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Investigating the Use of Post-Consumer LDPE Waste and Stone Dust in Sustainable Concrete Composites

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ABSTRACT

The construction industry is one of the largest producers of greenhouse gases and waste materials. One potential solution to reduce the environmental impact of construction is to use sustainable materials in the production of concrete. The effects of adding low-density polyethylene (LDPE) waste and stone dust on the mechanical properties of the 7-days cured composite materials adopting two independent categorical variables with five levels each, creating 25 groups were investigated. The dependent variables are compressive strength, tensile strength, flexural strength, and water absorption. The results show that increasing LDPE waste content and stone dust content improves the mechanical strength of the composite material but increases water absorption. The optimal combination of LDPE waste content and stone dust content is 30% LDPE waste and 40% stone dust, based on the highest values of compressive, tensile, and flexural strength and the lowest value of water absorption in the group. It also provides linear regression models and correlation analysis to determine the relationships between LDPE waste content and each dependent variable. On this basis, it suggests that LDPE waste can improve the mechanical properties of the composite material and its water resistance, but the optimal amount of LDPE waste depends on the type of material and application. The study concludes that incorporating LDPE waste and stone dust into composite materials can be a sustainable solution for waste management and the production of low-cost, high-performance materials.

INTRODUCTION

The infrastructural provision including housing, and other amenities essential to human settlement significantly depend on the construction sector of the economy. Nevertheless, while playing a crucial role, this sector additionally contributes to the volume of waste in the aspects of global warming with an adverse effect on the environment (Kabir, S. 2012). This is due to the use of energy-intensive materials and construction techniques, that discharge greenhouse gases. (Forsythe, P. and Ding, G. 2014). As a matter of fact, almost 8% of the world's carbon dioxide emissions comes from the manufacturing of cement, which is a main ingredient in concrete. Also, fossil fuel emissions from heavy machinery and equipment used in construction are also considerable (Nature, 2021), (Goetzler *et al.*, 2019).

Construction-related garbage, such as that produced during demolition and excavation, has a considerable negative impact on the environment. In landfills, where they frequently end up, these waste products release methane and other greenhouse gases that contribute to global warming (Bassani, M. and Tefa, L. 2018). Also, the use of virgin materials in building projects hastens environmental deterioration and exacerbates the

depletion of natural resources.

Therefore, reducing emissions of greenhouse gases and waste in the construction sector requires the technical management of a structure's entire life span. Energy-efficient building design (Aye, L. *et al.* 2012), the use of low-carbon materials (Guo, Z. *et al.* 2023), resource optimization (Mangmeechai, A. 2021), and the incorporation of circular economy ideas (Venkatesan, S. *et al.* 2023) are all components of this strategy. The most widely utilized building material worldwide, remains the concrete which serves as the cornerstone of contemporary infrastructure.

However, traditional concrete production methods have a significant environmental impact, as they rely on finite natural aggregates such as sand and gravel. The depletion of these resources is a major concern for the construction industry, and it has led to the exploration of alternative materials and production methods to lessen the negative effects of producing concrete on the environment (Chinnu, S.N. *et al.* 2021). Natural aggregates are essential components of concrete production, providing strength and durability to structures. The use of these materials in concrete is ubiquitous, as they are used in everything from buildings and roads to bridges and dams (Fuchs,

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A. *et al.* 2020). However, natural aggregates are finite resources rapidly depleting due to the increasing demand for concrete and unsustainable extraction practices (Natural Resources Extraction, 2014). Natural aggregate extraction exerts some detrimental effects on the environment, such as ecosystem devastation, water pollution, and soil erosion. Besides this, the long-distance transportation of these materials increases the footprint of carbon from the building industry by increasing the greenhouse gas emission levels (Neary, 2002). In response to these developments, researchers and engineers are exploring alternative materials and production methods to lessen concrete production's negative environmental effects. One approach is the recycling of materials such as crushed concrete, ceramic waste, and fly ash as substitutes for natural aggregates. The use of these materials curtails the demand for natural resources, diverts waste from landfills, and minimizes the effect of concrete on the environment (Chandrasekhar, 2023). Another approach is the use of alternative materials altogether.

For example, bamboo, hemp, and even bacteria are being explored as potential materials for building structures with comparable strength and durability to traditional concrete. These materials offer a renewable and more sustainable alternative to traditional concrete production, reducing the effects of on the environment construction activities (Lawrence, M. 2015). The binding component in concrete is cement, a fine powder is developed in a kiln by heating clay, limestone, and other materials to high temperatures. Concrete production requires a significant amount of energy, and this contributes to 7% of the world's carbon dioxide emissions (Andrew, 2020). The fossil fuels burning to heat the kiln and the chemical reactions that take place during production are the main causes of greenhouse gas emissions in the cement industry (Zhang, L. and Mabee, W.E. 2016).

