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Advancement in Mechanical Properties of Bioplastics Using Brown Algae and Eggshells-A Sustainable Method

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Abstract

Plastic pollution poses a major threat to ecosystems and human health due to the slow decomposition of conventional plastics. This study aims to develop a sustainable bio-plastic with enhanced mechanical properties using sodium alginate extracted from brown algae and calcium carbonate from organic eggshells. The bioplastic was fabricated and tested for tensile strength, water absorbability and biodegradability. The results revealed that the incorporation of sodium alginate and eggshell powder increased hanging strength by 1800% compared to control samples, while biodegradability improved significantly, with complete degradation achieved within seven days. However, an increase in water absorbability was observed, attributed to the hydrophilic nature of sodium alginate. Future studies will focus on enhancing the hydrophobic properties and thermal strength of the bioplastic. These findings contribute to the growing efforts to develop affordable, high-performance biodegradable plastics, supporting sustainability goals in the United Arab Emirates and beyond.

Keywords: Bioplastic, Brown algae, Eggshells, Tensile strength, Biodegradability, Sustainable materials, Calcium carbonate, Sodium alginate

Introduction

The widespread use of conventional plastics has led to significant environmental challenges, particularly in the form of plastic pollution affecting oceans, soil and the atmosphere. Global plastic production has surged from 2 million metric tons in 1950 to approximately 390.7 million metric tons by 2021, with an annual growth rate of about 4% [1]. Alarmingly, an estimated 8 million metric tons of plastic enter marine environments annually, posing a serious threat to ecosystems [2]. Traditional plastics are derived from non-renewable resources, require high energy consumption during manufacturing and produce significant greenhouse gas emissions, contributing further to climate change [3].

In response to these concerns, bioplastics have emerged as a promising alternative. They are derived from renewable resources, are often biodegradable and offer a potential pathway to reduce environmental damage. Polylactic Acid (PLA), one of the most common bioplastics produced from corn starch, exemplifies these challenges; while it is biodegradable, its mechanical properties do not yet match those of traditional plastics [4].

Recent studies have explored various methods to enhance the mechanical properties of bioplastics, including blending with natural fibers, adding nanoparticles and chemical modifications. However, debates remain regarding the scalability, cost-effectiveness and true environmental impact of these improved bioplastics, with some researchers warning that certain bioplastics degrade only under industrial composting conditions [5].

In this context, the present study aims to develop a sustainable and commercially viable bioplastic with enhanced tensile strength, flexibility and biodegradability by incorporating naturally sourced calcium carbonate (from eggshells) and renewable materials such as sodium alginate and various starches. Our work was motivated by the alarming level of plastic waste observed on our school campus, where approximately 500-600 plastic bottles were discarded daily. By improving the mechanical properties of PLA-based bioplastics, we seek to provide a practical alternative that addresses both environmental and commercial needs.

Our preliminary findings demonstrate that the addition of fine powdered eggshells significantly improves the tensile strength of PLA-based bioplastics, paving the way for broader applications. This paper presents the methods, experimental results and future directions for advancing bioplastics towards a more sustainable future.

Materials and Methods

All our experiments were performed at 21 degrees Celsius. The humidity level for each was kept at 60%.

Materials

The following materials were used in the preparation of bioplastics:

- Water (100 mL)
- Corn starch (5 grams)
- Glycerol (7 mL)

- Vinegar (4 mL)
- Sodium alginate (4 grams)
- Calcium carbonate (2.5 grams, extracted from eggshells)

Bioplastic preparation

Bioplastic was synthesized using the following procedure:

Preparation of the polymer base: Sodium alginate (4 grams) and corn starch (5 grams) were dissolved in 100 mL of water, creating a polymeric solution. The sodium alginate and corn starch serve as the primary binders to hold the bioplastic mixture together.

Plasticization: To enhance flexibility, 7 mL of glycerol was added to the mixture. Glycerol acts as a plasticizer, facilitating the conversion of the mixture into a pliable form.

Acidity adjustment: To further increase the flexibility of the bioplastic, 4 mL of vinegar was incorporated into the solution.

Addition of calcium carbonate: Calcium carbonate (2.5 grams), derived from eggshells, was added to the mixture. The eggshells were pretreated and ground to obtain pure calcium carbonate, which contributes to the structural properties of the bioplastic.

Heating process: The resulting mixture was heated to a temperature of 74°C and maintained at a constant high temperature of 90°C to facilitate complete integration of the components.

