FiberLean
Strength by Design

Microfibrillated Cellulose (MFC) produced using FiberLean wet stirred media mills: Applications in moulded and formed paper products

Presented by:

David Skuse
Managing Director

18 September 2025

Presentation Outline

- FiberLean company overview
- FiberLean MFC grinders
- Morphology of Grinder MFC
- Grinder MFC: Regulatory, end-of-life, ESG
- Grinder MFC in moulded and formed papers
- Practicalities
- Conclusions

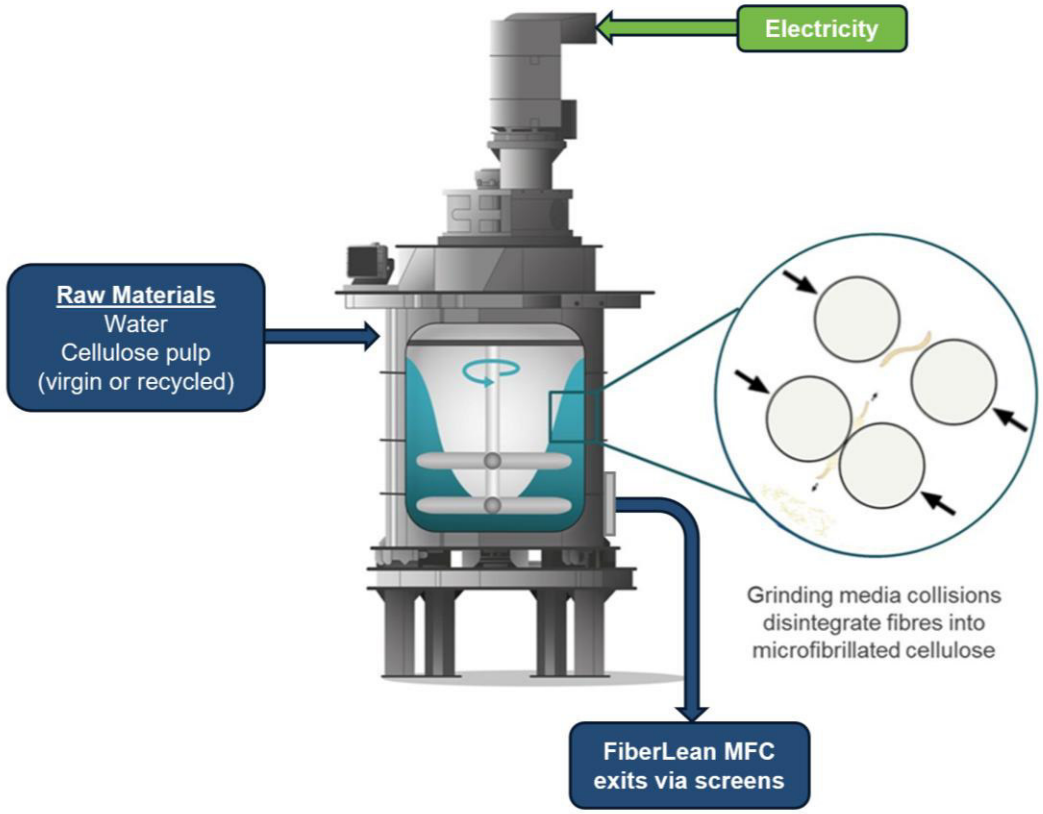
FiberLean Company Overview

Leading supplier of MFC equipment based on solid process knowledge

Leading independent MFC equipment supplier	Operating since 2016	World-class technical expertise in MFC technology and production
Operating industrial-scale MFC plant in Trebal, Cornwall	State-of-the-art industrial research and application laboratories	Capability to conduct onsite MFC trials worldwide
Experienced engineering and project implementation team	Leading research on MFC use and application with extensive patent portfolio	Equipment supply and fabrication partners

FiberLean MFC Grinders (Vertical Wet Stirred Media Mill Grinders)

Modular ~1200 and ~400 dry metric tonnes per year MFC modules



- Stirred vessel, charged with water, pulp and ceramic grinding media.
- Widely used in minerals and mining industry, adapted by FiberLean to fibrillate fibres into MFC.
- Fibrillation occurs when pulp gets trapped between colliding grinding media particles.
- Grinding media are the ‘working surfaces’ for fibrillation; very high active surface area; permits high throughput and efficient production of MFC.
- Continuous, single pass operation.
- Pulp suspension is added continuously to top of mill.
- Product exits continuously through screens near bottom of mill.
- Energy input is controlled with outlet flow rate and motor power.
- Robust, reliable, simple, cost-effective, energy efficient design.
- Mechanical, additive-free process.
- Production solids ~ 1-2% - on-site production.

Products: FiberLean MFC Grinders

Full-scale FiberLean MFC Grinders
Designed with the paper and board industry in mind. Capacity ~ 1200 dry metric tonnes of MFC per grinder per year.

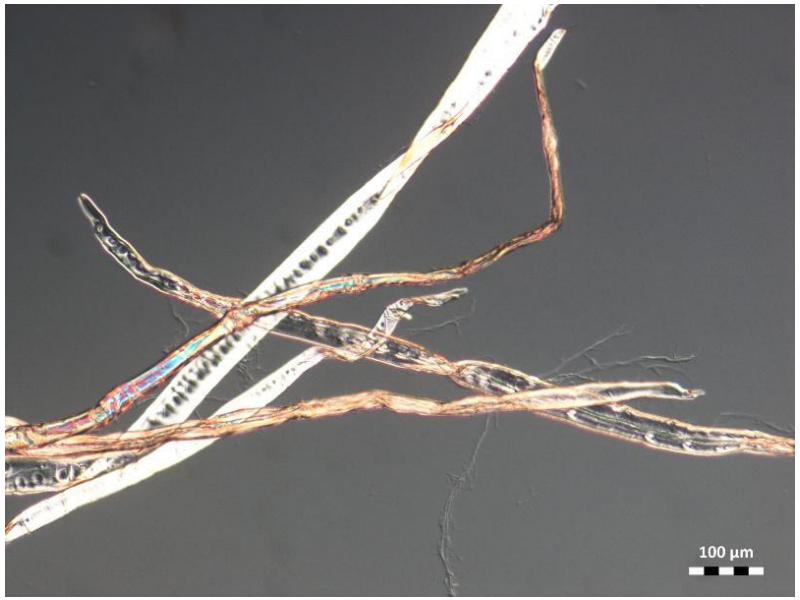
Small-scale FiberLean MFC Grinders
Capacity ~ 400 dry metric tonnes of MFC per grinder per year. Speciality applications, tissue, moulded fibre etc.

