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Physical, Mechanical, and Thermal Properties of Polyvinyl Alcohol/Nanocrystalline Cellulose Bioplastic Film

F. Yudhanto*[a], V. Yudha[b], H. S. B. Rochardjo[c], C. Budiyantoro[d], A. Khan[e], A. M. Asiri[e,f], M. J. M. Ridzuan[g]

[a] *Department of Automotive Engineering Technology, Universitas Muhammadiyah Yogyakarta, Indonesia*
[b] *Department of Mechanical Engineering, Institut Sains and Teknologi Akprind, Yogyakarta, Indonesia*
[c] *Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Indonesia*
[d] *Department of Mechanical Engineering, Universitas Muhammadiyah Yogyakarta, Indonesia*
[e] *Center of Excellence for Advanced Materials Research, King Abdulaziz University, Jeddah, Saudi Arabia*
[f] *Chemistry Department, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia*
[g] *Faculty of Mechanical Engineering & Technology, Universiti Malaysia Perlis, Malaysia*

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A B S T R A C T

The bioplastic film based on Polyvinyl Alcohol (PVA) for food packaging has been widely developed because of its biodegradable properties and safety. Nanocrystalline cellulose (NCC) is used as filler to improve mechanical strength. This study investigated how adding NCC into PVA films affects the physical, mechanical, and thermal properties. Combine acid hydrolysis 46 wt.% and ultrasonication process success to isolate commercial microcrystalline cellulose (MCC) became nanocrystalline cellulose (NCC). It has been characterized by x-ray diffraction (XRD), Fourier Transform Infrared (FTIR), Transmission Electron Microscope (TEM), Differential Scanning Calorimetry (DSC), and Thermal Gravimetric Analysis (TGA). NCC with needle shape form with an aspect ratio (L/D) of 12.4 has been high crystallinity index (76.4%). Addition of 6 wt.% NCC into PVA film improves the tensile strength and elongation by 35.30 MPa and 65.54%, respectively. The bioplastic film gives a barrier on the UV rays by 75% and still has good transparency. The thermal stability improves, indicated by the glass transition temperature (T_g) increase from 109 to 114°C and maximum temperature (T_{max}) from 275 to 300 °C.

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1. INTRODUCTION

Chemical treatment is one of the methods to isolate the cellulose nanocrystal. The treatment was carried out using hydrolysis by adding a sulfuric acid solution (H_2SO_4). The purified fiber has been done to minimize the hemicellulose and lignin content before the acid hydrolysis process. The acid hydrolysis aims to fibrillate and open bundle micro cellulose to nanocellulose. Several previous research like Morais et al. (1) isolated cotton fibers by adding a sulfuric acid solution (60 wt.%) in a bath a stirred at 200 rpm at a temperature of 45°C for one hour. It is successfully producing the nanocrystalline cellulose (NCC) with 12 nm of diameter and 177 nm of length. The aspect ratio (L/D) of NCC cotton is 19. Ghasemi et al. (2) have purified linter pulp followed by ultrafine grinder results the 30-70 nm of nanocellulose fiber's (NCF) diameter. The crystallinity index of nanocellulose is lower than purified fiber, it decreases from 79.5% to 65%. This phenomenon causes the decreased stability thermal of NCF from 280 to 240˚C. Tonoli et al. (3) isolated the eucalyptus pulp sheets with the same concentration at 45°C for 30 minutes to produce nanocrystalline cellulose with diameters and lengths of 30 and 200 nm, respectively. Jiang and Hsieh (4), isolated rice straw by adding a sulfuric acid solution (64 wt.%) at

*Corresponding Author Institutional Email: *ferriawan@umy.ac.id* (F. Yudhanto)

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preheat temperature 45°C for 45 minutes to produce NCC with 6.4 ± 1.8 nm of diameter and 113 ± 70 nm of diameter. Johar and Ahmad (5), isolated rice husks using a sulfuric acid of 10 mol/L at a preheat temperature of 50 °C for 40 minutes to produce NCC with 20 nm of diameter and 300 nm of length. It has an aspect ratio of 15. The aspect ratio depends on fiber resource, purified method, and fibrillated method. It is important to determine the NCC mechanical properties as filler in the polymer (6-9). Terzioglu and Parin (10) investigated the effect of adding lemon peel from 1 to 8 wt.% in the PVA (polyvinyl Alcohol)-starch biocomposite film. The mechanical strength increases by adding 1 wt.% lemon peel, showing good dispersion. The tensile strength increases from 24 to 25 MPa, whereas elongation rises from 260 to 275%. It is adding 2-8 wt. % causes aggregation in high concentration and starting to appear some voids in the matrix PVA-starch, it generates decreases in mechanical strength. Li et al. (11) developed bioplastic film combined the PVA 5 wt.%, it added by cellulose nanowhisker (CNWs) by 1 wt.%, concentration. The tensile strength and elongation PVA/CNWs bioplastic film are rises from 80 to 175 MPa and 170 to 330%, respectively. NCC's filler is known for high moisture absorption which leads to hydrophilic properties. To overcome this problem adding the biocompatible polymer is necessary to remove the reactivity of hydroxyl groups in the nanocellulose. The hydrophilic synthetics polymer, such as PVA, is easily dissolved in water, biodegradable, resistant to chemical conditions, and is an attractive material used for advanced applications. Furthermore, PVA is non-toxic to the human body, drug delivery systems, barrier materials, membranes, and yarn for surgery (12). Polymers can be degraded in two ways that are photodegradable or biodegradable. One definition of biodegradable polymer requires that the primary degradation mechanism is the result of the action and metabolism of microorganisms. Biodegradation can occur in either an aerobic or anaerobic environment. PVA is widely used as a sustainable plastic in the food industry because it is biodegradation; on the other hand, it has many advantages like high strength, good elasticity, lightweight, transparent, heat stable, and antimicrobial (13, 14).

