

Vilma Turunen

NANOCELLULOSE IN BIOBASED COM- POSITES

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Faculty of Engineering and
Natural Sciences
Sanna Auvinen
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ABSTRACT

Vilma Turunen: Nanocellulose in biobased composites
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Nanocellulose is an attractive material to use in bio-based composites and biocomposites. Cellulose is one of the most available biomaterial and the use of nanoscale cellulose fibers could add variety in the use of the material. The object of this work is to study the use of nanocellulose in composite structures.

In this work, the main components of composite structure, the importance of the interface between them, cellulose and nanocellulose are presented. Cellulose and nanocellulose are hydrophilic in nature and in many cases, this limits their use. Hydrophilicity can cause problems with moisture, as well as compatibility to many matrix materials. In some case studies the nanocellulose has been used alone but promising results have been got with the use of sizing agents and compatibility additives. One interesting, also biobased, additive has been rosin.

Rosin has both hydrophilic and hydrophobic structures. These enable the possibility to use it with nanocellulose to improve compatibility between cellulose and hydrophobic matrices, in example polylactic acid. Compatibility was improved by generating strong bonds between the components and this lead to improvement of important application specific properties like mechanical and water vapour barrier properties.

Keywords: Cellulose, nanocellulose, rosin, biobased composite, surface modification

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TIIVISTELMÄ

Vilma Turunen: Nanoselluloosan käyttö biopohjaisissa komposiiteissa
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Nanoselluloosa on houkutteleva materiaali käytettäväksi biopohjaisissa komposiittirakenteissa. Selluloosa on yksi helpoiten saatavilla oleva biomateriaali ja nanomittakaavan selluloosakuitujen käyttö tarjoaisi uusia mahdollisuuksia. Työn tavoite on selvittää nanoselluloosan käyttöä komposiittirakenteissa.

Tässä työssä esitetään komposiittimateriaalin rakenne, rakenteiden välisten rajapintojen tärkeys sekä tehdään kirjallisuuskatsaus selluloosan ja nanoselluloosan ominaisuuksista ja houkuttelevuudesta täyte- tai lujitemateriaalina komposiiteissa. Selluloosalla on hydrofiilinen rakenne ja tämä voi rajoittaa sen käyttöä tietyissä käyttötarkoituksissa. Hydrofiilisyyden huonontaa selluloosan kosteudenkestoa sekä sen yhteensopivuutta hydrofobisten rakenteiden kanssa. Selluloosalla on muuten houkuttelevia ominaisuuksia kuten hyvät mekaaniset sekä optiset ominaisuudet.

Työssä esitellään myös tutkimuksia, joita on tehty nanoselluloosan käytöstä eri matriisimateriaalien kanssa. Tutkimuksissa on muun muassa käytetty erilaisia pintakäsittelyaineita parantamaan selluloosan yhteensopivuutta hydrofobisten matriisimateriaalien, kuten polyaktidin kanssa. Yksi suosittu pintakäsittelyaine selluloosan kanssa käytettäväksi on biopohjainen viuluhartsin. Viuluhartsin rakenteessa on hydrofiilinen ja hydrofobinen osa, jotka mahdollistavat sen käytön pintakäsittelyaineena juuri esimerkiksi selluloosaa käytettäessä.

Esitetyissä tutkimuksissa nanoselluloosan yhteensopivuutta saatiin parannettua sopivan pintakäsittelyn avulla. Tämä johtui pääasiassa erilaisten vahvojen sidosten muodostumisesta komponenttien välille, joita ei voitu saavuttaa ilman tehtyä pintakäsittelyä. Yhteensopivuuden parantumisen myötä saavutettiin myös parempia tuloksia muunmuuassa mekaanisissa testeissä sekä vedenläpäisevyydessä. Myös muita käyttökohdespesifejä ominaisuuksia pystyttiin parantamaan.

Avainsanat: Selluloosa, nanoselluloosa, biopohjainen komposiitti, pintakäsittely

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1. INTRODUCTION

Fibre-reinforced composite structures have attracted a lot of interest and are used for example in different industrial applications, medicine and in automotive industry. Composites structures consist of two different components, fiber that give the structure strength and matrix that binds the fibers together. Typical fiber materials in composites are glass, carbon and aramid, and matrices used mainly synthetic polymer blends. Benefit of composite compared to one material system is that the properties of matrix material can be enhanced by adding fiber to the system and vice versa. [1]

Today interest towards renewable and eco-friendly materials have increased, but often oil-based matrix polymer and industrially produced synthetic fiber materials have still advantage on mechanical properties and more stable quality. To increase the use of biomaterials in composites either fiber, matrix or both are aimed to transfer into biomaterials. Cellulose is an excellent example of natural based fibrous material that can be used as a reinforcing filler in composite structures. [1]

Cellulose is a biomaterial that can be retrieved from plant cell wall. When one dimension of the cellulose fiber is in nanometer scale it is referred as nanocellulose. Nanocellulose have good mechanical properties like high stiffness and thus is a good option to be used as a reinforcing filler. [2]

The aim of this study is to examine how nanocellulose could be used in composites structures. The main challenge studied in this thesis is the compatibility of nanocellulose with the matrix material and how it can be achieved. As an example of good chemical for sizing, rosin is presented as well as studies concerning the use of rosin with nanocellulose in composite applications.

2. COMPOSITE STRUCTURE

Fibre-reinforced composite is two material system that consist of matrix and fibers. Composite materials are used in applications where certain properties are needed. For example, composite material reduces the specific weight of the system part when used instead of more conventional materials such as metals. In this chapter, the different components in composites are presented.

