Production of Pavement Blocks Using Low Density Polyethylene Product Waste

Aboje, A. A.[1 a]; Abbas, B. A.[2]; Kolo, D. N.[2]; Abubakar, M.[2]; Abdulsalam, A.[1b]

[1]*Chemical Engineering Department, Federal University of Technology, Minna, Nigeria*
[2]*Civil Engineering Department, Federal University of Technology, Minna, Nigeria*
[1a]*alen248@yahoo.com*, [1a]*bala.alhaji@futminna.edu.ng*, [1b]*daniel.kolo@futminna.edu.ng*,
[2b]*mahmud1879@futminna.edu.ng*

Abstract:

Waste sachet water packs cause considerable land pollution in Nigeria. In this research, pavement block was produced using low density polyethylene products waste (sachet water packs) as an alternative binder. The production was achieved by first converting the sachet water packs into pellets and blending it with sandstone in a mass ratio of 8:2 (A), 7:3 (B) and 6:4 (C) sandstone to pellets respectively. The compressive strength, %water absorption and curing time tests were carried out on the pavement block to determine it suitability and safety for low-traffic use. The compressive strength for polymer concrete samples A, B and C were 13.65N/mm^2, 16.99N/mm2 and 20.34N/mm^2 respectively. After carrying out the %water absorption test on the polymer concrete A, B and C the following result was obtained: 8.33%, 5.47% and 4.03% respectively. It should be noted that the polymer concrete samples and the control samples which (are cement concrete based) are for light-traffic use (pedestrian, plazas, shopping complexes ramps, car parks, office drive ways, rural roads with low traffic, and residential road).

Keywords: Polyethylene, sachet water packs, Sandstone, Pellets, Pavement block

Introduction

Financial development and altering intake patterns have led to a rapid increase in the usage and consumption of plastics on the planet. It is on record that the consumption of plastic materials increased from about 5 million tons in the 1950s to well over 100 million tons in the 2000s (Wusu-Sekyere et al., 2013). Specialists have also warned that this growth will not decrease unless people revise how they use and recycle natural resources. There has actually been a tremendous improvement in efforts to turn waste to wealth worldwide. Nigeria produces an estimated 32 million tons of solid waste each year - among the highest quantities in Africa, and of this figure, plastic makes up about 2.5 million tons of heaps (Isioma, 2012). Through its waste management authority (LAWMA), Lagos State has carried the concern of filth that turned its environment into an eyesore by transforming the waste into different helpful materials (Owolabi & Amosa, 2010). Most plastics do not biodegrade. Instead, they gradually break down into smaller-sized fragments referred to as micro plastics which have more adverse effects on human health. Studies show that plastic bags and containers made of polystyrene foam could decay up to thousands of years, polluting soil and water (Mishra, 2016). Polymers have been utilized in building and construction as earlier as the 4th millennium B.C., when the clay brick walls of Babylonia were developed utilizing the natural polymer, asphalt in the mortar. The temple of Ur-Nina in the city of Kish had masonry foundations constructed with mortar made from 25 to 35% bitumen, a natural polymer (Hirde & Dudhal, 2016). Making use of polymers in building works is ending up being typical worldwide. Its physical characteristic as well as its relatively low expense makes it a commonly used construction material. The strength, toughness and aesthetically pleasing surface areas have made paving obstructs attractive for many industrial and community applications such as parking lot, pedestrian strolls and roads (Gencel, 2012). Water-retentive cinder block pavements are also utilized in locations often visited by lots of people consisting of sideways, parks, and plazas (Karasawa et al., 2006). Standard Portland cement concrete has several limitations, such as low flexural strength, low failure strain, vulnerability to frost damage and low resistance to chemicals. These restrictions are well recognized by the engineer and can generally be enabled in most applications. Polymer customized binders however show improved adhesion and cohesion (Sulyman *et al*., 2016). Furthermore, cement is a main factor in high-energy use, CO_2 and dust emissions, and continuous ecological wear and tear (Koo et al., 2014). In addition, the importation of building materials has become difficult and expensive in the era of the COVID-19 pandemic which necessitates the use of alternative home-developed local materials. Even though concrete is a robust and reasonably durable structure material, it can become seriously compromised by poor manufacturing process or really aggressive environment. A variety of historical concrete structures display problems that are being resolved by applying polymers in concrete construction (Hing, 2008). Concrete pavement blocks (paver) have actually been in use for more than 50 years in Europe. Pavers have been used in heavy industrial port and airfield pavement from the 1970s in Europe (Abate, 1993). They were first produced in the Netherlands in 1924 and probably World War II led to the growth of concrete pavement blocks (Concrete Manufacturers Association, 2009). The objective of this research work was to convert waste into wealth by using waste water sachets (low-density polyethylene) to produce polymer modified pavement blocks suitable for applications in places such as light traffic pavements, parking lots and pedestrian strolls.