Cooling and solidification: After the heating process, the bioplastic mixture was allowed to cool, solidifying into a flexible sheet of bioplastic.

Results

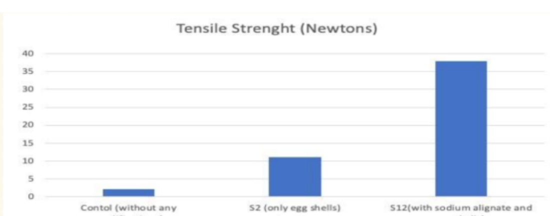
Mechanical and physical properties of bioplastics

Tensile strength comparison

- Two types of bioplastic samples were tested for tensile strength using a spring balance.
- Weights were gradually added to each sample until rupture occurred.
- The tensile strength was measured in Newtons (N).

Results

Bioplastic containing eggshell-derived calcium carbonate and sodium alginate demonstrated an increase in tensile strength by approximately 1800% compared to the control bioplastic (without eggshells and sodium alginate) (Figure 1).

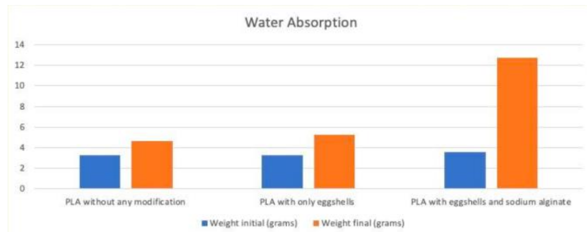


	Tensile Strenght (Newtons)
Contol (without any modifications)	2
S2 (only egg shells)	11
S12(with sodium alignate and eggshells)	38

Figure 1: The figure shows the three samples tensile strength result.

Water absorption comparison

- Bioplastic samples were weighed before and after immersion in water for two hours.
- Initial weight (Wi) of each sample: 3.255 grams.
- After 2 hours:
  - ➢ Bioplastic with eggshells and sodium alginate: 12.73 grams.
  - ➢ Control PLA bioplastic: 5.239 grams.
- Water absorption results:
- ➢ Bioplastic with eggshells and sodium alginate showed a 258.59% increase in weight.
- ➢ Control PLA bioplastic showed a 62% increase.
- The higher water absorption in the modified bioplastic is attributed to the hydrophilic nature of sodium alginate.
- Future Work: Research is ongoing to incorporate hydrophobic materials to reduce water absorption (Figure 2).



Water Absorption	Weight initial (grams)	Weight final (grams)
PLA without any modification	3.255	4.666
PLA with only eggshells	3.255	5.239
PLA with eggshells and sodium alginate	3.55	12.73

Figure 2: The figure shows the three samples water absorption result.

Biodegradability in soil

- Six samples were tested: three from the modified PLA with eggshells and sodium alginate and three from the control PLA sample.
- Initial dimensions:
  - ➢ Height: 6.67 cm
  - ➢ Width: 4.5 cm
  - ➢ Area: ~30 cm²
- Samples were buried in soil with a maintained pH of 6.4 and watered daily.
- Decomposition results after 14 days:
  - ➢ Bioplastic with eggshells and sodium alginate: 100% loss in area (completely degraded).
  - ➢ Control PLA bioplastic: 66.7% loss in area.
- These findings confirm that the incorporation of eggshells and sodium alginate significantly enhances the biodegradability of PLA-based bioplastics (Figure 3 and Table 1).

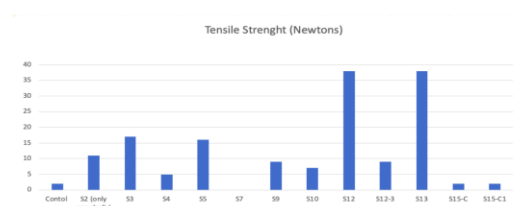


Figure 3: The figure shows all the tensile strength of the samples.

