Processing and Characterization of Polyvinyl Alcohol Based Nano Composites Reinforced with Cellulose-Silica

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ABSTRACT

The purpose of this work was to ascertain how well nanosilica (SiO_2) and nanocellulose (NC) reinforced Polyvinyl Alcohol (PVA) nanocomposites created from used oil palm fruit bunches. PVA based nanocomposites are a type of advanced Synthetic polymer PVA augmented with nanoscale materials to enhance its properties. These nanoscale materials are often nanoparticles or nanofillers, and they can be derived from various sources, including carbon, metals, oxides, or organic materials. Numerous disciplines, including mechanics, thermodynamics, X-ray diffraction (XRD), optics, and morphology, were studied in relation to the nanocomposites. Scanning electron microscopy demonstrated the uniform nanofiller dispersion at 3 wt%, & X-ray powder diffraction analysis revealed crystallinity fluctuations. By lowering matrix mobility, SiO_2 increased thermal stability. Light transmission was barely affected when 0.5wt% SiO_2 was added to PVA/NC composites that already contained 3wt% NC. PVA/NC films' tensile strength & modulus characteristics were enhanced by the addition of even a minute quantity of SiO2. These enhancements were also reflected in increased tensile strength and heat stability, two thermomechanical measures that indicated the reinforcing impact of SiO_2.

INTRODUCTION

Natural fibres have become more widely used as reinforcing agents in composite materials as environmental awareness has grown. Cellulose is a common type of natural fiber with considerable potential. The cellulose microfibrils can be separated into two types: crystalline (NC) and amorphous. Cellulose chains connected by H-bonds between OH groups possess exceptional rigidity and structural strength (Cho *et al.,* 2011; Ching *et al.,* 2014). Both natural cellulose crystal regions, which have elasticity moduli of Tashiro (1991) and Eichhorn (2010), respectively, have been found to be much more elastic than e-glass fibre, which has an elasticity 73-GPa modulus (Saheb et al., 1999).

Cellulose materials have many desirable quality such as biodegradability, low density, and biocompatibility, and can be generated at low cost and with minimal energy consumption. Their increased specific strength renders them less likely to break during processing (Mandal *et al.,* 2014; Kalaitzidou *et al.,* 2007).

NC's potential as a nanoscale reinforcement in composites is bolstered by the fact that it can be burned, emitting water and carbon dioxide (Azizi *et al.,* 2005). To create nanocomposites, nanoscale particles are incorporated into a polymer matrix. The incorporation of nanofillers into composites has the potential to produce materials with enhanced properties that are in step with the most recent technological advances (Whitesides, 2005).

The extraordinary mechanical properties of nanocomposite reinforced with conventional inorganic fillers, including their high-temperature rigidity, hardness, and strength (AL-Oqlaet al., 2022; Sugimoto et al., 2023; Zolet al., 2023; Liu et al., 2022).

Due to their ability to integrate desirable polymer and nanoparticle properties, polymer nanocomposites have attracted considerable attention. These advanced materials have enhanced mechanical, thermal, & barrier properties, creating new opportunities for packaging, automotive, electronic, and biomedical applications.

PVA stands out among these polymer matrices as a versatile and extensively used polymer due to its biocompatibility, biodegradability, & ease of processing. The incorporation of nanoparticles as reinforcements has become an area of active research in an effort to improve the material's properties.

Silica nanoparticles are a prominent type of nanoparticles used to reinforce polymer composites. Silica nanoparticles provide exceptional mechanical strength, a large surface area, & compatibility with a diverse array of polymers (Rahman et al., 2012). In addition, they can be functionalized to enhance adhesion between nanoparticles and polymer matrix. A synergistic effect can occur when oil palm empty fruit bunches is combined with natural cellulose nanoparticles derived from wood, cotton, or in this case, oil palm empty fruit bunches. Mechanical strength is provided by cellulose, which has a high aspect ratio and strong intermolecular connections, and silica, which is stiff and has a high modulus, so both contribute to reinforcing and thermal stability.