2.1 Fibers

Fibers give the composite structure its strength and stiffness. Properties of the composite vary depending on the type, shape and length of the fiber and also by the arrangement of the fibers in the structure. [3]

Fibers can be continuous or discontinuous, short or long. Long and continuous fibers give the composite structure higher stiffness and strength whereas short fibers do not provide the structure as much strength. Short fibers on the other hand allows more complex shapes than long fibers and more three-dimensional properties. In these kind of structures the matrix needs to provide more strength to the system. [3]

Fibers can be arranged in the composite structure as laminae, plies, that are thin layers of fibres. Direction of the fibers in the ply vary. For example, in unidirectional ply fibers are arranged in same direction and in biaxial ply the fibers are arranged in two directions. [3]

Plies are further arranged as laminate, that consist of several layers of plies. Laminate can be for example arranged so that all plies are unidirectional and all the layers are arranged in the same direction or fiber direction can vary between layers. The orientation and number of plies are designed according to the desired properties and end use of the composite. For example, laminate where all ply layers are unidirectional and fiber direction is the same has excellent strength in one direction. [3]

Fibers that are commercially used the most are glass fibre and carbon fibre. Also, natural fibers can be used in composites. Most studied natural fiber materials include flax, hemp and cellulose, that is presented in more detail later in chapter 3.

2.2 Matrix

Matrix is the part of the system that binds the fibers together and transfers the load to the fiber system evenly. Choosing the right matrix material for the purpose is important as matrix defines the composite properties such as heat resistance, flame retardancy and environmental resistance like corrosion resistance and low moisture absorption. Matrix also determines the manufacturing method for the composite material. This can limit the possibilities of fibers used. [4]

Most common matrix materials are polymer resins such as phenolic resin, unsaturated polyester resin or silicone resin. Polymer resins have high dielectric properties, good heat resistance and the processability is good. Examples of bio based materials that can be used as a matrix in composites include polylactic acid (PLA) and polyhydroxyalkanoates (PHAs). [4]

Polylactic acid is classified as aliphatic polyester and it is produced from lactic acid by condensation polymerization or ring opening polymerization. Lactic acid used in the polymerization is derived from example corn and sugar canes or other agricultural fermentation wastes by fermentation of sugars. PLA has two stereoisomers, L- and D - lactide that can be used separately or as a mixture of both. Chemical composition of PLA is presented in figure 1. [5]

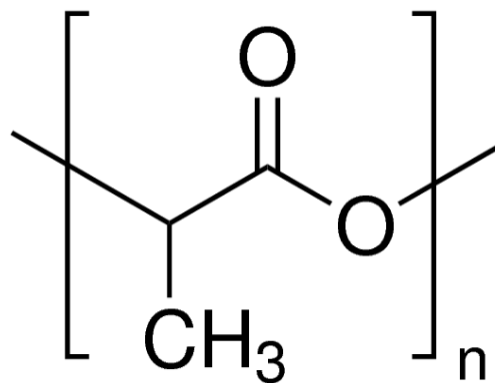


Figure 1. Repeating unit of polylactic acid. [6]

PLA is a hydrophobic due to the methyl group in the structure. PLA has good mechanical properties and the processability of it is good. There are also disadvantages with PLA. For example, it has high brittleness, high water absorption, low thermal stability and impact strength. These properties can limit the use of PLA in certain composite structures but can also be altered by choosing correct fibers for reinforcement to improve the disadvantages of PLA. Examples regarding this is presented later in chapter 5. [5]

Matrix resin properties can also be altered by using different additives combined with the main polymer. Fillers such as silica, silicates and mineral fillers are used to control the flow properties of the resin and to cheapen the raw material costs overall. Pigments can be added in order to achieve desired outlook in terms of colour of the composite part. Fire retardancy can be improved by incorporating halogenated material into the resin or by filler choice. These are just to mention few possible fillers and different additives that can be used in resins for composites. [7]

2.3 Matrix/fiber interface

Role of the matrix/fiber interface is to enable load transfer between the two materials in composite. If the interface is weak and has low shear strength, the full potential/efficiency of reinforcement provided by the fibers is not achieved, because low applied stress can lead to de-bonding of the fibers from matrix. A strong interface on the other hand allows the material to withstand higher stresses and the properties of fibers are utilized more efficiently. [8]

In figure 2, two matrix/fiber interfaces are demonstrated with SEM images. Interface in images a and b is weak as the matrix has fractured from the fiber surface that is left clean and smooth without residual matrix on the surface. Compared to the interface in images c and d where the interface is strong as the crack has propagated to the matrix instead of fracturing of the matrix from fiber completely. Interlaminar shear strength of this bond is higher. [9]

