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Nanocellulose: Preparation, Characterization and Applications

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Abstract:

The growth of nanocellulose has attracted outstanding interest in the last few decades due to its unique and potentially useful features. Novel nanocelluloses improve the strongly expanding field of sustainable materials and nanocomposites.CNCs and CNFs are two kind of nanocelluloses (NCs), and they own various superior properties, such as large specific surface area, high tensile strength and stiffness, low density, and low thermal expansion coefficient.Their application includesnanocellulose in transdermal drug delivery, Hydrogels, Aerogel Systems, Nanocellulose in Tablet Formulations and Nanocellulose in Microparticulate Drug Delivery [1]. Different methods of nanocellulose like pretreatment method, mechanical process and chemical hydrolysis used for the synthesis of nanocellulose. Characterization of cellulose includes scanning electron microscopy, x-ray diffraction (XRD) analysis of samples and thermogravimetric analysis.

Key words: nanocrystals; electro spun cellulose nanofibers; Bacterial cellulose; micro fluidization

Introduction

Cellulose is the main component of the plant cell wall and can be removed from a variety of sources, such as wood, fibers, grasses, seed fibers, marine animals, algae, fungi, invertebrates, and bacteria. Apart from cellulose, the plant cell wall also carries hemicellulose, lignin, and small amount of extractives. Even though wood species are the chief origin of cellulose, nonfood plants are accepting increasing interest due to their low-cost availability and bottom lignin content. Consequently, their fiber purification procedure are uncomplicated and less energy absorbing. For these causes, different agriculturalconsequences are under in-depth study for the manufacturing of various product ranges [2].Derivatizing cellulose obstruct with the orderly crystal-forming hydrogen bonding, so that even hydrophobic derivatives may grow the apparent solubility in water. Methylcellulose, Cellulose acetate, Ethyl cellulose, Carboxymethylcellulose and native cellulose have been used in various industrial applications and these include; barriers films, thickener and emulsifier, lubricant, glue and binder, artificial tears and saliva, optical and biomedical devices, pharmaceutical raw materials, flame retardants, resins and filters, blends and composites. Because of their low cost, toughness, natural feel, transparency, softness, comfort and other favorable aesthetic properties [3]. Nanocellulose has obtained growingprofit for a wide range of requesting relevant to the areas of materials science and biomedical engineering due to its renewable nature, anisotropic shape, excellent mechanical properties, better biocompatibility, tailorable surface chemistry, and interesting optical properties. A new scope of nanocellulose application is still under investigation in fields such as photonics, films and foams, surface modifications, nanocomposites [4], flexible optoelectronics, and medical devices like scaffolds for tissue regeneration. The most beneficial property of nanocellulose research is the green nature of the particles, their fascinating physical and chemical properties, and the diversity of applications that can be derived from this material [5].

Cellulose:

Cellulose was first find by Payen. Since then, the physical and chemical properties of cellulose have been considered intensively. It is a well-ordered fibrillar ranging that is primarily answered for the mechanical strength of plants [6]. It is considered as one of the most plentiful organic complex obtained from plant biomass. Around 1010 and 1011 t of cellulose biopolymer are produced each year but only about 6×109 t are used by various industries such as paper, textile, material and chemical industries, etc. In spit cellulose is a crystalline molecule its crystallinity is faulty; a notablepart of the cellulose building is less commanded and can be mentioned to as amorphous. Thus, the cellulose chain is a two-phase modelholding both crystalline (ordered) and amorphous (less ordered) regions [7]. The grade of crystallinity of domestic cellulose usually ranges from 40% to 70% depending on the origin of cellulose and the separationmethod. The cellulose is present in the form of the microfibrils, which are bound together by lignin and hemicellulose. These microfibrils are made up of tiny cells having width of 10–50µm, depending on the source [8].

Nanocellulose:

In recent years, nanocellulose synthesis and application has achieved remarkable growth as polymer reinforcement in order to create high-performance biomaterials. Cellulose molecules with at least one dimension in nanoscale (1–100nm) are mentioned to as nanocellulose. The main reason for increasing interest in nanosized material is due to the fact that highly uniform material with enhanced mechanical properties can be achieved by reducing the size of the cellulose fiber [8]. It is considered a sustainable material due to its biodegradable nature. The characteristic properties of nanocellulose like crystallinities, surface area, and mechanical properties vary with the extraction methods and processing techniques [9]. For example, CNC synthesis by sulfuric acid requires the selective hydrolysis of amorphous cellulose regions and results in highly crystalline particles with source-dependent dimensions. Negative charged sulfate groups are attached onto the surface of CNC particles, which restricts the aggregation of particles in aqueous suspensions due to electrostatic repulsion. Depending on the technique and synthesis conditions of nanocellulose, which determines its dimensions, composition and properties, it can be divided into three main categories:

1. cellulose nanocrystals (CNCs), also known as cellulose whiskers

2. cellulose nanofibrils (CNFs), also known as nano fibrillated cellulose (NFC), micro fibrillated cellulose (MFC) or cellulose nanofibers

3. bacterial cellulose (BC) and electro spun cellulose nanofibers (ECNFs)

Type of Nanocellulose

Cellulose nanocrystals:

Cellulose nanocrystals (CNCs) are frequently produced using acid hydrolysis of cellulosic materials dispersed in water. In general, concentrated sulfuric acid is used, which dissolves the amorphous regions of cellulose and the crystalline regions are left alone. Although this procedure produces a rod-like rigid CNC with almost 90% purity, the sulfate groups remain attached at the surface of the fibers as impurities [10]. The length and diameter of CNCs commonly vary from a length of 200–500nm to a diameter of 3–35nm.

Cellulose nanofibrils:

CNFs are long entangled fibrils (µm) with a diameter in nanometer range. CNFs are produced by high-pressure grinding of cellulosic pulp suspension and strongly entangled networks of nanofibrils are formed [11]. Unlike CNCs, which have near-perfect crystallinity (c.90%), CNFs contain both amorphous as well as crystalline cellulose domains within the single fibers. Typically, CNFs have a diameter of 5–50 nm and a length of a few micrometers. CNF extraction from cellulosic fibers can be obtained by three types of processes: (1) mechanical treatments (e.g., homogenization, grinding, and milling); (2) chemical treatments (e.g., TEMPO oxidation); and (3) a combination of chemical and mechanical treatments.

Bacterial cellulose:

Bacterial cellulose (BC) is also known as microbial cellulose. It is usuallyproduced from bacteria, (e.g., Acetobacterxylinum) as an unrelated molecule and does not need additional handling to remove contaminants like lignin, pectin, and hemicellulose.Furthermore, in disparity to CNC and CNF biosynthesis, BC biosynthesis requires the addition of molecules from tiny units (Å) to small units (nm) [12]. In the biosynthesis of BC, the glucose chains are provided inside the bacterial body and discharge out through minor pores present on the cell wall. Ribbon-shaped BC nanofibers are established when glucose is fused with the cell wall. This ribbon-like web-shaped structure build a 20–100 nm long unique nanofiber system.

Preparation of Cellulose Nanocrystals:

CNCsowngiant crystallinity with diameter less than 100 nm and length less than 500 nm, which are established through intermolecular interaction of cellulose macromolecules in a hydrogen bond way. CNCs are generally obtained through acid hydrolysis or enzymatic hydrolysis of cellulose pulp. Acid hydrolysis processes need to go through very harsh reaction conditions which usually require concentrated acid, while the enzymatic hydrolysis process requires really long time. There are mainly determined by the inherent stable structure of the materials that have been explained in a related review. During the hydrolysis activity, the amorphous regions of cellulose are more easily invested by acid compared to the crystalline regions, leading to first degradation of amorphous regions, while the crystalline regions are retained. Finally, whisker-like CNCs are obtained. In retrospect, the first successful mixture of CNCs was in 1947 all the time hydrolyzing cellulose with hydrochloric acid and sulfuric acid by Nickerson and Habrle. In 1951, Ranby prepared the stable CNCs colloidal suspensions ° through sulfuric acid hydrolysis of wood fiber. In 1953, Mukherjee and Woods proved that the needle particles obtained by sulfuric acid hydrolysis occult nanometer size by X-ray technology and electron microscope and found that their crystal structure was same as that of raw cellulose material. Subsequently, Marchessaults et al. found that the CNCs colloid suspension had birefringence. After that, some new methods to prepare CNCs seemsslowly, such as enzymatic hydrolysis, oxidative degradation, ionic liquid, solid acid hydrolysis, organic acid hydrolysis, and subcritical hydrolysis.

Mineral Acid Hydrolysis

The mineral acid hydrolysis is the most ordinary method for the preparation of CNCs. Many cellulose sources have been used for the preparation of CNCs by mineral acid hydrolysis, such as tomato peel, oil palm biomass, rice husk, and waste cotton cloth. The classic mechanism is that the hydrogen ions from acid can easily pervade the loose amorphous regions of cellulose to break the 1,4-β-glycoside bonds, resulting in the hydrolysis of amorphous regions, while the crystalline region of cellulose could be keep in the process which is ascribed to the inherent compact structure that averted the permeation of the acid. Hence, the relatively complete crystalline structure of CNCs can be obtained by the hydrolysis of mineral acid.

Fig:1 Schematic diagram of CNCs prepared by acid hydrolysis: (a) idealized cellulose microfibril showing one of the suggested configurations of the crystalline and amorphous regions and (b) CNCs after acid hydrolysis dissolved the disordered regions.

