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EXPERIMENTAL INVESTIGATION OF MECHANICAL AND BIODEGRADABILITY PROPERTIES OF PLA COMPOSITES FABRICATED BY COMPRESSION MOULDING

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***Abstract**:* This study focuses on optimizing the compression molding process to make biodegradable PLA composites reinforced with sustainable animal bone powder filler. We analyze the properties of PLA and bone powder, adjusting factors like temperature, pressure, and filler amount to improve composite strength while keeping them eco-friendly. By using statistical analysis and microscopy, we find the best conditions and examine composite structures. We also evaluate their biodegradability and environmental impact, highlighting their eco-friendliness. This research helps create green materials efficiently through compression molding.

Index Terms **–** polylactic acid , biodegradability ,animal bone powder , compression molding.

I. INTRODUCTION

The fabrication of Polylactic Acid (PLA) composites through compression molding presents a promising avenue for sustainable manufacturing in various industries. PLA, derived from renewable resources such as corn starch or sugarcane, offers biodegradability and low environmental impact, making it an attractive alternative to traditional petroleum-based plastics. By incorporating reinforcing materials like fibers or nanoparticles into the PLA matrix, the resulting composites can exhibit enhanced mechanical, thermal, and barrier properties suitable for a wide range of applications. However, achieving optimal performance and efficiency in the compression molding process for PLA composites requires careful consideration and fine-tuning of several key parameters. Compression molding involves applying pressure and heat to the material within a mold cavity to shape it into the desired form. Parameters such as temperature, pressure, molding time, and cooling rate significantly influence the consolidation of the composite materials and the final properties of the product. The optimization of these process parameters is essential to maximize the mechanical strength, dimensional accuracy, and surface finish of PLA composites while minimizing defects such as voids, warpage, and fiber breakage. Additionally, efficient optimization can lead to reduced energy consumption, shorter cycle times, and lower production costs, thereby enhancing the competitiveness of PLA composites in the market.

Furthermore, continuous advancements in material science and manufacturing technology offer opportunities to further enhance the properties and production efficiency of PLA composites. Research efforts are underway to explore innovative additives, processing techniques, and mold designs to address specific performance requirements and scalability challenges. Additionally, advancements in recycling and end-of-life management strategies for PLA composites contribute to their overall sustainability profile. As consumer demand for eco-friendly products continues to rise, the development of high-performance PLA composites through compression molding holds great potential for meeting market needs while reducing environmental impact. Collaborative efforts among researchers, manufacturers, and policymakers are crucial to driving innovation and widespread adoption of sustainable manufacturing practices in various industries.

In this context, this study aims to explore the effects of various compression molding process parameters on the fabrication of PLA composites and to develop strategies for their optimization. Through systematic experimentation and analysis, we seek to identify the optimal combination of parameters that yield composites with superior performance and consistency. By advancing our understanding of the compression molding process for PLA composites, we aim to support the widespread adoption of sustainable materials in manufacturing and contribute to the transition towards a more environmentally friendly future.

II. FABRICATION METHOD

Compression molding is a straightforward method for shaping materials. It involves heating a mold and placing material inside. The mold is then closed tightly, and heat and pressure are applied to shape the material. Once shaped, the material is cooled or allowed to harden. After opening the mold, the finished product is removed. This process is efficient and widely used for making various products with precision.

Compression molding is a widely used technique for shaping materials efficiently and precisely. The process begins with heating a mold to the required temperature. Once the mold is heated, the material, typically in the form of pellets, powder, or preforms, is placed inside the mold cavity. The mold is then closed tightly, ensuring proper alignment and containment of the material. With the mold closed, heat and pressure are applied, causing the material to soften and flow to fill the mold cavity completely. This combination of heat and pressure helps to compact the material, removing any voids or air pockets and ensuring uniform distribution within the mold. After a specified period, the material is cooled or allowed to harden, depending on its composition and desired properties. Once cooled, the mold is opened, revealing the finished product. The product is carefully removed from the mold, and any excess material, known as flash, may be trimmed off. Compression molding offers advantages such as high production rates, precise control over part dimensions, and the ability to mold complex shapes with ease. It is widely used across industries for manufacturing a diverse range of products, including automotive components, electrical insulators, and consumer goods.

