

Optimized Compression Molding Machine for Biocomposite Production from Agricultural Waste

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ABSTRACT

The Philippines faces ongoing challenges in managing agricultural waste, often disposed of through open burning or landfill, leading to pollution. Converting this waste into valuable materials using a compression molding machine can mitigate environmental harm and create economic opportunities in agriculture. This study explores bio-based composite development and effective agri-waste recycling. It aims to integrate agricultural waste, such as rice straw, coconut husk, and corn starch, into biocomposites using a modified machine with shredding, molding, and compressing capabilities. The year-long project involved material exploration, machine fabrication, and biocomposite testing. A two-level factorial experimental design revealed that temperature and binder percentage significantly affect material properties, with higher binder percentages and lower temperatures enhancing mechanical strength

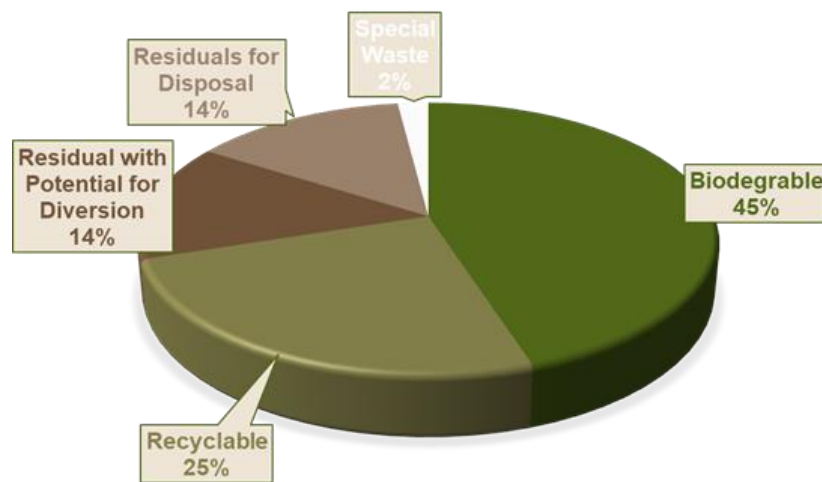
INTRODUCTION

The Philippines is primarily an agricultural country, having a total land area of 30 million hectares, of which 32 percent is agricultural. The total area devoted to agriculture is 13 million hectares distributed among food grains, food crops, and non-food crops.

Due to the increasing demand for agricultural production, the Philippines is experiencing serious waste issues from agriculture. From 2006 to 2010, it harvested 16 million tons of rice in Central Luzon, Western Visayas, Cagayan Valley, and the Ilocos region, producing roughly 9 million tons of rice straw per year. Around 30% of farmers burned their rice straw, while the majority were left in the fields; others mulched non-rice crops and utilized them as animal feed (EnviroNewsPH, 2014).

Among these agricultural derivatives, the most common agricultural wastes in the Philippines are rice husks, rice straws, coconut husks, corn husks, coconut shells, and bagasse (Zafar, 2021).

Based on the WACS data of the component city and municipalities, the Province of Bataan currently generates a total of 299,320.80 kg/day or 299.32 tons/day of solid waste. Agricultural crop wastes under biodegradable composition significantly contribute to this totality.



Source: Bataan, Philippines Ten-Year Solid Waste Management Plan 2018-2027
Figure 1. Bataan Waste Composition, CY 2016

The top five (5) contributors of biodegradable wastes in Bataan are Balanga City having 28,706 kg/day, Dinalupihan with 21,162.45 kg/day, Orion having 15,367.28 kg/day, Limay taking 9,531.19 kg/day, and Hermosa with 9,424.18 kg/day.

Table 1. Quantity of Waste Generated by City/Municipality and Corresponding Biodegradable Waste Percentage, CY 2016

LGU	Per Capita Waste Generation (kg/day)	Waste Generation (kg/day)	Biodegradable	
			Kg/ day	%
Balanga City	0.572	57,127.73	28,706.68	50.25%
Dinalupihan	0.584	56,127.73	21,162.45	49.96%
Hermosa	0.296	21,097.33	9,424.18	44.67%
Limay	0.396	25,628.38	9,531.19	37.19%
Orion	0.592	35,021.15	15,367.28	43.88%

Source: City and Municipal WACS; City and Municipal Ten-Year SWM Plans, Bataan Philippines

Materials Recovery Facility (MRF) is where the biodegradables are brought and segregated (Bataan ICM Program, 2006). At present, 10 out of 12 LGUs in Bataan have existing MRFs and composting facilities; Orion and Pilar do not have a central MRF, imposing a problem for the local farmers in managing their agricultural crop wastes during harvests. As for the final disposal, most collected wastes are taken to respective sanitary landfills and subjected to open burning.

With the rise in agricultural waste problems in Orion, such as inappropriate disposal and improper utilization, there is a necessity for a machine that can process agricultural crop wastes into high-value and usable products.

This study aims to integrate agricultural wastes into biocomposite using a modified machine that can mold and compress the raw materials combined with binders. Furthermore, the research focuses on enhancing the production process to achieve a competitive advantage.

The development of this study is significant in promoting more economic opportunities in Bataan, addressing agricultural waste treatment and disposal, promoting locally manufactured sustainable materials in the construction sector, and contributing to the growing body of scientific knowledge.

