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Improved the Mechanical and Thermal Properties of PVA/Starch Nanocomposite Incorporated with Nanocellulose

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ABSTRACT

Nanocomposites, which consist of a polymer matrix and reinforcement, obtained research interest for their excellent mechanical performance. Nanocomposites made using bio-based materials and nano reinforcement can reduce dependence on products that are not biodegradable and promote sustainability. The current study focused on prepared a nanocomposite with enhanced properties using Starch and PVA incorporated with nanocellulose via solvent casting method. The prepared nanocomposite were characterized using FTIR also, the reinforcement of nanocellulose showed a significant result in mechanical, thermal, water absorption and biodegradable properties. From the finding with the incorporation of 10 % of nanocellulose shows the best result. The nanocomposite found the tensile strength of 14.02 Mpa, elongation break was 220.97 % and tensile modulus of 23.94 MPa. With the increase of nanocellulose the water absorption properties, thermal and biodegradability were also improved. The developed nanocomposite which is completely biodegradable, can be used for food packaging purposes. As a result, this aspect has prompted current research focused on generating biodegradable materials aimed toward environmental sustainability.

Keywords: *Starch, PVA, Nanocellulose, Nanocomposite, Biodegradable, Packaging Application.*

Introduction

Currently, the demand for plastic materials is increasing rapidly, particularly in the realm of food packaging. Packaging serves to protect the product from its surroundings and to preserve the quality of the food. The amount of chemical migration from the packaging must remain below controlled safe levels [1], or else the food could be tainted, posing risks to consumer safety. Furthermore, it is crucial to address the substantial environmental challenges posed by food packaging, as many of the materials are neither eco-friendly nor biodegradable. The addition of polyvinyl alcohol (PVA) has seen a rise in global commercial use. The rise in popularity can be attributed to its unique chemical and physical characteristics which encompass non-toxicity, highly crystallinity, water-solubilty, and remarkable film form capacity, hydrophillic characteristics. Nevertheless, the primary drawback of PVA is its relatively high cost. As a result, PVA can be combined with natural polymers in order to minimize the cost of material, making its utilization more economical. Starch is one of the most commonly blended materials with PVA, as it has been shown to enhance the properties of PVA. This has been proven by many investigations undertaken by numerous researchers globally. [2–5]. Noted that both the polymers are polar compounds that consists of hydroxyl groups in its chemical structure. that can formed intermolecular hydrogen bonds [6]. On the other hand, there are considerable limitations to PVA/starch combinations are primarily their inadequate barrier properties, largely that includes the large quantity of hydroxyl groups and inherent hydrophilic nature. As a result, various research have suggested inclusion of nanoscale fillers in PVA/starch blends to enhance their water barrier properties. Previous research focused on the introduction of nanofillers includes MMT clay [7, 8], nano-silicon dioxide [9, 10], Na MMT clay [11], and

PMMA nanoparticles [12]. Nonetheless, these nanoparticles did not significantly affect the biodegradability of films. Therefore, this research was conducted to enhance the properties of starch and PVA blends through incorporation of nanocellulose as a reinforcing agent. Nano Cellulose obtained from cotton fibers has become increasingly popular due to its distinctive properties, which encompass affordability, reduced density, enhanced specific strength, favorable thermal characteristics, and biodegradability. In addition, research on PVA/starch blend films reinforced with nanocellulose is relatively scarce when compared to studies involving other fillers. Nanocellulose obtained from cotton fibers has become increasingly favoured due to its remarkable characteristics, such as affordability, decreased density, enhanced specific strength, beneficial thermal properties, and its ability to biodegrade. Apart from their use in food packaging, nanocomposites created from polymer matrices possess significant potential across numerous industries, including automotive, aerospace, optoelectronics, and biomedicine. The exceptional mechanical characteristics of these composites that utilize micro-sized fillers, can be attributed for dimensions of high aspect ratios and dimensions at nano-scale level. Additionally, exhibit an exceptional array of thermal, magnetic, optical, electrical, and various physicochemical characteristics. This study focused on examining the thermal and mechanical characteristics of a corn starch/ PVA nanocomposite that includes nanocellulose. The properties were evaluated through FTIR and TGA analysis. Furthermore, research also assessed the water absorption and biodegradability of nanocomposite.

Materials and Chemicals

Corn starch was purchased from Bionic chemicals Lucknow Uttar Pradesh, Polyvinyl alcohol, glycerol used as plasticizer was purchased from Loba Chemie Pvt Ltd. Banglore, Nanocellulose was Procured from Nano Research lab Himanchal Pradesh.

