Characteristic features of cellulose nanofibers derived from different tree species with various manufacturing processes

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Purpose of the study

To investigate whether the wood properties of raw material, pulping method and CNF manufacturing process will affect the CNF (cellulose nanofiber) characteristics.

Materials

Sakhalin fir (*Abies sachalinensis*) (TD)
Japanese white birch (*Betula platyphylla*) (SK)

Sample preparation

- Each trunk of the trees was divided into juvenile wood (J) (0～15-20th tree ring) and mature wood (M) (the rest).
- Wood sticks and blocks were cut from a wood board including the pith for analyzing wood properties.
- Both the juvenile and mature woods were chipped, pulped, and then converted into CNFs.
- Kraft pulping (KP) and soda-AQ pulping (AQ) were employed for pulp manufacturing. Waterjet fiber fibrillation technology including oblique collision (OC) and ball collision (BC), TEMPO-catalyzed oxidation (TO), and enzyme biotechnology (En) were used to manufacture CNFs.

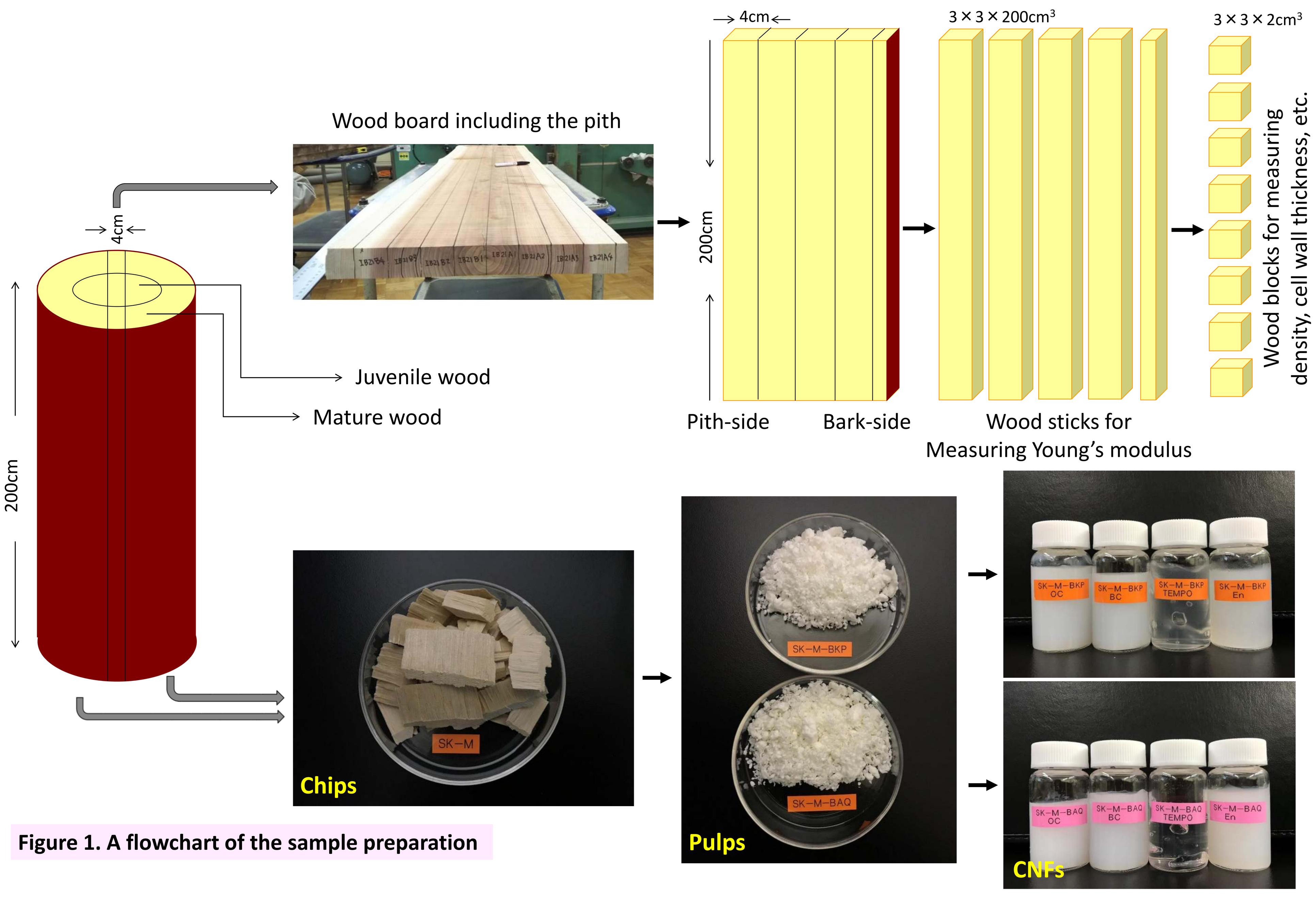
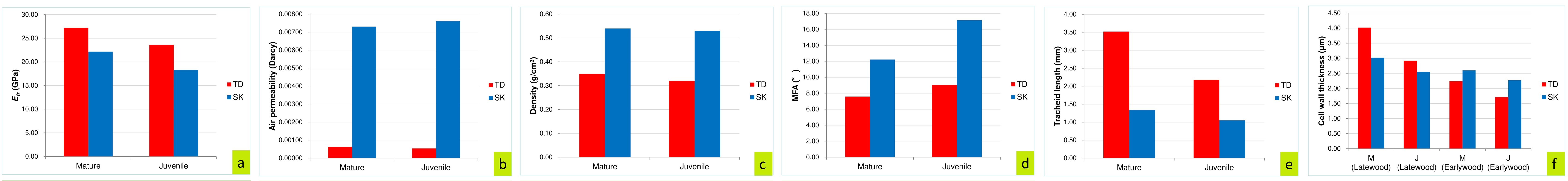


