Ecofriendly Polymeric Material : Paving The Way For Circular Bio-Economy

The Effect of Chitosan on Biodegradability and Water Resistance of Starch based Bioplastic

3rd Year

Problem

Today, petroleum-based plastic is a major part of our everyday life. Their chemical and insulating properties complimented by the low cost of manufacturing has made us dependent on them. On the downside, they are resistant to microbial degradation and hence continue to accumulate over a long period. Up to 12 million tons of plastic debris is entering the ocean every year, the UN calls it a "planetary crisis". In today's world, plastic waste is everywhere, they are in the air, soil and in the water. It's very important that we find an alternative to conventional plastic that will help maintain our lifestyle while eliminating or reducing the impact on the environment. Plastics made from biomass(organic resources) could be the solution to the issue at hand because of their biodegradability.

Engineering Goal

The goal of the experiment is to enhance biodegradability and water resistance strength of the "bio-fiber plastic" prototype developed in last year's project by adding chitosan, a compound derived from crustacean shell waste.

Materials and Method

The chitosan sources identified for this research are shellfish exoskeleton.

Starch based bio-fiber plastic samples from last year's research is used as a control in this year's research.

Key Materials and their Role:

Starch: Rice acts as biopolymer. Base ingredient and acts as bio-polymer.

Fiber : Recycled office paper are used to enhance the tensile strength.

Chitosan : Chitosan helps to enhance the bio-degradability and water resistance

Glycerin : Helps to enhance the plasticity and mobility of the polymeric chain.

Vinegar: Helps in breaking down the starch chain and makes them more usable.

Water: Helps to mix it all up and make the ingredients workable

Six different mixing ratios between Biofiber plastic and Chitosan were used to create the sample bioplastic.

Condition	Bio-Fiber	Chitosan	Food Color
90/10	1.26	0.14	Orange
80/20	1.12	0.28	Pink
70/30	0.98	0.42	Blue
60/40	0.84	0.56	Green
50/50	0.70	0.70	Red
40/60	0.56	0.84	Yellow

Testing Method:

Tensile strength will be calculated using the Maximum force (measured using digital force gauge) and thickness (using Vernier caliper).

Water resistance will be tested by performing a water absorption test, which measures the weight of water absorbed by the bioplastic sample when immersed in water for a specific period of time.

Biodegradability is measured by calculating the "loss of weight" of the bioplastic sample over a specific period of time when buried in compost soil at room temperature.

Flexibility will be tested by folding the bioplastic samples at 180 degrees and placing a weight (100 grams) repeatedly until it shows signs of a crease.

Project Idea

Bioplastics are a type of plastic derived from renewable biomass (e.g., plant material). All plastics are polymers, polymers can be either natural or synthetic and are created when small molecules, also known as monomers, combine chemically to form a larger network of connected molecules. Conventional plastics are made of "synthetic" polymers such as polyethylene, polystyrene etc. whereas Bioplastics are made of "natural" polymers such as starch, gelatin, etc. Approximately 50% of the bioplastics in use today are derived from Polysaccharides.

Inspired by the concept of circular bio economy, this project's aims to develop alternative materials to conventional plastics by upcycling the waste from the environment. The project goal is to improve biodegradability and water resistance of starch-based bioplastic by fusing it with cellulosic fiber from recycled paper and chitosan from marine waste, there by extending the useful life as a new bioplastic material. In this prototype, three different polysaccharides namely Starch, Cellulose and Chitosan are used to develop the bioplastic.

Figure - 1

Starch: Starch is an abundantly available biomass which can be a substitute for synthetic polymers. Starch is the complex carbohydrate that exists in many foods, including grains, vegetables, and fruits. Starch consists of two repeating glucose subunits: amylose [linear] and amylopectin [branched]. The ratio of Amylose and Amylopectin varies in different starch sources resulting in bioplastic of varied mechanical strength. Starch from Rice has the highest amylose content compared to other starch sources, making it an ideal candidate for starch-based bioplastic. Even though starch-based bioplastic exhibits similar characteristics as conventional plastics, they still lack in tensile strength and water resistance. In order to improve these properties, other biodegradable polymers can be blended to minimize the limitations of pure starch-based plastics.