Cellulose Chains — Disordered Region — Crystalline Regions — 100 nm

(a)

Cellulose Nanocrystals

(b)
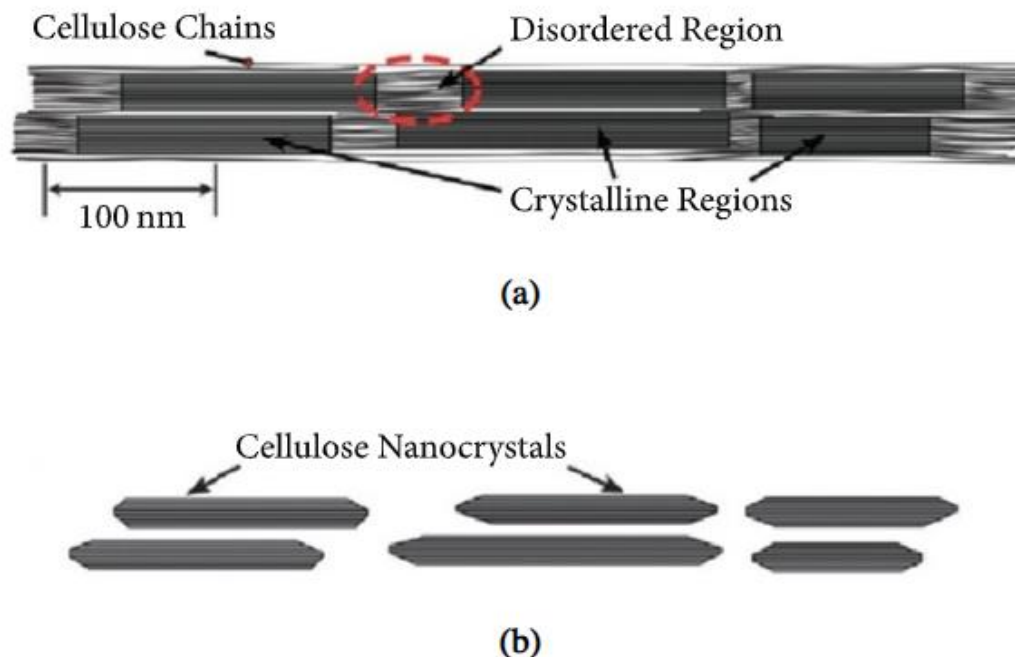
The usually used mineral acids are sulfuric acid, hydrochloric acid, phosphoric acid, hydrobromic acid, and their mixed acids. Sulfuric acid is the most usually used as it produces a negative surface charge on the particles which guide to more stable suspension. In general, the hydrolysis process needs the sulfuric acid congregation to be 60–65%, reaction temperature to be 40–50°C, and reaction time to be 30–60 min. However, the yield of CNCs is very low (less than 30 wt.%) due to the intemperate degradation. Fan and Li optimized the sulfuric acid hydrolysis circumstances with cotton pulp as raw material, and the yield of CNCs reached to 63.8%. Chen et al. found that the yield of CNCs could be remarkably improved by decreasing the concentration of sulfuric acid and prolonging reaction time. For example, the yield of CNCs could extend to 75.6% when 58 wt.% sulfuric acid was used at 56°C for 210 min. CNCs from sulfuric acid hydrolysis have poor thermal stability due to the sulfate group which is a remarkable barrier for thermal process in composites. The thermal stability of CNCs can be improved between neutralization with NaOH. The morphology of CNCs can be also changed by controlling the reaction conditions. The spherical CNCs with average dimension of 35 nm could be obtained by using 63.5% H_2SO_4 to hydrolyse microcrystal cellulose under the ultrasonic ministration combined with mechanical stirring for 3 h. Azrina et al. also reported a commom condition for the preparation of spherical CNCs. This reaction was carried out with 64% (w/v) H_2SO_4 solution at 45°C for 2 h in an ultrasound bath. In this reaction, the spherical CNCs with an average diameter of 30–40 nm were synthesised from oil palm empty fruit bunch pulp.

Hydrochloric acid also was frequently used for the preparation of CNCs. The classic acid concentration, reaction temperature, and reaction time are 2.5 N–6.0 N, reflux temperature, and 2–4 h, respectively. Due to the absences of charge on the surface of CNCs, the CNCs prepared by hydrochloric acid are easily flocculation in water. But the thermal stability of CNCs by HCl is more than that by H_2SO_4. Yu et al. used hydrochloric acid to treat raw cellulose materials under hydrothermal situations. The crystallinity of the resultant CNCs was 88.6% with greater yield of 93.7%. The maximum degradation temperature was 363.9°C which was resolved by TGA analysis. Cheng et al. described an inorganic chloride/hydrochloric acid system for extracting CNCs from microcrystalline cellulose (MCC) under hydrothermal conditions. Four inorganic chlorides including $FeCl_3 6H_2O$, $CuCl_2 2H_2O$, $AlCl_3$, and $MnCl_2 4H_2O$ were look over in this work. The research allow that the hydrolysis process was support significantly by inorganic chlorides especially ferric chloride via accelerating degradation of the amorphous region of cellulose. Phosphoric acid, which belongs to middle strong acid (pKa = 2.12), could be used for the preparation of CNCs with high thermal stability and stable suspension. Lu et al. reported a mechanochemical proceed towards to manufacture bamboo cellulose nanocrystals (BCNCs). In this action, the bamboo cellulose pulp was chemically treated by phosphoric acid. Finally, short rod-like BCNCs with the length of 100–200 nm and the width of 15–30 nm was obtained. The crystalline building transformed from cellulose I to cellulose II, and the crystallinity index reduced from 66.44 to 59.62%, while the thermal stability became lower.

Hydrobromic acid (HBr) hydrolysis circumstances assisted with ultrasonication to prepare CNCs were investigated by Sadeghifar et al. When the hydrolysis process was carried out at 2.5 M HBr under 100°C with sonication for 3 h, CNCs could be obtained at a yield of 60%. Moreover, Sucaldito and Camacho used HBr to hydrolyze fresh water green algae to attain the highly crystalline CNCs (crystallinity index of 94.0%). The resultant CNCs have a mean diameter of 20.0 (±4.4) nm, and the rotting temperature reached 381.6°C.
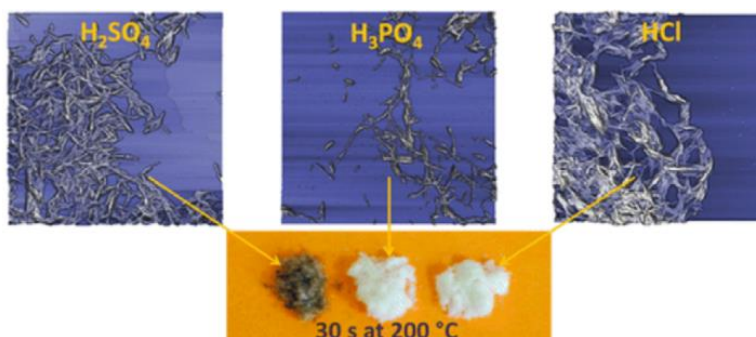
Fig:2 *Schematic diagram thermal stability contrast of CNCs from sulfuric acid hydrolysis, hydrochloric caid hydrolysis or phosphoric acid hydrolysis.*

Spherical CNCs could be also prepared by using a mixed acid system facilitated with ultrasonication from MCC. The mixed acid system is a mixture of sulfuric acid (98%, w/w), hydrochloride (37%, w/w), and H_2O at a ratio of 3: 1: 6 (v/v) which was reported by Zhang et al. The action was carried out at 80°C by ultrasonicator heating for 8 h. The diameters of produced cellulose nanoparticles are in the range of 60–570 nm. The hydrolysis condition provided by Wang et al. was, the ratio of sulfuric acid (98%, w/w), hydrochloride (37%, w/w), and H_2O was still 3: 1: 6 (v/v), while the ultrasonic treatment was at 50 Hz for 10 h. The resultant spherical CNCs suspension with the dimension of 10–180 nm showed liquid crystalline quality when the concentration was above 3.9%. A mixed acid system of hydrochloric acid and nitric acid (HCl/HNO_3) could be used to developcarboxylated cellulose nanocrystals (CCNCs) from MCC. When the reaction was support out under the mixed acid ($HCl/HNO_3 = 7: 3$ (v/v)) concentration being 4 M at 110°C for 3 h, the resultant CCNCs were rod-like morphology and had good suspension stability and excellent thermal stability.

Generally, mineral acid hydrolysis method to produce CNCs is a simple method and has gone to pilot scale (quite a few around the world) and even exhibition plant (1 tonne/day at CelluForce, Canada). However, there are still some demerits in this method. First, the corrosion problem of the equipment is serious which leads to the arrogant cost of production. Furthermore, a large amount of waste acid and other pollutants will be produced in the procedure of acid hydrolysis, and it is very difficult to dispose and recover. So, it is very necessary to develop green and low-cost CNCs production technologies.

