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CLAPET Pot: Development of Garden Pot Using Polyethylene Terephthalate (PET) Plastic Waste and Mangrove Clam Shells (Anodontia philippiana)

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I. Introduction

1.1 Background of the Study

Plastic waste pollution has been a huge problem worldwide, causing harm to people, animals, plants, and our planet. The polyethylene terephthalate (PET) plastic which is commonly used for bottled water, juices, and soft drinks. Usually, they are thrown away after use, and by then they will be part of plastic waste which contributes a large portion of the pollution to our planet earth and it causes damage. As plastics are versatile and convenient materials that is known to be used every day, their disposal poses a severe environmental problem as they are non-degradable and release harmful fumes when burned (Oluwakemi & Abas, 2022). According to the estimations from the scientists, only around 9% of the plastic waste that is generated worldwide being recycled, with the remaining 79% of plastic waste goes into landfills or the environment, and 12% percent or so get burned (UNDP, 2023). As the problem of waste has become much worse over time, there is an absolute need for the whole world to start recycling.

The Philippines is considered the first-largest contributor to plastic waste worldwide, contributing to at least estimated 0.75 million metric tons of plastics, yet also struggles with inadequate waste management systems and low recycling rates with only 2% are effectively recycled (Guevarra, 2022). The Philippines generates an estimate of 61 00 metric tons of solid waste daily, up to 24% is plastic (Subbontnitskiy, 2024). And it is expected to increase in the succeeding years, and with the ultimate solution to the problem we have the RA 9003 or the Ecological Solid waste Disposal in which it highlights the practices of proper disposal, waste diversion, and segregation (Coracero et al., 2021). As for the recycling industry faces problems such as contamination, market fluctuations for recycled materials, and the intensive energy management systems and low recycling rates. Despite these obstacles, the growing awareness of environmental issues and the economic potential of recycling are driving efforts to improve nations recycling practices.

The city of Zamboanga also faces challenges on solid waste management. With the poor solid waste management systems this leads to various problems in the city, such as destruction of the environment, negative effects for the health of the community, and socio-economic aspects (Molina & Catan, 2021). There are some places, like Campo Islam and Lunzuran, where garbage is scattered on the streets because people sometimes do not throw or put in a place in proper way. Even though there are garbage trucks for the barangay, people are just irresponsible for their trash. Most people are aware on the importance of solid waste management. However, the practices that they do were inadequate, since most of the waste generated being disposed in open spaces or worse burned (Atilano-Tang & Ledesma, 2023). Despite knowing the effect of it to the environment and community, there are people still doing the inappropriate way.

Discarded mangrove clam contributes to the pollution due to improper disposal, and the generation of odor which affect the community. However, it contained a potential compound which is Calcium Carbonate ($CaCO_3$), which can be used to replace commercial $CaCO_3$ (Hamester et al., 2012). High contents of calcium carbonate can be used in the formulation in construction or as filler in polymer materials.

This study explored the potential of garden pot using PET plastic waste and mangrove clam shells, to minimize solid waste from food waste like clam shells, and to promote sustainable practices.

1.2 Statement of the Problem

The increasing volume of PET plastic waste and the discarded mangrove clam shells pose significant environmental challenges in Zamboanga city. The disposal of these materials into landfills and waterways contributes to pollution, risks to human health and marine life. The harmful effects of improper waste management of PET plastic contribute to greenhouse gas emissions, soil and water contamination. It occupies landfill spaces and takes hundreds of years to decompose. Similarly, decomposing mangrove clam shells releases carbon dioxide which can contribute to ocean and landfill soil acidification. It can also release unpleasant odors that can affect nearby communities and can lead to pollution. Additionally, the use of PET plastic waste and discarded mangrove clam shells to develop a garden pot has not been done in any research. Therefore, this study aims to develop a sustainable and innovative solution to the community of Zamboangueños by using PET plastic waste and mangrove clam shells in developing garden pot.

1.3 Objectives of the Study

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The main objective of this study is to produce a usable product that helps address the PET plastic waste and dispose mangrove clam shell by developing a garden pot. Using three treatments (Clamshells: PET) by volume. The following are specific objectives of the study:

1. To evaluate the physical property of the different treatments in terms of water absorption.
   a. Treatment 0 (purely polyethylene terephthalate PET)
   b. Treatment 1 (1:1)
   c. Treatment 2 (1: 2.5)
   d. Treatment 3 (1:5)
2. To evaluate the mechanical properties of the different treatments in terms of tensile strength and flexural strength.
3. To identify which among the treatments is feasible to produce the optimum garden pot using PET plastic waste and discarded mangrove clam shells ratios (by volume); and
4. To compare the mechanical and physical properties of the experimental garden pot and commercial pot.

1.4 Significance of the Study

The development of garden pot using PET plastic waste and mangrove clam shells held significant implications for environmental sustainability and waste management in Zamboanga City. This study directly contributed to mitigating pollution by addressing the accumulation of these materials in landfills and waterways, which severely harmed marine life and local ecosystems. By converting challenging waste materials into a valuable, marketable product, the research established the principle of upcycling and showcased the economic potential of resource recovery. Moreover, this innovative product served as a functional instrument for community greening and urban horticulture, thereby fostering environmental awareness and community engagement and ultimately strengthening collective environmental responsibility by reducing the harmful disposal of mangrove clam shells and PET plastic waste.

1.5 Scope and Limitations

This study focused on the development of a garden pot using PET plastic waste and mangrove clam shells as the primary components. The PET plastic wastes we collected from the Materials Recovery Facility of Barangay Maasin, Zamboanga City, while the discarded mangrove clam shells were gathered from Puerto Princesa, Palawan. The scope encompassed the collection, processing, and combination of these materials for garden pot production. The study investigated the physical and mechanical properties of the developed pot through manual testing methods. Due to the lack of available advanced testing facilities in Zamboanga City. The analysis covered water absorption, tensile strength, and flexural strength, and the results were compared with a commercial garden pot made of high-density polyethylene (HDPE) to evaluate performance differences. The study examined varying proportions of mangrove clam shells and PET plastic waste, specifically purely PET, 1:1, 1:2.5, and 1:5 by volume, with ten trials conducted for each treatment with the limited exploration of other potential additives or reinforcements. It did not consider the environmental impact, long-term durability, or commercial production feasibility.

II. Review of Related Literature

This chapter presents relevant research and studies that provides a foundation for understanding the research topic. This chapter has three key areas about the: plastic, mangrove clam shells, garden pot, plant pot size, testing parameters, water absorption, tensile strength, and flexural strength with its figures and tables that was cited. This review aims to provide insights to deeply understand the literature in relation with developing garden pot using eco-friendly material and utilized these insights to meet the objectives of this study.

2.1 Garden Pot

Garden pots, also called plant pot, are usually made of plastics, they are also light weight. A study of Asante-Kyei (2018) revealed that plastic pots are portable to use, it is non-breakable. The study mentioned that researchers seek the recycling of this plastic waste by designing and creating a decorative flowerpot. Plastic waste has a big impact to our environment that brings negative effects such as to the health of the people, animals, natural habitats, and many more. The study recommended that artists could practice to use this plastic waste to create something such as flowerpot, also by this they can show their creativity, and skills in arts and crafts. Recycling plastics and turning them into pots could help the community and environment in many ways.

On another study, created a garden pot using biodegradable materials. There are so many waste that has been thrown all day, and agricultural waste is one of it and it could be for something like recycling to create pot (Aventurado et al., 2022). Experimental research was done by their study, the plant pot which was tested and compared in terms of specified properties that they used, the tensile strength and biodegradability properties. ANOVA test was also conducted on the study to calculate. For the findings, it was found that commercial pot was better than the treatment plant that they created. However, it was also found that it has a comparable plant pot ratio with the commercial control group. Their study suggested that this agricultural waste can be used for plastic pots, but there is still need improvement on the tensile strength of the pots.

Garden or plastic pots are usually made from variety of different materials such as high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), and high-impact polystyrene (HIPS) (APLS, 2019). The production of plant pots using plastic waste materials shows phenomenal growth and successes. Plastics are recyclable, instead of throwing it into landfills, it could be a use for developing new materials like garden or plant pots. According to the article of T.O Plastics Staff (2019) square pots are more efficient than round pots. It takes up less space, allowing to fit more plants in a smaller area. Square pots help conserve water and fertilizer because they have less run off 22% compared to round pots. It also holds more soil up to 8% than round pots, which means that plants can stay healthy longer, saving time and money. Square pots are great choice for variety of plants ideally for herbs, vegetables, root vegetables, compact trees, shrubs, and

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this also excel in space efficiency and root health (Griffin, 2024).

Another study by Ruggeri et al. (2024) investigated what makes consumer choose one gardening pot over another, specifically focusing on different sustainability features. The researchers surveyed almost 500 shoppers in Italy to understand their priorities when buying a pot. The study tested various attributes, such as whether a pot was made with recycled material, if the company used renewable energy, and what happened to the pot at its end-of-life, if it was reusable, recyclable, or biodegradable. And the findings of their study showed that consumers most strongly preferred reusable and recyclable pots. The use of recycled materials also scored high importance.

2.2 Recycled Composite Over Standard Garden Pots

Plant pots made out of recycled materials offers a sustainable solution to reduce waste and promote eco-friendliness. by transforming recycled materials into plant pots, it gives a new life and purpose while at the same time reducing the amount of waste that would have ended up in landfills or oceans. Also, with recycled materials by developing it into pots, it helps to conserve natural resources and reduces the need for virgin materials (Vyshnavi et al., 2023). With that their paper concluded that pots are made out of recycled materials are a sustainable eco-friendly alternative to traditional plant pots, and it can contribute more to the economy.

Some of the studies said that they use plastic waste like the study of Asante-Kyei (2018) the same with the article of Griffin in 2024, that means they use any different kinds of plastics that can be recycled to garden pots. On the other hand, there are some studies that uses agricultural waste. The difference of this study to other literature is that this will only focus on the usage of a specific kind of plastic waste which is the PET, where it is said that PET is a common material use for making carbonated beverages bottles due to its durability, heat resistance, and has the ability to maintain its shape under various conditions, also a resistant to chemicals and scratches (Sin & Tueen, 2023). On the other hand, using mangrove clam shells, specifically the *Anodontia philippiana* is not commonly seen to be used to create a pot. However, according to Taylor and Glover (2005), *Anodontia philippiana is* known for its durability. It is hard and thick which it provides excellent protection against predators and environmental stressors. Wherein this study will only use the PET and Mangrove Clam Shells (*Anodontia philippiana)* for experimental research.

The problem of plastic waste from traditional nursery pots is used in gardening kits. To create a more sustainable solution, the study of Ko et al., (2023) introduced a new type of biodegradable pot made from recycled waste leaf litter. The goal of their study is to see these new pots they created can help the environment by supporting a circular economy and reducing climate impact. The test was made over 90 days against common biodegradable pots. With that, the results showed that recycled waste leaf litter pots an excellent biodegradability, meaning that they broke down much faster than the other pots. The researchers also found that the thickness of pot did not slow down this decomposition or affect the soil health, which is great for manufacturing. This means that the new pot design not only offers a way to reduce plastic waste but also turns urban leaf litter into a valuable material that enhances soil quality and reduces carbon emissions.

The use of solid waste and different byproducts to create a pot wherein water absorption, solubility, tensile, and biodegrading test, also flexural test was done to determine the physical and mechanical properties of their pot, on the study of Fuentes et al., (2021). On the other hand, Manafi-Dastjerdi et al., (2021) created a pot that is made from cattle manure and wood waste, which is suitable alternative to plastic pot, where the field test showed pot produced with 80% manure and 20% sawdust performed best in terms of physical and mechanical properties.

