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Formation and Evaluation of Lahar/HDPE Hybrid Composite as a Structural Material for Household Biogas Digester

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Abstract**—**This study was an investigation on the suitability of Lahar/HDPE composite as a primary material for low-cost small-scale biogas digesters. While sources of raw materials for biogas are abundant in the Philippines, cost of the technology has made the widespread utilization of this resource an indefinite proposition. Aside from capital economics, another problem arises with space requirements of current digester designs. These problems may be simultaneously addressed by fabricating digesters on a smaller, household scale to reach a wider market, and to use materials that may accommodate optimization of overall design and fabrication cost without sacrificing operational efficiency. This study involved actual fabrication of the Lahar/HDPE composite at varying composition and geometry, subsequent mechanical and thermal characterization, and implementation of Statistical Analysis to find intrinsic relationships between variables. From the results, Lahar/HDPE composite was found to be feasible for use as digester material from both mechanical and economic standpoints.

Keywords—Biogas digester, Composite, High density polyethylene, Lahar.

I. Introduction

ONE of the current thrusts in worldwide research is the use of renewable energy. The role of materials engineering here is to provide the means for optimum utilization of resource through the development of advanced materials in equipment designs. The limiting factor remains as to the widespread acceptance of the technology, which hinges primarily on both financial and LOGISTICAL economics.

There are two pressing problems that pose challenges to our country's stability: energy crisis and pollution. Clearly, the natural resources for conventional energy have been depleted and its continuous supply in the future remains uncertain. Pollution can be generally attributed to the increasing number of people living in the metropolis, the declining capacities of landfills, and the extreme difficulty of finding new location for dumpsites.

Approximately 5800 metric tons of garbage is generated everyday with only 73% out of this volume being collected [1].

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Biogas technology is the only alternative technology that allows us to address these problems. The biogas technological process was developed as a means of obtaining fuel gases (CH_4, CO, H_2S) from the fermentation of organic materials. These reactions occur by the actions of microorganisms under anaerobic conditions, as promoted by a device called the biogas digester [2]. An agricultural country such as the Philippines has abundance on sources for organic materials, in piggeries, farms, etc., but the technology cannot penetrate a wider market due to economic constraints. Also, current studies on the engineering of the digester design required either reinforced concrete or PVC as construction materials, which have proven rather costly for extensive application.

A biogas digester (Fig. 1) is a device that provides the anaerobic condition in the biogas technological process. Present biogas digesters use reinforced concrete, cement, and coco lumber as construction materials. It should have excellent mechanical properties and a thermal capacity of 30-50^{o}C. It should be lightweight and resistant to wear and corrosion. It should be chemically stable to ensure that it will not interfere with the anaerobic digestion [1], [3]. It should be environment-friendly and have minimal cost.

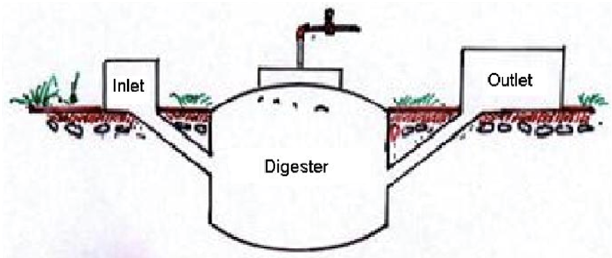

Fig. 1 Fixed-dome biogas digester design [3]

Lahar is a pyroclastic deposit that is mainly composed of silicon dioxide (SiO_2). Although it is associated with disaster, studies reveal its good quality in terms of compressive strength per unit weight. It has a 3.1 to 4.0 ratio of Al_2O_3 to SiO_2 that indicates suitability for element addition. About 5% to 8% of CaO is also present in Lahar that implies its capability as a binding material [4]. However, its principal drawback is its disposition to a catastrophic fracture in a brittle manner with very little energy absorption. Fortunately, creating a composite material can significantly improve the material's fracture toughness. High Density Polyethylene has greater stiffness, rigidity, improved heat resistance, and increased resistance to permeability as compared to other polymers.

This study, in effect, focuses on developing a potential for the wider acceptance of household biogas digesters through the optimization of both technology and economics by applying inexpensive, readily available, and easily fabricated materials for construction. Fabrication of a prototype model of the Lahar-HDPE based biogas digester was not covered in the study.