This research aims to investigate the effect of adding NCC into PVA bioplastic film on mechanical and physical properties. There are several parameters and characteristics of NCC biocompatible with PVA bioplastic composites like aspect ratio (L/D), volume fraction ($\%V_f$), and homogenized suspension (15). This research investigates commercial microcrystalline cellulose (MCC) isolated by sulfuric acid hydrolysis. The physical tests were carried out in this study, including evaluation of TEM (transmission electron microscope), SEM (scanning electron microscope), XRD (x-ray diffraction), FTIR (Fourier transform infrared), and Transmittance UV-Vis (Ultraviolet and Visible). The mechanical properties were tested through the tensile strength and then finally, the thermal stability was evaluated through TGA (thermal gravimetry analysis).

2. MATERIAL AND METHODS

2. 1. Materials Nanocrystalline cellulose was isolated from commercial microcrystalline cellulose (MCC) MERCK serial number 1.02330.0500, polyvinyl alcohol (PVA) fully hydrolyzed with 89-98 molecular weight from Sigma-Aldrich, sulfuric acid (H_2SO_4) purity 96% from Sigma Aldrich, Sodium Hydroxide (NaOH) purity 98% and distilled water. The tools used are a burette tube, clamp burette, Bekker glass, magnetic stirrer, pH meter, centrifuge, and ultrasonic homogenizer 12 mm diameter and the power set is 240W.

2. 2. Acid Hydrolysis Acid hydrolysis of the commercial MCC is isolated by sulfuric acid 46 wt.% H_2SO_4 with burrete tube into Erlenmeyer tube. The ratio of MCC powder and solution in the Erlenmeyer tube is 1:100. It was agitated at 350 rpm and preheated at 60°C for one hour by a magnetic stirrer. The acid hydrolysis process aims to break the cellulose chain into individual cellulose. The hydrolysis process starts by breaking the oxygen bonds in the β-1,4-Glycosidic chain, then the glycosidic ring bonds reacted with H_2O molecules. Cellulose increased surface area and rise the hydroxyl group content. Figure 1 shows intramolecular reaction the decomposition of substances in chemical reactions caused by H_2SO_4 and H_2O molecules.

The acid suspension in the ice bath could stop the ionized process. Then it is gently dropped the sodium hydroxide NaOH with the same concentration by 46 wt.% into the acid suspension. Furthermore, centrifugation helps rinse the suspension for five cycles until neutral (pH=7). The NCC suspension was ultrasonicated for 15 minutes with a power of 240 watts and set the temperature at 60°C. It aims to get a homogenized suspension of NCC (16, 17).

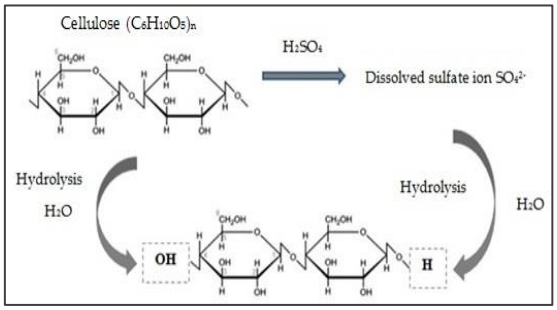

Figure 1. Scheme of chemical reaction of acid hydrolysis and nanocellulose

2. 3. Fabrication of PVA+NCC Bioplastic Film The fabrication of bioplastic films with different weight of NCC. Firstly, prepare the PVA powder with a 3 wt.% (density is 1.19 g/cm^3) and distilled water. It was mixed and heated constantly at 500 rpm at a temperature of 100ºC for one hour.

The PVA suspension was put into the desiccator with silica gel for one night until the bubble was gone. Secondly, the NCC gel has weight by 0, 3, and 6 wt.%, and it was mixed into the PVA solution. The PVA suspension is mixed with NCC gel at a temperature of 50ºC, stirred at 350 rpm for 30 minutes, followed by an ultrasonication of 240 watts for 15 seconds, 6 times. The last, it was poured into a hot Teflon plate at a temperature of 60˚C for 4 hours to get a bioplastic composite film. The schematic process and production steps of the bioplastic composite are shown in Figure 2.