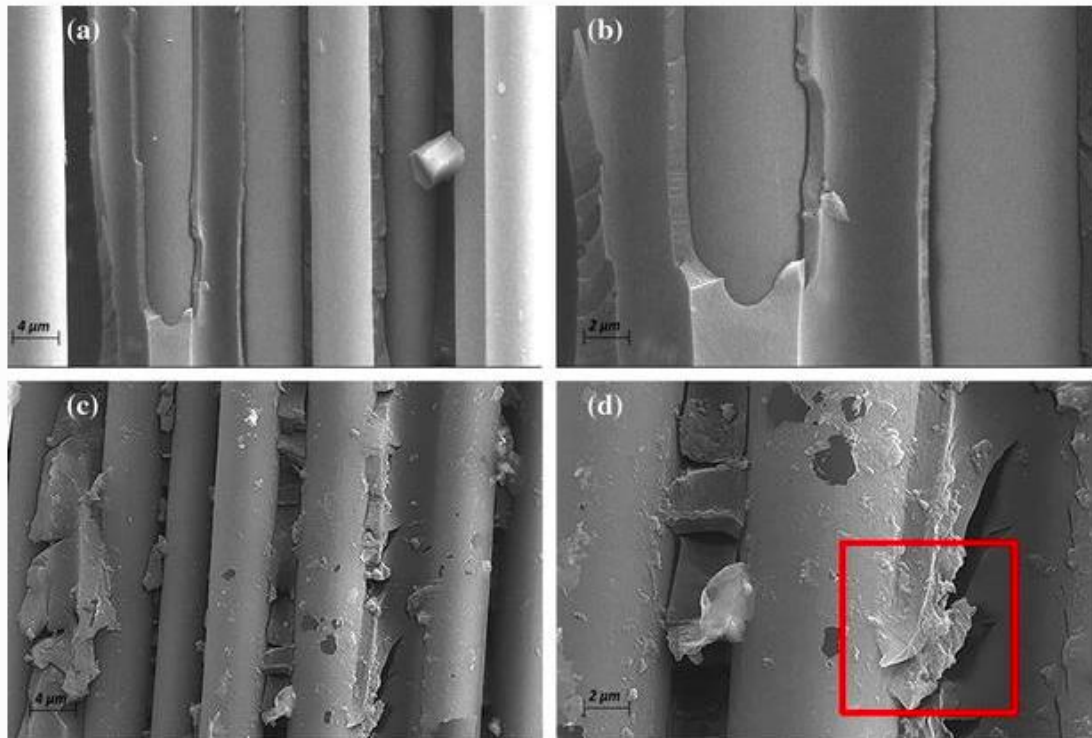


Figure 2. SEM images of fiber/matrix interface with carbon fibre/vinyl ester composites. Images a and b are CF/VE composite. C and d are same materials but with modification of CF with sizing agent. [9]

Compatibility of matrix and fiber is the key to a strong interface and it can be improved by surface treatment of fibers or by improving the wettability of matrix. Especially when using natural fibers as reinforcement the surface treatment of fiber is important as natural fibers are mostly hydrophilic compared to hydrophobic matrices. Different surface treatments include acetylation, plasma treatment and oxidation with peroxide. [10]

3. CELLULOSE

Cellulose is a biomaterial that can be synthesized mainly by plants, but also by bacteria. It is a structural component of plant cell wall and it is classified as a polysaccharide by its structure. [11] Structure of cellulose is a linear chain of repeating D-glucose units that are joined together by β -1,4 linkages, also called acetyl bonds. [12] Structure of cellulose is presented in figure 3. Due to the cyclic structure and hydroxyl groups in the molecule, cellulose is hydrophilic.

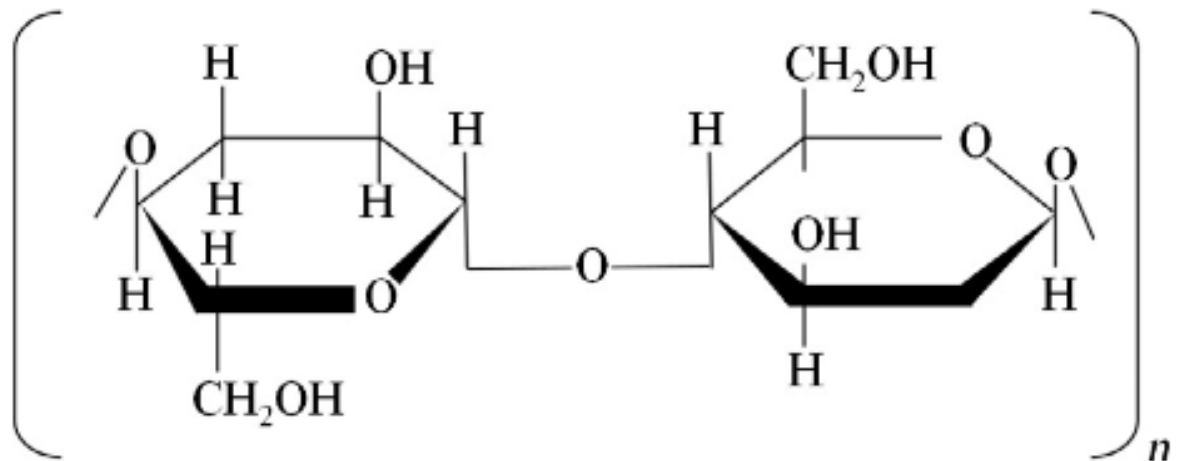


Figure 3. Molecular structure of cellulose. [12]

Cellulose chains form microfibrils when multiple chains are linked together by van der Waals bonds and hydrogen bonds. The hydrogen bonds are generated between hydrogen groups and hydroxymethyl groups from another cellulose chain. Microfibrils are then further arranged to bundles, which gives the cell walls strength and shape. In figure 4 the formation of microfibrils from cellulose chains and further to cell wall component is demonstrated. [11][12] Microfibrils have both crystalline and amorphous regions. Crystalline regions give the structure stiffness and strength while the amorphous regions give the structure flexibility. [2]