What is MFC?

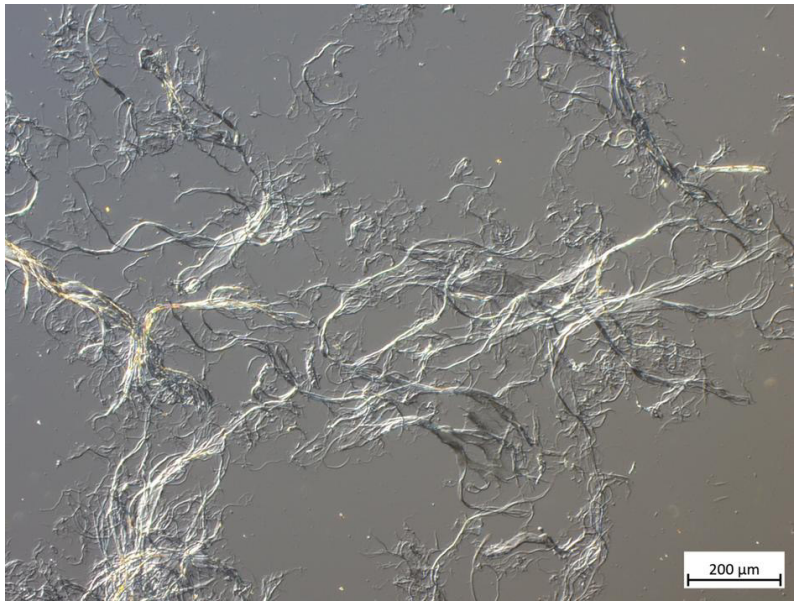
Micro-fibrillated Cellulose (MFC) is a **natural material** consisting of cellulose fibrils made from feedstocks such as wood pulp.

MFC fibrils **bond** strongly in fibre webs.

When added to the paper-making process benefits include **improved mechanical properties, reduced porosity, improved barrier properties, smoother surfaces** and an **improved environmental profile**.



