Effect of fiber reinforcement on tensile strength and flexibility of corn starch-based bioplastic

Jethoo A.S.
Department of Civil Engineering, Malaviya National Institute of Technology, Jaipur, India
Email: asjethoo.ce@mnit.ac.in

Abstract. Plastics are a vital asset for humanity, often providing functionality that cannot be easily or economically replaced by other materials. Bioplastics, made from biological materials represent an effective way of keeping the huge advantages of conventional plastics but mitigating their disadvantages. They can be prepared from plant, animal or bacterial sources. However, the majority of today’s available bioplastics is produced from plants rich in carbohydrate such as grains or sugarcane. They not only fulfill the current demands of the modern population but also provide sustainable development; as they are eco-friendly. This paper describes the effect of fiber reinforcement on mechanical properties of starch-based bioplastics. The results show that the strength of bioplastics can be increased by using various natural fibers such as cotton, jute, hair and wool.

1. Introduction
During the course of development, plastics have become an important part of our life. From waking up in the morning to going to sleep in the night, we use plastics in some or the other form. Each year over 140 million tons of petroleum-based polymers are produced worldwide and used in the production of such plastics as polyethylene, polystyrene, polyvinyl chloride, polyurethane, and others [1]. These plastics are highly resistant to micro-organism and other degradation forces because of their chemical and physical properties. This leads to environmental and land shortage problems for solid waste management [2].

The growing global trend in material research towards sustainability and materials from renewable sources has increased research efforts for development of alternative plastic materials and composites. Biopolymers and fiber-based bio-composites are one focus area of these new plastic materials. According to European Bioplastics, a plastic material is defined as a bioplastic if it is either bio-based, biodegradable, or features both properties. The feedstocks for bioplastics come from a variety of biological sources. Starch based bioplastics are usually made from wheat, corn, rice, potatoes, barley, and sorghum. Cellulose based bioplastics are commonly made from wood. Natural oils from soy, palm, and other plants have also been used to make bioplastics. Other bioplastics rely on bacteria to supply raw materials [3].

Bioplastics are bio-based and do not have any hazardous effect on environment on disposal. They release 2/3 times less green house gases than conventional plastics & thus, cause less air pollution and less global warming [4]. During decomposition also, they don’t release any toxic chemicals & by-products. In fact, their decomposition releases CO2, water and biomass which can be absorbed back into the earth. Moreover, it is much easier to recycle bioplastics. Industry for bioplastics is in its infancy but is developing rapidly. According to European Bioplastics, the worldwide production capacity for bioplastics will increase from around 1.2 million tonnes in 2011
to approximately 5.8 million tonnes by 2016. The high increase in production capacity is also an indication of the growing demand for these sustainable materials [5].

Currently, bioplastics are used for applications such as films, bottle, food service items, bags, packaging and mulching. However, this trend is expected to change in the coming years, with innovations and upgradation in quality being targeted to more demanding end-use segments. New bioplastics are poised to meet the expanding market demand with usage in products such as mobile phones, cameras, medical devices, electronics, as well as automotive parts. With improved crop yield and efficient farming, the demand of crops for bioplastics manufacturing can be achieved without any extra demand for agriculture land and food supply. Although, bioplastics are prepared from a variety of sources such as plant, animal or bacterial sources but mainly food crops are used. Starch based bioplastics make up the majority of the bioplastics market.

The bioplastic prepared from starch is known as thermoplastic starch (TPS). The transformation of granular starch into TPS is influenced by the processing conditions such as temperature and plasticizer content. Glycerol and water are basically used as plasticizers in TPS materials [6]. The amount of glycerol influences the flexibility and tensile strength of bioplastics prepared from corn starch.

In fiber reinforced thermoplastics, the fibers serve as reinforcement by giving strength and stiffness to the structure while the plastic matrix serves as the adhesive to hold the fibers in place so that suitable structural composites can be made [7]. This study was carried out with the objective to find out the effect of fiber reinforcement on tensile strength of TPS.