III. MATERIALS

Polylactic Acid (PLA):

Polylactic acid, commonly known as PLA, represents a significant advancement in the realm of biodegradable plastics. Derived from renewable resources like corn starch or sugarcane, PLA offers a sustainable alternative to traditional petroleum-based plastics, reducing reliance on finite fossil fuels. Its versatility is showcased across various industries, where it finds application in packaging, disposable tableware, textiles, medical implants, and even 3D printing. PLA is admired for its biocompatibility, making it suitable for medical and food-contact applications. Moreover, its transparency and ease of processing make it a favorite among manufacturers seeking environmentally friendly solutions. Perhaps most notably, PLA's compostable nature under certain conditions underscores its sustainability, providing a viable option for reducing environmental impact and advancing towards a circular economy.

Animal Bone Powder in Composite Materials:

In the quest for more sustainable materials, animal bone powder emerges as a promising ingredient in composite materials. When incorporated into a polymer matrix such as epoxy or polyester resin, bone powder acts as a reinforcing filler, enhancing the composite's mechanical properties. Beyond strength and durability, the use of bone powder imbues the composite with biodegradability, aligning with the growing demand for eco-friendly products. This eco-conscious approach not only benefits the environment but also offers a cost-effective solution compared to traditional fillers. By contributing to the production of composites with improved performance and sustainability, animal bone powder emerges as a valuable resource across various industries, paving the way for more environmentally responsible manufacturing practices.


Figure III.1 PLA


Figure III.2 Bone Powder

IV. METHODOLOGY

To optimize compression molding parameters for PLA composites, we follow a straightforward process. First, we review past research to understand what works best. Then, we choose PLA resin and reinforcing materials that go together well. Next, we plan experiments to test different settings for temperature, pressure, and time, using methods like Design of Experiments. Once we're ready, we mix the materials and shape them for compression molding. During the experiments, we carefully record how each parameter affects the process and the final product's quality. After molding, we check the samples for strength, thermal properties, and any defects. With this data, we analyze which parameters have the most impact and use statistical tools to find the best combination. We then adjust the parameters to optimize the process, considering factors like cost and practicality. Finally, we validate our optimized parameters to make sure they consistently produce good results. Throughout the process, we keep detailed records of our experiments and summarize our findings in a report for future reference.

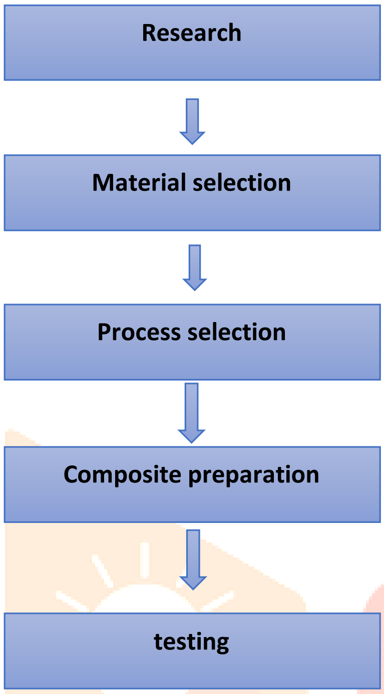

Figure IV.1 Methodology

The methodology for optimizing compression molding parameters for PLA composites begins with meticulous material selection, where high-quality PLA resin and compatible reinforcing agents are chosen to ensure the composite's integrity and performance. Once the materials are selected, the compression molding equipment is carefully set up, paying close attention to temperature, pressure, and cycle time settings to achieve optimal processing conditions. Identification of parameter ranges follows, establishing boundaries for key process variables such as temperature, pressure, mold design, and cooling strategies to be explored during experimentation. A systematic experimental design is then devised, outlining a series of tests to investigate the effects of varying parameters on PLA composite fabrication systematically. Sample preparation is a critical step, involving the creation of PLA composite samples with different combinations of parameters for subsequent testing. These samples undergo comprehensive testing and analysis, including mechanical, thermal, and microstructural assessments, to evaluate their performance under different process conditions. Data collection is conducted meticulously, capturing the performance metrics of PLA composites across the varied parameter settings. Statistical analysis is employed to analyze the collected data, identifying trends and determining the significance of process parameter variations on the performance of PLA composites. Optimization algorithms are then applied to the analyzed data to find the optimal combination of compression molding parameters that yield the desired composite properties. Through this methodical approach, the compression molding process for PLA composites is refined and optimized, ensuring enhanced performance, efficiency, and quality in composite fabrication.

