Manufacture of Transparent Paper Using Surface Nanofibrillated cellulose fibers

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Background

- Fabrication of flexible transparent substrates is one of the key technologies in development of flexible electronics.
- Instead of plastics, using cellulose materials to make flexible substrates has the advantages of nontoxicity, biodegradability, recyclability, renewability and sustainability.
- Paper-based substrate, i.e., transparent paper, is generally made from cellulose nanofibers due to the low transparency of conventional paper made from cellulose fibers.

Background

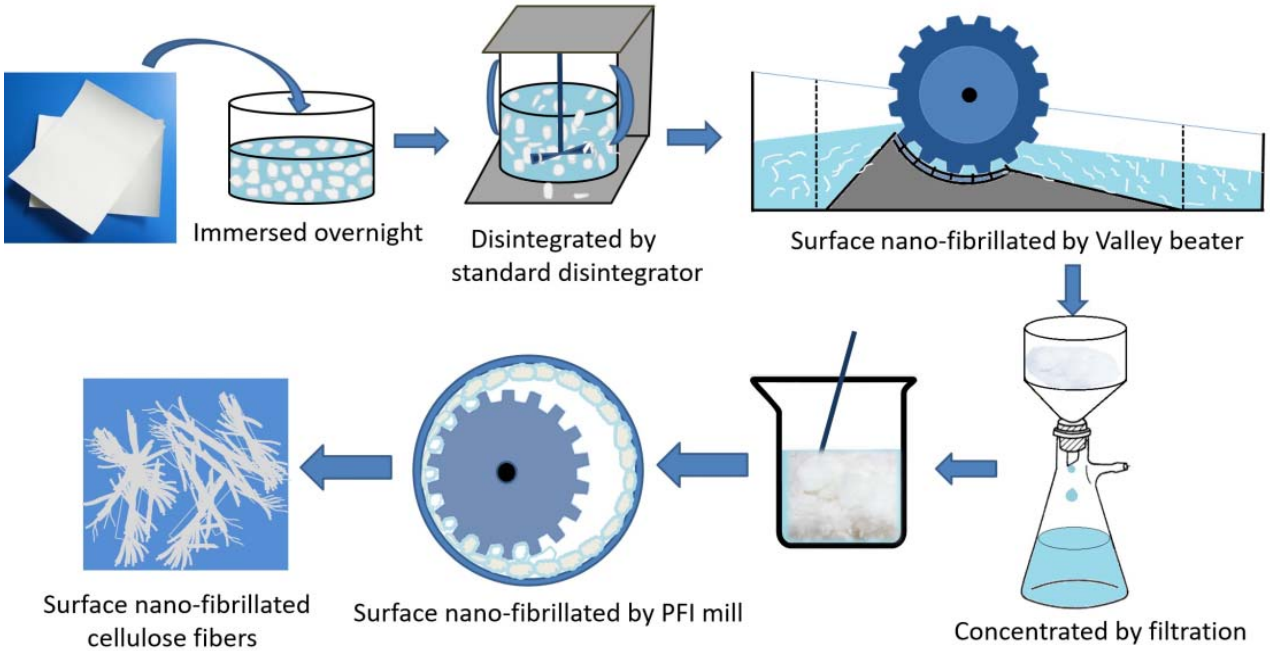
- Extraction of cellulose nanofibers is energy/chemical consuming, while manufacture of paper with cellulose nanofibers is time consuming.
- Beating/refining is a mechanical treatment to cellulose fibers for increasing the fibrillation, shortening fiber length, and improving the swelling of the fibers, which can be viewed as an incomplete extraction of nanofibers from cellulose fibers, which is expected to form cellulose fibers with microsized backbone and surface-linked nanofibers.