Moreover, the study focused solely on addressing improper agricultural waste disposal and treatment in Bataan, particularly in Orion. The agricultural wastes utilized were limited to crop wastes such as rice straw and coconut husk. Among the raw materials are adhesives which comprise corn starch, tapioca starch, and hydroxyethyl cellulose. The fabrication of the compression molding machine was closely monitored to ensure compliance with Philippine National Standards. Biocomposite materials, through manual production, were tested in terms of tensile, compressive, and flexural properties and based on the American Society for Testing and Material.

LITERATURE REVIEW

This part presents researches and innovations from various fields to explore different ways and processes for making biocomposite materials and the raw materials needed and their properties. The studies were selected to facilitate the search and decision-making process regarding what design, processes, and suitable raw materials to use. The review sought to determine which of the offered methods and materials would result in the most suitable combination for producing high-quality biocomposites.

Biocomposites composed of natural fibers and bio-based polymers have quite distinctive properties. The polymer bonds the fibers together, providing the composite structure, distributing stresses across fibers, resisting a small amount of stress, and often protecting the fibers from environmental exposure.

The inclusion of natural fiber in starch composite reduces brittleness and hence results in increased tensile strength. This is based on the results obtained from mechanical testing of rice husk and walnut shell reinforced biocomposites. Findings from several mechanical tests revealed that rice husk-based biocomposites had higher tensile strength, flexural strength, impact energy, and thermal stability than the walnut shell-based biocomposites, but poorer hardness and compressive strength. Increased reinforcing, which resulted in a very compact structure, may have contributed to the increase in hardness and impact energy. The compact structure prevents fracture propagation/growth, resulting in improved composite mechanical characteristics (Singh et al., 2019). Biocomposites have maximum tensile strength and stiffness values ranging from 20 to 200 MPa and 1 to 4 GPa, respectively (Christian, 2016).

Then, a study on biomass pellets with different binder percentages revealed a promising effect on mechanical properties. The cassava starch was chosen as the experiment's binder because it is relatively affordable. The binders enhance the strength of pellets formed from biomass exhibiting lower binding abilities. Samples with a 12% binder percentage recorded the highest mean value, while a 4% binder percentage recorded the lowest mean value (Ismail et. al., 2021). Bioceramics, however, require a minimum binder percentage to ensure compact uniformity when machined (Demarbaix et. al., 2020).

Other inquiries demonstrated the significance of composites in the construction industry as a partitioning and ceiling material. The materials used in the study of the optimization of parameters of biocomposite manufacturing using an experimental design are banana midribs or pseudo-stems. In a composite material, banana midribs or pseudo-stems have robust tensile strength and can be made into such a wide range of products. The focus of the study was to determine the ideal parameters for making bio-composite materials to optimize the utilization of pseudo-stems while maintaining environmental sustainability. Moreover, adhesive factor was emphasized, which is an important component in the manufacturing of composites and has a direct influence on the mechanical strength of the materials. As a result, it begins conducting experiments, evaluating the tensile strength of composite materials, and calculating the results. It also featured off-line quality engineering using experimental design, which is one method to improve quality.

The aforementioned studies are motivated by industry demands for the development of low-cost, lightweight, and environmentally friendly materials. The utilization of agricultural wastes for biocomposite production meets the market demand for such products and taps into its emerging market.

Aside from that, the use of tapioca and cassava starch in biocomposite production will be examined since a study using these as starches for biocomposites revealed that the structure could be changed and the tensile strength could be increased when exposed to acidic air with a pH of .5 (Suryanto et al., 2021). Cassava or tapioca starch will be considered to investigate a new approach to enhancing the mechanical properties of biocomposites. Plasticizer addition would be evaluated and explored because studies have shown its effectiveness in improving the mechanical properties of biocomposites.

Agriculture waste-based biocomposites were created by reinforcing corn starch resin with 5, 10, and 15% wt rice husk and walnut shell content. It was discovered that the physical properties of the biocomposites, such as density and water absorption, remained in the range of 1.20–1.32 g/cm³ and 4.32%–8.68%, respectively, as the content of rice husk and walnut shell increased (Singh et al., 2019). Corn starch for binders will be considered because it is commercially affordable compared to other binders, environmentally sustainable, and primarily used as a thickening agent. It has also been shown in previous studies that it improves the mechanical properties of biocomposites.

Processes for Biocomposite Production

The possibility of powdering the waste was taken into consideration in the production of biocomposite materials. The process would include microwave drying the Agri wastes then undergoing the same process as converting the grain into flour in which a roller mill is used for milling, grinding, sizing, reduction, and tailings systems (Safaripour et al., 2021). As a result, milling the agricultural wastes would be considered to obtain a powdered form but would prefer to use a hammer mill because it is one of the oldest and most widely used grinding mills.

The mixing process is a typical operation involving influencing a heterogeneous physical system to make it more homogeneous and commonly used in chemical, biological, pharmaceutical, petroleum, and food industries. Modern industrial processing usually requires some mixing processes. Liquid-solid mixing classifies as mixing to suspend coarse free-flowing solids or break up lumps of fine agglomerated solids (Jasper, 2018). Natural fibers-solid are combined with appropriate adhesive-liquid and or filler-liquid to form a homogeneous material in the production of biocomposites. To provide the ideal combination for biocomposite production, the researchers will use commercially available mixers with specifications for mixing natural fibers and specified adhesives.