After identifying the optimized parameters, the next crucial step involves validating their effectiveness and reproducibility. This validation process entails conducting additional compression molding experiments using the optimized settings to ensure consistent and reliable results. Moreover, it may involve testing a larger sample size to confirm the robustness of the optimized parameters across various conditions. Following validation, further refinement and fine-tuning of the optimized parameters may be necessary to achieve even better results. This iterative process allows for continuous improvement and optimization of the compression molding process for PLA composites. Subsequently, scaling up production and implementing the optimized parameters in a real-world manufacturing setting become essential. This transition from laboratory-scale experiments to full-scale production trials ensures that the optimized parameters can be effectively employed on a larger scale without compromising product quality or efficiency. Even after implementation, continuous monitoring and periodic reassessment of the optimized parameters are essential to ensure ongoing performance and efficiency. Regular quality control checks, process audits, and data analysis help identify any deviations or opportunities for further optimization. By maintaining a proactive approach to monitoring and optimization, manufacturers can ensure that the compression molding process for PLA composites remains efficient, cost-effective, and sustainable over time.

To optimize the compression molding process, meticulous attention to the condition and setup of the molding machine and heating system is paramount. Firstly, the compression molding machine must be thoroughly inspected to ensure it is in optimal working condition. This involves cleaning and maintaining the machine to prevent any contamination or malfunction during the molding process. Additionally, the machine should be set to the appropriate tonnage and pressure settings tailored to the specific material being used and the design requirements of the part being molded. Similarly, if heating is required for the compression molding process, it is crucial to ensure that the heating system is in proper working order. The heating elements or platens must be clean and free of any debris or residue that could affect the heating process. Additionally, the temperature settings should be adjusted to the precise level required for the material being molded, taking into account factors such as melting point and viscosity. By meticulously checking and configuring both the molding machine and heating system, optimal conditions can be achieved for the compression molding process, resulting in high-quality, accurately molded parts.

V. MECHANICAL TESTS

- Tensile Test:

The purpose of the tensile test is to measure the tensile strength, elastic modulus, and elongation at break of PLA composites, providing crucial insights into their mechanical properties. During the test procedure, samples of PLA composites are subjected to increasing tensile forces until they break. This allows researchers to assess how the composites respond to applied forces and determine their suitability for various engineering applications. The tensile strength indicates the maximum stress the composite can withstand before breaking, while the elastic modulus reflects its stiffness and resistance to deformation. Furthermore, the elongation at break offers insights into the material's ductility and flexibility.

- Flexural Test

The flexural test is conducted to assess the bending behavior and mechanical properties of a material under load, serving several important purposes in materials science, engineering, and quality control. This test helps understand how a material bends under force, providing crucial information about its strength and stiffness. By evaluating the material's response to bending, engineers can make informed decisions when choosing materials and designing structures. The flexural test is particularly valuable in assessing the performance of materials used in applications where bending and flexing are common, such as structural components in buildings, bridges, and automotive parts.

- Biodegradable Test

The purpose of the biodegradation test is to simulate industrial composting conditions and assess the biodegradability of PLA in a controlled environment. PLA samples are placed within a composting facility where temperature, humidity, and microbial activity are optimized to facilitate biodegradation. These conditions mimic real-world composting environments, allowing researchers to evaluate how PLA breaks down over time. Throughout the test, researchers periodically monitor the PLA samples for signs of degradation, including changes in weight, visual appearance, and chemical composition. By closely examining these indicators, researchers can gain insights into the rate and extent of PLA biodegradation under composting conditions. This information is valuable for assessing the environmental impact of PLA products and guiding the development of more sustainable materials.

