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Fabrication and characterization of bamboo fiber- reinforced polyethylene-polystyrene composites using glycerol as plasticizer

Kristin B. Labasan*, Faculty of Science, Technology and Mathematics, College of Teacher Development, Philippine Normal University, Manila, Philippines.

Aldrine Jay G. Espinosa, Faculty of Science, Technology and Mathematics, College of Teacher Development, Philippine Normal University, Manila, Philippines.

Rebecca C. Nueva España, College of Graduate Studies and Teacher Education Research, Philippine Normal University, Manila, Philippines.

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Abstract

Fiber-reinforced polymer composites are composed of a polymer matrix (PE-PS) combined with a fiber (bamboo fibers) to provide conspicuous reinforcement. In light of recycling plastic and natural fibers, the research aim to fabricate and characterize bamboo fiber-reinforced polyethylene-polystyrene composites using glycerol as plasticizer. Specifically, the study investigated the effect on the physical and mechanical properties and water absorption of the composites by varying the following parameters: substitution of glycerol instead of the usual cooking oil in fabrication of DRM, and bamboo fiber loading. Using 1:3 PE-PS ratio, glycerol incorporation was done in DRM by melting together plastic and styrofoam wastes using a densifying machine at 150˚C. DRM samples with 70% (w/w) glycerol incorporation were then compared to the original DRM samples with 70% (w/w) cooking oil. The modified DRM were then loaded with 1, 2 and 3% bamboo fiber-reinforcement using a two-roll mill at 200˚C and compression molding machine at 200˚C and 50 kg/cm2 for 5 mins in the aluminium mold. The composites were characterized by Universal Testing Machine (tensile strength) following the ASTM standard D638. In addition, water absorption of the fabricated composites was tested using the standard method specified by ASTM D570.The bamboo fiber-reinforced polyethylene-polystyrene composites at 1:3 PE: PS ratio rendered better tensile strength and less water absorbed using 70% (w/w) glycerol as plasticizer and at

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*ADDRESS FOR CORRESPONDENCE: **Dan Jiang,** Master of Information Technology in Education, Faculty of Education, the University of Hong Kong China. *E-mail address*: bjiang@kennesaw.edu

1% bamboo fiber loading. For future studies, it is recommended to study the impact of different parameters (glycerol percentage, time, temperature, pressure, fiber type and dimensions, fiber extraction, etc.) in the fabrication of the fiber-reinforced recycled plastic composites. Other characterizations of the fabricated plastic composite including thermal properties, leaching and biodegradation experiments and compressive and flexural strengths can also be done.

Keywords: Fiber-reinforced polymer, plasticizer, composites.

1. Introduction

The rapid population growth of world, especially in the Philippines, has paved way for the frequent piling up of wastes on the environment. Most of the wastes sit in landfills, possibly to remain there for long periods before time uncovers them again. Some go in rivers and seas, killing aquatic animals like turtles that mistake plastic bags for jelly fish. While the rest of these non-biodegradable wastes get stuck in drainage systems and estuaries bringing more complex problems like great floods during rainy seasons. Greater awareness of the need for new resources which are potentially biodegradable, eco-friendly in nature and has better overall performance resulted into extensive research and development efforts in the composites fields today.

Fiber-reinforced polymer composites are composed of a polymer matrix combined with a fiber to provide conspicuous reinforcement. Agro-based fibers (i.e., bamboo fibers) are combined with materials such recycled plastics (i.e., polyethylene and polystyrene) in order to produce new classes of composite materials which provide positive environmental benefits with respect to ultimate disposability and best utilization of raw materials. A compatibilizer or plasticizer (i.e., cooking oil and glycerol) can be also used to make the hydrophobe (plastic) mix better with the hydrophil (lignocellulosic) (Malkapuram, Kumar & Negi, 2009).

Natural fibers are composed mainly of cellulose and some lignin and are sometimes called lignocellulosic fibers (Hassan, You, He & Yu, 2012). Bamboo fibers known as ‘bundle sheaths’ for example, from the upright stems of the bamboo, called culms or canes, (Dobbs, 2008) contains 44.5 % cellulose, 20.5 % lignin, 32 % soluble matter, 0.3 % nitrogen and 2 % ash (Amada & Lakes, 1997). Its cellulose microfibrils are embedded in a matrix of lignin and hemicellulose. It appears that such an alignment renders maximum tensile and flexural strengths, in addition to providing rigidity in that direction of the fiber as observed in the case of bamboo (Kuruvilla, Romildo, Tolêdo, Beena, Sabu & Laura, 1999). It can therefore be expected that when these fibers are incorporated in low modulus polymer matrices, they would yield materials with better properties suitable for various applications.

The utilization of green, recycle draw materials in the study could provide an alternative way to solve the problems associated with agriculture residues and plastic wastes. Aside from that, combining a natural fiber to common plastic wastes like polyethylene (PE) and polystyrene (PS) could offer a cost reduction to the plastic industry, since prices for plastics have risen sharply over the past few years, but to the agro-based industry, this could signify an increased value for the agro-based component.

In light of recycling plastic and natural fibers, the research aimed to fabricate and characterize bamboo fiber-reinforced polyethylene-polystyrene composites using glycerol as plasticizer. Furthermore, this study provided a standard source of reliable and experts-tested mechanical properties (i.e., maximum load and tensile strength) and percent water absorption of the fabricated composites using bamboo fibers as reinforcement. The effects of the varied amounts of composite constituents - the fibers, matrix material, and plasticizer – on the bamboo fiber -reinforced plastic composites were also reported.

This study fabricated and characterized bamboo fiber-reinforced polyethylene-polystyrene composites using glycerol as plasticizer.

Specifically, this study answered the following questions:

1. What is the effect of incorporating glycerol instead of usual cooking oil in fabricating the densified recycled material, DRM?
2. What is the effect of reinforcing the modified DRM (with optimum ratio 1:3 PE: PS and glycerol incorporation) with bamboo-fiber at increasing fiber loading (1, 2, and 3%)?
3. What are the characteristics of the fabricated bamboo fiber -reinforced recycled plastic composites using glycerol as plasticizer in terms of:

3.1. Mechanical Properties;

    3.1.1. Maximum Load,

    3.1.2. Tensile Strength,

3.2. Water Absorption Test?

2. Densified Recycled Material

With the intensifying environmental awareness and growing health concerns about the disposal of plastics, recycling and fabrication of biodegradable polymers and its applications in various fields have received much attention (Tao, Yan, & Jie, 2009). At the same time, high demands on materials having better overall performance has led to extensive research and development efforts in the fiber-reinforced composites fields today.

“Mechanical Properties of Recycled PET Fibers in Concrete” by Pelisser Montedoa, Gleizeb, and Romanb (2012) explored the use of polyethylene terephthalate (PET), a polyester polymer obtained from recyclable bottles to produce fibers to obtain cement-based products with improved properties. While “Thermal and Mechanical Properties of LDPE/Sisal Fibre Composites Compatibilized with Paraffin Waxes” in the study by Nhlapo (2010) investigated the effects of maleic anhydride grafted Fitscher-Tropsch paraffin wax (MA-g-wax) and oxidised Fischer-Tropsch paraffin wax (OxWax) content on the morphology, thermal, mechanical and thermomechanical properties of LDPE/sisal fibre composites.