Hence, researchers have been investigating alternative approaches for producing cement to reduce these negative effects on the environment. One appropriate measure to mitigate emissions of greenhouse gases and improve the environmental sustainability of cement production is the use of alternative biomass as fuel resources in kilns (Dembla, A. and Mersmann, M. 2021). Formulation of concrete with other types of binders is another option. Researchers have been investigating the application of geopolymers, a polymer by product that can be isolated from industrial waste without high-temperature kilns. Similar in strength and durability to conventional cement-based concrete, geopolymers have the possibility of significantly lowering the environmental effect of concrete production (Zhang, H.Y. *et al.* 2015). Consequently, the impacts of development on the environment are a growing concern as the need for new infrastructure intensifies. A practically sustainable building material called green composite concrete has the ability to reduce the emissions produced through conventional concrete (Vishwakarma, V. and Uthaman. S. 2020). In the invention of composite concrete, recycled

materials are used to replace some of the natural particles. Unfortunately, construction sector currently underutilizes these easily available materials that tend to preserve the necessary mechanical qualities for building while reducing waste and greenhouse gas emissions.

Low-density polyethylene (LDPE) waste is a significant environmental problem today because inappropriate disposal puts the environment at great risk (Nademo *et al.*, 2023). Meanwhile, due to its advantageous characteristics which include flexibility, moisture resistance, and low cost of usage, LDPE is a durable plastic that is frequently used in packaging, shopping bags, and irrigation pipes (Ahn *et al.*, 2016). However, the material's inability to degrade easily makes it a persistent pollutant, contributing to the growing problem of plastic waste in landfills and natural habitats (Heyer, K.-U. *et al.* 2005). The breakdown of LDPE waste in landfills takes a considerable amount of time, with estimates suggesting it may require up to 100 years to fully decompose (Wojnowska-Baryla *et al.*, 2022). This prolonged decomposition process releases harmful chemicals and toxins into the soil and groundwater, leading to environmental degradation and health hazards. Additionally, when LDPE waste is not disposed of properly, it can be carried by waterways and blown away by the wind, contaminating natural habitats and endangering wildlife (Mahapram, S. and Poompradub, S. 2011).

Fortunately, recycling LDPE waste is a viable solution to this pressing issue as recycling programs can help diminish the volume of LDPE waste in landfills and mitigate the demand for new plastic production, thereby decreasing the implications of LDPE waste on the environment (Novarini *et al.* 2021). The recycling process involves sorting the waste by grade, cleaning and shredding it, and melting it down to form pellets that are usable to create new products. The economic benefits of LDPE waste recycling are substantial as well. The economy benefits greatly from recycling since it generates jobs and income for the recycling sector. The process also cuts the greenhouse gases by limiting the demand for fossil plastic production, that requires an enormous amount of energy with the emission of carbon dioxide to the environment (Tsai *et al.*, 2021). Governments and companies can encourage recycling by providing tax breaks and financial incentives for taking part in recycling programs in order to maximize the effectiveness of LDPE waste recycling (Waste Age/Recycling Times, 2020). Furthermore, education and awareness efforts can highlight the advantages of recycling and compel people to engage in waste management strategies that put sustainability and environmental protection ahead (Santos, 2017). Another part of the composite is stone dust which is a byproduct of stone-crushing processes. It is a finely crushed substance that is frequently used to make concrete, asphalt, and construction goods in place of sand. Due to its potential advantages and disadvantages, stone dust in construction applications has garnered interest recently (Gedik, 2021). The potential of stone dust to increase the hardness and lifespan of masonry and concrete products is one of

its main advantages. Stone dust can raise the concrete's compressive strength and decrease its permeability when used in place of sand in concrete (Charmkar, 2017). One big issue, though, is that green composite concrete is perceived as having inferior physical qualities to regular concrete. Concrete's strength and durability are essential qualities for building, and any decrease in these qualities could raise safety issues. The perception of the expense of implementing green composite concrete presents another barrier, and this implies green composite concrete may not be widely adopted if it is thought to be more expensive than conventional materials (Miraldo, S. *et al.* 2021). The aim of these investigations is to determine whether producing green composite concrete from stone dust and post-consumer plastic wastes is feasible in terms of its fundamental qualities.