2. 4. Morphology Analysis The dimension of cellulose, nanocellulose, and surfaces of bioplastic composite have been identified by SEM (JSM-6510, LA-JEOL) and TEM (JEM-1400). The SEM photo can be detected surfaces solid material on the micro scale from 50 to 20,000 magnification. The voltage of SEM was set to 40 kV. The specimen has been coated with Au and used a sputtering method. The voltage of TEM is set at a range of 20 to 110 kV to get an excellent image contrast. NCC diameter (D) and length (L) were calculated by image-J software to results in the aspect ratio. The TEM photo can be detected nano scale material in the liquid suspension from 1000 to 300,000 magnification.

2. 5. XRD Analysis The XRD diffraction patterns for crystal structure are based on the scattering angle peaks and intensities of bioplastic composite. It was tested by using the Rigaku Miniflex-600 type which run at 40 kW, 15 mA, and CuKα radiation (λ=1.54060Å). The bioplastic film test sample was scanned in 2θ range from 2˚ to 40° with a scan speed by 4° min^{-1} and sampling pitch 0.02°. The solid structure of bioplastic film has a crystal and amorphous structure which is determined by crystallinity index according to Segal Equation 1.

$$CI = \frac{I_{110} - I_{am}}{I_{110}} \quad (1)$$

where I_{110} is a semi-crystalline structure plane at a scattering angle on the 2θ=19.8º, and I_{am} is an amorphous structure at a scattering angle on the 2θ=16º.

2. 6. FTIR Analysis FTIR is an analytical test method used to identify organic polymeric materials. The product composition analysis method with FTIR uses infrared light to scan the test sample and observe its chemical properties. It is used in the analysis to transmit infrared radiation from the sample test by absorbing and passing some of it through radiation. It measured wavenumber spectra from 4000-400 cm^{-1} with a Shimadzu 8400S Spectrometer. Thin pellet samples were prepared with the help of potassium bromide (KBr).

2. 7. UV-VIS Analysis The transparency and ultraviolet barrier bioplastic composites were identified by spectrophotometer with Ocean optics USB-4000 of UV-Vis (ultraviolet-visible) obtained by continuously changing the wavelength of light. It is which separately passes through the test sample.