Once extracted, cellulose fibers are treated to create nanosize fibers, a modification that significantly increases their reinforcing capacity inside polymer matrices, even more so than regular cellulose fibers. Nanometer-scale fibres have better strength because of their crystallinity, surface area, and active interfaces (Panaitescuet al., 2008). Crystalline cellulose nanofibers, also called nanowhiskers, have an elastic modulus between 120 and 150 GPa. The remarkable phenomenon of nanowhiskers' proclivity to self-associate because of the close contact between surface OH groups is thoroughly explored (Van den berg et al., 2007). A strong network of nanowhiskers is created to accomplish

such extraordinary reinforcing ability. This network is composed of hydrogen bonds between the nanowhiskers(Capadona et al., 2009). It is important to note that interactions between these nanowhiskers during manufacturing may result in aggregation (Schroers et al., 2004).

The biodegradable polymer composite possesses incredible tensile strength, flexibility, film-forming, and emulsifying properties (Roohaniet al., 2008). It is formed by reinforcing NC or nanofibers in PVA. PVA is ideally suited for use in the creation of environmentally friendly nanocomposites because of its inherent biodegradability, particularly when cellulosic materials are utilised as fillers. Recently, there has been a significant uptick in the use of nanomaterials like SiO_2 in a variety of industries, but especially in the medical field (Nabeshiet al., 2011). SiO_2 offers a broad variety of applications, including fluorophore carrier (Ali et al., 2014), a controlled drug release agent, an antibiotic, and Monton et al. (2011) biosensor. Numerous silanol groups found in SiO_2 are involved in changing the polymer matrix's crystalline behavior, increasing the effects of hydrogen bonding, and affecting the fluorescence properties of composite materials. Studying how PVA-based nanocomposites reinforced with cellulose & silica nanoparticles are processed & characterized is central to the study's overarching goal. It is possible to get a balanced improvement in mechanical strength, thermal stability, and other important features when cellulose and silica are combined. The intricate interaction between these nanoparticles and the polymer matrix will be studied in depth, casting light on the mechanisms responsible for the observed performance enhancements of the nanocomposite. This study sought to determine whether adding highly reactive NC from oil palm empty fruit bunches (OPEFB) & SiO_2 to PVA changed its characteristics. Investigations were done into how adding SiO_2 and NC to PVA might affect its morphological, optical, and thermomechanical characteristics.

Through a comprehensive characterization approach that includes mechanical testing, thermal analysis, XRD, optical studies, & morphological analysis, In-depth knowledge of PVA-based nanocomposites reinforced with cellulose-silica nanoparticles is the goal of this study. Insights garnered from this study can not only advance the fundamental

understanding of these novel materials, but also pave the way for potential applications in a variety of industries where tailored properties are necessary for success in a wide range of environments and conditions.

The effects of incorporating cellulose nanocrystals from corncobs into the PVA matrix to improve its reinforcing characteristics were studied by (Esubalew et al., (2023). In order to extract cellulose nanocrystals from corncob using sulfuric acid hydrolysis, this study set out to identify the ideal conditions. The highest yield (41.8%) was attained at the parameter interaction of 65 weight percent H2SO4 acid concentration, 45degree reaction temp., & 60minute hydrolysis time. Fourier transform infrared spectroscopy (FTIR) measurements of the CNC produced by hydrolyzing isolated cellulose in H2SO4 revealed that they had a needle-like shape, length on average of 170.3 nm & a crystallinity index of 79.3 percent. According to XRD, the crystallinity index of cellulose nanocrystal was 79.3, while that of isolated cellulose was only 76.4. A solution casting technique was used to create nanocomposite films with 2, 4, & 6 weight percent cellulose nanofillers employing pure PVA as the starting material. Therefore, the tensile stress and modulus both rose by 17.9 and 67.15% after 6% nanocrystalline cellulose was dispersed in PVA polymer. The inclusion of cellulose nanocrystals (CNC) at a weight of 6 wt increased the material's tensile strength by 56.7%. Thermogravimetric measurements revealed a significant weight loss of 6 wt% CNC-increased PVA (approximately 84% of total weight) between 265.6 and 491.61°C.

