MFC produced using FiberLean Wet Stirred Media Mills: Applications in molded and formed fiber products

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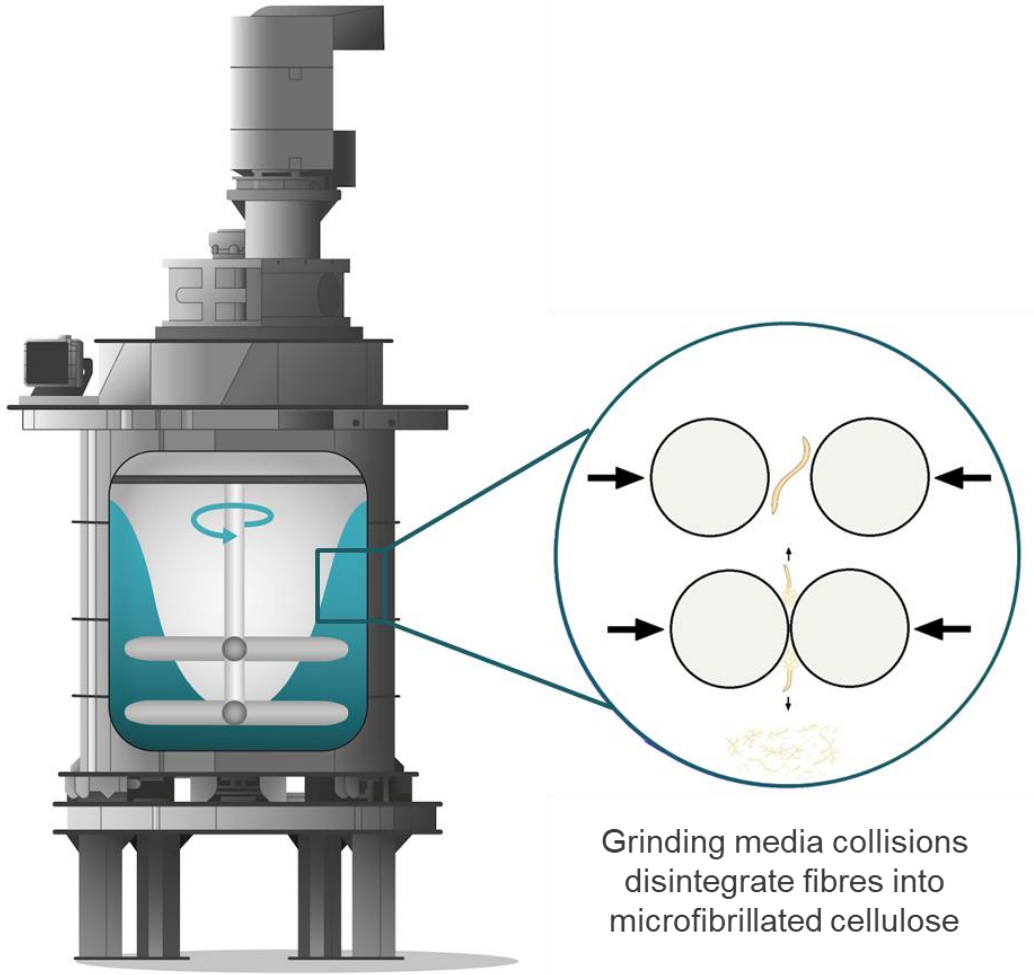
FiberLean MFC Grinders (Vertical Wet Stirred Media Mill Grinders)