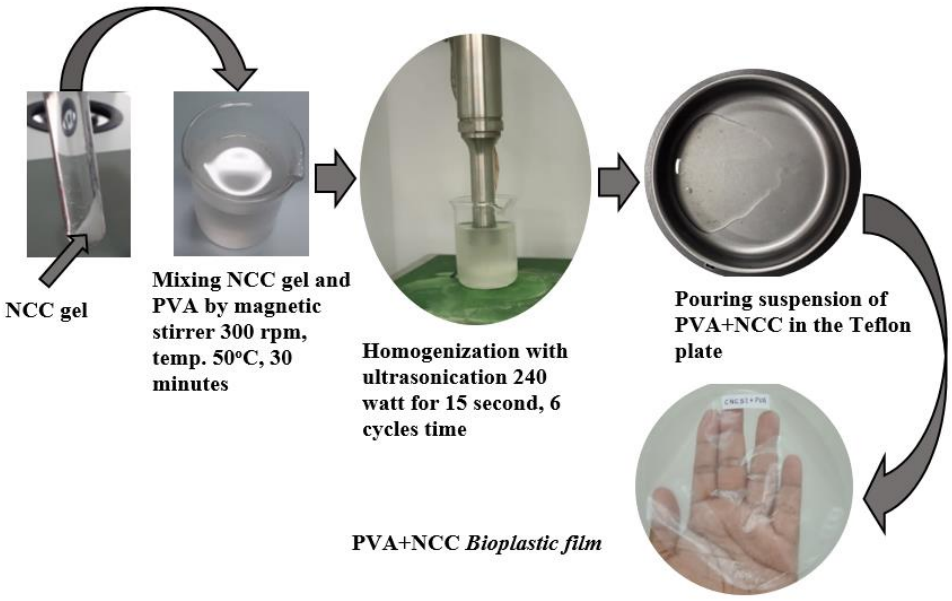

Figure 2. Scheme of fabrication of PVA+NCC bioplastic film

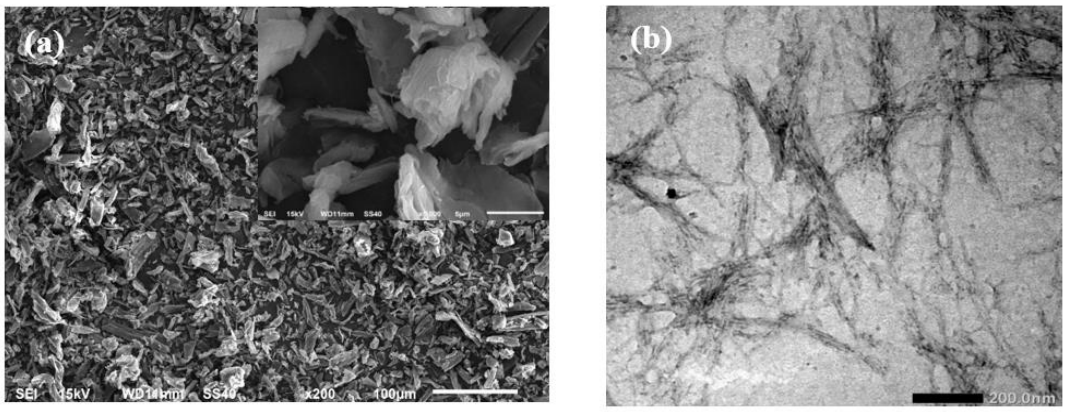

Figure 3. The photo of (a) MCC by SEM, (b) NCC by TEM

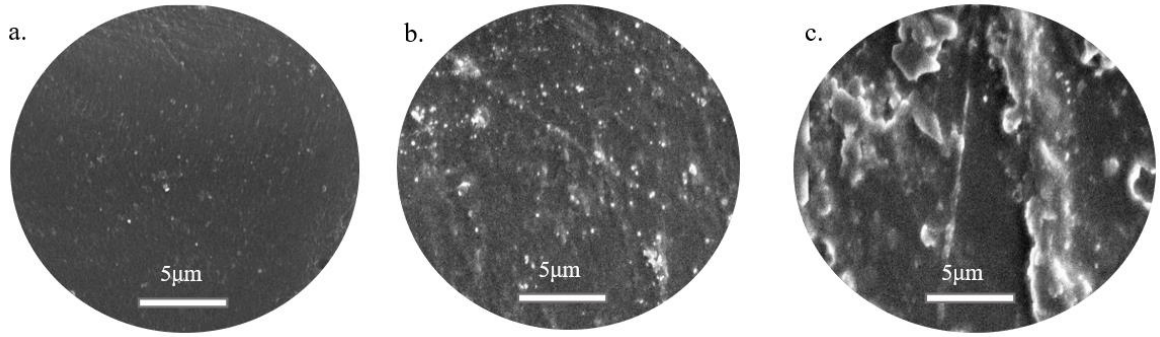

Figure 4. Surfaces morphology of bioplastic film: a) Neat PVA, b) PVA+NCC3%, and c) PVA+NCC6%

In an array spectrometer, light with a full wavelength that passes through the test sample is diffracted by a reflection and then received by the detector. As a result, it can provide a complete scan spectrum by 200–800 nm.

2. 8. Mechanical Analysis The mechanical analysis used the tensile test of ASTM D-882 for thin plastic sheets, including film less than 1 mm. The paper test specimen is 100 mm in overall length; the specimen test is 25 mm gage length and 5 mm in width. The UTM (universal testing machine) by Pearson Panke Equipment Ltd has a maximum load of 400 N and a set cross-head speed of 2 mm/minute.

2 .9. TGA Analysis The TGA (Thermogravimetric Analyzer) Mettler Toledo can run on a single temperature program (a constant heat rate at 10◦C/min from 30 to 600◦C with a nitrogen gas flow rate of 60 mL/minute). The bioplastic composite sample was tested in thin sheet film with a weight of 10 mg. Thermal degradation can be used to generate polymer degradation at different temperatures. Some examples of mass change processes are decompositions and oxidations. On the other hand, the TGA curve data are coupled with a derivative thermogram (DTG) curve to give the results better.

2. 10. DSC Analysis The Thermal degradability of bioplastic film can be calculated with DSC (Differential Scanning Calorimetry). DSC is one of the necessary tests to determine how much the energy a bioplastic film absorbs or release. This thermal analysis measures the heat energy absorbed and emitted by the test sample as a function of time and temperature. The glass temperature occurs when the material changes from the semi-liquid to the liquid phase (T_g). The final melting temperature occurs when most of the liquid has been burned (T_m). The gas used is nitrogen (N_2) with an average flow rate (flow rate) of 10 ml/minute at a temperature range of 30-300ºC.

3. RESULT AND DISCUSSIONS

3. 1. Morphology Analysis of NCC Figure 3a shows the morphology of MCC was investigated by SEM (Scanning Electron Microscope), and it found that the diameter of MCC is ±20 µm. Figure 3b shows NCC by acid hydrolysis process combined with ultrasonication. The NCC has a diameter and length of around 25 nm and 310 nm with aspect ratio 12.4. Furthermore, other similar research by Krishnadev et al. (18) has been isolated Agave americana fiber by chemical extracted by 4 wt.%

NaOH in hot water 80ºC for two hours followed by bleaching treatment using 2 wt.% $NaClO_2$ in hot water 80ºC for 4 hours and It's followed by acid hydrolysis with a nitric acid solution of 70% and acetic acid of 80% at a hot temperature 100ºC for 30 minutes. Its morphology results in that the NCC has a diameter of 18.2 ± 10 nm by TEM.

3. 2. Morphology Analysis of Bioplastics Film Figure 4a shows the morphology of PVA bioplastic composite products without addition of NCC. The surface morphology of bioplastic composites looks likes smooth and clear. Addition of NCC in the PVA bioplastic composite resulted in intermolecular cross-linked chemical bonds between NCC and PVA. It shows a little wrinkle spread on the surface structure (Figure 4b). Figure 4c shows big wrinkle spread well on the surfaces of the PVA matrix.