Most of these researches focused on recycling wood wastes as source of reinforcing fibers, and little has explored the use of plastic wastes as raw materials for the composite matrix (Gotico, 2011). It is in this viewpoint that the innovative approach of recycling plastic wastes (Figure 1a) in local communities comes into play

Figure 1a The plastic waste recycling process

Figure 1b DOST Densifying Machine in Marikina City

The technology on processing waste styropor using the "Styro Oven" or now the Densifier was developed in cooperation with the Packaging Council of the Philippines (PCP) in 2004. In 2006, the Philippine Plastic Industrial Association (PPIA) adopted the same technology (improved) for processing waste plastic bags (PE, PS). Plastic wastes, especially PS and PE, in Marikina City has been densified into different materials using the pilot-scale densifying machine of DOST (Figure 1b). The Densified Recycled Material (DRM) is a portable, mobile unit that mainly involves the densification of "waste styro" or "plastic bags" by melting them with vegetable cooking oil at a controlled heating temperature; converting the waste styro/plastic bags into rigid functional products. The technology offers simple, affordable, environmentally decentralized plastic recycling method at community level.

Figure 2a Molding of molten waste plastic by casting

Figure 2b Application of DRM as planters, tabletops and bricks

The LPG-fired three-line burner styrofoam oven/plastic densifier is made up of a steel casserole with cover, double jacketed body with a melting capacity of 50 kgs per batch, a motorized blunger for homogeneous mixing, and a cylindrical steel downspout to facilitate the discharge of melted plastic during casting into the metal molds (Figure 2a).Its features also include an exhaust/chimney installed with a charcoal stack to absorb smoke emission during melting and a temperature recorder for the melting temperature (Monsada, 2011).

The resulting molten waste plastic (DRM) is easily molded by casting into the metal moulds which displayed potential uses for tabletops, planters, blocks for pathways, floorings, and other valuable functional products (Figure 2b). However, the commercialization sustainability of densified styro and plastics may be uncertain due to limited product markets and the novelty products of densification are still not competitive with the conventional alternatives. Thus, the reinforcement of the DRM with bamboo fibers could help yield materials with better properties suitable for various applications.

3. Fiber-reinforcement

The discovery of using fibers as reinforcement in composite materials is never new to mankind. Man had used this idea for a long time, since the beginning of our civilization when grass and straw were used to reinforce clay and mud to make an adobe brick (Nhlapo, 2010). This reinforcement greatly improved the strength of the early buildings.

To improve the mechanical properties of the DRM, the research explored the aspect of fabricating fiber-reinforced polymer composites using recycled plastics as the polymer matrix and natural fibers as reinforcement filler. Conventional fiber-reinforced composites using glass, carbon, and aramid fibers show high mechanical and thermal properties but they produce residues upon disposal by incineration causing environmental problems (Gotico, 2011). Thus, to overcome this drawback, utilizing natural fibers from plants and woods were sought after. Natural fiber-reinforced biodegradable polymer composites promote the use of lignocelluloses bio fibers in place of synthetic fibers as reinforcing materials. Plants, such as grass, cotton, abaca, palm tree, sisal, coconut, pineapple, bamboo, banana, etc., as well as wood, as a source of lignocellulosic fibers, appears to be advantageous especially since they are abundant to most agricultural lands in the Philippines. With the Philippines' abundant supply of bamboo, the fabrication of bamboo fiber-reinforced DRM would help promote bamboo industry in the country.

Kuruvilla et.al (1999) surveyed research works published in the field of sisal fiber reinforced polymer composites with special reference to the structure and properties of sisal fiber, processing techniques, and the physical and mechanical properties of the composites. Singha and Thakur's (2008) study on the synthesis and mechanical properties of new series of green composites involving *Hibiscus sabdariffa* fiber as a reinforcing material in urea–formaldehyde (UF) resin based polymer matrix reported that mechanical properties such as tensile strength, compressive strength and wear resistance etc. of the urea–formaldehyde resin increases to considerable extent when reinforced with the fiber. Hassan et al. (2012) found out that natural fibers reinforced PLA composites are a completely renewable materials with a promising mechanical properties as compared to non-renewable petroleum based products. Okubo, Fujii and Yamamoto (2009) developed hybrid bio-composites based upon a biodegradable (PLA) matrix reinforced with micro fibrillated cellulose (MFC) and bamboo fiber bundles. They found that by adding just 1wt% of MFC with a high degree of dispersion an increase in fracture energy of nearly 200% was obtained.

In recent times, natural fiber-reinforced plastic composites receive increasing market demand in applications such as transportation (automobiles, railway coaches, aerospace), military applications, building and construction industries (ceiling paneling, partition boards), packaging, consumer products, etc. (Tudu, 2009).

4. Bamboo Fibers

Natural fibers are composed mainly of cellulose and some lignin and are sometimes called lignocellulosic fibers (Hassan et al., 2012).These cellulose fibrils are aligned along the length of the fiber, irrespective of its origin, whether it is extracted from stem, leaf or fruit. Bamboo fibers (Figure 3a) for example, came from the upright stems of the bamboo, called culms or canes (Figure 3b), consist of nodes (rings where branches originate) and internodes (the spaces between the nodes) (Dobbs, 2008).

Figure 3a Bamboo fibers (powdered form)

Figure 3b Culms of Bambusa blumeana

From a botanical point of view, bamboo is not wood but grass. Many bamboo species exist, but the one used the study is the *Bambusa blumeana* under the family *Poaceae/Graminae*. It is known locally in Philippines as Kawayang Tinik. *Bambusa blumeana* is a thorny bamboo with slightly arching green culms of 15-25 m tall. The internodes are 25-35 cm long, with 8-15 cm in diameter and an average wall thickness of 2-3 cm. At the base of the culms, wall thickness is mostly solid, especially in dry areas or poor soils. Lower culm nodes show a ring of aerial roots, with a gray or brown ring below and above the sheath scar. (® Guadua Bamboo, 2013)

Bamboo fiber contains 44.5 % cellulose, 20.5 % lignin, 32 % soluble matter, 0.3 % nitrogen and 2 % ash (Amada & Lakes, 1997). Its cellulose microfibrils are embedded in a matrix of lignin and hemicellulose. It appears that such an alignment renders maximum tensile and flexural strengths, in addition to providing rigidity in that direction of the fiber as observed in the case of bamboo.

Furthermore, these fibers exhibit high electrical resistance in addition to being thermally and acoustically insulating (Kuruvilla et al. 1999). It can therefore be expected that when these fibers are incorporated in low modulus polymer matrices, they would yield materials with better properties suitable for various applications.

In a study by Sudin and Swamy (2006) the development of eco-friendly bamboo and wood fiber cement composites from agriculture wastes for applications in the housing and building industries, and for sustainable infrastructure regeneration has been undertaken. They found out that with the bamboo, the composition of the particleboard was then optimized in terms of bamboo-cement ratio and the type and amount of chemical admixture to produce a composite with satisfactory strength and dimensional stability. A study by Mounika et al. (2012), focused on thermal conductivity characterization of bamboo fiber-reinforced composite by varying volume fraction, temperature and fiber angles (0˚, 45˚ and 90˚). The results of the study indicate that the developed composite is an insulating material which can be used in building and "automotive industry to save energy by reducing rate of heat transfer. Okubo et al.’s (2009) study on the “Development of bamboo-based polymer composites and their mechanical properties” revealed that the bamboo fibers (bundles) had a sufficient specific strength, which is equivalent to that of conventional glass fibers.