Code	Plasticizer	Polymer	Stiffening	Curing	Vehicle	Notes	Status
Control	3 ml Glycerin	8.542 g Corn Starch	None	3 ml Vinegar	50 ml Water	Sticky, low tensile strength (2 N), flexible but less durable.	Done
S2	3 ml Glycerin	8.542 g Corn Starch	0.86 g $CaCO_3$/Eggshells	3 ml Vinegar	50 ml Water	Stronger than Control (11 N).	Done
S3	3 ml Glycerin	8.542 g Corn Starch + 2 g Sodium Alginate	0.86 g $CaCO_3$/Eggshells	7 ml Vinegar	50 ml Water + 1 g $CaCl_2$	Stronger than S2 (17 N), needed more vinegar.	Done
S4	3 ml Glycerin	8.542 g Corn Starch + 5 g Sodium Alginate	2 g $CaCO_3$/Eggshells + 2 g $CaCl_2$	5 ml Vinegar	100 ml Water	More flexible, still sticky, 5 N tensile strength.	Done
S5	4 ml Glycerin	12 g Sodium Alginate	4 g $CaCO_3$/Eggshells	4 ml Vinegar	100 ml Water	Sticky, flexible.	Canceled
S6	5 ml Glycerin	8.542 g Corn Starch + 10 g Sodium Alginate	1.5 g $CaCO_3$/Eggshells	5 ml Vinegar	50 ml Water	-	(Tensile strength 18 N?)
S7–S11	3–10 ml Glycerin	Various amounts Corn Starch + Sodium Alginate	0.86–1.5 g $CaCO_3$/Eggshells	3–5 ml Vinegar	50–100 ml Water	Varied, some brittle due to rain, some canceled or destroyed.	Mixed Results
S12–S12-3	7 ml Glycerin	5 g Corn Starch + 4 g Sodium Alginate	2.5 g $CaCO_3$ (mixed powder/eggshells)	4 ml Vinegar	100 ml Water	Achieved high tensile strength (38 N), flexible, durable, water absorption tested.	Done
S13	7 ml Glycerin	5 g Arrowroot Starch + 4 g Sodium Alginate	2.5 g $CaCO_3$ (mixed)	4 ml Vinegar	100 ml Water	Arrowroot starch reached 38 N.	Done
S14	7 ml Glycerin	5 g Tapioca Starch + 4 g Sodium Alginate	2.5 g $CaCO_3$ (mixed)	4 ml Vinegar	100 ml Water	Canceled.	Canceled
S15-C	9 ml Glycerin	25.5 g Potato Starch	None	9 ml Vinegar	150 ml Water	Dried in lab conditions.	Done
S15-C1	3 ml Glycerin	8.542 g Potato Starch	None	3 ml Vinegar	50 ml Water	Dried in lab conditions.	Done

Table 1: Summary of Bioplastic Formulations and Observations. **Note:** Shows all experiments done.

Evaluation of different types of starch for PLA bioplastics

Starch type comparison for tensile strength

- In this part of the study, different starches were tested to identify the strongest candidate for PLA bioplastic production.
- Based on previous research, arrowroot starch was hypothesized to produce the strongest PLA polymer. This hypothesis was tested using samples S13 and S12.

Samples and Methodology:

- S15-C and S15-C1: Bioplastics made with potato starch.
- S12: Bioplastic made with cornstarch (control sample).
- S13: Bioplastic made with arrowroot starch.
- All samples were subjected to tensile strength testing under standardized conditions.

Results:

- Samples S15-C and S15-C1 (potato starch) exhibited tensile strengths comparable to each other but lower than the control sample (cornstarch).
- Bioplastics made from potato starch demonstrated lower durability compared to those made from cornstarch.
- Samples S12 (cornstarch) and S13 (arrowroot starch) showed identical tensile strength values of 39 N, indicating that arrowroot starch and cornstarch produce bioplastics with similar mechanical strength.

Conclusion:

- There was no significant difference in tensile strength between bioplastics made from arrowroot starch, cornstarch and potato starch.
- Therefore, arrowroot starch, potato starch and cornstarch can all be used to produce PLA bioplastics with comparable mechanical properties, although cornstarch remains the most reliable option based on durability and availability.

Discussion

The experiments showed that adding calcium carbonate and sodium alginate significantly improved the tensile strength and durability of bioplastics compared to the control. The best result, reaching 38 N, was achieved by optimizing polymer blends, plasticizer amounts and drying conditions. Using arrowroot starch also proved effective, while tap-ioca starch was less successful. These findings align with previous studies but emphasize the importance of precise formulation and processing. Future work should explore other natural additives, drying methods and long-term performance testing.

Conclusion

This study demonstrated that adding calcium carbonate from eggshells and sodium alginate greatly enhanced the tensile strength and biodegradability of bioplastics. However, while strength improved by 1800% and complete degradation occurred within seven days, the addition of alginate also significantly increased water absorption. Future work will focus on reducing hydrophilicity while maintaining the improved mechanical and environmental properties, aiming to create more durable and sustainable packaging solutions.

Acknowledgments

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Conflict of interest

Authors declare there is no conflict of interest.

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