Compression molding is a type of processing used in the production of plastics. It is a forming method in which a heated metal mold is used to soften and mold the plastic material to the form of the mold while applying pressure. The heat and pressure are maintained until the material has been cured. Compression molding is suitable for complex molding and can be used for woven fabrics, randomly oriented fiber mats, or chopped strands. The process provides a high production rate, good surface finish with preferred texture and style, good

dimensional accuracy as it reduces twisting and shrinkage of the product, and lowest cost molding methods compared to others (Jasper, 2018). In biocomposite making, the pre-shape charge material, pre-measured volume of powder, or viscous mixture of liquid-resin and filler measures is placed directly into a heated metal mold cavity, usually around 200 degrees Celsius or higher (Abba et al., 2013).

One study demonstrated the Response Methodology Surface (RMS), which has been used to improve the mechanical properties of woven flax/PLA composites, through the application of design of experiments for parameters optimization in compression molding for flax-reinforced biocomposites (Akila et al., 2016). In addition, the researchers include three independent variables, such as molding temperature, time, pressure, and heating time, which are the most important parameters influencing the mechanical properties of the materials. The ideal processing parameters for maximizing the impact strength of woven flax/PLA were discovered to be 200°C molding temperature, 3 minutes molding time, and 30 bar molding pressure. According to the findings, an attempt was made to improve the mechanical properties of the woven flax/PLA composites, including strength, by optimizing the hot press forming process. It shares some similarities with the compression molding forming process used for agricultural crop waste in the present study, but it requires a unique design. Choosing the correct compression molding parameters is critical for producing the best composite products.

Utility Models and Patents

Bayer et al., 2019, developed a strong, non-toxic material grown from mycelium, the root structure of mushrooms, which offers a sustainable and alternative to plastics and polystyrene foams. The inventors use mycelium, the root structure of mushrooms, as a natural glue to bind together agricultural residue and produce a new material which is molded into packaging or other end products.

Agricultural waste is fed to live mycelium in a mold or form at room temperature in typical warehouse conditions over several days. This results in a shaped, non-toxic, and strong material that is free of fungi spores. A precise temperature is used to dry and bake the material, which makes it biologically inactive and prevents mushrooms from sprouting. The material is recyclable or compostable and biodegradable within 45 to 180 days.

Another significant development on green composites was the development by Joong et al., 2010 of a synthesis methods using biodegradable poly (lactic acid) (PLA) fibers, paired with general-purpose polypropylene fibers for manufacturing bio-composites that eliminate the brittleness associated with injection-molded PLA bio-composites.

The manufacturing process includes carding poly (lactic acid) (PLA) fibers as a base polymer and natural fibers as reinforcement to produce webs; processing the webs under a predetermined pressure to create a mat, and compression molding the mat to produce a bio-composite plate. Even when PLA and PP fibers are combined, the present invention ensures strength and biodegradability in the bio-composites. Due to a certain degree of mechanical strength, the bio-composites of the present invention find application in various industrial fields that require mechanical strength, such as cases for electronics appliances and cars. Similar to

the innovation, the researchers used compression molding as one of the processes involved in biocomposite production.

Theoretical Framework

This part presents scientific structure and classification of biocomposites to determine the underlying composition. The findings and conclusions were selected to facilitate the search and decision-making process regarding the materials and process to be used. The theoretical framework serves as the basis for the data analysis and interpretation of the research data.

Classification of Biocomposites

Biopolymer composites, also known as biocomposites, are reinforced polymeric materials wherein one or both the fiber and the matrix components are bio-based. (Hybrid Composites, 2020).

Partial Biodegradable

Natural fibers are combined with a non-biodegradable polymer matrix derived from petroleum, resulting in partially biodegradable composites. Other combinations include bio-based matrices reinforced with synthetic fibers and non-biodegradable polymer matrices reinforced with bio-fibers, such as traditional thermoplastic polymers and thermoset polymers. (Hybrid Composites, 2020).

Completely Biodegradable

Bio-fibers are used in complete biodegradable biocomposites, and the matrices are composed of biodegradable polymers such as renewable biopolymer matrices or petro-based biodegradable polymers. Since both fibers and the matrix are biodegradable, this composite will decompose and return to the natural environment at the end of its life (Bahrami, Abenojar, & Martinez, 2020).

Hybrid Biocomposites

A combination of two or more polymers reinforced with one or more fibers results in hybrid composite materials, which provide a new strategy for overcoming the limitations of purely natural fibers or matrices. (Bahrami, Abenojar, & Martinez, 2020).

Properties of Biocomposite Materials

Composites are heterogeneous, complex material systems. The majority of fiber-reinforced materials are anisotropic. Different processes can produce composites with very different properties based on the same matrix material and reinforcement (Zweben, 2015).

Mechanical Properties

The mechanical properties of a material influence how it responds to applied loads. Furthermore, this property is not constant and frequently changes as a result of temperature and other conditions (IOWA State University, 2021).

Tools and Equipment for Biocomposite Production

Biocomposites were subjected to various preparations and procedures to guarantee their quality, thus their production necessitates several methods, tools, equipment, and machine parts.

