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Study on Some Mechanical Properties of Waste PET and Sand Composites

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Abstract

The escalating issue of plastic waste, particularly polyethylene terephthalate (PET), poses significant environmental challenges in Nigeria due to its resistance to natural degradation. This study aims to investigate the feasibility of recycling waste PET into composite materials by incorporating sand sourced from three distinct locations. Composites were formulated by blending PET waste with sand in varying ratios, designated as samples A, B, and C. We meticulously evaluated the mechanical properties of these composites, focusing on impact strength, compressive strength, tensile strength, and hardness. The findings reveal that increasing sand content correlates with a decrease in impact strength, a trend consistent across all samples as PET content diminishes. Although compressive strength initially exhibits a slight increase with additional sand, it ultimately enhances with greater PET proportions. Conversely, tensile strength experiences a modest rise with increased sand and a significant improvement with elevated PET levels. Notably, hardness decreases with rising sand content but improves with higher PET levels. These results highlight the potential of

PET-sand composites as sustainable construction materials, representing a practical approach to mitigating plastic waste while contributing to eco-friendly building practices.

Keywords: Waste PET, Plastic-Sand Composites, Mechanical Properties, Recycling, Sustainable Construction Materials

INTRODUCTION

More than 12% of municipal solid trash is produced as a result of the substantial increase in the use of plastic products in many different areas. The life cycle of plastic materials terminates at municipal solid waste disposal sites in water bodies since plastics are not biodegradable, which means they cannot swiftly re-enter the natural carbon cycle (Alexander *et al.,* 2022a). Globally, more than 380 million tonnes of plastic are produced annually as of 2017. Millions of tonnes of plastic waste were discarded in many countries worldwide (Kameshwar *et al.,* 2022). Given their capabilities, synthetic polymers have been gradually replacing natural materials in practically every industry for more than a decade. According to the World-Wide Fund for Nature (WWF) report, this production can increase by 4% by 2030 (Ahmed *et al.,* 2021).

It is essential to control plastic waste, and it is critical to comply with energy and environmental protection laws. Some plastics can be recycled safely, while others cannot, so they litter the environment (Alexander *et al.,* 2022b). Plastic waste is constantly replacing aggregates in the production of construction materials (Amir, 2023). Aggregates such as concrete, which is made up of admixtures, water, cement, sand, and natural coarse aggregates (NCA). Concrete's strength, durability, adaptability, and on-site casting capabilities are the primary factors contributing to its extensive use in the construction sector (Geyer *et al.,* 2017). Using this method, plastic waste is not involved in any effective recycling treatment and can be used directly as a replacement for conventional aggregate (Amir, 2023). This study aim to produce and test the mechanical properties of a composite obtained from Polyethylene terephthalate waste plastics and sand.

Plastic waste has become a global concern due to its persistent nature and the increasing volume generated annually. Polyethylene terephthalate (PET) is one of the most widely used thermoplastic polymers, primarily utilized in the packaging industry for bottles, food containers, and synthetic fibers. Its durability, chemical resistance, and lightweight properties make it highly desirable in manufacturing but problematic in waste management. Studies by Geyer *et al.* 2017) reported that only 9% of the plastic ever produced has been recycled, with the remainder either incinerated or accumulating in landfills and the environment.

Saikia & de Brito (2014) reviewed the potential of plastic waste in concrete and highlighted that PET could improve the ductility of concrete composites while reducing their weight. Recent investigations have focused on blending PET waste with sand to form polymer-sand composites suitable for paving and tiling. These composites are generally manufactured by melting PET and mixing it with sand to form a homogeneous blend that is molded and cooled. The properties of the resulting material depend on the PET-to-sand ratio, mixing conditions, and type of sand used.

METHODOLOGY

Preparation of hot resin of PET wastes

The small pieces of Polyethylene terephthalate waste plastics were dissolved of the solution prepared from phenol and 1,1,2,2-tetrachloroethane at the ratio 1:2.5; the solution was heated with continued steering on a hot plate at the temperature (160-180)^{o}c. (Abbas, 2022).