Bamboo fibers can be extracted through mechanical needling, scraping, retting, or through a steam explosion process (Okubo et al., 2009; Kongkeaw, Nhuapeng & Thamajaree, 2011; Mounika, Ramaniah, Prasad, Mohana & Hema, 2012). Bamboo fiber can be also in a pulped form in which the material (as used in the study) is extremely fine and in a powdered state. Once the fibers are obtained, various approaches of its use in composites and as an additive in biopolymers for construction include powder/particle size, short fiber and long fiber reinforcement. It has been established that with particle reinforcement, compressive strength increases to a much more extent than short and long fiber reinforcement. Furthermore, it was observed that particle reinforcement is more effective in decreasing wear rate than short and long fiber reinforcements (Malhotra, Sheikh, & Rani, 2012).

Filler load of the fibers can be also varied into different volumes. Li et al. (2010) reported that flax fiber content from 10- 30% by mass was mixed with high density polyethylene (HDPE) by extrusion and injection molding to produce bio-composites. The results showed that increasing fiber content resulted in increasing tensile properties initially, it peaked at 20 % by volume; it then dropped. On the other hand, the tensile strengths of 20-mesh hardwood fibers reinforced HDPE composites reduced with increasing fiber loading. While a study on the “Fabrication of Coconut Fiber-reinforced Densified Recycled Material (DRM) using a Laboratory Scale Densifier” by Gotico (2012) revealed that at 1, 2, 3, 4% coconut fiber loading, the mechanical properties such as tensile strength of the DRM were at its best. Consequently, increased fiber loading decreased the strength of the DRM.

Bamboo fibers’ price, availability, renewability, low density, and lack of residues upon incineration as well as satisfactory mechanical properties make them a valuable component used in the manufacturing of polymer composites (Sahari & Sapuan, 2011).

5. PE and PS polymer matrix

The matrix part of a composite is composed of polymers (plastic), preferably thermoplast resin such as recycled polyethylene (PE) or polystyrene (PS) wastes. The polymer serves as the glue to hold the fibers together and mainly functions to transfer stress between the reinforcing fibers, and keep the fibers from mechanical and environmental damage (Gotico, 2011). Thus, the composite strength is determined not only by the strength of the fiber but also by the ability of the matrix to transmute stress to the fiber.

As shown in studies, (Gotico 2011; 2012) polymer blends of PE and PS sheets with ratios 1:0,1:1,1:2,1:3,3:1, 2:1,0:1 showed no observable differences in physical appearance with the exception of pure PE (1:0) being colorless. While a uniform blend were observed at pure PE, pure PS, 3:1 PE: PS, and 1:3 PE: PS indicating good mixing. The mechanical properties of the sheets of polymer blends of PE and PS were also analyzed using a UTM (using ASTM D638) as summarized in Table 1.

Table 1. Tensile strength and energy absorbed by blends of PE and PS (Gotico, 2011)

Ratio of PE: PS	Tensile Strength (MpA)	Energy (J)
Pure PE 1:0	19. 75	2.26
3:1	17.44	0.82
2:1	16.59	0.40
1:1	12.31	0.18
1:2	7.45	0.07
1:3	16.00	0.28
Pure PS 0:1	31.00	1.14

PE dominated blends (pure PE, 3:1 and 2:1) exhibited high toughness (greater energy at fracture) and low tensile strength while PS dominated blends (pure PS and 1:3) exhibited high tensile strength but low toughness. The increase of tensile strength and toughness of the blend at (1:3), showed better adhesion between the polymer components that resulted to reinforced properties of the blends. Gotico, showed the optimized mechanical properties of DRM can be achieved using 1:3 PE: PS ratio. Thus, 1:3 PE: PS ratio was utilized in the study.

Plastic (PE) and styrofoam (PS) wastes have been two of the major contributors in the accumulation of non-biodegradable wastes in Marikina City. In order to provide help and give potential solution to the problem, recycling efforts have been made in the locality including making fertilizers out of vegetable wastes and densification of plastic and styrofoam wastes (called Densified Recycled Material, DRM) into tiles, bricks, pots, and tabletops.

Recyclable plastic materials such as PE and PP are combined with wood fiber to make valuable reinforced thermoplastic composites. The use of plastic wastes such as polyethylene (PE) combined with polystyrene (PS) as the matrix resin of the polymer composite do not only reduce the amount of solid waste to be disposed into the landfills but also makes available large volumes of valuable raw materials for use instead of virgin resources. The fabricated composites made from recycled plastics reduce both costs for raw materials and renders alternative solutions to the problem in solid waste management and disposal of the country.

6. Glycerol Plasticization

Glycerol, a simple, colorless, odorless and viscous, low toxicity polar compound is central backbone to triglycerides in cooking oil (Figure 4). It has a density of 1.26130 grams per cubic centimetre (g/cm^3) and a boiling point of 290 °C or 563 K. It is abundant especially since it is a by-product in soap-making. It has three hydroxyl groups that are responsible for its high solubility in water and its hygroscopic nature.

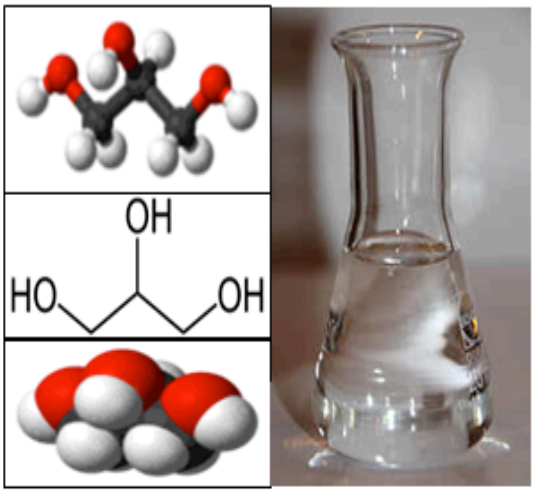

Figure 4. Glycerol structure and appearance

Glycerol as used in the research, acts as a plasticizer which increases the plasticity or fluidity of the material by decreasing the glass transition temperature of the material to which they are added. They decrease the viscosity of the polymer melt as they embed themselves between the chains of polymers, spacing them apart. In addition, glycerol has a higher-thermal conductivity (0.29 W/mk) compared to cooking oil (0.15 W/mk), making it ideal as a heating element in melting together the plastic wastes (European Council for Plasticizers and Intermediates).

Most of the current researches concentrated on using a compatibilizer or plasticizer to make the hydrophobe (plastic) mix better with the hydrophil (lignocellulosic), identify glycerol as one of the common sources (Funke, Bergthaller & Lindhauer, 1998; Angeles, 2001). The two components remain as separate phases, but if delimitation and/or void formation can be avoided, properties can be improved over those of either separate phase. Similar studies proved that glycerol can provide better interaction to the polar side groups of the natural fiber (made out of cellulose and lignin) thereby promoting better interfacial adhesion between the fiber and the polymer matrix (Bergthaller, 1995; Angeles, 2001; Gotico, 2011).

Analysis of fiber-reinforced DRM samples (Gotico, 2011) revealed that there is an increase in the transition temperature of the DRM with glycerol (120˚C) compared to using cooking oil (106˚C). This indicates that the material have become more rigid in the presence of glycerol. Because of the greater polarity of glycerol compared to cooking oil, it has not successfully embedded itself between the polymer chains thereby enhancing the free volume of the chains and hence the transition temperature. Furthermore, observations in the resulting material shows not only good texture (glossy and less waxy), but also the bad smell from cooking oil was significantly reduced. On top of that, glycerol has actually made the material stronger as shown in the evaluation of the mechanical properties of a fabricated DRM. It showed that good tensile strength and toughness of the material were achieved using glycerol compared to using cooking oil (Gotico 2011; 2012).