MATERIALS AND METHODS

Materials Preparation

Post-consumer low-density polyethylene (LDPE) wastes were collected and cleaned to remove impurities. The LDPE wastes were then shredded into small pieces using a shredder. Stone dust was collected from a local quarry and sieved to obtain particles with a size distribution of 0-4mm. The LDPE waste and stone dust were mixed in different ratios (10-50% LDPE waste and 10-50% stone dust) to prepare the green composite concrete.

Green Composite Concrete Preparation

The LDPE waste and stone dust were combined in a concrete mixer according to the predetermined ratios to create the green composite concrete. To ensure that the components were distributed evenly, the mixture was thoroughly stirred while heated for 5 minutes till uniform

slurry is achieved. A vibrating table was used to condense the mixture after it had been placed into a pre lubricated mold.

Curing and Testing

The composite concrete that were allowed to cured for 7 days under standard temperature and relative humidity were characterized for their mechanical and physical parameters.

Green Composite Concrete property

Compressive and Tensile Strength Test: The compressive strengths were determined using a compression testing machine according to ASTM C39 (ASTM, 2005).

Flexural Strength Test: The flexural strength of the green composite concrete was tested with a three-point bending test in line with ASTM C293 (ASTM, 2010).

Tensile Strength Test: The tensile strength of the green composite concrete was conducted according to ASTM C307-17 (Miraldo, S. *et al.* 2021).

Water Absorption Test: The water absorption of the green composite concrete was tested according to ASTM D570-98 (ASTM, 2018).

RESULTS AND DISCUSSION

Statistically, there are the two independent variables, and they are both categorical variables with five levels each (10%, 20%, 30%, 40%, and 50%). The combination of these two variables creates 25 different groups or samples. Compressive strength, tensile strength, flexural strength, and water absorption are the dependent variables, and they are all continuous variables measured in MPa or %. Compressive strength refers to the ability of a material to withstand compressive loads without failing (Hedjazi, S.

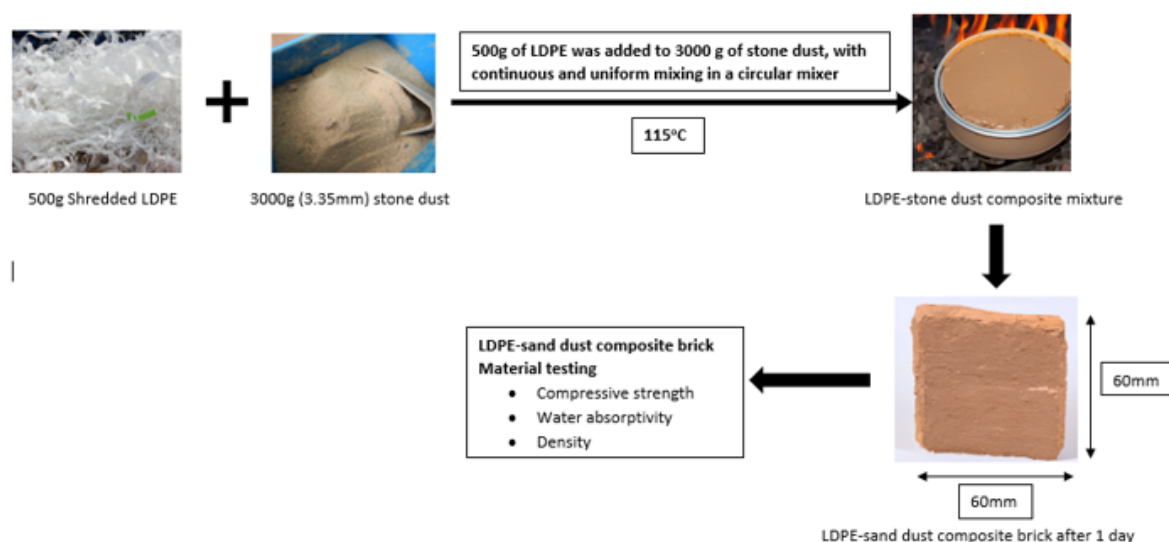


Figure1: Development of LDPE-stone dust composite brick

Table 1: The Experimental design and outcomes of LDPE Waste and Stone Dust Content on the Performance of Composite Materials