In order to gather paper manuscripts stained with madder extract, (Abdel-Hamied et al., (2022) examined the usage of nanocomposites of cellulose nanofiber (CNF)/PVA and MPSNP/PVA. There are three strengths available: 1%, 3%, and 5%. The nano-sized composites were analysed by scanning electron microscopy, transmission electron microscopy, X-ray diffraction, atomic force microscopy, Fourier transform infrared spectroscopy, & overall colour change (E) by spectrophotometer before and after the ageing process. The surface morphology data from a scanning electron microscope showed that the MPSNP/PVA core-shell nanocomposite was effective at 5% when consolidating the aged coloured paper samples. Paper fibres become strong and distinct after processing. The E values

decreased to 5.22 when MPSNP/PVA nanocomposite was utilised at 5%, whereas the E values for CNF/PVA nanocomposite were 11.66. To determine the efficacy of 5% MPSNP/PVA nanocomposites, mechanical tests (tensile strength & elongation) were performed on samples of aged coloured paper. When the suggested treatment was applied to a material sample, the results were 84.8 N/nm2 tensile strength and 1.736% elongation. The sample's tensile strength & elongation were increased by the CNF/PVA nanocomposite to 38.2 N/nm2 & 1.166%, respectively. According to FTIR studies, the MPSNP/PVA nanocomposite-treated sample was 5 percentage points brighter than the control sample in the CH2 stretching band, which represents the crystallinity of cellulose.

(Sri Aprilia et al., 2022) explored the reinforcement of PVA with nanocrystalline cellulose (NCC) to improve UV light stability. For this investigation, we strengthened a PVA-NCC film with NCC derived from waste palm oil and exposed it to UV radiation (22 W, SUV-16 254 nm) for an extended period of time. To gauge how much UV light had impacted the samples, scientists looked at their weight loss percentage. Additionally, the structural, morphological, and tensile characteristics of the samples were examined both before and after they were subjected to UV radiation using FT-IR, SEM, & a tensile test. The outcomes show that the addition of NCC physically deteriorated PVA while enhancing its morphological & tensile properties. When exposed to UV radiation, the PVA matrix with NCC substantially decreased the rate of degradation. It has also been demonstrated that weight loss as a percentage varies with UV exposure time.

(Bacha *et al.,*2022) investigated how incorporating NC into PVA changed its mechanical characteristics. The polymer's biodegradability, thermal stability, or tensile strength were tracked over time, as were its elongation at break, water absorption, light transmission, or thermal stability. By adding 2% NC, the tensile strength rose from 24:5±0:53 to 35:5±0:55 MPa & by adding 5% NC, it increased from 40:6±0:73 MPa. After 2% NC & 7% NC reinforcement, the elongation at break increased to 45:7±0:53% and then reduced to 32:2±0.75%. The data show that whereas 2% NC decreases the water absorption capacity of clean PVA from 84:6±0:56% to 73±0:78%. The water uptake capacity and

NC concentration were linearly correlated; increasing the NC loading from 0% to 7% decreased the water uptake capacity from 100% to 61.0: Results from 59% UV-V is spectroscopy show that the transmission through pure PVA & PVA-2%NC composite film drops to 85.4% & 78.2%, respectively, at 600 nm. Thermogravimetric analysis (TGA) shows that incorporating NC particles into PVC lowers its thermal stability. Clean PVA loses 70:7±1:7% of its weight after 90 days, whereas PVA composite films reinforced with 1, 3, & 7% lose 65±1:85%, 57:1±57%, 55:6±0:64%, 52:1±1:72%, and 9% of their weight, respectively. NC is dispersed in a matrix, as seen here in a scanning electron micrograph of a PVA-6%NC nanocomposite film.

(Yang *et al.,* 2021) studied starch-based bioplastic composites reinforced with citric acid (CA) treated empty fruit bunch fibers from oil palms. They looked at the mechanical, thermal, and hydrophobic characteristics of the bioplastic composites. By using FTIR, it was discovered that CA esterified starch and that H-bonds were created between starch, fibers, & CA. SEM pictures of the samples showed that starch retrogradation or fibre clumping occurred at concentrations more than 10 wt%, while lower concentrations resulted in homogeneous fibre distribution throughout the composites. Fiber's ability to mix with starch was substantially improved by the use of CA. Although it was shown that CA had a dose-dependent influence on thermal characteristics. the introduction of fibres improved the composites' thermal performance. When fibres or CA were added to the composites, their tensile strength dramatically increased while their water resistance barely changed.