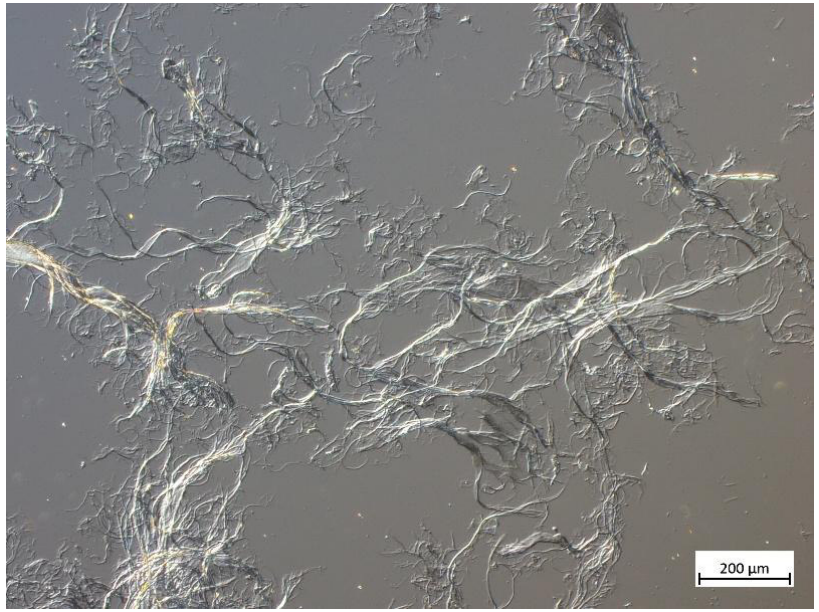
Unprocessed pulp

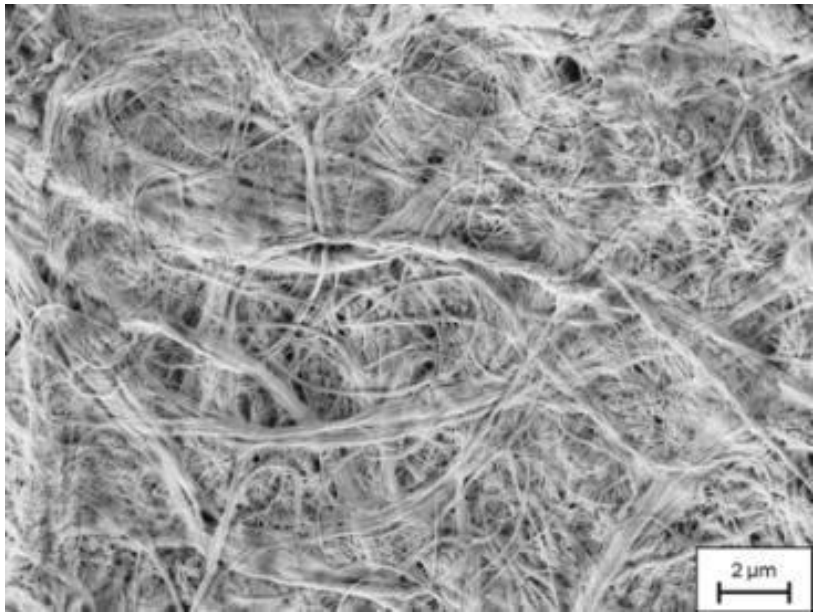


Optical micrograph showing MFC

Morphology of Grinder-Produced MFC

Optical micrograph showing MFC **coarse macrostructure**





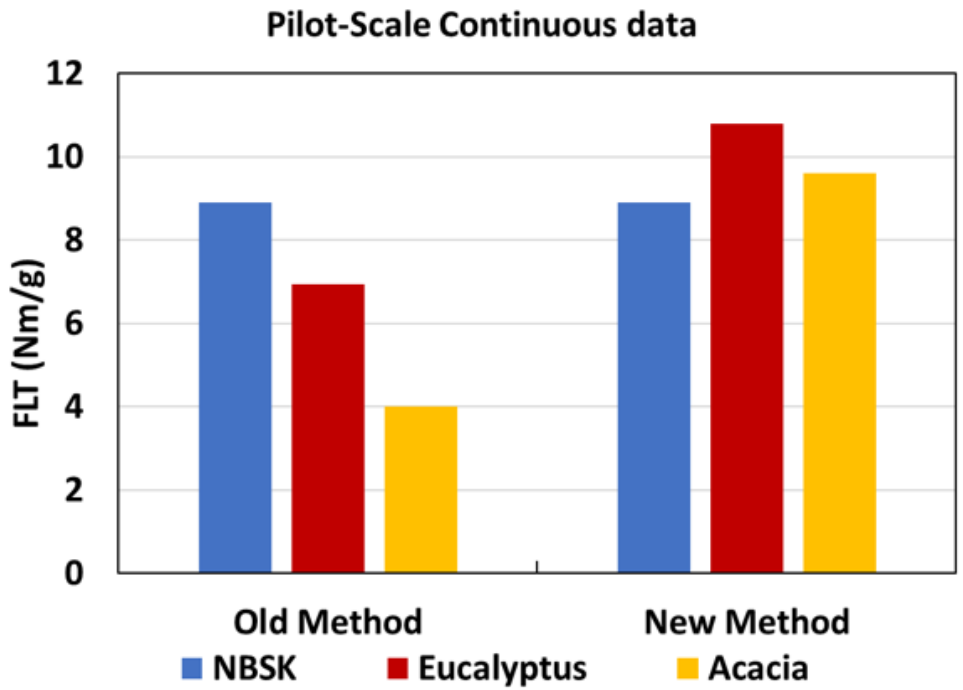
SEM showing MFC fibrillar **micro and nano structure**

- Grinder-produced MFC is best described as **'surface-nanostructured macromaterial'.**
- **Micrometre and nanometre scale fibrillar surface structure** on 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 objective is to efficiently generate a high level of micro and nano fibrillation whilst retaining coarse macrostructure.

FiberLean MFC Grinders Optimisation

- Effective MFC production requires **high levels of micro** and **nano fibrillation** whilst retaining **long fibrils** and **coarse macrostructure.**

- Stirred mills have the key advantage that the ***strength of forces can be varied by many orders of magnitude with little to no equipment modification.***
  - Machine parameters – specific energy input, impeller speed, media fill fraction, impeller geometry.
  - Grinding media parameters – density, elasticity, size, shape, surface roughness.
  - Feedstock parameters – fibre dimensions, fibre strength, fibre chemistry (hemicellulose, lignin), solids content.



High quality MFC can be produced from a wide range of feed fibres.

Grinder-Produced MFC: Regulatory, End-of-life, ESG

- 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*.
- **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:
  - **Recyclable** – PTS-RH 021:2012 – bleached and unbleached MFC coated papers passed.
  - **Biodegradable** – OECD 301B – MFC suspensions with and without biocide were biodegradable.
  - **Compostable** – ISO 14855 – bleached and unbleached MFC coated papers were biodegradable under industrial composting conditions.
- Allows lighter products, reducing transport related emissions.
- Supports recyclability and circular economy by enabling plastic replacement in packaging.

**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*

Grinder MFC in Moulded and Formed Paper Products

MFC can be applied internally **in the furnish** or **on the surface** of moulded and formed paper products.

Internal application

Improved formation

Improved wet and dry strength
Improved wet and dry elongation
} Improved runnability and lightweighting

Reduced porosity
Increased smoothness
} Improved products and more effective coating