3. 3. XRD Analysis of Bioplastic Film Figure 5 shows the value of the crystallinity of bioplastic composites. The reference value in the crystallinity area with a value of 2θ=19.8º (plane 110) and the amorphous area at a value of 2θ=16º. Plane 110 of bioplastic film materials corresponding to d spacing 4.4801 Å, and it indicates the semi-crystalline typical structure (19, 20). The NCC's crystallinity by 76.4% higher than commercial MCC (Sigma Aldrich) by 74.8% (16). Adding NCC in the PVA impacted the bioplastic film crystallinity raises fraom 48.7% to 65.1%.

The crystallinity index of Neat PVA, PVA+NCC 3%, and PVA+NCC 6% there are 48.7%, 62.0%, and 65.1%, respectively. The crystallinity and amorphous intensity summarized in Table 1. Ilyas et al. (21) isolated the palm fiber by chemical purification followed by hydrolysis of 60 wt.% sulfuric acids, 45ºC intermolecular for 45 minutes. The results of this treatment process increased the crystallinity index value from raw fiber to NCC from 55.8% to 85.9%.

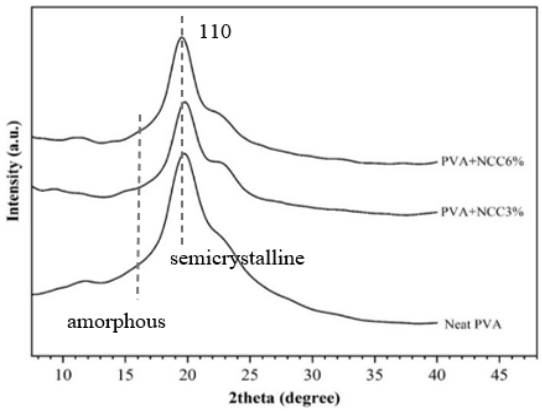

Figure 5. XRD diffraction of bioplastic film

The selection of concentration, time, and temperature parameters for acid hydrolysis determine the aspect ratio of NCC. Aspect ratio (L/D) and crystallinity indexed are important parameters to determine mechanical properties.

3. 4. FTIR Analysis Figure 6 shows the bioplastic films' wavenumber spectra region in four main areas. The relative content of functional groups or groups of atoms in the material was estimated by intensity ratio of optical density (22). The first wavenumber is 3490 cm^{-1}, it indicates O-H stretching (23). The NCC's hydroxyl make intermolecular cross-link bonded to PVA's hydroxyl (-OH) which is shown in Figure 7. It indicates by the peak

TABLE 1. Crystallinity index of bioplastic films

Samples	I_{110} (2θ=19.8º)	$I_{amorphous}$ (2θ=16º)	CI (%)
Neat PVA	158	81	48.7
PVA+NCC 3%	308	117	62.0
PVA+NCC 6%	395	138	65.1

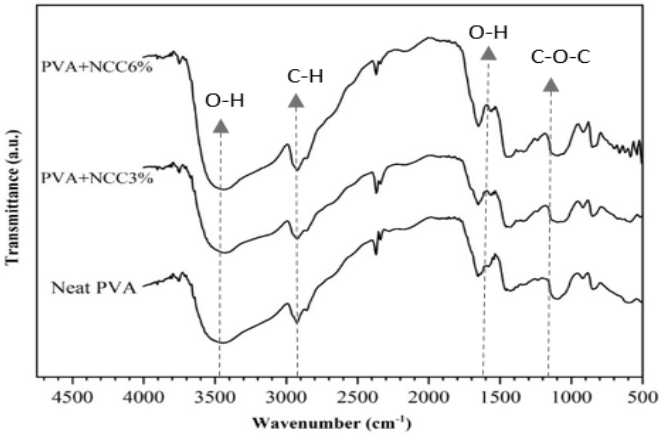

Figure 6. FTIR wavenumber spectra of bioplastic film

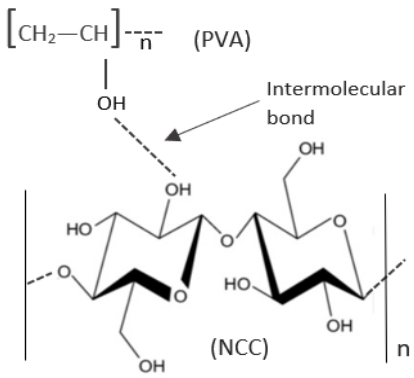

Figure 7. Schematic of intermolecular bond between PVA and NCC

of PVA+NCC sharper than neat PVA. The second area wavenumber region is 2931 cm^{-1}, meaning that the C-H stretching vibration. The third region is 1627 cm^{-1}, showing the O-H bending vibration means adsorbed of H_2O (water vapor) content. It indicates that NCC material is suitable for combination with the same hydrophilic properties as PVA (24). The four region is 1190 cm^{-1}, showing the asymmetric stretching vibration C-O-C indicates the glucose ring structure of cellulose (25).

Adding more NCC into PVA decreases the water vapor permeability of bioplastic film. Another study using hydrophilic polymers besides PVA like a Polylactic Acid (PLA) developed by Mirabolghasemi et al. (26). It was found that addition of NCC causes a decrease in the value of water vapor permeability (H_2O) content. The nano-scale of NCC homogeneous structure increases the crystallinity of bioplastic film material which inhibit the water vapor.

