a central backing for circularity in the plastic value chain, with policies in place to regulate waste management and checkmate pollution in Nigeria, up to 90% of waste still finds its way into the landfill (CSIRO, 2020). From an all-inclusive perspective the Circular Economy (CE) model, underpinned by a transition to renewable materials, combines waste management functional activities and the forward supply chain while placing a high premium on recovery through re-use and recycling (CSIRO, 2020). Therefore, to tackle the enormous challenges posed to the environment, plastic waste would have to be deployed as a resource, thus plugging the gap between circulating material resources and waste management. This is what this study seeks to achieve through the recycling of plastic bottles.

Whilst a lot of progress has been made in the area of policy making by the government, there is still a lack of strategic approach to carrying the consumers of single-use plastic materials along. This is the first obstacle to achieving commercial development of products made from plastic waste. Olatayo et al. (2022) identified ban and suspension as key ingredients of the enforcement of the instrument of regulations aimed at ridding African cities of plastic waste. Good as they appear, reports showed that not much has been achieved with this instrument, as African cities still grapple with the challenge of effective waste administration and transitioning to commercial recycling. This is the first step towards commercialization. Other instruments employed, according to researchers are the economic instruments which include a levy, financial rewards and information and guidance which are promoted by campaigns, education and research. However, the success rate with these remains relatively insignificant.

Godfrey and Oelofse (2017) reported that the national policy timeline for wide-ranging waste administration in many African countries has come of age, having traversed four stages of development (landfilling, recycling, regulation and drive for extended producer responsibility) that hold every stakeholder in plastic value chain responsible

for its management. It is currently at the fifth stage of a circular economy where sustainability takes centre stage. This study will, therefore, explore innovative approaches to value enhancement of plastic waste through the execution of a circular economy within the context of re-manufacturing of products from plastic wastes in the building industry to contribute to reducing the already disturbing national housing deficit.

The rapid growth of energy use and the fossil fuel used daily have severe environmental impacts in the form of ozone layer depletion, global warming, climate change, etc. (Saidur, 2009). From an economic, energy and environmental conservation point of view, there is a dire need for energy regulation such as heating or air conditioning in buildings (Iwaro and Mwasha, 2010; Aktacir et al., 2010). Energy consumption is very high in air-conditioning; therefore, the use of thermal insulation is regarded as one of the most energy-efficient improvements in buildings. Hence, there is a need to turn to circularity in the building industry

CONCEPTUALISATION

Landfilling

Landfilling is a long-term process involving the storage and decomposition of organic matter. There are two major products obtained from landfilling. These include landfill leachate and landfill gas (Babu et al, 2021). MSW leachate consists of fulvic acids, humic acid, volatile compounds and organic pollutants (Gunarathne et al., 2019). The landfill gas consists of equal proportions of carbon dioxide and methane. The gas can be collected and utilized for electricity production (Agency, USEP, 2018). Although landfilling is considered an easy and low-cost technology worldwide, the degradation of the organic fraction leads to the emission of greenhouse gases, namely, methane and carbon dioxide. In this way, landfills are a major contributor to greenhouse gas emissions worldwide. The operational procedures in landfilling technologies are also responsible for additional emissions. As per recent reports, 15.5% of the world's total greenhouse gas emissions were from China (Yang et al., 2013). In light of this data, China needs to develop newer technologies for the collection and utilization of greenhouse gases with a zero-emissions approach.