Experimental Methodology

Preparation of Corn Starch/PVA/Nanocellulose Nanocomposite

Corn starch was dissolved with 100 milliliters of distilled water and blended using a mechanical stirrer for one hour. At the same time, a heating mantle was utilized to keep the temperature at 70°C. In a similar way, PVA & Nanocellulose solutions both were prepared using 100 ml of deionized water was integrated into the starch blend & stirred for 10 minutes. Initially, 40 wt % of glycerol was adding to the mixture. The solution was then poured into a petri dish and drying the oven for 24 hrs at 50°C. Prepared nanocomposite is depicted in Fig. 1.

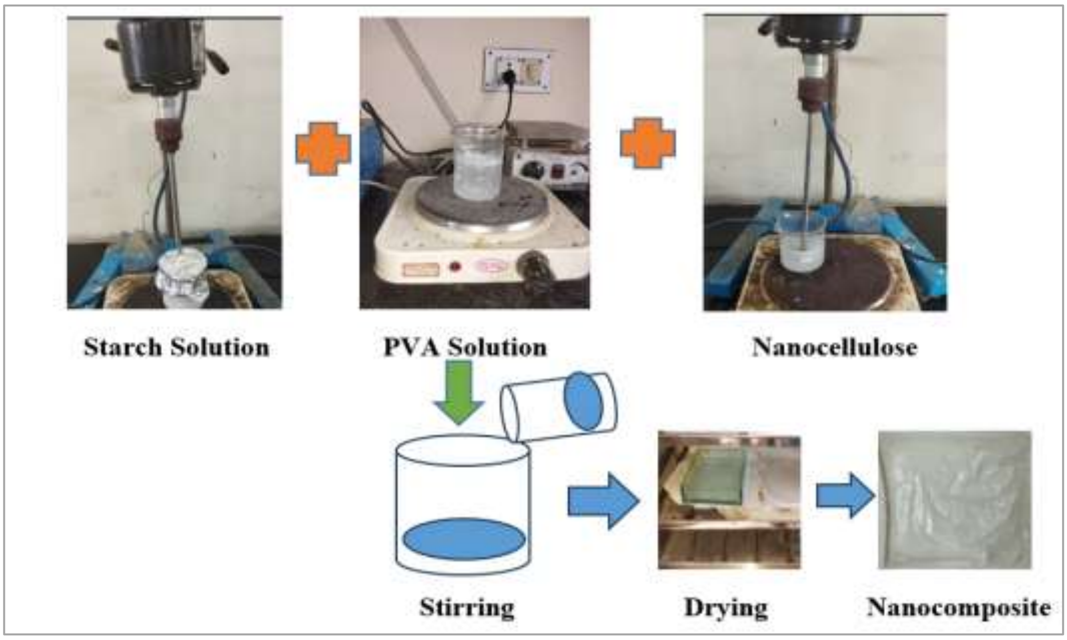

Fig 1. Preparation of Nanocomposite

Testing and Characterization

FTIR

The FTIR Spectrometer (Thermo-Scientific Nicolet 6700) was utilized to analyze the FTIR spectra of the prepared nanocomposite. The spectrometer functions within the wavenumber range of 4000-400 cm^{-1}.

TGA

The thermal attributes of the nanocomposite were investigated between 10 and 800°C utilizing Perkin Elmer TGA 8000^{TM} (Waltham, USA), the process were conducted with a 10°C/min heating rate set at in a nitrogen atmosphere.

Mechanical Properties

An evaluation of the mechanical properties of the developed nanocomposite was conducted using a UTM Testing Machine (Model 3382), as specified by ASTM D882.

Water Absorption Test

An investigation into the water absorption properties of the nanocomposite was conducted following the guidelines of ASTM D570. The formula listed below was employed to calculate the percentage of water absorption.

$$\% \text{ Weight of absorption} = (W_1 - W_2) / (W_2) \times 100$$

Where, W_1 = Initial weight

W_2 = Final weight

Biodegradation Test

For the assessment of the biodegradability of the prepared films using the soil burial technique, both laboratory and natural conditions are utilized. To examine the biodegradation, 10×10 cm^2 pieces were cut from each nanocomposite and placed in compost. These pots were then situated in the environment for a period of 14 days. Following the allocated period, the samples were removed from the soil, thoroughly clean and dry in oven. The percentage of weight loss was calculated using designated formula