Hammer Mill

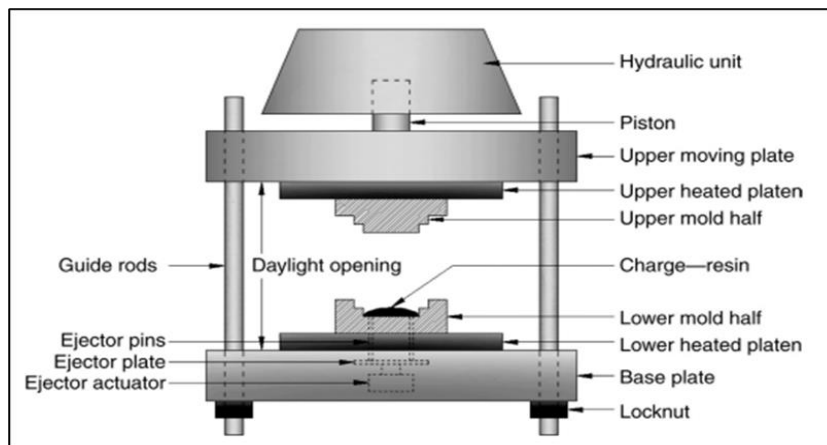
A hammermill is a machine that reduces particle size by the impact of rapidly moving hammers. The material is delivered into the mill's chamber by gravity through a feed chute, where it is repeatedly pounded until reduced in size that can pass through a neighboring screen.

Mixer

Mixing is a unit operation in industrial process engineering that includes modifying a heterogeneous physical system to make it more homogenous.

Compression-Molder

One of the basic techniques of material processing was compression molding. The common method is heating a thermoset resin under high pressure within a closed mold cavity until the resin is cured by a chemical reaction of cross-linking polymer chains. Under pressure, the resin liquefies and flows, conforming to the shape of the mold cavity before hardening into the intended component or product.



Source: Tatara, 2017

Figure 2. Schematic View of Components of a Typical Compression-Molder

A compression molding machine is primarily a heated vice-like press, and a schematic overview of the machine is shown in Figure 3.2. The device is compact but heavy, and it frequently has its support structure. The press's heavy-duty metal base plate supports a lower plate and four guide rods, allowing the hydraulics to move up and down. The lower platen can be heated in different ways, including electric cartridge heaters, hot oil, and steam.

Electric heaters are conveniently controlled, in the typical molding temperature range of 300–400°F (150–200°C), however, the hot oil is used when higher temperatures are necessary. This platen not only acts as a basis for any mold but also directly heats the mold's lower portion. The higher plate is located directly above the lower plate and is similarly heated to transfer thermal energy to the top surface of an upper mold half. An ejector system consisting of ejector pins attached to an ejector plate may be connected to the platen system or a separate component of the mold. The hydraulic unit, which consists of a hydraulic-powered piston, or ram, is housed.

METHODOLOGY

The machine is designed in consideration of the user's requirements, ensuring that it is easy to use, safe, and simple to operate, by at least one person. The three main parameters considered are the temperature, the ratio of the reinforcement and binder, and the thickness of the biocomposite boards.

Table 2. Design Parameters and Specifications

PARAMETERS	SPECIFICATIONS
Temperature	180 deg C - 200 deg C
Ratio	35:65 and 70:30
Thickness	1/16'' and 1/4''

The most traditional polymers are processed at a temperature ranging from 180°C to 200°C. According to (Singh et al., 2019), the thermal degradation of starch and rice husk contents begins at 200 °C. Thus, limiting the range for processing biocomposites to 200°C would avoid the degradation of agricultural wastes, as this is the stated limit for natural fibers. On the other hand, the biocomposite with a proportion of 35:65 by weight (PU matrix to EFB fibers) demonstrated superior adhesion between the matrix and the EFB fibers. Comparable to corkboards, the typical thickness is 1/16'' and 1/4'' as a suitable thickness for wallboards (Cohen, 2020).

Various factors are considered and determined whether they are dependent, independent or extraneous variables. These factors may affect the quality of the final product.

Table 3. Independent, Dependent, and Extraneous Factors

Independent variables	Dependent variables	Extraneous variables
Type of agricultural waste Type of binder Temperature Percentage of the Binder	Tensile strength Flexural Strength Compressive strength	Ambient temperature Skills of Person-tasked

Among the factors that directly influence outcomes are the study's independent variables the type of agricultural waste, temperature, binders, and binder-to-agricultural-waste ratio. The dependent variables are variables that are being evaluated and measured and are dependent on the independent variable. These factors include the tensile, flexural, and compressive strength of a material. On the other hand, variables that are not investigated that can still potentially affect the outcomes are the ambient temperature and the person's skill in conducting the experiment.

The study employed a 2k factorial design and analysis of variance (ANOVA) for statistical analysis to determine the relationship between the independent and the dependent variables. All the independent factors were sorted and narrowed down based on which element would significantly influence the outcome. The factors that can be calculated are the temperature and percentage of the binder, and the categorical factors are the type of binder and agricultural wastes, which are the four most relevant independent factors. A center point consisting of a 180C temperature and 35% binder was established for a more accurate result.

