



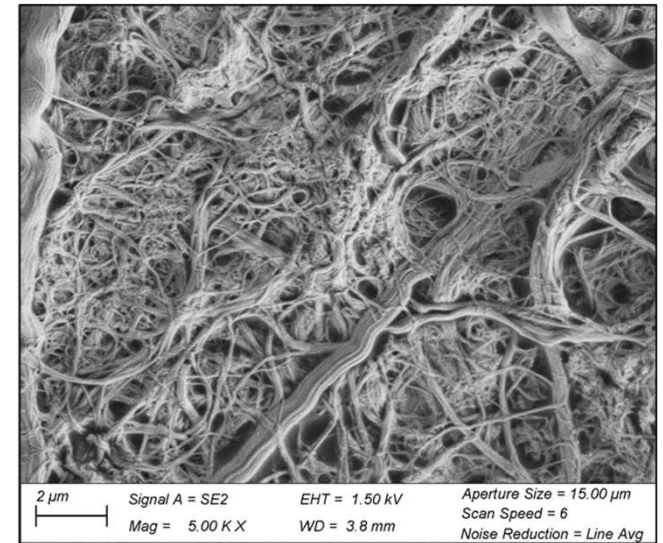
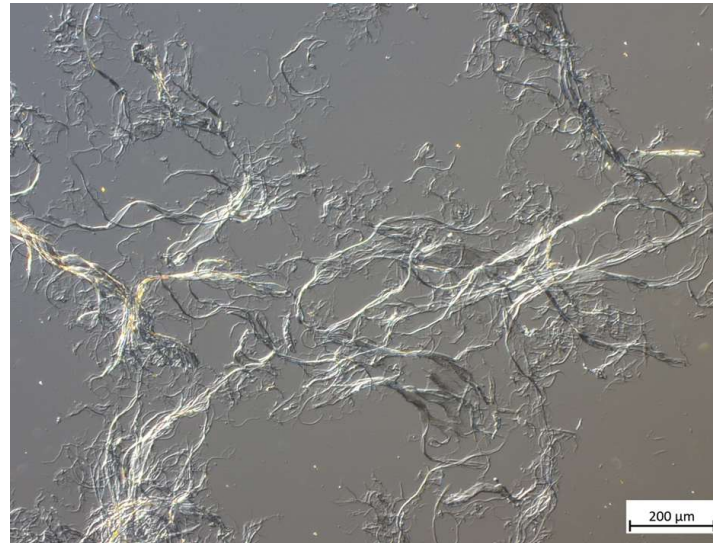
# Microfibrillated Cellulose (MFC) Products from Wet Stirred Media Mills: Applications in Paper and Board Products

David Skuse – Managing Director, FiberLean Technologies Ltd.