Fabrication and Characterization

- **Surface-nanofibrillated cellulose fibers**: using refining technique to form cellulose fibers with surface-linked nanofibers.
- **Transparent paper**: fabricating transparent paper with hierarchical structures: microsized fiber network backbone and nanosized surface-linked nanofiber networks

Surface-nanofibrillated cellulose fibers

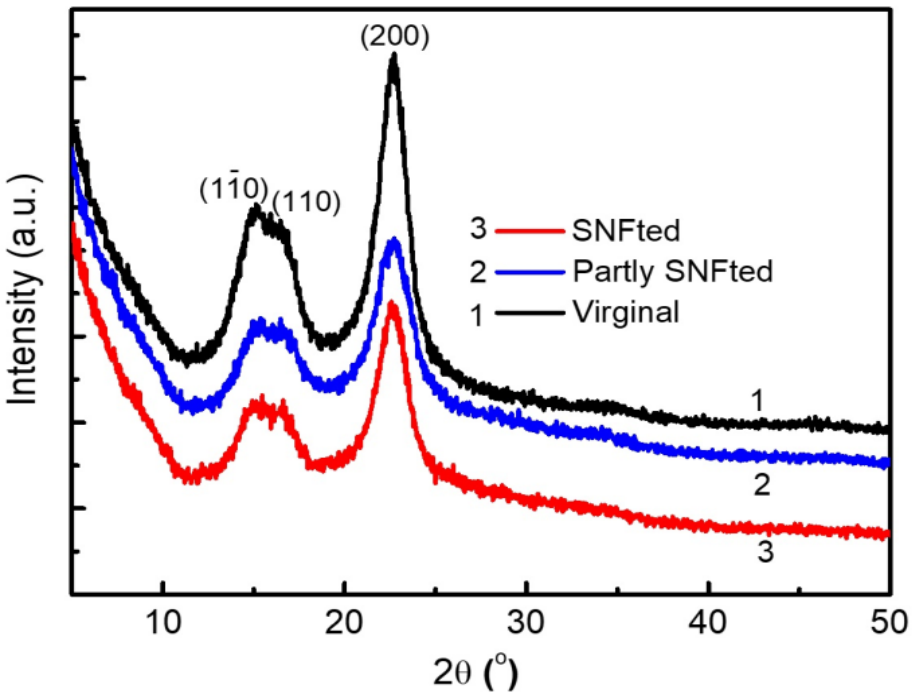
Fabrication



Two-step refining by a Valley beater and a PFI mill.

Surface-nanofibrillated cellulose fibers

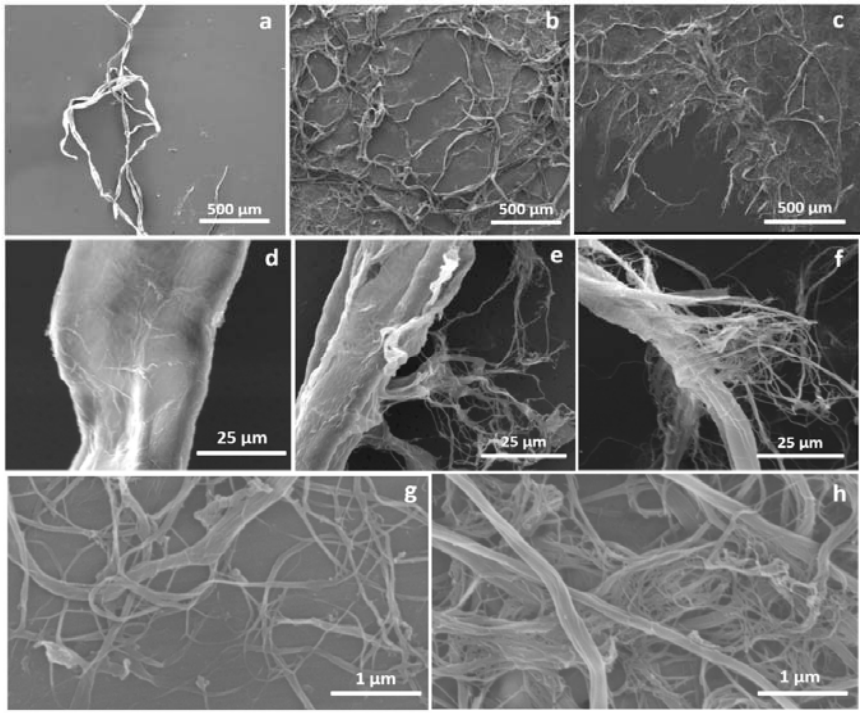
Characterization



- SNFted: surface-nanofibrillated cellulose fibers (CFs) prepared by the two-step refining of Valley beater and PFI mill.
- Partly SNFted: prepared by refining CFs with Valley beater.
- The crystalline phase of the CFs remained.
- crystallinity index is reduced.