(Pramanik *et al.,* 2019) examined the impact of NC on the morphological and mechanical characteristics of xerogels made of PVA. Incorporating NC fibres and crystals into the matrix is a common practise for increasing the polymer's mechanical strength. Here, NC is mass-loaded into PVA at concentrations of 7%, 13%, & 18%, after which the material is thermo-morphologically and physically evaluated. As its concentration increases, NC's thermal degradation temperature drops. Weak cellulose-rich patches develop when more NC crystals are introduced, which leads to the xerogel bursting. This is especially apparent in xerogel which contains 18% NC crystals. Similar to this, adding more NC fibers to xerogels makes them more fragile and prone to breaking. This behavior is most noticeable in xerogel that contains 18% NC fibers. By limiting molecular chains & immobilizing polymer chains, it has been discovered that adding NC to a system reduces creep strain and stress relaxation.

Using three different NC fibre concentrations (0.35, 0.55, and 0.75% by weight of cement), (El-Feky *et al.,* 2019; Jahan *et al.,* 2012) studied the mechanical characteristics & microstructure of cement composites. The tensile strength of these nano systems was found to improve by around twice as much as the control mix with 0.35% NCell particles. Microstructural investigations also revealed that nano silica particles had successfully altered the interface between nano cellulose fiber & cementitious matrix, improving the reinforcement's effectiveness, particularly when applying compression or tensile forces from outside the composite.

The literature review emphasizes the potential for strengthening polymer matrices with NC, SiO2, and other components to enhance mechanical properties and functionality. However, there is still much to learn about the combined reinforcement effects of NC and SiO2 in a PVA matrix. While Bacha et al. &Esubalew et al. have previously explored the impacts of NC-PVA and SiO2-PVA systems separately; our study is the first to look at the combined impact of these two nanomaterials. This combination approach is an effort to take benefit of the special properties of NC & SiO2, which could lead to improved mechanical properties, thermal stability, & other aspects. The main focuses of the current research are mechanical properties, morphological changes, and biodegradability. Contrarily, the focus of our research is on the differential changes in crystallinity, hydrogen bonding effects, and fluorescence properties brought about by the incorporation of various silanol groups into SiO2. By presenting a more comprehensive picture of the several ways in which the cellulose-silica reinforcement in PVA might alter its properties, our research attempts to fill in some of the gaps in the current understanding of nanocomposite materials.

MATERIALS AND METHODS
Materials

PVA (Kuraray PVA-220S) was produced in India. Fibers derived from OPEFB were imported from India. The OPEFB was sieved to obtain fiber particles between 4 and 6 mm in diameter. Next, A fine powder with a particle size distribution of 100 to 150 m was obtained by grinding and sieving the fibers. Nanocomposites were manufactured using Aerosil R972 fumed silica from Degussa Chemicals, this has 16 nm in size on average and 130-m2g-1 specific surface area. The H2O2 & HCOOH were supplied by Fisher Scientific (USA). The received forms of other compounds and solvents (of analytical purity) were employed.

Pretreatment of OPEFB Fibers

To get rid of any dirt or debris, the OPEFB fibres were first repeatedly washed in a detergent solution (1.0 wt%). The raw OPEFB fibre was cleaned before being washed again. It was then dried at a constant weight in an SOV 70B, Thermocline oven at 100 ± 2 °C. The fibre was subsequently dewaxed using a Soxhlet apparatus (Favourite) in ethanol (70% v/v) for 6 hours. The ethanol was removed from the fibres by rinsing them in distilled water after they had been dewaxed. A solution of 10% NaOH and 10% H2O2 was used to suspend the dewaxed fibers for further processing. In an autoclave for 1 hour at 1.5 bar and 120 °C. They were properly cleansed after being freed from the brownish supernatant containing the fibers.

Extraction of OPEFB Cellulose

The fibers were dipped in a 1:1 volume-to-volume (v/v) mixture of formic acid (at a concentration of 20%) and hydrogen peroxide (at a concentration of 10%) during the extraction process. The mixture was cooked for two hours in a water bath at 85 °C [30]. Delignified fibers were subjected to filtration, and samples were washed with 10% HCOOH before being cleaned Using distilled water. It created cellulose that had a somewhat yellow hue. A 10% concentration of cellulose was resuspended in H2O2 (pH 11) for 90 minutes at 60° C.