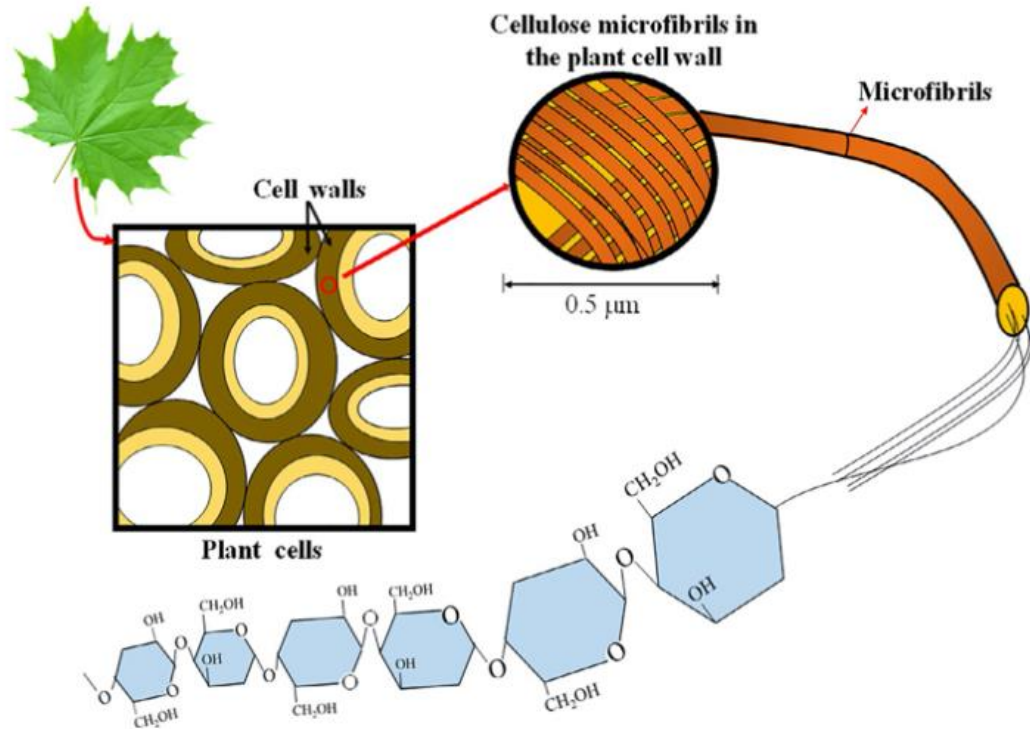


Figure 4. Cellulose microfibrils consist of cellulose chains. Microfibrils form bundles that are key structural element of cell wall. [12]

Cellulose fibers are defined as nanocellulose when one dimension of the structure is in nanometer scale. Nanocellulose can be divided/categorized into different types according to their production methods and structure. The most common types are cellulose nanofibrils (CNFs), cellulose nanocrystals (CNCs) and bacterial cellulose (BC) [13]

The shape of CNCs is rod-like and diameters vary from 3 to 50 nm depending on the source of the cellulose. CNCs are obtained from cell wall of plants by acid hydrolysis. After the hydrolysis, the crystalline parts of the cellulose fibrils can be separated from the amorphous parts. [14] Bacterial cellulose is produced by microorganisms extracellularly and thus is pure cellulose without lignin and hemicellulose. Average diameter of BC is from 20 nm to 100 nm. [15]

Cellulose nanofibrils can be further divided into nanofibrillated cellulose (NFC) and microfibrillated cellulose (MFC) and the difference between them is in the diameter of the fiber. MFCs diameter is from 25 nm to 100 nm and NFCs diameter changes from 5 nm to 30nm. Characteristics for the CNFs are their ability to form network structures that are entangled and also the high aspect ratio of CNF. [13] Length of the fiber in CNF is longer than in CNCs which leads to higher surface area and also to more hydroxyl groups that are needed for possible surface modifications. CNFs also have both crystalline and amorphous regions of cellulose unlike CNCs. [2].

CNF's is retrieved from wood pulp fibers with different extraction processes. These are combinations of chemical and mechanical treatments or just mechanical or chemical treatments. Mechanical treatments include for example grinding, homogenization and milling. One example of a chemical process is TEMPO oxidation. [15]

Nanocellulose form agglomerates easily due to the strong attractive forces between the cellulose molecules. Because of this, preparing a homogenous dispersion of nanocellulose in matrices or aqueous solution is difficult. Surfactants and chemical functionalization is used to improve the storage stability of the nanocellulose dispersions. [16]

As cellulose is biomaterial this can cause problems with variability of physical and mechanical properties. There can be variation in composition and chemical structure like orientation of molecular chains, crystallinity and degree of polymerization. This needs to be taken into account when designing products containing cellulose. [16]

Water absorption of cellulose is high due to the hydrophilic nature of cellulose molecule. This property can limit the possible uses of cellulose in applications where moisture absorption is critical. Water absorption of cellulose can though be improved with different surface treatments that decrease the hydrophilicity of the system. [16]

Properties that make nanocellulose a desirable candidate to replace synthetic materials include good mechanical properties, transparency and free hydroxyl groups in the structure that allow surface modifications. Of course, the biodegradability and eco friendliness of cellulose and nanocellulose can be listed as desirable properties for materials to be studied and used more in the future. [16]

4. ROSIN

Rosin is a natural resinous material that can be extracted from conifers, especially pine. As a biomaterial, rosin can be used as an alternative in different applications for petroleum-based materials and chemicals, for example in adhesives, cosmetics, medicines and chewing gums. [17][18]

Rosin can be divided into three types according to the source of the material. Gum rosin is collected from living pine trees by tapping into the resinous exudates. When the rosin is collected from wood stumps it is called wood rosin. Tall oil rosin is collected from crude tall oil by fractional distillation. The crude tall oil needed is extracted from pulp and paper processes. [19]

Rosin is a mixture of different acid groups, resin acids. Main component is abietic acid and other primary groups are levopimaric acid and pimaric acid. Structure of the different acids differ by the location and number of the double bonds in the structure. [18][19] Structure of abietic acid is presented in figure 5.

