Improved Mechanical-tribological Properties of Ultra-high Molecular Weight Polyethylene by the Incorporation of Cellulose Nanofibrils via Melt-blending

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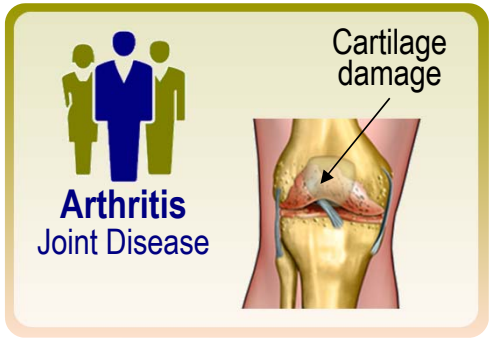
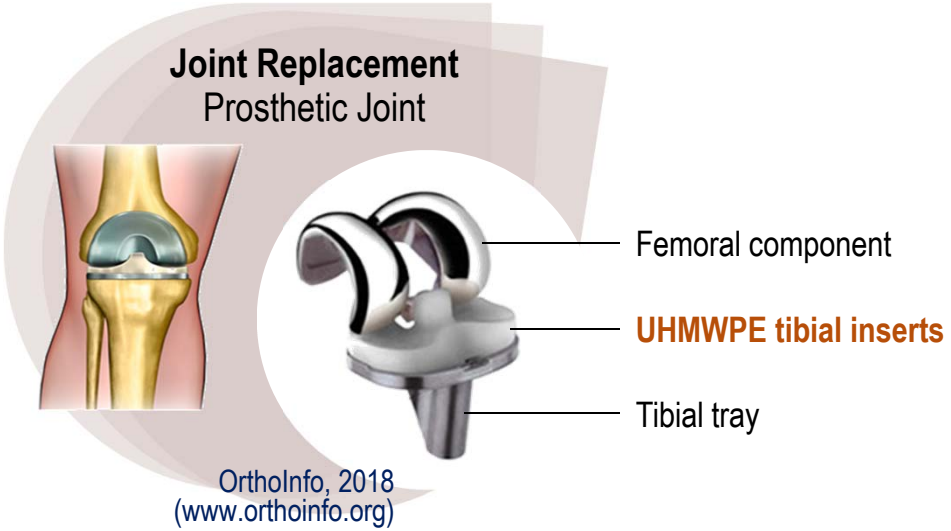
Presentation Outline

1. Introduction
2. Problem Statement
3. Methodology
4. Findings
5. Conclusion
6. Acknowledgement

Introduction





Limited longevity of UHMWPE tibial inserts (10 - 15 years)

External load; sliding/rolling motion

↓

Polymer on metal load bearing component:
Abrasion & fatigue

↓

Polymer Damage;
Wear & Failure

Due to relatively **low hardness & stiffness** of UHMWPE as compared to metal femoral component

Baena *et al.*, 2015 (doi: 10.3390/lubricants3020413)

Problem Statement

Current approach to enhance hardness & stiffness of UHMWPE:

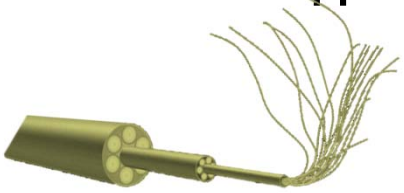
- **Crosslinking –** radiation and addition of Vitamin E as antioxidant
- **Filer Incorporation** – *i.e.* carbon nanotube, graphene.

Hard and inorganic nanofiller that improved wear resistance UHMWPE **could be toxic** and **may lead to inflammatory reaction and osteolysis**.