Solid Acid Hydrolysis

Tang et al. reported a cation interchange resin hydrolysis method for the preparation of CNCs. By hydrolyzing MCC with cation trading resin

(NKC-9), an optimum yield (50.04%) was achieved with a ratio of resin to MCC (w/w) being 10 and at 48°C for 189 min. The results showed that the diameter of CNCs was about 10–40 nm and the length was 100–400 nm. The crystallinity of resin-CNCs was excessive than that of H_2SO_4-CNCs. In counting to the recoverable capacity of cation exchange resin, the cation exchange resin-catalysed hydrolysis is a favourable approach for manufacturing of CNCs. Liu and co-workers reported the phosphotungstic acid (HPW) catalysed-hydrolysis procedure with bleached hardwood pulp as raw material. CNCs with the diameter of 15–40 nm were given, which had high thermal solidity and stable dispersion in watery phase. The reaction was support out with 75 wt.% phosphotungstic acid at 90°C for 30 h; the yield of CNCs was up to 60%. Phosphotungstic acid could be retrieve through extraction with available ethyl ether. Since this method is a solid/liquid/solid three-phase reaction, the reaction efficiency is low and the reaction time is comparatively long compared with the mineral acid hydrolysis method. Further research results showed that the response time was notably shortened under the optimal conditions, and the obtained CNCs had a high crystallinity index (79.6%) with a 84% yield. Torlopov et al. also reported a CNCs preparation procedure using phosphotungstic acid/acetic acid method to destruct cotton cellulose. The resulting CNCs have high-crystalline method and rod-like morphology.Contrast with the typical mineral acid hydrolysis method, solid acid hydrolysis method has mild surrounding and low corrosion to equipment, and the solid acid can be recycled. Moreover, the yield of CNCs is higher. However, the reaction order is low and the reaction time is pretty long. Allocate physical approach (such as microwave and ultrasound assisted) or suitable catalyst could be used to better the reaction efficiency. At present, solid acid hydrolysis method to prepare CNCs is still in the phase of laboratory research.
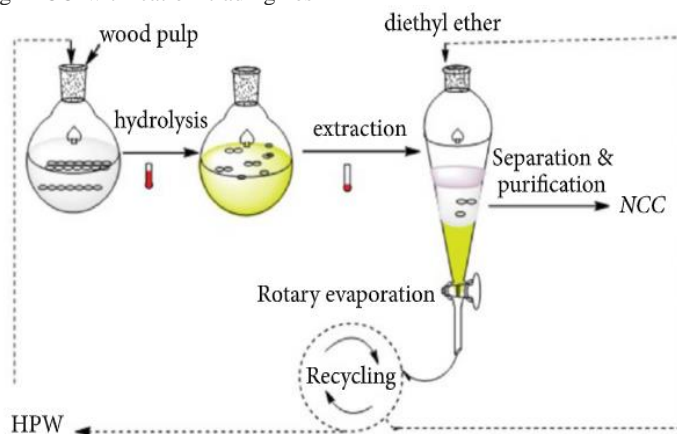

Fig:3 *The overall procedure for manufacturing CNCs by using HPG*

Organic Acid Hydrolysis

Recently, organic acid hydrolysis was introduce to produce NCs due to the fact that the organic acid is mild, recyclable, and environment-friendly and of low corrosiveness. However, in order to improve the efficiency of hydrolysis, higher temperature and prolonged reaction time are necessary because of the weak acidity of organic acid. Li and co-workers reported a two-step master plan to produce CNCs from bleached chemical pulp under mild conditions. In the first stage, formic acid (FA) was used to hydrolyse the amorphous region of cellulose and free CNCs. In the second stage, the cause CNCs were further oxidized by TEMPO in order to grow the surface charge. The results manifested that the crystallinity index of resultant CNCs could reach 75% when 0.015 M $FeCl_3$ was used. Moreover, up to 90% FA can be retrieve by rotary evaporation, $FeCl_3$ could be recovered in the form of Fe (OH)$_3$ precipitation cause by ammonia treatment, and the generated ammonium salt can be used as fertilizer. Thus, the $FeCl_3$-catalyzed FA hydrolysis action was more sustainable than the normal sulfuric acid hydrolysis process. Then, dicarboxylic acid was used for CNCs production suggested by Chen et al.
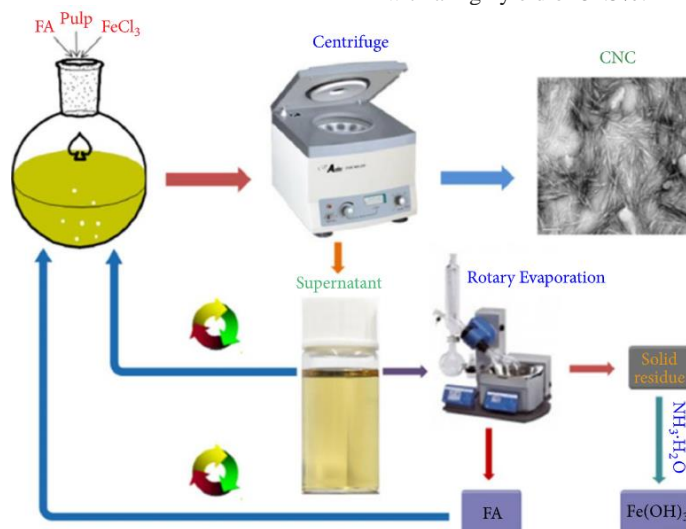
Similarly, CNCs usually were obtained at a low yield due to the low reactive pursuit of dicarboxylic acid. Thus, most of the hydrolysedresult are the insufficiently hydrolysed fibers which can be used for preparing CNFs through following mechanical disintegration. The merits of using dicarboxylic acid for the mixture of NCs are that (1) carboxyl groups are introduced on the surface of CNCs and CNFs, as ester group could have been shape by the reaction of dicarboxylic acids with cellulose ; (2) solid dicarboxylic acid (e.g., oxalate and maleic acid) is of low corrosion to equipment and could be totally recovered by using crystallization technology; (3) the resultant CNCs and CNFs are thermally stable which is beneficial for the manufacture of compound. Li and co-workers used molten oxalate dihydrate to tend cellulose fibrils which is a free solvent for the preparation of CNCs. In this operation, the hydrolysis and esterification of cellulose could be carried out in one pot. CNCs could be reached in a high yield (80.6 wt.%). Xu and co-workers successfully prepared the CNCs with a mixed acid collected of hydrochloric acid and oxalate. The optimal problem is that the concentration of oxalate is 0.11 M with 10% HCl at 95°C for 4 h. Results showed that CNCs could be acquire with a high yield of 81.5%.

Fig:4 *Overall flow process diagram of preparation of CNCs by fecl3*

Maleic acid was also used for the preparation of CNCs and the pre-treatment of cellulose. Wang and co-workers reported the preparation of CNCs utilize maleic acid to hydrolysecellulose. CNCs were obtained at a low yield, about 5%. The fibrous cellulosic solid residue could be converted to CNFs through the backing mechanical disintegration. Bian et al. used concentrated maleic acid to hydrolyse unbleached mixed hardwood kraft pulp. The results were that the lignin-contain CNCs and CNFs were successfully prepared. Bian and co-workers also reported a maleic acid catalysed-hydrolysis response for the preparation of CNCs and CNFs. The bleached eucalyptus pulp and unbleached mixed hardwood kraft pulp were used as the raw materials, and classic operating conditions were acid concentrations of 50–70 wt.% at 100–120°C for 1-2 h. The results showed that CNCs with the length of approximately 239–336 nm were prevail, and CNFs could be reached by the further mechanical fibrillation of fibrous cellulosic solid residue. Yu et al. described an approach for extracting carboxylated CNCs by citric acid/hydrochloric hydrolysis of MCC. In this work, rod-like CNCs with the length of 200–250 nm and the width of 15–20 nm were prevail. The CNCs extracted for 4 h had the greatest carboxylic group content and high zeta potential value (up to −46.63 mV). By applying organic acid hydrolysis, some absorbing functional groups could be introduced to the surface of CNCs through the ester bond between organic acid and CNCs in the hydrolysis process. For example, Boujemaoui et al. used 2-

bromopropionic acid, 3-mercaptopropionic acid, 4-pentenoic acid, and 2-propynoic acid, respectively, to catalyse the hydrolysis of raw cellulose materials. Some active functional groups such as Br-, HS-, alkenyl, and alkynyl were grafted on the surface of CNCs correspondingly, which could be advantageous to further modify CNCs despite the very long reaction time (10 days).Generally, organic acid hydrolysis is more sustainable and environment-friendly than mineral acid hydrolysis for CNCs production. It is believed that the industrialization of CNCs by using organic acid hydrolysis will be perceive in recent years.

Enzymatic Hydrolysis

Cellulase is a multicomponent enzyme system. Its active partincludes endoglucanases (EG), cellobiohydrolases (CBH), and β-glucosidase (GB). The action mechanism of each part on cellulose is shown in Figure 5 . EG mostly acts on the amorphous region of cellulose to randomly hydrolyse the β-1,4-glycosidic bond, so the long chain cellulose molecules are shorten into small molecular cellulose in the interior of cellulose; CBH mainly acts on the end of linear cellulose molecular to demolish the crystalline region of cellulose; GB is used to hydrolyse cellulose into glucose . When CNCs are prepared by enzymatic hydrolysis, the demolish of the crystalline area of cellulose by CBH should be avoided as much as possible. Therefore, three part of cellulase should be isolate from each other. EG is used to hydrolyse cellulose

amorphous regions, and much more crystalline regions are kept in the process. Filson and co-workers successfully prepared CNCs utilize endoglucanase to hydrolyse recycled pulp. They found that when the endoglucanase was increased to 420 EGU per 1 g pulp and the reaction temperature was at 50°C with microwave heating for 60 min, the CNCs with the diameter of 30–80 nm and the length of 100 nm–1.8 μm could be obtained, the yield was up to 38.2%, the average zeta potential was −31.37 mV, and birefringence could be observed for the CNCs dispersion. Chen et al. prepared a ball-shaped nanosized cellulose by the enzymatic hydrolysis of pulp fibers. This research allows that enzymatic hydrolysis of pulp could give spherical CNCs with the diameter of ca. 30 nm, which had
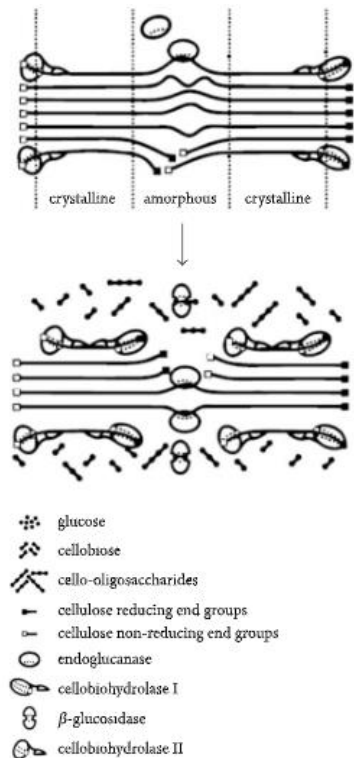