Surface-nanofibrillated cellulose fibers

Characterization

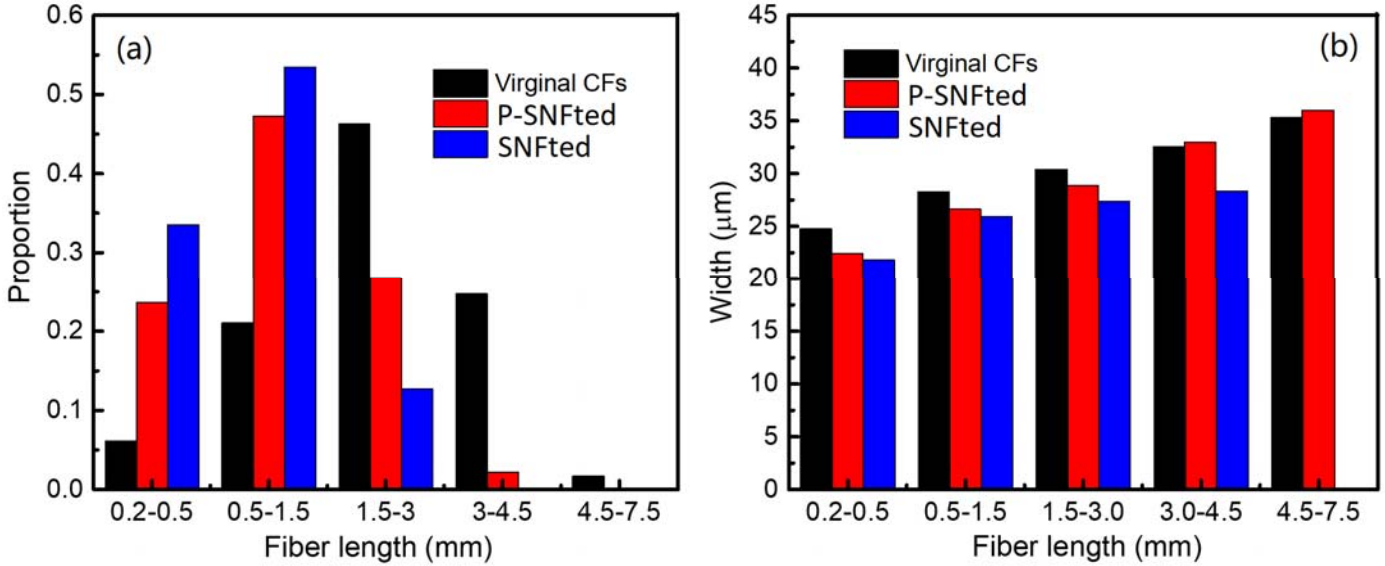


(a, d) Virginal CFs; (b, e, g) partly SNFted CFs; (c, f, h) SNFted CFs

- Virginal CFs: have diameters in microns and lengths in millimeters.
- After one-step refining: CFs were shortened and partly SNFted, resulting in reduced diameter and formation of nanosized fibrils.
- After two-step refining: large amount of nanosized fibrils formed, yet the microsized backbones of CFs still occurred.