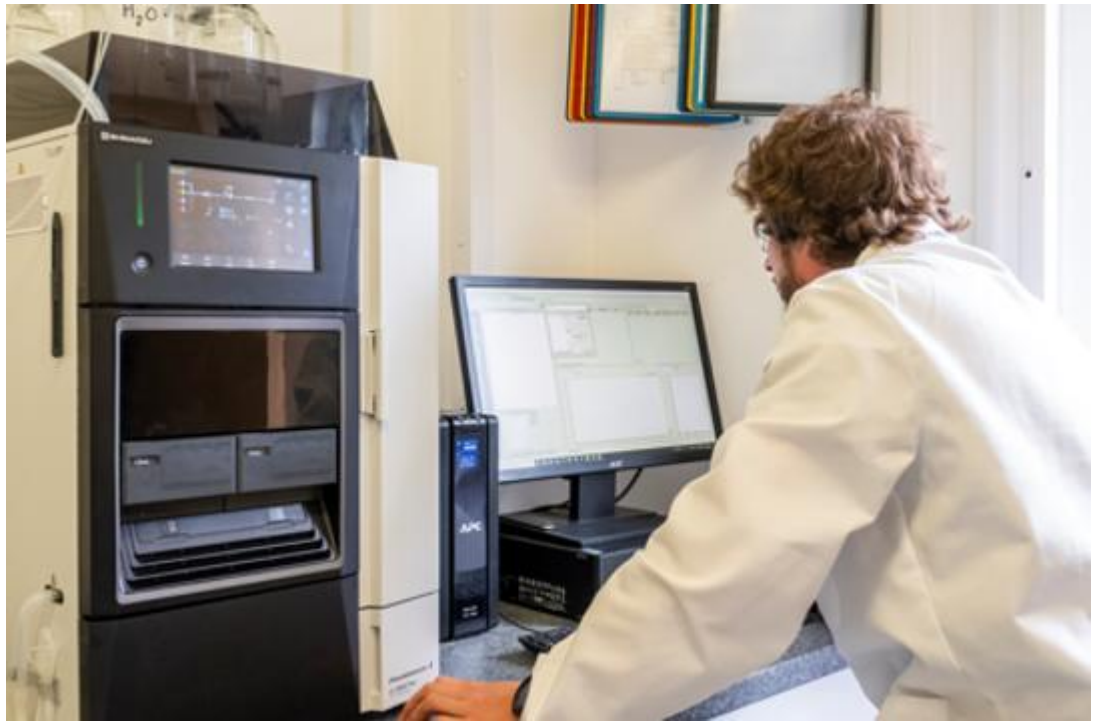


Grinding media collisions disintegrate fibres into microfibrillated cellulose

- Fortified stirred vessel, where collisions between grinding media beads break intervening particles.
- Widely used in minerals and mining industry, adapted by FiberLean to break and fibrillate fibres into MFC. Required modifying design, operating principles, and theory.
- Grinding media are the ‘working surfaces’ for fibrillation; very high active surface area that scales with vessel volume; permits high throughput and efficient production of MFC.
- Typically operated in continuous mode, where energy input is controlled with outlet flow rate and motor power.
- Robust, reliable, simple, low cost, energy efficient design.
- Mechanical, additive-free process.
- Modular. ~1200 and ~400 dmtpa MFC modules.

FiberLean MFC Grinders and MFC production plants

Products: FiberLean Services



Trials

Support customer evaluations of grinders with samples, trial support and application support at any scale from laboratory to multi-day machine trials

Support

Full support; commissioning, trouble-shooting, MFC applications development and regulatory support

FiberLean Demonstration Plant & MFC press cake

Demonstration plant in Cornwall, UK

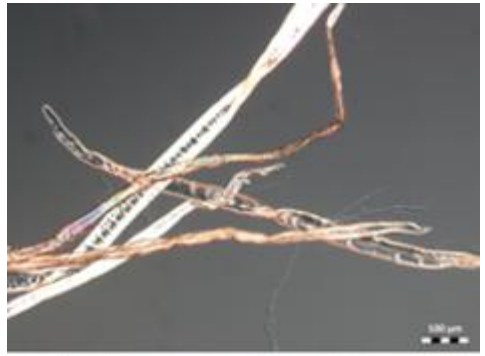
- Full-scale MFC production facility
- MFC Pilot plant
- Development and characterisation laboratories

Industrial-scale MFC press cake

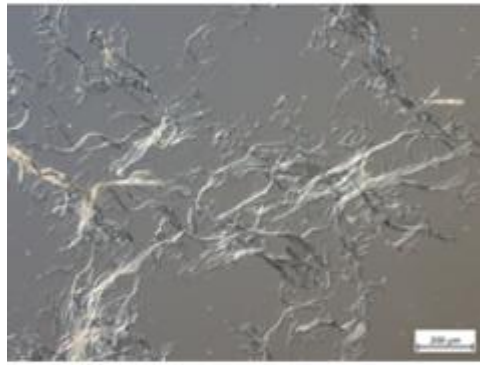
- 1000 kg bags on pallets, 20 wt.% solids MFC

Morphology of Grinder-Produced MFC

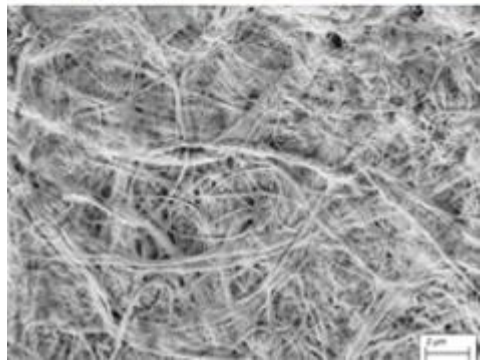
- Grinder-produced MFC is best described as ‘surface-nanostructured macromaterial’.
- Micro and nano scale fibrillar surface structure anchored to a sub-millimetre scale macrostructure.
- Fine and long micro and nano fibrils in the nanostructure enhance bonding at fibre-fibre joints and with filler particles.
- A coarse macrostructure improves bridging between fibres and improves retention.
- The challenge is to efficiently generate a high level of micro and nano fibrillation whilst retaining long fibrils and coarse macrostructure.