Cellulose: Cellulose is a complex carbohydrate, which contributes to the basic structural component of plant cell walls. About 33 percent of all vegetable matter is cellulose making it the most abundant of all naturally occurring organic compounds. The chemical links between the individual glucose subunits have a strong tendency to aggregate to highly ordered structural entities resulting in strong mechanical properties. The strong mechanical property of Cellulose makes it a suitable choice as a co-polymer of starch-based bioplastic to improve tensile strength. Paper products manufactured from trees, typically contains 90–99% cellulose fibers. Paper wastage facts show that 85 million tons of paper waste are created each year.

Chitosan: Chitosan, is a derivative of chitin, obtained by deacetylation of chitin. Chitin is the structural material of crustaceans, insects, and fungi, and is the second most abundant biopolymer after cellulose on earth. Deacetylation process improves the reactivity and solubility nature of Chitin. Chitosan is a linear polysaccharide with similar molecular structure as cellulose, however the hydroxyl group in the cellulose is replaced with acetyl amine group resulting in a stronger hydrogen bond making chitin stronger than cellulose. The hydrophobic and biodegradation nature of chitosan makes it a suitable choice as a co-polymer of starch-based bioplastic to improve water resistance and biodegradable properties. The food industry generates 6 million to 8 million metric tons of crab, shrimp and lobster shell waste every year. Depending on the country, those claws and legs largely get dumped back into the ocean or into landfills.

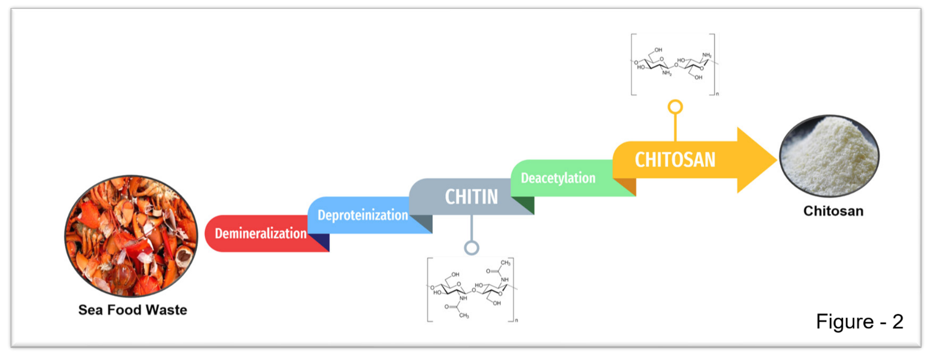


Figure - 2

Including cellulose from paper waste and Chitosan from sea food waste in creating bioplastic enables the upcycling of waste materials and extends the useful life of waste materials paves the way for bio circular economy.

Formulas

Tensile Strength s= P/a

s : Tensile Strength in Nm-2

P : force required to break in Newton

a : cross-sectional area

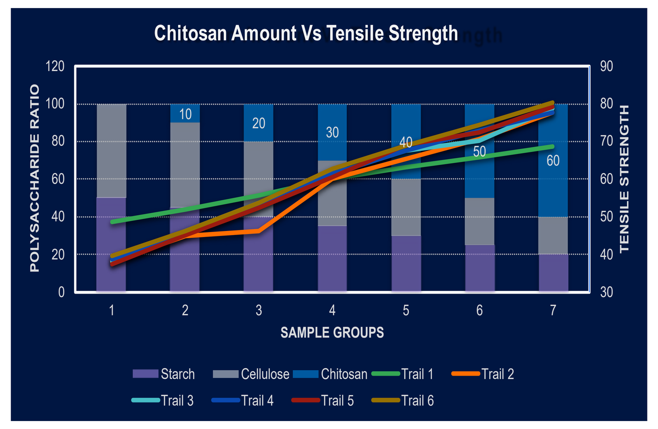
Biodegradability: $\left[\frac{Wo-W}{Wo}\right] 100$

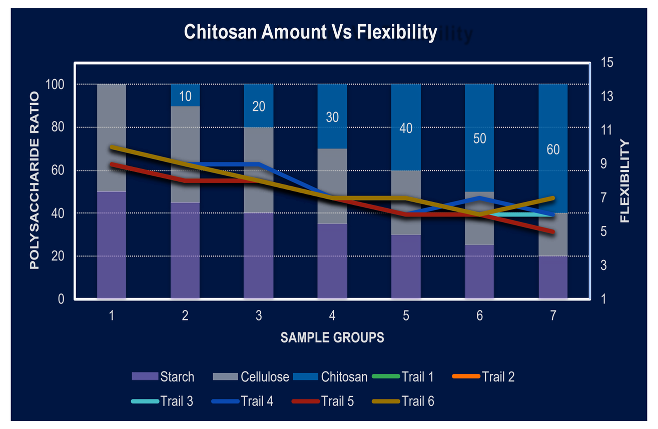
Wo : Weight of dry sample (g)
W : Weight of sample after 45 days buried in the compost soil (g)