2.3 The Characteristics and Properties of PET

PET is a highly versatile, semi-crystalline polyester known for its wide-ranging applications and favorable properties, making it a staple in modern life (SpecialChem, 2025). It's highly valued for its strength, lightweight nature, impact resistance, and shatter-proof qualities, often serving as a glass replacement. PET exhibits good barrier properties against gases like oxygen and carbon dioxide and moisture, is an excellent electrical insulator, and is stable across a broad temperature range -60 to 130°C. In its natural state, it is a flexible, colorless, and semi-crystalline resin that can be processed to be semi-rigid or rigid, possessing good dimensional stability and chemical resistance to substances like alcohols and diluted acids. Furthermore, PET is recyclable and has been globally approved by health agencies for safe food and beverage contact, with its performance continually being tailored to meet demanding, high-end applications.

The study of Wythers (2021) the PET is also an established, semi-crystalline, aliphatic-aromatic thermoplastic polyester recognized globally for its substantial commercial and industrial significance, placing it among the most highly utilized plastics worldwide. Its popularity, particularly as a food packaging material, stems from an optimal combination of mechanical properties, including high tensile strength, light weight, and flexibility, coupled with excellent resistance to various chemicals and a wide thermal operating range. Beyond packaging for beverages and food, PET's versatility extends into the manufacturing of synthetic fibers for the textile industry and, increasingly, into specialized fields such as the construction of artificial vascular scaffolds, solidifying its position as a highly demanded polymer across diverse sectors.

According to McClements (2022), PET (polyethylene terephthalate) is a thermoplastic polyester characterized by a relatively rigid molecular structure that can form either amorphous or semi-crystalline regions depending on processing conditions. This structural versatility contributes to its favorable combination of mechanical and thermal properties, making it suitable for a wide range of packaging and engineering applications. PET exhibits high tensile strength (approximately 22–95 MPa), high stiffness with a modulus of elasticity ranging from about 1.57 to 5.2 GPa, and good flexural strength of roughly 55–135 MPa, indicating its ability to withstand substantial mechanical loads with minimal

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deformation. It also demonstrates moderate elongation at break, reflecting lower flexibility compared to more ductile polymers such as HDPE. In comparison, HDPE typically exhibits lower tensile and flexural strength, with tensile strength ranging approximately from 15.2 to 45 MPa and flexural strength from about 16.5 to 91 MPa, depending on processing conditions and material grade, further highlighting PET's superior stiffness and load-bearing capacity.

In terms of thermal behavior, PET has a melting temperature ranging from 200–260°C and a maximum service temperature that varies from 60–225°C depending on its grade and crystallinity. These properties allow it to maintain structural integrity under moderately high-temperature conditions. Physically, PET typically has a density of about 1.3 g/cm³ and may appear transparent or opaque depending on its degree of crystallinity, which also influences its dimensional stability and performance. Additionally, it possesses good electrical insulating properties, with a dielectric constant ranging from approximately 2.4 to 3.7.

Despite its strength and rigidity, PET is less flexible than HDPE and may become brittle under highly crystalline conditions or specific stress environments. Nevertheless, its excellent strength-to-weight ratio, clarity, thermal resistance, and stability make it highly suitable for beverage bottles, food packaging, synthetic fibers, and engineering applications (McClements, 2022).

2.4 Mechanisms of Polymer Degradation

Chain scission is a fundamental degradation mechanism in polymers in which the covalent bonds along the polymer backbone are cleaved, resulting in the formation of shorter molecular chains and a corresponding decrease in molecular weight. As the chain length decreases, there is a significant reduction in key mechanical properties such as tensile strength, flexural strength, elasticity, impact resistance, and viscosity. These changes occur because polymer performance is strongly dependent on chain entanglement and molecular weight distribution. As a result, progressive chain scission leads to embrittlement and overall weakening of the material (Taylor & Francis, 2019).

In contrast to cross-linking, which involves the formation of bonds between polymer chains and can increase rigidity and apparent molecular weight, chain scission is a destructive process that reduces structural integrity (Taylor & Francis, 2019). During polymer aging, both processes may occur simultaneously, but environmental conditions determine which mechanism dominates.

According to Taylor & Francis (2019), chain scission is commonly initiated by oxidative degradation pathways. Exposure to ultraviolet (UV) radiation can break chemical bonds along the polymer backbone, generating free radicals. These reactive species then interact with oxygen, forming additional radical intermediates that propagate a self-sustaining reaction. This oxidative chain reaction leads to continuous molecular fragmentation and accelerates material degradation.

In environmental conditions such as soil or outdoor exposure, heat, moisture, and reactive oxygen species also contribute to chain scission. These factors attack vulnerable sites within the polymer structure, causing random breaks along the chain or, in some cases, preferential cleavage in specific regions depending on the polymer's structure and crystallinity (Sustainability Directory, 2026). Amorphous regions are generally more susceptible to degradation due to their higher molecular mobility and greater exposure to reactive agents.

As degradation continues, shorter polymer chains lose their ability to effectively distribute stress, resulting in the formation of microcracks and surface embrittlement. This increases the material's surface area, further accelerating degradation processes. Ultimately, chain scission represents one of the primary initial steps in the long-term breakdown of polymers in the environment, eventually leading to fragmentation into smaller particles and progressive material deterioration (Sustainability Directory, 2026).

Plastic shrinkage refers to the decrease in its part size as it cools and solidifies from molten state, caused by polymer chains packing more tightly together (SpecialChem, 2025). In the study of Mold (2021), also said that the shrinkage of plastics signifies the volume contraction of polymers where this occurs during the cooling step of the process, as this is due to the difference in the density of polymers from the melt state and cooled, rigid state. The process continues slightly after the part is removed as it reaches ambient temperature, and minute adjustments in size may still occur until both the internal temperature and moisture levels have fully leveled off.

2.5 The Characteristics and Properties of Mangrove Clam Shells

Mangrove clam *Anodontia philippiana*, also known as imbao, are bivalve mollusks that thrive in the muddy bottoms of mangrove forests in the Philippines (Bersaldo et al., 2022). Majority of the clams were found at Kinablangan, Lucod, and Salingcomot, somewhere in Davao, is with the sizes range of 3.5-4.4 cm, while there are larger clams in Bobonao, around 4.5-5.4 cm. The also observed lighter clams which is 10-19.9 g, while other one is 20-29.9 g, and the heavier clams weighted 30-39.9 g. The study revealed that the length and weight have a positive relationship, that means when length of the clams increases, a proportional increase in weight is also been observed. As this clam shells can be transformed into variety of useful products through recycling process. By recycling these clam shells, it can help to reduce waste, and it can contribute to the whole community. Discarded clam shells are often dumped at sea or in landfills, harming marine life and polluting soil and water. These shells represent a significant waste product that should be repurposed (Popović et al., 2023). They have various potential uses, including agriculture, medicine, construction, and cosmetics.

Mangrove clams are part of the Lucinidae family, which is known for hosting symbiotic bacteria (Lumogdang et al., 2022). These clams often reside in brackish water environments rich in sulfides, particularly when their diet is high in protein. On the other hand, these mangrove clams have oval shells with a greenish-brown outer layer. The interior shell displays a distinct muscle scar separate from the edge and lacks hinge teeth. The clam's shell is held together by a long, broad ligament. The mantle is thick and folded, joining beneath the intake opening.

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The clam has a tube-like foot ending in a muscular tip. Its gills enclose the body and contain noticeable reproductive organs. This mangrove clam shells possess significant potential for recycling, as it is high in calcium carbonate content which makes its characteristic the hardness and durability.

Mangrove forests are important place for bivalves, mangrove clams are usually found there as it is their habitat (Yahya et al., 2020). On the article, it says that around 175 bivalve species were recorded in the mangroves of Southeast Asia, with 6 species are listed as an alien species in some other regions which are the classified as Least Concern, 71 were categorized as not evaluated, and the other 98 were not included in the International Union for Conservation of Nature's Red List of Threatened Species. However, the article concluded that it is still sustainable for the use of bivalves in the Southeast Asia but with there should be a continuous monitoring conducted for the appropriate date for proper management of the mangroves.

Mangrove clam shell had a pH level of 8.87, with $CaCO_3$ of 95.94 (Hapinant, n.d). it was revealed that this kind of shellfish has a potential to be use a raw material for something valuable. On the study it was measured and tested for the enhancement on their study which is to produce a lime using shell as raw material. Shells are proven that it can be used as alternative for commercially produced agricultural lime. As for the results, it revealed that shellfish can be a potential source of alternative liming material for agricultural lime in dealing with soil acidity, and with this it has a lowest cost for farm production. Therefore, it was concluded that with this production development from these shells is recommendable for mass production.

The edible clam, *Anodontia philippiana*, is found in abundance in some certain areas of Surigao del Sur, Philippines (Ecleo et al., 2024). However, because of human activities harms its population and quality. This study measured the levels of lead, nickel, chromium, and mercury in both the sediments and the flesh of these clams. It also analyzed the relationship between the size and weight of the clams. Only chromium levels exceeded safe limits in the sediments from one location. All heavy metal levels in the clam flesh were below safe limits. The growth patterns of the clams differed between the two study areas, possibly due to environmental factors. While heavy metals in the clams and their environment were generally low, the observed growth pattern suggests potential environmental problems. The study recommends regular monitoring of heavy metals and further research on clam growth and distribution.

2.6 The Use of PET as Alternative Materials to Other Products

A study by Bui et al., (2018) investigated the potential engineering of Recycled PET Bottles Waste (RPET) and Recycled Woven Plastic Sack Waste (RWS) fiber reinforced Recycled Aggregate Concrete (RAC). It is said that with the rapid increase of plastic waste and becoming a burden nationwide, with creating a study that can help to reduce the amount of solid waste is a good solution for waste management and it helps to preserve the environment. The study was evaluated based in mechanical properties and durability concrete. On the other hand, the study of Tomy Muringayil Joseph et al., (2024) says that PET is a widely used polymer in different industries around the world due to its excellent physical and chemical properties. With the increase usage of PET products this had led to a global crisis in waste management. However, the study summarizes that with recycling technologies for plastic waste, focusing on the bio-recycling of PET, with that this aims for a sustainable, economical solutions worldwide.

With the environmental threat of PET waste is critical for sustainable development (Albatayneh & Akhtar, 2024). With their study shows how PET plastic waste such as water bottles and containers into a useful material for the construction industry. The study goal was to see if it is possible and beneficial to use a waste replacing natural sand or to add it as a small ingredient to cement. With the study aims to help the environment by reducing plastic pollution while also creating more eco-friendly materials that is made of PET plastic waste.

Plastics has been seen to save natural resources before, but now we are facing a huge problem with plastic waste (Moheyeldin Mahmoud, 2024). The study investigated how to use these recycled PET panels to make better products. It shows that these PET panels are good material for improving several product qualities. Such as it can boost a endurance and durability of a product. These PET can also help lower production costs because the raw material is essential a cheap waste. The researchers concluded that due to their low price and many beneficial properties, these eco-friendly PET panels should be used as a smart replacement for many materials currently used in product design. With that, this approach offers a valuable dual benefit. By improving product quality while also providing a simple solution for getting rid of plastic waste.

2.7 The Use of Mangrove Clam Shell as Alternative Materials to Other Products

Utilizing clamshell powder as a substitute for fine aggregate (Abdullah et al., 2021). On the study it said that concrete is one of the most used construction materials, consisting of water, aggregate and cement, wherein a cement manufacture of concrete shows a negative impact to our environment. Therefore, they investigated for an alternative solution that can be done to replace some of the cement content. The study aims to create a high-quality Self Consolidating Concrete that is environmentally friendly with simple steam curing method. As for the partial substitute for sand 9% of powdered clamshells where used, and other percentage for other different materials. The testing of concrete comprehensive strength aged 1 day is expected to produce concrete with a minimum strength of 30 MPa.