Figure 1. A flowchart of the sample preparation

Results and Discussion

Figure 2. Data of the wood properties



a	b	c	d	e	f
Specific Young's modulus	Air permeability	Density	Microfibril angle	Tracheid length	Cell wall thickness
Mature > Juvenile TD > SK	Mature ≒ Juvenile TD < SK	Mature ≒ Juvenile TD < SK	Mature < Juvenile TD < SK	Mature > Juvenile TD > SK	Mature > Juvenile TD > SK (Latewood) ; TD < SK (Earlywood)

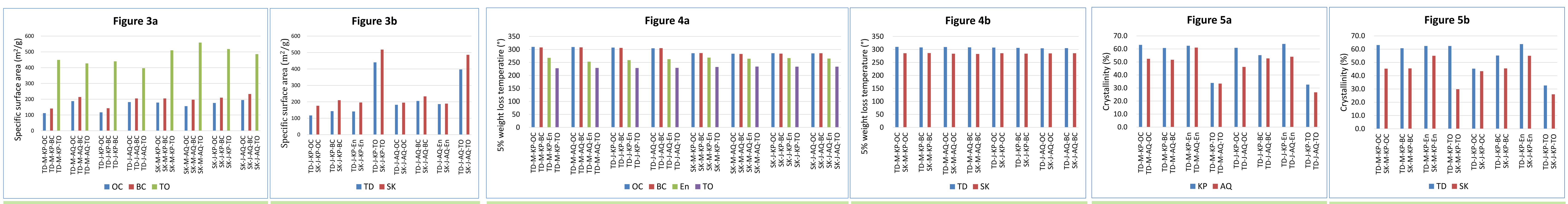


Figure 3a	Figure 3b	Figure 4a	Figure 4b	Figure 5a	Figure 5b
OC < BC < TO	SK > TD In juvenile wood	Waterjet (OC ≒ BC) > En > TO In all sample pairs	TD > SK In waterjet fiber fibrillation	KP > AQ In Sakhalin fir (TD)	TD > SK In KP pulping

Specific surface area increases as the CNF size becomes small. Figure 3a suggests that fibrillation degree was higher in the order of TEMPO, ball collision, and oblique collision CNFs, and it is supported by the electron micrographs (Figures 7a-a', 7b-b', 7c-c'); Figure 3b shows the CNF derived from Japanese white birch was easier to be fibrillated compared to that from Sakhalin fir in juvenile wood. It appears that the large MFA of Japanese white birch (Figure 2d) resulted in a higher degree of fibrillation.