Preparation of pet/sand composites

The composite mixture was made by varying the amount of PET from (5-20) g while sand remains constant (10 g), and another set was produced by varying the amount of sand while the PET remains constant. This procedure was repeated with the un used bottles which is the reference composite.

Impact strength test of the composite

Using Cat. NV. 412, the impact tests were performed on the created composite samples. 80 x 10 x 10 mm3 standard impact test samples with a 2 mm notch depth were created in accordance with the standard and at a 450° angle. Each composition used three spacemen, and the average value was measured in Joules (J). Using equation 3.12, the composite's impact strength was determined.

$E = \frac{e}{w} \times h$ ……………………………………………..………..Equation 3.12

where: E = impact strength required to shift the specimen, kJ/m^2;

e = impact energy needed to change the sample, kJ; b

w = width of the test specimen, m;

h = thickness of the test specimen, m (Jamila *et al.,* 2023)

Compressive strength test of the composite

The force applied to a test sample's top and bottom until it fractures, deforms, or the material's resistance breaks under compression is known as its compressive strength. The Deepak Universal Testing Machine (DTRX) was used to test the compressive properties of composite specimens, which had standard dimensions of 40 × 50 × 20 mm3. Each composite was tested on five samples, and the average result was noted. (Akinterinwa *et al.,* 2020)

Tensile strength test of the composite

Using a load cell of 5 kN, the tensile test was conducted on equipment of the EMIC brand. using the typical 80 x 10 x 10 mm3 measurements. An EMIC testing machine (model DL2000) with pneumatic claws and a 5 kN load cell was used to assess the composite. (Dass *et al.,* 2016)

Hardness Test of the composite

Hardness is defined as a substance's resistance to indentation; the higher the resistance, the harder the material, and vice versa. A modified Meyer hardness tester was used for the test. The samples' hardness was calculated using equation 3.13.

$$BHN = \frac{F}{\frac{\pi}{2}(D-\sqrt{D^2-D_i})} \quad \text{.......................................Equation 3.13}$$

Where,

F = The imposed load

D = Diameter of the indenter

D_i = Diameter of the indentation

RESULTS AND DISCUSSION

Effect of the amount sand concentration in composite on impact strength at constant temperature and time

Figure 1 shows the effect of the amount of sand in composite on impact strength at constant temperature and time, the result shows that the impact strength of all the composite decreased with increase of sand content. This may be due to sand particles being rigid and brittle. Therefore, reducing the overall ductility and energy absorption capacity of the composite. Steady decrease on impact strength as from 5 to 15 g of sand. However, beyond 15 g, the decrease in impact strength was almost negligible. Mahdi *et al.* 2020, reported that the decrease observed in composite may be attributed to the increase in rigid of composite particles. According to Kumi-Larbi et al. (2018), the rigidity in sand particles limited the plastic deformation of the PET/Sand composite, thereby leading to reduced energy absorption during impact events.