On the other hand, the study of Yusra et al., (2025) shared that the addition of 2% clamshell powder can increase the split tensile strength of normal concrete by 10.48%, and an increase in concrete compressive strength of 21.98% in the substitution of 6% shell powder. Using shellfish shells powder were 0%, 2%, 4%, 6%, and 8% for the comparison test object. For each variation of shell powder, 3 (three) cylindrical specimens were made with test time of 7 and 28 days. The test results of their study shows that the split tensile strength of concrete at 28 days of concrete age with a variable of 2% and compressive strength of a variation of 4%. The study concluded that the use of shell powder with 6% substitution to replace cement, which produces a significant concrete compressive strength, namely 0% shellfish powder has a compressive strength of 26.610 MPa compared to 6% substitution, which has a strength of 32.460 MPa. On the study of Mahshuri et al., (2023), their study also focuses on comprehensive strength of concrete containing different percentages of municipal waste clamshell powder. With the amount cement replaced by 5%, 10%, and 15% of clam shell powder. The result shows that the compressive strength increases with the clam shell powder content. The concrete containing 15% clamshell powder has a lower compressive strength compared to those containing 5% and 10% clam shell powder. The concrete containing 15% clam shell powder is almost similar to the control concrete.

2.8 Plant Pot Size

Most of the size of a plant pot is measured by its volume in liters. However, pots smaller than a liter are often identified by the width of their opening, usually in centimeters such as P9 pot is roughly square, measuring about 9 x 9 cm pot. The plant pot sizes are shown in Table 2.1.

Table 2.1. Plant Pot Size

Pot Sizes (inches)	Pot Equivalent (U.S. Gallons) *	Suitable Plants	Soil Needed (cu.ft.) and Weight (lbs)*
4"	0.125	Nursery plants/ Seedlings	0.01 ft3 / 0.137 lbs
5-6"	0.25	Small succulents/ 1 Annual	0.03 ft3 /0.27 lbs
7-8”	1	Largwe succulents/2 Annuals/ Ornamental Grass	0.13 ft3 / 1.1 lbs
10"	3	Small herbal such as Chives/ Upto 3 annuals	0.40 ft3 / 3.3 lbs
12"	5	Lettuce/ Spinach/ Strawberries	0.66 ft3 / 5.5 lbs
14"	7	Larger herbes such as Rosemary	0.94 ft3 / 7.7 lbs
16"	10	Small shrubs/ Small fruits such as Rasberry	1.33 ft3 / 11 lbs
18"	15	Vegetables such as totato plants/ Mix of annuals	2.00 ft3 / 16.5 lbs
24"	25	Evergreen shrubs/ Dwarf trees	3.34 ft3 / 27.5 lbs
30"	30	Larger plants/ Small trees	4.01 ft3 / 30 lbs
32"	35	Large shrubs & trees: Palm trees, Boxwood	4.68 ft3 / 35.5 lbs
36"	40	Larger trees: Orchard fruit trees such as Apple	5.00 ft3 / 37 lbs
44"	45	Fully grown trees: Pine, Spruce, Hawthorn	5.53 ft3 / 41 lbs

Note: Table 1 How to Measure Plant Pots | Industry Guide, 2022. Creative Design Manufacturing.

2.9 Testing Parameters

The testing parameters are the specific conditions or factors that are controlled or measured during an experiment. They are essential for ensuring the accuracy, reliability, and consistency of the test results. See the parameters shown below and their testing.

2.9.1. Water Absorption

ASTM D570 is a test used to measure how quickly materials absorb water. The test involves soaking a sample in water for a set amount of time and then measuring how much its weight has increased. The standard also includes different procedures for testing various materials under different conditions. The test procedure for the water absorption test, the specimens are dried in an oven for a specified time and temperature and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed. The material is then emerged in water at agreed upon conditions, often 23°C for 24 hours or until equilibrium. Specimens are removed, patted dry with a lint free cloth, and weighed. Materials and specifications for water absorption are shown in Table 2.2.

Table 2.2. Materials and Specifications for Water Absorption

Type of materials	Specifications
Molded plastics	The samples have to be in the form of disks of 50.8 mm (2 in) in diameter with a 3.2 mm (1/8 in) thickness.
Homogeneous plastics	The dimensions of the samples are 60 mm by 60 mm by 1 mm.
Sheets	The samples have to be in the form of bars of 76.2 mm (3 in.) long by 25.4 mm (1 in.) wide The thickness has to be specified, but a thickness of 3.2 mm (1/8 in) has to be used in order to compare with molded plastics.
Rods	The diameter of the sample is the same as the finished product. If the diameter is 25.4 mm or less, the length is 25.4 mm (1 in.). If the diameter is greater than 25.4 mm, the length is 12.7 mm (1/2 in.).
Tubes	If the inside diameter is less than 76 mm (3 in.), the test specimens shall be the full section of the tube and 25.4 mm (1 in.) long. If the inside diameter is greater than 76 mm (3 in.) a rectangular sample shall be cut 76 mm in length in the circumferential direction of the tube and 25.4 mm in width lengthwise of the tube.

Note: Table 2 ASTM D570 | Typical Experimental Parameters for ASTM D570 Testing

2.9.2. Tensile Strength

Plastics are used in variety of items every day and increasingly used in transportation due to their strength and lightweight. To ensure the safety and reliability of these applications, it is important to understand the mechanical properties of these plastics. ASTM D638 provides methods for testing and calculating the tensile strength of plastics, along with accuracy requirements for the testing equipment. Table 2.3 shows the tensile strength ASTM D638 for test specimen basis.

According to Trento (2025), the test evaluates critical properties such as tensile strength at yield, tensile strength at break, elongation at break, and modulus of elasticity (Young’s modulus), which collectively describe a material’s resistance to deformation, stiffness, ductility, and fracture behavior.

Tensile strength at yield refers to the maximum stress a material can withstand before undergoing permanent deformation. For instance, high-density polyethylene (HDPE) typically yields at approximately 20–30 MPa, while polycarbonate (PC) may reach 60–70 MPa, indicating higher resistance to deformation. Tensile strength at break, on the other hand, represents the stress at which a specimen ultimately fractures. Brittle plastics such as polystyrene tend to fail near the yield point, whereas ductile materials like polyethylene can undergo significant deformation prior to breaking (Trento, 2025).

Table 2.3. Tensile Strength ASTM D638

Type	Full length, l^3	Parallel length, l^2	Gauge length, l^1	Parallel section width, strong[1]	Thickness, h	Grip section width, strong[2]	Distance between grips
I	165	57	50	13	7 mm or less (recommended 3.2±0.4 mm)	19	115
II	185	57	50	6	7 mm or less (recommended 3.2±0.4 mm)	19	135
III	165	57	50	19	7 mm to 14 mm	29	115
IV	115	33	25	6	4 mm or less	19	65
V		63.5		7.62	4 mm or less	9.53	25.4

Note: Tensile Test Methods for Plastics: ASTM D638 - Specs. Shimadzu.

Another key parameter measured under ASTM D638 is elongation at break, expressed as a percentage increase in length before fracture. HDPE, for example, may exhibit elongation values of 400–600%, demonstrating high ductility, while polystyrene typically shows less than 5%, indicating brittleness. The test also determines Young's modulus, which represents material stiffness based on the slope of the initial linear portion of the stress–strain curve. Materials such as polypropylene have a modulus of about 1.5–2 GPa, while PVC can reach up to 3–3.5 GPa (Trento, 2025).

In addition to material characterization, ASTM D638 is widely applied in research and development to evaluate the effects of additives, fillers, and reinforcements on plastic performance. For example, the incorporation of glass fibers into polypropylene can significantly increase tensile strength from approximately 30 MPa to over 80 MPa while reducing elongation at break. The standard is also essential in quality control and regulatory compliance, ensuring that materials used in medical devices, food packaging, and electronic components meet required mechanical performance standards and safety regulations.

2.9.3. Flexural Strength

The flexural strength of plastics and composites can be determined using ASTM D790. This test measures a material's ability to resist cracking or breaking when bent. When designing a product that will be subjected to loading or pressure, it is crucial to select materials that can withstand the stress. ASTM D790 is widely used to evaluate reinforced and unreinforced plastics, thermoplastics and thermosets, electrical insulation materials, and high modulus composites. Table 2.4 shows the materials for ASTM D790 for test specimen basis.

Table 2.4. Materials for ASTM D790

Dimensions of a Specimen	
Molded Materials	Generally, 3.2 mm thick (deep), 12.7 mm wide, and 127 mm long (0.12 x 0.5 x 5 in) and use a support span equal to specimen depth times 16.
Cut Sheet Materials	The standard sets the rules for testing sheet materials. For sheet materials less than 1.6 mm (0.06 in) in thickness the geometry shall be 50.8 x 12.7 mm (2 x 0.5 in) with a 25.4 mm (1 in) support span Sheet materials with a thickness between 1.6 and 3.2 mm (0.06 and 0.12 in) will have a width of 12.7 mm (0.5 in) and a span defined as specimen thickness times 16 Sheet materials thicker than 3.2 mm (0.12 in) will have a width and span proportional to their thickness

Note: Table 4. ASTM D790 Flexural Test of Plastics & Composites (2023).

2.10 Related Literature on Material Properties

The evaluation of material performance for plant pot applications requires the assessment of physical and mechanical properties such as water absorption, tensile strength, and flexural strength. These properties determine the durability, stability, and suitability of materials, particularly when exposed to varying environmental conditions.

2.10.1 Water Absorption (ASTM D570)

Water absorption is a critical physical property that measures the ability of a material to resist moisture penetration. According to ASTM International under the standard ASTM D570, materials such as plastics are generally non porous and exhibit minimal water absorption, typically ranging from 0 percent to 0.5 percent. This low absorption rate is essential for applications like plant pots, where prolonged exposure to moisture is expected.

Studies indicate that materials with negligible water absorption maintain their structural integrity and prevent water retention, which could otherwise lead to degradation or damage to plant roots. Furthermore, low moisture absorption contributes to dimensional stability and resistance to swelling, making the material more reliable for outdoor use (Callister & Rethwisch, 2020).

2.10.2 Tensile Strength (ASTM D638)

Tensile strength refers to the maximum stress a material can withstand when subjected to tension before breaking. Based on ASTM D638, plastics typically exhibit tensile strength values ranging from 50 MPa to 75 MPa. This level of strength ensures that the material can endure handling, loading, and environmental stress without failure.

According to Callister (20200, tensile properties are fundamental indicators of a material's mechanical performance and resistance to deformation. Materials with adequate tensile strength are particularly suitable for plant pots, as they must support soil weight and plant growth while maintaining shape and integrity over time.

2.10.3 Flexural Strength (ASTM D790)

Flexural strength measures a material's ability to resist deformation under bending forces. As specified in ASTM D790, plastics commonly demonstrate flexural strength values between 70 MPa and 110 MPa. This property is especially important for plant pots, which may experience uneven loading or external pressure.

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Research suggests that materials with high flexural strength are less likely to crack or deform, thereby ensuring long term usability. Flexural performance also contributes to the overall toughness and rigidity of the material, which are essential for both indoor and outdoor applications (Ashby, 2011). Table 2.5 shows the physical and mechanical properties standard under ASTM standard.

Table 2.5. Physical and Mechanical Properties Standard Under ASTM Standard

Properties	Testing	Criteria	Standard
Physical Properties	Water Absorption	0% to 0.5% (typically close to zero as plastics are non-porous and should not absorb water). The material should demonstrate minimal or no water absorption to ensure structural integrity and avoid moisture retention that could lead to plant root damage.	ASTM D570
Mechanical Property	Tensile Strength	Typically shows good tensile strength in the range of 50-75 MPa, making it suitable for both indoor and outdoor plant pots.	ASTM D638
	Flexural Strength	Typically exhibits flexural strength in the range of 70-110 MPa.	ASTM D790

III. Methodology

3.1 Secondary Data Gathering

The data were gathered through searching related studies from the internet. This included searching for studies on mixing PET plastic waste and mangrove clam shells, and other related literature from libraries and reliable online sites such as ResearchGate, Emerald, ScienceDirect, and other sources that supported the study.

3.2 Research Design

The study used an experimental research design method. This enabled the researcher to test and revise theories, make predictions, and guide practical applications within the scope of the research. Four proportions by volume were used to develop the pot:

- Treatment 0 = (0 :1)
- Treatment 1 = (1:1)
- Treatment 2 = (1: 2.5)
- Treatment 3 = (1:5)

3.3 Research Locale

The experimental study and testing were performed at the researcher's residence in Barangay Maasin, Zamboanga City. The location was chosen because of its availability, sustainability, and large space for conducting the experiment.