3. 5. The UV-Vis Absorbance Figure 8 shows that addition of NCC to the PVA matrix decreases the transparency of the bioplastic composite. Neat PVA has excellent transparency, which means the visible light transmission by 70% on the 650 nm wavelength. Adding NCC in PVA increases the absorbance of The UV rays at 300 nm wavelength. UV-A has a long wavelength of 400 nm, and UV-B has a short wavelength of 300 nm (27). Figure 9 shows that small transmittance on the wavelength range 300-400 nm, it indicates the material has good blocking of UV rays. Adding NCC 3 and 6 wt.% in the PVA could be reduced 70% and 75% of UV-A rays compared to without NCC. Therefore, the bioplastic composite could reduce UV rays to be applied as packaging. The average transmittance of visible light neat PVA is 70%. Addition of 3 and 6 wt.% CNF caused the decreases in the transmittance light to 45% and 37%, respectively.

3. 6. Mechanical Analysis Figure 10 shows the tensile properties and elongation at break of bioplastic films. The thickness of bioplastic film is 25-30 μm. Adding NCC as filler into the PVA could improve the performance of the bioplastic composite with more strength and elasticity than neat PVA. The interaction between NCC and PVA by intermolecular bonding of the hydroxyl functional group can raise the toughness of bioplastic composite. The tensile strength and elongation at break of neat PVA by 26.61 MPa and 46.95 %, respectively. Addition of 3 wt.% NCC slightly increases the effect by 35.30 MPa of tensile strength and 65.54% of elongation at break. Whereas adding 6 wt.% of NCC gives an excellent improvement in the tensile strength and elongation properties increase by 38.67 MPa and 84.06%. This condition shows that NCC provides a good stress distribution in the PVA bioplastic composite matrix. The other research by Fortunati et al. (28) has isolated the MCC (Sigma Aldrich) by hydrolysis by sulfuric acid 64 wt.% at a temperature of 45˚C for 30 minutes. It was produced at 10 nm in diameter and 200 nm in length. Adding NCC 5wt.% as filler in the PVA bio-nanocomposite film has increased tensile strength and elongation at the break by 44.3% and 300%, respectively. Previous research using PVA polymer as the matrix was conducted by Yudhanto et al. (29) extracted NCC from Agave cantala fiber with a combination process of sulfuric acid hydrolysis by 44 wt.% at temperature 60˚C for one hour followed by ultrasonication (240Watt, diameter probe is 12 mm, 30 minutes times). It produced 45 nm of diameter and 1975 nm (aspect ratio is 43.8) NCC. Adding 8 wt.% in PVA/NCC film results in the highest tensile strength of 76.7% and elongation at the break of 112%. Addition of NCC 10 wt.% results in agglomeration NCC, and it causes stress concentration and affects low tensile properties. Frone et al. (30) isolated MCC with ultrasonication (20 kHz, 19 mm diameter probe, 200 Watts) for 20 minutes. It produces the NCC 70-150 nm in diameter. Adding the NCC filler 5 wt.% in the PVA matrix increases the tensile strength by 39%.

3. 7. Thermal Degradability Analysis Thermogravimetric analysis (TGA) and corresponding derivative thermogravimetry (DTG) curves of the NCC is shown in Figure 11. It shows that the thermal stability of NCC is high. The weight mass loss could be divided into three stages.

The first stage is the evaporation of adsorbed water in the NCC and bioplastic composite before a temperature 100˚C. The second stage started at 230-300°C, the initial degradation temperature (T_{onset}). It degrades an amorphous material such as hemicellulose and lignin. It is similar to conducted research by Babu et al. (31), that lignin of *Phaseolus vulgaris* fiber (PVFs) content degrades in the same temperature range. The third stage

is a maximum temperature (T_{max}) of NCC by 325°C, the cellulose degradation temperature range of 322-347°C. Figures 12 and 13 are shown the TGA and DTG curves of bioplastic film. Adding NCC into PVA causes the crystalline structure functional groups in the NCC to be able to inhibit heat flow. Furthermore, another research by Wang et al. (32), adding NCC into PVA and UPy (Ureido-Pyrimidinone) causes a rise the thermal stability. Table 2 shows an increase in thermal stability in each variation of bioplastic composites. The initial and maximum degradation of neat PVA is 253°C (T_{onset}) and 275°C (T_{max}) which are shown in Figures 12 and 13.