$$\text{Weight loss} = [(S_0 - S_1)/S_0] \times 100\%$$

Where,

S_0 = Initial weight of Nanocomposite

S_1 = Final weight of Nanocomposite

Results and Discussion

FTIR Analysis

The characterization of the Starch/PVA/Nanocellulose nanocomposite was conducted using FTIR, as illustrated in fig 2. The examination of functional groups and the fingerprint region was performed between 4000 cm^{-1} to 450 cm^{-1}. The spectra of the nanocomposite displayed peaks at 1042.8 cm^{-1}, suggesting the presence of a polysaccharide due to C-O stretch. The O-H group vibration was observed at 1641.8 cm^{-1}, attributed to the interaction that exists between nanocellulose and the hydroxyl group of starch. The band situated at approximately 1412.8 cm^{-1} is identify the CH_2 group. The peak at 2941.8 cm^{-1} associated with C-H stretch vibration. In addition, the O-H stretching, resulting from both inter- and intra-molecular hydrogen bonding was observed at 3396.7 cm^{-1}. Additionally, the bands ranging from 575.5 cm^{-1} to 922.2 cm^{-1} relate to C-O-C vibrations of carbohydrates. These alterations in typical spectral peaks indicate chemical interactions. [13]. These findings demonstrate a strong compatibility and interaction among the (starch/PVA/nanocellulose) nanocomposite.

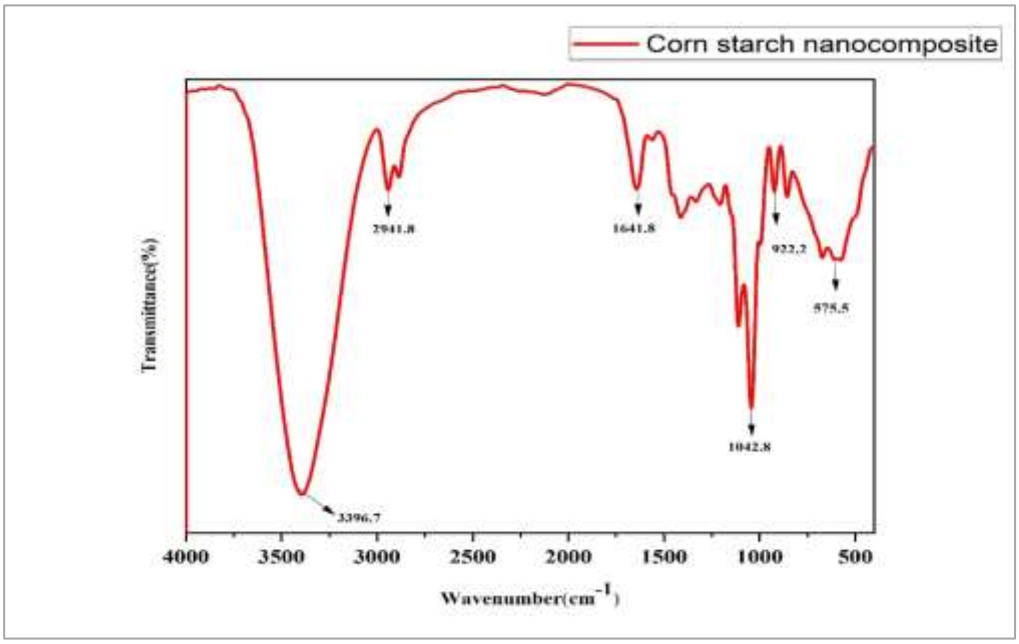

Fig 2. FTIR Analysis of Nanocomposite

TGA Analysis

The Thermogravimetric analysis was conducted in a nitrogen atmosphere, with temperatures reaching up to 650°C, and the heating rate was maintained at 10°C per minute. The thermal degradation is illustrated in fig 3. It was observed that the thermal degradation of the nanocomposite occurs in three stages. The initial weight loss in nanocomposite was reported within the temperature range of 89.25 °C, 96.40°C, 110.85°C, and 137.94°C. This mass reduction was attributed to the loss of water. The second weight loss was noted within the temp. range of 195.61°C, 190.53°C, 185.22°C, and 210.22°C, respectively. This phase is linked to a complex process that involves depolymerization and the breakdown of hydroxyl chain units. In comparison to PVA, the thermal breakdown temperature of nanocomposite increased only slightly with larger concentrations of nanocellulose. The final weight loss occurred in the temperature range of 272.85°C, 285.43°C, 287.46°C, and 291.64°C; this significant weight loss is due to the unsaturated molecular structure of starch, while the remaining residue was composed of inorganic material resulting from the pyrolysis of carbonated compounds [14].