Preparation of PVA/NC film reinforced with SiO2

The composite films' primary component, PVA, was created using solution casting. When making a PVA aqueous solution (10 wt%), we avoided clumping by stirring the liquid at 1,000 rpm at room temp. The PVA solution was sonicated for 5 min after being stirred for 2 hours at 90 °C. PVA/NC composites with 1–7% wt% NC content has been

developed. After adding 0.5 weight percent nano silica, the suspension was agitated for one additional hour. After pouring in the solutions, the mound was allowed to dry for seven days at room temp. The optimal film thickness was determined to be about 150 m. After 24 hours in a 50 °C oven, the resulting thin composite films were dry enough to be characterized.

Characterization methods

The mechanical properties of the composite sheets were measured at 10 mm/min using a universal testing equipment (model AG-IS, Shimadzu, Japan). For analysis, each composite and test received five samples. Swiss-based Mettler Toledo 851e TGA/SDTA was used to perform the thermal decomposition analysis. At a scan rate of 20 degrees Celsius per minute, samples were heated from 30 to 600 degrees Celsius. Each experiment recorded the results using a sample weight between 5 and 10 mg. The Siemens D5000 was used to conduct XRD analysis on the nanocomposite samples. During the experiments, the anode current was 40 mA, & the voltage was 40 kV. With a step size of 0.02 & a timer set to 0.5 seconds, this data was collected continuously covering a 2-scan range of 4° to 80° using Cu K radiation (= 0.15405 nm). We examined the optical transmission properties of the cellulose & OPEFB solutions between 200 and 800 nm employing a Varian-Cary-50 UV-Vis spectrometer.

SEM (Hitachi S-3400N, Thermo Scientific) images taken at 10 kV were used to examine the fracture surfaces of the samples and determine their morphology. Ten seconds were spent in a vat of liquid nitrogen with the composite film. After that, a freeze-fractured surface was created on the sample by performing an instantaneous fracture. Electrostatic charge and poor-quality pictures were erased from the SEM observation of the sample film after 1 hour of sputter-coating the surface of the fractured film's cross-section covered in gold.

RESULT AND DISCUSSION
Mechanical properties
Tensile strength

The graph in Fig. 1(a) shows how strong PVA is when it's just by itself and when we add tiny particles to make it stronger. When we mix in a small amount (1 wt%) of NC

with the PVA, its strength gets a lot better. As we add more NC (from 0 to 7 wt%), the strength keeps increasing. Increasing the SiO2 content to 0.5 wt% in these PVA/NC blends increases their strength even further. This happens because nano silica particles are very structured and help make the material stronger. But, after we added more than 5 wt% of NC, the strength didn't increase much more. Other researchers have also found this, and it's because a small amount of these tiny particles makes strong bonds with the PVA, helping them spread out really well in the PVA. This makes the PVA really good at carrying the load and becomes stronger with both NC and SiO2 helping out.
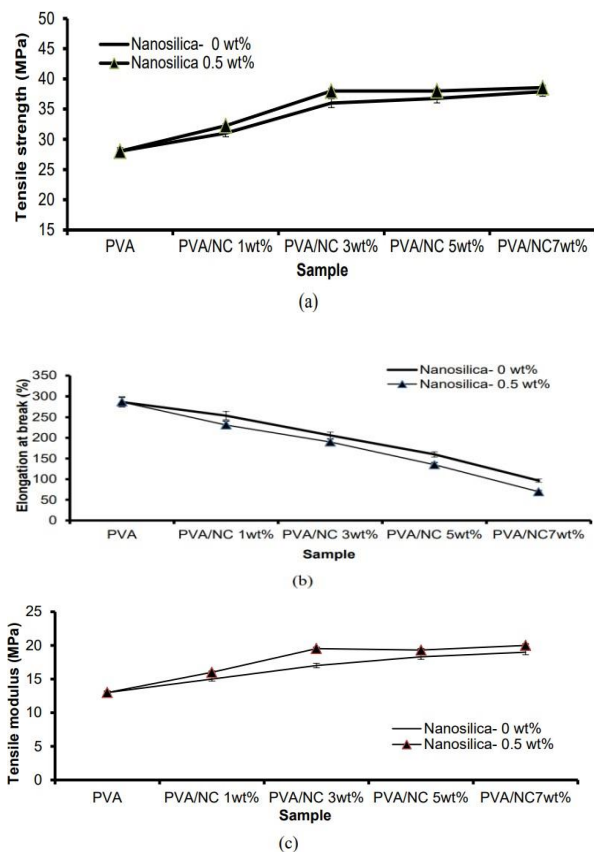