Unprocessed pulp



Optical micrograph showing MFC coarse macrostructure



SEM showing MFC fibrillar micro and nano structure

Grinder-Produced MFC: Regulatory, end-of-life

- BfR, FDA, Canadian and Chinese food contact paper clearance.
  - FDA FCN 002413
  - BfR Recommendations XXXVI, XXXVI/1, XXXVI/2 & XXXVI/3
- Not a nano-material according to US EPA and EU definitions.
  EU Nano or not nano: An unbiased approach to classifying FiberLean microfibrillated cellulose, Hewson et al, Cellulose, (2024). *https://doi.org/10.1007/s10570-024-05980-z*
- No negative health effects found.
  - https://pmc.ncbi.nlm.nih.gov/articles/PMC6994281/
  - https://pmc.ncbi.nlm.nih.gov/articles/PMC7329166/
  - https://pmc.ncbi.nlm.nih.gov/articles/PMC6474143/
- MFC not a final product but we have carried out the following testing to confirm MFC has no negative impact on end of life:
  - Recyclability – PTS-RH 021:2012 – bleached and unbleached MFC coated papers passed.
  - Biodegradability – OECD 301B – MFC suspensions with and without biocide were biodegradable.
  - Compostability – ISO 14855 – bleached and unbleached MFC coated papers were biodegradable under industrial composting conditions.

Using MFC as an additive in fibre-based products

(Paper, packaging, tissue, specialty paper and pulp products)

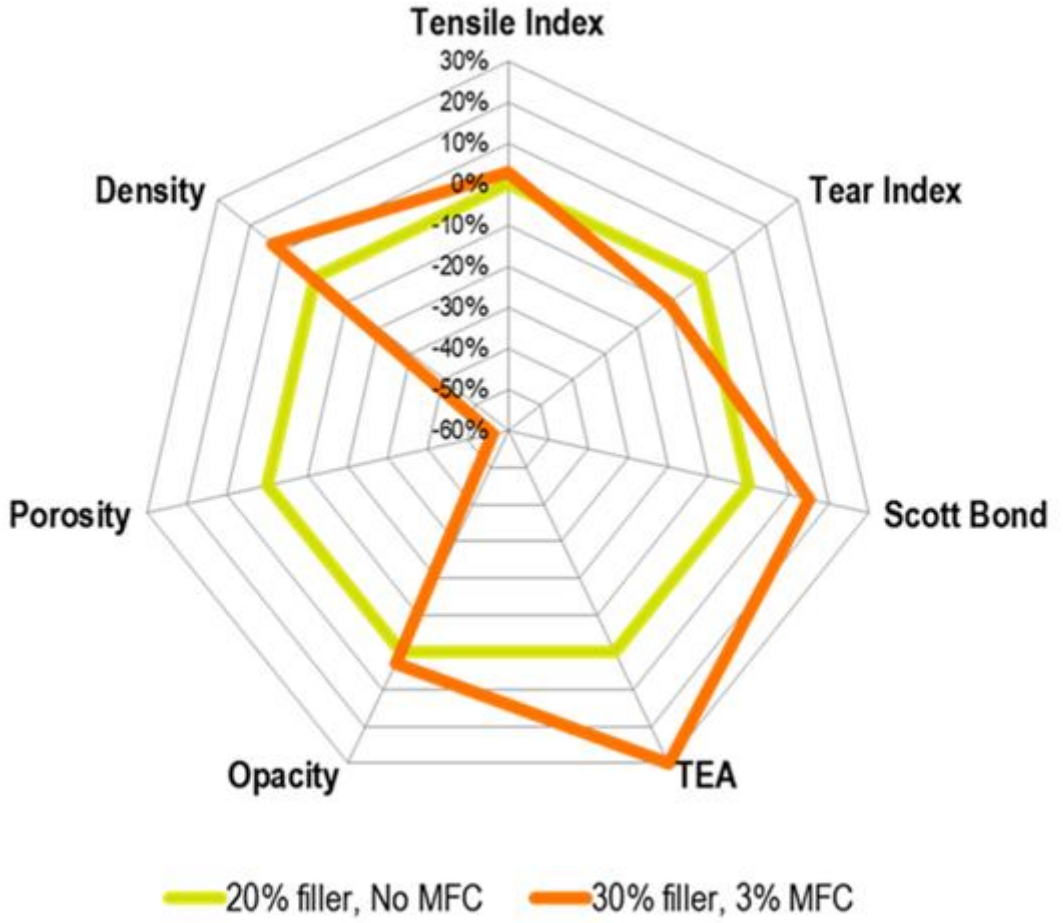
- Enhanced bonding within fibre-based structures
- Formation of closely packed, low porosity layers
- Wide regulatory clearance
- Recyclable, compostible, sustainably sourced

- Light weighting
- Reduce long fibre use
- Increase filler use
- Improve mechanical & elastic properties
- Improve coverage
- Barrier properties
- Improve environmental performance
- Improve runnability

Grinder-Produced MFC: Paper Performance

Typically, use of MFC in a web-based system is associated with:

- Increased initial wet web strength.
- Minimal impact on wet end chemistry.
- Improved dry mechanical properties.
- Improved opacity.
- Improved formation.
- A much tighter sheet (reduced porosity).
- Improved coating hold out.
- Improved smoothness.
- Loss of bulk and slower drainage are negatives but can be managed.