3.4 Collection of Raw Materials

The PET plastic wastes were collected from the Materials Recovery Facility of Barangay Maasin, Zamboanga City and discarded mangrove clam shells, were sourced from Puerto Princesa City, Palawan, where they are an abundant and readily accessible resource. The amount of PET plastic waste and discarded mangrove clam shells needed was then determined (see Annex B for computations).

A total of 11.5 kg of mangrove clam shells and 16 kg for polyethylene terephthalate (PET) plastic waste were collected.

3.5 Preparation of Materials

The other materials utilized for the experiment were purchased in Zamboanga City and from online shops. Table 3.1 shows the list of materials that were utilized in the experimental set-ups.

Table 3.1. Materials and their Quantity Needed for the Production of Garden Pot

Materials/ Equipment	Quantity
Digital Weighing scale	1 pc
Wooden spatula	1 pc
Oven	1 pc
Stainless steel container	1 pc
Mortar and pestle	1 pc
Lumber	1 pc
Iron sheet	1 sheet
Clamps	2 pcs
Oven thermometer	1 pc
Digital spring weighing scale	1 pc

3.6 Preparation of Mangrove Clam Shell

The preparation of discarded mangrove clam shells is a crucial step to ensure their suitability for use in the experiment. Proper processing is necessary not only to remove adhering impurities such as organic residues, sand, and salts, but also to significantly reduce moisture content that may affect the quality and stability of the final composite material. In addition, converting the shells into a fine and uniform particle size is essential, as it improves surface area and promotes better interaction and bonding with PET, thereby enhancing the mechanical properties of the composite. To achieve these objectives, a systematic and carefully controlled preparation procedure was implemented. This involved sequential steps such as washing, drying, crushing, and sieving to ensure consistency in particle size distribution. Maintaining cleanliness throughout the process was also a priority to prevent contamination that could interfere with experimental results.

1. *Collection and Washing of Mangrove Clam Shells*

A total 11.5 kg of discarded mangrove clam shells were collected from Puerto Prinsesa City, Palawan, as shown in Figure 3.1, weighing 11.5 kg and thoroughly washed with water to remove remaining impurities such as dirt, salts, and other contaminants. This step is essential because impurities may weaken the interfacial adhesion between the clam shell particles and PET.

2. *Sun Drying of Mangrove Clam Shells*

The washed shells were subjected to sun drying for one (1) day to reduce their initial moisture content. Removal of moisture is important to prevent unwanted reactions during mixing and to improve the interaction between the shell powder and PET. As shown in Figure 3.2, the shells were evenly spread under direct sunlight to ensure uniform drying. This method also helps maintain consistent drying conditions, minimizing variations in moisture levels across the sample.

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Figure 3.1. Weighing of the Mangrove Clam Shells

Figure 3.2. Discarded Clam Shells Undergoing Sun Drying Process

3. *Crushing and Pulverization of Mangrove Clam Shells*

Once fully dried, as shown in Figure 3.3, the clam shells were crushed into a fine powder using a mortar and pestle to achieve a more refined particle size suitable for mixing. This step is critical in increasing the surface area of the material, which promotes better interaction and bonding with PET. Achieving a finer particle size also contributes to improved homogeneity of the composite mixture

Figure 3.3. Crushing of the Clam Shells Using Mortar and Pestle

4. *Sieving of Mangrove Clam Shell Powder*

The powdered clam shells were sieved using a No. 50 (0.300mm) sieve to obtain a uniform particle size, ensuring consistency in the experimental mixture before use. This process ensures that only particles of uniform size are used in the experimental mixtures, thereby improving consistency and reproducibility of results. Sieving removes larger, unground particles that may create irregularities in the composite structure. Uniform particle distribution is essential for achieving better packing, reduced void content, and improved mechanical and thermal performance of the insulation panels.

Figure 3.4. Sieving the Powdered Clam Shells Using Sieve No. 50 (0.30mm)

5. *Powdered Clam Shells after Sieving*

The final product of the preparation process is the finely powdered clam shells obtained after sieving, as shown in Figure 3.5. The resulting powder exhibits a more uniform particle size distribution, which is ideal for incorporation into the composite mixture. This uniformity ensures better dispersion within the matrix and contributes to improved bonding and material performance with PET. The prepared clam shell powder was then stored in a dry container to prevent moisture absorption prior to its use in the experimental procedures.

Figure 3.5. Powdered Clam Shells after Sieving

3.7 Preparation of PET Plastic Waste

The preparation of PET plastic waste involved a series of steps to ensure cleanliness, dryness, and appropriate particle size for use in the experiment. Proper processing is necessary to eliminate contaminants, remove moisture, and achieve a consistent particle size that allows for better interaction with the mangrove clam shells used in the composite.

1. *Collection and Washing of PET Plastic Waste*

A total of 16 kg of PET plastic waste was collected and thoroughly washed with water to remove dust, dirt, and other contaminants. Figure 3.6 shows the collection of PET plastic waste at Materials Recovery Facility of Barangay Maasin, Zamboanga City.

Figure 3.6. Collection of PET Plastic Waste in Barangay Maasin

2. *Sun Drying of PET Plastic Waste*

The washed PET plastic waste was subjected to sun drying for one (1) day to ensure complete moisture removal. Drying is a critical step because residual moisture may interfere with the melting behavior of PET and weaken its bonding capability during processing.

3. *Cutting of PET Plastic Waste*

After drying, the PET plastic waste was manually cut into smaller pieces measuring approximately 1 × 1 cm, as illustrated in Figure 3.7. Reducing the size of the plastic materials facilitates easier handling, uniform distribution, and improved mixing with the mangrove clam shells. Smaller and more uniform pieces also enhance the melting and softening behavior of PET during fabrication.

Figure 3.7. Cutting of PET Plastic Waste

3.8 Production Process

The production of the garden pot involved a series of controlled thermal and mechanical processes to ensure proper integration of PET plastic waste and powdered mangrove clam shells.

1. *Reheating and Melting of PET Plastic Waste*

The oven was preheated for 10 minutes prior to the addition of the PET plastic waste. In Figure 3.8, the plastic waste was then added and allowed to melt. Once molten, the plastic was removed from the oven, and the powdered mangrove clam shells were incorporated and thoroughly mixed.

Figure 3.8. Placement of PET Plastic Waste in the Oven

2. *Mixing and Reheating Process*

When the mixture became sticky and partially solidified, it was returned to the oven to ensure proper integration of the PET plastic and powdered mangrove clam shells. This procedure was repeated according to the specific treatment ratios (Treatment 0, 1, 2, and 3).

3. *Final Heating and Melting*

After completing the mixing cycles, the final mixture was oven-heated for a total of one (1) hour and forty (40) minutes to achieve complete melting and proper bonding of the materials.

4. *Molding of the Mixture*

While in a molten state, the mixture was poured into the bottom mold measuring 10 cm × 10 cm × 10 cm (length × height × width) and covered with a top mold measuring 8 cm × 9 cm × 8 cm to form the shape of a plant pot. The mixture was then left for a few minutes to partially harden. Figures 3.9 and 3.10 shows top and bottom of the fabricated mold and Figures 3.11 and 3.12 shows top and bottom of the actual mold used.

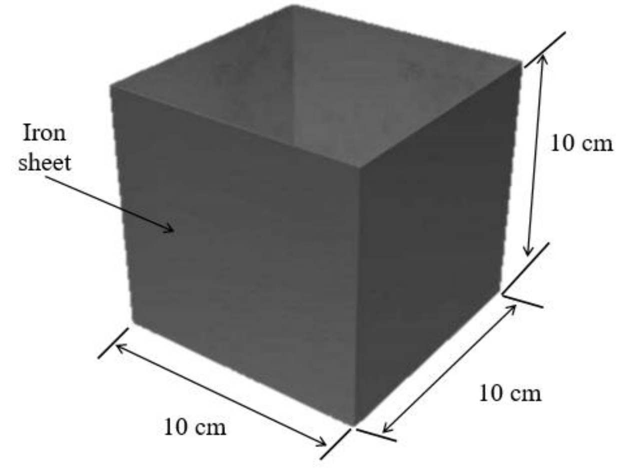

Figure 3.9. Fabricated Bottom Mold Utilized in the Production of Garden Pot

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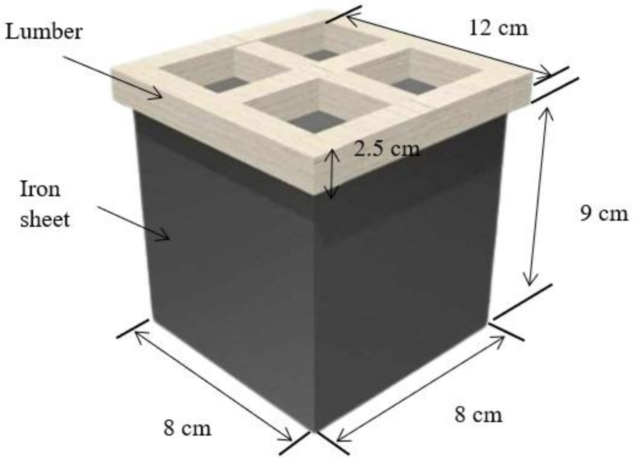

Figure 3.10. Top Mold Utilized in the Production of Garden Pot

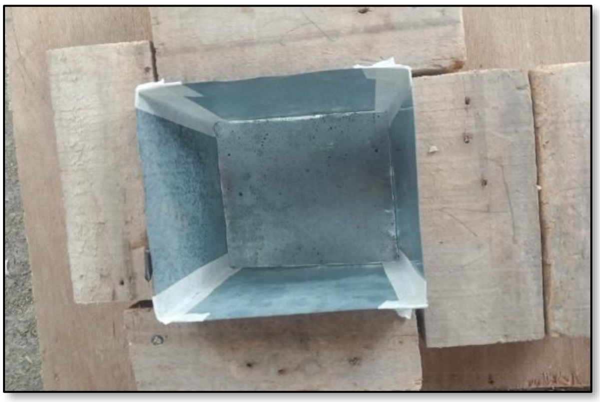

Figure 3.11. Bottom Mold Used in the Actual Experimental Setup

Figure 3.12. Top Mold Used in the Actual Experimental Setup

5. Compression and Shaping

Clamps were evenly attached to each side of the mold, applying equal pressure for one (1) hour with a force of 49 N to ensure proper compaction and shaping of the garden pot. Figure 3.13 shows the compaction of the garden pot.

6. Demolding and Curing

After one hour, the garden pot was demolded and allowed to cool and cure through air-drying for 24 hours to achieve full hardness and structural stability.

7. Finishing of the Product

The final product was then trimmed and shaped to the desired form and size. The process was repeated for each treatment to produce the required samples. Figures 3.14 shows the isometric view, 3.15 shows top view and 3.16 presents the front view experimental design of the garden pot and Figure 3.17 presents the actual isometric view of cured garden pot.