2. Experiment
The experiment was carried out by taking four types of bio-composites using natural fibers, namely, cotton (BC), jute (JC), hair (HC), and wool (WC) as a reinforcement, and thermoplastic starch as a biodegradable polymer matrix was prepared. The Figure 1 to 4 showing respectively.

3. Materials
Materials used for the experiment was a biopolymer (corn starch), glycerol, de-ionized water, 5% acetic acid solution, natural fibers like cotton, jute, hair and wool.

4. Methodology
Solution prepared by 5g of commercial starch was mixed with 30ml of water, 2ml of glycerol and 2ml of acetic acid. The solutions were added with varying amount of different types of natural fibers (2%, 4%, 6%, 8% and 10%). The solution was then heated on a hot plate at 150 °C for 15 minutes with continuous stirring using glass rod. When the solution became viscous and its transparency was lost, heating was stopped. After the solution turned clear again, it was removed from the hot plate and was spread on aluminum sheet for drying at room temperature. Each sample was weighed every day and when their weight became constant they were tested for tensile strength.

![Figure 1. Cotton fiber based bioplastics](image1.png)

![Figure 2. Jute fiber based bioplastic](image2.png)
Figure 3. Hair fiber based bioplastics

Figure 4. Wool fiber based bioplastics

The average thickness of each bioplastic sample, reinforced with different types of natural fibers was calculated. Then, each sample was cut in size of (6cm x 1.5cm) and loaded on tensiometer with fixed specifications of load range, extension range & speed. The tensile strength of each sample was determined and corresponding graphs were obtained.

5. Results and conclusions

The total 20 bioplastic specimen samples, reinforced with natural fibers like wool, cotton, hair & jute, were prepared and tested for their mechanical strength. The thickness of different samples is presented and average thickness is also mentioned in Table 1.

Normally, starch based bioplastics are slightly hard & brittle in nature, they break easily when folded. The brittleness is removed by using adequate amount of plasticizer as excess amount of plasticizer decreases the tensile strength of bioplastics.

The tensile strength of bioplastics depends on the amount of fiber reinforced in it and the strength increases on increasing the amount of fibers up to a certain limit but beyond that it decreases which may be due to decrease in the binding material i.e. biopolymer. The tensile strength of various bioplastics with different type of natural fibers and varying percentage of fibers is presented in Table 2.

Table 1: Thickness of different bioplastic samples

| S. No. | Samples | Thickness (mm) | Average thickness(mm) |
|--------|---------|----------------|------------------------|
|        |         | (i)           | (ii)                   | (iii)                   |
| 1      | BC1     | 1.041          | 0.965                  | 1.066                   | 1.024                  |
| 2      | BC2     | 1.092          | 1.066                  | 1.168                   | 1.108                  |
| 3      | BC3     | 1.219          | 0.584                  | 0.723                   | 0.842                  |
| 4      | BC4     | 1.066          | 0.863                  | 0.698                   | 0.531                  |
| 5      | BC5     | 0.711          | 0.711                  | 0.825                   | 0.749                  |
| 6      | BH1     | 0.800          | 0.914                  | 0.736                   | 0.816                  |
| 7      | BH2     | 0.660          | 0.685                  | 0.685                   | 0.676                  |
| 8      | BH3     | 0.647          | 0.660                  | 0.660                   | 0.655                  |
| 9      | BH4     | 0.774          | 0.812                  | 0.749                   | 0.778                  |
| 10     | BH5     | 0.685          | 0.660                  | 0.698                   | 0.681                  |
| 11     | BJ1     | 0.787          | 0.812                  | 0.749                   | 0.782                  |
| 12     | BJ2     | 0.762          | 0.965                  | 0.762                   | 0.829                  |
| 13     | BJ3     | 0.965          | 1.016                  | 0.787                   | 0.922                  |
Table 2: Tensile Strength of various Bioplastics