7. Materials and Methods

This chapter describes the details on the fabrication and characterization of bamboo fiber-reinforced PE-PS composites using glycerol as plasticizer. The experiment was done by dividing the procedure into three phases as shown in Figure 5.

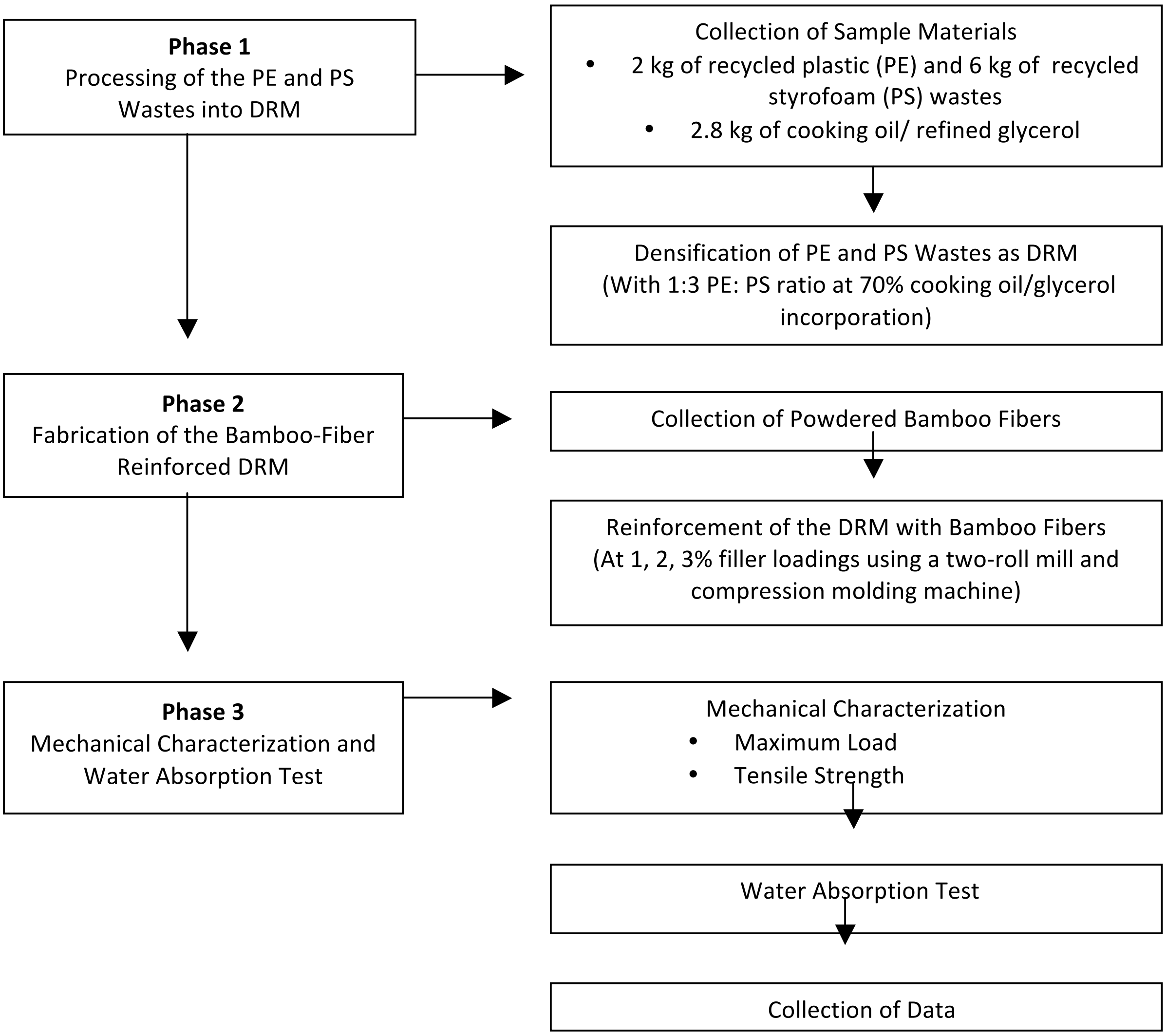

Figure 5. Schematic Diagram of the Methodology

8. Research Design

DRM samples composed of recycled PE and PS wastes, controlled at 1:3 ratio were incorporated with 70% (w/w) glycerol. These DRM samples were compared (in terms of physical and mechanical properties) to the original DRM produced using 70% (w/w) cooking oil as the heating element. The fiber reinforcement was varied into increasing fiber loadings (1, 2, and 3%) with its effect on the composites' physical, mechanical properties and water absorption observed. All composite samples have the same mass, 1:3 PE: PS ratio, glycerol incorporation and type of fiber reinforcement (powdered bamboo fibers).

Phase 1- Processing of the PE and PS Wastes into DRM

9. Collection of Sample Materials

Plastic and styrofoam wastes and used cooking oil were procured from City Environmental Management Office at Marikina City. A total of 2kg of plastic (PE) and 6kg of styrofoam (PS) wastes were gathered onsite, following the 1:3 PE: PS ratio. Refined glycerol samples were bought from chemical stores at Bambang, Sta. Cruz Manila City. A total of 2.8 kg of used cooking oil /refined glycerol which constituted 70 % of the total weight of wastes were used to melt the waste mixture at 150˚C as shown in Table 2.

Table 2. Amount of PE, PS and glycerol at different glycerol incorporation and 1:3 PE: PS ratio

% Plasticizer (w/w)	Amount of PE (kg)	Amount of PS (kg)	Total mass of the DRM (kg)	Oil/ Glycerol (kg)
Oil 70	1	3	4	2.8
Glycerol 70	1	3	4	2.8
Total	2	6		

10. Densification of PE and PS Wastes as DRM

Refined glycerol was used as a heating element and plasticizer in mixing heterogeneous plastic and styrofoam wastes in a densifying machine of City Environmental Management Office (CEMO), Marikina City. A total of 2.80kg of refined glycerol, which constituted70% of the total weight of waste from plastic (1kg) and styrofoam (3kg) was used to melt the waste mixture at 150˚C. The heating element, glycerol was placed inside the densifying machine for pre-heating until the temperature reaches 150˚C, at 150˚C the plastic wastes were added. After 15 mins, the styrofoam wastes were added. The melting of the plastic and styrofoam wastes were timed for 2 hours, after which the melt was poured into bricks and sheet molds for cooling.

Physical and mechanical properties of the resulting DRM samples with 70% (w/w) glycerol were compared with to the original DRM produced using 70% (w/w) cooking oil as plasticizer.

Phase 2- Fabrication of the Bamboo-Fiber Reinforced DRM

11. Collection of Powdered Bamboo Fibers

Bamboo fibers, used as reinforcing filler were bought initially as bamboo culms at Brgy. Isabang, Lucena City, Quezon Province. The bamboo culms came from a bamboo with the scientific name *Bambusa blumeana* under the family *Poaceae/Graminae*. Powdered bamboo fibers were obtained through mechanical scraping without any chemical treatment/modification.