Fig:5 schematic diagram of different cellulase impact of cellulose

good monodispersity and uniformity. When the concentration of composite enzymes was 20 u/mL (cellulase: xylanase = 9: 1), the yield of CNCs reached to 13.6%. However, when the single cellulase was used, even if the enzyme concentration extended up to 200 u/mL, only a blended of strip and granular flocculation was obtained. Meyabadi et al. also reported the enzymatic hydrolysis method to manufactured the spherical CNCs with waste cotton as raw material merge with sonication. The particle sizes of gained CNCs were less than 100 nm. Overall, compared with the mineral acid hydrolysis, the enzymatic hydrolysis process for the preparation of CNCs is environment-friendly, while the experimental circumstances are harsh, the yield of CNCs is low, and the reaction time is long. Enzymatic hydrolysis of raw cellulose materials is promising for the industrial manufacturing of CNCs, so further research of efficient enzymatic hydrolysis is peremptory and urgent.

Oxidation Degradation

The hydroxyl groups on cellulose have high reactivity. They are easily oxidized by strong oxidants to aldehydes, ketones, and carboxyl groups so that their structures are destructed and the degree of polymerization is decreased. Therefore, some scientists have successfully prepared CNCs by use of the oxidation degradation method. Yang et al. adopted two-step oxidation procedure to prepare CNCs: softwood pulp was firstly oxidized by sodium periodate and then further oxidized by sodium chlorite, andultimately two-step centrifugation was implemented to give CNCs (diameter/length, 13 nm/120–200 nm) and microfibrils (diameter/length, 120 nm/0.6–1.8 μm). The resultant microfibrils could be further relocated to CNFs by mechanical agitation. The isolated CNCs with carboxyl groups on the surface had a high crystallinity (91%) and high charge density which could form a stable suspension in aqueous phase.

Ammonium persulfate (APS) as well could be used to prepare carboxyl CNCs. Hu et al.'sinvestigatesresults showed that the spherical shape particles with diameters of 20–70 nm were obtained by this method, and the crystallinity of CNCs was remarkably improved after a series of chemical treatments. The researchoutcome of Mascheroni and co-workers showed that CNCs produced through the APS treatment displayed higher charge densities, crystallinity, lucidity of the solution and transparency of the coating contrast to the CNCs produced by the H_2SO_4 hydrolysis. Leung and co-workers used the APS to oxidize the flax fibers to make the surface-carboxylated CNCs. The CNCs were needle-like with diameter of 3.8 nm and length of 150 nm, and the particle size distribution was uniform. In this method, the raw materials (such as hemp, flax, straw etc.) could be used directly for the preparation of CNCs without pre-treatment process for the delignification. The reason is that APS has the delignin task in addition to oxidative degradation. Cheng and co-workers prepared the CNCs with 1 mol/L APS aqueous mixture to oxidize lyocell fiber at 80°C for 16 h. The prepared CNCs were spherical with the diameter of 35 nm and a prominent deal of carboxyl groups were initiate on the surface of CNCs. The crystal kind of resultant CNCs was cellulose II.

TEMPO was also used as oxidation to prepare carboxyl CNCs. Although, only subfraction of raw cellulose materials was oxidized to CNCs by using TEMPO; the rest of oxidized cellulose had much larger dimensions. It indicated that TEMPO was not as potent as APS on cellulose oxidation. Moreover, CNCs from TEMPO oxidation are highly carboxylated , which provides the opportunity for functionalization .

Altogether, compared with the mineral acid hydrolysis and enzymatic hydrolysis, the yield of CNCs was higher by the oxidation degradation method. However, in the process of reaction, a large number of oxidants were consumed, and the reaction time was longer. Also, a large amount of water and energy need to be consumed which leads to the fact that the cost of CNCs production was very high.

Ionic Liquid Method

Ionic liquid is a type of organic salt solution with low melting point (less than 100°C) composed of organic cations and other anions. Contrast to the traditional solvent, ionic liquid has advantages in terms of chemical stability, thermal stability, nonflammability, and low vapor pressure. It is also called "green solvent". In recent years, due to the unique belongings on of ionic liquid, it has been widely used to dissolve and separate
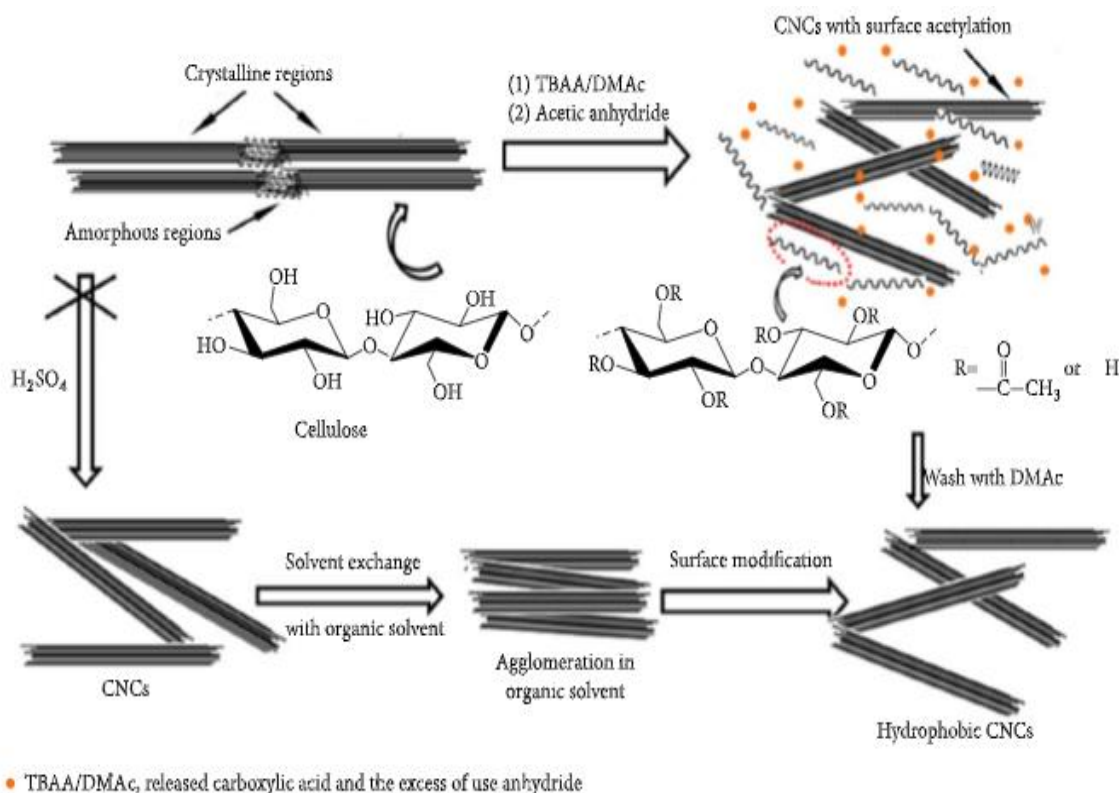
Fig:6 *one-pot preparation of hydrophobic CNCs in TBAA with acetic hydride.*

Lignocellulose and to prepare CNCs. Man, and co-workers treated MCC with 1-butyl-3-methylimidazolium bisulfate ($[BMIM]HSO_4$) to give CNCs with the diameter of 14–22 nm and the length of 50–300 nm. It was found that, compared with the authentic MCC, the CNCs remained cellulose I, while the thermal stability was notablydecreased. Mao and co-workers treated MCC with $[BMIM]HSO_4$ aqueous solution at 120°C for 24 h to allow the CNCs at 48% yield.Later, they hydrolysed softwood, hardwood, and MCC by the optimizing two-stage method with $[BMIM]HSO_4$ aqueous, and the yield of CNCs was 57.7%, 57%, and 75.6%, respectively, which was close to the theoretical value. Tan et al. used $[BMIM]HSO_4$ as both catalyst and solvent to prepare CNCs from MCC. Highly crystallized CNCs with diameter of 15–20 nm and length of 70–80 nm were obtained at 90°C. Lazko and co-workers reported another system which is that cotton fibers were infiltrated firstly by [BMIM]Cl at 80°C, and 1–4 wt.% sulfuric acid was added subsequently. Then the reaction was kept for 2–16 h, and the CNCs were successfully prepared with the diameter of about 20 nm and the length of 150–350 nm. The analysis results showed that the CNCs prepared by [BMIM]Cl had less sulfonic class content on the surface than that of $[BMIM]HSO_4$, and their thermal stability was obviously increased. Iskak et al. used [BMIM]Cl as ionic liquid to formulateCNCs. In this work, they investigated the effects of the reaction time and temperature on the yield, size, and crystallinity index of CNCs. The results showed that CNCs with the particle size of 9 nm and the crystallinity index of 73% were prevail when the reaction time was 30 min. For now, when reaction temperature was 100°C, CNCs were obtained with a yield of 90% and crystallinity index of 76%. Abushammala and coworkers personally treated wood with 1-ethyl-3-methyl imidazole acetate ([EMIM][OAc]), and the surface acetylated CNCs were successfully prepared in a 44% yield. The type of resultant CNCs was cellulose I, and the crystallinity was 75%. The research showed that [EMIM][OAc] had three main functions in the process: (1) dissolving cellulose in situ when cotton fibers were infiltrated, (2) reducing intermolecular cohesion in wood by acetylation;

(3) catalysing the hydrolysis reaction of cellulose. Miao and co-workers used tetrabutylammonium acetate/dimethylacetamide (TBAA/DMAc) system with acetic anhydride to treat hardwood pulp to gain the hydrophobic CNCs remarkably. The traditional method of preparing hydrophobic CNCs included three steps: firstly, CNCs were prepared by sulfuric acid hydrolysis; secondly, CNCs were dispersed in an organic solvent by solvent exchange; finally, the CNCs were hydrophobically alter in organic solvent. Compared with classical method, TBAA/DMAc and acetic anhydride structure can be used to prepare hydrophobic CNCs in one pot. The process is simple, and the prepared CNCs with high thermal stability have acetyl group on the surface.