Materials And Methods

Materials

The materials used are mainly sachet water packs and sandstone. The sachet water packs serve as the alternative binder in place of cement. Whereas in contrast, the sandstone is the coarse aggregate.

Methods

Pretreatment and Size Reduction

Sachet water packs were collected from the environs of the Federal University of Technology Minna, Niger State. The sachets were evaluated, washed with cleaning agents remove and debris, sun-dried until absolutely no wetness existed, and then sorted. Size reduction or pelletizing was performed utilizing a 35-40kg shredding machine. The purpose of decreasing the size of the sachet water packs is to allow it to melt rapidly to attain the required molten state. Size reduction also allows harmony in the mixing stage because particles of similar size tend to blend quicker. After reducing the waste water sachets into smaller sizes, they are fed to a plastic pellet making maker. The plastic pellets making device is utilized to process and recycle waste plastics and make recycled plastic pellets. The waste plastic is squashed by a crusher and sent out to the feeder by an automated hoist and then the feeder feeds the material into the plastic pellets maker. After entering the plastic pellet mill, the product is re-plasticized and combined under the action of compression and external heating of the screw. With the increasing of temperature level and pressure, it presents a thick circulation state and is pressed to the head part. The plasticizer is cut into pellets by a "cutter". The plastic pellets are then cooled through the cooling system.

Mixing

The mixing was performed at various mixing ratio. The polymer block (Interlock) was produced using just the polymer pellets and sandstone. The mixing of sandstone to polymer was performed in the ratio of 8:2 (A), 7:3 (B), and 6:4 (C) respectively. This blend indicates that for the 8:2 blending, the mix consist of 80% sandstone and 20% low density polyethylene (LDPE) pellets, 7:3 mixing indicates 70% sandstone and 30% LDPE pellets. Lastly for the 6:4 mixing, we have 60% sandstone and 40% LDPE pellets. This is summarized in Table 1.

Table 1: Samples Composition

Samples	A	B	C
Compositions (standstone: pellets)	80:20	70:30	60:40

Heating and Cooling

After the desired mixing ratio was achieved, the mixture was poured into a stainless pot and heat was applied manually using coal. The heating process was carried out in other to melt the LDPE pellets into a molten state. The sachet water packs pellets were heated to a temperature of about 125 $°C$ which is the melting temperature for LDPE.

Moulding

The mould was fabricated in-house. The shape of the mould was that of an interlock pavement block. The uniform mixture of molten wax and sandstone was poured into the mould and allowed to take the shape of the mould. The essence of moulding is to give shape and size to the pavement block. The moulded polymer concrete composite was then immersed in water for about a minute in other for it to cool, and likewise solidify. Among the significant properties of LDPE is it capability to cool at a quick rate. The cooling process also helps to strengthen the molten wax mixture consequently providing it with the preferred shape and size. The cooling stage is the last step in producing the polymer-modified pavement block. The stages are captured in Figure 1.

Polymer Pellets and Sandstone

Heating stage

Molding stage

Final polymer modified concrete

Figure 1: Different Stages of the Polymer Concrete Production Process

Results And Discussion

Table 2 compares the compressive strength of the polymer pavement block samples produced with control samples, which are commercial pavement blocks produced with cement as a binder, and are of the same size and shape as the polymer pavement blocks produced. The compressive strength of the samples was determined using the equation