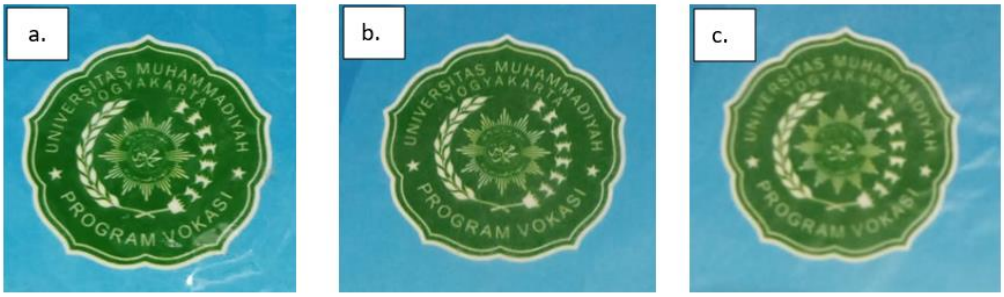

Figure 8. Transparency of bioplastic film (a) neat PVA, (b) PVA+NCC3%, (c) PVA+NCC6%

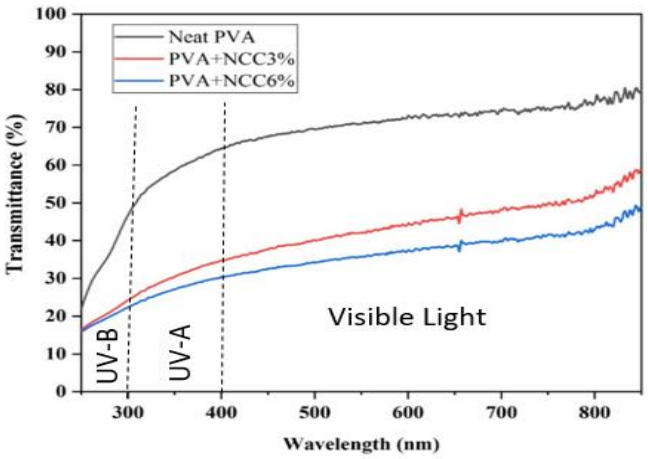

Figure 9. UV-Vis. transmittance spectra of bioplastic film

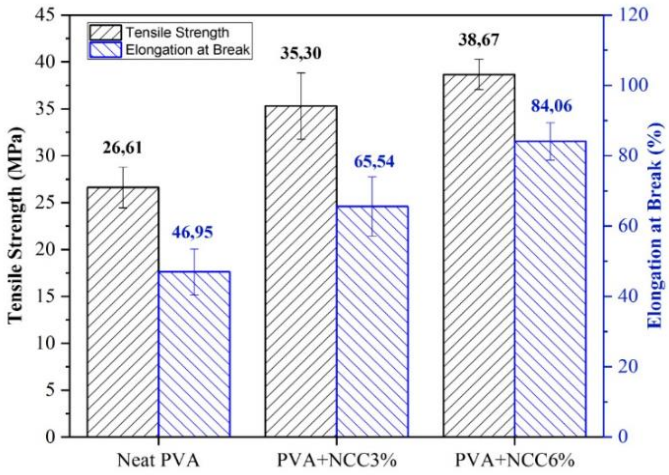

Figure 10. Tensile properties of bioplastic films

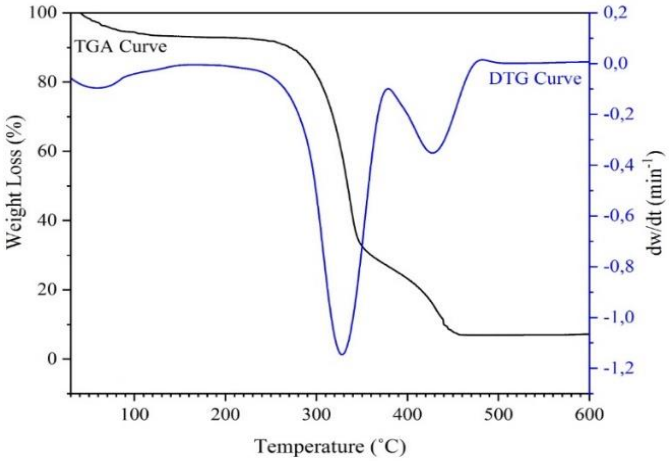

Figure 11. TGA/DTG curves of Nanocrystalline Cellulose (NCC)

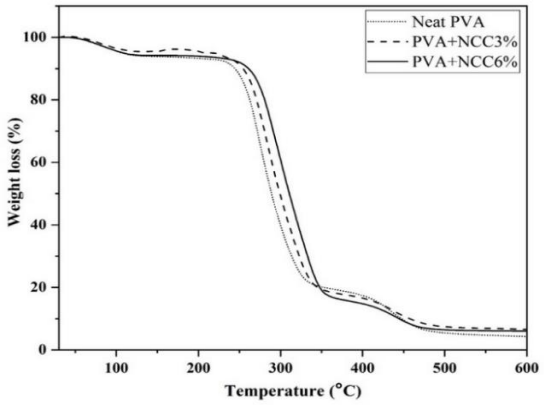

Figure 12. TGA curves of bioplastic film

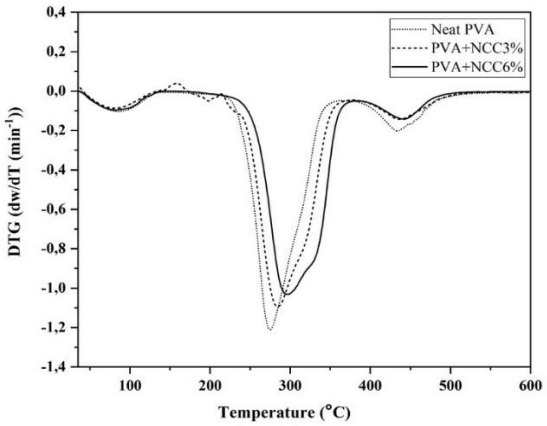

Figure 13. DTG curves of bioplastic film

According Gan et al. (33), addition of NCC into polymer as matrix give rise to intermolecular bonding between it, which rise the elongation at break and improvement the glass transition temperature (T_g), and T_{max}. The excellent bonding between hydrogen the filler (NCC) and the matrix can be improvement the stability thermal of bioplastic film.