Sample ID	LDPE waste content (%)	Stone dust content (%)	Compressive strength (MPa)	Tensile strength (MPa)	Flexural strength (MPa)	Water absorption (%)
A	10	10	31.2	2.9	6.3	6.0
B	20	10	36.7	3.2	7.5	5.2
C	30	10	42.1	3.6	8.8	4.4
D	40	10	47.4	4.0	10.0	3.6
E	50	10	50.6	4.3	11.3	2.8
F	10	20	34.1	3.1	6.8	5.8
G	20	20	39.5	3.5	8.0	4.9
H	30	20	44.9	3.9	9.2	4.0
I	40	20	50.1	4.3	10.5	3.2
J	50	20	55.2	4.7	11.8	2.4
K	10	30	36.4	3.3	7.2	5.3
L	20	30	41.8	3.7	8.4	4.4
M	30	30	47.0	4.1	9.7	3.6
N	40	30	52.0	4.5	11.0	2.8
O	50	30	56.9	4.9	12.3	2.0
P	10	40	39.1	3.6	7.8	4.9
Q	20	40	44.4	4.0	9.1	4.0
R	30	40	49.6	4.4	10.4	3.2
S	40	40	54.7	4.8	11.7	2.4
T	50	40	59.5	5.2	13.0	1.6
U	10	50	41.7	3.8	8.1	4.4
V	20	50	47.0	4.2	9.5	3.6
W	30	50	52.1	4.6	10.8	2.8
X	40	50	57.0	5.0	12.2	2.0
Y	50	50	61.8	5.4	13.5	1.2

The table summarizes the experimental findings of the green composite concrete prepared with the stone dust and post-consumer low-density polyethylene (LDPE) waste as each of the samples, which were labelled A through Y, had varied amounts of stone dust and LDPE waste.

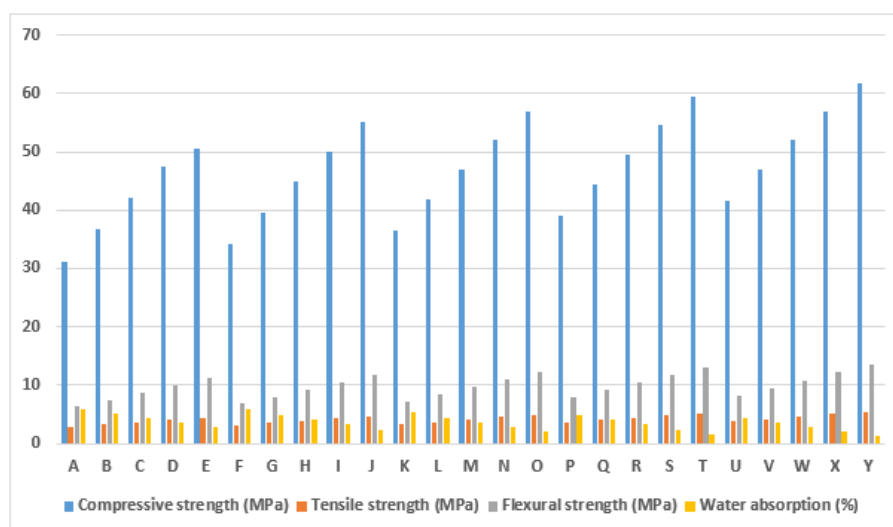


Figure 2: The Effect of LDPE Waste and Stone Dust Content on the Performance of Composite Materials

2020). The results show that as the LDPE waste content and stone dust content increase, the compressive factor also increases. This indicates that the composite material's capacity to sustain compressive loads is enhanced by the introduction of LDPE waste and stone dust as material's tensile strength is its capacity to withstand tensile loads without breaking (Suryono, J., and Pranoto, Y. 2021). The findings demonstrate that the tensile strength of the composite material improves along with the amount of LDPE waste and stone dust present. This demonstrates that the composite material's abilities to resist tensile loads is enhanced by the addition of LDPE waste and stone dust. Flexural strength describes a material's capacity to withstand bending loads without breaking (Tamil *et al*, 2018). The outcome reveals that as the LDPE waste content and stone dust content increase, the flexural strength of the produced composite also increases. This further implies the addition of LDPE waste and stone dust improves the ability to resist bending loads. A material's tendency to absorb moisture is described as its water absorption capacity (Singh, 2021). In this context, the analysis indicate that the water retention capacities of the composites increased as LDPE waste

content and stone dust content also increased. This pointed that the composite material could be more vulnerable to water damage because of the addition of LDPE waste and stone grit. This implies that the addition of LDPE waste and stone dust can enhance the composite material's mechanical qualities but also could make it more vulnerable to water damage (Siddique *et al*, 2021) (Yadav, R. 2021).

Also, the optimal combination of LDPE waste content and stone dust content for achieving high mechanical strength and low water absorption is 30% LDPE waste and 40% stone dust, as evidenced by the highest values of compressive, tensile, and flexural strength and the lowest value of water absorption in group.