Approach & Hypothesis

UHMWPE
Tough & Strong

+



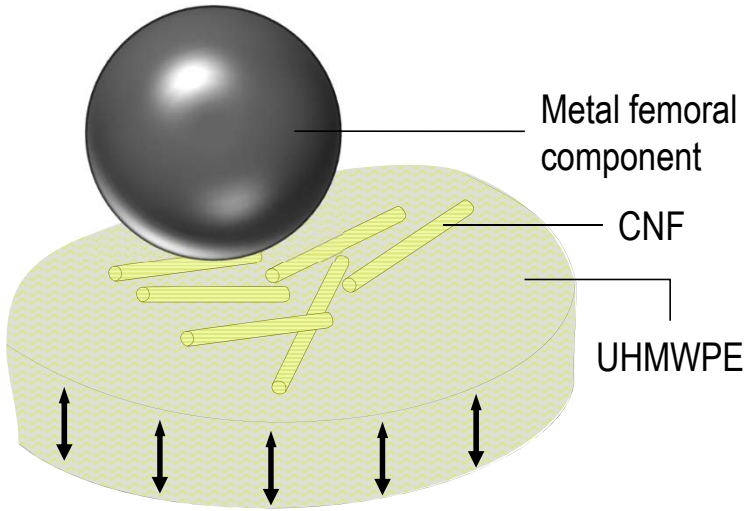
Cellulose Nanofiber (CNF)
Flexible & Non toxic natural filler

Higher stiffness; Cytocompatible

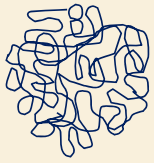
UHMWPE/CNF bio-nanocomposite

CNF as filler can **reduce wear rate** by:

- Improved stiffness & Young's modulus
- flexible filler by acting as solid lubricant



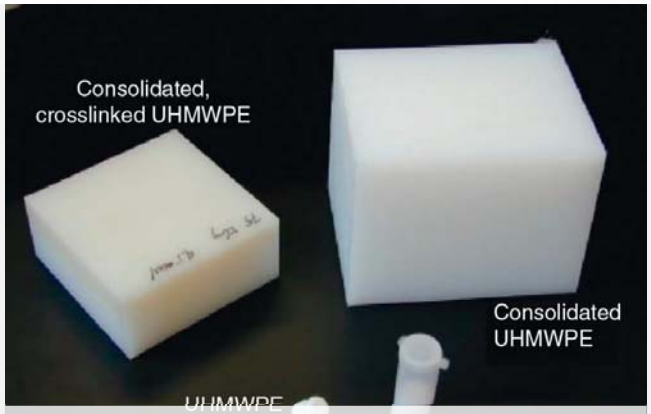
Challenge to incorporate **CNF** as filler into **UHMWPE** matrix



Extremely high melt viscosity

CNF agglomeration

Compounding limitation of UHMWPE & CNF



Spiegelberg *et al.*, 2016. (doi.org/10.1016/B978-0-323-35401-1.00029-6)

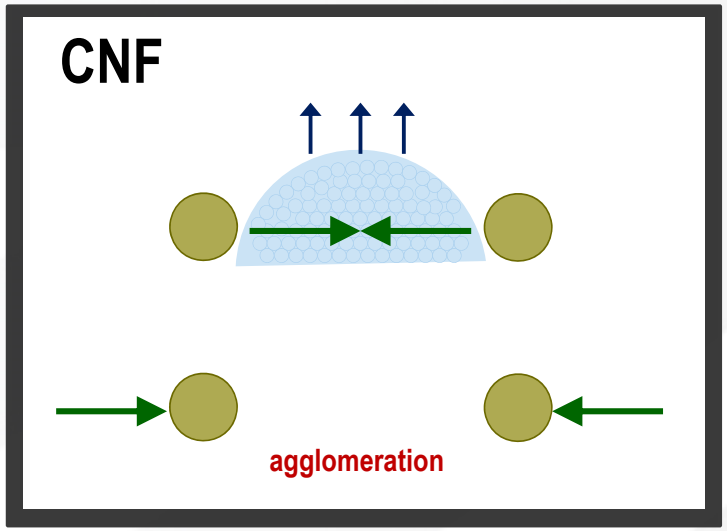
UHMWPE

Processing limited by:

High molecular weight
Very low melt flow index
(0.005g/10 min)

Does NOT FLOW!!