Figure 3.13. Garden Pot Undergoing Compaction

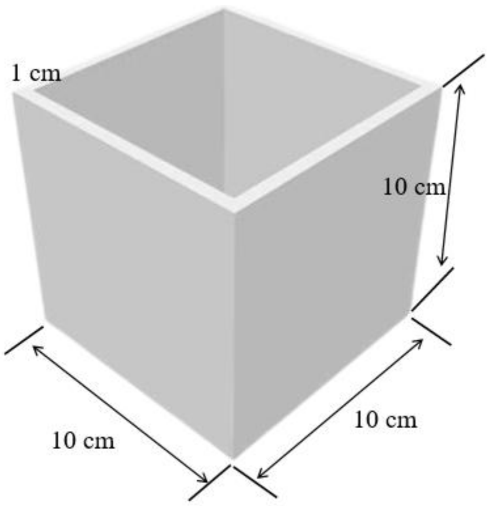

Figure 3.14. Isometric View Experimental Design of Garden Pot

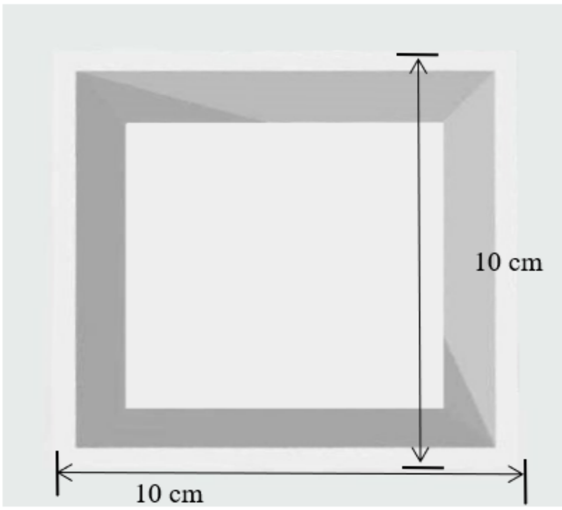

Figure 3.15. *Top View Experimental Design of Garden Pot*

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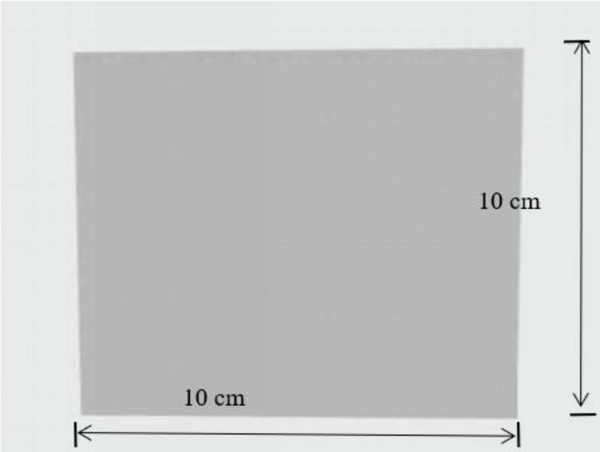

Figure 3.16. Front View Experimental Design of Garden Pot

Figure 3.17. Actual Isometric View of Garden Pot after the Experimental Process

3.9 Testing

This study investigated the physical and mechanical properties of the garden pot through three distinct tests: water absorption, tensile strength, and flexural strength. These tests collectively provided a comprehensive assessment of the garden pot's performance in terms of durability, strength, and overall suitability for practical applications. Table 3.2 and 3.3 presents the number of raw materials needed and number of samples per treatment, respectively.

Table 3.2. Amount Needed for Each Treatment Per Test

Treatments	Mangrove Clam Shells	Polyethylene Terephthalate (PET) Plastic Waste
Treatment 0	0 cm^3	424 cm^3
Treatment 1 (1:1)	212 cm^3	212 cm^3
Treatment 2 (1:2.5)	121.15 cm^3	302.85 cm^3
Treatment 3 (1:5)	70.65 cm^3	353.35 cm^3

3.9.1 Physical

The water absorption test was conducted using ten (10) samples per proportion, each measuring 50.8 mm in diameter and 3.2 mm in thickness as shown in Figure 3.18. The samples were placed in a shaded area for 24 hours for curing and were weighed afterward. Then it was submerged in water for a 24 hours duration and at room temperature. After removal, the samples were dried and weighed again to determine the amount of water absorbed. Water absorption was expressed as the percentage increase in weight. The percentage water absorption of each sample was calculated using the following equation:

$$WA = \frac{Ww - Wd}{Wd} \times 100\% \quad (3.1)$$

Where:

WA= Water Absorption of the sample (%)
Wd= Initial dry weight of the sample (g)
Ww= Wet weight of the sample (g).

Table 3.3. Number of Samples from Each Portion for the Test

Test	Treatment 0 (1) No. of Sample	Treatment 1 (1:1) No. of Sample	Treatment 2 (1:2.5) No. of Sample	Treatment 3 (1:5) No. of Sample
Water Absorption	10	10	10	10
Tensile Strength	10	10	10	10
Flexural Strength	10	10	10	10

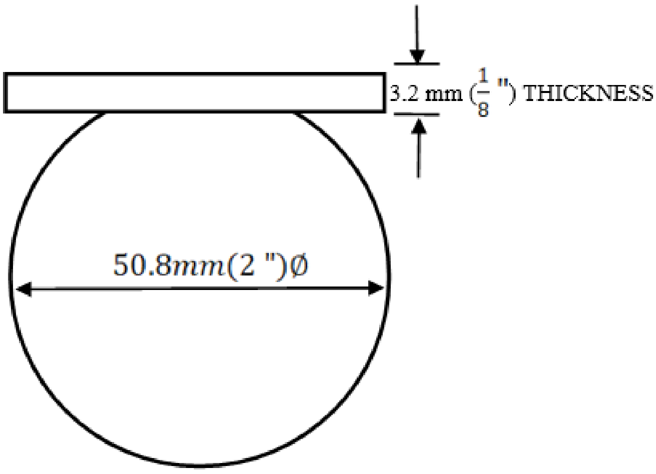

Figure 3.18. Water Absorption ASTM D570 Test Specimen

In Figure 3.19, it shows the actual test specimens were arranged in two rows, consisting of 10 specimens for water absorption. Each specimen is individually labeled and shows uniform size and thickness.

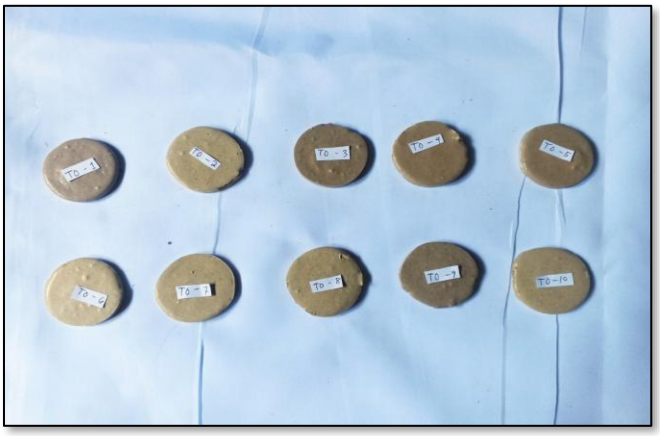

Figure 3.19. Test Specimens for Water Absorption ASTM D570

3.9.2 Mechanical

The tensile strength test was performed using ten (10) samples per proportion. Figure 3.20 presents that each sample measures 165 mm in total length, 57 mm in parallel length, 50 mm in gauge length, 13 mm in parallel section width, 4 mm in thickness, 19 mm in grip section width, 115 mm in distance between grips, and 25 mm in radius. The specimens followed the ASTM D638 standard and were dumbbell shaped. The test involved stretching each sample until failure to determine the maximum load the material could withstand before rupture.

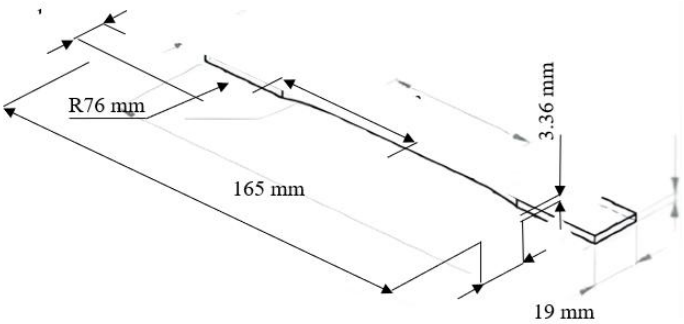

Figure 3.20. Tensile Strength ASTM D638 Test Specimen

Each sample was held upright using clamps attached to both ends, while another clamp was connected to the bottom to support a spring scale and an empty bucket. Sand gradually added to the bucket until the specimen broke. The weight at the point of failure was recorded, and the tensile strength of each sample was calculated using the corresponding equation.

$$TS = \frac{F}{A} \quad (3.2)$$

Where:

TS=Tensile Strength of the sample (MPa)
F= Maximum force (N)
A= Cross-sectional area (m^2)

Figure 3.21 presents the actual specimens for tensile strength test and are arranged in two columns and labeled. The samples are uniform in size, shape, and thickness.

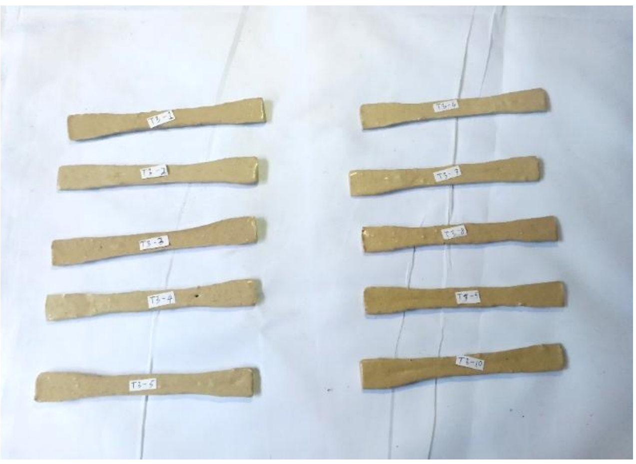
Figure 3.21. Treatment 0 Test Specimens for Tensile Strength ASTM D638

The flexural strength was performed using ten (10) samples per proportion. Figure 3.22 presents that each sample measures 3.2 mm, 12.7 mm, and 127 mm. To test the flexural strength, each sample was placed vertically with a rope tied to its center. A bucket was then hung from the rope, and sand was gradually added until the sample broke. The weight of the sand at the point of failure was used to calculate the flexural strength. The flexural strength of the sample was calculated using the following equation:

$$FS = \frac{3FL}{2WD} \quad (3.3)$$

Where:

FS= Flexural Strength of the sample (MPa)
F= Maximum force (N)
L= Support Span (m)
W= Width (m)
D= Depth (m)

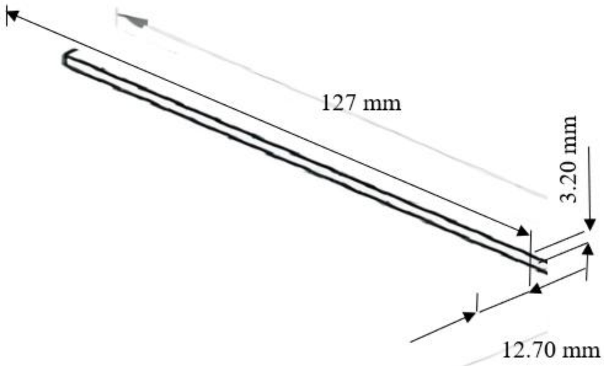

Figure 3.22. Flexural Strength ASTM D790 Test Specimen

Figure 3.23 shows the actual test specimens for flexural strength test and are arranged in two columns and labeled. The samples are uniform in size, shape, and thickness.

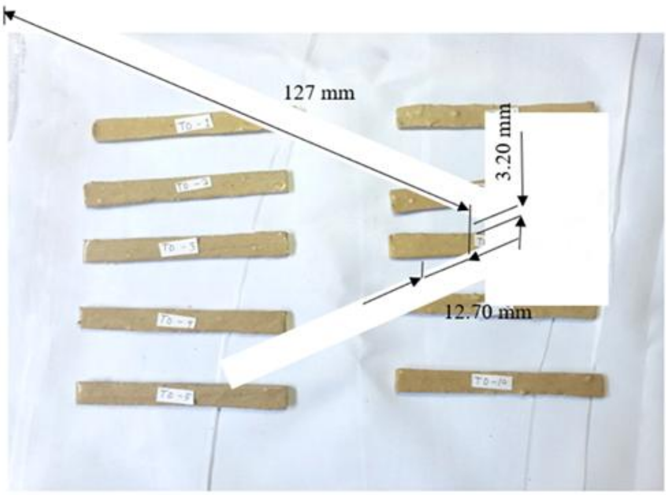

Figure 3.23. Test Specimens for Flexural Strength ASTM D790

3.10 Data Analysis

Table 3.4 presents the required physical and mechanical properties for testing the garden pot, including water absorption, tensile strength, and flexural strength. It also outlines the corresponding criteria and standard testing methods used to evaluate the material's performance.