Grinder-Produced MFC: Paper segments

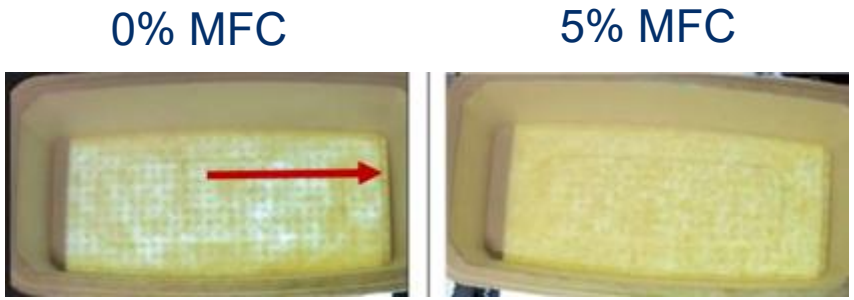
Typical uses of MFC :

- Graphic paper – Filler increase and softwood reduction. Potential savings €25 – 35/ t
- Folding Box Board outer layers – chemical pulp reduction. Potential savings €25 – 35/ t
- Tissue – fibre reduction by light weighting. Potential savings €30 – 40/ t
- 3D molded objects – fibre reduction by light weighting, improved formation, reduced porosity and some barrier properties.
- New Product Developments:
  - Barriers, FiberLean on Top.

Use of MFC “in” molded objects

Use of grinder produced MFC allows fiber reduction by lightweighting, improved formation, and reduced porosity.

- Formation / molding quality improvement (added value)



- Improved strength & lightweighting potential (cost reduction & quality improvement)
- Improved hold-out of oil and coatings (permeability and density control)

FiberLean Applications for 3D molded Fibre Forms

*"**Internal**" MFC application: Commercial scale-up in progress with selected partners*

(0% FiberLean® MFC)
KIT = 0 out of 12

(10% FiberLean® MFC)
KIT = 0 out of 12

(17% FiberLean® MFC)
KIT = 4 out of 12

FiberLean® MFC) Content (%)	Tray Basis Weight (g/m²)	Tensile stiffness index (N m g⁻¹)	Tensile strength index (N m g⁻¹)	Tensile stiffness (N m⁻¹)	Tensile strength (N m⁻¹)	Bendtsen Porosity (ml min⁻¹)
0	480	2.63	21.2	1270	10.2	2750
10	**380**	**3.45**	**37.2**	**1300**	**14**	**160**
17	**280**	**5.04**	**53**	**1430**	**15.1**	**15**
25	**175**	**5.37**	**56.4**	930	**9.8**	**4**

- molded objects such as trays prepared from bleached pulp can benefit from FiberLean® MFC:
  - Up to 50% reduced object weight whilst maintaining strength, stiffness and mouldability.
  - Greatly improved smoothness, and reduced permeability.
    - Improved hold-out of functional coatings applied (e.g. Barriers) and effectiveness of sizing.
  - OGR barrier properties (≥30% MFC results in KIT 12).
    - Opportunity for replacement of PFAS.

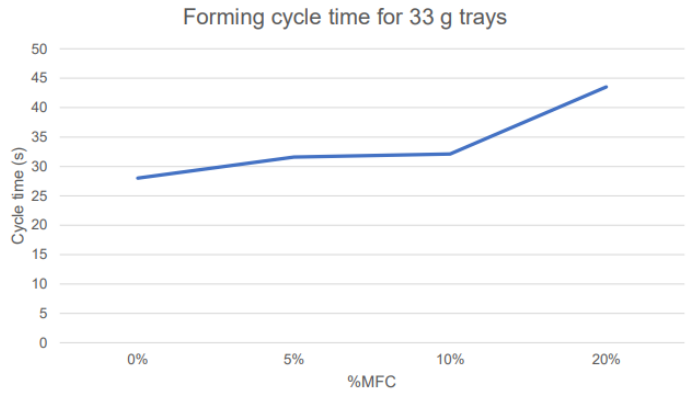
FiberLean Applications for 3D molded Fibre Forms

*"**Internal**" MFC application: **Commercial trial results***

Operational aspects

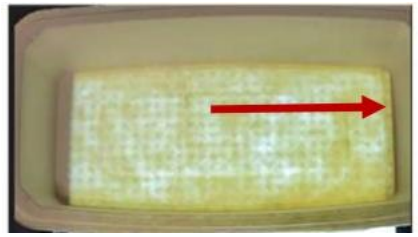
%MFC → Water retention → Drying time → Cycle time