VI. RESULTS AND DISCUSSIONS

1. TENSILE TEST

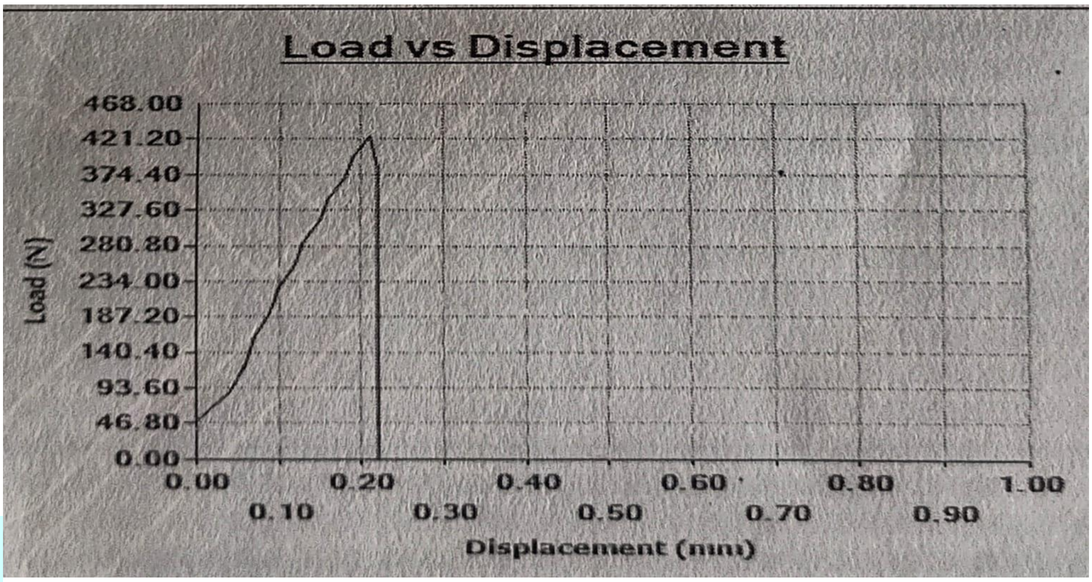

Figure 3 Load vs Displacement of PLA(tensile)

Specimen	Ultimate load (N)	Ultimate Tensile Strength (MPA)
Specimen 1-PLA	425	6.45
Specimen 2-PLA & 25% Bone powder	404	7.44

Table.1 Tensile test

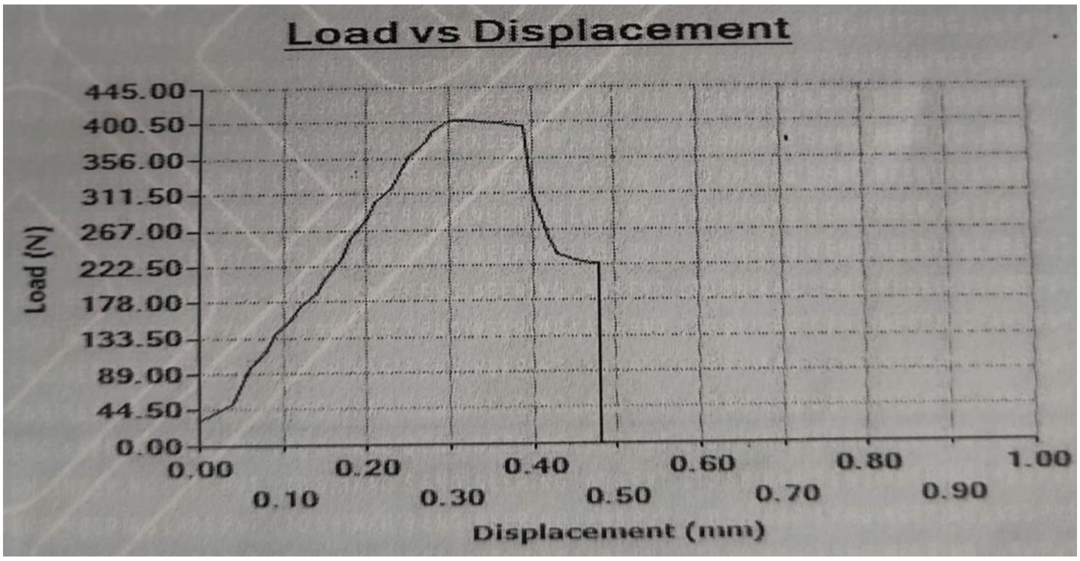

Figure 4 PLA+25% Bone Powder(tensile)

In the study, two types of specimens were tested to evaluate their ultimate load and ultimate tensile strength. The first specimen consisted of pure PLA, while the second specimen was composed of PLA blended with 25% bone powder. The results revealed that the addition of bone powder to the PLA composite slightly reduced the ultimate load from 425 N to 404 N. However, the ultimate tensile strength of the composite increased from 6.45 MPa for pure PLA to 7.44 MPa for the PLA composite with 25% bone powder. These findings suggest that incorporating bone powder into PLA can enhance the material's tensile strength while maintaining a comparable ultimate load. Further analysis and optimization of the blend ratio may yield even more significant improvements in mechanical properties, offering potential applications in various fields such as biomedical engineering and sustainable materials development.

