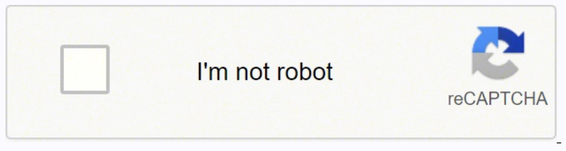

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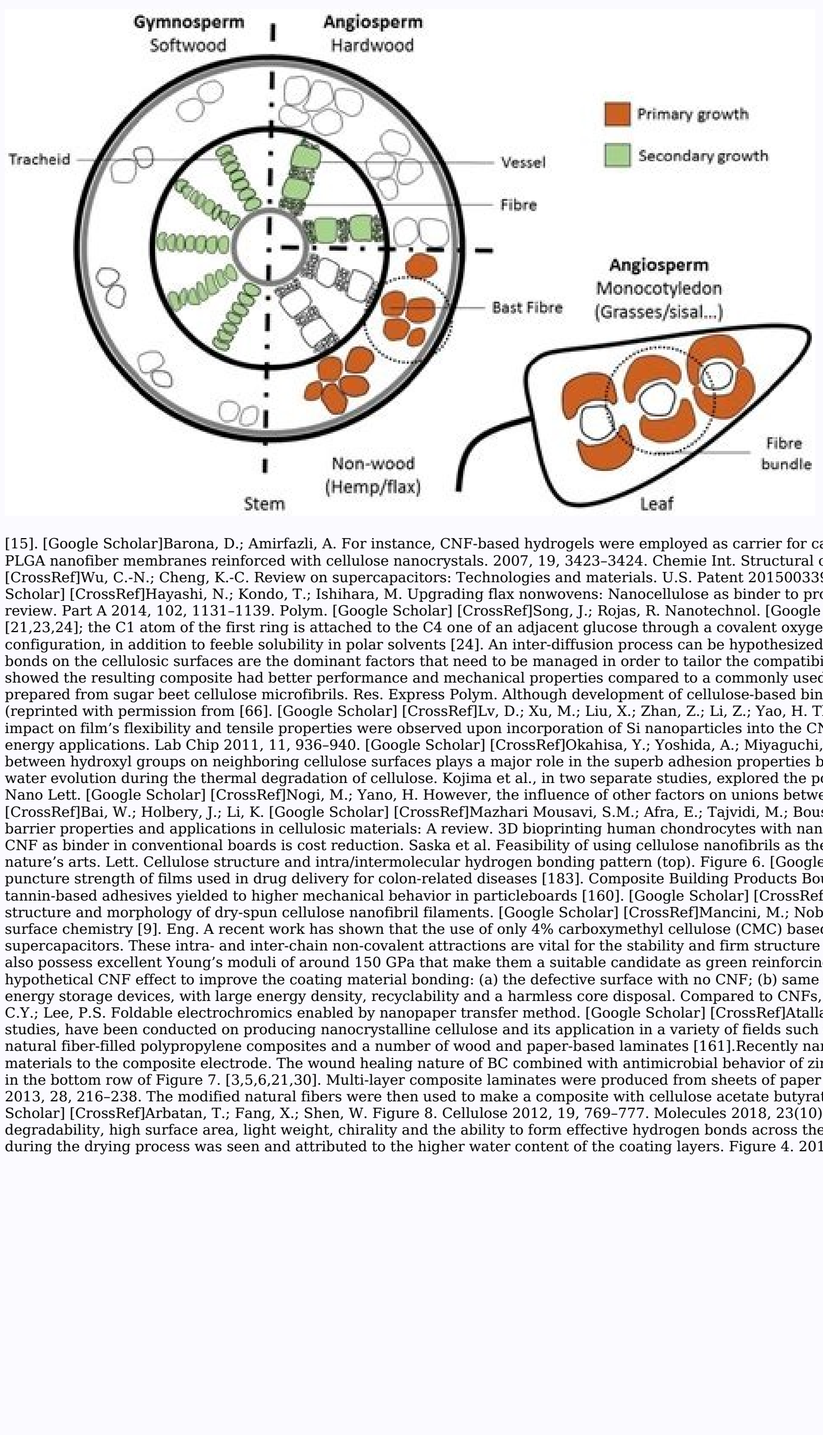

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Each repeating unit is rotated 180 degrees around the axis of the cellulose backbone relative to the neighboring ring, linking together via a β-(1,4)-glyosidic bond [21,23,24]; the C1 atom of the first ring is attached to the C4 one of an adjacent glucose through a covalent oxygen bond.As illustrated in Figure 1, the electrostatic attractions between oxygen and hydrogen atoms of the adjacent rings, inducing intra-molecular hydrogen bonding, cause more stabilized glycosidic linkage motifs, linear-chain configuration, in addition to feeble solubility in polar solvents [24]. An inter-diffusion process can be hypothesized when CNF dries in contact with the rough and porous surface of wood particles in the panel. [Google Scholar] [CrossRef] [PubMed]Guo, R.; Lan, Y.; Xue, W.; Cheng, B.; Zhang, Y.; Wang, C.; Ramakrishna, S. 2014, 3, 723–733. 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(a) Produced bacterial cellulose in static cultivation; (b) scanning electron microscope image of a BC network (reprinted with permission from [66]. [Google Scholar] [CrossRef]Lv, D.; Xu, M.; Liu, X.; Zhan, Z.; Li, Z.; Yao, H. The strong attachment of Si particles to the porous nanocellulose-carbon nanotubes matrix resulted in a high specific capacitance and excellent charge-discharge cycling performance applicable for lithium-ion batteries.Besides, no adverse impact on film's flexibility and tensile properties were observed upon incorporation of Si nanoparticles into the CNC-CNT matrix. They soaked hemp and flax fiber in nanocellulose suspensions and produced tapes and yarns by laying the fibers flat or spinning them, respectively. Wood-derived materials for green electronics, biological devices, and energy applications. Lab Chip 2011, 11, 936–940. [Google Scholar] [CrossRef]Okahisa, Y.; Yoshida, A.; Miyaguchi, S.; Yano, H. Fabrication and characterization of superhydrophobic high opacity paper with titanium dioxide nanoparticles. Chem. [Google Scholar]Leijonmarck, S.; Cornell, A.; Lindbergh, G.; Wågberg, L. The formation of hydrogen bonds between hydroxyl groups on neighboring cellulose surfaces plays a major role in the superb adhesion properties between cellulose fibers and makes CNF an excellent binder material for nanocomposite applications [142]. To tackle such issue, CNF was suggested as a binder to achieve the desired hydrophobicity on the paper [15,110]. Overview of water evolution during the thermal degradation of cellulose. Kojima et al., in two separate studies, explored the possibility of mixing CNF and lingocellulose nanofibers (LCNF) with wood flour. [Google Scholar] [CrossRef][Green Version]Kojima, Y.; Ishino, A.; Kobori, H.; Suzuki, S.; Ito, H.; Makise, R.; Higuchi, I.; Okamoto, M. 2012, 43, 2065–2074. Nano Lett. [Google Scholar] [CrossRef]Nogi, M.; Yano, H. However, the influence of other factors on unions between fibers has been confirmed as well.Understanding the molecular level interactions between cellulosic surfaces is necessary to better control the attractive forces responsible for fiber to fiber surface linkages. [Google Scholar] [CrossRef]Bai, W.; Holbery, J.; Li, K. [Google Scholar] [CrossRef]Mazhari Mousavi, S.M.; Afra, E.; Tajvidi, M.; Bousfield, D.W.; Dehghani-Firouzabadi, M. [Google Scholar] [CrossRef] [PubMed]Tayeb, A.H.; Hubbe, M.A.; Zhang, Y.; Rojas, O.J. Effect of lipoxygenase oxidation on surface deposition of unsaturated fatty acids. Microfibrillated cellulose—Its barrier properties and applications in cellulosic materials: A review. 