Fig 1. Impact of SiO2 on PVA/NC composite (a) tensile strength, (b) % of elongation at break, (c) tensile modulus

Elongation at break

As seen in Fig. 1(b), the addition of NC to the PVA reduced the material's elasticity. This stretching ability, called "elongation at break," decreased a lot when NC was added,

and it got even lower as we added more NC (up to 96% reduction with 7 wt% NC). When we also added a bit of SiO2, the stretching ability decreased even more. This is similar to what happens in other materials when we add small particles (like filling a bucket with sand). The reason for this change is because PVA forms strong connections, like tiny bridges, with the NC. This makes the PVA less stretchy but more structured. Just like how tightly packed things are harder to bend or stretch. Other researchers, found that when materials are strongly connected like this, they can't stretch as easily (Cheng *et al.,* 2014). This is because the NC and SiO2 aren't as flexible as the PVA, so their strong connections with the PVA stop it from stretching.

Tensile modulus

In Figure 1(c), we see what happened when we added SiO2 to PVA that was already reinforced with different amounts of NC. First, when even a little NC (1 wt%) was added, the material's stiffness, which we call "tensile modulus," got much better. Then, when we added SiO2, the stiffness improved even more. This is because SiO2 is like a stiff chain that restricts movement in the material, making it stiffer. This stiffness got even better because the SiO2 and NC spread out evenly in the PVA, and they stuck together really well. Composite with 3 wt% NC and 0.5 wt% SiO2 was the strongest. But when we added more NC (up to 7 wt%), the stiffness didn't get much better. This tells us that SiO2, with its large surface area, can make the material much stiffer, especially when the NC is distributed well up to 5 wt%.

Morphological Analysis

In Figure 2, we looked closely at the broken surfaces of both plain PVA and PVA mixed with nanomaterials. This helped us understand how these materials broke and how they interacted with each other. When we compared it to the PVA film without anything added, we could clearly see differences in the way PVA mixed with NC and SiO2 broke.
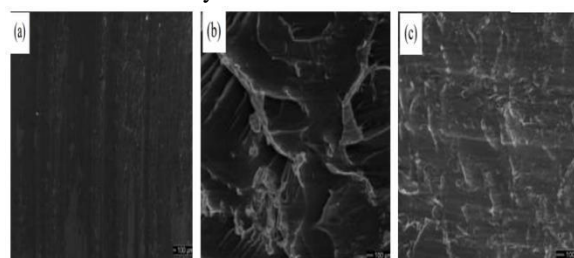
Fig 2. SEM images of a fractured surface of (a) PVA, (b) PVA composites reinforced with NC (3.0 wt%), (c) PVA composites reinforced with both NC (3.0 wt%) and SiO2 (0.5 wt%).

When we added NC (shown in Figure 2(b)) and NC with SiO2 (shown in Figure 2(c)) to the PVA, the surfaces of the broken parts showed scattered bumps that were not aligned. This is what usually happens when something breaks in a rigid way. These bumps are bits of agglomerated cellulose sticking out from the broken surface. This kind of sticking out explains why the stretchiness of PVA with these mixtures got worse compared to plain PVA. In our research, we found that when NC was added to PVA, it formed bigger groups on the broken surface. These groups might have affected how well the material performed mechanically. But when we added 0.5 wt% of SiO2, we saw a few small particles and a more even spread of nanofillers in the PVA mixture (as shown in Figure 2(c)). This suggests that SiO2 helped the PVA and cellulose mix together better. We also saw that the stiffness of the PVA mix got a lot better due to the stiff nature of the nanofillers, especially SiO2. This is common when we add tiny particles to materials, like what others have found (Haafiz et al. 2013).