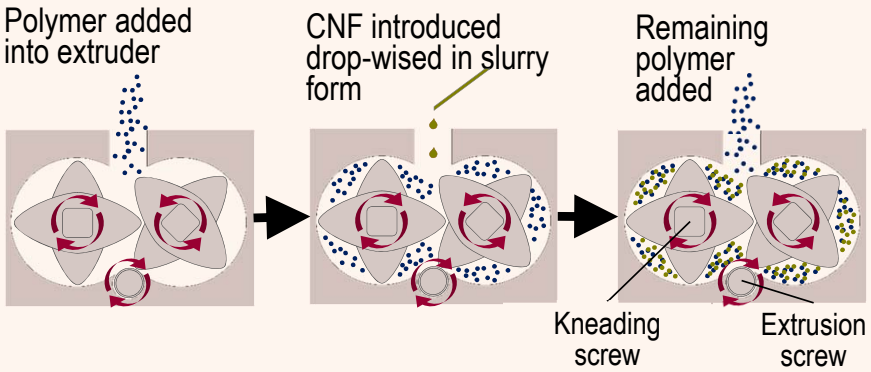
re-entanglement of molecules upon melting.



Drying CNF will cause agglomeration
(Kargarzadeh *et al.*, 2017. doi.org/10.1002/9783527689972)

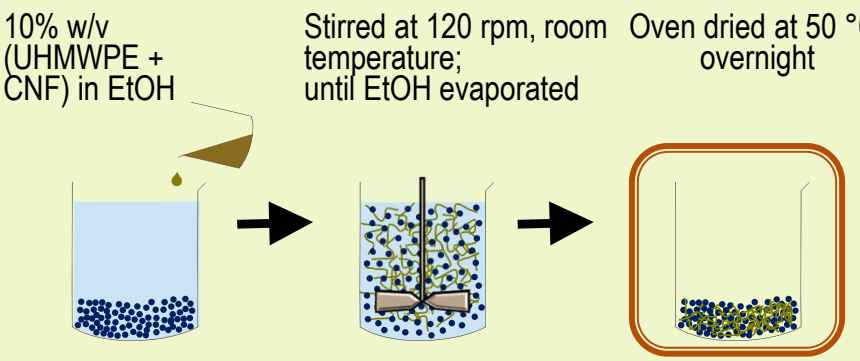
Methodology

Melt blending [1] (150 °C, 60 rpm, 45 minutes)



vs.

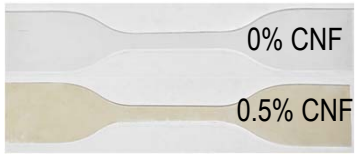
EtOH mixing [2]



Moulding – (175 °C, 45 min, 15 MPa) [3]

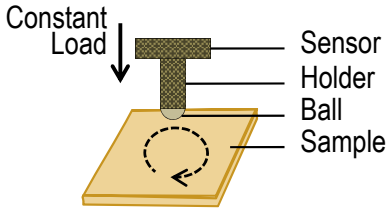
Analysis

Mechanical Properties [4]

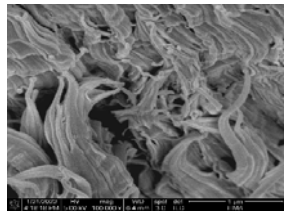


Tensile specimen

Wear Test [5]
Pin-on-disk tribometer



Morphological Analysis
➢FE-SEM



[1] Sharip et al. (2020). *Molecules*, 25(19), 4498.
[2] Wang et al., 2016 (doi.org/10.1021/acsnano.5b04393v)
[3] Kurtz et al. (1999) *Biomaterials*, 20, 1659–1688.
[4] ASTM D638. Standard Test Method for Tensile Properties of Plastics
[5] ASTM G99. Standard Test Method for a Wear Testing with a Pin-on-Disk Apparatus

Legend: UHMWPE CNF

Prepared sample:

Sample	Blending process	CNF content (wt%)	Remarks
Neat-UHMWPE	none	0	control for blending effect
MB-UHMWPE/0	Melt blending	0	control for CNF addition effect by melt blending
MB-UHMWPE/0.5	Melt blending	0.5	-
EM-UHMWPE/0	Ethanol mixing	0	control for CNF addition effect by ethanol mixing
EM-UHMWPE/0.5	Ethanol mixing	0.5	-