3D bioprinting human chondrocytes with nanocellulose–alginate bioink for cartilage tissue engineering applications. C 2016, 58, 389–395. Transl. Int. Better WA and TS performances were attained for CT pressed panels with smaller wood particles.One major consideration in using CNF as binder in conventional boards is cost reduction. Saska et al. Feasibility of using cellulose nanofibrils as the sole binder in a "no-added formaldehyde binding process" for particleboard manufacture was first introduced by University of Maine [152], and later was briefly discussed in the work by Tajvidi et al. Bacterial cellulose—A masterpiece of nature's arts. Lett. Cellulose structure and intra/intermolecular hydrogen bonding pattern (top). Figure 6. [Google Scholar] [CrossRef]Lu, H.; Behm, M.; Leijonmarck, S.; Lindbergh, G.; Cornell, A. Crops Prod. Correlation between stiffness of sheets prepared from cellulose whiskers and nanoparticles dimensions. Also, CNF was used to enhance puncture strength of films used in drug delivery for colon-related diseases [183]. Composite Building Products Bound with Cellulose Nanofibers. Adding 1 wt % of CNF (on a dry basis) resulted in enhancing the mechanical properties of particleboard and OSB panels with a more promising performance in OSBs. Also introduction of nanocellulose to the tannin-based adhesives yielded to higher mechanical behavior in particleboards [160]. [Google Scholar] [CrossRef]Frackowiak, E. BioResources 2017, 12, 4986–5000. [Google Scholar] [CrossRef] [PubMed]Ghasemi, S.; Tajvidi, M.; Gardner, D.J.; Bousfield, D.W.; Shaler, S.M. Effect of wettability and surface free energy of collection substrates on the structure and morphology of dry-spun cellulose nanofibril filaments. [Google Scholar] [CrossRef]Mancini, M.; Nobili, F.; Tossici, R.; Marassi, R. While pristine cellulose has little reactivity, CNCs can easily be modified to form numerous derivatives and impart physiochemical features such as transparency, stiffness, low density and inducing tunable surface chemistry [9]. Eng. A recent work has shown that the use of only 4% carboxymethyl cellulose (CMC) based on the dry weight of the CNF can lead to a substantial drop in viscosity and better coverage of the paper surface [87]. [Google Scholar] [CrossRef] [PubMed]Fukuzumi, H.; Saito, T.; Iwata, T.; Kumamoto, Y.; Isogai, A. Emergence of fiber supercapacitors. These intra- and inter-chain non-covalent attractions are vital for the stability and firm structure of cellulose, the latter of which is essential for plants and some marine creatures. Electron. cm−2 along with significant resistance to bending was reported [138]. Langmuir 1996, 12, 2125–2127. Power Sources 2014, 246, 283–289. They also possess excellent Young's moduli of around 150 GPa that make them a suitable candidate as green reinforcing materials in composites [23,60,61].Another group of cellulose nanoparticles differing from the fiber-like CNF and needle-shape CNC is bacterial cellulose (also referred to as microbial nanocellulose, or biocellulose). Schematic of hypothetical CNF effect to improve the coating material bonding: (a) the defective surface with no CNF; (b) same surface with CNF incorporation. Such an approach, if proved successful, can highly benefit packaging and food storage industries in which water barrier properties are at the center of interest.There is a high demand for low-cost green energy storage devices, with large energy density, recyclability and a harmless core disposal. Compared to CNFs, cellulose nanocrystals have lower aspect ratios (100–500 nm in length and 10–50 nm in width) and depending on the process condition, a high degree of crystallinity (50–90%) [30,48]. [Google Scholar] [CrossRef]Kang, W.; Yan, C.; Foo, C.Y.; Lee, P.S. Foldable electrochromics enabled by nanopaper transfer method. [Google Scholar] [CrossRef]Atalla, R.; Brady, J.; Matthews, J.; Ding, S.