		Temperature	
		170 °C	190 °C
% Binder	30%	A 1, 5	B 2, 6
	40%	C 3, 7	D 4, 8

E 180 °C Temperature 35% Binder 9, 10, 11, 12
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Figure 3. 2k Factorial Design (Temperature and Percentage of the Binder)
Conceptual Framework

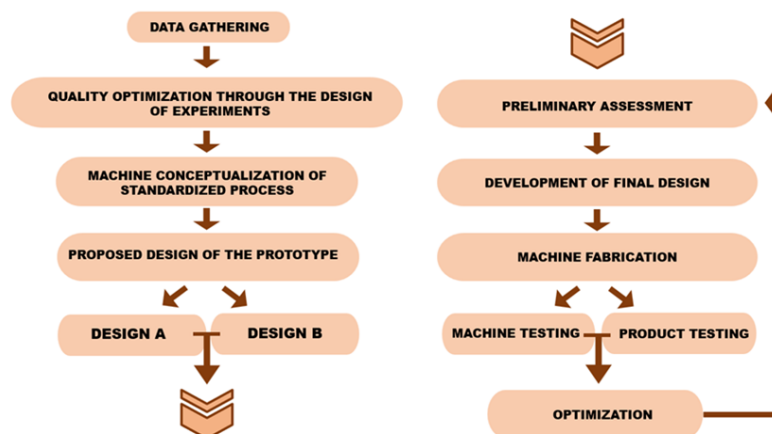


Figure 4. Flowchart of Conceptual Framework

This study has been developed with a feasible conceptual framework to be effective. The first step entails the collection of data to gain a better understanding of the study's significance and the identification of materials. Quality optimization includes material exploration, procurement, and the design of experiments that are carried out to ensure the quality of biocomposite materials using an experimental procedure to get the appropriate parameters for the machine's standardized process. Machine designs were developed and underwent pre-assessment to arrive at the final design.

Fabrication took place after the development of the final idea. The fabricated machine is tested and utilized to process biocomposites, and the generated products undergo several characterizations. Optimization is performed based on the results, whereby it undergoes preliminary assessment, testing, and modifications until the desired result is achieved.

RESULT AND DISCUSSION

Final Equipment Design

A detailed description of the final equipment design and specification can be found in this section. The primary systems are described as well as their overall layout.

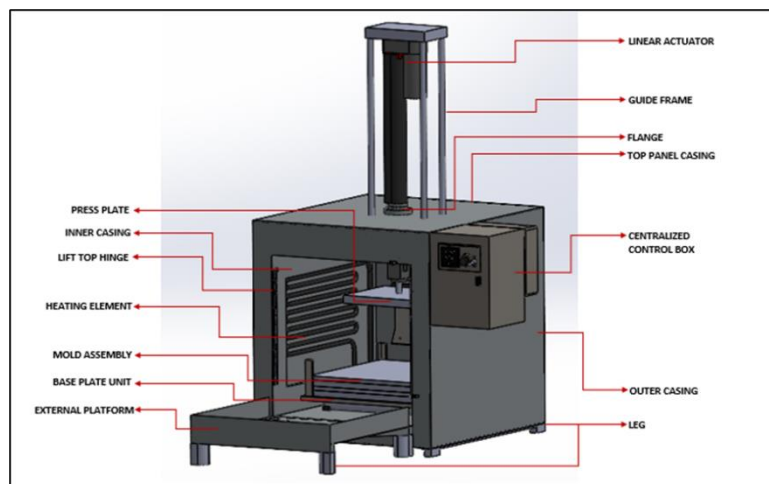


Figure 5. Isometric View of Final Prototype Design

Linear Actuator

A linear actuator with 250 mm-shaft is situated on the top panel of the assembly and is used as the source of the downward force for the press plate. It is controlled by a non-momentary rocker (protruding and retracting) switch and supplied with 220V-12V DC. The mouth of the actuator is placed on the top panel casing through an opening, with a metal flange, and its tail with a guide frame, accordingly.

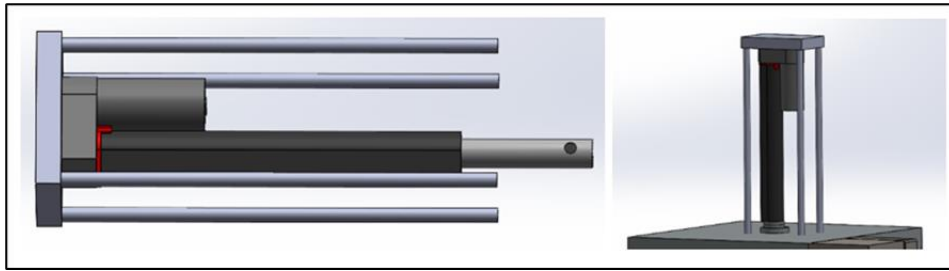


Figure 6. Arrangement of the Linear Actuator Unit Installed in the Machine

Inside the oven casing, the actuator's moving shaft is connected to the press plate unit via a splined yoke that is vertically fixed to provide a secured gripped extension.

Heating System

The heating system inside the compression molding machine is composed of two (2) 300x290 mm coils/pipes that are tested to achieve a heating range of 180-200 degrees Celsius. These elements are bolted on both sides of the inner casing with U-bolts and wired through the wall gap. The control and monitoring of the heating are through a digital temperature control relayed with a solid-state module with heat sink and a thermocouple.