II. Methodology

The experimentation design employed in this study considered Lahar: HDPE mass ratio and sample thickness as the working variables.

A. Preliminary Investigation

Preliminary investigation of the raw materials was done to provide elementary information on the state and quality of Lahar samples and virgin HDPE. The Lahar samples were processed with metallographic sieves to achieve a reported particle size of 100% passing 650 microns. HDPE pellets were supplied by JG Summit Petrochemicals, Inc.

B. Sample Fabrication

The manufacturing technique used was the Compressive Melt Method [5]. In this method, the raw materials were mixed in a two-roll mill for 10 minutes at 200^{o}C. The molten mixture was molded at 250^{o}C using a Shinto Compression Molding Machine with a pressure at the cylinder side of 50 kg/cm^2. Fig. 2 presents the schematic diagram for the processing of samples.

C. Characterization and Evaluation

Characterization of the experimental products applied four (4) analytical techniques: (1) SEM was used to reveal the microstructure; (2) UTM (ASTM E8) measured the tensile strength; (3) Three-Point Bend Flexure Test (ASTM D790-02) measured the flexural strength; and (4) SDT-TGA measured weight changes as a function of temperature, and consequently determined the thermal stability of the composite.

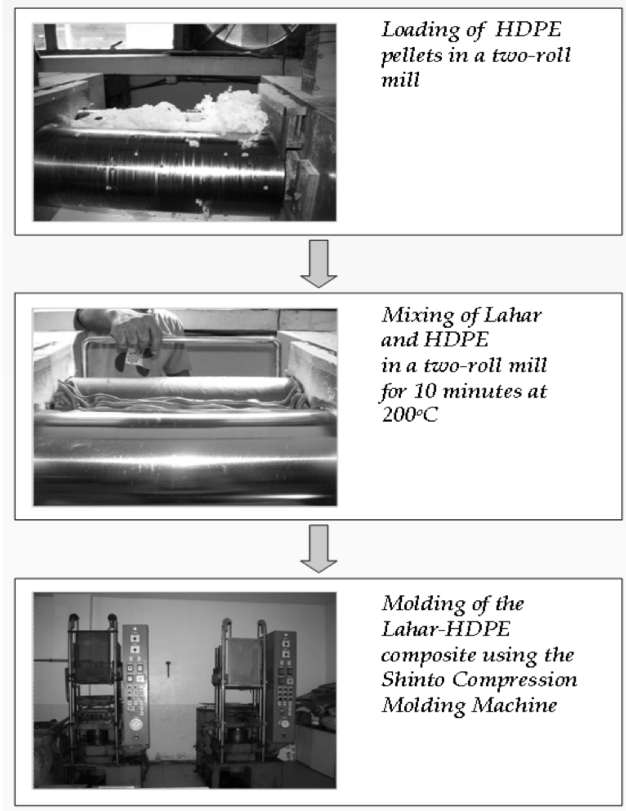

Fig. 2 Diagram of the compressive melt method used to fabricate Lahar/HDPE composite

Since the study offered a technology that will help mitigate pollution and solve our energy crisis, the production cost and environmental implication of the over-all process were also evaluated. Statistical Analysis was done to determine if there was significant interaction between the effective variables and the physical, mechanical, and thermal properties of the composite. From the results obtained after analysis and evaluation of the experimental product, the effectiveness of Lahar-HDPE composite was determined by comparing the properties exhibited by the fabricated material to the requirements of the structural design.

III. Results and Discussion

Result of the study showed that the Lahar-HDPE composite could be effectively utilized as structural material in constructing a small-scale biogas digester. Lahar-HDPE composite passed the required specifications of the digester design.

A. Physical Properties

The composites were generally black in color with a porous surface. Fig. 3 presents a summary of the physical properties for the 10 mm thick samples. Treatments with higher amount of Lahar component show a more intense dark color. Warping occurred due to localized couple of tensile and compressive stresses. It is especially displayed by 2mm thick samples and is mostly negligible for 10mm thick samples.