| S.No. | % Of Natural Fibers | Cotton Bioplastics | Wool Bioplastics | Jute Bioplastics | Hair Bioplastics |
|-------|---------------------|-------------------|-----------------|-----------------|-----------------|
|       | Sample              | Sample            | Sample          | Sample          | Sample          |
| 1.    | 2                   | BC 1              | 21.576          | BW 1            | 24.401          | BJ 1            | 13.694          | BH 1            | 14.581          |
| 2.    | 4                   | BC 2              | 15.336          | BW 2            | 22.096          | BJ 2            | 11.685          | BH 2            | 28.408          |
| 3.    | 6                   | BC 3              | 21.597          | BW 3            | 23.677          | BJ 3            | 16.039          | BH 3            | 23.351          |
| 4.    | 8                   | BC 4              | 36.168          | BW 4            | 17.620          | BJ 4            | 22.984          | BH 4            | 28.398          |
| 5.    | 10                  | BC 5              | 33.354          | BW 5            | 41.002          | BJ 5            | 15.805          | BH 5            | 27.450          |
| Average Tensile Strength | 25.6062 | 25.7592 | 16.0414 | 24.4376 |

Strength of fiber reinforced bioplastics also depends on the distribution of fibers throughout the sample. Thus, proper mixing and distribution of natural fibers is required during sample preparation of bioplastics. Apart from this, the property of tensile strength is also governed by the properties of fiber like, mechanical strength, thickness, etc. being reinforced in the bioplastics.

The Comparison of tensile strength of bioplastics having different types of natural fibers graphically shown in Figure 5.

Jute fibers have the highest mechanical strength but samples made from jute fibers showed lower average tensile strength. This may be because jute fibers are much thicker than other natural fibers resulting in poor mixing and distribution of jute fibers within the bioplastic samples. Although cotton, wool and hair have low mechanical strength but their samples showed higher average tensile strength than jute. This may be because cotton, wool & hair are fine, thereby allowing proper mixing and uniform distribution of natural fibers within the samples. Bioplastics reinforced with wool showed the highest tensile strength among all the samples because of the same reason.

The tensile strength of bioplastics reinforced with wool fiber showed the maximum average tensile strength of 25.7592 Kg/cm² as compared to bioplastics reinforced with cotton, hair and jute fibers. This may be due to proper mixing and uniform distribution of natural fibers within the bioplastic samples.
Figure 5: Comparison of tensile strength of bioplastics having different types of natural fibers

This work has shown that bio-composites on the base of thermoplastic starch reinforced with natural fibers, both of which are renewable materials, can be a potential alternative for conventional plastics, which adversely affect the environment and also require ample amount of precious fossil fuel for its manufacturing. The major limitation of present biopolymers is that their production is often more energy intensive than petro-plastic production and cost more than petroleum-based plastics but renewable resource based bioplastics are currently being developed and need to be researched more to overcome the performance limitations.

References

[1] Barry E. DiGregorio, ‘Biobased Performance Bioplastic: Mirel’, Journal of Chemistry & Biology, Vol. 16, Issue 1, 2009, pp 1-2.
[2] Shah A.A., Hasan F, Hameed A, Ahmed S, ‘Biological degradation of plastics: a comprehensive review’, Biotechnol Adv., Vol. 26, Issue 3, 2008, pp 246–265.
[3] Momani B, ‘Assessment of the Impacts of Bioplastics: Energy Usage, Fossil Fuel Usage, Pollution, Health Effects, Effects on the Food Supply, and Economic Effects Compared to Petroleum Based Plastics’, Worcester Polytechnic Institute, Worcester, Massachusetts, United States, 2009, pp1-58.
[4] Reddy R.L, Reddy V.S, Gupta G.A, ‘Study of Bioplastics As Green & Sustainable Alternative to Plastics’, International Journal of Emerging Technology and Advanced Engineering, 2013, Vol 3, pp. 82-89.
[5] ‘Bioplastics industry overview guide’, The Society of the Plastics Industry, 2012
[6] Jeroen J.G. van Soest, Remko C. Bezemer, Dick de Wit, Johannes F.G. Vliegenthart: ‘Influence of glycerol on the melting of potato starch’, Industrial Crops and Products, Vol. 5, 1996, pp. 1-9.
[7] S. Kuciel, P. Kuźniar, A. Liber-Kneć: ‘Polymer biocomposites with renewable sources’, Archives of Foundry Engineering, Vol. 10, 2010, pp. 53-56.