Cellulose nanofibrils synthesis methods:

Cellulose nanofiber, nanofibrillar cellulose, and cellulose nanofibril are the conditions used for nano fibrillatedcellulose. The mixture of CNFs needs strong mechanical machining. However, according to the properties of raw materials and stage of processing, chemical pretreatments are carried out before mechanical machining. A detail is that appropriate pretreatments of cellulosic fibers can increase the inner surface, alter crystallinity, and break hydrogen bonds of cellulose.

Pretreatment Method:

Pretreatment of wood cellulose fibers is a procedure to reduce the energy depletion of mechanical nano fibrillationoperation to improve the degree of nano fibrillation. Since energy consumption is the main drawback for the production of nanofibers by mechanical isolation processes, the pretreatment process has become an important step [13]. Furthermore, it improves the fibrillation process with increase in production of nanofibers.

### Solvent-Assisted Pretreatments

Traditionally, the cellulose pulp is pre-treated by dilute base. For instance, bleached kraft bagasse pulp was pre-treated with the aqueous solution of

5% NaOH at 50°C for 45 min so as to get clear of the residual hemicellulose and lignin and then was further ground to obtain the CNFs. Degree of polymerization and cellulose pacify of the resultant CNFs were higher than the ones untreated or hydrolysed with xylanase enzyme. Lee and co-workers used a low-concentration alkaline solution as pre-treatment condition (2 wt.% NaOH solution below 0°C) to make CNFs. The resulting CNFs with 90 nm diameter had relatively elevated thermal stability. The maximum thermal decay temperature was 343°C, while it was 310°C for the CNFs prepared without the NaOH pre-treatment. Since urea and ethylenediamine have the capacity to loosen the hydrogen bonds and solubilize cellulose, they could be applied to pre-treat cellulose. Before further mechanical disintegration, a microemulsion (surfactant–oil–water systems) as well as urea or ethylenediamine was applied to treat kraft pulps. It was found that urea and ethylenediamine pre-treatment could virtually accelerate the isolation of CNFs.

Organic Acid Hydrolysis Pretreatment

Recently, some organic acids, for example, formic acid and oxalate, were used to ease the cellulose. Co-workers used highly distilled formic acid to hydrolyse bleached softwood pulp; then the formic esterified MCC passed through homogenizer without clogging to permitCNFs. The resultant CNFs showed high thermal stability (onset decomposition temperature ac. 291°C) and good dispersibility in DMSO, DMAc, and DMF, respectively, due to the introduction of surface formic ester groups. Bian et al. used -toluene sulfonic acid (50–80 wt.%) for the rapid and nearly complete dissolution of wood lignin at 80°C for 20 min (see Figure 10) . In this action, the birch wood fiber fractions were hydrolysed to lignocellulosic solid residue (LCSR) that was subsequently fibrillated into lignocellulosic nanofibrils (LCNFs). The dissolved lignin could be precipitated as lignin nanoparticles (LNPs) by diminish the concentration of -TsOH to less than 10%, and the -TsOH could be retrieve by using commercially proven crystallization technology. The dicarboxylic acid was also used as the pre-treatment of lignocellulose to prepare lignin restrain cellulose nanocrystals (LCNCs) and LCNFs by Bian et al. The resultant LCNCs and LCNFs were less carboxylated contrast to those lignin-free CNCs and CNFs. Therefore, they had under charges. Overall, organic acid hydrolysis is amethodicalpre-treatment method, which is recycle and has low corrosion to equipment, and ester groups or carboxyl groups are transplant onto the surface of cellulose in the pre-treatment process.
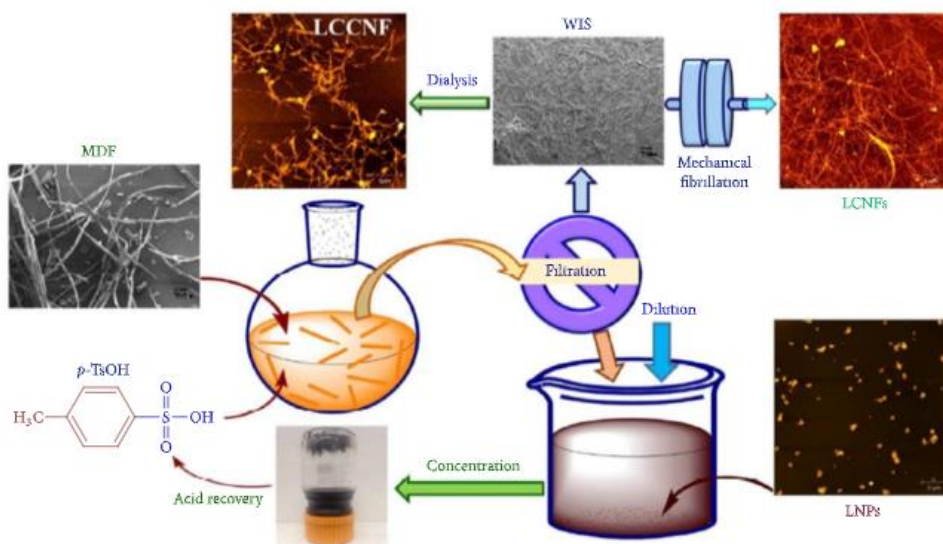
Schematic diagram of preparation of LCNFs LNPs by using p-TsOH pretreatment

Alkaline–acid:

Alkaline–acid pretreatment is the most common method used for lignin, hemicellulose, and pectin solubilization before mechanical isolation of NFC. This method included the following steps. 1. Sodium hydroxides (NaOH). Soaking fibers in 12–17.5% wt solution for about 2 hours. This raises the surface area of cellulosic fibers and eases the hydrolysis. 2. Hydrochloric acid (HCL). Drenched fibers in 1M solution at 60–80°C. This solubilizes the hemicelluloses [14]. 3. Sodium hydroxides (NaOH). Treating with 2wt% solution for 2 hours at 60–80°C. This disrupts the lignin structure, and breaks the linkages between carbohydrate and lignin. Alkaline pretreatment is an successful method that can enhance cellulose yield from 43% to 84%. It also helps to removed lignin and hemicelluloses partially from soy hull fibers and wheat straw [15].

Ionic liquids:

Ionic liquids (ILs) are organic salts owning special possessions such as nonflammability, thermal and chemical stability, and infinitely low vapor pressure [16]. It is an increasing interest of researchers to study as solvents of cellulosic materials. Li, Wei treated sugarcane bagasse with 1-butyl-3-methylimidazolium chloride [(Bmim) Cl] as ionic liquid and followed the high-pressure homogenization (HPH) technique to prepare NFC. The pulp passed through homogenizer without clogging; these fibers were then precipitated in water solution and regenerated by freeze-drying.

Mechanical Process:

Cellulosic materials are required to go through mechanical treatment for defibrillation. Pretreatment processing, either by chemicals or enzymes, is done before mechanical fibrillation to ease the process. Chemical treatments help in widening the space between hydroxyl groups, increasing the inner surface, altering crystallinity, and breaking cellulose hydrogen bonds, thus enhancing surface areas, which helps boost the reactivity of the fibers [17]. There are many mechanical methods for converting cellulosic fiber to nanocellulose, such as homogenizing,micro fluidization, grinding,cryocrushing, and high-intensity ultrasonication.

Micro fluidization:

 Microfluidizers work near to HPH in the manufacturing of nanocellulose fiber. Microfluidizers use an intensifier pump to enhance pressure, while

the interaction chamber is used for shear and impact forces against colliding streams to defibrillate the fibers. Lee et al. studied the particular ratio of cellulose fiber and noticed that NFC fiber with higher surface area could be acquired by multiple passes through the microfluidizer [18]. The cellulose fibrils revealed a higher amount of hydroxyl (OH) groups as well as agglomeration operation due to more surface area. The number of passes between the homogenizer determine the size of NFC and its surface area.

Ball milling process:

Ball milling is a mechanical process in which cellulose suspension is placed in a hollow cylindrical container for the production of CNF. This hollow cylindrical container is partially filled with balls made up of ceramic, zirconia, or metal; the container rotates and breaks cellulose cell walls through the high-energy collision between the balls. Zhang, Tsuzuki studied various factors affecting manufacturing of CNF such as ball size, ball-to-cellulose weight ratio, grinding time, moisture content, and carboxylic charge [19]. Maintaining homogeneity of the produced CNF is always a major challenge in this method.