The link between compressive strength and LDPE waste content in concrete containing stone dust is shown in figure 3 above. The dependent variable was the compressive strength (MPa), while the independent variable was the various percentages of stone dust (10%, 20%, 30%, 40%, and 50%). The table demonstrates that the compressive strength of the concrete improves along with the amount of LDPE waste present. The positive slope (Y) values for each model equation serve as a

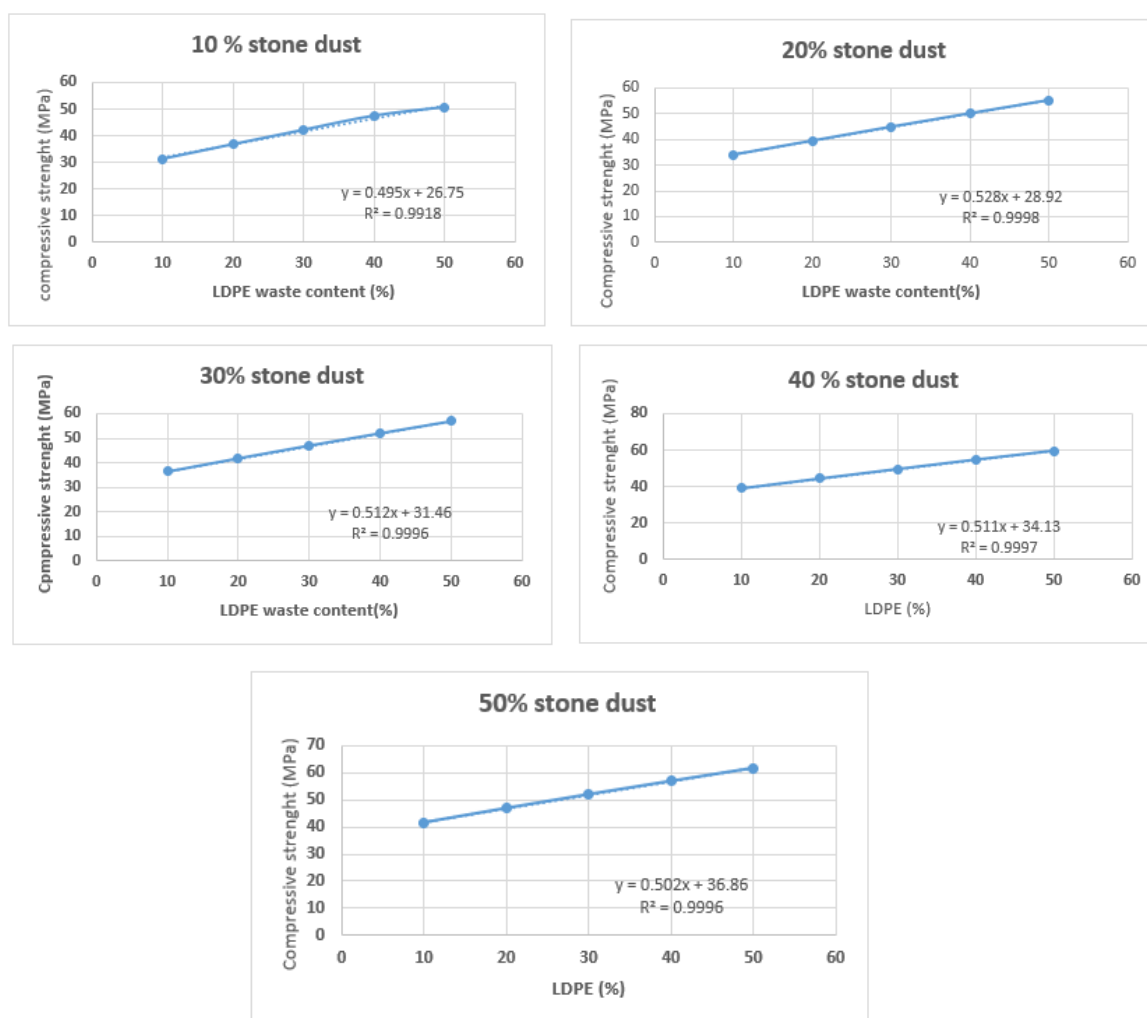


Figure 3: Relationships between LDPE Waste Content and Compressive Strength of the formulated green composite concrete.