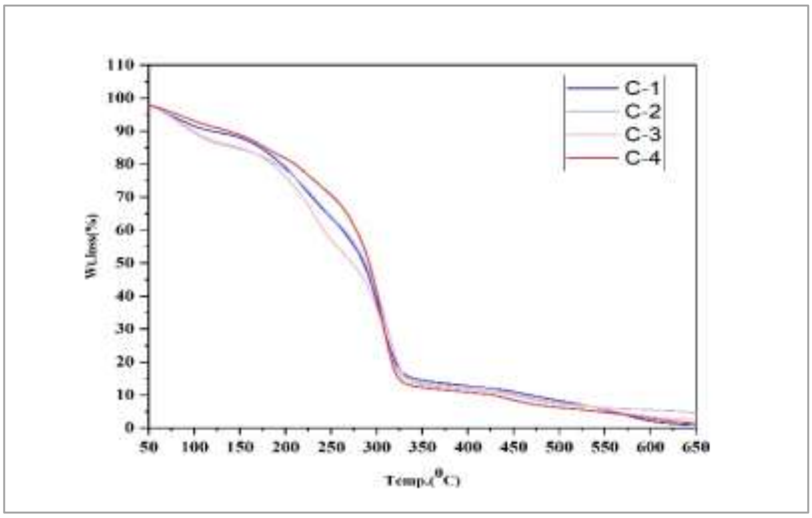

Fig 3. TGA Analysis of Nanocomposite

Mechanical Properties

The Starch/PVA/Nanocellulose blend nanocomposite was evaluated for its mechanical properties using a universal testing machine, as illustrated in fig 4. demonstrates an increment in both T.S and T.M (14.02 MPa and 23.94 MPa), while a reduction in % elongation at break (220.97) was observed. 17The addition of nanocellulose also positively influenced these properties. This advancement can be connected to the powerful hydrogen bonding interactions among the hydroxyl (-OH) groups that are present in the starch. As a gelatinization stage starts, the structural arrangement of the starch molecules is affected., enabling the OH groups to establish hydrogen bonds. Consequently, the chemical bonds within the nanocomposite were stronger and less prone to breaking. However, as the concentration of starch gradually rose, tensile strength decreased due to the increased presence of amylopectin, which has a branched structure. The branching structure of amylopectin causes the polymer chains to become separated, resulting in weaker hydrogen bonds [15]. Additionally, when glycerol was added at a constant weight percentage (40%), Both tensile strength and tensile modulus decreased, whereas % elongation at break increased with increasing starch concentration. This could be explained by the greater amount of free space created by the glycerol, enabling glycerol molecules to move more freely between the amylose and amylopectin chains. This movement reduces the polymer's ability to interact internally. preventing the formation of rigid structures, which simultaneously softens the polymer and enhances the elasticity of the blend film.

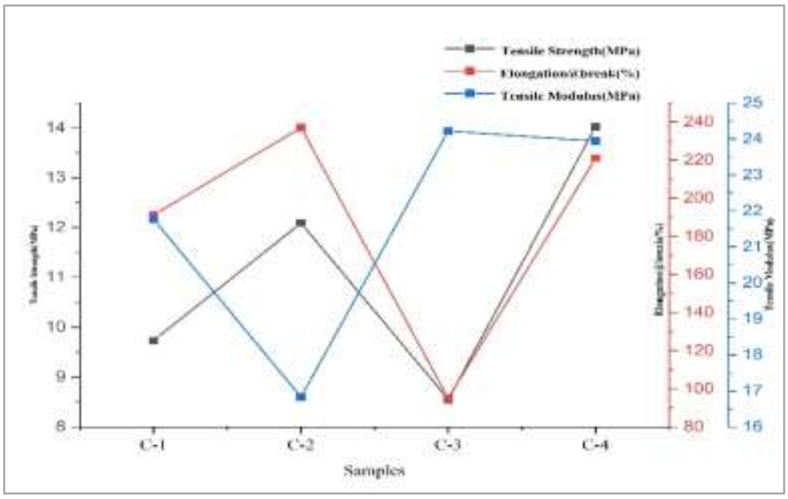

Fig 4. Tensile Properties of Nanocomposite

Water Absorption Test

The prepared nanocomposite was analysed through water absorption test. It was clearly noted that the nanocomposite exhibited a higher percentage of water absorption, which gradually decreased as amount of Nanocellulose increase. Due to effect of the structure mechanism obtained between the nanocellulose and the PVA/starch material, that prevents molecules of water that dissolved & increases resistance to water [16]. Additionally, the introduction of nanocellulose fibers modifies the channel for water molecules to enter the nanocomposite shifting it from a direct diffusion route to a more circuitous one, thereby resulting in the improved water barrier properties shown in figure 5.