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Table 3.4. Requirements Under Physical and Mechanical Properties for Testing

Properties	Testing	Criteria	Standard
Physical Properties	Water Absorption	0% to 0.5% (typically close to zero as plastics are non-porous and should not absorb water). The material should demonstrate minimal or no water absorption to ensure structural integrity and avoid moisture retention that could lead to plant root damage.	ASTM D570
Mechanical Property	Tensile Strength	Typically shows good tensile strength in the range of 50-75 MPa, making it suitable for both indoor and outdoor plant pots.	ASTM D638
	Flexural Strength	Typically exhibits flexural strength in the range of 70-110 MPa.	ASTM D790

The data were gathered after conducting physical and mechanical testing, such as water absorption, tensile strength, and flexural strength. To ensure the validity of parametric testing, two preliminary tests were conducted: the Shapiro–Wilk Test to check the assumption of normality, and Levene's Test to confirm the assumption of homogeneity of variances.

Once these assumptions were met, a one-way ANOVA was applied to determine any significant differences among the three treatments, using a strict 0.05 confidence level. The results were also compared to existing literature to support the findings and conclusion of the study, providing valuable insight into the production process.

IV. Results and Discussion

This chapter presents the findings from the experimental development of a garden pot using PET plastic waste and discarded mangrove clam shells. Tensile and flexural strength tests were conducted to evaluate mechanical properties, while water absorption was used to assess physical characteristics. The results of each treatment are analyzed and compared to identify the most feasible treatment for producing an optimum garden pot, along with a comparison to commercially available pots to determine performance and potential application.

4.1 Physical Test Results

This subsection presents the results of the physical tests conducted to evaluate the material's performance in terms of physical properties. The findings are discussed to determine whether the material meets the required standards, particularly under ASTM D570 for water absorption.

4.1.1 Water Absorption Analysis

This section presents the result of water absorption analysis for the developed PET-clam shell composites under different treatments.

The variation is due to differences in composition that affected porosity and permeability. Materials with more voids or weaker bonding absorbed more water. Treatment 1 showed higher absorption because its more porous structure allowed easier water penetration. According to Huang et al. (2006), water absorption in composite materials is strongly influenced by porosity, fiber distribution, and matrix bonding, were poor interfacial adhesion and increased void content lead to higher moisture absorption. Since Treatment 1 exhibited the highest mean value, the material under this treatment may have developed more pores that facilitated water penetration.

Huang et al. (2006) further explained that increased water absorption in composite and coating materials is often associated with microcracks, voids, and weak interfacial bonding within the structure. These defects allow water to diffuse into the material and accumulate over time. Therefore, the higher absorption in Treatment 1 suggests that the formulation may have produced a less dense structure, resulting in greater moisture absorption.

In contrast, Treatment 0 showed the lowest water absorption, which may have been due to a denser structure with fewer voids. A compact material structure reduces pathways for water to enter, thereby limiting moisture penetration. According to research on polymer and composite materials, lower water absorption is typically observed in materials with improved particle bonding and reduced porosity. These characteristics enhance resistance to moisture and improve durability.

In terms of consistency, Treatment 1 also has the highest standard deviation (0.1074), suggesting greater variability in its structure. On the other hand, Treatment 3 shows the lowest standard deviation (0.0342), indicating more uniform properties across samples. Furthermore, studies on material performance indicate that water absorption is a critical factor affecting dimensional stability and long-term durability. Materials with excessive water absorption may experience swelling, weakening, and deterioration when exposed to moisture (Huang et al., 2006). Thus, the lower water absorption observed in Treatment 0 and Treatment 3 suggests better resistance to moisture penetration and greater suitability for applications requiring low moisture uptake, while the higher absorption in Treatment 1 and Treatment 2 indicates greater susceptibility to water absorption due to higher porosity or weaker internal bonding.

The results of the study demonstrated significant variations in water absorption among the different treatments. Treatment 0 has the ranked of lowest mean absorption with (0.1049), second to the lowest is Treatment 3 (0.1568), followed by Treatment 2 (0.3191), and Treatment 1 recorded the highest mean absorption (0.3768). This indicates that Treatment 0 is the least absorbent and likely the most compact, while Treatment 1 has the most porous structure or weakest bonding, allowing more water to penetrate, as shown in Table 4.1.

Table 4.1. *Water Absorption Test Results*

Water Absorption Analysis (%)				
Sample no.	**Treatment 0**	**Treatment 1**	**Treatment 2**	**Treatment 3**
1	0.1488	0.3723	0.2442	0.1943
2	0	0.2437	0.3571	0.1204
3	0.1692	0.6376	0.2716	0.1943
4	0.1612	0.3036	0.4021	0.1809
5	0.1629	0.3186	0.3963	0.1906
6	0.1572	0.3186	0.3759	0.1845
7	0.1661	0.3759	0.2759	0.1265
8	0	0.4429	0.2616	0.1244
9	0.0838	0.4049	0.323	0.1241
10	0	0.3502	0.2833	0.1279
Mean	**0.1049**	**0.3768**	**0.3191**	**0.1568**
Standard Deviation	**0.0764**	**0.1074**	**0.0595**	**0.0342**

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The results of the study demonstrated significant variations in water absorption among the different treatments. Treatment 0 has the ranked of lowest mean absorption with (0.1049), second to the lowest is Treatment 3 (0.1568), followed by Treatment 2 (0.3191), and Treatment 1 recorded the highest mean absorption (0.3768). This indicates that Treatment 0 is the least absorbent and likely the most compact, while Treatment 1 has the most porous structure or weakest bonding, allowing more water to penetrate.

The water absorption results show that all treatments fall within the acceptable range of ASTM D570 (0%–0.5%), indicating generally low moisture uptake and adequate material performance. Among the treatments, Treatment 0 exhibited the lowest absorption (0.1049), followed by Treatment 3 (0.1568), Treatment 2 (0.3191), and Treatment 1 with the highest (0.3768). Despite these differences, all values remain within the standard limit, suggesting that the materials are sufficiently resistant to water penetration. Lower absorption in Treatment 0 and Treatment 3 indicates a denser and less porous structure, which is desirable for maintaining structural integrity and preventing moisture retention that could lead to deterioration or plant root damage, while the relatively higher absorption in Treatment 1 and Treatment 2 suggests increased porosity but still acceptable performance. Table 4.2 presented the ranking of treatments based on mean water absorption performance.

Table 4.2. Ranking of Treatments Based on Mean Water Absorption Performance

Ranking	Mean Value (%)	Remarks
Treatment 0	0.1049	Passed ASTM D570; Exhibited the lowest water absorption, indicating the most compact and least porous structure
Treatment 3	0.1568	Passed ASTM D570; Showed low water absorption with good moisture resistance and improved material uniformity
Treatment 2	0.3191	Passed ASTM D570; showed moderate water absorption but still within the acceptable range, indicating acceptable but less efficient moisture resistance.
Treatment 1	0.3768	Passed ASTM D570; recorded the highest absorption among treatments but remained within the standard limit, indicating higher porosity and weaker moisture resistance compared to other treatments.

Table 4.3 presents the Shapiro-Wilk Test results whereas it revealed that Treatment 0 and Treatment 3 were not normally distributed since their p values were less than 0.05. Meanwhile, Treatment 1 and Treatment 2 showed normal distribution with p values greater than 0.05. Because not all groups satisfied the normality assumption, a non-parametric statistical test was considered for further analysis.

Table 4.3. Water Absorption Shapiro-Wilk Test Results

Treatment	Test Statistic	p value	Interpretation
Treatment 0	0.735	0.002	Not normally distributed
Treatment 1	0.857	0.071	Normally distributed
Treatment 2	0.895	0.191	Normally distributed
Treatment 3	0.753	0.004	Not normally distributed

Levene's Test, indicated homogeneity of variance among the treatments since the computed p value (0.184) was greater than the 0.05 level of significance. This confirms that the variability of water absorption across the different treatments is statistically equal, satisfying the assumption of homogeneity of variances. Since the assumption of normality was not met for all treatments, the Kruskal Wallis test was utilized instead of one-way ANOVA. Table 4.4 presented the water absorption Levene's Test results.

Table 4.4. Water Absorption Levene's Test Results

Source	DF	Sum of Squares	Mean Square	F Statistic	p value
Between	3	0.00936	0.00312		
Within	36	0.06599	0.00183	1.702	0.184
Total	39	0.07536			

the Kruskal-Wallis Test showed a significant difference among the treatments in terms of water absorption ($H = 30.225$, $p = 1.24 \times 10^{-6} < 0.05$). This indicates that the different treatments significantly affected the water absorption capacity of the garden pot. The results suggest that variation in treatment composition influences the ability of the garden pot to absorb moisture, which is an important factor in determining garden pot durability and storage stability. Table 4.5 presented the water absorption Kruskal-Wallis Test Results.

Table 4.5. Water Absorption Kruskal-Wallis Test Results

Test	H Statistic	p value	Interpretation
Between Treatments	30.225	1.24×10^{-6}	Significant

4.2 Mechanical Test Results

This section presents the results of the mechanical tests—tensile strength and flexural strength—conducted to evaluate the performance of the specimen. The results were compared across the different treatments to determine variations in performance and to identify any significant differences among them. The analysis is guided by the relevant standards under ASTM D638 for tensile strength and ASTM D790 for flexural strength in testing the garden pot specimens.

4.2.1 Tensile Strength Analysis

This subsection presents the results of the tensile strength test conducted to evaluate the specimen's resistance to tensile forces. The analysis focuses on the maximum stress the specimens can withstand before failure. Figure 4.1 presents the specimen after the tensile strength analysis.

The results showed that Treatment 0 obtained the highest mean tensile strength ($M = 1.828$ MPa, $SD = 0.046$), while Treatment 1 recorded the lowest mean tensile strength ($M = 1.373$ MPa, $SD = 0.027$). This variation suggested that the composition used in each treatment influenced the bonding strength and internal structure of the material. A stronger matrix formation and better particle interaction resulted in higher tensile strength, whereas weaker bonding led to reduced tensile performance.

The high tensile strength observed in Treatment 0 indicated that the material developed a more compact and well bonded structure. When particles or components are uniformly distributed, stress is transferred effectively throughout the

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material, improving resistance to tensile loading. According to Fiore et al. (2015), tensile strength of composite materials increases when there is improved interfacial adhesion between components and reduced void formation. The higher mean value of Treatment 0 suggested that the formulation enhanced cohesion and minimized structural defects.

Figure 4.1. Specimen after Tensile Strength Analysis

Treatment 3 exhibited the second highest tensile strength (M = 1.673 MPa, SD = 0.020), indicating that this treatment also improved bonding characteristics but not as much as Treatment 0. The low standard deviation showed consistent results across samples, which implied uniform material properties. This suggested that the treatment produced a stable structure capable of withstanding tensile forces with minimal variation.

Meanwhile, Treatment 2 showed moderate tensile strength (M = 1.530 MPa, SD = 0.023). This indicated that the material possessed acceptable mechanical performance but slightly lower resistance compared to Treatments 0 and 3. The reduction in tensile strength may have been due to slight increases in voids or weaker interfacial bonding within the material structure.

In contrast, Treatment 1 recorded the lowest tensile strength among all treatments. This suggested that the material under this treatment had weaker bonding and reduced ability to resist tensile forces. According to ASTM D638, materials with lower tensile strength fail earlier under applied stress due to poor cohesion and structural discontinuities. The lower mean value observed in Treatment 1 indicated that the formulation produced a less dense structure with reduced load bearing capability.

Overall, the results indicated that tensile strength decreased from Treatment 0 to Treatment 1, then increased in Treatments 2 and 3. This trend suggested that the composition significantly affected the mechanical properties of the material. Higher tensile strength values observed in Treatments 0 and 3 indicated better structural integrity and resistance to tensile loading, while the lower value in Treatment 1 indicated weaker mechanical performance.