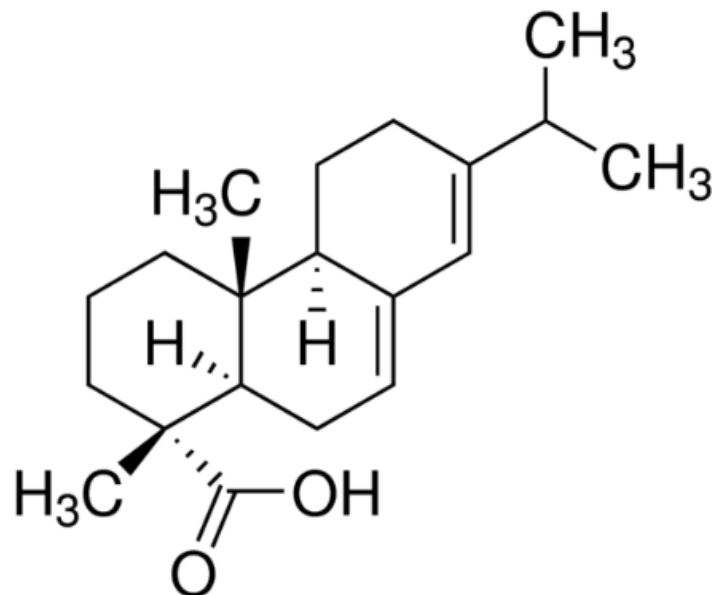


Figure 5. Structure of abietic acid that is the main component in rosin. [20]

Structure of the abietic acid consist of three fused carbon rings that give the molecule good chemical and thermal properties. The carbon rings also are the hydrophobic skeleton for the molecule. The reactive components in the structure are the double bonds and the hydrophilic carboxylic acid group (-COOH). [17]

Because of the hydrophobic and hydrophilic structures in rosin it enables the surface modifications of other material/compounds. For example, there have been studies in how properties of bamboo can be modified by rosin treatment. Na Su et al studied how to increase the water resistance of bamboo in "Hydrophobic treatment of bamboo with rosin". [21]

Rosin can be used in surface modifications of cellulose which is a hydrophilic molecule because of the large number of hydroxyl groups. Hydroxyl groups of cellulose causes a problem when trying to combine it with hydrophobic matrices like PLA but also due to the high amount of hydroxyl groups in cellulose, surface modification with rosin is possible. [22] Surface modification improves the compatibility of cellulose with various hydrophobic matrices. In figure 6 the reaction between rosin's carboxylic acid group and hydroxyl group of cellulose is illustrated.

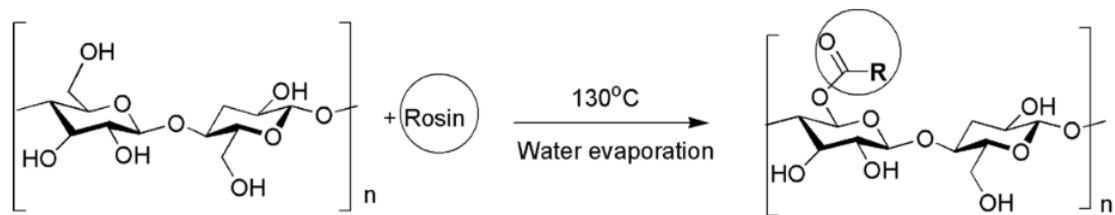


Figure 6. Rosin reacts with the hydroxyl group of cellulose. *R* in the structure describes the resin acid of rosin. [22]

Hydrophilic carboxylic acid group of rosin enhance the surface modification of cellulose. Carboxylic acid group and the hydroxyl group of cellulose react together in hydrolysis forming ester bond between the two molecules. Now the hydrophobic part of rosin enhances the combining of the molecule with different hydrophobic matrices. [22] Different studies of using rosin with nanocellulose in composite structures are presented later in chapter 5.

5. NANOCELLULOSE IN COMPOSITE STRUCTURE

Cellulose and particularly cellulose nanofibers has many properties that make it desirable reinforcement filler for composite structure as described earlier in chapter 3. In this chapter, different studies and possible industrial applications concerning the use of nanocellulose in composite structures with and without surface modification with rosin are presented.

5.1 Study of rosin modified cellulose nanofiber in composite film

Rosin modified cellulose nanofiber that was used as a reinforcement filler with polylactic acid as a matrix is an example of a studies that has been done concerning the use of rosin and cellulose in bio composites. In the study by X. Niu et al. a composite film was prepared that had polylactic acid (PLA) as a matrix and CNF modified with rosin was used as reinforcements. PLA/r-CNF film was also coated with chitosan (CHT). This two-layer composite film was designed for food packaging. [22]

R-CNF was prepared at elevated temperature of 130 °C by adding rosin powder to CNF suspension with adjusted pH of 4. Mixture was stirred for 24 h and after that excess rosin was washed with ethanol. After centrifugation of the solution, a solvent exchange process to dichloromethane was done for the R-CNF. PLA pellets were dissolved to dichloromethane and the solution was mixed with different concentrations of R-CNF and regular CNF. Mixtures were then sonicated and later dried on top of chitosan layer. [22]