12. Reinforcement of the DRM with Bamboo Fibers

With the optimum ratio of PE and PS at 1:3 and 70% (w/w) glycerol incorporation, bamboo fibers were added to the DRM. Powdered bamboo fibers were dried in an oven at 150˚C for one hour. The dried fibers were initially mixed with the DRM at 1%, 2% and 3% filler loadings as shown in Table 3.

Table 3. Mass of DRM with optimum glycerol amount and bamboo fiber

% Glycerol (w/w)	Mass of DRM w/glycerol (g)	Mass of Fiber (g)	% Fiber Loading (w/w)	Sample Number
70	200.0	0.0	0	1
	200.0	2.0	1	2
	200.0	4.0	2	3
	200.0	6.0	3	4

The mixtures were then passed through a two roll mill (LabTech Engineering Company Ltd.) at 200˚C for 10mins. The polymer blend was placed in a 203.2mm x 203.2mmmold with a thickness of approximately 4mm and was compression-molded (Shinto Compression Molding Machine) at a temperature of 200˚C and pressure of 50kg/cm^2 for 5mins. The samples were air-dried.

Phase 3- Mechanical Characterization and Water Absorption Test

14. Mechanical Characterization

The tensile strength of the composites were determined using a Shimadzu Universal Testing Machine (UTM) at the Standards and Testing Division of Department of Science and Technology (DOST-STD) in Bicutan, Taguig City. Dog bone-shaped samples were cut from compression molded sheets following ASTM D638 type I, as shown in Table 4 and Figure 6.

Table 4. ASTM D638 Type 1 Specifications

Specimen Aspect	Dimensions (mm)
Width of narrow section, W	13
Width overall, WO	19
Length of narrow section, L	57
Length overall, LO	165
Radius of fillet, R	76

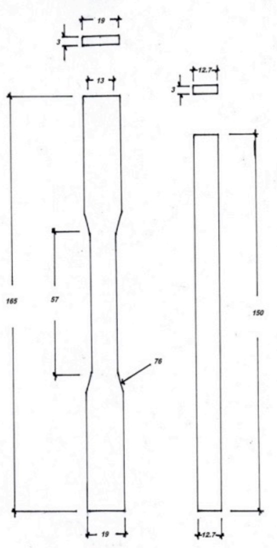

Figure 6. Sample Specimens for ASTM D638

The UTM, with test speed 1mm/min can measure the maximum force or stress the sample can withstand before undergoing deformation. It presents the data through a graph of stress vs. stroke strain. Tensile strength was calculated by dividing the maximum force experienced by the sample with the maximum cross-sectional area of the dog-bone sample. Maximum load, on the other hand, was correlated to the force in Newton (N) absorbed by the sample when it fractured.

15. Water Absorption Test

Water absorption of the fabricated composites was tested using the standard method specified by ASTM D570. The test specimens were cut in the form of a bar 3 in. long by 1 in wide by 4mm thickness of the material. The specimens were dried in an oven for 24 hours at 50˚C, cooled in a dessicator, and immediately weighted to the nearest 0.0001g. The conditioned specimen was placed in a container of distilled water entirely immersed at room temperature. At end of 24 hours of immersion, the specimens were removed from the water one at a time, all surface water wiped off with a dry cloth, and immediately weighed to the nearest 0.0001g. The specimens were then reconditioned for 24hours at 50C, cooled in a dessicator, and immediately reweighed to the nearest 0.0001g. The percentage water absorbed was calculated as follows:

$$\%\text{water absorbed} = \text{increased in weight} + \text{soluble matter lost}$$

$$\text{The increase in weight, } \% = \frac{\text{Wet weight- conditioned weight}}{\text{Conditioned weight}} \times 100$$

$$\text{Soluble matter lost, } \% = \frac{\text{Conditioned weight-reconditioned weight}}{\text{Conditioned weight}} \times 100$$

16. Collection of Data

The physical appearance of the DRM and composites were compared based on how the plasticizer (glycerol) and different amounts of the filler (bamboo fiber) varied the DRM and composites' texture, color, and odor. The effect on the tensile strength of the DRM and composites with 70% (w/w) glycerol and fiber incorporation (1, 2 and 3%) were determined using a stress vs. stroke strain graph presented by the UTM. Tensile strength was measured in MegaPascals (MPa) while maximum load, correlated to the force absorbed by the sample when it fractures was measured in Newton (N). The water absorption of the composite was measured in percentage mass using the standard method specified by ASTM D570, and calculated by the aforementioned formula.

17. Results and Discussion

17.1. Effects of Glycerol on DRM with 1:3 PE: PS ratio

Following the optimized 1:3 PE: PS ratio, plastic and styrofoam wastes were melted together in different heating elements (one with traditional heating element , used cooking oil and the other with the glycerol plasticizer) using the densifying machine of CEMO at Marikina City. The resulting densified material, as shown in Figure 7, show difference in the appearance and texture of using cooking oil and glycerol as heating element.

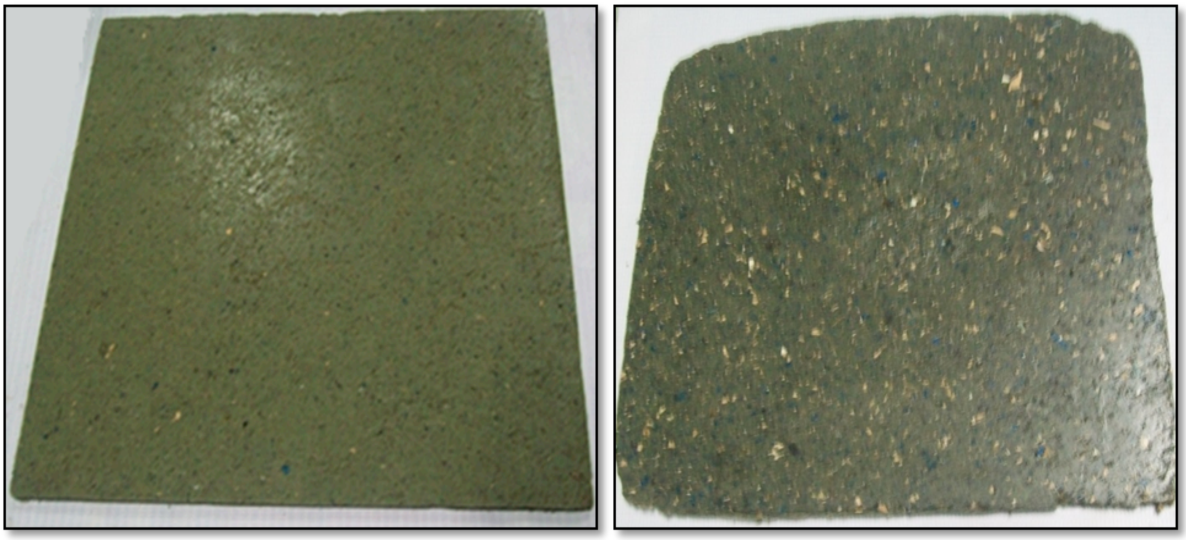

Figure 7. Appearance of densified recycled material using (a) oil and (b) glycerol

Using cooking oil made the material rough and waxy compared to that of the smooth and glossy texture when glycerol was incorporated. There were also color differences, as shown in the figure the DRM with oil was colored light green while the DRM with glycerol was colored dark green. The observed color differences were not due, however, to the use of the glycerol but rather to the variability of the styrofoam wastes present during experimentation. When glycerol was used, the Styrofoam wastes included colored ones which resulted to the darker color of the DRM with glycerol. This color difference does not significantly affect the mechanical properties of the materials but limited to the DRM’s physical appearance only.