Surface-nanofibrillated cellulose fibers

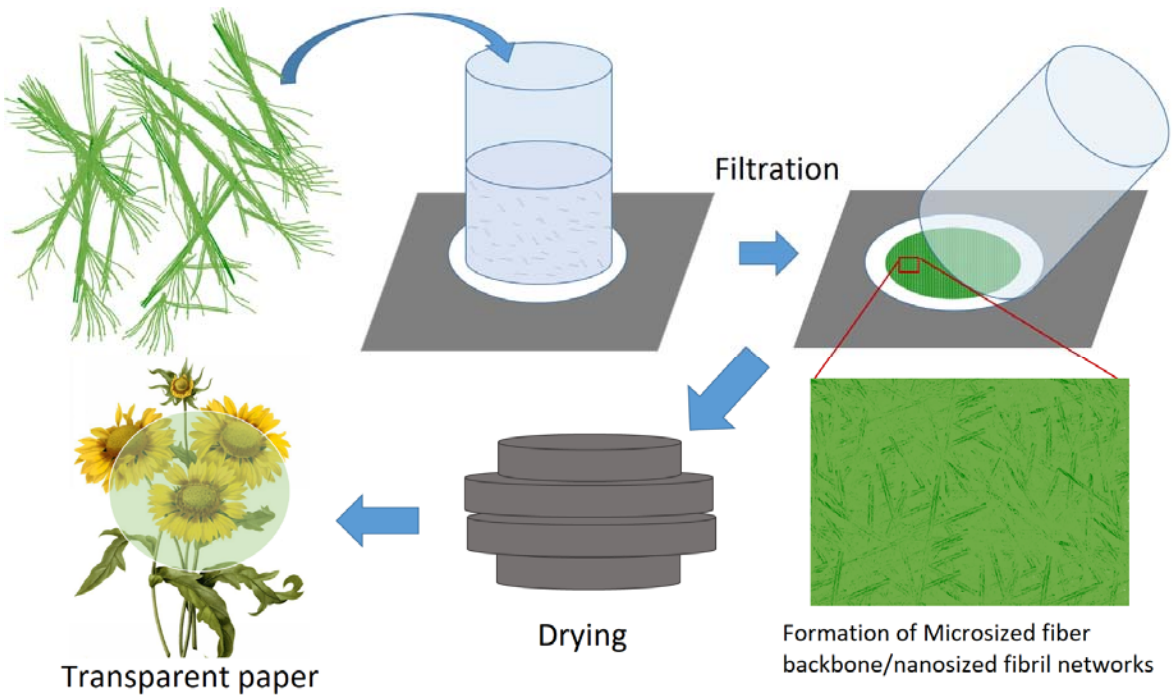
Characterization



The first step of refining significantly reduced the fiber length, the main component's length reduced from 1.5-3 mm to 0.5-1.5mm, while the second step of refining made the fiber length more concentrated on 0.5-1.5mm. The two-step refining did not significantly reduce the fiber diameter.

Transparent paper

Fabrication



Transparent paper

Fabrication and Characterization

Table 1 Sheet-forming time, thickness, and density of paper made from virginal, partly SNFted, SNFted cellulose fibers, and CNFs; the basis weight of papers is fixed at 20 g/m^2.

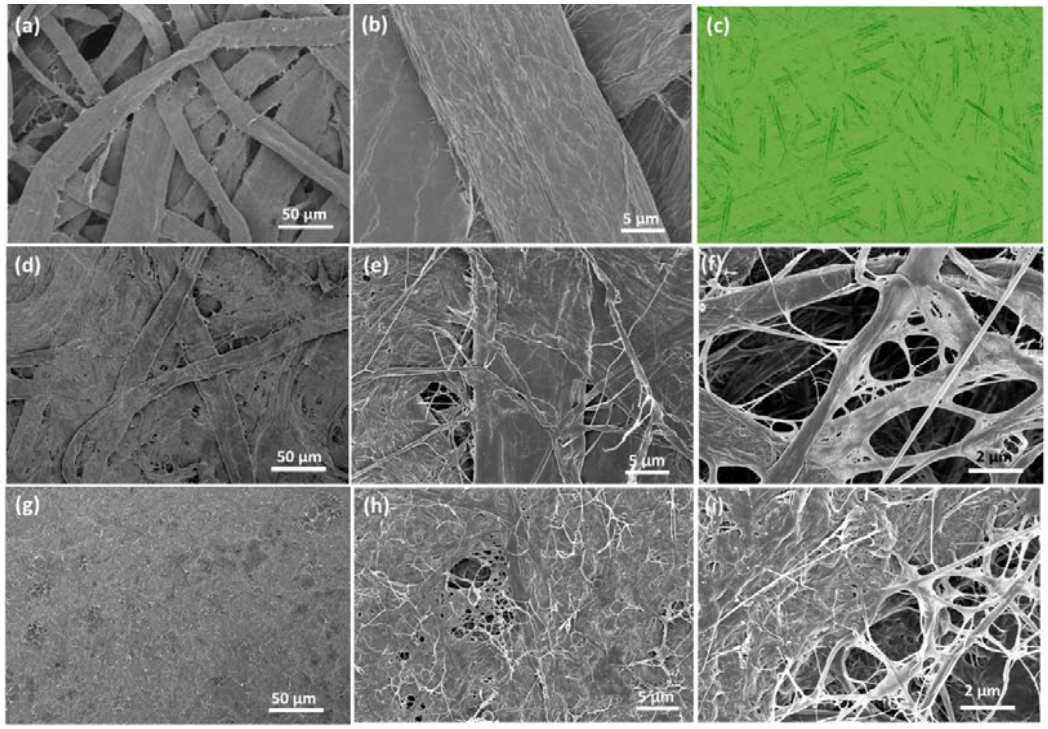
Paper made from	virginal CFs*	partly SNFted CFs	SNFted CFs	CNFs
Sheet forming time (min)	0.67	1.25	1.93	>180
Thickness (μm)	76	64	42	42
Density (g/cm^3)	0.263	0.313	0.476	0.476