A study by Fiore et al. (2015) evaluated the tensile properties of natural fiber reinforced composites using ASTM D638 and found that improved bonding between matrix and reinforcement increased tensile strength, while poor interfacial adhesion reduced mechanical performance. The researchers reported that voids and weak particle interaction led to lower tensile strength values, which supported the present findings where Treatment 1 exhibited the lowest tensile strength and Treatments 0 and 3 showed improved mechanical performance.

Table 4.6 shows the summary of tensile strength results for different treatments.

Table 4.6. Tensile Strength Results Summary

	Tensile Strength			
Sample no.	**Treatment 0 (MPa)**	**Treatment 1 (MPa)**	**Treatment 2 (MPa)**	**Treatment 3 (MPa)**
1	1.745	1.322	1.528	1.643
2	1.812	1.367	1.552	1.679
3	1.797	1.351	1.521	1.685
4	1.777	1.379	1.556	1.641
5	1.889	1.375	1.537	1.673
6	1.852	1.367	1.505	1.696
7	1.863	1.415	1.566	1.681
8	1.869	1.402	1.505	1.689
9	1.809	1.355	1.512	1.692
10	1.862	1.397	1.514	1.646
Mean	**1.828**	**1.373**	**1.530**	**1.673**
Standard Deviation	**0.046**	**0.027**	**0.023**	**0.020**

Based on the mean tensile strength results, Treatment 0 ranked the highest flexural strength (1.828 MPa), second to the highest is Treatment 3 (1.673 MPa), followed by Treatment 2 (1.530 MPa), Treatment 1 recorded the lowest mean tensile strength (1.373 MPa). Treatment 0 demonstrated the best tensile strength, indicating superior bonding and a more compact internal structure, while Treatment 3 followed closely with slightly lower strength but more consistent results, as shown by its lowest standard deviation. Treatment 2 exhibited moderate performance, suggesting acceptable but weaker interfacial bonding, whereas Treatment 1 showed the poorest performance, indicating the weakest structural integrity and resistance to tensile forces.

The ranking of treatments based on mean tensile strength performance is shown in Table 4.7.

The results showed all treatments produced tensile strength values that are significantly lower than the typical range specified by ASTM D638, which is approximately 50–75 MPa for materials suitable for applications such as indoor and outdoor plant pots. The relatively low tensile strength of the developed composites may be attributed to weak interfacial bonding between the reinforcement and the matrix, which limits efficient stress transfer throughout the material. Natural fiber-based composites commonly exhibit poor compatibility due to the hydrophilic nature of the fibers and the hydrophobic characteristics of most polymer matrices, resulting in reduced mechanical performance. A study from Ng et al. (2020) has shown that inadequate interfacial adhesion, poor fiber dispersion, moisture absorption, and non-uniform processing conditions can significantly decrease tensile strength and overall structural integrity. Consequently, improving fiber treatment methods, matrix compatibility, and fabrication techniques is necessary to enhance the tensile properties of the composites and enable compliance with industry standards for structural applications.

Table 4.7. Ranking of Treatments Based on Mean Tensile Strength Performance

Ranking	Mean Value (MPa)	Remarks
Treatment 0	1.828	Exhibited the highest tensile strength among all treatment. However, it is far below the ASTM D638 requirement, indicating insufficient structural strength for load-bearing applications.
Treatment 3	1.673	Showed relatively good performance compared to other composites but still significantly below ASTM D638 standards, indicating limited tensile capacity.
Treatment 2	1.530	Demonstrated moderate tensile strength, but remains far from meeting ASTM D638 requirements, suggesting weak mechanical performance for structural use.
Treatment 1	1.373	Recorded the lowest tensile strength, indicating the weakest mechanical integrity and the greatest deviation from ASTM D638 standards.

The Shapiro-Wilk Test results in Table 4.8 showed that all treatments had p values greater than 0.05, indicating that the tensile strength data for Treatment 0, Treatment 1, Treatment 2, and Treatment 3 were normally distributed. Since the normality assumption was satisfied, parametric statistical analysis using one way ANOVA was considered appropriate.

Table 4.8. Tensile Strength Shapiro-Wilk Test Results

Treatment	Test Statistic	p Value	Interpretation
Treatment 0	0.940	0.555	Normally distributed
Treatment 1	0.977	0.949	Normally distributed
Treatment 2	0.911	0.290	Normally distributed
Treatment 3	0.845	0.051	Normally distributed

Levene's Test indicated that the variances among treatments were not homogeneous since the computed p value (0.012) was less than the 0.05 level of significance. This means that the assumption of homogeneity of variances was violated as presented in Table 4.9.

Table 4.9. Tensile Strength Levene's Test Results

Source	DF	Sum of Squares	Mean Square	F Statistic	p Value
Between	3	0.00324	0.00108		
Within	36	0.00825	0.000229	4.716	0.012
Total	39	0.01149			

The Kruskal-Wallis Test revealed a significant difference among the treatments in terms of tensile strength ($H = 36.592$, $p = 5.61 \times 10^{-8} < 0.05$). This indicates that the different treatments significantly affected the tensile strength of the garden pot. The results suggest that variation in treatment composition influences the mechanical strength of the garden pot, which is an important factor in determining durability during handling, transportation, and storage.

Since the homogeneity assumption was not met, the Kruskal Wallis test was utilized instead of one-way ANOVA as shown in Table 4.10.

Table 4.10. Tensile Strength Kruskal-Wallis Test Results

Test	H Statistic	p Value	Interpretation
Between Treatments	36.592	5.61×10^{-8}	Significant

4.2.2 Flexural Strength Analysis

This subsection presents the results of the flexural strength test conducted to evaluate the specimen's resistance to bending forces. The analysis focuses on the maximum stress the specimens can withstand under load and compares the results across different treatments. Figure 4.2 shows the specimen after the flexural strength analysis.

Figure 4.2. Specimen after Flexural Strength Analysis

Flexural strength results of the samples under different treatments based on the procedures of ASTM D790. Flexural strength measures the ability of a material to resist deformation under bending load. This property is important in evaluating stiffness, rigidity, and load bearing capacity of materials. Higher flexural strength indicates stronger resistance to bending and better structural integrity.

The results showed that Treatment 0 obtained the highest mean flexural strength ($M = 10.205$ MPa, $SD = 0.284$), while Treatment 1 recorded the lowest mean flexural strength ($M = 4.037$ MPa, $SD = 0.318$). This variation suggested that the composition used in each treatment significantly influenced the bending resistance of the material. Materials with improved bonding and denser structure exhibited higher flexural strength, whereas weaker bonding resulted in reduced stiffness.

The high flexural strength observed in Treatment 0 indicated that the material developed a more rigid and compact structure. Under ASTM D790 three point bending conditions, materials with fewer voids and stronger interfacial bonding distributed the applied load more efficiently, resulting in higher flexural strength. The results suggested that Treatment 0 produced better resistance to bending deformation and improved load carrying capability.

Treatment 3 exhibited the second highest flexural strength ($M = 7.761$ MPa, $SD = 0.398$), indicating that this treatment also improved bending performance compared to Treatments 1

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and 2. The slightly higher standard deviation suggested moderate variation among samples, but the values still indicated consistent flexural behavior. This implied that Treatment 3 produced a relatively stable structure capable of resisting bending loads.

Meanwhile, Treatment 2 showed moderate flexural strength (M = 5.245 MPa, SD = 0.284). This indicated that the material possessed acceptable stiffness, but lower bending resistance compared to Treatments 0 and 3. The reduction in flexural strength may have been due to slight increases in voids or weaker bonding within the material structure. Mehdikhani et al. (2019) explained that voids and weak interfacial adhesion decrease the efficiency of stress transfer within composite materials, leading to stress concentration points that encourage crack initiation and propagation under bending loads. These defects consequently reduce the structural integrity and flexural performance of the composites.

In contrast, Treatment 1 recorded the lowest flexural strength among all treatments. This suggested that the material under this treatment had the least resistance to bending deformation. According to ASTM D790, materials with lower flexural strength fail earlier under bending stress due to insufficient stiffness and weak internal bonding. The lower mean value observed in Treatment 1 indicated that the formulation produced a less rigid structure with reduced load bearing capability.

A study conducted by Sathishkumar et al. (2014) evaluated the flexural properties of natural fiber reinforced polymer composites using ASTM D790 and reported that improved interfacial bonding increased flexural strength, while poor adhesion and void formation reduced bending resistance. The researchers found that materials with stronger bonding exhibited higher stiffness and better load carrying capacity under bending conditions, which supported the present findings where Treatment 0 showed the highest flexural strength and Treatment 1 exhibited the lowest value. In Table 4.11, the summary of the results of the flexural strength analysis are presented.

Table 4.11. Flexural Strength Results

Sample no.	Flexural Strength			
	Treatment 0 (MPa)	**Treatment 1 (MPa)**	**Treatment 2 (MPa)**	**Treatment 3 (MPa)**
1	10.157	3.526	4.711	7.912
2	9.694	3.900	5.063	8.156
3	10.091	3.839	5.028	7.388
4	10.045	4.464	5.604	7.295
5	9.937	4.522	5.410	8.110
6	10.366	4.155	5.441	7.765
7	10.269	3.784	5.013	8.512
8	10.578	3.800	5.283	7.620
9	10.442	4.267	5.213	7.376
10	10.466	4.113	5.685	7.473
Mean	**10.205**	**4.037**	**5.245**	**7.761**
Standard Deviation	**0.284**	**0.318**	**0.284**	**0.398**

Overall, the results indicated that flexural strength decreased from Treatment 0 to Treatment 1, then increased in Treatments 2 and 3. This trend suggested that treatment composition significantly affected bending performance. Variations in composite composition are known to influence flexural strength because changes in reinforcement content, matrix distribution, and interfacial bonding directly affect stress transfer and load-bearing capacity. Higher flexural strength values observed in Treatments 0 and 3 indicated better stiffness and structural stability, while the lower value in Treatment 1 indicated reduced resistance to bending loads. According to Jawaid et al. (2011), the mechanical and flexural properties of natural fiber-reinforced composites are highly dependent on fiber loading, dispersion, and the quality of adhesion between the fiber and matrix, all of which influence bending resistance and stiffness.

The ranking of flexural strength based on the mean flexural strength values, the Treatment 0 ranked the highest (10.205 MPa), Treatment 3 is the second highest (7.761 MPa), followed by Treatment 2 (5.245 MPa), and Treatment 1 recorded the lowest flexural strength (4.037 MPa). Treatment 0 demonstrated the best flexural performance, indicating superior resistance to bending forces and suggesting a stronger and more cohesive internal structure that allows efficient stress distribution under load. Treatment 3 ranked second, showing relatively high flexural strength and acceptable consistency, which implies that its composition also promoted good material integrity, although not to the same extent as Treatment 0. Treatment 2 exhibited moderate performance, reflecting a material that can withstand bending but with reduced stiffness, possibly due to weaker interfacial bonding or minor structural defects. In contrast, Treatment 1 showed the lowest flexural strength, indicating poor resistance to bending and suggesting a less rigid and less compact structure.

The flexural strength results revealed clear differences in bending performance among the treatments, with Treatment 0 obtaining the highest mean value. Despite these variations, all treatments produced flexural strength values that are substantially lower than the typical range specified for structural composite materials under ASTM D790 standards. This significant disparity indicates that, although the developed composites show relative improvements in flexural behavior, their overall strength remains insufficient for applications requiring high load-bearing capacity. Lower flexural strength in composite materials is commonly associated with inadequate fiber–matrix adhesion, void formation, uneven reinforcement dispersion, and insufficient stress transfer within the material structure. These factors reduce the ability of the composite to resist deformation and crack propagation under bending loads (Mehdikhani et al., 2019; Jawaid et al., 2011). Consequently, further enhancement in material composition, processing methods, and interfacial adhesion is necessary to improve flexural strength and achieve compliance with established standards.