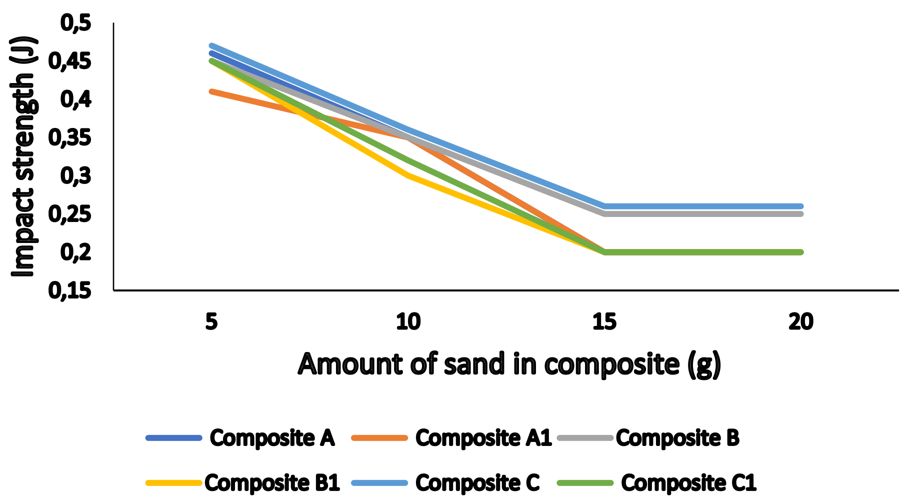

Figure 1: Effect of the Amount of Sand in Composite on Impact Strength at Constant Temperature and Time

Effect of the amount of PET in composite on impact strength at constant temperature and time

Figure 2 shows the effect of the amount of PET in composite on Impact strength at constant temperature and time, the result shows that the impact strength of all the composite increase with an increase in the amount of PET. This may be because PET is a polymer, and this can improve ductility and energy absorption capacity of the composite. Also, increases in polymeric ductility property incorporated into the composite as the amount of PET increases which enhance the impact strength of the composite. Also, Alaloul et al. (2020) reported similar result in composites for construction applications and found that increasing the PET content led to improved impact resistance. Mahdi et al. (2020) reported that the increase in impact strength witnessed as the amount of PET increases was as a result of ductile nature of PET, which allows for better energy dissipation during impact events. Also, Kumi-Larbi et al. (2018) reported that the polymer network formed by PET contributed to better energy absorption and crack resistance in a composite, as the amount of PET increases. The study observed that the addition of PET particles boosted the ability of the composite to absorb energy during impact.

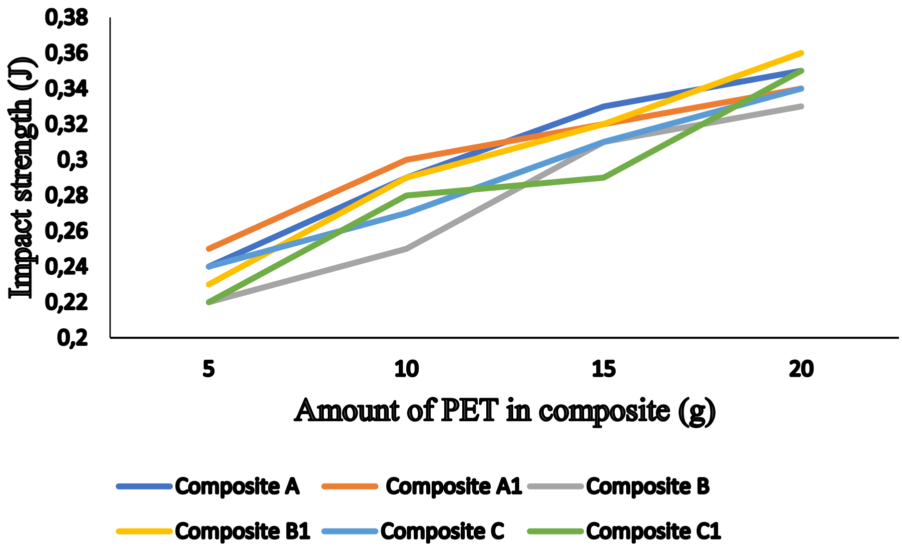

Figure 2: Effect of the Amount of PET in Composite on Impact strength at constant temperature and time

Effect of the amount of sand in composite on compressive strength of the at constant temperature and time

Figure 3 shows the effect of amount of sand in composite on compressive strength at constant temperature and time. The result shows that increasing in the amount of sand improves the compressive strength of the composite at 5 to 15 g, while at 20 g of sand, a slight declined in compressive strength was observed. This behaviour may be attributed to decreasing adhesive force within the composite as the rigid component of sand increase, which may reduce workability and encourages segregation among the PET and sand particle (Rahmani *et al.,* 2023). Similar trend of compressive strength was observed by Thorneycroft et al. (2018). Also, Gu,, & Ozbakkaloglu, (2016) reported that concrete mixtures with up to 20% of sand replaced by PET particles showed comparable or slightly higher compressive strength than conventional concrete. However, beyond this point, strength began to decrease. This suggests that a higher sand-to-PET ratio can improve compressive strength at a strategic blending ratio. However, Sharma, & Bansal, (2016) reported that the addition of cementitious materials such as ash or silica fume could help optimize the sand-to-PET ratio for the improvement of strength.