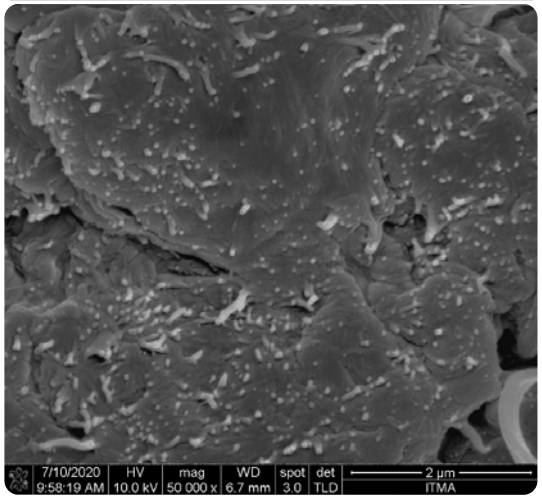
Findings – Processing Effect on Mechanical properties

	Neat UHMWPE Properties	Mechanical Properties (% Difference Compared to Neat-UHMWPE)			
		MB-UHMWPE/0	MB-UHMWPE/0.5	EM-UHMWPE/0	EM-UHMWPE/0.5
Tensile strength (MPa)	**62.1 ± 5.0**	↓ 31.8 ± 3.1 **(−49)***	28.4 ± 1.2 **(−54)***	55.4 ± 3.3 **(−11)**	36.6 ± 1.1 **(−41)***
Yield strength (MPa)	**20.6 ± 0.6**	↑ 23.8 ± 0.8 **(+15)***	25.9 ± 0.5 **(+26)***	20.0 ± 0.2 **(−3)**	20.3 ± 0.1 **(−2)**
Elongation (%)	**691.1 ± 37.4**	726.0 ± 45.2 **(+5)**	749.6 ± 2.0 **(+8)***	694.2 ± 40.6 **(0)**	465.1 ± 4.2 **(−33)***
Young's modulus (MPa)	**267.9 ± 22.4**	↑ 334.3 ± 14.4 **(+25)***	407.9 ± 24.3 **(+52)***	254.1 ± 17.4 **(−5)**	276.8 ± 0.2 **(+3)**
Toughness (J/m^3)	**245.7 ± 21.3**	↓ 128.8 ± 40.7 **(−48)***	168.4 ± 3.2 **(−31)***	224.3 ± 17.3 **(−9)**	116.5 ± 5.8 **(−53)***

MB: melt blend, EM: ethanol mixed, UHMWPE: ultra-high molecular weight polyethylene.
Asterisk (*) indicates significant difference of samples with neat UHMWPE ($P < 0.05$).

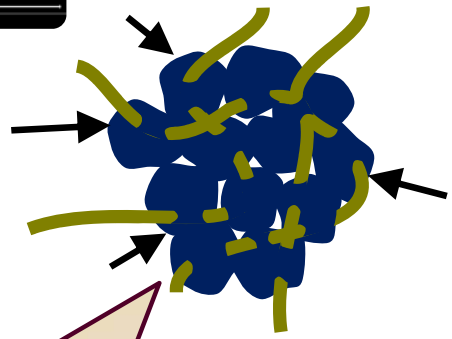
Findings – Processing Effect on Morphological Properties *(50 000 x magnification)*

Melt blended



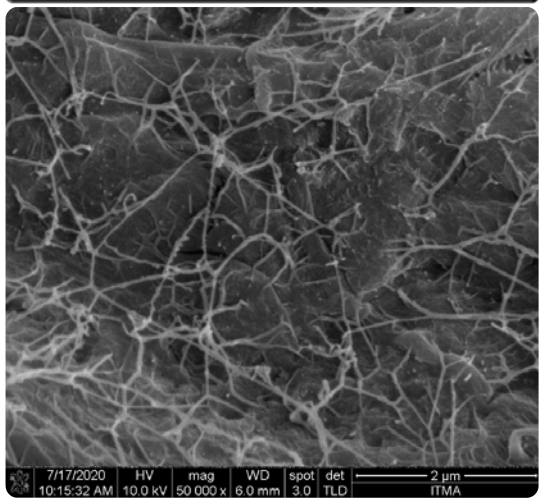
- **CNF** embedded and fractured along with UHMWPE
- Mixing CNF in **molten UHMWPE (Temp: 150 °C)**
  – allowed penetration of CNF into UHMWPE resin particle