Table 4.12 shows the ranking of treatments based on mean flexural strength performance.

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Table 4.12. Ranking of Treatments Based on Mean Flexural Strength Performance

Ranking	Mean Value (MPa)	Remarks
Treatment 0	10.205	Exhibited the highest flexural strength, indicating the best bending resistance, but still far below the ASTM D790 requirement
Treatment 3	7.761	Demonstrated good flexural performance among composites yet remains significantly below ASTM D790 standards.
Treatment 2	5.245	Exhibited moderate flexural strength, indicating limited bending resistance and not meeting ASTM D790 requirements.
Treatment 1	4.037	Recorded the lowest flexural strength, showing poor bending resistance and the greatest deviation from ASTM D790 standards.

The Shapiro-Wilk Test results in Table 4.13 showed that all treatments had p values greater than 0.05, indicating that the flexural strength data for Treatment 0, Treatment 1, Treatment 2, and Treatment 3 were normally distributed. Since the assumption of normality was satisfied, parametric statistical analysis using one way ANOVA was considered appropriate.

Table 4.13. Flexural Strength Shapiro-Wilk Test Results

Treatment	Test Statistic	p value	Interpretation
Treatment 0	0.970	0.891	Normally distributed
Treatment 1	0.956	0.738	Normally distributed
Treatment 2	0.972	0.908	Normally distributed
Treatment 3	0.929	0.437	Normally distributed

Levene's Test shown in Table 4.14 indicated homogeneity of variance among the treatments since the computed p value (0.514) was greater than the 0.05 level of significance. This confirms that the variability of flexural strength across the different treatments is statistically equal, satisfying the assumption of homogeneity of variances. Since both assumptions of normality and homogeneity of variances were met, a one-way ANOVA was applied.

Table 4.14. Flexural Strength Levene's Test Results

Source	DF	Sum of Squares	Mean Square	F Statistic	p value
Between	3	0.06969	0.02323		
Within	36	1.01724	0.02826	0.822	0.514
Total	39	1.08693			

Table 4.15. Flexural Strength ANOVA Test Results

Source	DF	Sum of Squares	Mean Square	F Statistic	p Value
Between	3	222.675	74.225		6.11×10^{-32}
Within	36	3.828	0.106	698.159	
Total	39	226.503			

Shown in Table 4.15, the ANOVA results indicated that there were significant differences among the treatments in terms of flexural strength ($F(3,36) = 698.159$, $p = 6.11 \times 10^{-32} < 0.05$). This suggests that the flexural strength significantly varies across the different treatments. The results indicate that treatment composition has a significant influence on the bending strength of the material, which affects resistance to fracture and structural performance during loading.

4.3 Comparative Analysis of the Mechanical and Physical Properties of Experimental and Commercial Garden Pots

This section presented the comparative analysis between the best performing experimental garden pot formulation and the commercial garden pot. Based on the results of water absorption, tensile strength, and flexural strength, Treatment 0 demonstrated the most favorable overall performance among all experimental ratios. It consistently exhibited the lowest water absorption, indicating a denser structure with fewer voids and reduced moisture penetration, which is essential for durability. In addition, Treatment 0 achieved the highest tensile strength and flexural strength, reflecting superior resistance to both pulling and bending forces. Thus, Treatment 0 was selected for comparison with the commercial garden pot.

Table 4.16 shows the comparison of the mechanical and physical properties of the best experimental ratio and the commercial garden pot.

Table 4.16. Comparative Mechanical and Physical Properties of the Best Experimental Garden Pot and Commercial Garden Pot

Property	Best Experimental Ratio (Treatment 0)	Commercial Garden Pot	Remarks
Water Absorption (%)	0.1049	0.0014	The commercial garden pot exhibited superior moisture resistance
Tensile Strength (MPa)	1.828	22.127	The commercial pot shows significantly higher tensile strength
Flexural Strength (MPa)	10.205	25.683	The commercial pot provides greater resistance to bending, the experimental pot

A comparative evaluation between the optimized experimental formulation (Treatment 0) and the commercial control reveals distinct variations in both physical and mechanical characteristics. In terms of water absorption, the commercial garden pot exhibited a significantly higher density and superior moisture resistance, yielding a mean absorption of 0.0014%. In contrast, Treatment 0 recorded a higher mean absorption of 0.1049%. These results indicate that the experimental composite possesses a more porous micro-structure compared to the commercial product; nevertheless, Treatment 0 demonstrated the highest resistance to water ingress among all the experimental variations. Structural defects such as microcracks and weak bonding promote moisture infiltration and retention in composites (Huang et al., 2006).

Regarding mechanical properties, the commercial garden pot outperformed the experimental specimens in both tensile and flexural testing, achieving values of 22.127 MPa and

25.683 MPa, respectively. According to McClements (2022) High-density polyethylene (HDPE) is known for its toughness, flexibility, and impact resistance rather than high strength. Compared to PET, it typically has lower tensile (15.2–45 MPa) and flexural strength (16.5–91 MPa), depending on material grade and processing. Although the results in this study did not meet ASTM D638 and ASTM D790 standards. By comparison, the most effective experimental ratio (Treatment 0) yielded a tensiby strength of 1.828 MPa and a flexural strength of 10.205 MPa. As the chain length decreases, there is a significant reduction in tensile strength and flexural strength (Taylor & Francis, 2019). The disparity in tensile performance suggests that the internal bonding within the experimental matrix is less robust than that of the industrial-grade HDPE used in commercial manufacturing. However, within the scope of the experimental group, Treatment 0 consistently exhibited superior structural cohesion, rigidity, and deformation resistance.

4.4 Data Analysis of the Comparison Between Best Experimental Garden Pot (Treatment 0) and Commercial Garden Pot

The comparison between the best experimental garden pot formulation (Treatment 0) and the commercially available garden pot highlights differences in water absorption, tensile strength, and flexural strength. The experimental garden pot demonstrated acceptable but higher water absorption and lower mechanical strength, while the commercial garden pot exhibited superior resistance to moisture and greater mechanical performance. To determine whether these observed differences are statistically significant, an independent sample t test was performed using the average values of the parameters. The data used in the analysis were obtained from the summarized comparison results of the experimental and commercial garden pots.

Table 4.17 shows the summary of the comparison between the best experimental ratio and the commercial garden pot.

Table 4.17. Summary of Average Comparison Between Best Experimental Garden Pot (Treatment 0) and Commercial Garden Pot

Parameters	Experimental Pot (Treatment 0)	Commercial Garden Pot
Water Absorption (%)	0.1049	0.0014
Tensile Strength (MPa)	1.828	22.127
Flexural Strength (MPa)	10.205	25.683

The group statistics show that the experimental garden pot obtained a mean value of 4.0466 with a standard deviation of 5.307, indicating moderate variability among the measured properties. Meanwhile, the commercial garden pot recorded a higher mean value of 15.9371 with a standard deviation of 13.391, suggesting greater dispersion due to the large differences in tensile and flexural strength values. The higher standard deviation in the commercial pot is mainly influenced by its significantly higher tensile strength compared to the other parameters. Table 4.18 shows the group statistics.

Table 4.18. Group Statistics

Group	N	Mean	Std. Deviation	Std. Error Mean
Experimental Pot	3	4.0466	5.307	3.064
Commercial Pot	3	15.9371	13.391	7.730

The Levene's Test result showed a significance value of 0.214 which is greater than 0.05, indicating that equal variances can be assumed between the experimental garden pot and the commercial garden pot. This means that the variability between the two groups is not significantly different.

The independent sample t test produced a computed t value of approximately -1.36 with a significance value greater than 0.05. This indicates that there is no statistically significant difference between the overall performance of the experimental garden pot and the commercial garden pot at the 5% level of significance. The mean difference between the two groups was notable; however, the variability within the data contributed to the non-significant result as shown in Table 4.19.

Table 4.19. Independent Sample t-Test

Levene's Test for Equality of Variances	t test for Equality of Means
F	Significance
2.184	0.214

V. Conclusion and Recommendations

This section presents the conclusions drawn from the results of the study and provides recommendations for improving the developed garden pot and guiding future research to enhance the feasibility and sustainability of the developed product.

5.1 Conclusions

Based on the findings and analyses carried out in this study, the following conclusions are drawn in alignment with the established research objectives:

1. Treatment 0 (pure PET) had the lowest water absorption value (0.1049%), indicating a dense and less porous structure. Among the composite treatments, Treatment 3 (1:5 ratio) exhibited the lowest water absorption, suggesting improved material uniformity and reduced permeability. In contrast, Treatments 1 and 2 demonstrated higher water absorption, which can be attributed to increased porosity and weaker interfacial bonding within the material. Statistical analysis further confirmed that there is a significant difference among the treatments, indicating that the composition of the material strongly influences its moisture absorption behavior. In relation to ASTM D570, which requires plastics to exhibit minimal water absorption (0%–0.5% for non-porous materials), all treatments passed the acceptable range. However, Treatment 0 performed best as it is closest to an ideal non-porous condition, while the composite treatments showed slightly higher but still acceptable absorption levels, indicating maintained structural integrity and reduced risk of moisture-related degradation

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2. Treatment 0 exhibited the highest tensile strength (1.828 MPa) and flexural strength (10.205 MPa), indicating superior structural integrity. Treatment 3 ranked second in both tensile (1.673 MPa) and flexural strength (7.761 MPa), making it the best-performing composite among the modified formulations. In contrast, Treatment 1 showed the weakest mechanical performance, which can be attributed to poor interfacial bonding within the material. Statistical analysis further confirmed that there are significant differences in tensile and flexural strength across the treatments, highlighting the strong influence of material composition on mechanical performance. However, when evaluated against ASTM D638, which typically requires tensile strength in the range of 50–75 MPa for durable applications such as indoor and outdoor plant pots, and ASTM D790, which typically requires flexural strength in the range of 70–110 MPa, all treatments failed to meet the required standards. Although Treatment 0 and Treatment 3 showed relatively better performance among the samples, their values remain significantly below the recommended thresholds, indicating insufficient structural strength for full-scale commercial or load-bearing applications.
3. Treatment 0 is the most feasible in terms of overall performance, as it exhibited the best mechanical and physical properties. However, among the composite formulations, Treatment 3 is considered the most feasible, as it provides a balance between acceptable strength and sustainability through higher utilization of waste materials.
4. In comparison with the commercial garden pot, the experimental pot exhibited higher water absorption and lower tensile and flexural strength. The commercial pot demonstrated superior durability and structural integrity. The results show that material composition affects both physical and mechanical properties. Recycled PET combined with mangrove clam shells can be used for making garden pots, but further development and improvement is needed to match the quality of commercial products.

5.2 Recommendations

Based on the results of the study and its alignment with the stated objectives, the following recommendations are suggested:

1. The use of BASF Joncryl® ADR-4400 or ADR-4468 as reactive chain extenders in PET processing is recommended. These additives can increase the molecular weight and intrinsic viscosity of recycled PET, improve bonding between PET and clam shell particles, enhance tensile and flexural strength, and reduce micro voids that cause water absorption to improve the mechanical properties of the composite material.
2. The SSP process should be applied to improve PET quality by increasing intrinsic viscosity and molecular chain length, enhancing thermal stability and strength, reducing recycling-related degradation, and producing higher-quality recycled PET suitable for structural use. This step may help the material achieve properties closer to commercial plastics (Elant Machinery, 2025).
3. Chemical treatments such as silane coupling agents are recommended to improve compatibility between PET and clam shell particles, enhance bonding and stress transfer, and reduce voids and water absorption.
4. Processing should be improved through better material mixing and dispersion, controlled temperature and pressure during molding, and optimized extrusion or compression molding to reduce defects and improve product quality.

Datu Mohammad Alsabri K. Tajul and Engr. Ilde B. Deloria, "CLAPET Pot: Development of Garden Pot Using Polyethylene Terephthalate (PET) Plastic Waste and Mangrove Clam Shells (Anodontia philippiana)," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 9, Issue 2, pp. 912-932, July 2026.