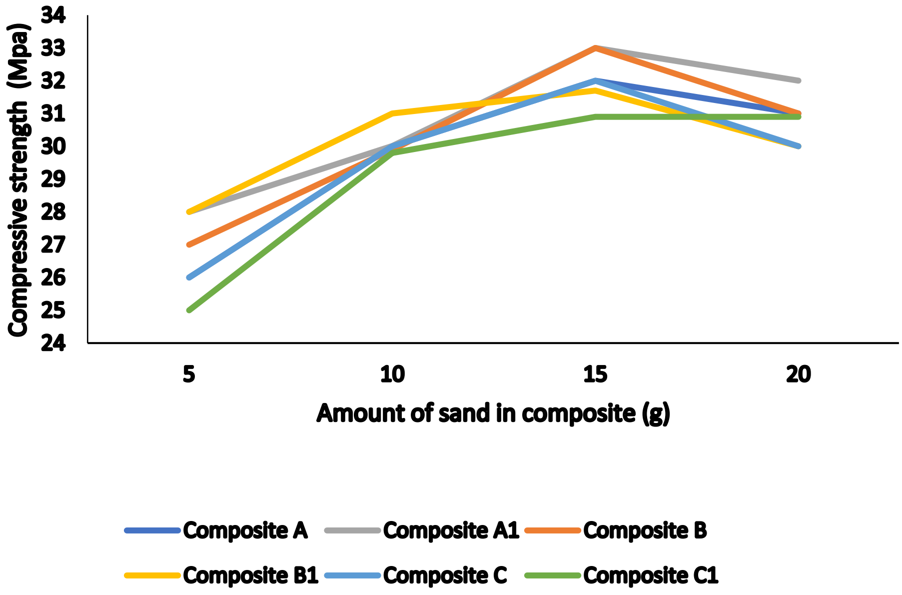

Figure 3: Effect of Amount of Sand in Composite on Compressive Strength at Constant Temperature and Time

Effect of the amount of PET in composite on compressive strength at constant temperature and time

Figure 4 shows the effect of the amount of PET in composite on compressive strength at constant temperature and time. The result shows that the compressive strength of the entire composite in this study increases with an increase in the amount of PET. This is may be due to the plasticity effect of PET on the composites. According to Mahdi *et al.,* (2018), the increase in compressive strength as the amount of PET increases could be due to the improved bonding between the PET and sand grains. Previous study reported that maximum compressive strength of composites usually observed to be within 20% of PET.

For instance, achieved highest compressive strength of composite at 20% PET loading, while Jassim, (2017) reported that the highest compressive strength was achieved with a PET content of 12.5%. Rahmani et al. (2023) observed that very high PET contents (above 30%) led to a decrease in compressive strength which could be due to reduced cohesion between particles which suggests that there's a "sweet spot" for PET content in the composite. He also stated that, factors such as particle size, additives and curing conditions are known to influence the compressive strength of a composite.