Thermal resistance was higher in the order of waterjet, enzyme, and TEMPO CNFs (Figure 4a); Sakhalin fir produced CNF of a higher thermal resistance than Japanese white birch in waterjet fibrillation (Figure 4b). High Young's modulus, small MFA and long tracheid of Sakhalin fir (Figures 2a, 2d, 2e) probably contributed to the result.

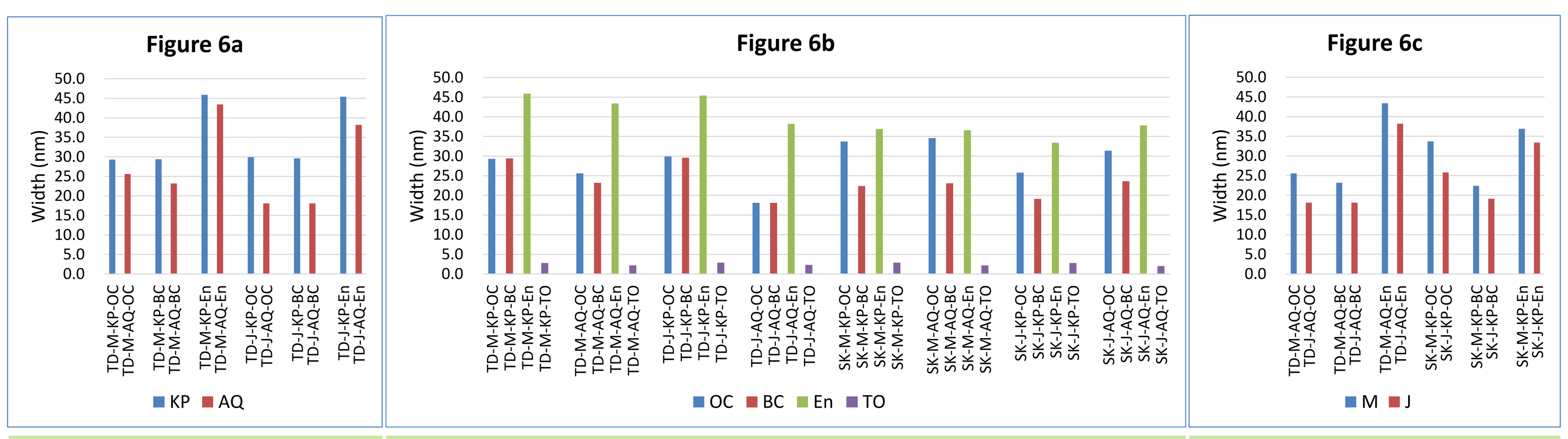
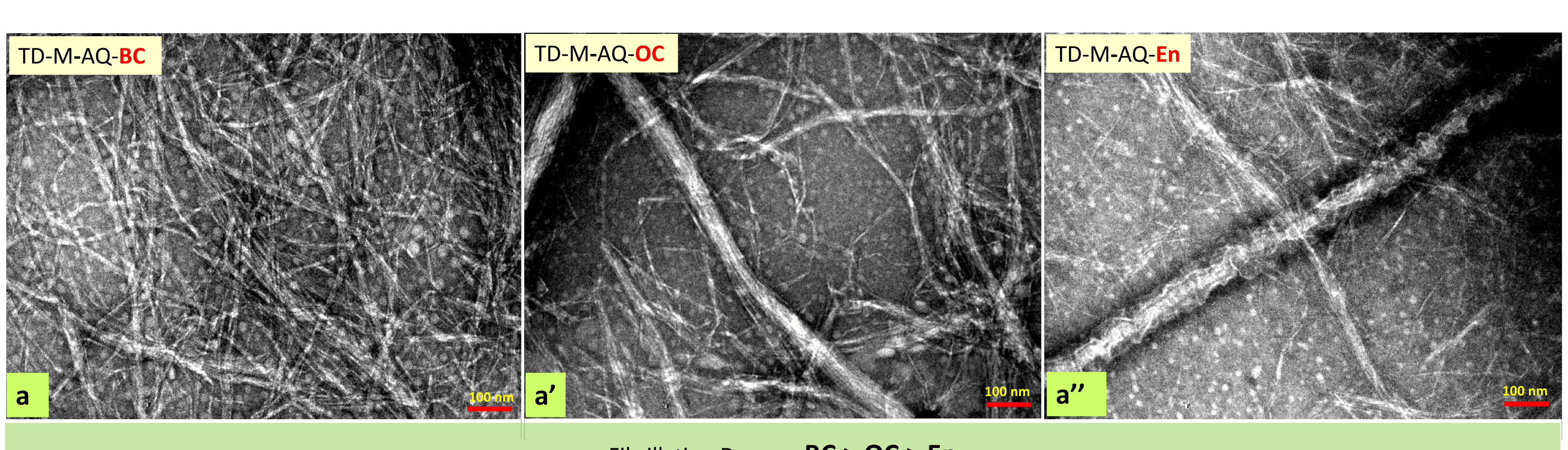