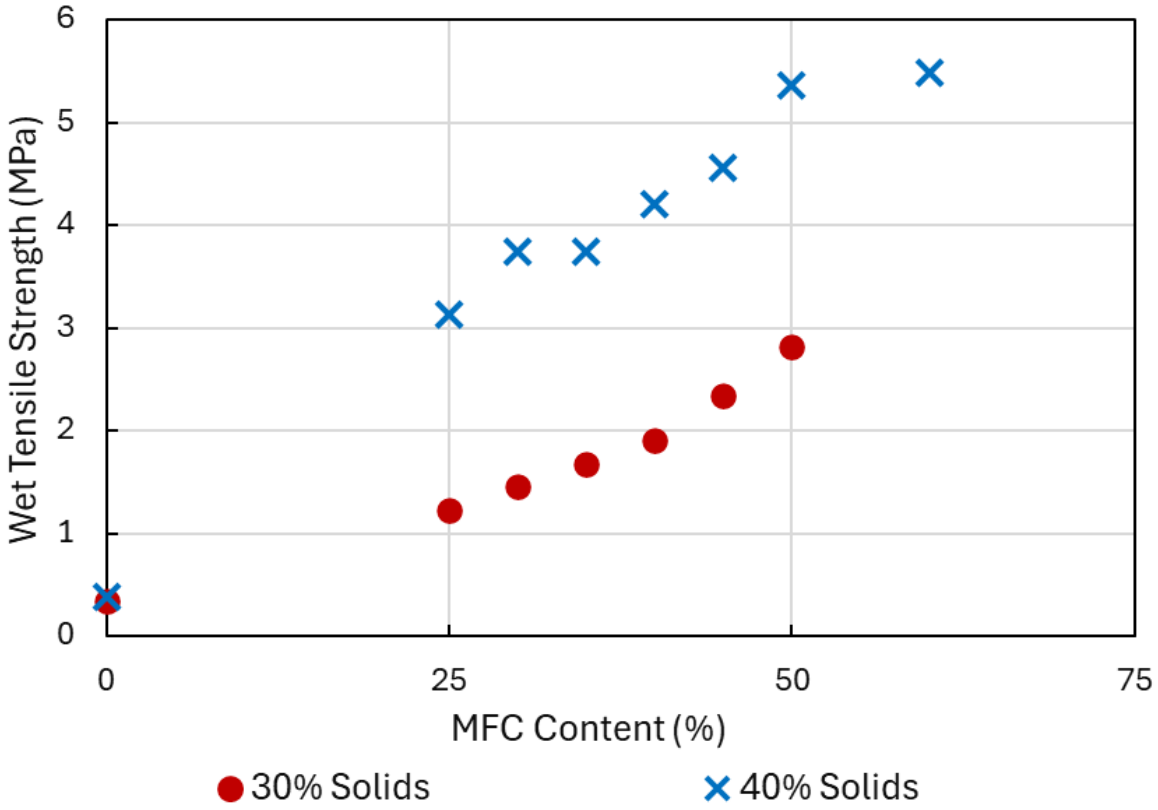
Grease barrier

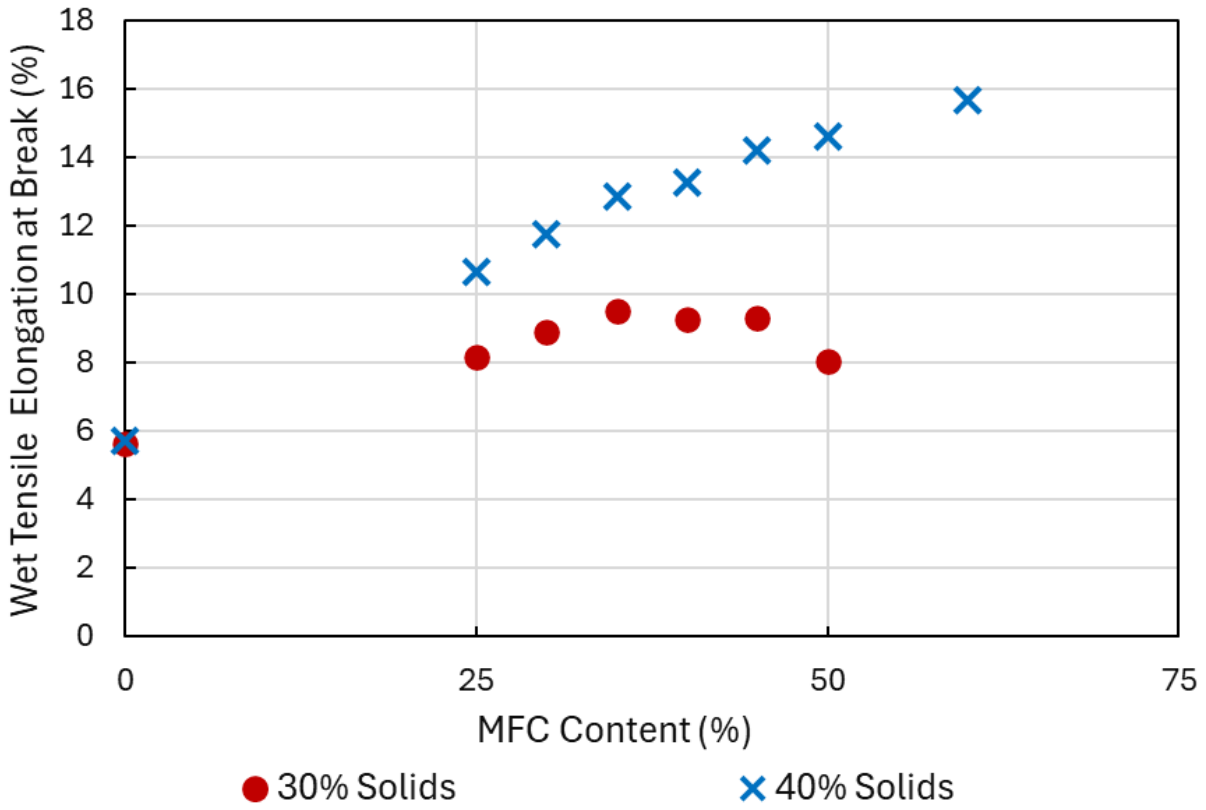
Surface application

Reduced porosity
Increased smoothness
} Improved products and more effective coating