Rosin modification helped in making the PLA cellulose dispersion more stable compared to dispersion with cellulose without surface modification. This was demonstrated with TEM images of CNF and r-CNF shown in figure 7. [22]

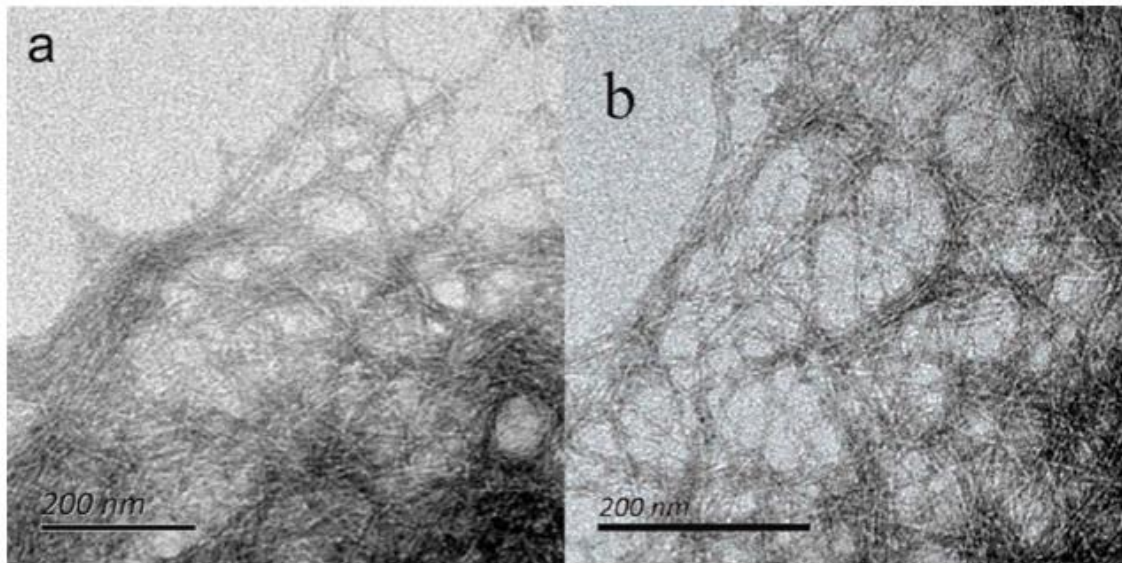


Figure 7. TEM images of CNF (a) and rosin modified CNF (b) from the study by X. Niu et al. [22]

In figure 7, the image b (r-CNF) shows less agglomeration of fibers compared to image a (CNF). Amount of hydrogen bonds in the structure was decreased by surface modification where hydrogen groups were converted to ester groups, this leading to better dispersion of CNF. [22]

Different amounts of r-CNF were added to chitosan/PLA film to test the r-CNF's effect on mechanical properties. Optimal mechanical properties for the purpose were achieved with 8 % of rosin modified CNF in PLA. Tensile strength, Young's modulus and elongation at break all increased compared to pure chitosan/PLA film until the r-CNF amount was increased over 8 %. Results were also compared to similar chitosan/PLA film with 8 % addition of CNF without rosin modification. Tensile strength and Young's modulus were at the same level as with pure chitosan/PLA film but the elongation at break decreased compared to pure chitosan/PLA. Without rosin modification, the addition of CNF to the chitosan/PLA didn't improve the mechanical properties considerably or at all. The evolution of tensile strength and elongation at break are presented in figure 8. [22]

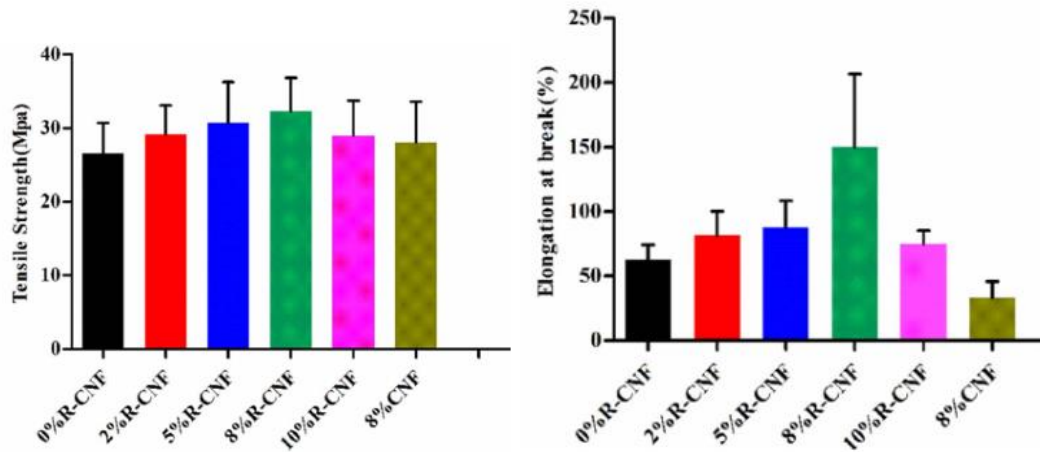


Figure 8. Tensile strength and elongation at break of chitosan/PLA film with different amounts of r-CNF and CNF additions. [22]

The results indicate that the compatibility of the CNF to chitosan/PLA matrix was improved with the rosin modification. CNF modified with rosin had a distinct impact on the mechanical properties of the composite film and as well improved the stability of the dispersion. [22]