* CFs present cellulose fibers.

The formation time of the paper made from SNFted CFs is much shorter than the time required for the formation of nanopaper made from CNFs.

Transparent paper

Characterization

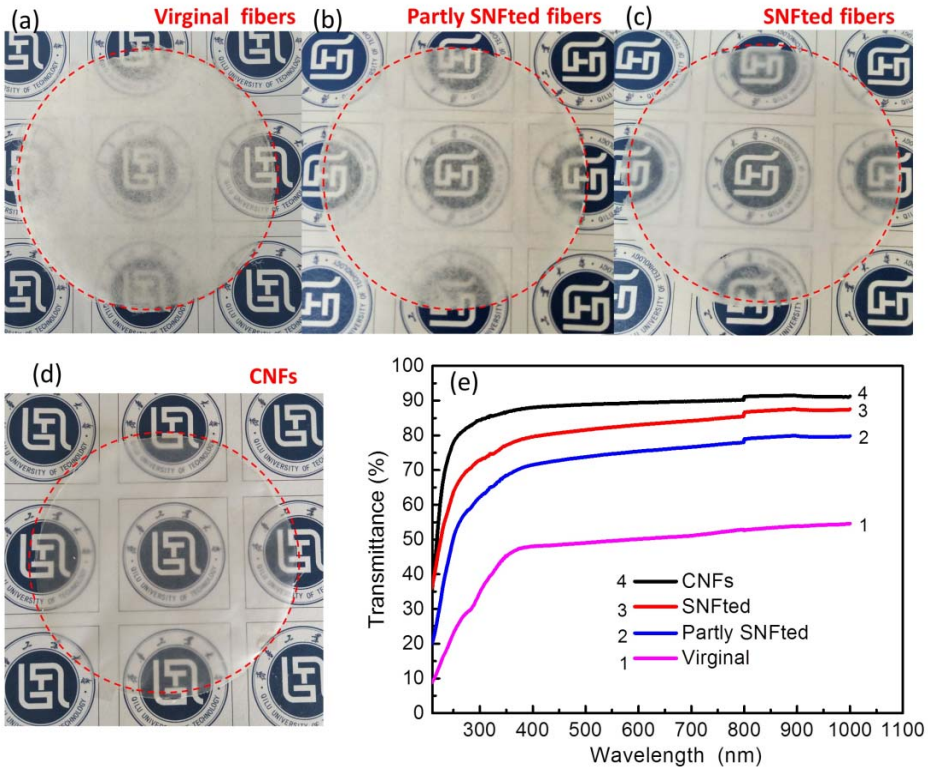


With formation of more nanosized fibrils, the microsized fiber backbone is gradually buried in the nanosized fibril networks.