2. FLEXURAL TEST

Table 2 Flexural Test

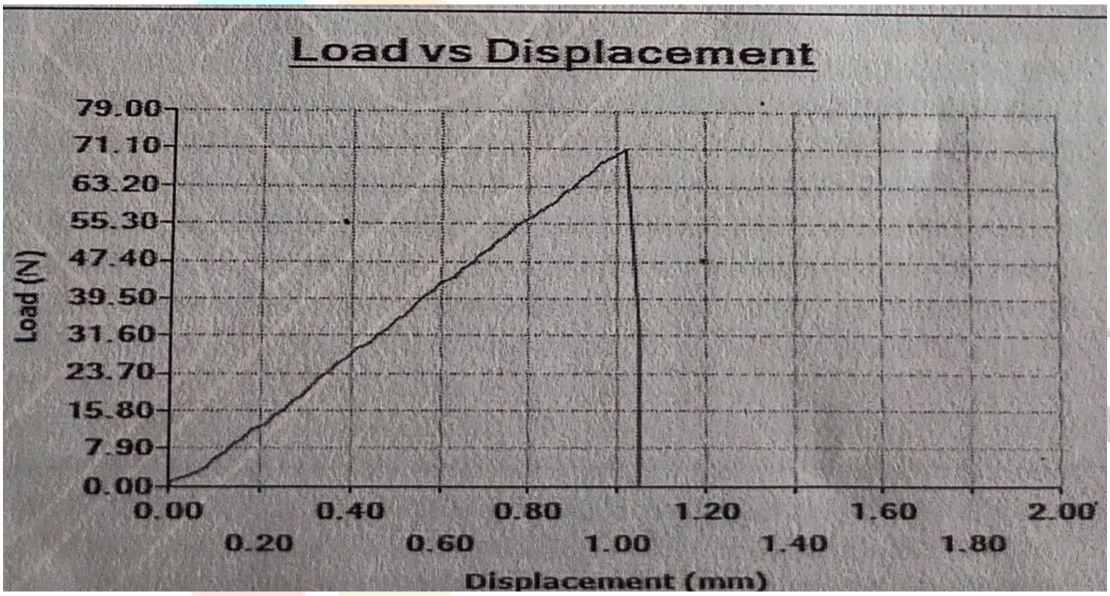

Figure 5 PLA(Flexural)

Specimen	Ultimate Load(N)	Flexural strength(MPA)
Specimen 1-PLA	71	10.4
Specimen 2-PLA & 25% Bone powder	15	4.72

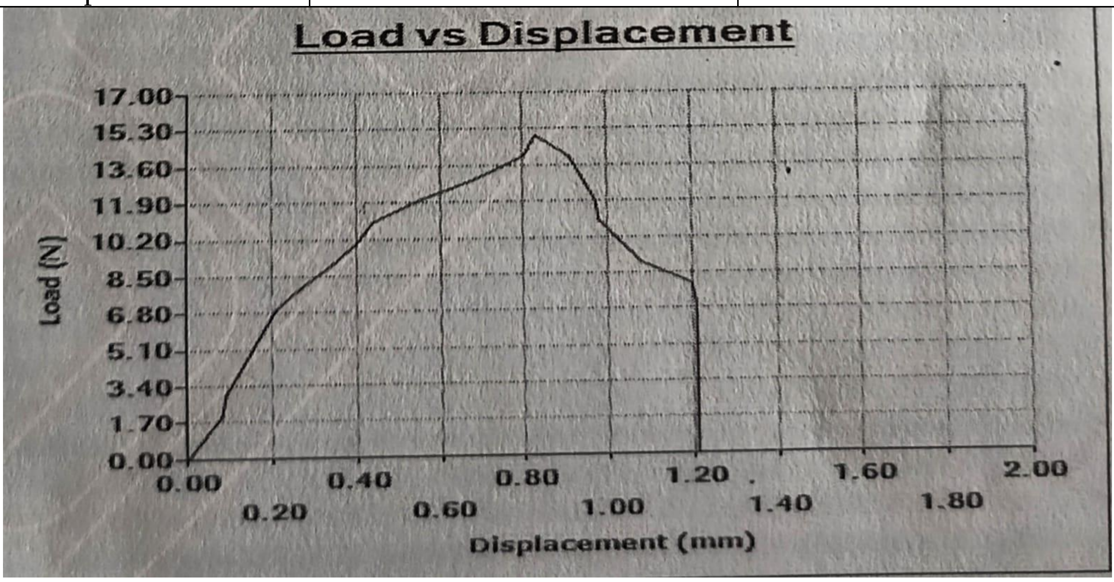

Figure 6 PLA+25% Bone Powder (Flexural)