5.2 Study of rosin modified nanocrystals in composite film

Rosin modification has also been studied with cellulose nanocrystals. Rosin-grafted cellulose nanocrystal (r-CNC) was used in gelatin films in a study by Liliame S.F. Leitite et al “Eco-friendly gelatin films with rosin-grafted cellulose nanocrystals for antimicrobial packaging”. In the study, a r-CNC gelatin was successfully prepared and the benefits of modification CNC with rosin were identified. R-CNC was prepared similarly as described earlier with R-CNF with minor differences by combining the two in elevated temperature of 130 °C. After that the r-CNC was washed with ethanol and collected by centrifugation. R-CNC gelatin composite film was then prepared by solvent casting. [23]

Properties that could be improved with the addition of rosin to nanocrystal cellulose were water vapor barrier, tensile properties and films optical properties. For example, with the mechanical properties, it was recognized that the r-CNC gelatin film exhibited approximately 30 % higher tensile strength than the regular CNC gelatin film with the same filler content of 4 w-%. The tensile strength and elongation at break results are presented in figure 9. [23]

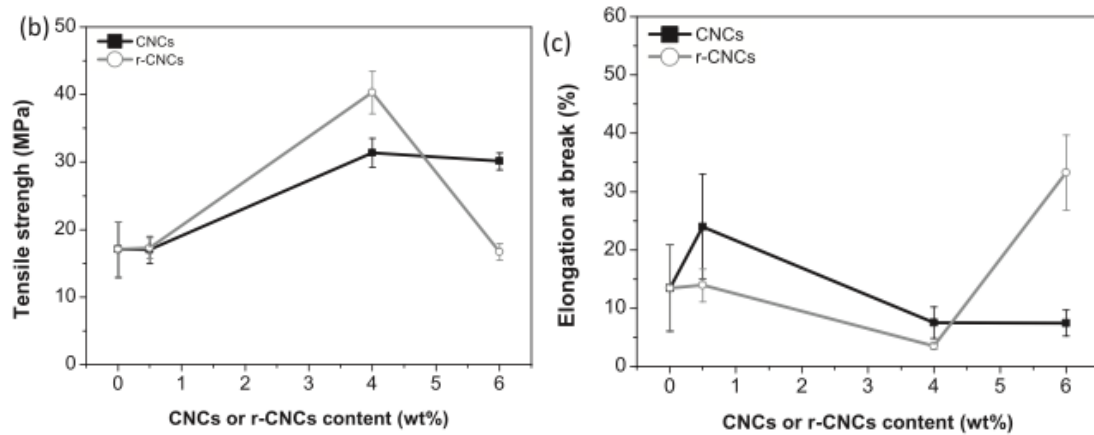


Figure 9. Tensile strength and elongation at break evolution of gelatin film with different loadings of CNC and r-CNC. [23]

From the figure 9 it can be noticed that when the r-CNC and CNC amount is increase over 4 w-% the regular CNC has better results. Elongation at break on the other hand increases when the addition of r-CNC is 6 w-% implying that the film is more flexible compared to gelatin CNC film, but with the addition of 4 w-% the gelatin CNC without rosin has higher elongation at break. In SEM images, it was noticed that there were agglomerates in the film with 6 w-% addition of r-CNC. This implied that the loading of 6 w-% was too much and the r-CNC did not have good compatibility to the gelatin. [23]

5.3 Rosin modification to matrix in cellulose nanocrystal composite

Rosin can also be used to modify the matrix material before combining the nanocellulose as a reinforcement. He Liu et al. studied the properties of rosin modified polyurethane composite with cellulose nanocrystal acting as reinforcing filler. Examples of testing include mechanical testing that was performed for polyurethane cellulose nanocrystal composite (PUCNC) and rosin modified polyurethane nanocrystal (RPUCNC). [24]

Waterborne polyurethane (WBU) is more environmental friendly than conventional solvent based polyurethane but it has lower mechanical strength and thermal stability than solvent borne. To improve the properties of WBU reinforcing fillers such as cellulose nanocrystals has been added. It has been noticed that addition on CNCs increase the mechanical strength and adds antimicrobial property to WBU composites, but the tendency of CNCs to form agglomerates in the mixture can also lower the mechanical strength. The compatibility of the mixture was improved by introducing rosin to WBU matrix. Results of the mechanical test performed for the films prepared are presented at figure 10. [24]

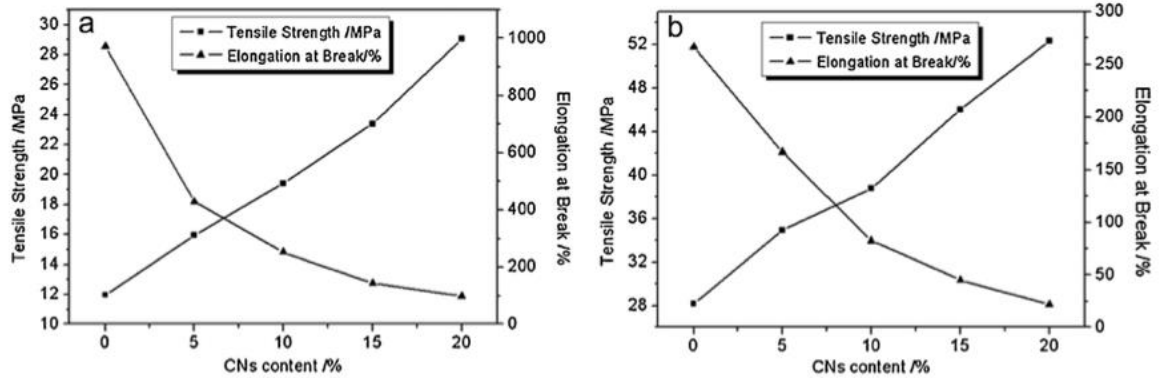


Figure 10. Elongation at break and tensile strength of films prepared from PUCNC (a) and RPUCNC (b). [24]