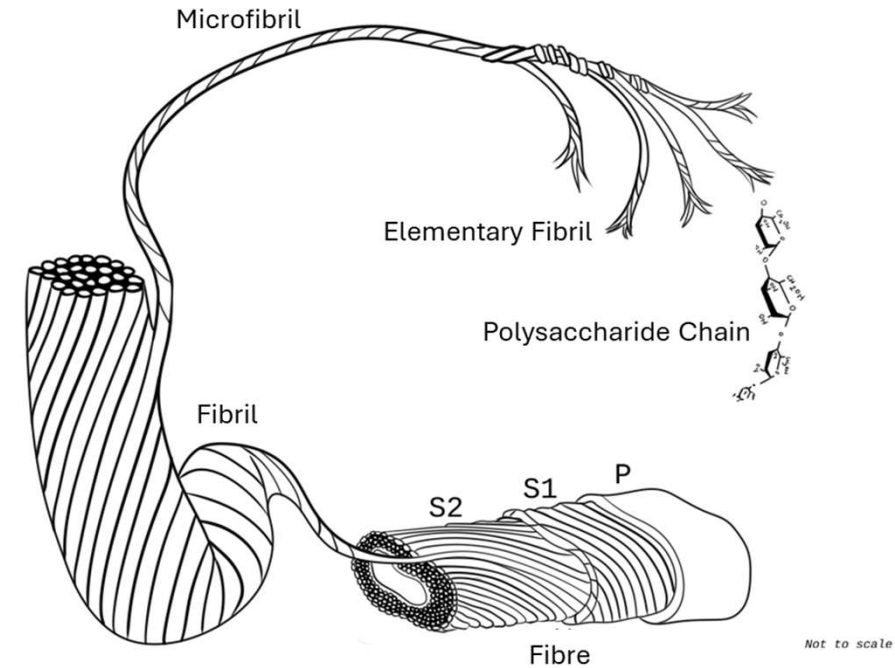
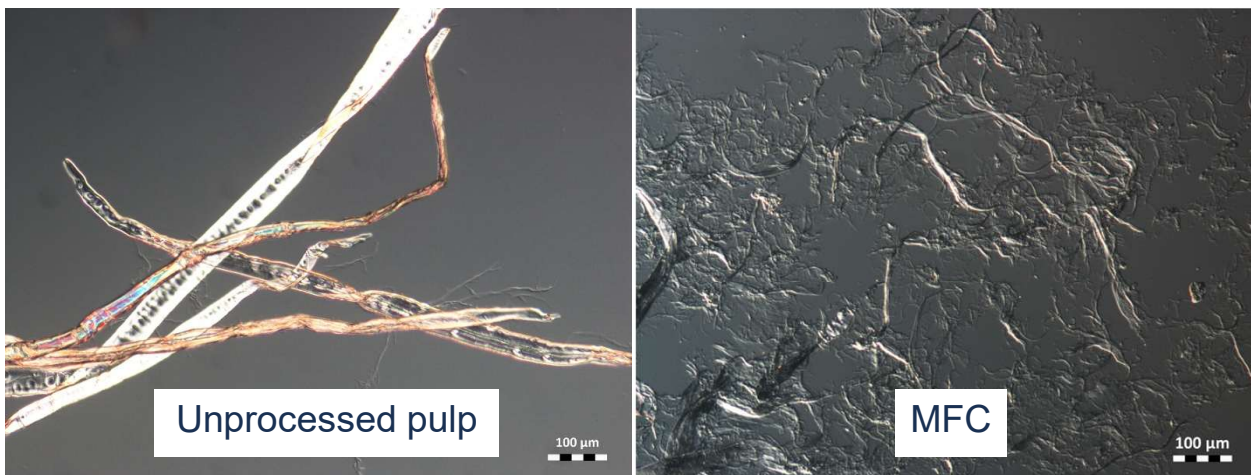
# Introduction

- **Wet Stirred Media Mill Grinders** are used for the production of microfibrillated cellulose.
- **Entirely mechanical process**, no chemical or enzymatic pre-treatment.
- **Flexible operating conditions** enable tailoring product characteristics and optimising for a wide variety of fibre feedstocks.



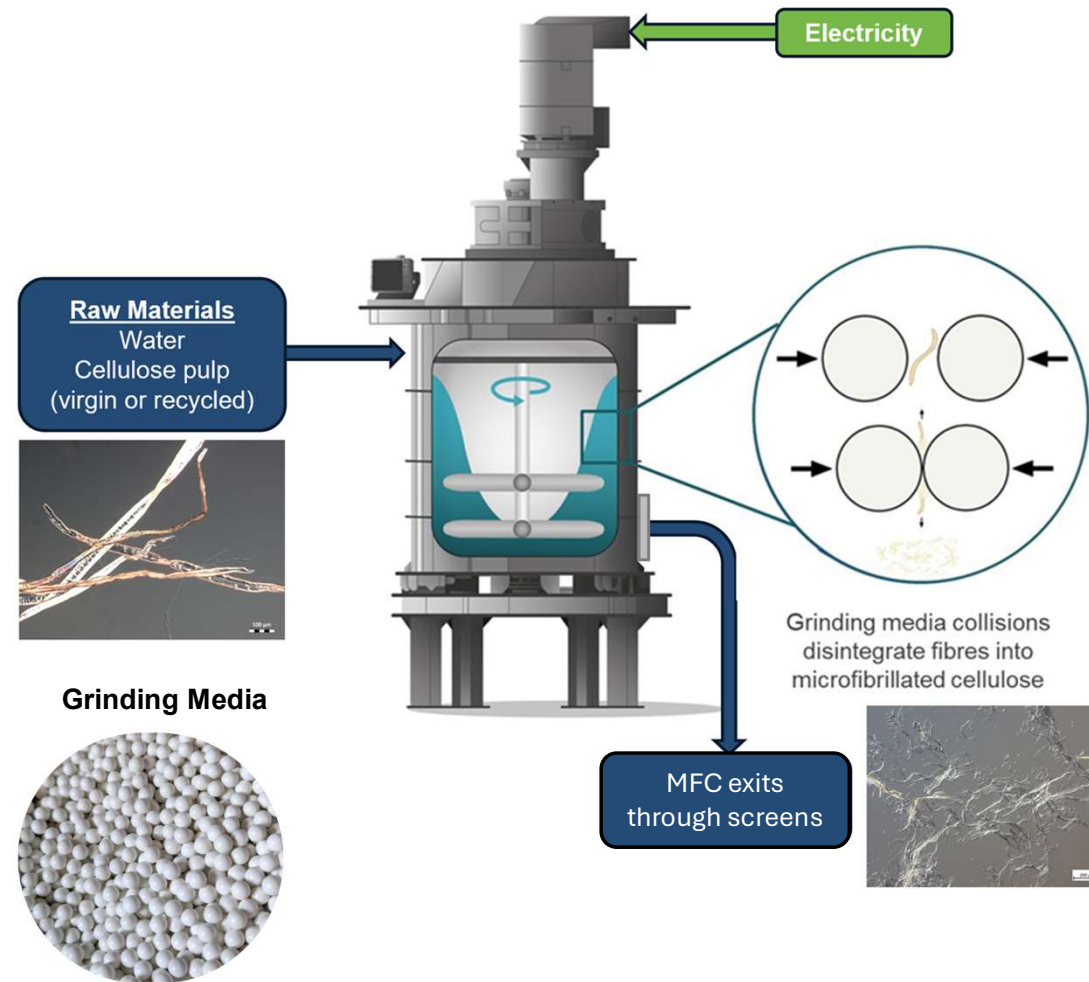
# What is MFC?