Grease barrier

Grinder MFC in Handsheets 1: Wet Sheet Properties

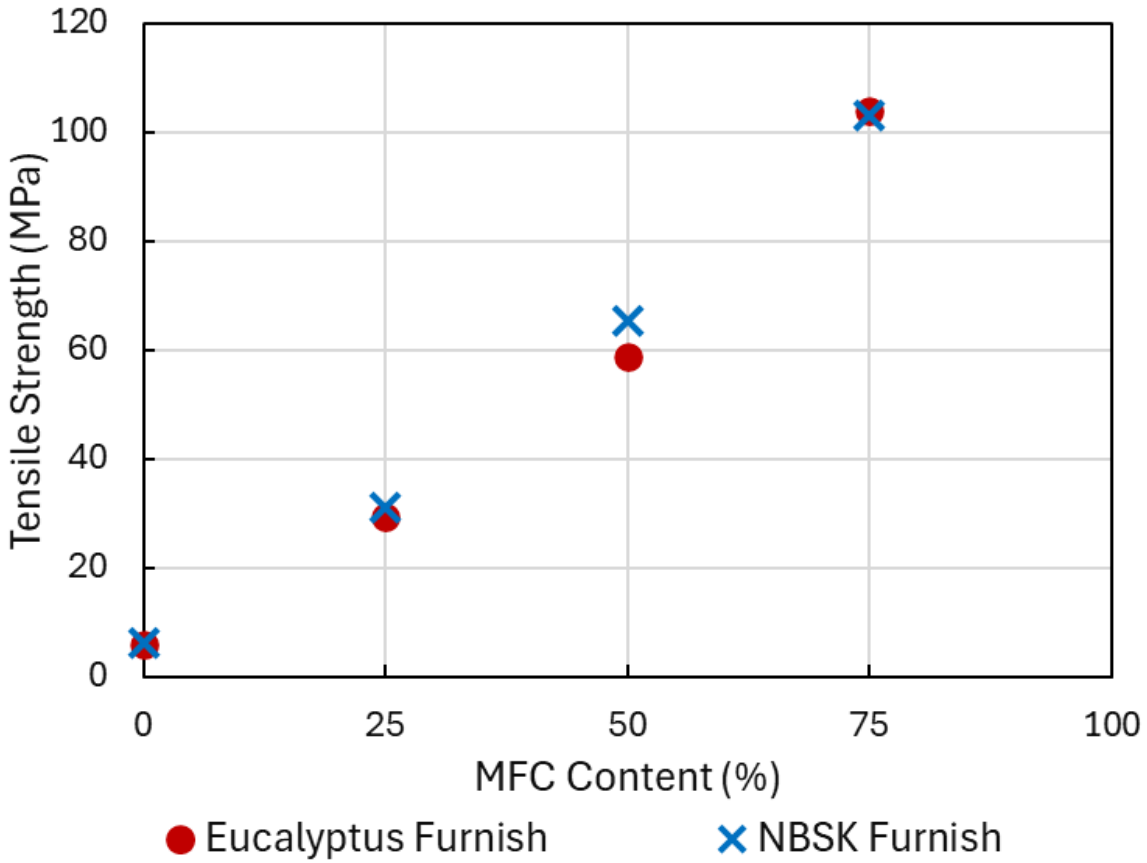




Increased wet tensile strength and **breaking elongation** with MFC addition

Tested on 225 gsm handsheets in a NBSK furnish with MFC contents varying from 0% to 60%. Sheets measured after pressing but before drying.

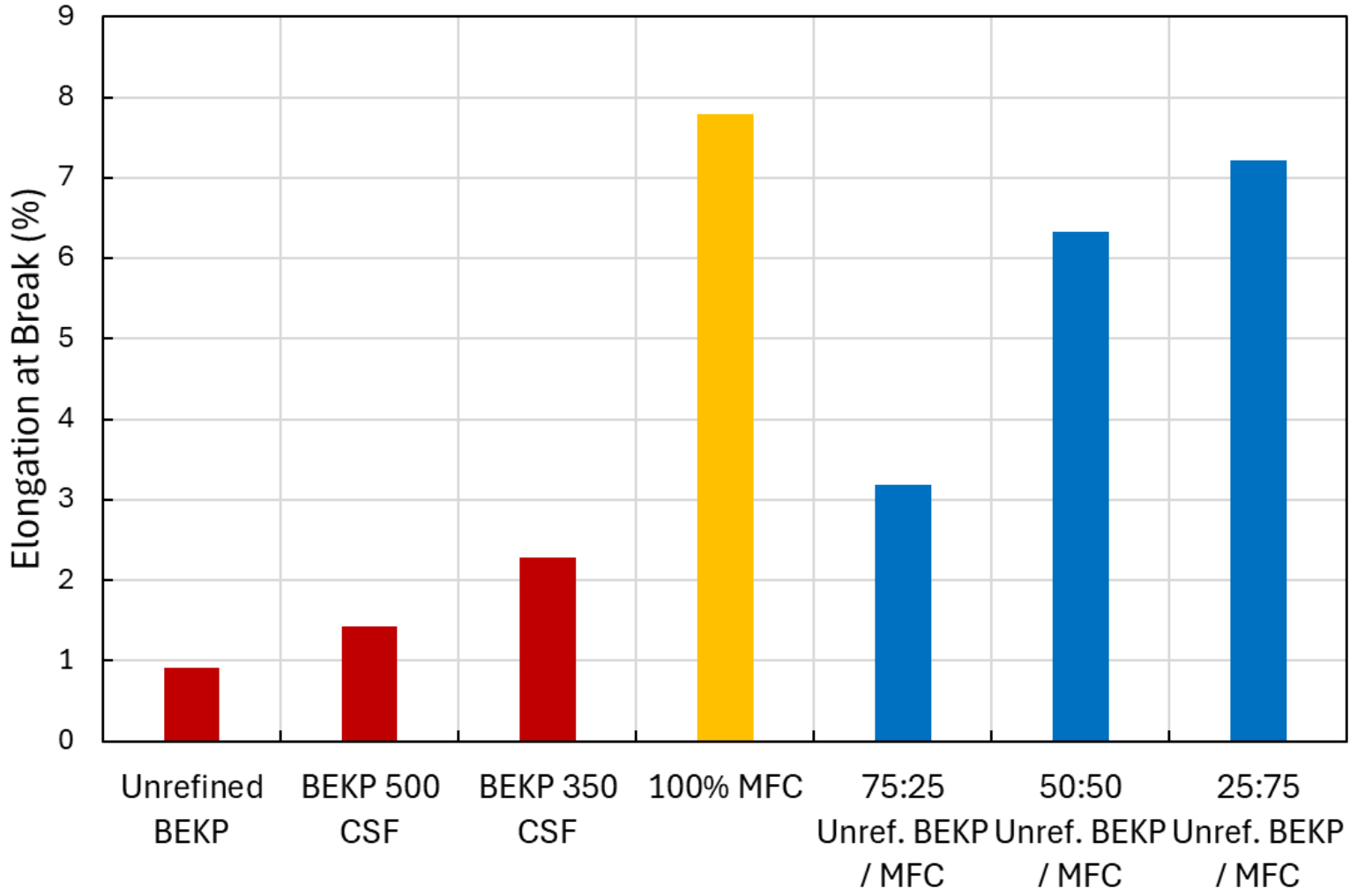
Grinder MFC in Handsheets 2: Dry Tensile Properties



Increased tensile strength with MFC addition

Results are average of 250 and 350 GSM handsheets comprised of unrefined fibres and 0% - 75% MFC.