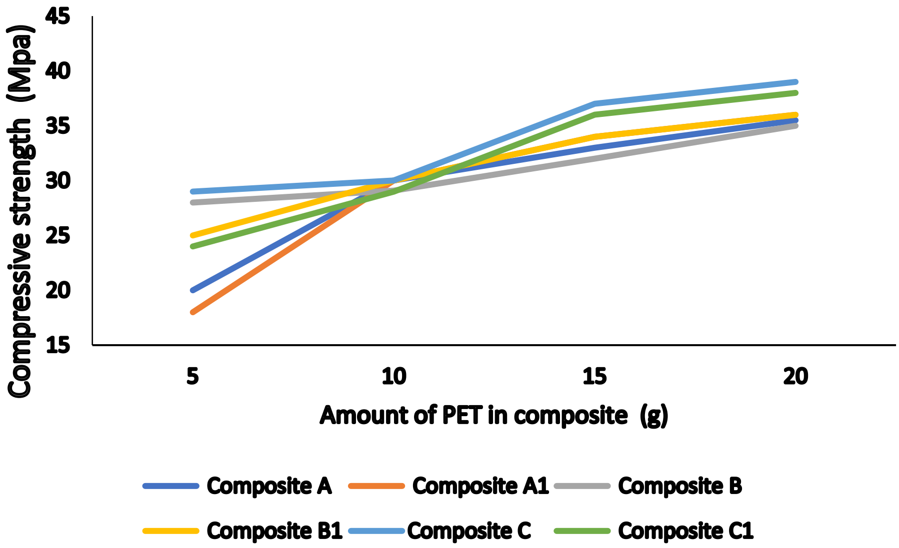

Figure 4: Effect of the Amount of PET in Composite on Compressive Strength at Constant Temperature and Time

Effect of the amount of sand on tensile strength of the composite at constant temperature and time

Figure 5 shows the effect of the amount of sand in composite on tensile strength at constant temperature and time. The result revealed that as the amount of sand increases, the tensile strength slightly of the composite increased. This could be ascribed to the interfacial bonding between sand particles and the matrix. Jassim, (2017) reported that increasing the sand content in composite led to improved tensile strength up to a certain point. This is to show that optimal mix of sand and PET could enhance the overall tensile properties of the composite. Factors such as particle size and shape have influence on the tensile strength of the composite. Mahdi et al., (2018) reported that finer sand particles usually contribute to better tensile strength. However, Umasabor, & Daniel (2020) found that the addition of certain admixtures could help to optimize the sand-to-PET ratio for improved tensile performance.

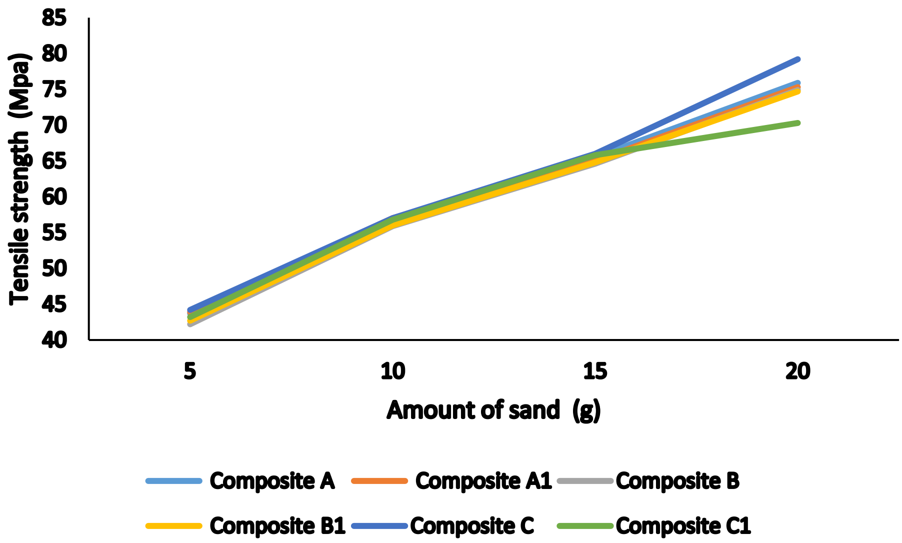

Figure 5: Effect of the Amount of Sand in Composite on Tensile Strength at Constant Temperature and Time

Effect of the amount of PET in composite on tensile strength at constant temperature and time