Grinding Method

Ultrafine friction grinding is another ordinary technique for the preparation of CNFs. The commonly used equipment is Super masscolloider grinder. Taniguchi and Okamura used Masuko's colloider grinder for the first time to grind 5–10 wt.% cellulose materials for 10 times and remarkablyformulated CNFs with diameter of 20–90 nm. Since then, this procedure has attracted wide attention. Gane et al. determined that adding kaolin or calcium carbonate is helpful for accelerating grinding in the grinding operation and will prepare composite of CNFs and a mineral. The working principle is that cellulose materials are sent to the grinding area consisting of a portable disc and a fixed disc, and the process of high-speed grinding and shearing was carried out to give CNFs lastly. Compared to the high-pressure homogenization method, grinding process has the advantages of high efficiency, large capacity, low energy consumption, and being less prone to material clogging. However, because of the strong mechanical force in the grinding procedure, the fiber damage is more serious. As a result, the CNFs property is not well, such as low crystallinity and lesser thermal stability, which leads to the low physical strength of CNFs and the enhancement result of material not as good as CNFs prepared by high pressure homogenization.

Twin-Screw Extrusion Method

Twin-screw extrusion is another procedure for CNFs production. In the preparation action, cellulose pulp is fibrillated by two corotating, intermeshing screws mounted in a closed barrel. The merits of twin-screw extrusion is that CNFs can be obtained with high solid contents (25–40 wt.%), which is very beneficial for transportation and storage. The twin-screw extrusion procedure of the composites from thermoplastic starch and TEMPO-oxidized cellulose fibers was studied by Cobut and co-workers. The CNFs with the diameter of ca. 30 nm were obtained during extrusion procedure. Hietala and co-workers studied this procedure for the bleached cellulose from softwood flour (particle size of 200–400 μm) as raw materials. The result was that CNFs were not gained; however, fibers with good dispersion in the starch matrix were given. Ho and co-workers studied this technique for the preparation of CNFs from never-dried refined needle-leaf bleached kraft pulp, and the resultant CNFs were obtained at a solid content of 45 wt.%. Overall, twin-screw extrusion technique is promising for the scale production of CNFs.

Cryocrushing Method

Cryocrushing technique for the preparation of CNFs was studied by Dufresne and co-workers for the first time. The process is that water swollen cellulosic fibers were frozen firstly by liquid nitrogen and subsequently crushed by mortar grinding. Under mechanical impact, the pressure on the cell walls obtained from ice crystals caused cell wall to break and release cell wall fragments. Sain and co-workers studied the fibrillation of agricultural crops using cryocrushing technique. The results showed that the CNFs with the diameter of 50–100 nm and the crystallinity of 48% could be derived, and the soybean stock nanofibers could be dispersed in acrylic oligomer emulsion as good as in water.

Blending Method

Uetani and Yano remarkably prepared CNFs by using the high-speed blender to shear never-dried bleached softwood pulp. The resultant CNFs had a constant diameter of 15–20 nm when 0.7 wt.% cellulose pulp suspension was blended at 37,000 rpm. Jiang and Hsieh blended the cellulosic fibers suspension at 37,000 rpm and 97°C under distinct time conditions (up to 2 h) to give the NCs with bimodal size distribution: (i) one was with the diameter of 2.7 nm and the length in range of 100–200 nm; (ii) the other was with the diameter of 8.5 nm and the length with few micrometres . Nakagaito and co-workers improved the blender bottle, and the results showed that the time was halved for fibrillation procedure.

Aqueous Counter Collision

Aqueous counter collision (ACC) is an another technology for CNFs preparation. Under high coercion, two jets of cellulose suspensions collide against each other, leading to wet pulverization of cellulose and freeing of CNFs. Kose et al. prepared CNFs from the previously homogenized bacterial cellulose aqueous suspension at a concentration of ≤0.4 wt.% using ACC technique. The procedure was carried out under the ejecting pressure of 200 MPa for 80 passes. The result was that CNFs with the diameter of ca. 30 nm were make and cellulose Iα changed to cellulose Iβ after ACC. But the crystallinity was still kept at >70%. Kondo and workers reported the preparation of CNFs from MCC by using ACCsystem. The diameter of CNFs was ca. 15 nm and the length was ca. 700 nm. It is worth noting that in sequence to avoid clogging, the size of processed cellulosic material should be less than the nozzle diameter (ca. 150 μm).

Enzyme Hydrolysis

The hydrolysis of cellulose can be catalysed by some enzymes and the fibrillation can also be improved. The enzyme pre-treatment has a mild state and a high selectivity and can make fibers produce holes, peeling, and fine fibrosis, which is conducive to the nano fibrillation of cellulose in following mechanical processes and reduces the probability of blocking the homogeneous valve by cellulose slurry. The enzyme system could be multicomponent enzyme blend or the nanocomponent. According to the reports, the monocomponent endoglucanase seems to give a better pre-treatmenteffect.

TEMPO Oxidation

As we all know that the negatively charged groups (such as carboxyl or carboxymethyl) are introduced into cellulosic fibers and then the delamination of the nanofibrils can be initiate, since there is electrostatic repulsion in the middle of cellulose nanofibrils with negative charge. The procedure of 2,2,6,6-tetramethylpiperidine-N-oxyl (TEMPO) radical oxidizing the primary alcohol groups of monosaccharides to carboxylic groups was reported by Davis and Flitsch in 1993 which has become one of the most sizeable research topics in the area of oxidation of cellulose. The classical oxidation system for cellulose is TEMPO/NaBr/NaClO, which has been extensively used for the pre-treatment of raw cellulose materials ahead mechanicaldisintegration.
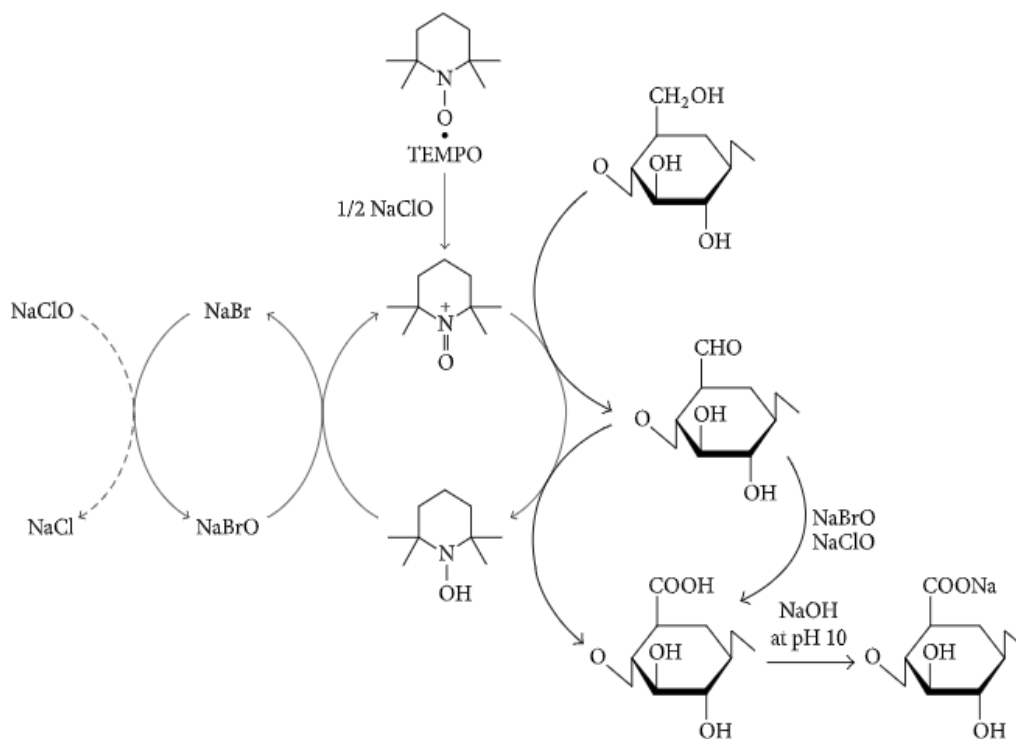
Fig regioselective oxidation of c6 primary hydroxyls of cellulose to c6 carboxylate groups by TEMPO system in water at pH

Nitrosonium ions (+N=O) are generated in situ during the reaction of TEMPO radicals with the oxidants and they are used to oxidize the cellulose fibers. Consequently, the primary alcohol groups are first oxidized to aldehydes and further converted to carboxyl groups. At the same time, the depolymerization phenomenon of cellulose appears. There are two phenomena which may be caused by cellulose depolymerization: (i) β-elimination could occur owing to C6 aldehyde groups presented in an alkaline environment and (ii) the cleavage of a hydro glucose unit took place unpaid to the existing of hydroxyl radicals. TEMPO/NaClO/NaClO$_2$ structure was also applied which overcame the depolymerization. The reaction was carried out in the neutral or weakly acidic environment and at 60°C for 72 h. The results demonstrated that most of original DP remained unchanged. TEMPO oxidation pre-treatment remarkably reduced the energy consumption for the further mechanical disintegration of cellulose. Nelson et al. evaluated that the mechanical energy consumption after TEMPO oxidation was around 570 KWh/t, which was far lower than that of 70000 KWh/t without any pre-treatment.