%MFC	0%	5%	10%	10%	20%	20%	20%	30%
Tray weight	33g	33g	25g	33g	18g	25g	33g	18g
Cold press time (s)		10	10	10	12	12	12	12
Suction power(%)		100	100	100	100	100	100	100
Suction time (s)		2,3	1,45	3	4	6	12	7
Cycle time (s)	28	31,6	31,2	32,1	33,3	36,5	43,5	36,3



- An increase in cycle time is observed with the addition of MFC at a constant article weight.
- Lightweighting the object can help to offset the negative impact on cycle time.

Enhanced properties with lighter weight

	0% Reference	5% FiberLean MFC
		
Article weight, g	33	28 **(-15%)** ⇩
Density, cm³/g	0.50	0.58 **(+16%)** ⇧
Gurley Porosity, Sec	3	41 **(+1,250%)** ⇧
PPS roughness, µm	9.1	8.6 **(-5.5%)** ⇩
Scott Bond, J/m²	123	274 **(+120%)** ⇧
Tear strength, mN	2718	5327 **(+96%)** ⇧
L&W Stiffness, mN	82	100 **(+22%)** ⇧
*Traction, N	256	482 **(+88%)** ⇧
Tensile Stiffness, kN.m/g	2.53	2.91 **(+15%)** ⇧
Tensile Index, N.m/g	18.7	35.1 **(+87%)** ⇧
SCT, kN/m	4.7	5.3 **(+13%)** ⇧
*Centred finger, N	52.8	118.5 **(+125%)** ⇧

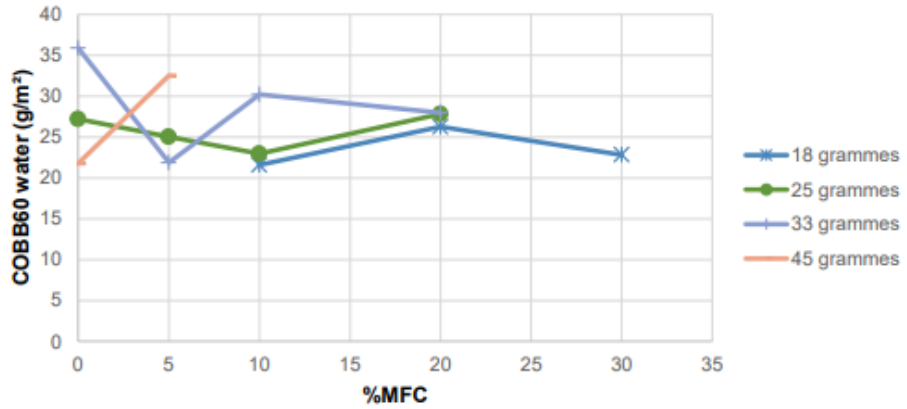
** = Customer testing*

FiberLean Applications for 3D molded Fibre Forms

*"**Internal**" MFC application: Commercial scale-up trial results*

WATER

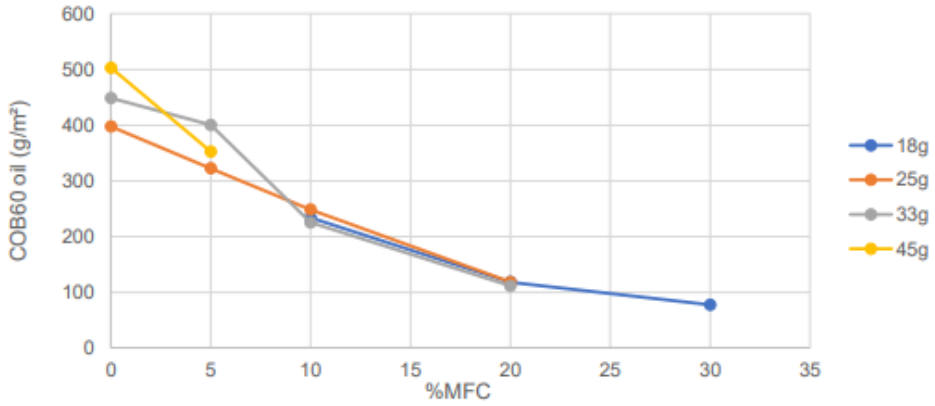
Cobb60 water (g/m²)	18	25	33	45
0		27	36	22
5		25	22	32
10	22	23	30	
20	26	28	28	
30	23			



No impact of MFC on the water barrier

OIL

Cobb60 oil (g/m²)	18	25	33	45
0		398	449	503
5		322	400	353
10	234	248	225	
20	118	118	111	
30	77			



MFC improve the oil barrier. With 10%, Cobb index is divided by 2 and with 20% by 4.