X-Ray diffraction

In Figure 3, we compared the XRD patterns of different materials: PVA, NC, SiO2, & the mixtures of these. We noticed a big peak at 19.5°, which is a sign of the structure of partially hydrolyzed PVA. The intensity of this peak was higher in PVA because of some special groups it has. Adding NC didn't affect this peak because the NC has its own structure that doesn't interfere with it. However, when 3.0 wt% NC was added, the mixture's structure was a bit less crystalline than pure PVA. This was because the process used to mix the materials together caused them to form differently. But, when we added SiO2, the peak became stronger than in the NC mix. SiO2 increased the overall crystalline nature of the mix. And when we added 0.5 wt% of SiO2, its strong crystalline nature caused even more tiny structures to form in the mix.
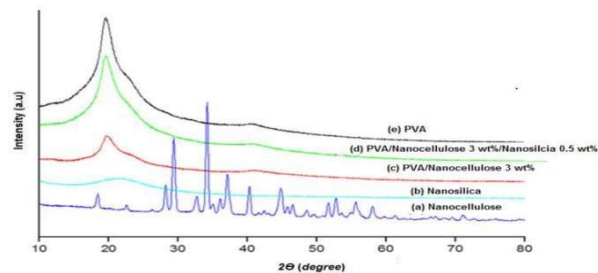

Fig 3. Comparison of XRD patterns between pure PVA, nanofillers, and PVA composites reinforced with nanomaterials

Optical Transparency Analysis

In Figure 4, we looked at how much light went through different materials: PVA, PVA mixed with NC, & PVA mixed with NC & SiO2. When we added NC, less light passed through compared to plain PVA. This might be because the clumps of NC blocked some of the light. Adding 0.5 wt% SiO2 to the PVA with NC further reduced the amount of light that penetrated. This happened because as we added more of these tiny materials, they started sticking together inside the PVA. This sticking together made the material less transparent to light.
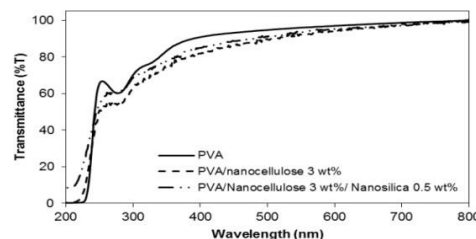

Fig 4. Comparison of UV-Vis's transmittance spectra of PVA, PVA composites reinforced with NC, and PVA composites reinforced with NC and SiO2.

Thermogravimetric Analysis

Figure 5 shows how PVA mixed with NC and SiO2 behaves when we heat it. When heated initially (between 70 and 150 °C), the PVA/NC mixture lost more weight than pure PVA. This happened because the NC is not as heat-resistant as PVA, so it breaks down faster. The PVA mixture was less stable at lower temperatures, but it stabilised during the second (300–450 °C) and third (>500 °C) stages of heating. When we added a little bit of SiO2, the mix became even more stable, showing that SiO2 is good at handling heat. This happened because the tiny SiO2 particles connected well

with the PVA mix, making it stronger against heat. So, adding a small amount of SiO2 made the mix better at handling high temperatures. This also means that the well-spread SiO2 particles helped the PVA mix to resist heat better.
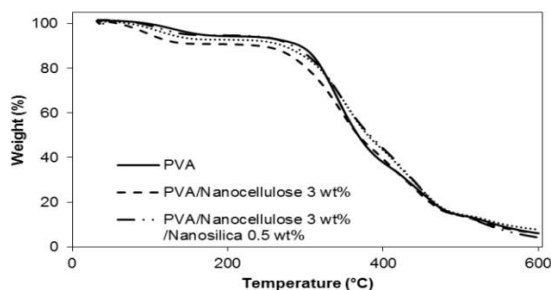

Fig 5. TGA thermogram of PVA, a composites of PVA/3 wt5 NC, and a composites of PVA/3 wt% NC/0.5 wt% SiO2.

CONCLUSION

The focus of this study was on the development and evaluation of PVA nanocomposites augmented with NC and SiO2. Through exhaustive mechanical, thermal, XRD, optical, and morphological evaluations, important insights into the properties of these nanocomposites were attained. SiO2 was added to PVA/NC composites, which significantly increased their heat stability by limiting the mobility of the matrix molecules. The XRD patterns disclosed the altered crystallinity caused by NC and SiO2, with SiO2 contributing to the overall increase in crystallinity. The UV-Vis spectra demonstrated the effect of NC and SiO2 additions on light transmission. The addition of NC and SiO2 together significantly improved the nanocomposites' thermal stability and exhibited strong nucleation. Our findings provide light on the possible applications of PVA-based nanocomposites reinforced with cellulose-silica and add to our understanding of their production and features.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.