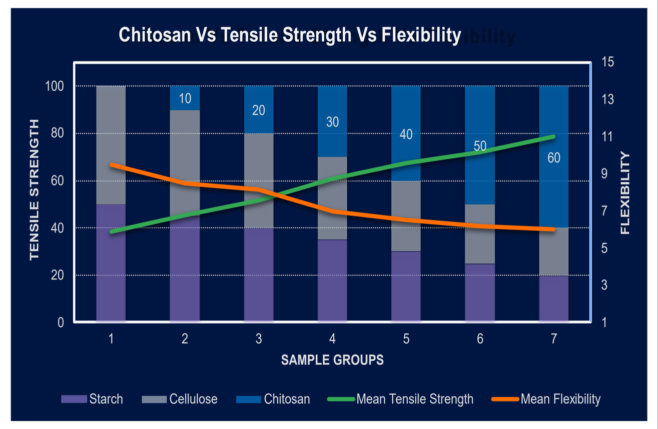
Water Resistance: $100 - \left[\frac{W-Wo}{Wo}\right] 100$

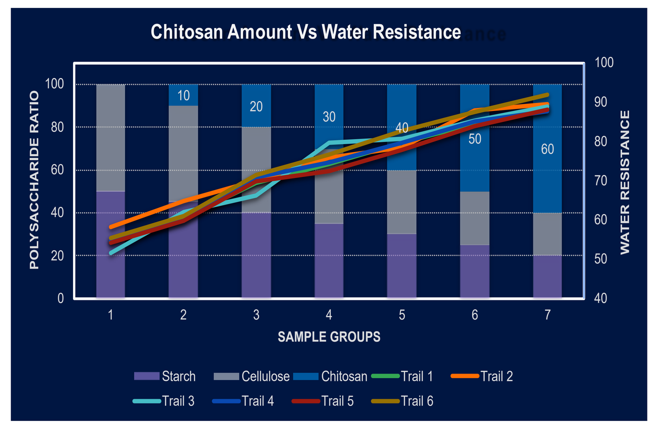
Wo : Weight of dry sample (g)
W : Weight of sample after 24 hours of immersion in distilled water (g)