Aside from the differences in the appearance of the materials, one main distinction was also distinguished during the process of melting the wastes. When glycerol was used, the DRM melt became more viscous than when cooking oil was used, the augmented viscosity of the melt (using glycerol) made it hard to pour it in the mold. The drying and cooling down of the whole melt was also easily achieved within 30 minutes when glycerol was used as compared to using cooking oil which took about 1 and half hours for the melt to dry and cool, the faster it took for the DRM to cool, the more difficult it is to shape into molds. Furthermore, the incorporation of glycerol produced enormous amounts of white smoke during the melting which was theorized as a decomposition product, acrolein. The white smoke produced is painful to the eyes but only slightly irritating to smell than the boiling used-cooking oil which has a very filthy odor.

The incorporation of 70% (w/w) glycerol was helpful in some ways though. Observations in the modified DRM shows not only good appearance and texture (glossy and less waxy), but also the foul smell from cooking oil was considerably reduced. These modifications were of course desired because the original DRM made from 70% (w/w) cooking oil can't be further tailored because of the difficulty of varnishing the waxy surface. Moreover, the smoothness of the modified DRM made it more pleasing as compared to the DRM with oil.

Glycerol has truly made the material stronger as shown in the evaluation of the tensile strength of the material. It was observed that the good tensile strength were achieved using glycerol. On the other hand, low tensile strength was observed when cooking oil was used. Analysing the tensile strength values of the materials, as shown in Table 5, shows that there is an increase in the tensile strength of the material.

Table 5. Tensile Strength DRM with Oil and Glycerol at 1:3 PE: PS ratio

Sample	Tensile Strength (MPa)
DRM with Oil	2.32
DRM with Glycerol	3.30

This mechanical reinforcement provided by glycerol is due to the increased interfacial adhesion that glycerol provided for better blending of the plastic and styrofoam wastes (Gotico, 2011). Though glycerol has actually made the polymer melt viscous, it has significantly improved the adhesion between the polymer components. This can be attributed to the more polar nature of glycerol compared to cooking oil. Because of this, glycerol does not significantly embed in between polymer blends, thus providing avenue for the polymers to have better contact/mixing. On the other hand, the long hydrophobic chains of cooking oil can easily penetrate in between the polymer networks, spacing them apart. This good adhesion, that glycerol provides, makes the stress transfer easy and consequently results to better mechanical properties compared to using cooking oil.

18. Bamboo Fiber Reinforcement

Using the optimized 1:3 PE: PS ratio for plastic and styrofoam wastes and 70% glycerol incorporation, powdered bamboo fiber was reinforced to the densified recycled material at 1, 2 and 3% fiber loading. Based on their appearances, as shown in Figure 8, fiber reinforcement doesn't significantly affect the physical appearance of the material. This observation is desirable because no physical changes (i.e, surface roughness) were noted and can still be tailored with fiber reinforcement even without significant changes in the mechanical properties of the material.

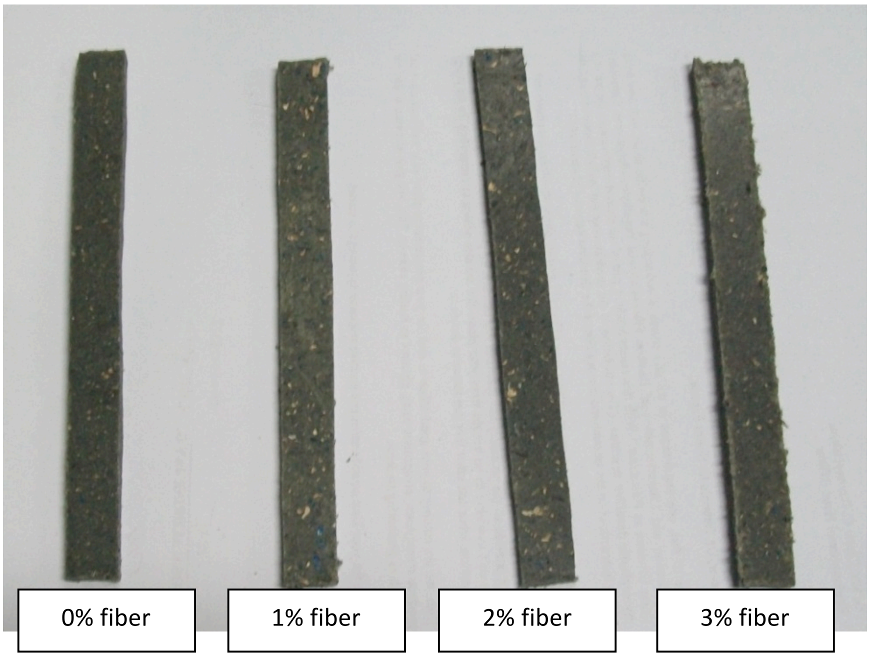

Figure 8. Before tensile test appearance of the composites at various fiber loading

Mechanical properties of the fabricated fiber reinforced composites were characterized using the UTM to determine the maximum load and tensile strength of the composite. Figure 9 shows the fracture points after the tensile test and it can be observed that the fracture points vary and are mostly concentrated near the middle of the strips. The maximum force sustained by the composites during tensile loading was divided by the cross sectional area of the composites to determine the tensile strength of the material.

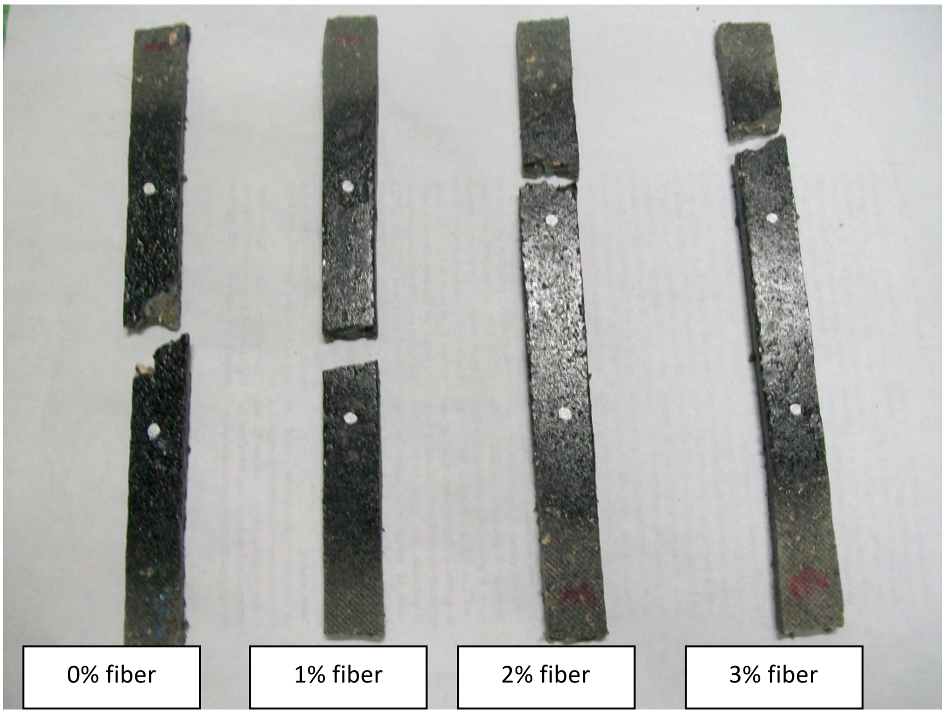

Figure 9. After tensile test appearance of the composites at various fiber loading

The stress strain graph exploring the changes in the mechanical properties of the material at various fiber loadings (each with triplicate specimens) as shown in Figure 10a – 10d, suggest optimized reinforcement at 1% fiber loading for DRM using 70% (w/w) glycerol.