CNF UHMWPE

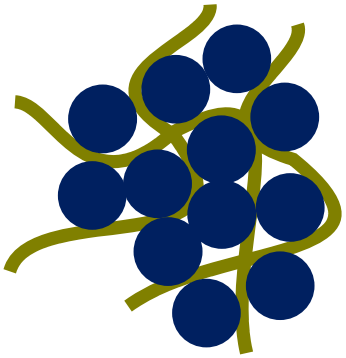


Better **mechanical interlocking** between filler & matrix

Ethanol mixed



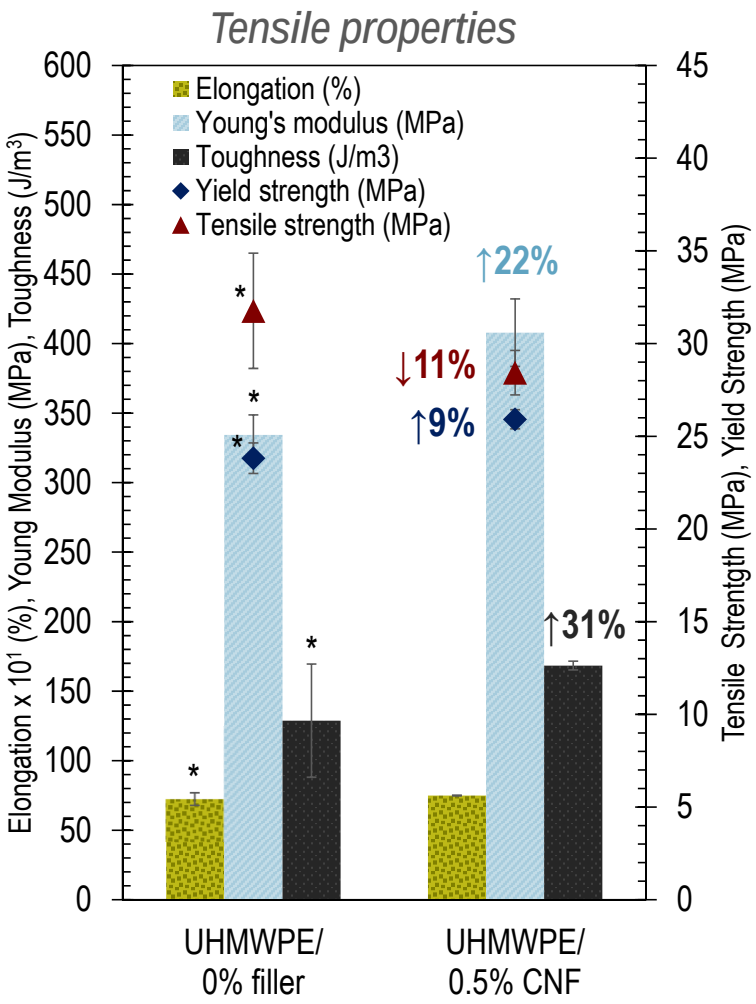
- Mesh–like **CNF** cover the fractured UHMWPE
- Mixing CNF with UHMWPE while ethanol evaporated **(Temp: 24 -50 °C)**
  – UHMWPE resin entrapped between CNF