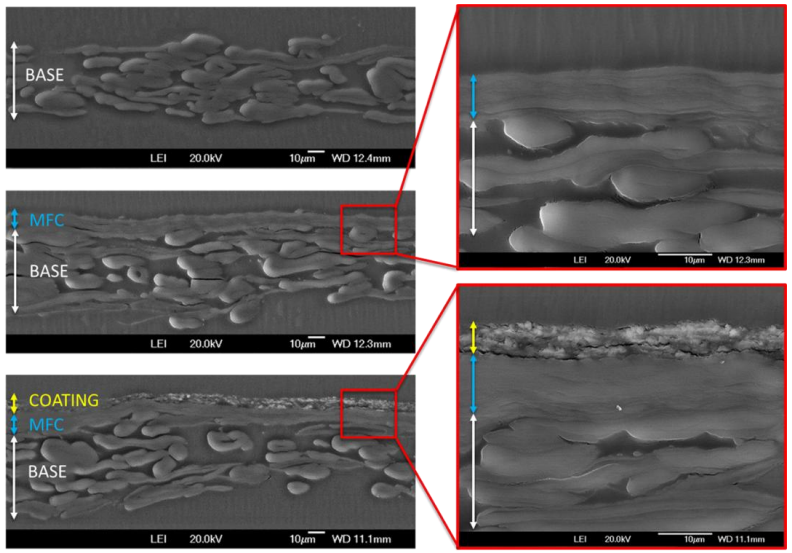
**Each value is an average of 6 measurements (1 per cavity)*

FiberLean Applications for 3D molded Fibre Forms

*"**Surface**" MFC application: Commercial scale-up in progress with selected partners*

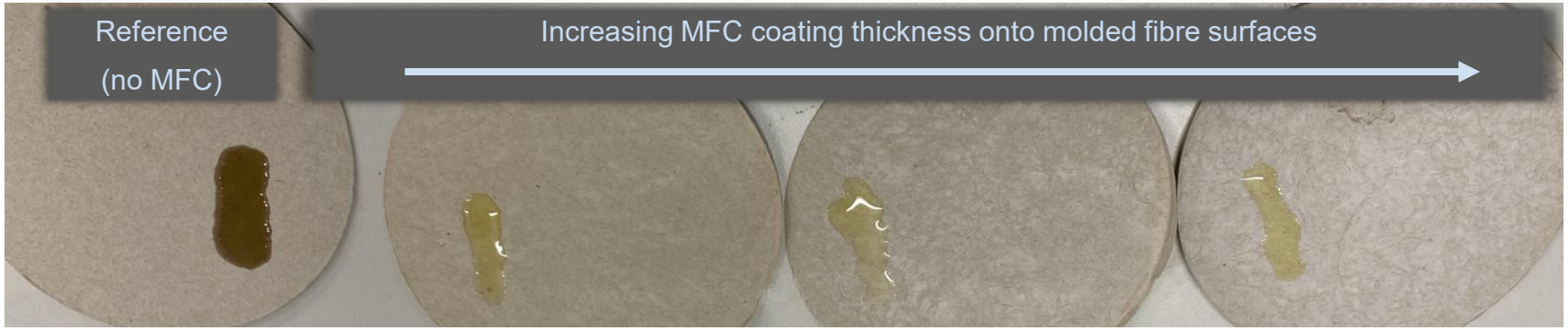
Sustainable Barriers & Precoated Surfaces

- ✓ Oil & Grease resistance.
- ✓ Oxygen & Aroma barrier.
- ✓ Mineral oil barrier.
- ✓ Very smooth & closed surface.
- ✓ Excellent substrate for coatings.
- ✓ High-strength & durable layer.
- ✓ High bio-based content, sustainable packaging.



Cross-section Imaging: Scanning Electron Microscopy (SEM)

- The MFC layer has a very closed structure, preventing penetration of oil and permeability of air.
- The surface serves as an excellent substrate (primer) for subsequent coatings.



- Initial trials applying MFC to the surface of molded articles.
- A simple test with olive oil drops demonstrates the MFC effect.

Use of MFC “on” molded objects: FiberLean on Top (FLOT)

New opportunity for application of MFC

FiberLean are the inventors & patent owners of this game-changing technology.