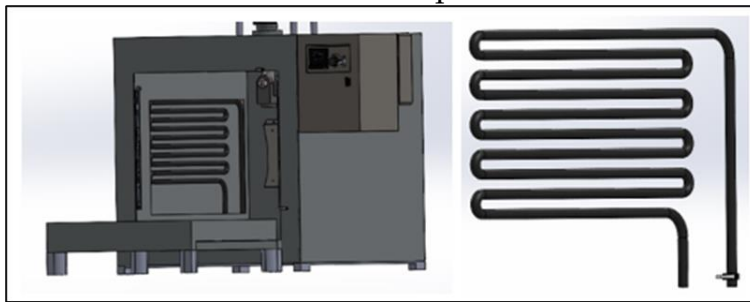


Figure 7. Arrangement of the Heating Element Unit Installed in the Machine

An exhaust fan is placed at the center of the rear wall casing of the machine. Metal blades for the fan are chosen to withstand heat that will be sucked out and regulated inside. A limit switch (normally closed) placed on the oven door will control the fan.

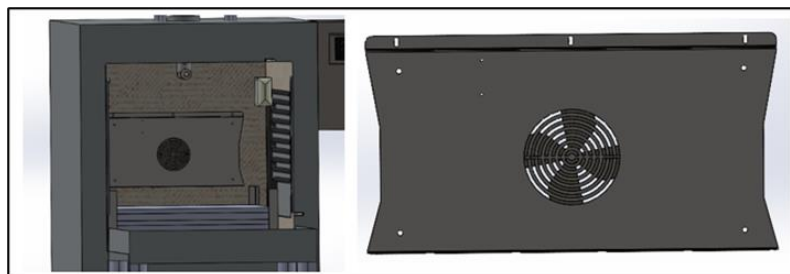


Figure 8. Arrangement of the Exhaust Fan Unit Installed in the Machine

A ceramic fiber insulation pad is lined within the 2-mm gap between the outer and inner wall casing. It is graded at 1260 degrees Celsius.

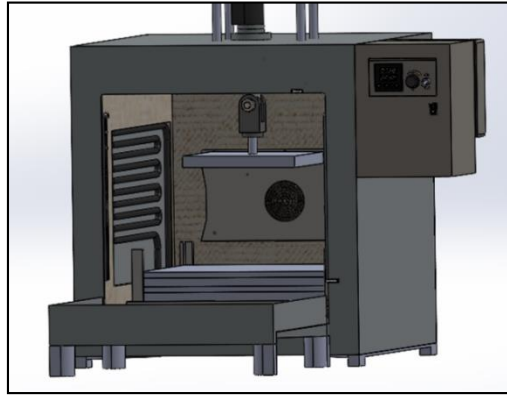


Figure 9. Ceramic Fiber Insulation Lining

Oven Door

The door is designed to be tight-sealed and easy to operate. It is built with an insulated glass and guided by a lift-top hinge for an upward opening and closing motion. A rubber lining is placed surrounding the inner sides of the door. Two (2) limit switches are placed on the top and bottom side of the door opening that controls the light bulb and exhaust fan, accordingly. As the door opens, the light turns on; subsequently, the fan turns on after closing the door.

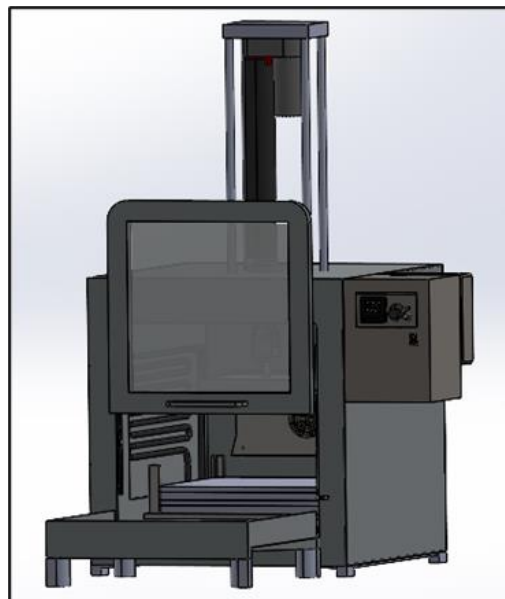


Figure 10. Arrangement of the Oven Door Unit

Control Box

The control box unit is situated on the top side of the compression molding assembly. A separate metal casing houses the controls for the heating and compression systems. The said controls are wired inside and relayed to their respective switches as well as the terminal for integrating the circuits. A 12V DC cooling fan is used to ensure the air movement inside the control box- which usually runs with increasing temperatures (mainly from the solid-state module and the heat from the oven).