At 0% fiber loading, specimen 1 and 3 absorbed a mean force of 203.56 N with a SD of 2.37. The mean tensile strength of the two specimens was 3.30 MPa with a SD of 0.03.Specimen 2 was excluded due to irregular graph. Thus, its tensile stress will not be considered due to machine did not sense the break point of the specimen.

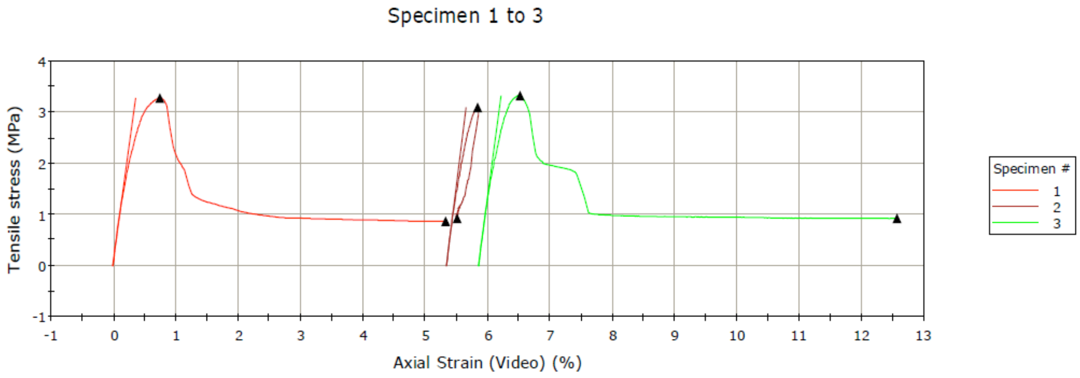

Figure 10a Sample PG (70% Glycerol, 0% Fiber)

At 1% fiber loading, specimen 1and 2 absorbed an average force of 380.29 N with a SD of 13.37. The average tensile strength of the two specimens was 5.88MPa with a SD of 0.10. Specimen 3 was excluded because no data was given on yield point.

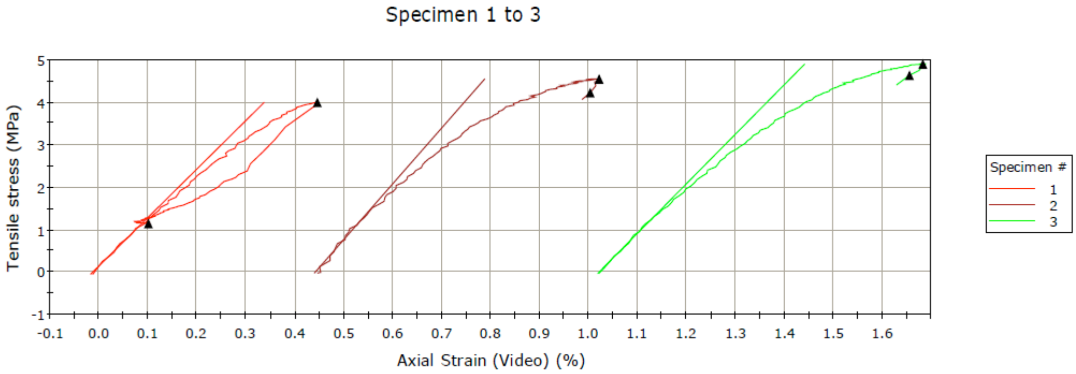

Figure 10b Sample 1G (70% Glycerol, 1% Fiber)

At 2% fiber loading, specimen 2 and 3 absorbed an average force of 287.51 N with a SD of 26.18. The average tensile strength of the three specimens was 4.73MPa with a SD of 0.25. Specimen1 was excluded due to irregular graph.

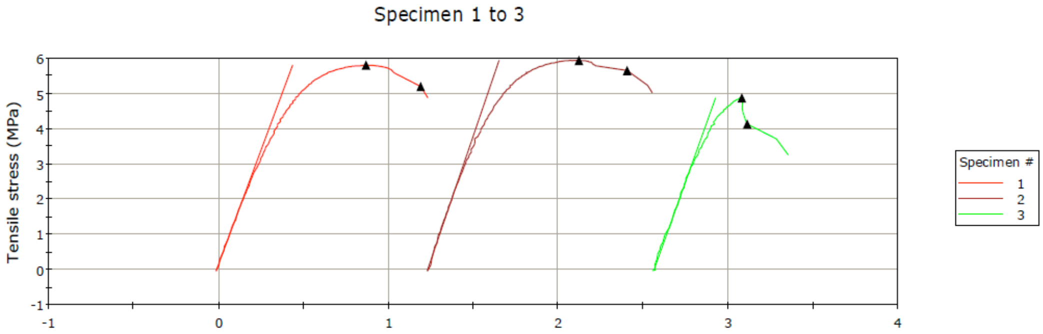

Figure 10c Sample 2G (70% Glycerol, 2% Fiber)

At 3% fiber loading, specimen 1and 2 absorbed an average force of 442.67 N with a SD of 66.03. The average tensile strength of the two specimens was 5.60MPa with a SD of 0.59 Specimen3 was excluded due to irregular graph.

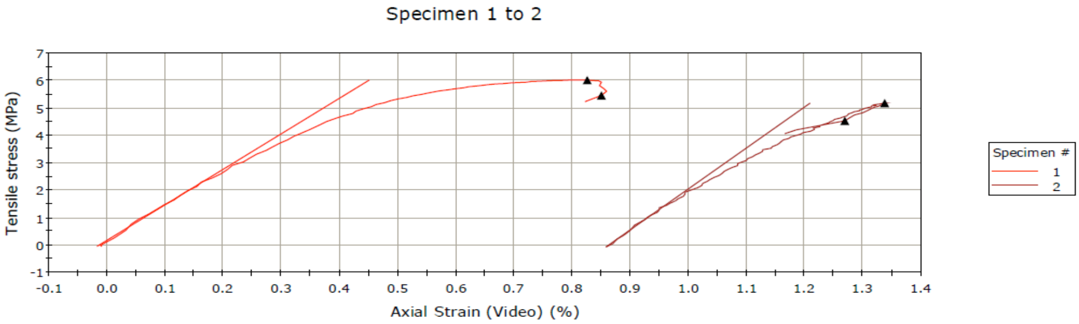

Figure 10d Sample 3G (70% Glycerol, 3% Fiber)

Looking closely to the stress-strain graph of DRM using glycerol, as shown in Figure 10b at 1% fiber loading, there was an increase in the tensile strength of the material compared to the DRM with glycerol without any fiber reinforcement in Figure 10a. Further increased of fiber loading beyond 1% maintained relatively good tensile strength as shown in Figure 10c and 10d.