Figure 6 shows the effect of the amount of PET in composite on tensile strength at constant temperature and time. The result shows a decrease in the tensile strength at initial upto 10g PET in the composite and then a general increase of tensile strength was observed with increase in the amount of PET. This increase in tensile strength may be as a result of the ductile nature of PET, which can enhance the composite's ability to resist tensile stress Frigione, (2020). Previous studies agreed with the enhanced tensile strength as the amount of PET increases. Rahmani et al. (2023) found that the tensile strength of concrete containing PET particles as sand replacement increased up to 10% replacement, after which it began to decrease. While Thorneycroft et al. (2018) observed peak tensile strength at around 10% PET when sand was replaced. This behaviour maybe as a result of the size and shape of sand particles. Also, Sharma, & Bansal (2016) identified additive as one of the contributing factors to the tensile strength of composite. However, incorporating PET fibres rather than particles, can have a more pronounced positive effect on tensile strength (Foti, 2016).

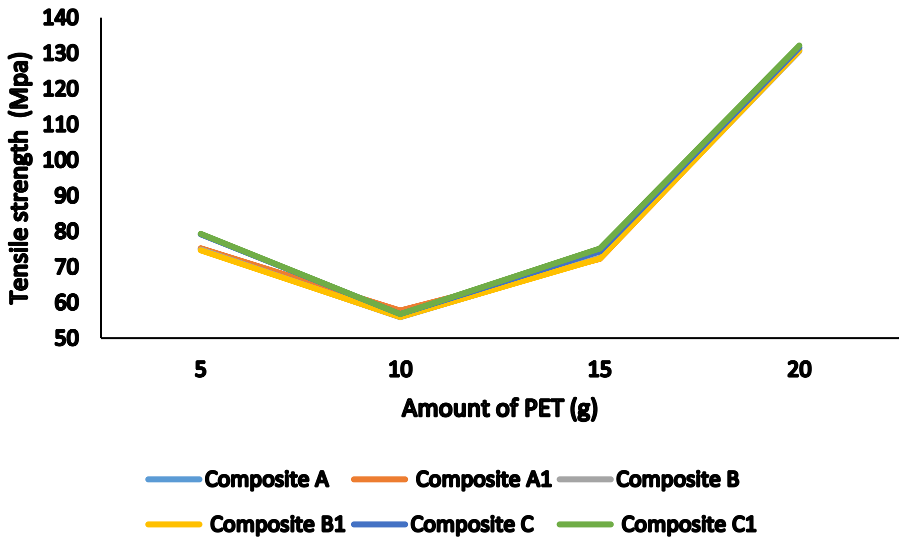

Figure 6: Effect of PET Concentration in Composite on Tensile Strength at Constant Temperature and Time

Effect of the amount of sand on hardness of the composite at constant temperature and time

Figure 7 shows the effect of the amount of sand in composite on hardness at constant temperature and time, the result reveals that at the initial state the hardness decreases rapidly as the amount of sand increases and then tend to increase with more amount of sand, this increase may be as a result of the composite ratios which might reflect the varying characteristics of the sand, such as grain shape, size distribution as the particles act as reinforcement dispersed throughout the PET matrix, a similar result was reported by Ku et al. (2011) which says that the dispersion of the reinforcement within the matrix increases the hardness of the composite by providing more resistant to deformation. The increase in density reported earlier in Fig 7 may also be the reason for the increase in hardness as the amount of sand increases as the sand particles occupy space within the matrix there by reducing the amount of free volume. Kumar et al. (2017) also reported that increased density of a composite improves the hardness of the composite.