The research findings indicate that the incorporation of 25% bone powder into PLA composites resulted in a reduction in both ultimate load and flexural strength compared to pure PLA specimens. Specifically, Specimen 2, composed of PLA and 25% bone powder, exhibited a significantly lower ultimate load of 15N and flexural strength of 4.72 MPa, in contrast to Specimen 1, which showed an ultimate load of 71N and flexural strength of 10.4 MPa. These results suggest that the addition of bone powder adversely affected the mechanical properties of the PLA composite, potentially due to inadequate bonding between the PLA matrix and the bone powder particles. Further investigation and optimization of processing parameters may be required to enhance the mechanical performance of PLA composites containing bone powder additives.

3. BIODEGRADABLE TEST

The experimental data illustrates the weight loss of PLA (Polylactic Acid) and PLA composites with varying percentages of bone powder over a period of 50 days. It is evident that all specimens experienced a marginal decrease in weight over the duration of the study. Specifically, the PLA specimens maintained a consistent weight throughout the observation period, with a negligible loss of 0.02 grams. Similarly, the PLA composites with 10%, 15%, and 25% bone powder content exhibited minimal weight loss, with reductions of only 0.02 grams and 0.01 grams for each respective composite. These findings suggest that the inclusion of bone powder additives did not significantly impact the degradation rate of the PLA composites over the 50-day period. Further analysis and long-term studies may be necessary to assess the influence of bone powder content on the degradation behavior and environmental sustainability of PLA-based materials.

	Initial weight (gm)	After 10 days	After 20 days	After 30 days	After 40 days	After 50 days	Loss in weight (gm)
PLA	2.13	2.13	2.12	2.12	2.11	2.11	0.02
PLA+10% bone powder	2.16	2.16	2.15	2.15	2.14	2.14	0.02
PLA+15% bone powder	2.15	2.15	2.15	2.14	2.14	2.14	0.01
PLA+25% bone powder	2.17	2.17	2.17	2.16	2.16	2.16	0.01