$$compressive\ strength\ (N/mm^2) = \frac{Crushing\ Load}{Area} \quad (1)$$

Table 2 shows the compressive strengths of each sample after curing (immersion in water) for 7, 14 and 28 days respectively. The compressive strength of a solid material helps to determine the maximum load it can withstand before failure. Of the many tests applied to the concrete, the compressive strength is the most important, as it gives an idea about the characteristics of the concrete. The higher the compressive strength of a material, the greater it ability to withstand a large load. Conversely, the lower the compressive strength of a material, the lower the amount of load it can withstand (Wang, 2006). Compressive strength was computed in conformity with BS8110 (2011). Figure 2 is a bar-chart representation of the information from Table 2. Again, A, B and C are the polymer-modified concretes produced with different mixing ratio of polymer to sandstone. For sample A, the mixing ratio was 80:20 (80% sandstone and 20% LDPE pellets) and the compressive strength was 13.58 N/mm^2 on average. For sample B, the mixing ratio was 70:30 (70% standstone and 30% LDPE pellets) and the compressive strength was 16.92 N/mm^2 on average. For sample C, the mixing ratio was 60:40 (60% sandstone and 40% LDPE pellets) and the compressive strength was 20.31 N/mm^2 on average. From the chart, it can be seen clearly that with an increment in the proportion of the LDPE pellets, the compressive strength of the sample increases.

Table 2: Sample compressive (N/mm^2) strength after curing for a given number of days

Samples	**7days Compressive Strength**	**14days Compressive Strength**	**28days Compressive Strength**
A	13.53	13.56	13.64
B	16.88	16.92	16.97
C	20.29	20.31	20.33
D_{cs}	2.31	2.50	3.12
E_{cs}	2.10	2.33	2.74

where D_{cs} = Control Sample D, and E_{cs} = Control Sample E.

Table 3: Individual Samples Water Absorption

Samples	**Water absorption (%)**
A	8.33
B	5.47
C	4.03
D_{cs}	19.64
E_{cs}	24.00

Nonetheless, the three polymer concrete samples all satisfy the minimum requirement for a Grade 10 (M10) concrete as according to BS8110 (2011) which is $>10\ N/mm^2$. On the other hand, the control samples Dcs and Ecs have compressive strengths of only about 2.48 N/mm^2 and 2.35 N/mm^2 respectively. Recall that the control samples are the commercial grade samples. We can see that the compressive strengths of the control samples are way below the BS8110 (2011) standards, which speaks a lot about substandard products in Nigeria. Comparing the results of this research to other similar work in the literature, we see from the work of (Nwaigwe et al., 2019), that the compressive strength obtained from the polymer concrete was 10.5 N/mm^2. And also, the result obtained from the work of Agyeman et al. (2019), the compressive strength of the polymer sample was 8.53 N/mm^2. It should be noted that the concrete produced, i.e., the polymer sample and the control sample are for light-traffic (pedestrian plazas, shopping complexes ramps, car parks, office drive ways, rural roads with low traffic, residential roads, etc.). The different curing time for each sample gives an idea of the time it takes for each sample to reach it maximum strength after production. The essence of the curing time test is to determine whether the samples strength increases as it is been cured by water immersion. From the chart, we can see that the difference in the compressive strength of polymer samples A, B, and C after 7days immersion in water and crushing was 13.53 N/mm^2, 13.56 N/mm^2, and 13.64 N/mm^2 respectively, which is negligible. After 14 days of curing, polymer samples A, B, and C had the following compressive strength: 16.88 N/mm^2, 16.92 N/mm^2, and 16.97 N/mm^2, respectively. Finally, the compressive strength of the polymer samples A, B, and C after 28 days of curing was 20.29 N/mm^2, 20.31 N/mm^2 and 20.33 N/mm^2, respectively. From this, we can see that there is just little variation in the compressive strength of the polymer samples after the 7days, 14days and 21days curing time.

From this, we can deduce that the polymer pavement blocks gained most of their strength very quickly after production (i.e., they have a very short curing time). The control samples on the other hand vary significantly in their curing times. From figure 2 we can see the variation in the compressive strength of each control sample after 7, 14, and 28 days of curing, respectively. The compressive strength of control sample Dcs after 7, 14, and 28 days of curing was 2.3 N/mm^2, 2.50 N/mm^2, and 3.12 N/mm^2, respectively. Whereas control sample Ecs has the following compressive strength after 7, 14, and 28 days of curing: 2.10 N/mm^2, 2.33 N/mm^2, and 2.74 N/mm^2 respectively.