Periodate-Chlorite Oxidation

Periodate-chlorite is an effective oxidation structure for transferring secondary alcohols of cellulose to carboxyl groups. Liimatainen et al. used this procedure to oxidize cellulose to advance further mechanical decomposition of cellulose. During the reaction, secondary alcohols of cellulose were firstly converted to aldehydes by sodium periodate, which were further oxidized to carboxyl groups by sodium chlorite. The CNFs with the diameter of 3–5 nm were obtained through sequential high-pressure homogenization for up to 4 passes. In this method, the glucopyranose ring was opened to prepare 2,3-dicarboxylic acid cellulose. Moreover, the strength property of CNFs was not decreased by ring opening reaction.

(a)

(b)
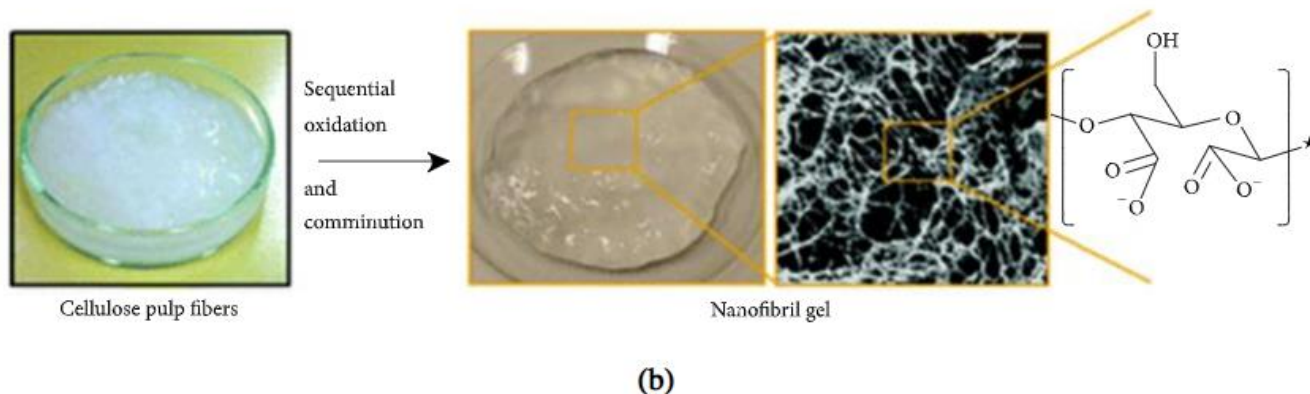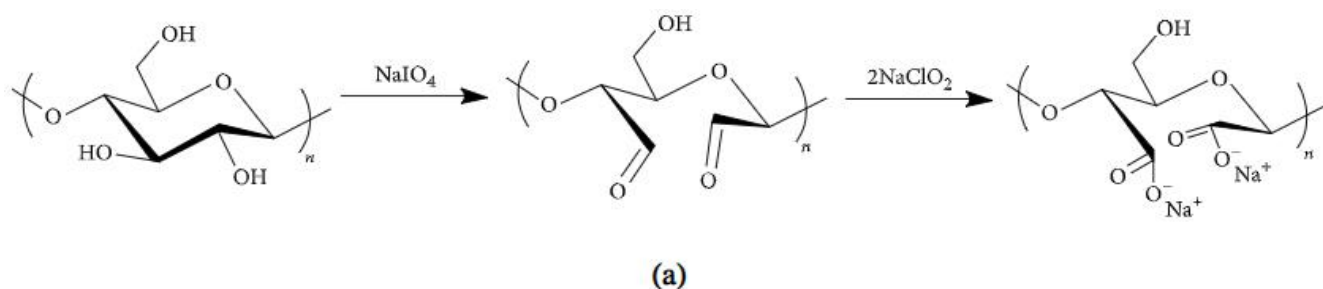
schematic diagram of cellulose carboxylation via periodate-chloride;

a. chemical formula for cellulose carboxylation

b. preparation of CNFs by periodate-chlorite oxidative system.

Oxidative Sulfonation

Oxidative sulfonation of cellulose is another procedure for introducing negative charge groups onto the surface cellulose and can be used to enhance the fibrillation process. Liimatainen et al. treated bleached kraft hardwood pulp with periodate and bisulfite, and CNFs with typical diameter of 10–60 nm were obtained by the following high-pressure homogenization for 5 times. In this method, the used periodate could be efficiently recycled, so it is a potential green procedure for the pre-treatment of cellulose.
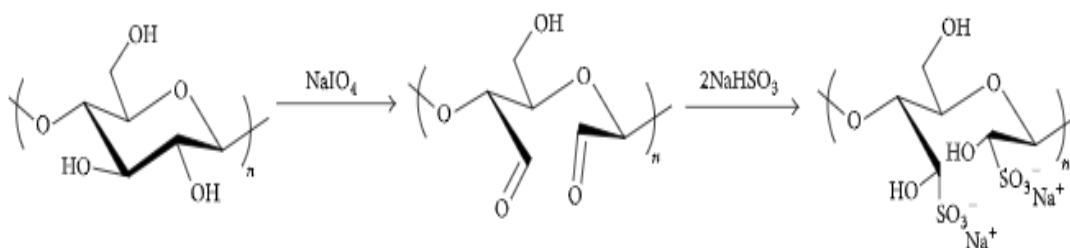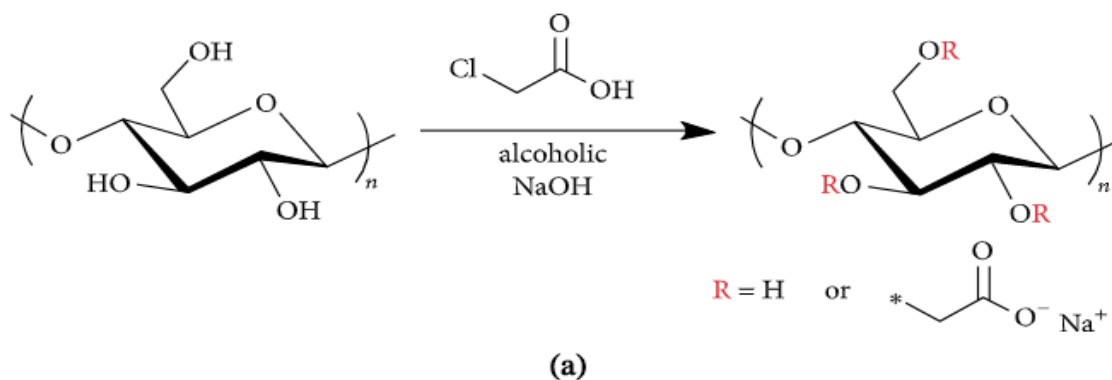

Schematic diagram of cellulose sulfonation via periodate treatment

Carboxymethylation

Carboxymethylation is another procedure for the pre-treatment of cellulose. The hydroxyl groups on cellulose could react with 1-chloroacetic acid under strong alkaline conditions to give the carboxymethylation products. Wågberg et al. reported the manufacture of CNFs from carboxymethylated cellulose by high pressure homogenization. The resultant CNFs had a cylindrical cross section with the width of 5–15 nm and the length of ca. 1 μm. Chen et al. reported the preparation of CNFs by high pressure homogenization of carboxymethylated cellulose raw fiber. In this work, the carboxymethylation pre-treatment included two steps: (1) basification of raw oven-dried cellulose fibers by using anhydrous NaOH/dimethyl sulfoxide; (2) further sodium acetoxylation of cellulose raw fibers by using sodium chloroacetate. Then the resultant MCC was extracted by deionized water which was beneficial to the collapse of the cell wall of cellulose fibers. Finally, the pre-treated cellulose fiber suspension passed through homogenizer to give the CNFs. The resultant CNFs were used for manufacture of nano paper which exhibited 90.5% optical transparency. Carboxymethylation pre-treatment was also used by other researchers for preparing CNFs. Overall, the carboxymethylation method is also a potential green pre-treatment technology for the preparation of CNFs.

R = H or

(a)

schematic diagrams of a. chemical formula for carboxymethylation of cellulose by using chloroacetic acid and b. carboxymethylation pre-treatment of cellulose for the preparation of CNFs and the application of resultant CNFs as nano paper and flexible electrode.

Cationization

The cationization of cellulose could be used for encourage the nano fibrillation of cellulose. In the process, the cations were initiate on the surface of cellulose by the quaternization of cellulose. The fibrillation of cellulose was promoted by the electrostatic repulsion between the quaternary ammonium cations. This method has been used for preparation of CNFs combination with following mechanical disintegration: (2,3-epoxypropyl) trimethylammonium chloride, (2-chloroethyl) trimethylammonium chloride, and (2-hydrazinyl-2-oxoethyl)-trimethylazanium chloride were commonly used as cationization reagents. The process was carried out under alkaline environment, for example, NaOH/H$_2$O/-PrOH, NaOH/DMSO. Recent studies showed that, owing to significant antibacterial properties of cationic CNF film, and without quaternary ammonium leaking to the environment, they could be applied into wound healing, food packaging, tissue, and so on.