Composting

In composting, organic carbon is broken down so that it can be used in the soil as fertilizer. It consists of two phases, namely, activation and maturation (Babu et al., 2021; Awasthi et al., 2018). Initially, the mesophilic microorganisms act on the MSW and the temperature of the pile increases. Following that, thermophilic bacteria come into play (Ayilara et al., 2020; Dahiya et al., 2018). The temperature in the thermophilic phase reaches 50–70 ◦C, which helps kill pathogens (Richard et al., 2019;

Awasthi et al., 2016; Awasthi et al., 2020) and decreases the viability of the seeds present in organic solid waste (Veverkova et al., 2020; Zhou et al., 2021). Additionally, if the temperature exceeds 65 ◦C, then it can reduce the viability of microbes, hindering the decomposition rate. Mixing and aeration are the two key processes to keep the temperature in a viable range [(Ayilara et al., 2020; Awasthi et al., 2018). The maturation phase is characterized by a reduction in pile temperature due to a decrease in the organic fraction. In this phase, the organic matter is stabilized and humidified (Richard et al., 2019; Duan et al., 2020). In composting, the major product obtained is compost. It is a source of organic matter, and it improves soil characteristics when used as fertilizer. Various factors affect compost characteristics.

Circular Economy

Circular Economy (CE) is regarded as a promising solution to harmonize economic growth and environmental protection. Although CE is a contested concept with various implications in different domains (Korhonen et al., 2018), it is generally defined as a sustainable initiative that entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system (EMF, 2015). Essentially, CE seeks a paradigmatic shift from linear to circular practices and generates economic, environmental, and social value by designing out waste and pollution, keeping products and materials in use, and regenerating natural systems (EMF, 2015). Regarding the core principles incorporated within CE, various R frameworks have been used by scholars and practitioners for decades ranging from 3R to 10R (Kirchherr et al., 2017) and a critical discussion of different Rs in a 10R framework is provided by Reike et al. (2018). Particularly, the 3R (Reduce-Reuse-Recycle) framework is recognized as the most fundamental and inclusive CE principle (Brennan et al., 2015; Ghisellini et al., 2016). It is at the core of the CE promotion law 2009 in China (National People's Congress, 2008) and also serves as the foundation of the Waste Framework Directive in the European Union (EU) with an added dimension of 'Recover' (European Commission, 2008a).

Conventional waste-to-resources technologies (Inclusion)

In the waste-to-resources process, incineration is such an economical and reliable technology it is considered an important procedure in developing countries such as Nigeria (Alzate et al., 2019). Being the major producer of municipal solid waste, Nigeria depends mainly on landfills and incineration to reduce the volume of solid waste in the environment. In the process, the whole waste mass is incinerated, which reduces the MSW volume by about 10–20%. The heat generated during the process is used for boiling water and steam generation in some climes. The produced steam, in China, for instance, is used to turn the turbine and generate electricity. They also

separate the carbon dioxide produced in the process in a chamber with HCl and CuCl2. At the end of the process, fly and bottom ashes are obtained, which can be used for the construction of roads Alzate et al., 2019; Chen et al., 2021). In China, incineration technology for MSW treatment has been improved in terms of resource utilization in recent years (Ding et al., 2021; You et al., 2017). The MSW incineration capacity of China increased to 102 Mt/year in 2018, which accounts for 45% of the total MSW (Ding et al., 2021). Incineration plants have increased recently in China, accounting for 74 in 2008, which increased to 290 in 2017. Kitchen waste in China consists of a higher portion of non-classified and moisture-rich materials compared to other countries. In this way, before sending MSW waste to the incineration process, a pre-treatment step is needed to remove water. Therefore, China needs to develop incineration technology more efficiently. This will help in improving the conversion rate of energy to electricity. Incineration technology can be integrated with more new advancing technologies to obtain more by-products (Ching et al., 2021; Sarsaiya et al., 2018; Cao et al., 2019).

LITERATURE REVIEW

Environmental pollution has emerged as one of the world's most critical environmental problems in recent years due to sustained fast profitable growth and industrialisation over the last several decades, especially in developed countries (Wang et al., 2019; Tsai et al., 2020). China has collected six billion tonnes of unprocessed MSW, and approximately 200 of the country's 660 metropolises are experiencing "trash siege" problems (Lv et al., 2020). While improper management of MSW poses a serious threat to human beings and the surrounding environment, it is becoming recognized as an important renewable resource (Awasthi et al., 2015; Ding et al., 2021). The MSW composition varies significantly from place to place, and it is well established that it is significantly influenced by the socioeconomic level and meteorological elements in the local area. Organic wastes as well as various inorganic wastes (for example, stones, pottery, and ashes) are all common physical components of MSW (Cheng et al., 2010). This MSW presents a technological challenge for incineration due to low caloric content in most cases (Wang et al., 2019; Chong et al., 2021).