-Y.; Himmel, M. Part A Appl. 2016, 58, 1189–1206. 2016, 45, 1308–1330. Hierarchical composites reinforced with robust short sisal fibre preforms utilising bacterial cellulose as binder. A number of studies, have been conducted on producing nanocrystalline cellulose and its application in a variety of fields such as hybrid composites [54], barrier films, electronic devices [55], antimicrobial films, emulsion stabilizers, etc. Elastic modulus and strength of the laminates met or exceeded those of a short glass fiber reinforced polypropylene and various natural fiber-filled polypropylene composites and a number of wood and paper-based laminates [161].Recently nanocelluloses have been used for reinforcing other natural fibers taking advantage of their binder properties. Reprinted with permission from [123]. Electrode binders should be electrochemically stable and are used to attach active materials to the composite electrode. The wound healing nature of BC combined with antimicrobial behavior of zinc yielded an efficient burn wound dressing. It is extremely difficult to squeeze out the water from a 3% solids content CNF suspension however once mixed with wood particles, even a mild squashing can result in water separation as seen in the bottom row of Figure 7. [3,5,6,21,30]. Multi-layer composite laminates were produced from sheets of paper bonded together via CNF and the effects of nanocellulose solids content, press time/temperature on the physical and mechanical properties of the laminates were evaluated. Langmuir 2017, 33, 4559–4566. Adhes. 2017, 164, 258–267. 2013, 28, 216–238. The modified natural fibers were then used to make a composite with cellulose acetate butyrate (CAB) and poly-l-lactic acid (PLLA). Similarly, a CNF network (as binder) was placed around graphite platelets via a simple water-based casting method to induce porosity, flexibility and high charging capacity to graphite anode. [Google Scholar] [CrossRef]Arbatan, T.; Fang, X.; Shen, W. Figure 8. Cellulose 2012, 19, 769–777. Molecules 2018, 23(10), 2684; Received: 18 September 2018 / Revised: 3 October 2018 / Accepted: 13 October 2018 / Published: 18 October 2018 Cellulose nanomaterials (CNs) are of increasing interest due to their appealing inherent properties such as biodegradability, high surface area, light weight, chirality and the ability to form effective hydrogen bonds across the cellulose chains or within other polymeric matrices. Screw and nail withdrawal strength and water soak properties of wet-formed cellulose nanofibrils bonded particleboard. Nevertheless, an adverse effect on the energy consumption during the drying process was seen and attributed to the higher water content of the coating layers. Figure 4. 2013, 1, 195–211. [Google Scholar] [CrossRef]Balu, B.; Berry, A.D.; Hess, D.; Breedveld, V. Langmuir 2008, 24, 4785–4790. However, a key issue for using CNF in the coating process is its rheology, that even at low solid content (

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