Paper made from (a, b) virginal CFs, (d, e, f) partly SNFted CFs, (g, h, i) SNFted CFs.

Transparent paper

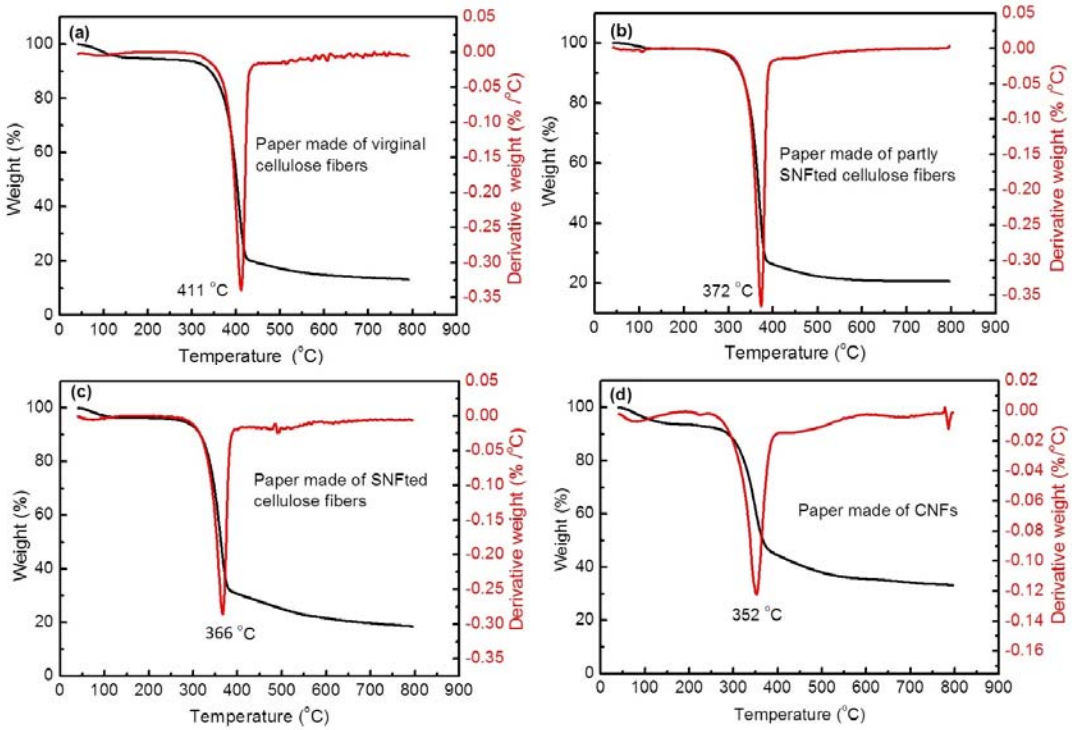
Characterization



The paper made from SNFted CFs is almost transparent. It is comparable to, but lower than, that of the paper made from CNFs due to the existence of microsized skeleton.