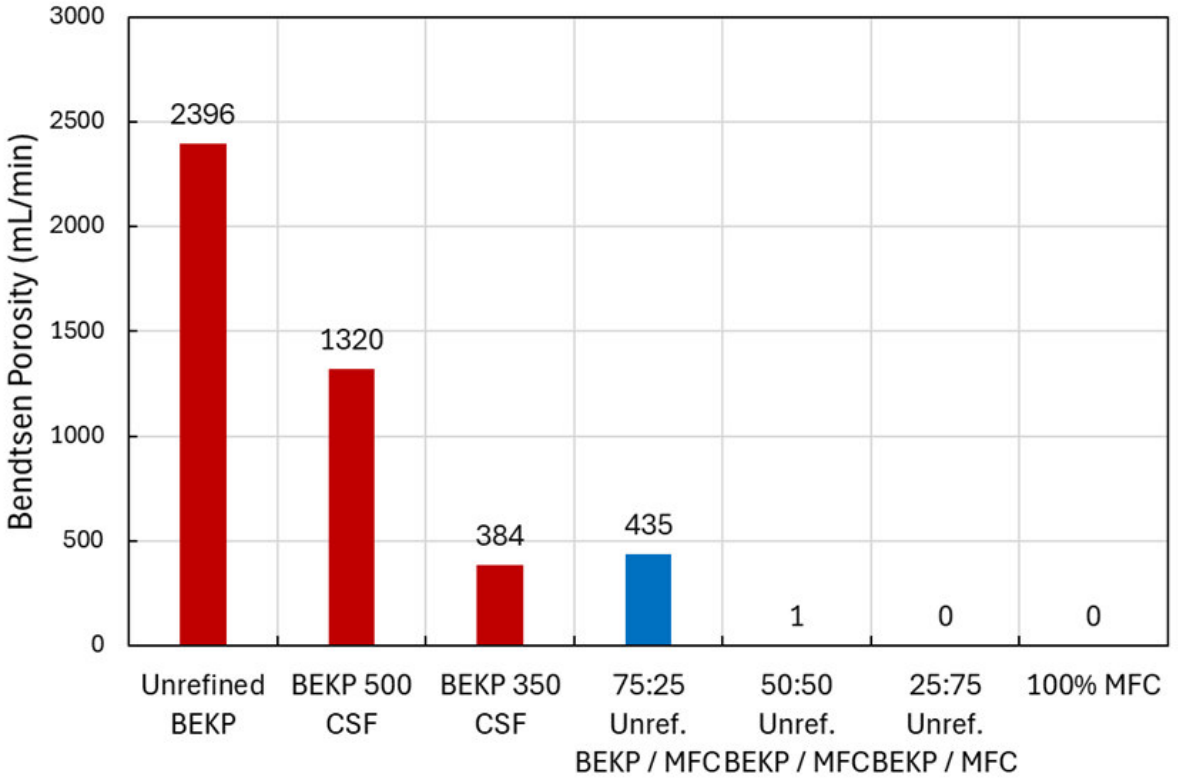
Grinder MFC in Handsheets 3: Elongation at Break

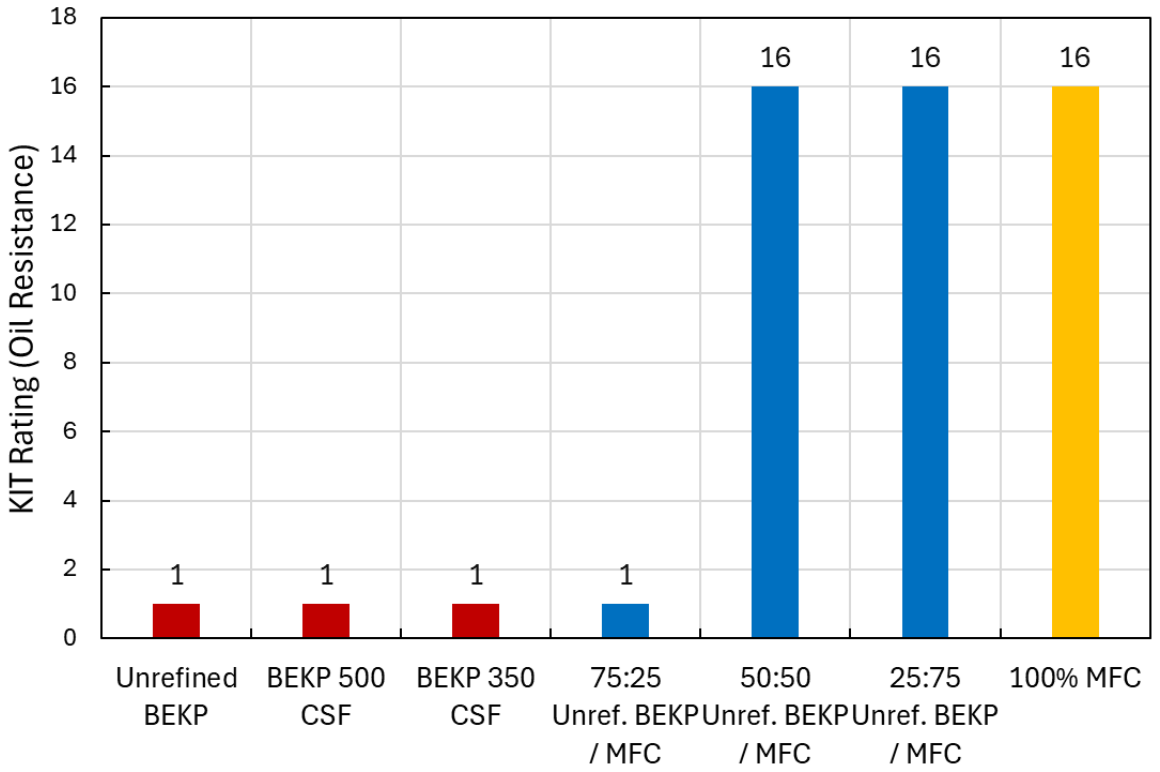


Increased elongation at break with MFC addition

Results are average of 250 and 350 GSM handsheets comprised of unrefined fibres and 0% - 75% MFC.

Grinder MFC in Handsheets 4: Oil Resistance and Porosity





Reduced porosity and **increased KIT** with MFC

Tested on 220 GSM handsheets.
N.B., KIT values of 13 – 16 are used by FiberLean to distinguish higher oil resistances beyond the limit of 12 set by the standard test. NB Low porosity samples still absorb water and have low moisture barrier.