A circular economy is operationalized through three product designs and business model strategies. Two fundamental strategies are (1) slowing the loop through the design of long-life goods and product-life extension, the utilization period of the product is extended, and (2) closing the loop through recycling, the loop between post-use and production is closed, while the third focuses on (3) narrowing the loop using fewer resources per product (Bocken et al., 2016). The 3R framework contributes to the realization of these strategies as a guideline at different production levels

(Kirchherr et al., 2017). A circular economy can also be seen as a useful approach to achieving local, national, and global sustainability (Rodriguez-Anton et al., 2019). As stated in the EU action plan for CE: "This action plan will be instrumental in reaching the Sustainable Development Goals (SDGs) by 2030, in particular, Goal 12 of ensuring sustainable consumption and production patterns." (European Commission, 2015). The relationships between CE and SDGs exist inherently in their policy definitions. Several studies investigated the extent to which CE practices are relevant for the implementation of SDGs and identified which SDGs have significant relationships with the concept of CE (Schroeder et al., 2019; Rodriguez-Anton et al., 2019). Since CE is closely related to sustainable development, it gains weight as a prominent part of the national policy agenda aiming to substitute the make-use-disposal paradigm across different industries (European Commission, 2011a).

Particularly, the construction industry attracts significant attention from the government because of its high resource intensity and waste pollution. However, CE implementation in this industry is still hindered by various barriers and challenges (Adams et al., 2017; Ghisellini et al., 2018). Current literature recognizes that CE implementation in the built environment is an interlinked challenge that relates to both public and private stakeholders (Pomponi & Moncaster, 2017; Ruiz et al., 2020). Not only should the industrial actors strive for a circular future by revising their business models, behavioural patterns, and expectations from products, but the government needs to actively provide regulatory guidance to align the strategic agendas of public authorities and industrial actors (Adams et al., 2017; Ghisellini et al., 2018; Schraven et al., 2019; Heurkens & Dabrowski, 2020). The regulatory guidance here covers a broad range of policies, regulations, ordinances, and initiatives introduced by local or national governments.

MATERIALS AND METHODS

Materials

The materials used for this study include clay samples sourced from Ngor-Okpala, Owerri West Local Government Ares of Imo State, Nigeria. The plastic water bottles (Mangero) used were collected around the campus at strategic waste collection points. After sorting, the most popular plastic waste on the campus of the Federal University of Technology, Owerri was favoured as it constitutes a huge environmental risk. Other materials include thermocouples to measure temperature change, plastic bowls of different sizes for clay preparation, metallic pots of different sizes for melting the plastic bottles, a 425-micron sieve for sieving the clay sample and a mortar and pistol for crushing the raw clay sample. Metallic moulds were also produced for the moulding of the clay/plastic composite.

Methodology

The clay sample (Plate 1.1) was sun-dried for 24 hours after which foreign materials were carefully removed by hand picking. To reduce the percentage of non-clay materials to the barest minimum, the sample was crushed in the laboratory using mortar and piston to achieve uniform particle sizes. Lighter particles were winnowed off during the process and stones and wooden particles were easily removed. The clay sample was then kept in a plastic container in readiness for mixing with the polymer binder.



Clay Sample

The sorted plastic bottles were washed with clean water. Since they are water containers, the use of soap for washing was rather unnecessary (Plate 1.2). Oil stains were easily removed using clothing materials soaked in soapy water. Thereafter, the bottles were shredded to make the melting process go smoothly.