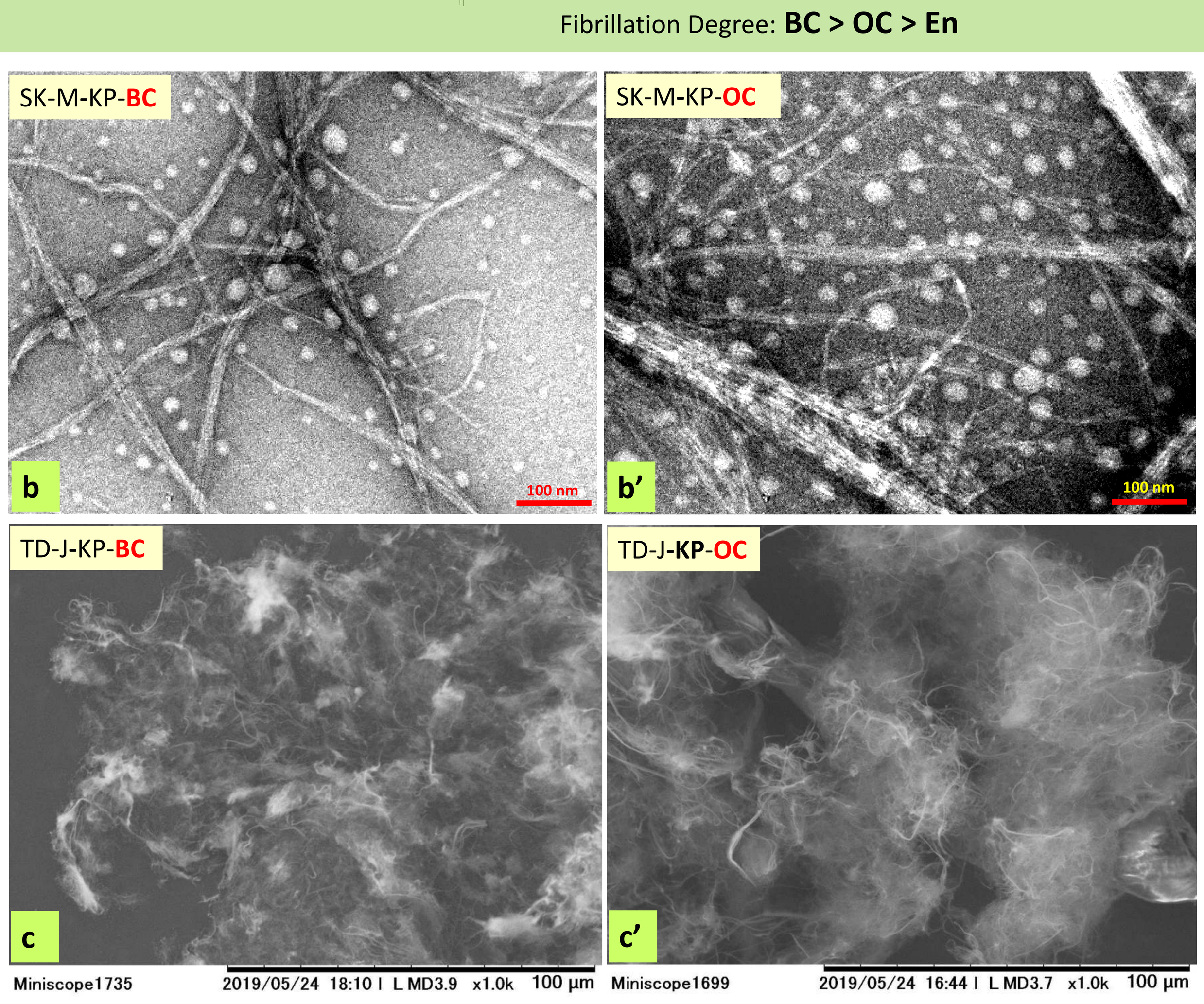
Figure 6a	Figure 6b	Figure 6c
KP > AQ In Sakhalin fir (TD)	En > OC ≳ BC > TO In all sample pairs	M > J TD, AQ & SK, KP