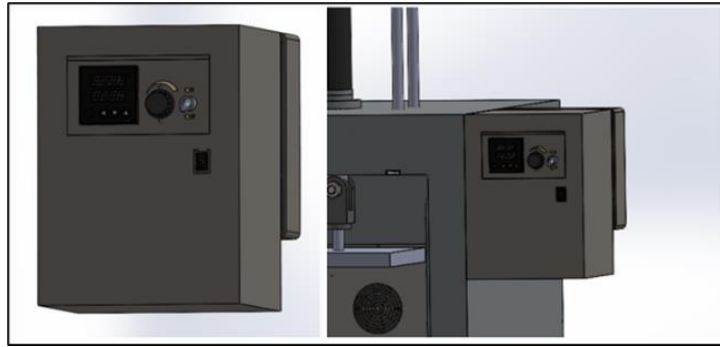


Figure 11. Arrangement of the Control Box Unit Installed in the Machine Frame and Casing

Galvanized Iron is used as the material for the structural frame of the machine. These frame supports the stainless-steel flat bars which are the inner and outer wall. A thicker flat bar is set for the top and bottom panels to support the loads of the linear actuator and mold assembly, respectively.

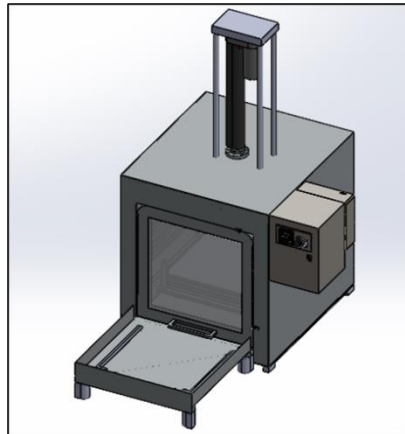


Figure 12. Frame and Casing of the Machine

An extended external platform is placed outside the doorway of the machine with the dimensions of 400mm x 378mm. The design of this platform is included to support the extraction of the molds after the compression molding operation.

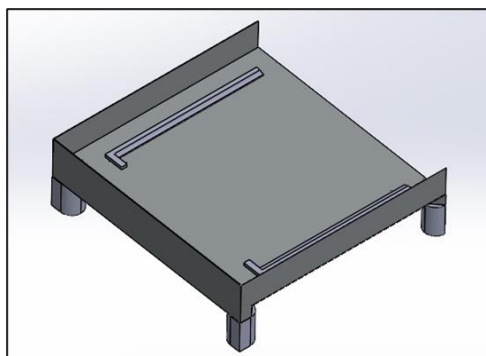


Figure 13. External Platform of the Machine

Mold Assembly

The mold assembly for the final design comprises of three molds that would produce a hexagonal shaped biocomposites. The dimensions of the mold are 350mm x 350mm each.

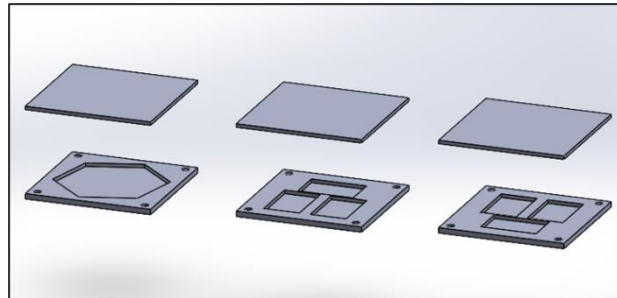


Figure 14. Arrangement of the Mold Assembly

Base Plate with Rollers

The base plate is a separate unit from the machine and is mobile. It is where the mold assembly is placed and pressed. It has the dimensions of (380mm x 380mm). The base plate has 4 (four) guide posts in each of its top corners that secures the mold assembly and prevents misalignment with the press plate during compression.

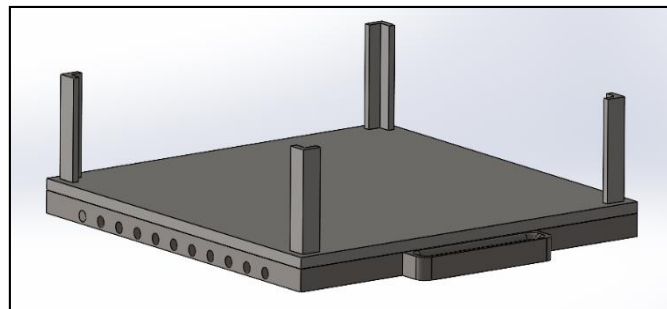


Figure 15. Arrangement of the Base Plate

Ten pieces of 300mm length and 25.4mm diameter rollers are positioned at the bottom side of the base plate with enough clearance against each other. It lets the base plate move in and out of the machine manually with the help of a handle.

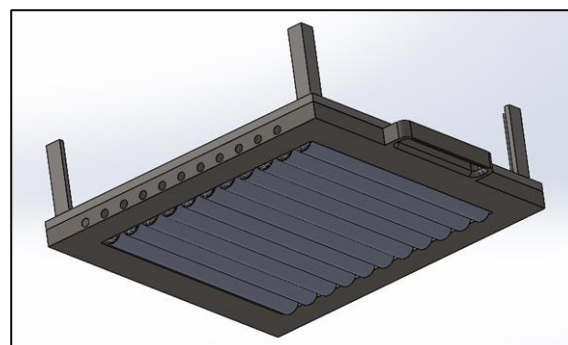


Figure 16. Base Plate Rollers

Experimental Results

This section presents the mechanical testing results from samples obtained through manual experimentation. ASTM D3039, ASTM D7264, and ASTM D3410 were used to assess the tensile, compressive, and flexural strength of biocomposites.