Image: 3-meter wide FiberLean on Top (FLoT) applicator operating on a paper machine running at 500 m/min

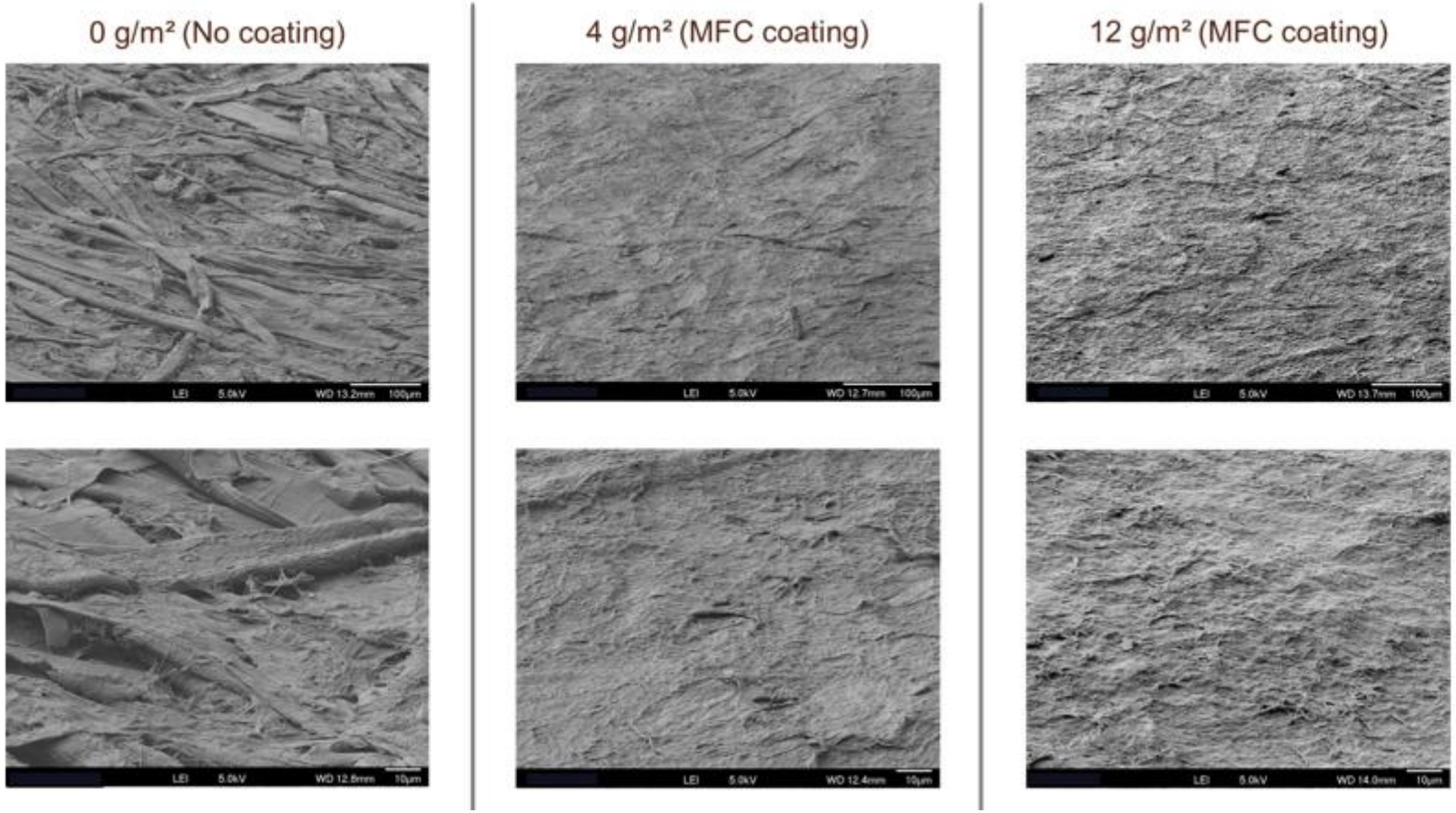
MFC is applied during the paper making process using FLOT applicator

Barrier

Providing barrier properties to help **reduce plastic** and other **harmful chemicals**