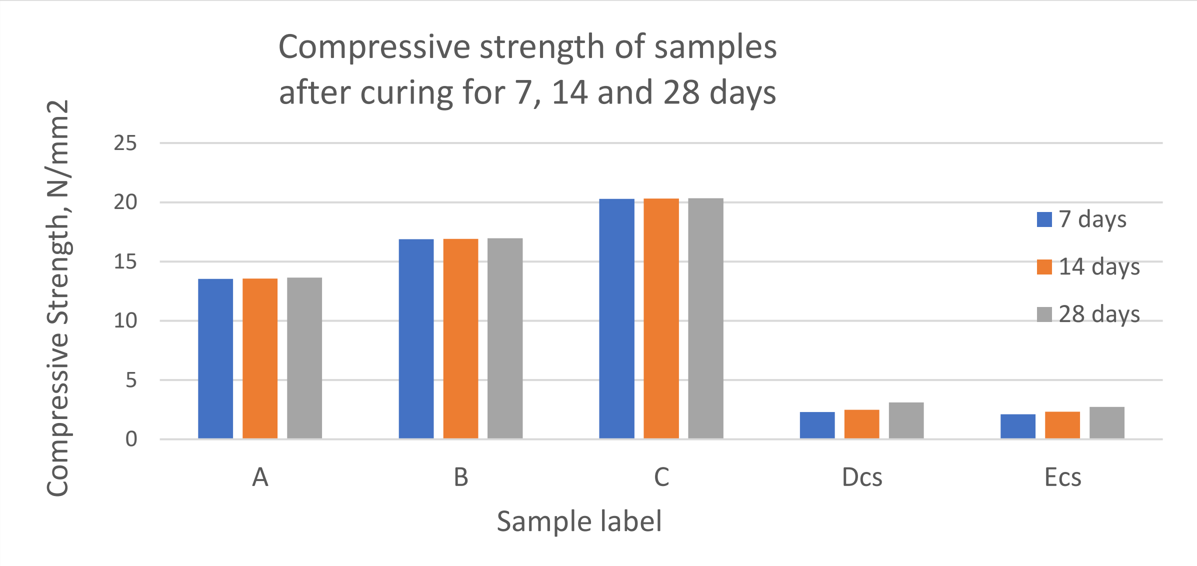

Figure 2: Compressive strength of each sample (N/mm2) after curing for a Number of Days

The results show how the cement pavement blocks takes a longer time to get cured, unlike the polymer modified concrete which gains 85% of its strength just 24 hrs after production. Table 3 presents the result of the %water absorption of each sample, and Figure 3 is a bar-chart representation of this result. The water absorption test aimed to determine the moisture absorption capacity of the various samples. The water absorption test was carried out by immersing each sample in water for 24h, after which the mass of the samples was taken. From figure 3 we can observe that polymer samples A, B, and C, had %water absorption of 8.33%, 5.47%, and 4.03% respectively. These values show a particular trend in the sense that greater the composition of polymer, the less water is absorbed. From the literature, the more a sample absorbs water, the higher it tendency to lose it structure thereby leading to failure. Sharma & Batra, (2021) stated that the water absorption for a pavement block should not be in excess of 7% by mass which is in line with ASTM D2171. From the chart, we can see that polymer sample A has water absorption of 8.33% which is a bit higher than what is stipulated by Sharma and Batra. Whereas polymer sample B and C meet the 7% water absorption requirement. On the other hand, the control samples Dcs and Ecs both have water absorption of 19.64% and 24% respectively which are both in excess of the 7% stipulated by Sharma & Batra, (2021). From the result obtained from the water absorption test, we can deduce that polymer pavement blocks absorb less water than the cement pavement block controls, making it very suitable for construction in a waterlogged site.