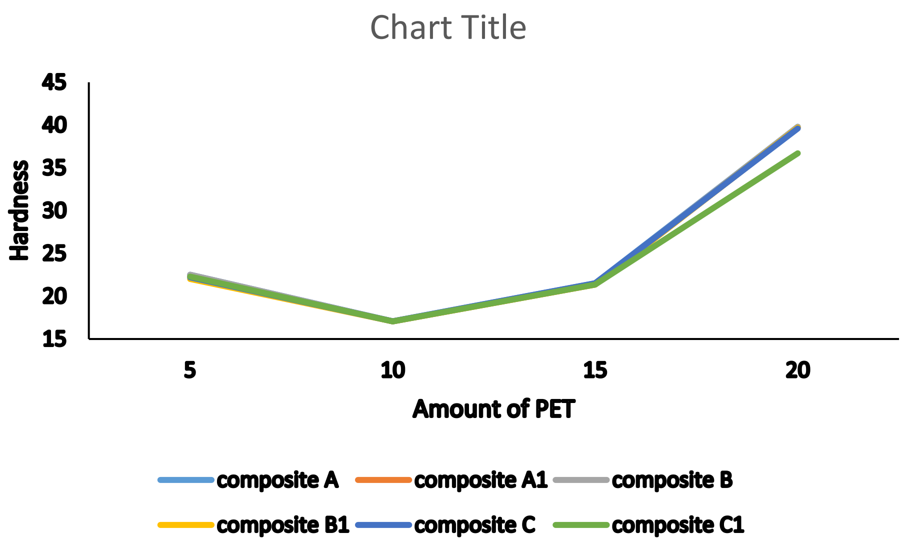

Figure 7: Effect of the Amount of Sand on Hardness of the Composite at Constant Temperature and Time

Effect of the amount of PET in composite on hardness at constant temperature and time

Figure 8 shows the effect of the amount of PET in composite on hardness at constant temperature and time, the result shows that the hardness decreases as the amount of PET increases, this may be as a result of the ductile nature of PET material as it becomes more prone to deformation. A similar result was reported Li et al. (2018) which reported that the increase in ductility reduces the hardness of a composite. Excess PET weaken the interfacial bonding of the composite which also reduces the hardness of a composite as reported by Zhang et al. (2021) which says that weaker interfacial bonding reduces the hardness of composites.

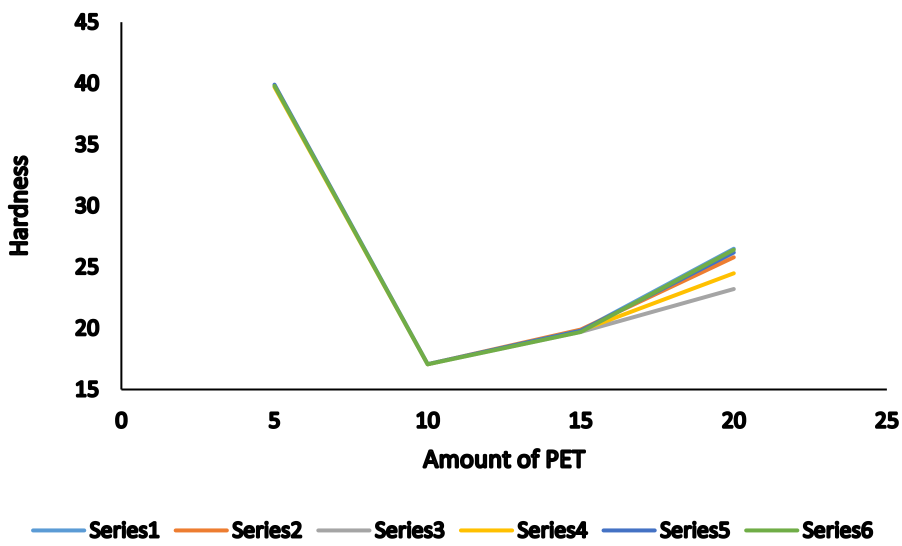

Figure 8: Effect of the Amount of Sand in Composite on Hardness at Constant Temperature and Time

CONCLUSION

This study concluded that composites were successfully prepared from the samples sand (A,B,C), and all the composites have improved mechanical property with well-integrated particles is a suitable composite for construction materials such as building blocks and bricks; infrastructure such as road construction with asphalt and industrial application such as industrial flooring and machine base requiring vibration damping etc.

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