Transparent paper

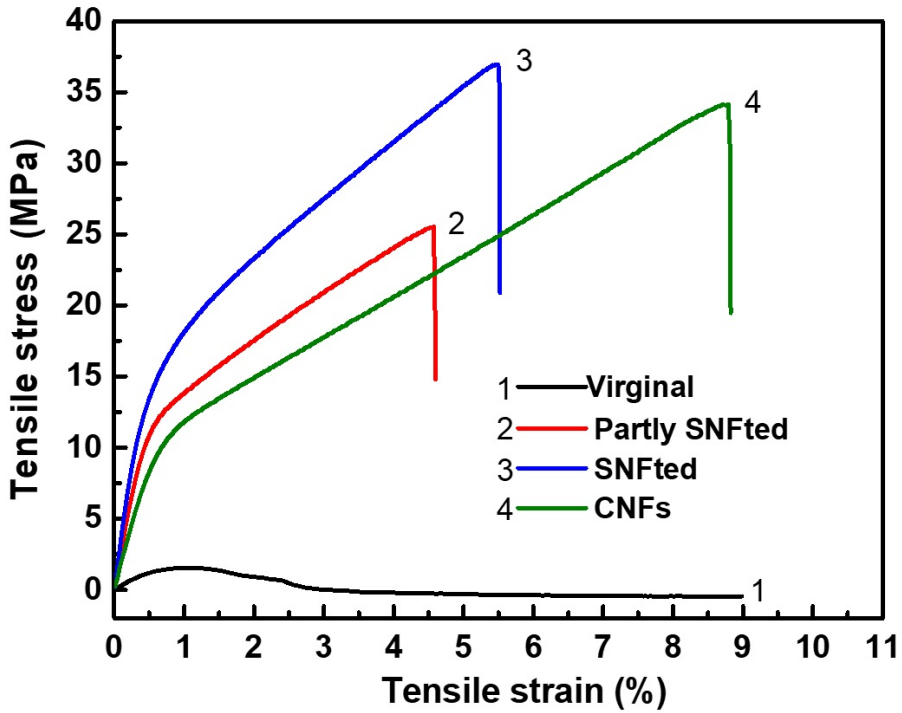
Properties



The paper made from SNFted CFs has lower weight loss than the nanopaper made from CNFs by moisture evaporation, but higher thermal stability.

Transparent paper

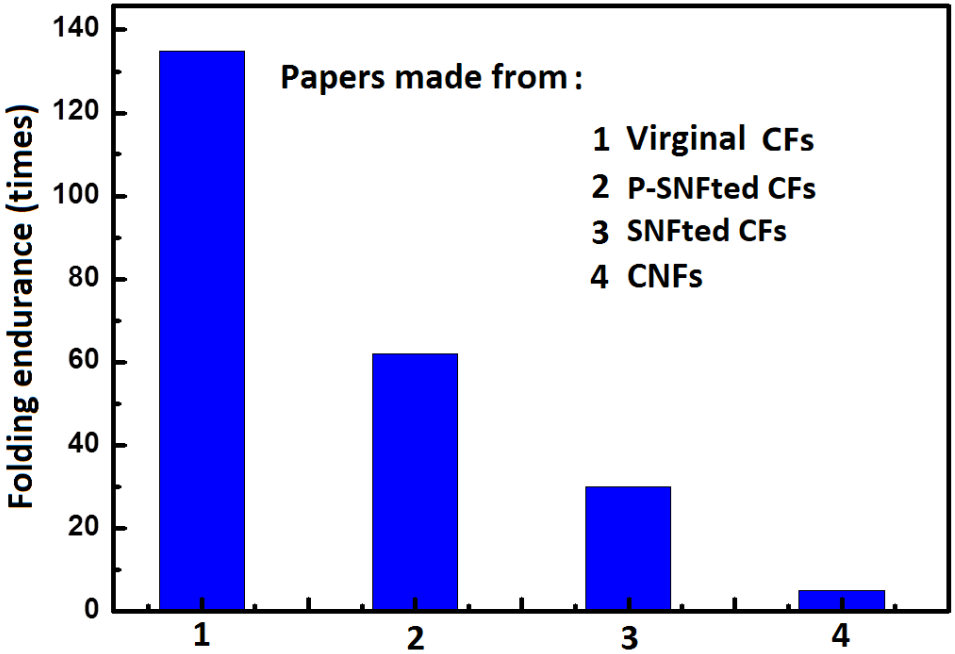
Properties



The paper made from SNFted CFs has greater Young's modulus and higher tensile strength, yet lower elongation at break than the nanopaper made from CNFs.

Transparent paper

Properties



Paper made from SNFted CFs shows higher folding endurance, i.e., higher flexibility, than paper made from CNFs.

Conclusions

- CFs can be SNFted by a two-step refining process using a Valley beater and a PFI mill.
- The paper made from SNFted CFs has hierarchical microfiber/nanofibril networks and shows high transparency that is comparable to that of the paper made from CNFs.
- The formation time of paper made from SNFted CFs is much shorter than the time required for the formation of nanopaper made from CNFs.
- The transparent paper made from SNFted CFs shows higher thermal stability, higher tensile strength, and better flexibility than the nanopaper made from commercial CNFs.

Acknowledgments

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Thank you

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