Grinder MFC in wet-moulded fibre furnish: Pilot study

Bleached NBSK unrefined

(**0%** FiberLean® MFC) (**10%** FiberLean® MFC) (**17%** FiberLean® MFC)

KIT = 0 out of 12 KIT = 0 out of 12 KIT = 4 out of 12

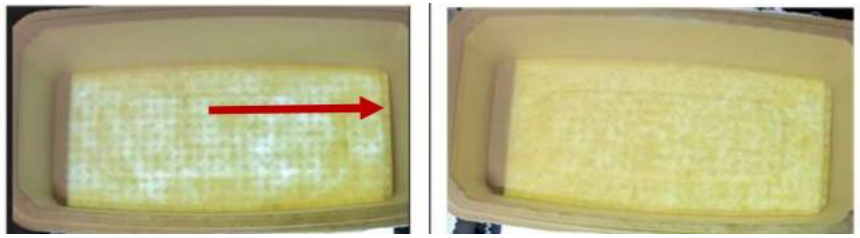
FiberLean® MFC) Content (%)	Tray Basis Weight (g/m^2)	Tensile stiffness index ($N\ m\ g^{-1}$)	Tensile strength index ($N\ m\ g^{-1}$)	Tensile stiffness ($N\ m^{-1}$)	Tensile strength ($N\ m^{-1}$)	Bendtsen Porosity ($ml\ min^{-1}$)
0	480	2.63	21.2	1270	10.2	2750
10	**380**	**3.45**	**37.2**	**1300**	**14**	**160**
17	**280**	**5.04**	**53**	**1430**	**15.1**	**15**
25	**175**	**5.37**	**56.4**	930	**9.8**	**4**

- Up to **50% reduced object weight** whilst maintaining strength, stiffness and mouldability.
- **Greatly improved smoothness**, and **reduced permeability**.
- **Potential improved hold-out** of functional coatings and effectiveness of sizing.
- **OGR barrier properties** (≥30% MFC results in KIT 12).
- ***Opportunity for replacement of PFAS.***

Grinder MFC in wet-moulded fibre furnish: Full-scale study

Commercial trial results, 5% grinder MFC

0% Reference 5% FiberLean MFC



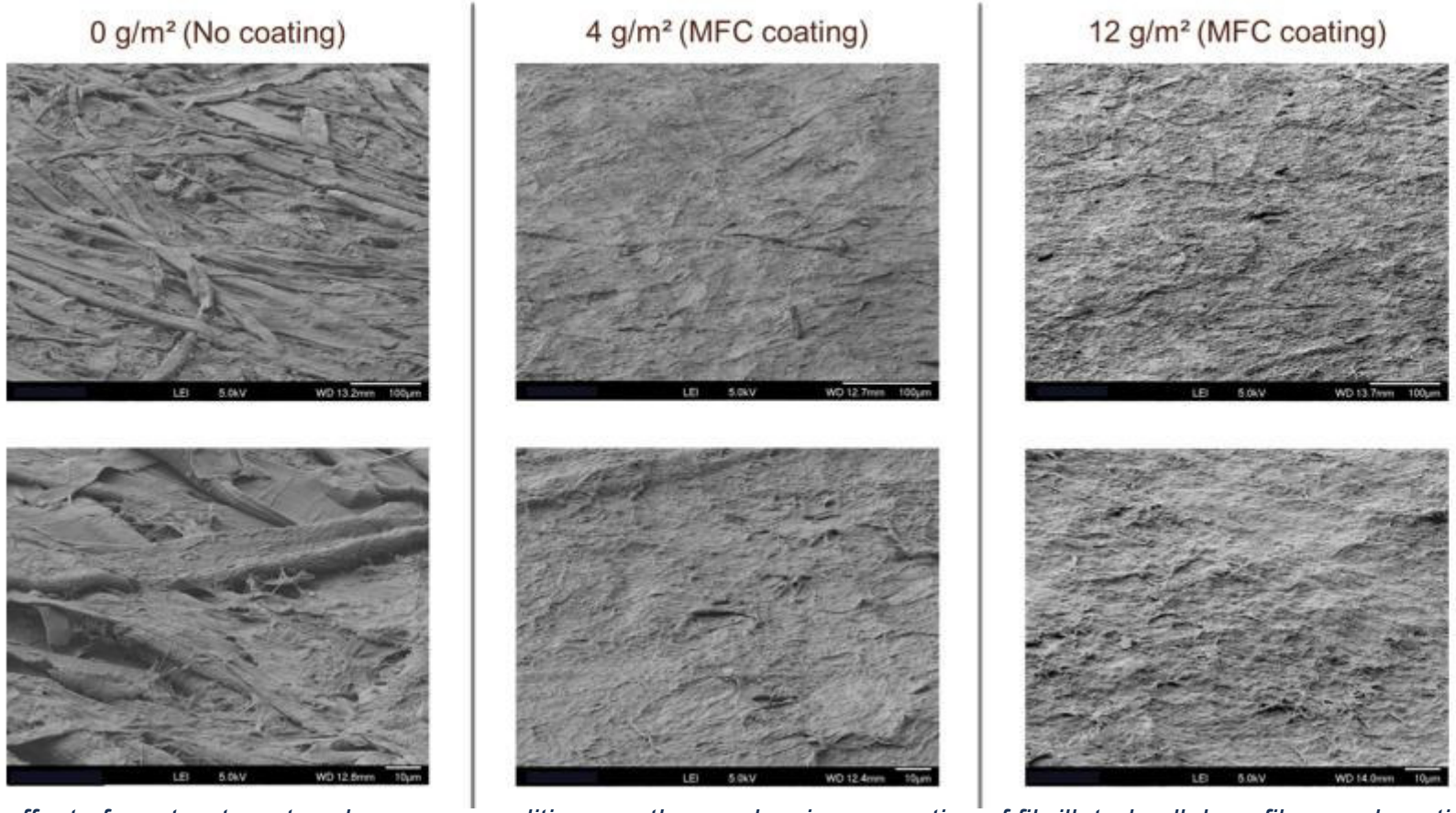
Improved Formation

Property	Performance
Article weight	-15%
Density	+16%
Gurley porosity	+1250%
PPS Roughness	-5.50%
Scott Bond	+120%
Tear strength	+96%
Tensile stiffness	+15%
SCT	+13%

- **Most properties improved** with addition of MFC.
- An increase in cycle time was observed with the addition of MFC at a constant article weight but this was offset by lightweighting.