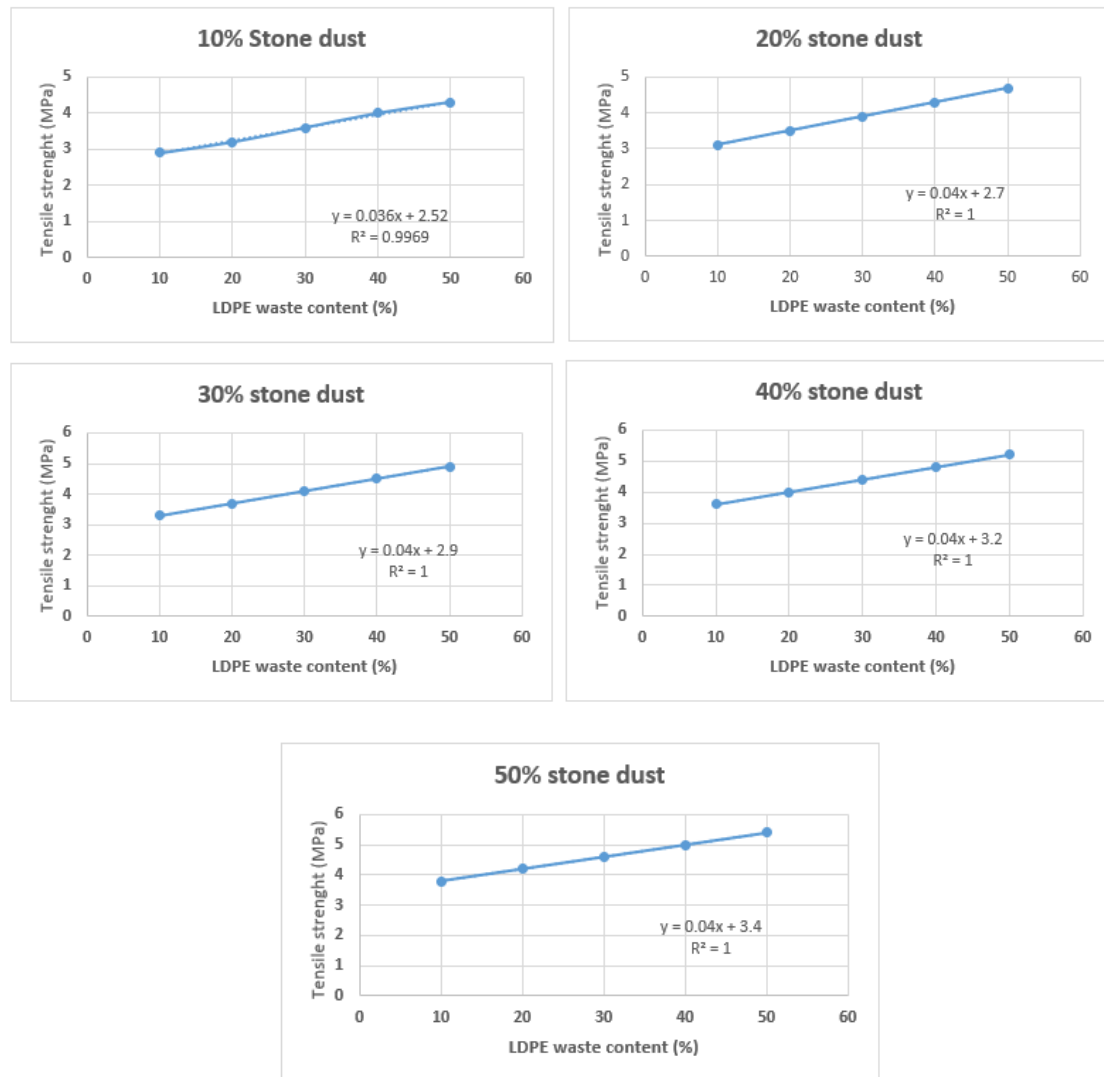
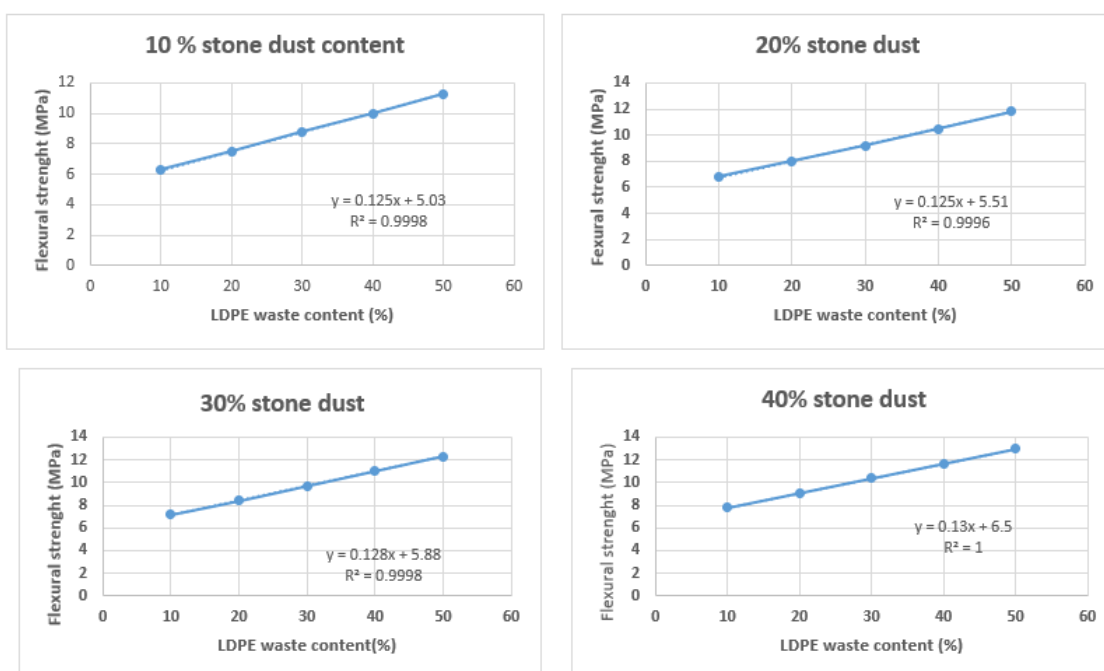