- Micro-fibrillated Cellulose (MFC) is made from cellulosic feedstocks such as wood pulp, which are ***mechanically disintegrated*** to liberate their ***fibril and microfibril sub-structures***.
- This greatly increases specific surface area and fibril aspect ratio. Enhances bonding ability.



- When added to the paper-making process, improved mechanical and barrier properties, reduced porosity, smoother surfaces.

# Stirred Media Mill Grinder Working Principles



**Stirred vessel**, charged with water, pulp and **ceramic grinding media**.

**Mechanical method**, no chemical / enzyme pretreatment needed.

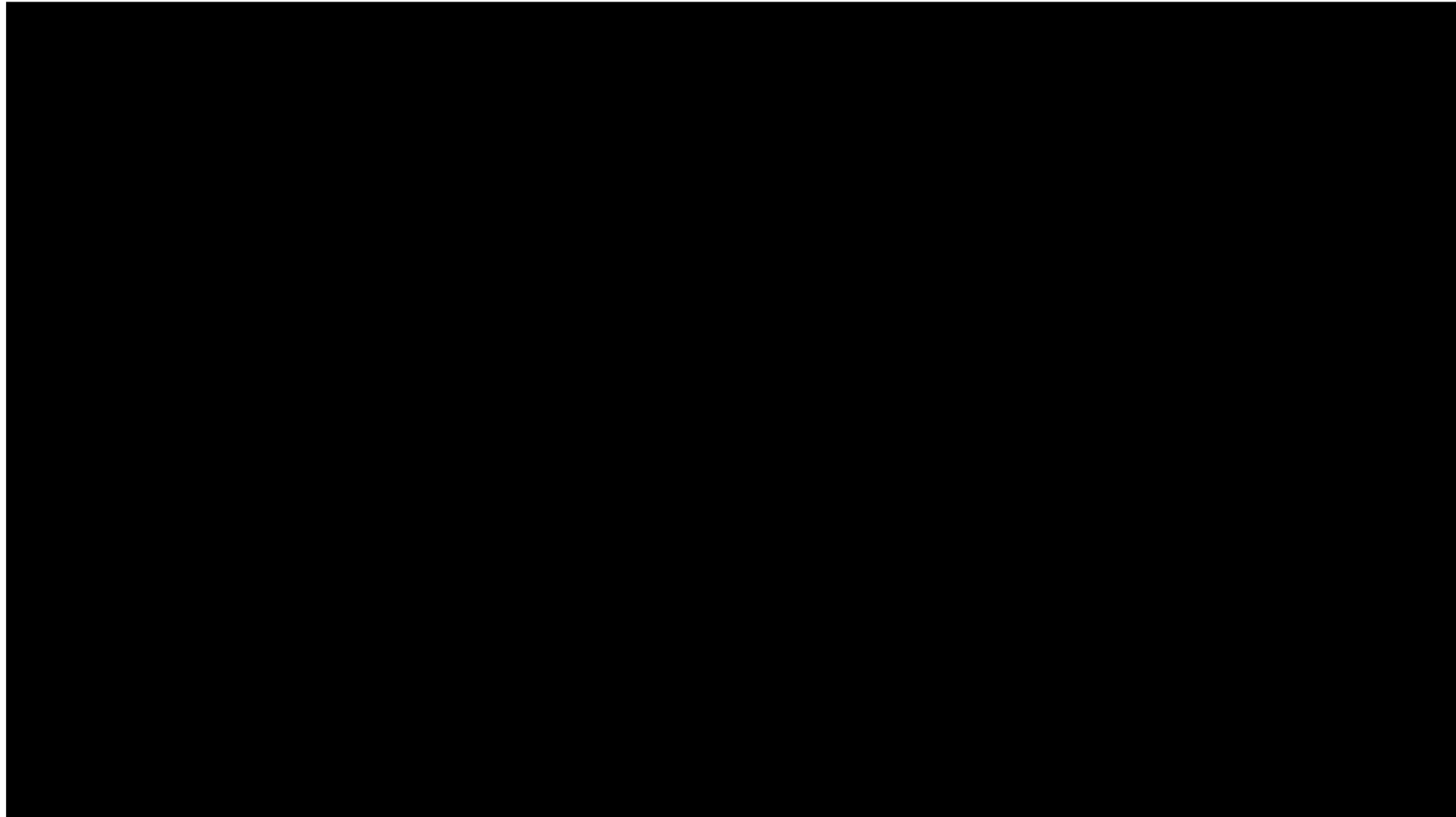
Fibrillation occurs when fibres gets trapped between colliding grinding media particles.