Grinder MFC on Paper Surfaces: Laboratory Studies 1

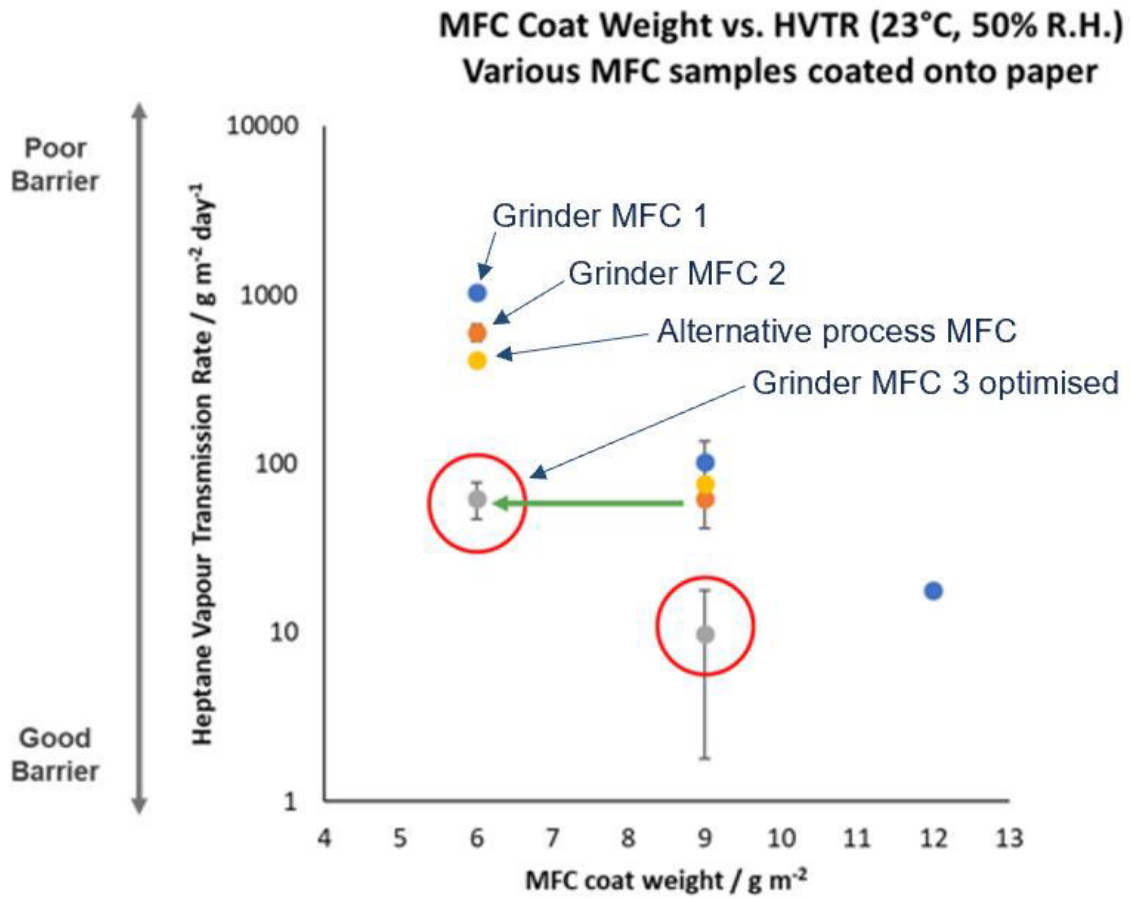
Scanning Electron Microscope (SEM) Images of MFC coated papers.



Surface-coated MFC ***substantially reduces surface roughness and porosity***

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

Grinder MFC on Paper Surfaces: Laboratory Studies 2



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.**

Surface-coated MFC allows **significantly reduced heptane vapor transmission**.

Indicative of **good grease barrier** behaviour.

Grinder MFC on Paper Surfaces: Full-scale Studies

FiberLean on Top (FLoT)

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 to paper web during the paper making process using FLOT applicator and drained through the web

MFC on paper 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

Practicalities: Idea to Implementation

Introduction meeting → Value creation refinement → Onsite MFC trials → Commercial offer → Contract negotiation → Grinder installation/ commissioning

Co-develop MFC value add

1. Identify the possible uses of MFC.
2. Develop business case.
3. Possible visit at Cornwall, UK.

Demonstration plant in Cornwall, UK

- Full-scale MFC production facility
- MFC produced in bags @ ~ 20% solids for trials.

Paper machine trial to validate performance

1. Grinder MFC in bags from FiberLean demonstration plant.
2. In some cases, FiberLean team and equipment can travel to trial site and operate the trial within the customer's process.

MFC Re-suspension unit

End-to-end project delivery support by FiberLean:

1. Project engineering services to support design, procurement and construction.
2. Commissioning support and services.
3. Training for customer personnel.
4. Post-commissioning support available as needed.

Summary

- FiberLean grinders are an efficient and high throughput method for producing high quality MFC.
- The resultant MFC has:
  - ***High levels of surface micro and nano fibrillation*** whilst maintaining a ***coarse macrostructure***.
  - ***Broad food contact clearance***, is ***not a nano-material*** according to US EPA and EU definitions and ***no observed negative health effects***.
  - Recyclable, biodegradable and compostable.
- Use of MFC from FiberLean grinders ***allows lighter products***, reducing transport related emissions and supports recyclability and the circular economy requirements.
- Grinder MFC used as a ***furnish component*** for moulded and formed paper products can give ***improved wet tensile properties***, ***improved dry mechanical properties*** and ***considerably reduced porosity***. Hence, considerable product improvement and lightweighting are possible.
- Grinder MFC used as a ***surface coating*** for moulded and formed paper products can give ***very smooth and low porosity surfaces***, ***oil and grease resistance***, and excellent substrates for coatings.
- Implementation of FiberLean grinders is well established and follows a proven route via full-scale trials using MFC from FiberLean's demonstration plant. FiberLean can support all project engineering stages.

Thank you

david.skuse@fiberlean.com

www.fiberlean.com

FiberLean Technologies

info@fiberlean.com