Figure 4: Relationships between LDPE Waste Content and Tensile Strength of the formulated green composite concrete



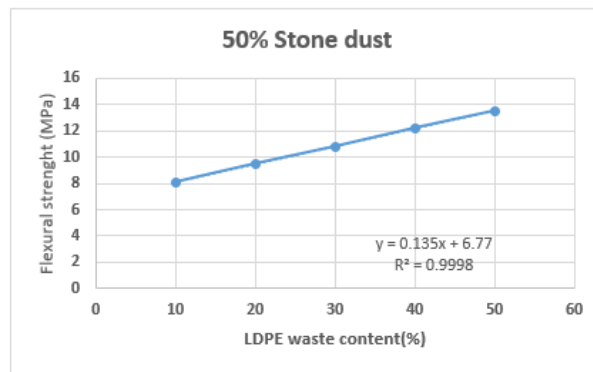


Figure 5: Relationships between LDPE Waste Content and Flexural Strength of the formulated green composite concrete

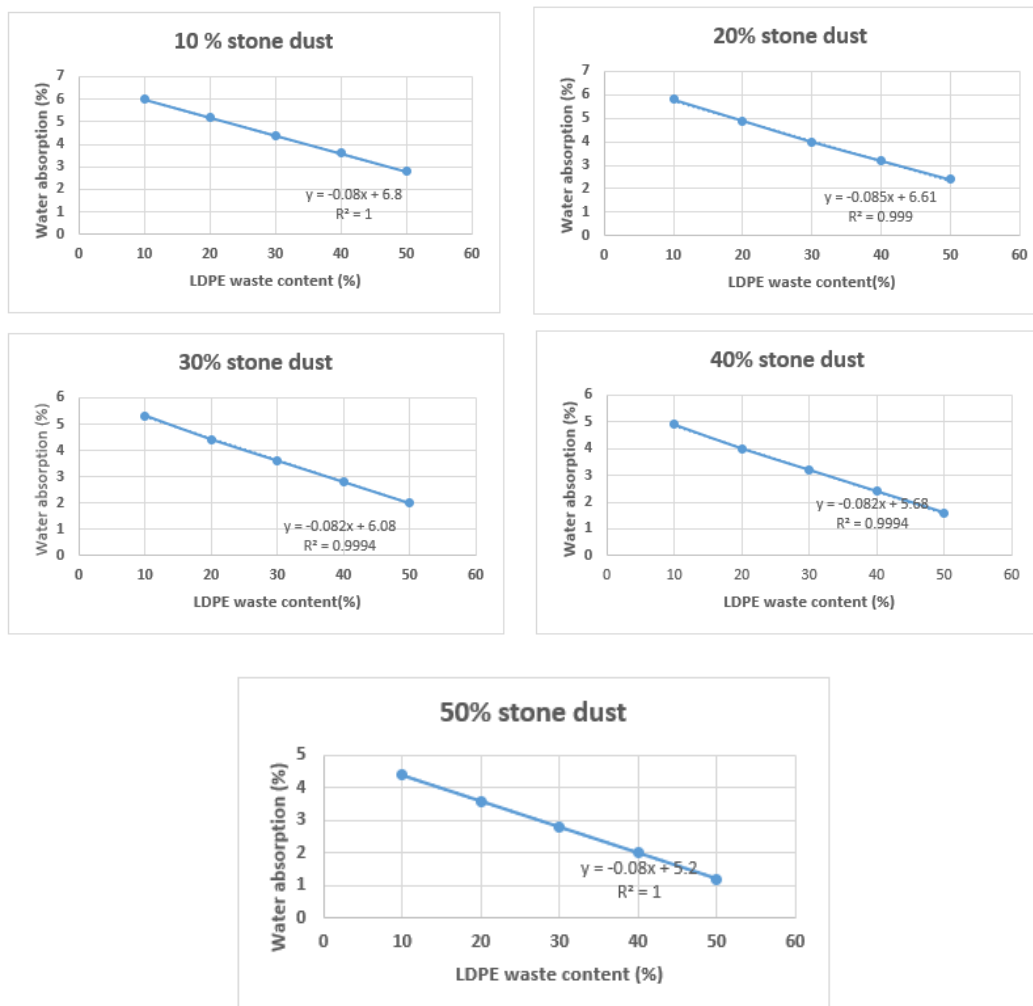


Figure 6: Relationships between LDPE Waste Content and Water absorption of the formulated green composite concrete

signal for this. Also, the models' high R2 values (0.9918, 0.9998, 0.9996, 0.9997, and 0.9996) imply that they are very accurate and that the independent and dependent variables are strongly correlated.

Evidently, the slope values for each model equation are slightly different, indicating that the effect of LDPE waste content on compressive strength varies depending on the percentage of stone dust used. This could be

due to the different characteristics of the stone dust at each interaction percentage (Arsana *et al*,2021). Figure 4 shows the relationship between tensile strength and the percentage of LDPE waste content in a material. The data suggests that as the percentage of LDPE waste content increases, the tensile strength also increases. The linear equations presented in the table show that there is a positive correlation between the two variables.

The tensile strength increases by some particular amount as the LDPE waste content is raised by 1% as showed by the slope of the equation. Also, in all the models' R² values are quite high (equal to or very close to 1), implying that the linear regression model and the generated data fit the data precisely as the addition of LDPE waste can increase its tensile strength, which may have broader implications for how LDPE waste is used in diverse applications (Danwittayakul *et al*, 2017).

Figure 5 shows that as the percentage of LDPE waste in the material increases, the flexural strength also increases and the models reflects a positive correlation between LDPE waste content and flexural strength, with R² values ranging from 0.9996 to 1, with a very strong relationship between the two variables. Specifically, the models reveal that for every 10% increase in LDPE waste content, the flexural strength of the material will also increase by approximately 1.25 to 1.35 MPa. This information can be useful for material scientists and engineers who are interested in developing new materials with desired flexural strength properties, especially when considering the use of LDPE waste as a potential raw material.