Plate 1.2: Sorted Plastic Waste (left) and Set-Up for Composite Production (right)

The metallic pot containing a shredded plastic bottle was placed on a heater and heated until the plastic melted and became fluid. A thermocouple was used to monitor the temperature gradient of the melting exercise. When the plastic had been sufficiently melted and could freely flow, a measure of the prepared clay sample was gradually poured into the molten plastic and mixed to achieve a homogenous mixture. More clay sample was added as the mixing continued until a super-saturated sample of the mixture was achieved. This was subsequently loaded into a 222 mm long by 106 mm wide by 73 mm high mould of imperial size compressed manually and left to cool under the compressive weight. Other smaller sizes were also produced for testing.

Testing of Samples

The standards and guidelines for conventional masonry units (CMUs) applicable in Africa will serve as the benchmark for testing the materials developed from the recycled plastic/sand composite.

Table 1 Summary of Some Tests and Methods

S. No	Tests	Methods
1	Compressive/crushing strength	BS EN 722-1 (2011)
2	Modulus of Elasticity & Poisson's ratio	BS EN 12390-13 (2013), ASTM C469/C469M (2010)
3	Dry density	BS EN 722-13 (2000)
4	Water absorption	ASTM C140

The compressive strength of individual masonry units was determined according to the procedure set out in BS EN 772-1 (2011) at the bed-face and head-face (Figure 3.1) experimental set-up. A 2 MN Instron Materials Testing Machine were employed for the tests. The units were tested in the bed-face orientation at 7, 14, 28, 56 and 91 days.

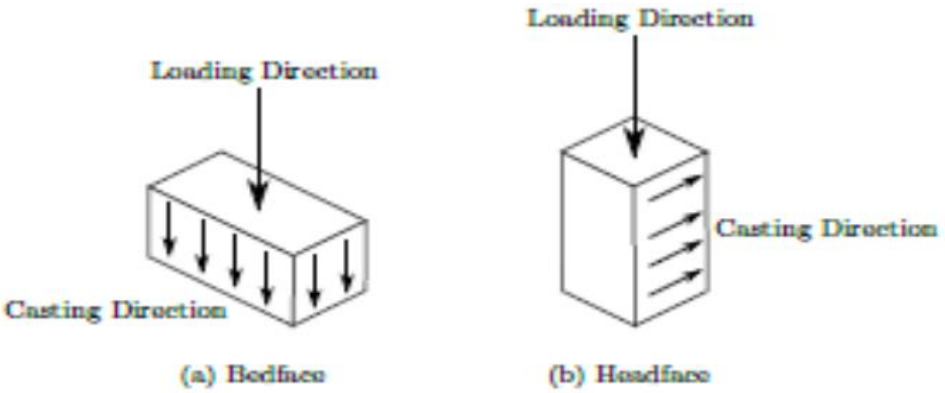


Figure 1.1: Orientation, loading direction and casting direction of bed-face and head-face Specimens

Modulus of elasticity (MoE) tests followed BS EN 12390-13 (2013) on seven cylindrical specimens at a curing age of 28 days. The CMU and plastic waste/clay composite specimens had the same dimensions of height of 220 mm and diameter of 106 mm. The same machine used for the compressive tests will be employed for the MoE tests. Tests for Poisson's ratio were conducted according to the guidelines from ASTM C469/C469M (2010). They followed the same time and on the same specimens as the Modulus of Elasticity, tests to allow both the transverse and longitudinal strain to be measured at the same time under the same loading procedure. The same set-up applied for modulus of elasticity also applies to this.

The wedge-splitting tests were conducted to determine the specific fracture energy of the masonry. Between 6 and 12 units needed to be tested because of the sensitivity of the test and cured in 28 days. The tests are conducted on cubical specimens with a notch at the top and a starter groove in the notch as shown in Figure 3.2.