CNFs derived from Kraft pulps had a higher crystallinity and wider width than that from soda-AQ pulps in Sakhalin fir (Figures 5a, 6a), and it is supported by Figures 7d-d'; Sakhalin fir produced CNF with a higher crystallinity than Japanese white birch in Kraft pulping (Figure 5b).

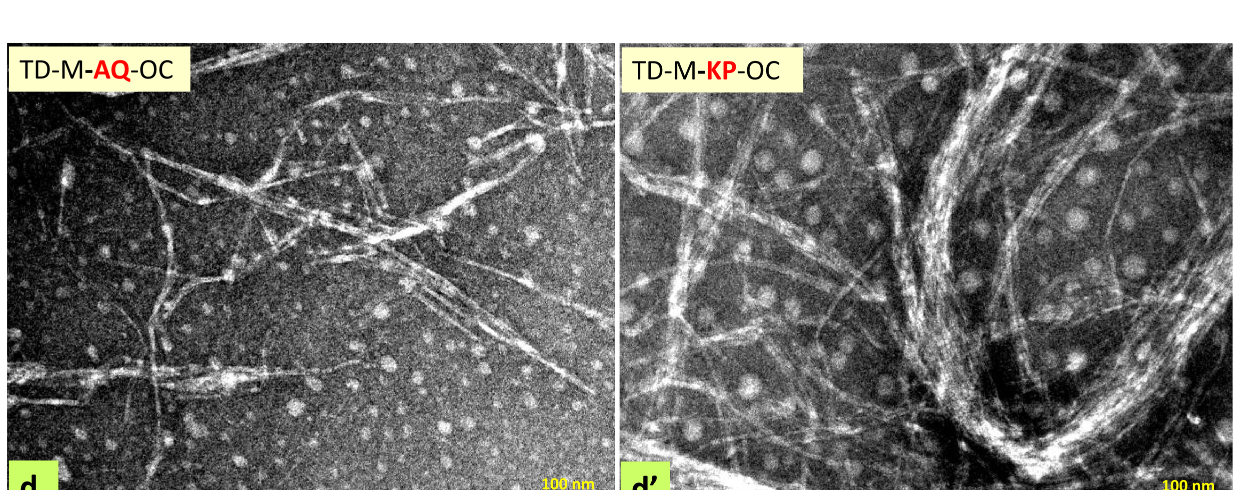
CNF width was wider in order of Enzyme, oblique collision, ball collision, and TEMPO CNFs (Figure 6b), and it is supported by Figures 7e-e''; CNFs derived from mature wood showed a wider width than that from juvenile wood in Sakhalin fir with soda-AQ pulping and Japanese white birch with Kraft pulping (Figure 6c).