The tensile strength of the film increases when the CNC content of the film increases. It can also be noticed from the figure 8 that the tensile strength of RPUCNC is clearly higher than PUCNC. Also, the elongation at break decreases with RPUCNC compared to PUCNC film. This indicates that the rosin improved the interactions between the WBU matrix and CNCs resulting in more rigid film. [24]

5.4 Enhancing cellulose/PVA composite properties by using hydroxyl crosslinking

Using cellulose with polyvinyl alcohol (PVA) matrix is one example of a study where no surface modifications were directly done to the fiber or matrix. Y. Xie et al. studied creating cellulose and PVA composite by using hydroxyl crosslinking to improve the properties of cellulose PVA composite film for food packaging by reducing the hydroxyl content of the film. The hydroxyl groups of cellulose and PVA were both used to create the crosslinking structure between the two chemicals. Epichlorohydrin, ECH, was used as crosslinking agent in the process. Both cellulose and PVA were dissolved in alkali urea solution and combined together with ECH. Mixture was poured to mold and placed to 60 °C altogether for total of 8 h for the crosslinking reaction to occur. Afterwards the formed film was further thermal treated at 165 °C for 30 min. Films containing only PVA and cellulose/PVA were also prepared at the same manner to compare the results. In figure 11 the crosslinking structures achieved in the process are illustrated. [25]

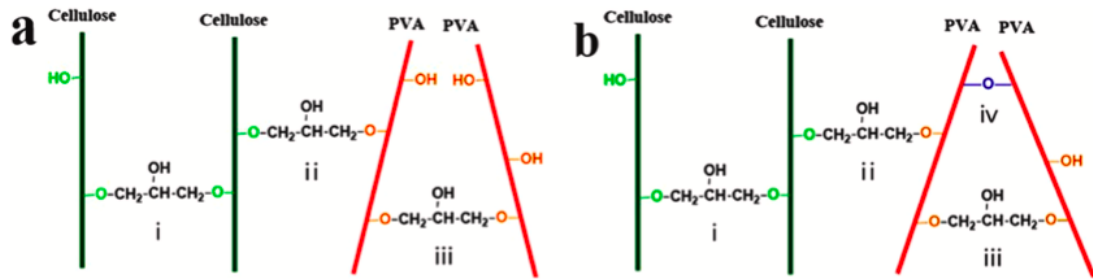


Figure 11. Different bonds achieved in the crosslinking process of cellulose and PVA. In image a, crosslinking structure is presented that was achieved using ECH. Similarly, in image b is presented the ether bond that can be achieved between PVA-PVA with thermal induced crosslinking. [25]

Similarly, like with surface modification, better mechanical properties were achieved with the hydroxyl crosslinked film compared to regular cellulose/PVA film. It was also noticed that the thermal treatment at 165 °C increased the tensile strength of the composite film but lowered slightly the elongation at break. During the thermal treatment, the crystallinity of the film increased further causing worse flexibility for the composite film. Other important properties for packaging film including water resistance and oxygen barrier properties were maintained and improved in the crosslinked structure because the –OH content of the structure was decreased in the crosslinking process. [25]

5.5 Comparison of the studies

In all of the studies properties of the nanocellulose composites could be improved. Stability of the dispersion was improved by lowering the amount of hydrogen bonds formed by nanocellulose due to rosin modification or with the hydroxyl crosslinking. Also, mechanical properties were enhanced in the processes. In all studies presented tensile strength increased compared to film without nanocellulose and film with nanocellulose without any modification.

Elongation at break of the films on the other hand behaved different with different components. For example, when comparing the mechanical test results from the chitosan/PLA r-CNF composite film and gelatin r-CNC composite film it is noticed that the tensile strength behaves in similar manner but the evolution of elongation at break is different. In the chitosan/PLA composite the CNF fibers increase the brittleness of the PLA due to their high stiffness whereas the CNC's make the gelatin film more rigid thus lowering the elongation at break. [22] Nanocellulose type as well as the matrix material behave in different manner and this needs to be taken into account when choosing the components for the purpose. Also, the amount of nanocellulose that is added needs to be tested to find the correct combination of mechanical properties for the purpose.

6. CONCLUSIONS

Nanocellulose has excellent properties for uses as a reinforcing material in composite structures such as the mechanical properties. There are also problems with using different nanocellulose mainly due to the hydrophilic nature caused by the hydroxyl groups in the structure. The hydrophilicity has an influence on the water absorption of cellulose and compatibility of cellulose with hydrophobic matrix materials.

Hydroxyl groups in the structure of cellulose on the other hand enable the possibility to perform surface treatment for it and alter its properties. Rosin can be used in surface modifications of cellulose due to its hydrophilic and hydrophobic structures. Addition of rosin to nanocellulose and matrix materials have been studied and results are promising.

Nanocellulose in films for food packaging is one area of research that has been done with different nanocellulose type combined with different matrix materials. With surface modification important properties for packaging films were obtained. These include mechanical properties like tensile strength of the film. Also, better optical properties and lower water absorption were achieved by the aid of the modification.

Compatibility of the nanocellulose to hydrophobic matrices was one of the key factors that was improved with the different surface modification types. The better compatibility between the components in composite allowed also the improvement of other application specific properties.

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