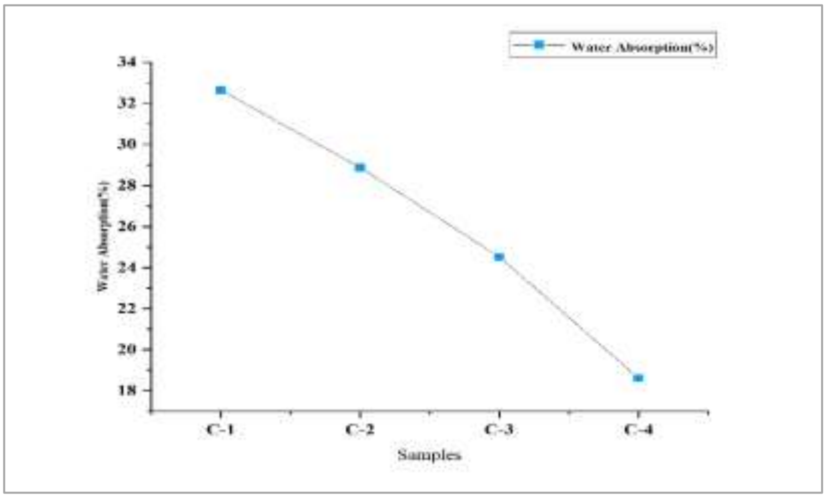

Fig 5. Water Absorption Test of Nanocomposite

Biodegradability Test (Soil Burial Method)

The weight loss of the nanocomposite was examined over 14 days, as illustrated in fig. 6 for the various samples. It was noted that samples that degraded slowly exhibited less weight loss compared to others, which is attributed to the presence of nanocellulose. This naturally occurring polymer is highly vulnerable to microbial degradation, resulting in the blended nanocomposite breaking down at a faster rate [17]. When the weight percentage of nanocellulose increases, a notable impact on the biodegradation of the fabricated nanocomposite is observed.

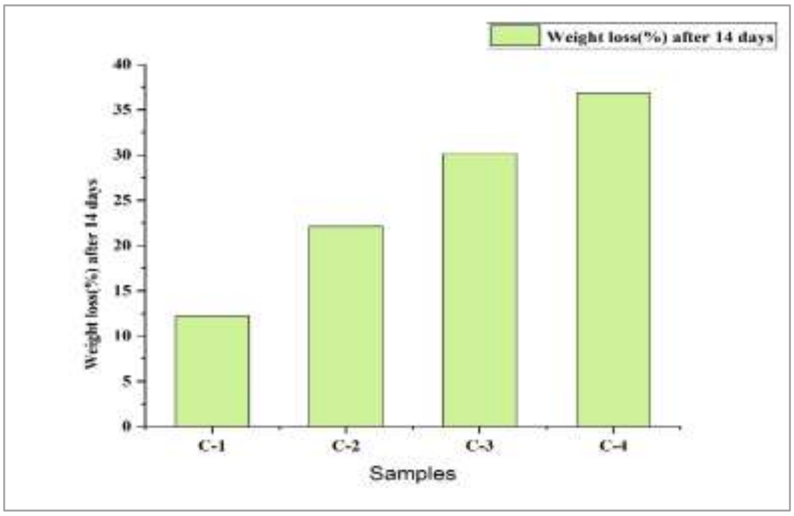

Fig 6. Weight Loss After14 Days of Prepared Nanocomposite

Conclusion

Nanocomposites were successfully created using the solvent casting technique. Additionally, the impact of nanocellulose on various properties was investigated. Nanocellulose was incorporated at different weight percentages of 5%, 10%, 15%, and 20%, alongside varying starch weight percentages of 1%, 2%, 4%, and 6%, while maintaining a constant 40% weight of glycerol. Using a UTM Machine, the tensile properties of the nanocomposite were measured, indicating an enhancement, while the elongation at break percentage showed a reduction. The blend films exhibited hydrophobic characteristics, and biodegradability tests conducted using the soil burial method indicated a significant percentage of weight loss. The analysis of functional groups and the fingerprint region was conducted using FTIR. A peak corresponding O-H stretching, attributed the intermolecular hydrogen bonding, was detected at 3396.7 cm^{-1}. This peak indicates the interaction between nanocellulose and the hydroxyl group of PVA alongside peaks at 1042.8 cm^{-1} that suggest the presence of a polysaccharide. The O-H stretching vibration were found at 1641.8 cm^{-1}, Due to the complex interaction between nanocellulose & the hydroxyl group in starch. TGA results demonstrated optimal thermal stability. Overall, the study found excellent results regarding mechanical properties, water absorption, and biodegradability, while also showing good compatibility among Starch/PVA/Nanocellulose. the findings indicates that the developed blend film was suitable for packaging applications.

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