Deep Eutectic Solvent Pretreatments

Deep eutectic solvent (DES), which is composed of two or more compounds, has lower melt point than any component of its own. Due to its low cost, low toxicity, and recyclability, DES has been widely used in various fields. Sirviö and workers proposed a bio-based DES consisting of urea and choline chloridewhich could be used to the pre-treatment of cellulose pulp. Li and co-workers used the urea-based DES as the pre-treatment for the preparation of CNFs. In this work, DES was composed of urea and ammonium thiocyanate or guanidine hydrochloride and was used to tend wood-derived cellulose fibers. The results showed that the cellulose fibers were well loosened and swelled by both DES systems. Then CNFs with the width of 13.0–19.3 nm were smoothly obtained through further mechanical nano fibrillation without clogging. A method for the preparation of anionic CNFs using DES as reaction medium was proposed by Sirvio and Visanko. As is shown in Figure 16, the DES consisted of triethyl methylammonium chloride (TEMACl) and imidazole was liquid at room temperature. The ground wood pulp with a 27.4 wt% lignin was carboxylated by succinic anhydride during the DES pre-treatment process under mild reaction conditions (2 h at 70°C). Then the anionic CNFs could be prevail through the followed micro fluidization of carboxylated ground wood pulp. A microwave-assisted DES pre-

treatment method for fast CNCs production was proposed by Liu and co-workers. It took only a little time (not more than 3 min) for the pre-treatment of cotton, and then a high-intensity ultrasonication process was adopted. The resultant CNCs with the diameter of 3–25 nm and the length of 100–350 nm were obtained at a yield of 74.2%. Overall, DES pre-treatment is efficient and environment-friendly and is a promising technology for the industrial production of NCs.

Chemical Hydrolysis:

The NFCs produced by mechanical methods consist of alternating crystalline and amorphous regions within the single cellulose domains. In order to dissolve the amorphous domain and permit longitudinal cutting of microfibrils, strong but controlled acid hydrolysis treatment is performed. The obtained nanocellulose, as an aqueous suspension reveals crystallinity greater than 90%, are termed as CNCs. In the acid hydrolysis process, the hydronium ion enters the amorphous regions of cellulose chains and promotes the hydrolytic cleavage of the glycosidic bonds. A mechanical treatment for nanocellulose dispersion, such as sonication, is required to prevent agglomeration. Various strong acids have been studied successfully to degrade cellulose fiber but the most common are hydrochloric and sulfuric acids. However, for the preparation of crystalline cellulosic nanoparticles, phosphoric acid, as well as hydrobromic and nitric acids, were recommended [20]. The benefit of using sulfuric acid as hydrolyzing agent is it initiates the esterification process on the cellulose surface and promotes the grafting of anionic sulfate ester groups. Furthermore, the presence of anion groups induces the formation of a negative electrostatic layer on the surface of the nanocrystals and helps their dispersion in water. However, it reduces the agglomeration and reduces the thermostability of the nanoparticles. The reduced thermal stability of H2SO4-prepared CNCs can be improved by 270 Cellulose-Reinforced Nanofiber Composites neutralizing by sodium hydroxide. However, these nanoparticles possess high aspect-ratio, rod-like nanocrystals, their geometrical dimensions depend on the source of cellulose and hydrolysis methods. The length of the CNCs varies widely in the range of a few hundred nanometers due to the diffusion control nature of the acid hydrolysis, while the width is in the range of nanometers [21]. Acid hydrolysis is the easiest and oldest method of CNC preparation. Recently, some other methods have been studied that degrade the

amorphous domain from cellulosic fibers, such as enzymatic hydrolysis treatment, TEMPO-mediated oxidation, and treatment with ILs.

Characterization:

Scanning Electron Microscopy:

The surface morphology of the samples was carried out using Phenom World ProX desktop scanning electron microscope with fully integrated and specifically designed EDS detector made in Eindhoven Netherlands [22].

FT-IR results of Cellulose, Methylcellulose and Cellulose acetate nanoparticles:

The FT-IR spectra of samples were recorded FT-IR-8400S Fourier Transform Infrared Spectrophotometer in the spectra range of 4000-400 cm-1. Samples were run as (Kbr) pellets.

X-Ray Diffraction (XRD) Analysis of samples:

X-ray diffractometry in reflection mode was carried out using a diffractometer (DLMAX-2550, Japan), with monochromatic Cu Kα radiation ($\lambda = 0.154$ nm), with a divergence and scatter at 1.00o, and a receiving slit at 0.30 mm, generated at 40 kV and 30 mA, at room temperature. The samples were scanned within 2.00 - 70.00° 2θ in continuous scan mode with a step of 0.02° and a rate of 0.10 sec. The crystallite index of cellulose was calculated using the Kim's empirical method.

CI = (I002-Iam)/I002 x 100 Where CI is the crystallinity index, I002 is the maximum intensity and represents crystalline material, while Iam represents maximum intensity of the amorphous material.

Thermogravimetric Analysis (TGA):

Thermal behavior of the prepared samples was examined by Thermogravimetric Analyzer model Schimadzu TGA-50H (Kyoto, Japan) from 28 °C to 900 °C. A heating rate of the analysis was 10 °C / min under nitrogen atmosphere and at a flow rate of 20 mL / min.

BET Analysis:

The surface area of the prepared samples was examined by BET analysis using Quanta chrome NovaWin-Data Acquisition and Reduction for NOVA instruments version 11.03.

Applications of nanocellulose:

Nanocellulose in Microparticulate Drug Delivery:

The importance of encapsulating drugs, food actives, flavors, or even cell for improved performance and preservation has been well appreciated across different scientific fields. A broad range of natural and synthetic polymeric materials are available for encapsulation, the choice of which mainly rested upon the desired performance of the end products. Nanocellulose is an emerging natural polymer that has received considerable interest in recent years as the encapsulating polymer for drug delivery [23]. It has also been widely investigated to enhance the mechanical properties and influence drug delivery behavior of microcapsules prepared with other natural polymers. A study was conducted to estimate the influence of three polysaccharide nanocrystals (PNs) such as CNCs, starch nanocrystals, and chitin whiskers on the mechanical and drug release properties of sodium alginate microspheres. All the three PNs resulted in ameliorated mechanical properties and pH sensitivity of the microspheres. All the PNs were found to restrict the motion of the sodium alginate polymer chains and inhibit diffusion of the drug, resulting in the slow dissolution of theophylline from the microspheres, and diffusion transport was found to be the drug release mechanism from the systems.

Nanocellulose in Tablet Formulations:

Cellulose and its derivatives in different forms have been indispensable components in the preparation of tablets for a long time. Cellulose derivatives such as MCC, hydroxypropyl methylcellulose, ethyl cellulose, carboxymethylcellulose, and others are extensively used in conventional as well as controlled-release tablet formulations. With the practical edge supplied by nanocellulose in numerous functional properties being realized and appreciated, a few investigations have explored its potential as functional excipients in tablet formulations. The potential of spray-dried cellulose nanofibers as novel tablet excipients was evaluated and compared against two commercial MCC, Avicel PH-101 and Avicel PH-102, which are the two most commonly used direct compression excipients [24]. Cellulose nanofibers were found to possess better compressibility and were amendable to both wet granulation and direct compression methods of tablet preparations. Cellulose nanofibers formulated through direct compression method showed faster disintegration and drug release showing its potential as direct compression excipients. Freeze-dried CNC prepared from water sugarcane bagasse was also shown to increase the dissolution of diltiazem hydrochloride tablets prepared with the nanocellulose.

Aerogel Systems:

Aerogels are insubstantial materials with excellent surface area and open porosity, suitable for high loading of active compounds. They are nano porous systems procured from the wet gels or hydrogels through an acceptable drying technology that keeps the porous texture of the wet material intact. Due to their web like structure, high porosity, and high surface reactivity, aerogels prepared from nanocelluloses possess a high mechanical flexibility and ductility with ability for water uptake, which makes them an excellent applicant for the removal of dye pollutants, thermal insulation materials, and drug delivery system [25]. As a result, different types of nanocelluloses, due to their outstanding and acceptable properties, have become the subject of keen interest in the preparation of aerogels for drug delivery.

Hydrogels:

Hydrogels are produced by cross-linking of polymer chains through the interactivity that may be of ionic, physical, or covalent, having the capacity to absorb water [26].Hydrogels expand in water but do not dissolve in it. Due to their ability to display sol–gel transitions that can be induced by a slight changes in the environmental conditions such as temperature, pH, ionic strength, phase separation, wavelength of light, crystallinity, and others, bright polymeric hydrogels are extensively used in biomedical fields such as in the growth of controlled-release drug delivery systems, tissue engineering, and regenerative medicine[27]. Several smart hydrogels such as injectable hydrogels, shape-memory bacterial nanocellulose hydrogels, supramolecular hydrogels, double-membrane hydrogels, temperature-sensitive hydrogels, and many others with possibilities for drug delivery have been developed, which were based on nanocellulose.

Nanocellulose in Transdermal Drug Delivery:

Delivery of drugs through the skin offers several leads over other routes as well as elimination of first-pass metabolism, minimization of pain, prolonged release of the drug, and the potential to terminate drug absorption by removing the patch from the skin [28]. Nanocellulose, mainly bacterial cellulosic sources, has entice a great deal of interest in the development of controlled transdermal drug delivery and woundalleviate preparations.

Conclusion:

Nanocellulose prepared from wood cellulose has unique and promising properties, such as high crystallinity, aspect ratio, Young's moduli, and tensile strengths, which originate from the properties of natural wood

cellulose microfibrils. A change in processing technique changes the properties of the resulting nanocellulose, which is reflected in the final product. Besides the conventional mechanical methods traditionally used to prepare CNFs, such as grinding or homogenization, other promising methods are discussed, which can be instrumental to further research and industrialization of these materials.This review explains the preparation methods of CNCs and CNFs. For the preparation of CNCs, promising abilities were discussed besides the conventional mineral acid hydrolysis, such as organic acid hydrolysis, subcritical hydrolysis, AVAP method, and ionic liquid hydrolysis. Most of them have great feasibility for further industrialization.Different methods of nanocellulose like pretreatment method, mechanical process and chemical hydrolysis used for the synthesis of nanocellulose. Characterization of cellulose includes scanning electron microscopy, x-ray diffraction (xrd) analysis of samples, thermogravimetric analysis (TGA).

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