The maximum force and stress handled, as well as the maximum deformation of the test specimens, are indicated below for each combination at a given temperature and binder percentage.

Table 4 shows the result of the mechanical tests conducted in reaction to the two factors temperature and percentage of the binder. The combination of coconut husk with the binder HEC with 40% binder at 170C induced the maximum tensile strength among the other combinations. On the other hand, the combinations coconut husk with tapioca starch, and coconut husk with corn starch both with 30% binder at 170C induced the highest flexural and compressive strength.

Table 4. Mechanical Test's Results.

Test	Maximum Strength (MPa)	Combination	Temperature	%Binder
Tensile	4.93036	Coconut husk + HEC	170 deg C	40%
Flexural	14.0330	Coconut husk + Tapioca Starch	170 deg C	30%
Compressive	8.40941	Coconut husk + Corn Starch	170 deg C	30%

Temperature and percentage of the binder are significant considerations for developing biocomposite materials but only for a particular agricultural waste to binder combination, evident in rice straw with hydroxyl ethyl cellulose (RSHEC) and coconut husk with corn starch (CHCS). The tensile strength of the biocomposite material was substantial at low temperatures and with a higher proportion of the binder. The results indicate how biocomposites can be used in various applications for their considerable tensile strengths.

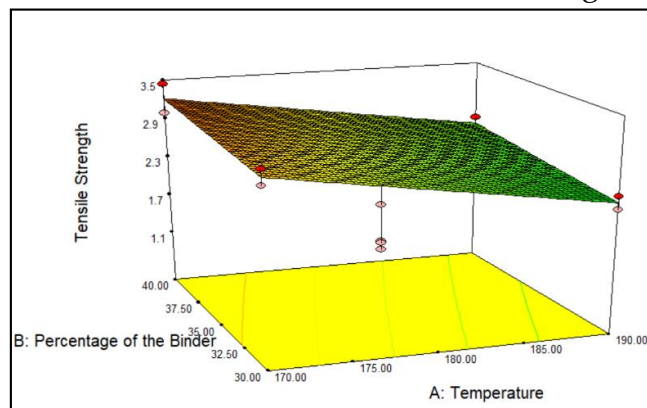


Figure 17. A 3D Model Graph of Interaction for Rice Straw-HEC Tensile Strength

The model graph, as presented in Figure 17, shows the significance of temperature for Response 1. The tensile strength of the Rice Straw-HEC biocomposite material increases as the temperature decreases.

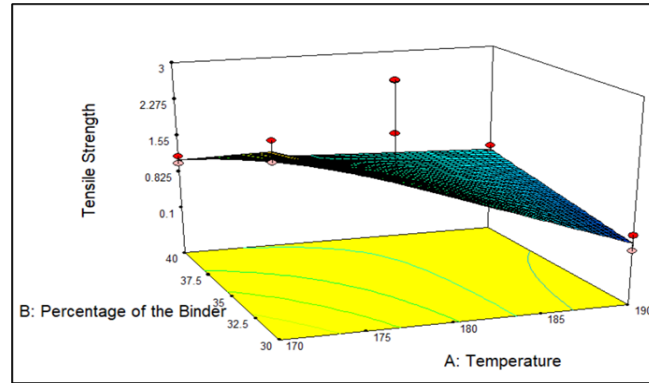


Figure 18. A 3D Model Graph of Interaction for Coconut Husk-Corn Starch Tensile Strength

The model graph, as presented in Figure 18, shows the significance of temperature and the interaction of the factors for Response 1. The tensile strength of the Coconut Husk-Corn Starch biocomposite material increases when the temperature interacts with the percentage of the binder. The interaction of a high percentage of the binder with temperature creates a significant tensile strength value.

CONCLUSIONS AND RECOMMENDATIONS

Temperature and percentage of the binder are significant considerations for developing biocomposite materials but only on particular agricultural waste: binder combinations. These include the RSHEC or rice straw with hydroxyethyl cellulose and CHCS or coconut husk with corn starch combinations. Biocomposites products were characterized by ASTM standards, including tensile, flexural, and compressive strengths, and met the quality criteria for biocomposites. The machine is fabricated but not fully prepared to run for 50 kg per hour.

The mechanical properties, such as tensile, flexural, and compressive strengths, of the biocomposite material with low temperature and more percentage of the binder were significant. The results indicate how biocomposites can be used in various applications for their considerable mechanical properties. Future investigations may further enhance the properties and functionalities of biobased composite materials.

The researchers would like to address various recommendations for the compression molding machine and the biocomposite manufacturing process. For the prototype, a linear actuator may be utilized to operate the door, and the roller connected to the base plate for automatic operation. However, other methods can be employed as well. Then, an ejector can be incorporated into the mold instead of Teflon coating. In addition, adopting a better mold material is advisable since it could reduce molding and heating time and subsequently increase the biocomposite's thickness. For higher production rates, the scaling-up phase of the machine may be employed.

Introduction of biocomposite products in the market could be explored and studied as people's increasing desire for sustainable materials is one of the driving forces in biocomposite's market expansion. Moreover, the integration of shredder and mixer in the prototype could also be explored and evaluated. Then, for biocomposites, reinforcing other agricultural crop wastes could be studied to further increase the mechanical and physical properties as well as cater in decreasing the agricultural wastes produced.

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