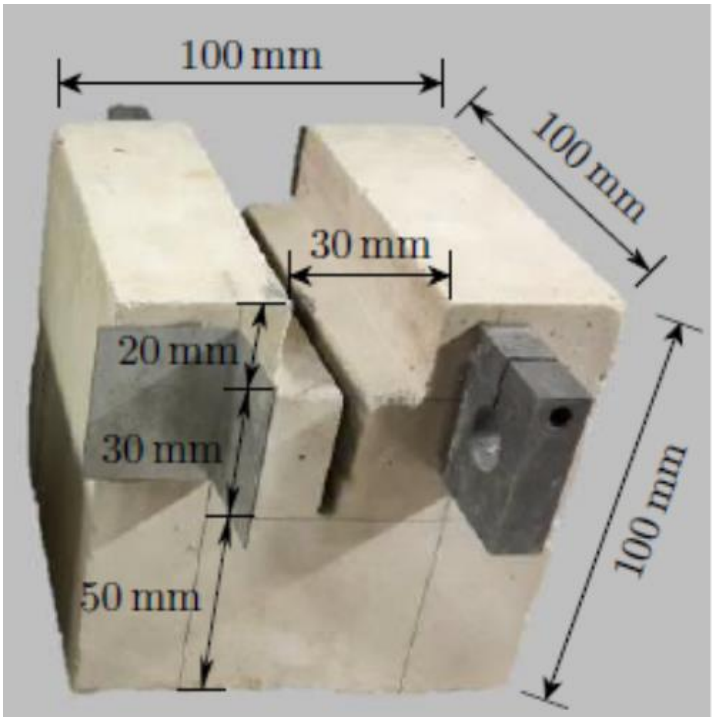


Figure 1.2: Dimensions for wedge splitting unit

Dry density tests would be carried out according to BS EN 772-13 (2000). Six full-size materials would be tested for 28 days. All density tests will be conducted on units that are dried to a constant mass in a ventilated oven at a temperature of 70 ^{C}. The specimen will be placed in the oven for 24 h intervals after which it will be cooled and weighed. Constant mass is reached when mass loss becomes less than 0.2% of the total mass after the previous 24 hours. The sample's density is computed by dividing the constant mass by its volume.

Water absorption tests of the specimens will be performed by ASTM C140. The test specimen is immersed in water at a temperature of 15.6 to 26.7 °C for 24 h. The specimen is then weighed while suspended by a metal wire completely submerged in water and recorded as W_i (immersed weight). It is then removed from the water and allowed to drain for 60±5 seconds by placing it on a 9.5 mm or coarser wire mesh,

removing visible surface water with a damp cloth. Afterwards, it is weighed and recorded as W_s (saturated weight).

Following saturation, the specimen is dried in a ventilated oven at 100 to 115 °C for not less than 24 h and until two successive weighing at intervals of 2 show an increment of lo not greater than 0.2 % of the lt previously darnedest e specimen. This is recorded again as W_d (dry weight). The absorption is calculated as follows:

$$Absorption, Kg/m^3 = \frac{(W_s - W_d)}{(W_s - W_i)} \times 1000 \quad (1)$$

$$Absorption\ (\%) = \frac{W_s - W_d}{W_d} \times 100 \quad (2)$$

Conclusion

This study is focused on the formulation of clay/plastic composite for building bricks. It can be concluded Nigeria and indeed the Federal University of Technology Owerri can leverage the abundance of clay sand and plastic wastes to increase her financial fortune and contribute significantly to the circular economy drive of the United Nations. Mechanical mixing of the two materials in the right proportion resulted in improved properties of the composites; leading to their preference for other competing materials for low-cost building applications.

In summary, the following conclusions were drawn based on various analyses conducted in this study. Adopting the use of plastic wastes in place of cement which hurts the environment can contribute to mitigating climate effects and preserving the ecosystem, investments in a circular economy pay off as it creates employment for everyone in the value chain, and the environment can be rid of harmful plastic solid wastes by turning them into wealth by embracing a circular economy.

Recommendations

It is strongly recommended that the university should prioritize research in circularity to join the global research village in salvaging the hailing global environment. The research could have been more successful but for the constraint of time. Therefore, we recommend that another set of students should look at this report and start earlier to achieve what our team could not accomplish. It is relevant to investigate the use of sand instead of clay and compare results with conventional masonry units and the ones produced in this study.

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