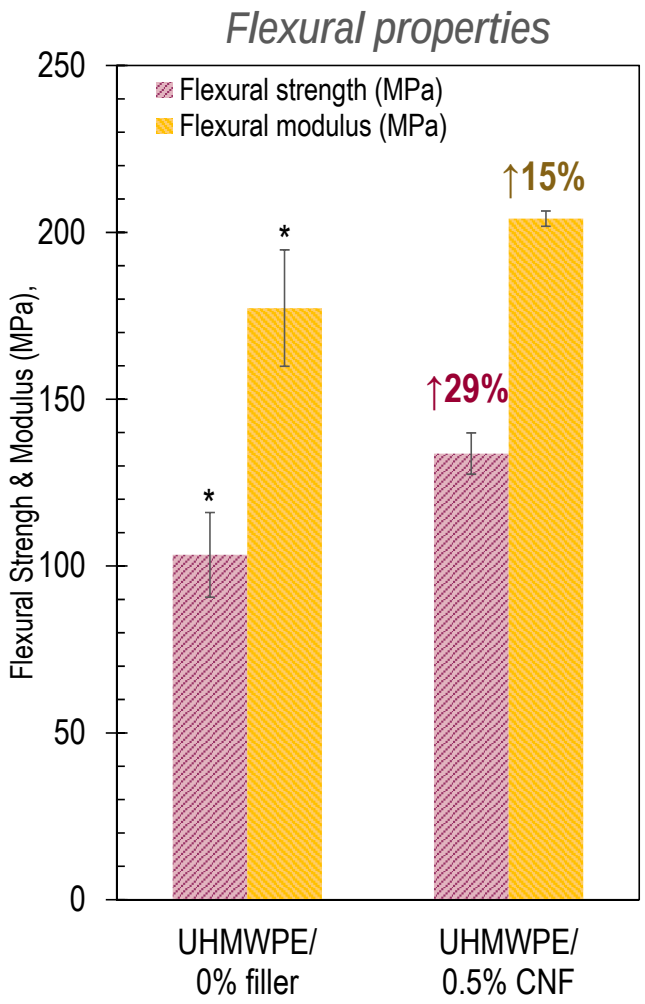


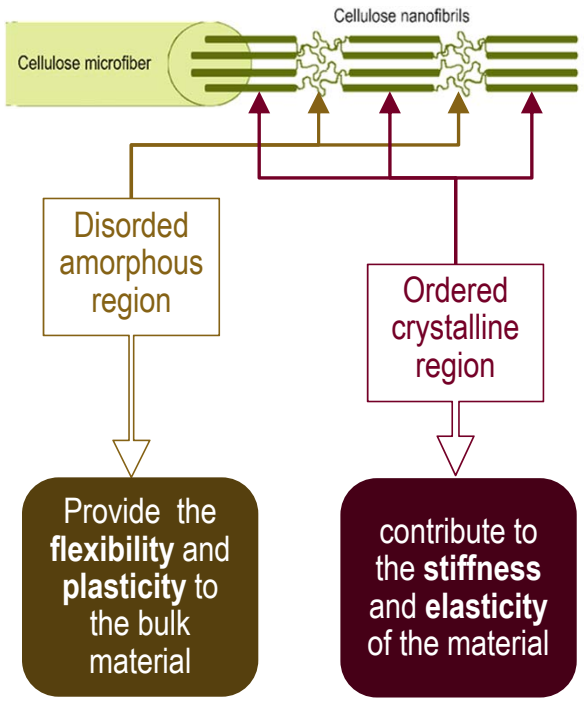
Melt blend UHMWPE/0.5% CNF:

28% ↑ Yield Strength; 61% ↑ Elongation; 45% ↑ Toughness; 47% ↑ Young's Modulus(in comparison to EtOH mixed bionanocomposites)