Table 6. Maximum load and tensile strength absorbed by fiber-reinforced DRM

Sample	Maximum Load (N)	Mean Tensile Strength (MPa)	Standard Deviation
DRM with Oil_ 0% fiber	-	2.32*	-
PG_DRM with glycerol_ 0% fiber	203.56	3.30	2.37
1G_DRM with glycerol_ 1% fiber	380.29	**5.88**	13.37
2G_DRM with glycerol_ 2% fiber	287.51	4.73	26.18
3G_DRM with glycerol_3% fiber	442.67	5.60	66.03

**(Gotico, 2011)*

The tensile strength and maximum load values, as summarized in Table 6, it is evident reinforcement of the mechanical properties of the material was achieved at 1% fiber loading. The effect of bamboo fiber loading on the tensile strength and maximum load of the composites is also summarized in Table 6 (maximum load of DRM with Oil_ 0% fiber was not obtained).

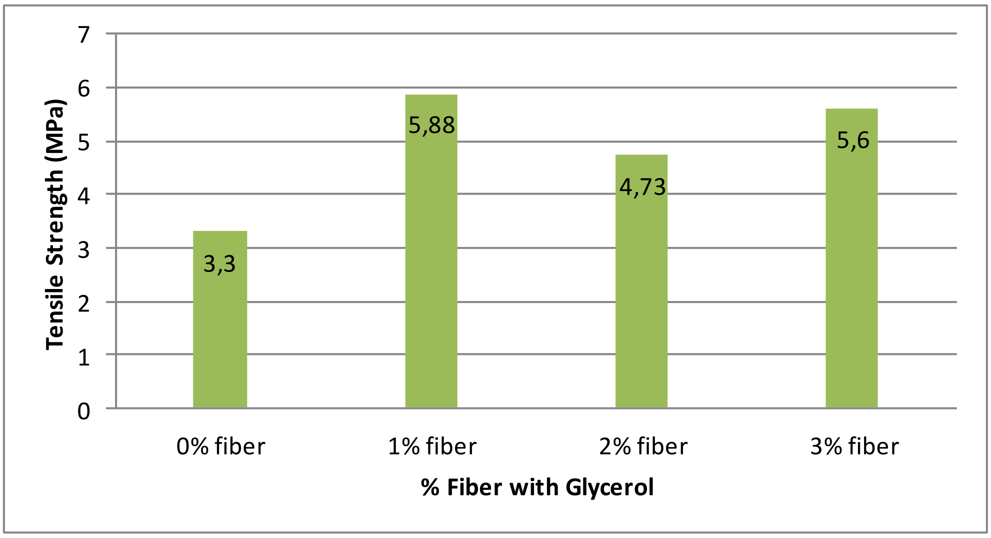

Figure 11. Changes in the tensile strength of the composites at various fiber loading

It can be observed in Figure 11 that fiber loading improved the tensile strength of the composites without fiber incorporation. But it is also noticeable that beyond 1%, the tensile strength of the composite decreased. Though it was expected that at higher fiber loadings there will be an increase in the tensile strength of the material because the fiber should have acted as mechanical reinforcement to the otherwise weak matrix, the results show the opposite, that is, the tensile strengths of the composites decrease with increasing fiber loading. This increase in tensile strength can be affected by several factors. Santiago (2007) in his study “Fabrication and characterization of Polyethylene-coir composites,” showed that fiber may have inferred with the crystallinity of the polymer matrix or several voids might have been generated with the increase in fiber content of the composite, thereby contributing to the decrease in the tensile strength of the material.

19. Water Absorption Test

In addition, the decrease in the mechanical properties of the composites with increased fiber loading can be correlated to the water absorption of the composites. Water absorption test (ASTM D570) was performed at the composites, and the percent water absorbed after 24h immersion in water is summarized in Table 7 and Figure12.

Table 7. Water absorption of composites at various fiber loading

% Fiber with Glycerol	Increase in Weight, %	Soluble Matter Lost, %	% Water Absorbed
0	0.2711	0.0748	0.3459
1	0.5092	0.4074	**0.9166**
2	1.3563	0.1160	1.4723
3	1.9913	0.2445	2.2358

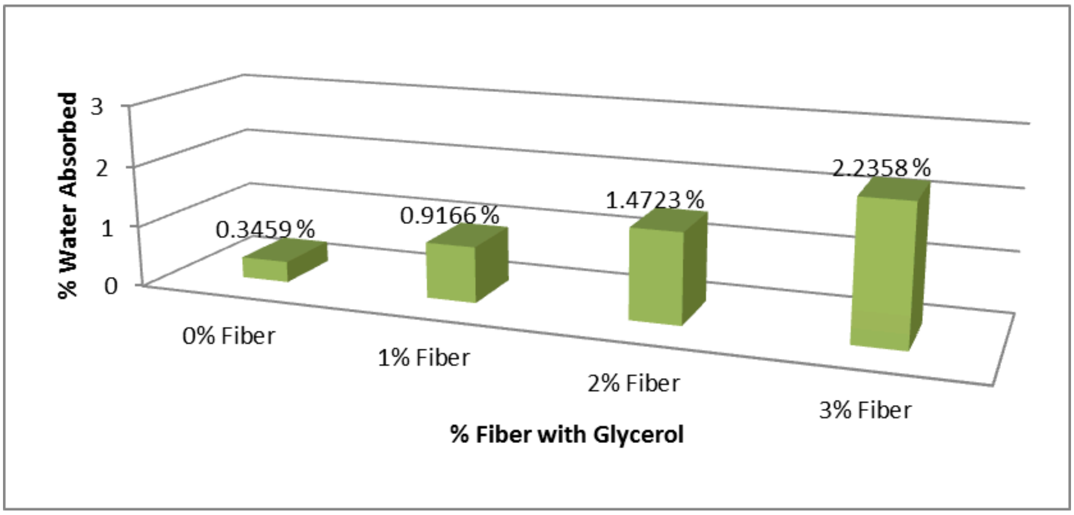

Fig 12. Water absorption of the composites at various fiber loading

It can be observed in Figure 12 that as the fiber loading is increased, the percent water absorbed also significantly increased. This increased in water intake of the composites at increased fiber loading can be attributed to the increased number of fibers with polar –OH groups on its surface that could form hydrogen bonds with water, corresponding to increased water intake. The increased in water absorption could therefore be correlated to the observed decrease in the mechanical properties of the composite because of the increased number of polar groups that could separate the polar fiber from the hydrophobic matrix.

20. Conclusions

Bamboo-fiber reinforced recycled plastic composites were successfully fabricated using the densifying machine of the City Environmental Management Office (CEMO) located at Marikina City. Investigations revealed that improved properties of the DRM, in terms of tensile strength can be achieved using 70% (w/w) glycerol incorporation at 1:3 PE: PS ratio. Glycerol, used as a heating element and plasticizer, improved the texture and tensile strength of DRM compared to using cooking oil. In addition, fiber reinforcement of the DRM was achieved at 1% fiber loading having the best tensile strength and least percentage of water absorbed.

21. Recommendations

For future studies, it is proposed to study the influence of different parameters (glycerol percentage, time, temperature, pressure, fiber type and dimensions, fiber extraction, etc.) in the fabrication of the fiber-reinforced recycled plastic composites. Other characterizations of the fabricated plastic composite including thermal properties (degradation temperature and thermal stability), leaching and biodegradation experiments and compressive and flexural strength can also be done.

It is also suggested to utilize a better plasticizer that doesn't release any toxic gas when processed under high temperatures. The use of compatibilizer and other additives which are cheap, economical and environment friendly may also be explored to further improve the adhesion of the bamboo fibers to the polymers. Concrete applications of the composite are also encouraged, in order to help people in every community in having an extra source of income.

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