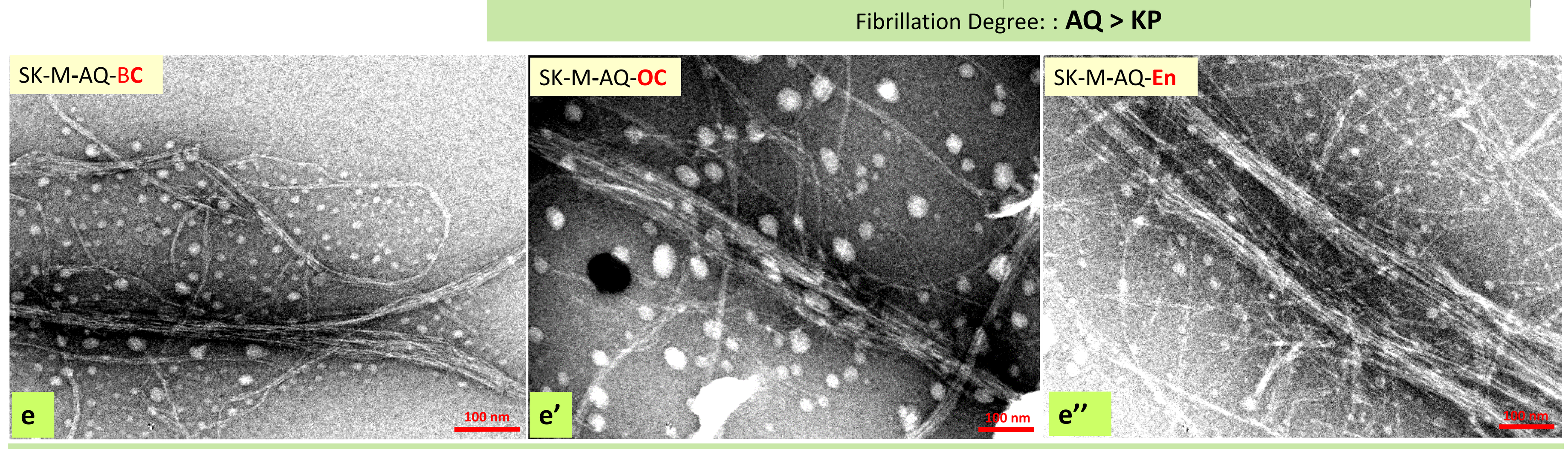
Fibrillation Degree: **BC > OC > En**



Fibrillation Degree: **BC > OC**



Fibrillation Degree: : **AQ > KP**



Width: **BC < OC < En**

Figure 7. TEM images of uranium acetate negative stained CNFs (a-a'', b-b', d-d', e-e''), and SEM images of critical point dried CNFs (c-c'). TD: Sakhalin fir; SK: Japanese white birch; M: Mature wood; J: Juvenile wood; AQ: Soda-AQ pulping; KP: Kraft pulping; BC: Ball collision; OC: Oblique collision; En: Enzyme treatment and wet beads mill.

Conclusion

Tree species, tree age, pulping method, and CNF manufacturing process will all affect the CNF characteristics more or less. CNFs made by different manufacturing methods from different raw materials each have their own unique characteristics. Knowing this fact will help us make the best use of CNFs.

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