Table 3 Biodegradable Test

4. SEM Analysis

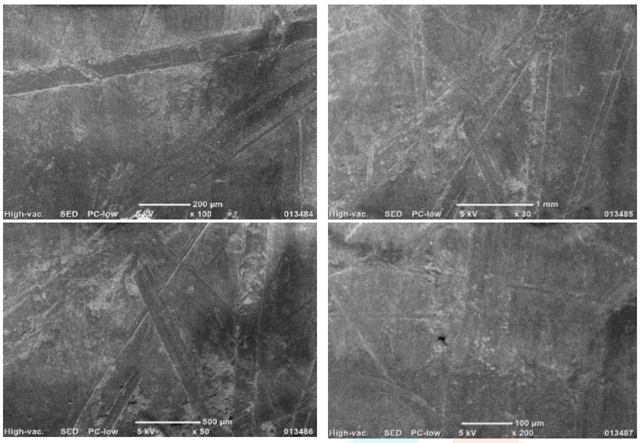

Figure 7 PLA

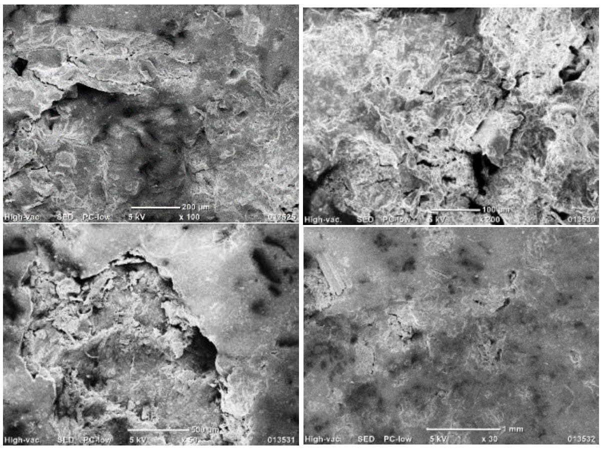

Figure 8 PLA+25% bone powder

VII. CONCLUSION

In conclusion, our study focused on refining compression molding parameters for PLA composites to improve material properties and production efficiency. Key findings include: Parameter Impact: We found that compression molding parameters like temperature, pressure, and time significantly affect PLA composite properties such as strength and surface finish. Optimal Settings: Through analysis, we identified optimal parameter combinations balancing strength, defects, and cycle time. Enhanced Performance: Optimized parameters led to PLA composites with better mechanical properties and production efficiency, benefiting industries like automotive and packaging. Future Directions: Further research should explore additional parameters and assess scalability and sustainability. In summary, optimizing compression molding parameters presents a promising avenue for creating high-quality, sustainable PLA composites, offering benefits for both industry and the environment.

VIII. REFERENCES

1. Martín del Campo, A. S., Robledo- Ortíz, J. R., Arellano, M., & Perez-Fonseca, A. A. (2022). Influence of agro-industrial wastes over the abiotic and composting degradation of polylactic acid bio composites. *Journal of Composite Materials*, *56*(1), 43–56. https://doi.org/10.1177/0021998321104769
2. Chieng, B. W., Ibrahim, N. A., & Yunus, W. M. Z. W. (2012). Optimization of Tensile Strength of Poly(Lactic Acid)/Graphene Nanocomposites Using Response Surface Methodology. *Polymer - Plastics Technology and Engineering*, *51*(8), 791–799. https://doi.org/10.1080/03602559.2012.663043
3. Ketabchi , M. R., Khalid, M., Ratnam, C. T., Michael, F. M., & Walvekar, R. (2019). Investigating the effects of processing parameters on poly(lactic acid) properties–a central composite design approach. *Plastics, Rubber and Composites*, *48*(3), 95–102. https://doi.org/10.1080/14658011.2019.1570444
4. Werchefani M, Lacoste C, Belguith H , et al. Effect of chemical and enzymatic treatments of alfa fibers on polylactic acid bio-composites properties. J Compos Mater 2020; 54: 4959–4967.
5. Antunes A, Popelka A, Aljarod O, et al. Effects of rutile-TiO2 nanoparticles on accelerated weathering degradation of poly(lactic acid). Polymers 2020; 12: 21–23.
6. Qi X, Ren Y and Wang X. New advances in the biodegradation of poly(lactic) acid. Int Biodeterioration Biodegradation 2017; 117: 215–223.
7. Lizarraga-Labor´ ´ın LL, Quiroz-Castillo JM, Encinas-Encinas JC, et al. Accelerated weathering study of extruded polyethylene/poly (lactic acid)/chitosan films. Polym Degrad Stab 2018; 155: 43–51.

8. Gonzalez-López M. E., Mart´ ´ın del Campo A. S., RobledoOrt´ız J. R., et al. Accelerated weathering of poly(lactic acid) and its biocomposites: A review. Polym Degrad Stab 2020; 179: 109290.
9. Gupta M and Singh R. PLA-coated sisal fibre-reinforced polyester composite: water absorption, static and dynamic mechanical properties. J Compos Mater 2019; 53: 65–72.
10. Siakeng R, Jawaid M, Ariffin H, et al. Physical properties of coir and pineapple leaf fibre reinforced polylactic acid hybrid composites. IOP Conf Ser Mater Sci Eng 2018; 290: 012031.
11. Stepczynska M and Rytlewski P. Enzymatic degradation of´ flax-fibers reinforced polylactide. Int Biodeterioration Biodegradation 2018; 126: 160–166.
12. Janczak K, Da˛browska GB, Raszkowska-Kaczor A, et al. Biodegradation of the plastics PLA and PET in cultivated soil with the participation of microorganisms and plants. Int Biodeterioration Biodegradation 2020; 155: 105087.
13. Pattanasuttichonlakul W, Sombatsompop N and Prapagdee B.Accelerating biodegradation of PLA using microbial consortium from dairy wastewater sludge combined with PLAdegrading bacterium. Int Biodeterioration Biodegradation 2018; 132: 74–83.
14. Siakeng R, Jawaid M, Asim M, et al. Accelerated weatheringand soil burial effect on biodegradability, colour and texture of coir/pineapple leaf fibres/PLA biocomposites. Polymers 2020; 12: 458.