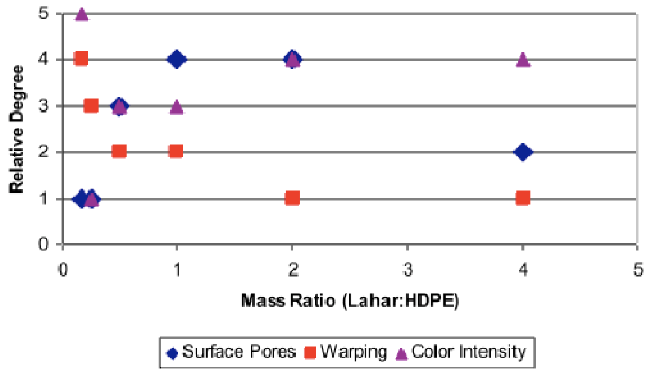

Fig. 3 Effect of Mass Ratio to the surface porosity, warping, and color intensity of the Lahar/HDPE composite

B. Microstructure and Mechanical Properties

The morphology of the composite in question, which is the interaction between Lahar and HDPE, was examined under the SEM. The micrograph revealed a weak adhesion for samples in which there is a large difference in the relative constituency (Fig. 4).

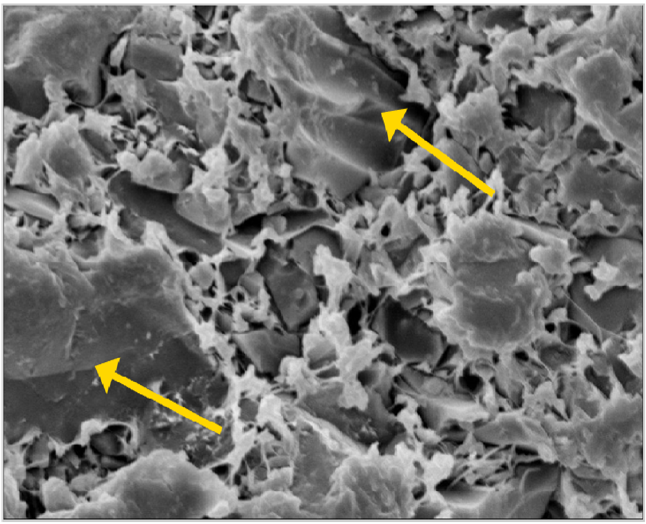

Fig. 4 Fractured surface of the Lahar/HDPE composite (arrows indicate lahar crystals)

Samples with larger relative amount of HDPE exhibit higher tensile strength. The composite gave a mean UTS of 23.58 MPa. Mass ratio however is not statisically significant at 95% confidence level.

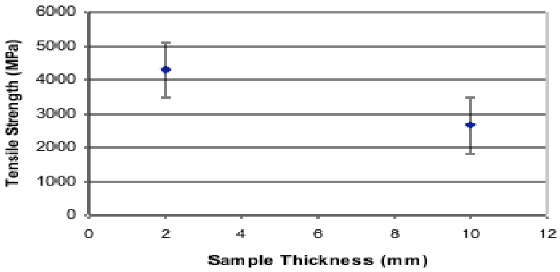

Fig. 5 Effect of sample thickness to tensile strength

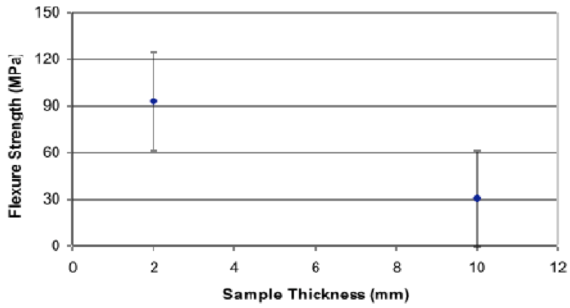

Fig. 6 Effect of sample thickness to flexure strength

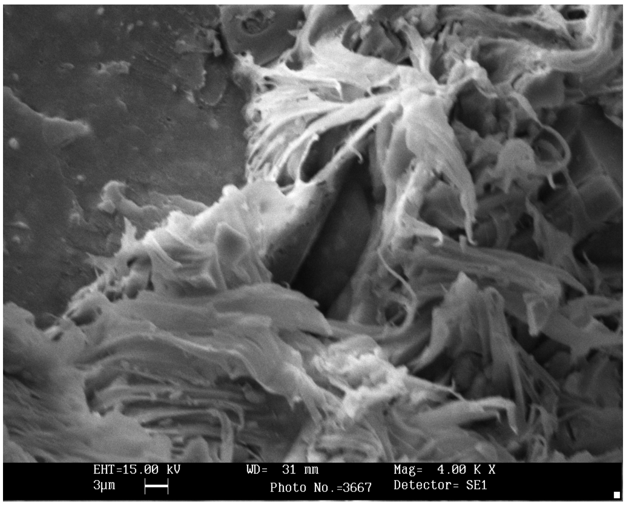

Fig. 7 SEM micrograph of Lahar/HDPE composite that failed due to brittle fracture (4000X)