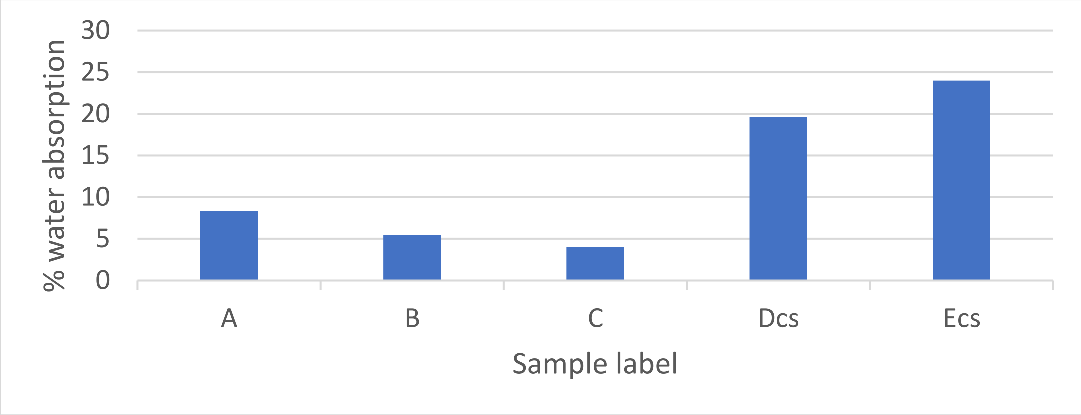

Figure 3: Water Absorption Chart of the Samples

Conclusions

This research produced pavement blocks using LDPE (sachet water packs) as an alternative binder. The modified pavement blocks produced from LDPE meet the required standard for light-traffic pavement in terms of compressive strength. The modified pavement block obtained from this research work is seven times stronger than the control samples, which were cement pavement blocks. The results from this research affirms that pavements blocks can be produced using polymers as alternative binders. Sachet water packs as we all know is one of the major sources of land pollution in Nigeria and it is also classified as waste which is dumped anywhere in the street. Producing pavements blocks from these sachet water packs will go a long way in reducing the pollution caused by the sachet water packs and also serve as a means of recycling, maximizing profit and reducing wastage. The perpetual increment in cement price in the country has led to substantial increment in the price of pavements blocks in the country. Using sachet water packs as the alternative binder will go a long way in reducing the cost of production of these pavers thereby making it affordable to the populace.

Acknowledgements

I would like to acknowledge the Department of Civil Engineering of the Federal University of Technology Minna for their generosity in permitting me to use their Laboratory. I also thank Mr Abiodun Emmanuel for his valuable effort in gathering of information and data collection.

References

Abate, L. M. (1993). An overview of Concrete paving blocks: Final technical report. Research projects T9903, task 3, subtask 3 TRAC special programs. Washington state transport centre (TRAC) University of Washington JD :10: University district building.

Agyeman, S., Obeng-Ahenkora, N. K., Assiaman, S., & Twumasi, G. (2019). Exploiting recycled plastic waste as an alternative binder for paving blocks production. Science Direct, 11(1), 246–256.

BS8110. (2011). Composition, Specifications and Conformity Criteria for Common Cements. British Standards Institution, London, UK.

Concrete Manufacturers Association. (2009). Concrete block paving manual.

Gencel, O. (2012). Properties of concrete paving blocks made with waste marble. Journal of Cleaner Production, 62–70.

Hing, E. (2008). Universiti Teknologi Malaysia Borang Pengesahan status Tesis. A report submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Civil Engineering Faculty of Civil Engineering.

Hirde, S. K., & Dudhal, O. S. (2016). Review on polymer modified concrete and its application to concrete structures. International Journal of Engineering Research, 5(3), 766–769.

Isioma, M. (2012). Lagos: Harvesting wealth from waste.

Karasawa, K., Ezumi, N., Kamaya, K., & Toriiminami, K. (2006). Evaluation of performance of water-retentive concrete block pavements. European International Journal of Science and Technology, 1(3), 233–242.

Koo, B. K., Jang-ho, J. K., Sung-bae, M., & Sungho, M. (2014). Material and Structural Performance Evaluations of Hwangtoh Admixtures and Recycled PET Fiber-Added Eco-Friendly Concrete for CO2 Emission Reduction. Materials, 7(1), 5959–5981.

Mishra, B. (2016). A Study on Use of Recycled Polyethylene Terephthalate (PET) as Construction Material. International Journal of Science and Research (IJSR, 724–730.

Nwaigwe, D. N., Sulymon, N. A., Bello, T., & Amiara, C. A. (2019). An Investigation into the properties of concrete containing polyethylene (pure water sachet waste). International Journal of Engineering Trends and Technology, 67(8), 5550–5562.

Owolabi, R. U., & Amosa, M. K. (2010). Laboratory Conversion of Used Water Sachet (polyethylene) to Super Wax/Gloss like Material. International Journal of Chemical Engineering and Applications, 1(1), 2022–2032.

Sharma, S. M., & Batra, G. (2021). Effect of water absorption on mechanical and technological properties of Indian ramie/epoxy composites. Proceeding of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology.

Sulyman, M., Haponiuk, J., & Formela, K. (2016). Utilization of recycled polyethylene terephthalate (PET) in engineering materials. International Journal of Environmental Science and Development, 7(2), 206–418.

Wang, R. (2006). Influence of polymer on cement hydration in SBR-modified cement pastes. Cement and Concrete, 36(1), 1744–1751.

Wusu-Sekyere, E., Issaka, K., & Abdul-Kadri, Y. (2013). An Analysis of the Plastic Waste Collection and Wealth Linkages in Ghana. International Journal of Current Research, 5(1), 205–209.