TABLE 2. Thermal stability of NCC on TGA and DTG test

Samples	T_{onset} (°C)	T_{max} (°C)
NCC	295	330
Neat PVA	253	275
PVA+NCC3%	270	290
PVA+NCC6%	280	300

The data obtained from the DSC (Differential Scanning Calorimetry) test include the glass transition temperature (T_g) and melting temperature (T_m). The glass transition is the initial transition temperature of the change in the material phase, which is rigid glass to rubbery (ductile stretching), meaning that the higher glass temperature shows the bioplastic film more rigid and elastic. In Figure 14 shows adding NCC into PVA film raises the glass temperature (T_g) from 109 to 114°C

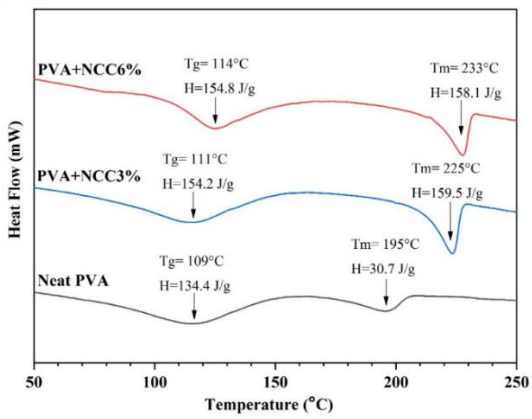

Figure 14. DSC curves of bioplastic film

and melting temperature (T_m) from 195 to 233°C. The enthalpy (H) on meting point shows that the high absorbs energy need to degrades the PVA+NCC 6 wt.% by 158.1 J/g. The neat PVA only absorbs energy by 30.7 J/g, it was caused the neat PVA film degrades earlier at the glass temperature (T_g).

4. CONCLUSION

NCC has been isolated from MCC was successful in combining acid hydrolysis and ultrasonication. The resulting NCC measures 25 nm in diameter and 310 nm in length with an aspect ratio of 12.4. The addition of 6 wt.% NCC into PVA increased the tensile strength and elongation at the break by 45.3% and 79.0%, respectively. The good mechanical strength correlated with the high crystallinity index by 65.1%. In addition, the TGA/DTG for maximum temperature (T_{max}) increases from 275 to 300°C. The DSC test shows rising the heat enthalpy and transition glass temperature (T_g), from 134.4 J/g (109 ˚C) to 154.8 J/g (114°C). It indicates adding NCC improving the thermal stability. The transparency properties are still good, and it was excellent barrier of UV rays by 75%. It's suitable to be applied to plastic packaging.

5. ACKNOWLEDGEMENT

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Persian Abstract

چکیده

فیلم بیوپلاستیک مبتنی بر پلی وینیل الکل (PVA) برای بسته بندی مواد غذایی به دلیل خواص زیست تخریب پذیر و ایمنی آن به طور گسترده توسعه یافته است. سلولز نانو کریستالی (NCC) به عنوان پرکننده برای بهبود استحکام مکانیکی استفاده می شود. این مطالعه بررسی کرد که چگونه افزودن NCC به فیلم‌های PVA بر خواص فیزیکی، مکانیکی و حرارتی تأثیر می‌گذارد. ترکیب هیدرولیز اسید ٤٦ درصد وزنی و موفقیت فرآیند فراصوت برای جداسازی سلولز میکروکریستالی تجاری (MCC) تبدیل به سلولز نانوبلور (NCC) شد. با پراش اشعه ایکس (XRD)، تبدیل فوریه فروسرخ (FTIR)، میکروسکوپ الکترونی عبوری (TEM)، کالریمتری اسکن تفاضلی (DSC)، و آنالیز وزنی حرارتی (TGA) مشخص شده است. NCC با فرم سوزنی شکل با نسبت ابعاد 4/12 (L/D) دارای شاخص کریستالینیتی بالا (٧٦/٤ درصد) بوده است. افزودن ٦ درصد وزنی NCC به فیلم PVA استحکام کششی و ازدیاد طول را به ترتیب ٣٥.٣٠ مگاپاسکال و ٦٥.٥٤ درصد بهبود می بخشد. فیلم بیوپلاستیک تا ٧٥ درصد مانعی بر روی اشعه ماوراء بنفش ایجاد می کند و همچنان شفافیت خوبی دارد. پایداری حرارتی بهبود می یابد که با افزایش دمای انتقال شیشه ای (Tg) از ١٠٩ به ١١٤ درجه سانتی گراد و حداکثر دما (Tmax) از ٢٧٥ به ٣٠٠ درجه سانتی گراد نشان داده می شود.