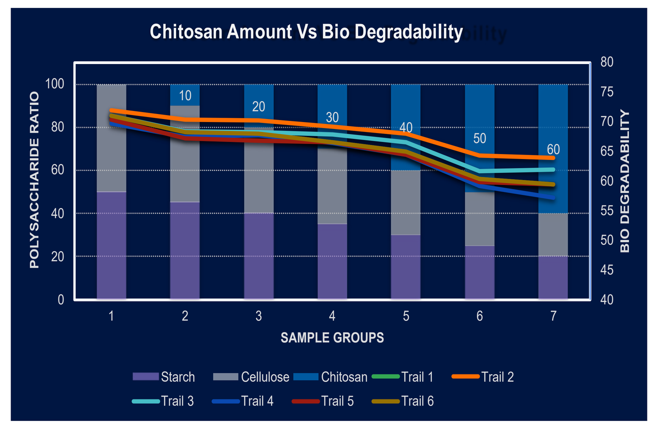
Data / Charts

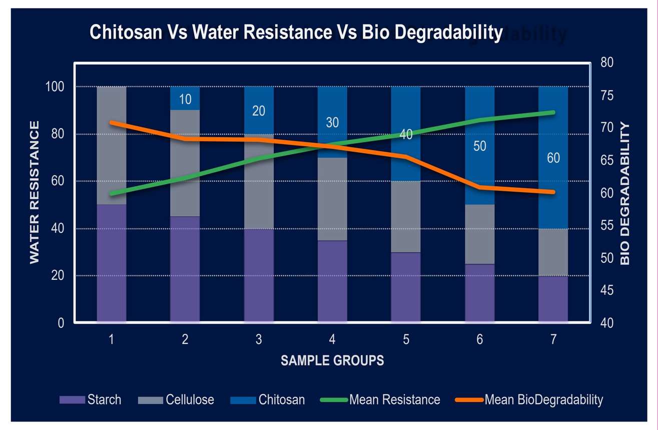




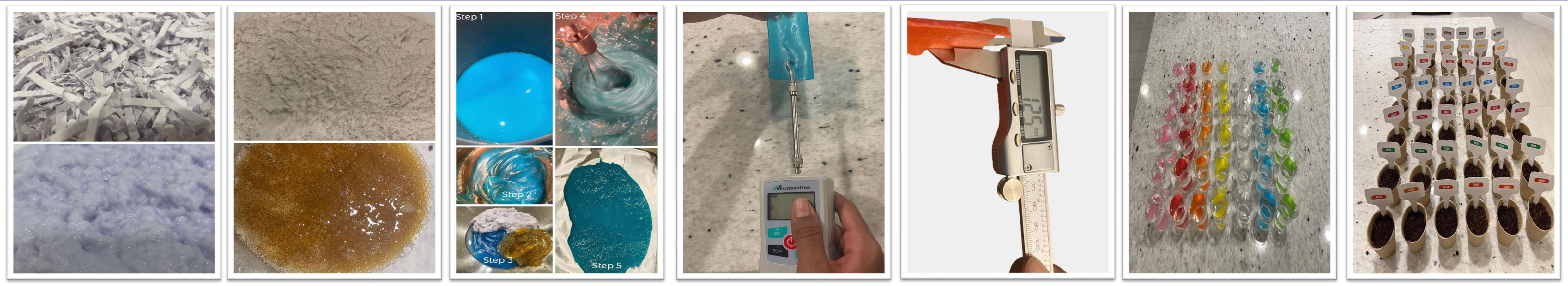








Photos



All photos except figure 1 and figure 2 are taken by Researcher. All data and graphs created by Researcher
Figure 1, Figure 2 : "Polysaccharides (Starch, Cellulose, Glycogen)." Infinity Learn, 27 Dec. 2022, https://infinitylearn.com/surge/blog/neet/polysaccharides-starch-cellulose-glycogen/.

Results & Discussion

The Water absorption test data trend indicates that Chitosan reinforced bioplastic samples had lower water intake capability than the bioplastic without Chitosan. The decrease in water absorption can be attributed to the hydrophobic nature of Chitosan which has lessen the hydrophilic nature of the starch molecules. Another factor that has decreased the water intake is due to the hydrogen bonding between the starch and Chitosan which prevents water molecules from penetrating through the prototype

The biodegradability test data trend indicates that addition of Chitosan reduced the biodegradability as compared to the control prototype. The decrease in the biodegradability can be attributed to the fact that biodegradability of any material decreases with decrease in water intake capability. Anti-microbial nature of chitosan could be an equally contributing factor to the decrease in the biodegradability rate.

The Tensile strength test data trend indicates that with the addition of Chitosan tensile strength has improved as compared to the bioplastic without Chitosan. The increase in the tensile strength can be attributed to the stronger hydrogen bond between the bordering polymers.

The flexibility test data indicates that Chitosan reinforced bioplastic prototype reduced the flexibility as compared to the control prototype. The decrease in the flexibility can be attributed to the fact that flexibility of any material decreases with increase in their Tensile strength. As the Tensile strength of Chitosan reinforced prototype increased, it had a minor reduction in the flexibility of the prototype.

Conclusion

The engineering goal was fairly achieved. The Chitosan upcycled from the seafood waste improved the Tensile strength (~ 50%) while diminishing the flexibility by a moderate amount. Chitosan infusion to the bioplastic improved the water resistance (~ 40%) capability with a minor impact on the bio degradation rate. It is also observed that the amount of Chitosan has a positive correlation to the change in Tensile strength and water resistance. Based on the above, it can be concluded that by varying the ratio of Chitosan, bioplastic of different water resistance, biodegradation rate, tensile strength and flexibility can be produced to meet the different needs. In addition, the project paves the way for a circular bioeconomy by recycling waste and extending its useful life as new products. This transition of treating waste as a untapped resource is an important step towards achieving long-term sustainability and conserving resources.

Future Enhancements

For bioplastics to be a true eco-friendly alternative to conventional plastics, production must not be dependent on potential food sources. Further research can be conducted to reduce the use of potential food sources (starch) by identifying non-food sources to produce second-generation bioplastics.

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