Flexure and tensile tests revealed that 2mm composite have notable mechanical strength as compared to its 10mm counterpart (Figs. 5 and 6). This performance was explained by the fact that smaller samples consequently had smaller number of defects. Treatments with thickness of 2mm gave a mean of 92.99 MPa while 1 cm thick samples gave a mean of 30.46 MPa. Analysis of Variance reveals that sample thickness is a significant factor of tensile and flexure strength at 95% confidence level.

C. Thermal Properties

The melting and degradation temperature of the different samples were extracted from the differential thermal diagram. From the thermal analysis curve, the thermal stability against composition of the composite was deduced. The melting and degradation temperature of the different samples were extracted from the differential thermal diagram. The composite was found out to be thermally stable with a capacity of up to 141^{o}C ± 5^{o}C.

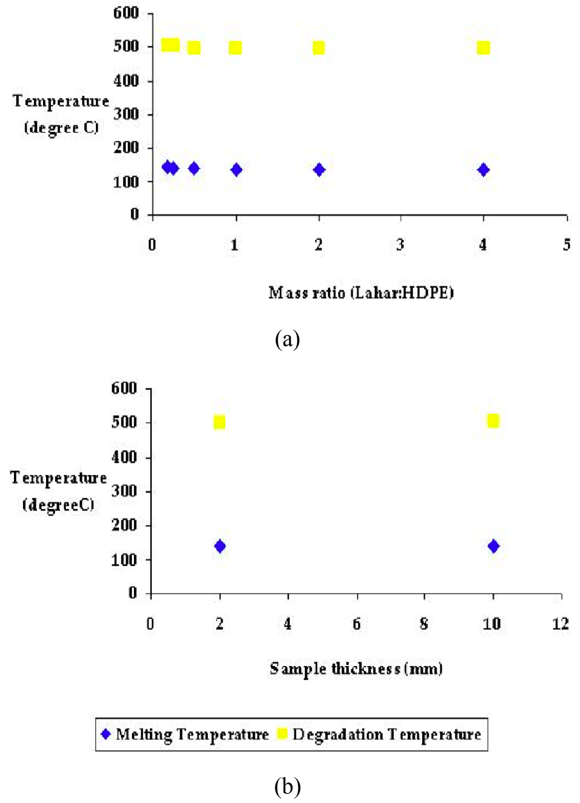

Fig. 8 Effect of (a) mass ratio and (b) sample thickness to the thermal properties of the composite

D. Engineering Analysis

The experimental results were compared to the material specifications required by the household biogas digester design, and are presented in Table I. Economic analysis has shown that a Lahar-HDPE digester would cost around PhP2081.97/m^3, as opposed to a concrete-based unit which required PhP5000/m^3 to construct.

TABLE I
DESIGN SPECIFICATIONS OF A SMALL-SCALE DIGESTER AND PROPERTIES OF LAHAR-HDPE COMPOSITE

Parameters	Requirement	Lahar/HDPE Composite
Strength, MPa	2 ksi or 13.8 MPa	23.58 MPa (mean)
Thermal Capacity	40 °C to 50 °C	up to 141°C ± 5°C
Weight	Relatively Lightweight	100 kgs
Chemical Resistance	Excellent	Excellent
Corrosion Resistance	Excellent	Excellent
Environment Friendly	Yes	Yes
Low cost	Yes	Yes

IV. CONCLUSION

It can be concluded that good quality Lahar-HDPE composite can be fabricated using the Compressive Melt Method. The Lahar-HDPE composite exhibited good mechanical properties and thermal stability. The tensile and flexure strength of the composite is significantly affected by the sample thickness. Lahar-HDPE composite-based biogas digester is more cost-effective and has a lower production cost compared to the presently available concrete-based biogas digesters. The process and the product do not pose any threats to our environment. The fabricated Lahar-HDPE can therefore be used as structural material for household biogas digester.

Based on the inferences of this investigation, the author recommended Lahar-HDPE composite be utilized in constructing household biogas digester. Seeing the potential of this technology, it is also recommended that this innovation be promoted to help alleviate our economy and mitigate our problems on environment degradation.

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