New Product Developments Barriers

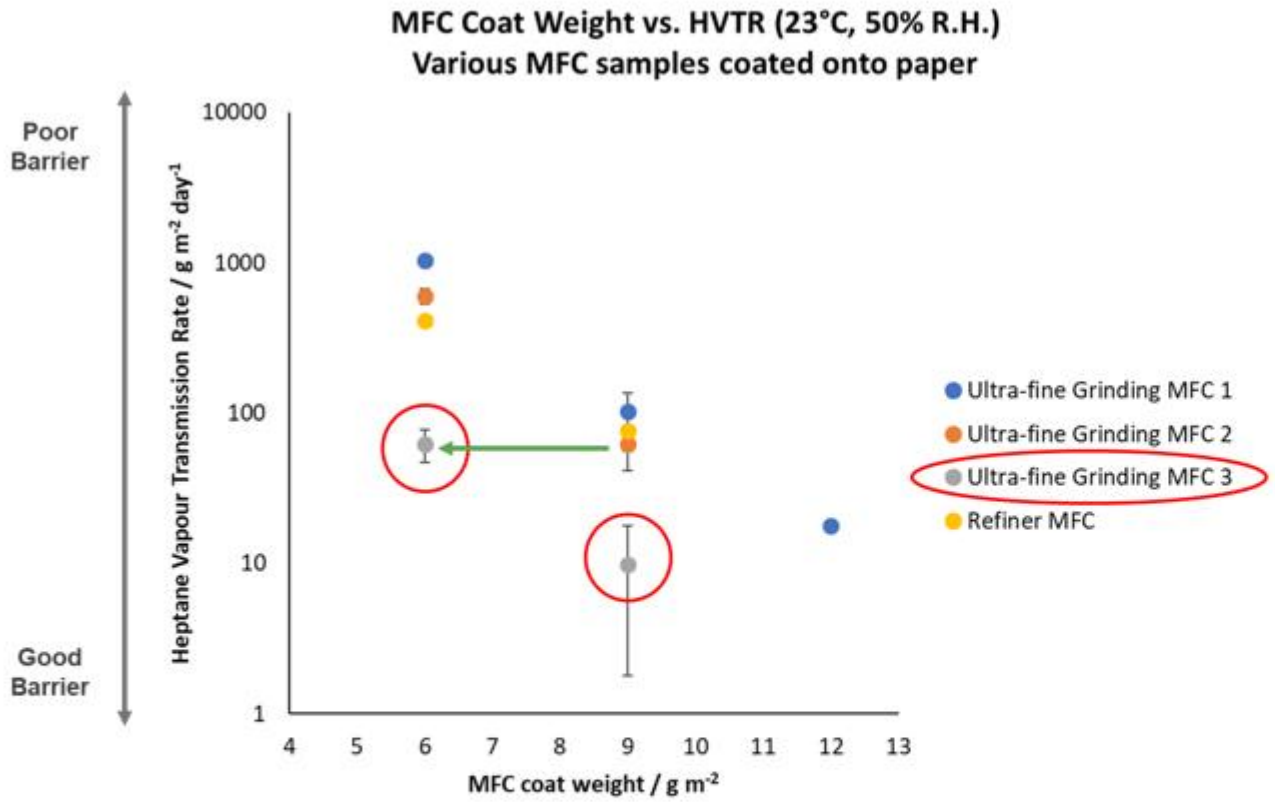
Scanning Electron Microscope (SEM) Images of MFC coated papers



- The lowest coat weight, 4 g/m² provided substantial changes to the surface topography and structure.
- By 12 g/m², the MFC has formed a film and reached sufficient thickness to achieve high barrier properties.

The effect of pre-treatment and process conditions on the gas barrier properties of fibrillated cellulose films and coatings: A review, Hill et al, Carbohydrate polymers 337 (2024) 122085

New Product Developments Barriers

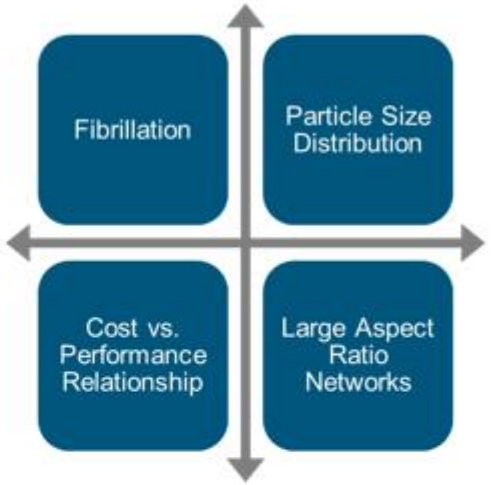


HVTR = Heptane Vapour Transmission Rate; is a barrier / permeation test method to evaluate the transmission rate of a volatile organic compound (n-Heptane), acting as a mineral oil simulant, through paper and plastic packaging materials.

○ = Product recommended for barrier MFC surface application.

✓ **Significantly lower coat weight required or higher performance.**

Tailored MFC Properties for Wet End Coating



- Barrier performance
- Strength / Durability
- Network bridging / film-forming
- Porosity control
- Surface hold-out
- Binding capability
- Viscosity & Drainage

- Avoidance of applicator blockages
- Coating uniformity / formation
- Process throughput to match peak demand
- Dose / Coat weight required
- Cost effectiveness

Summary

- Stirred media mill grinders are an efficient and is a high throughput method for mechanically producing MFC, utilising collisions between grinding media beads.
- Compared to alternative technologies, grinders can generate high levels of surface micro and nano fibrillation whilst maintaining a coarse macrostructure, with particular benefit to paper properties that are improved by both inter-particle bridging (e.g. MFC retention, porosity, tensile strength) and bonding (Scott bond).
- Use of MFC in paper and board leads to generally enhanced mechanical properties and reduced porosity sheets.
- Use of MFC offers opportunities for considerable cost savings in many paper and board segments.
- Use of MFC both “in” and “on” molded objects offers opportunities for both lightweighting and property improvement.

Thank you

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