The fact that these results were acquired under particular experimental circumstances means that they might not necessarily apply to all materials or situations. Figure 6 shows that the water absorption reduces as the LDPE waste content rises. This implies that adding waste LDPE to the material can increase its water resistance (Inazumi *et al*, 2010). Each LDPE waste content level's trendline has a negative slope, which shows that when the LDPE waste content rises by 1%, the water absorption falls by the slope's equivalent amount.

The water absorption, by conclusion will drops by 0.08% for every 1% increase in LDPE waste content at 10% LDPE waste content. Hence, here is a significant association between LDPE waste content and water absorption, evidenced by the high R² values (almost 1) for each trendline. Adding LDPE waste to a material may increase its ability to withstand water, which is helpful for applications where water exposure is a concern.

CONCLUSION

Using post-consumer plastic wastes and stone dust in the production of green composite concrete solves reduce the environmental impact of construction activities. Our results show that the resulting green composite concrete can maintain adequate mechanical strength and have a lower environmental impact compared to traditional concrete under the study's condition especially of 7 days curing period. Future research could investigate the scalability and economic feasibility of using these materials in large-scale construction projects. The findings of this study have important implications for the construction industry and environmental sustainability. The results of our study show that green composite concrete made from post-consumer plastic wastes, stone dust, cement, and water is a workable alternative to traditional concrete as various mixtures of these materials

were evaluated regarding the compressive strength, flexural strength, and water absorption.

Future Work

Further research is needed to explore the full potential of green composite concrete and to evaluate its performance in real-world applications.

Conflict Of Interest: None

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