Findings – Mechanical properties of UHMWPE/CNF by melt blending

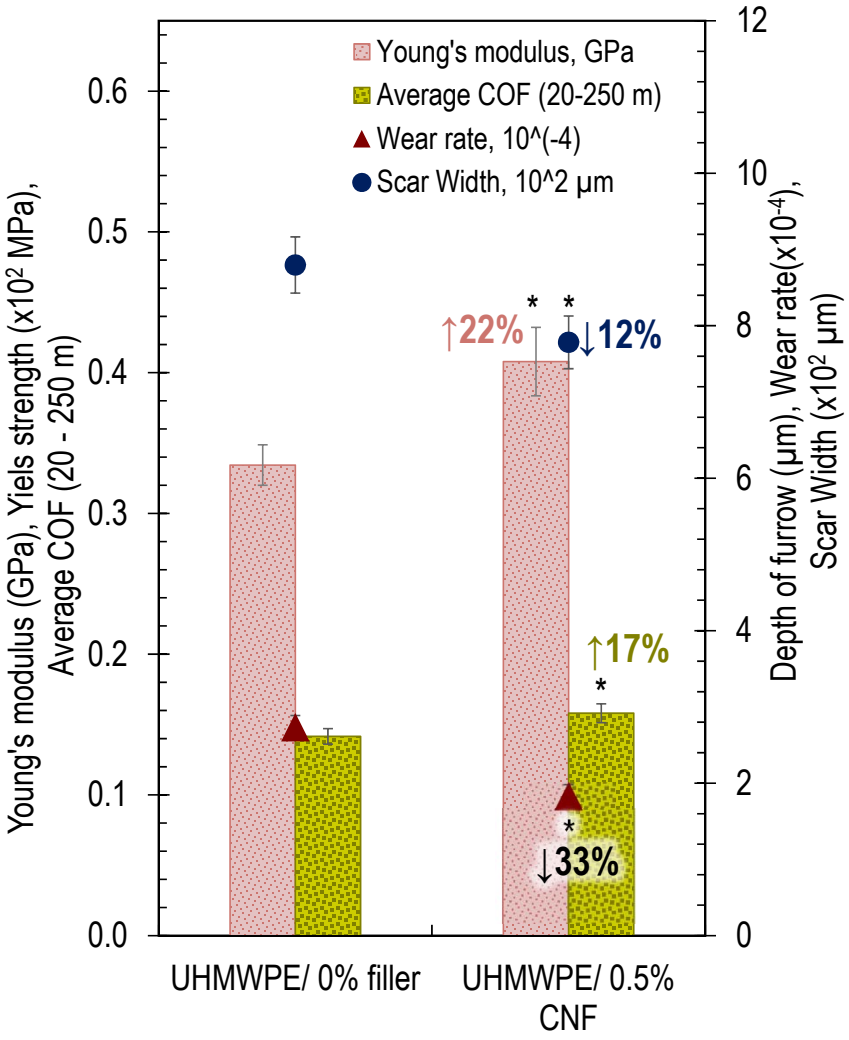




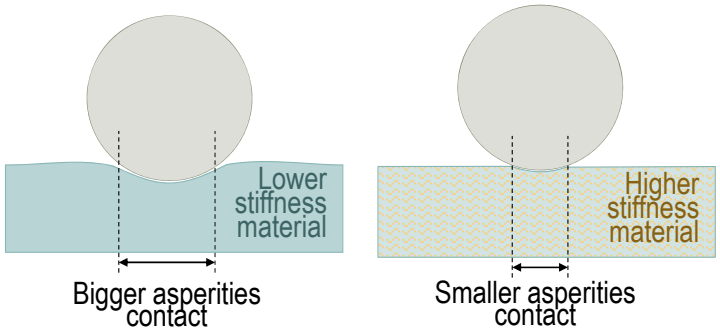


[6] Rashid et al. (2018). *Polymers for Advanced Technologies*, 29(6), 1531-1546

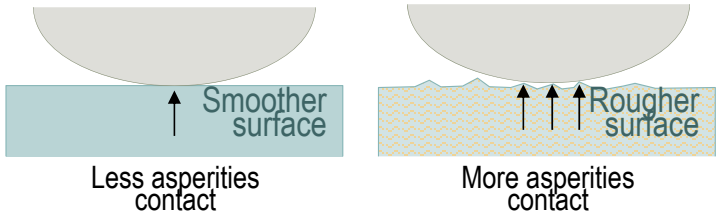
Findings – Tribological Properties *(friction, lubricant & wear)*



- Stiffness (Young's modulus) increased; asperities contact decreased → **lower scar width; lower wear rate**



- Increased roughness due to presence of filler; number of asperities increased → **higher COF**



[6] Chand, N., & Fahrim, M. (2008). Introduction to tribology of polymer composites. *Tribology of Natural Fiber Polymer Composites, Woodhead Publ. in Composite Sci. & Technol*, 59-83.

[7] Arnell, D. (2010). Mechanisms and laws of friction and wear. In *Tribology and Dynamics of Engine and Powertrain* (pp. 41-72). Woodhead Publishing.

Conclusion

UHMWPE
Tough & Strong

Cellulose Nanofiber (CNF)
Flexible & Non toxic natural filler

Higher stiffness & toughness

↓

Lower wear rate

CNF can be potentially used as natural filler for UHMWPE tibial inserts application

Acknowledgement

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- ✓ Kyushu Institute of Technology (Kyutech, JAPAN) for short-term study and research activities in Japan.

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