**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; energy input controlled by flow rate and motor power.

Production solids ~ 1-2% - on-site production

# Video of Standard-Scale Grinder in Operation



# 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 / circular economy by enabling plastic replacement in packaging.

# MFC Grinder Sizes



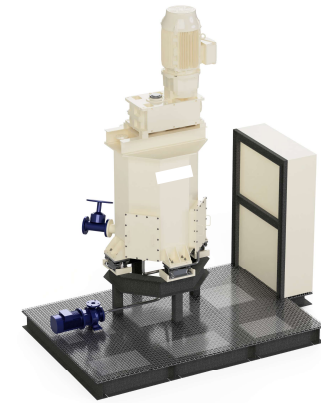
## Large MFC Grinder

Capacity ~ 1200 dry metric tonnes of MFC per grinder per year. Appropriate size for most paper and board applications.



## Medium MFC Grinder

Capacity ~ 400 dry metric tonnes of MFC per grinder per year. Small paper mills, tissue mills.



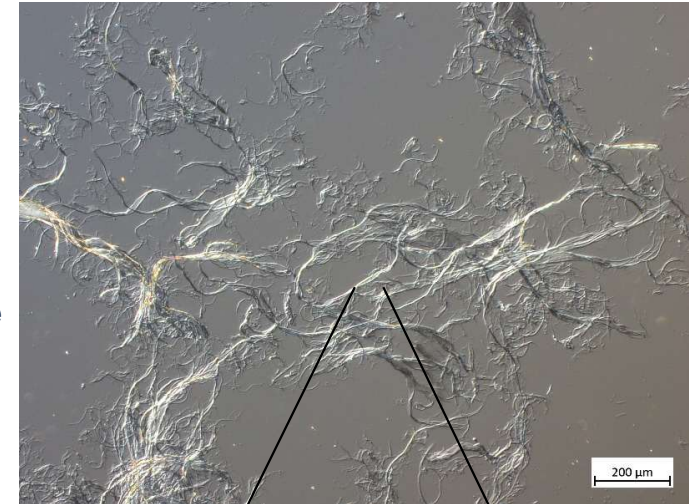
## Small MFC Grinder

Capacity ~ 100 dry metric tonnes of MFC per grinder per year. Speciality applications, moulded fibre etc.

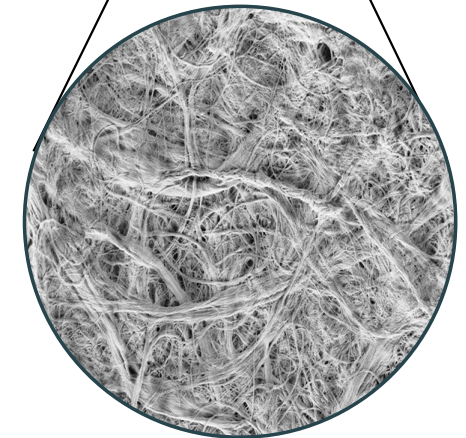
# Morphology of Grinder Produced MFC

- 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 MFC retention**.
- The objective is usually to efficiently generate a **high level of microfibrillation whilst retaining coarse macrostructure**.

Optical micrograph showing MFC coarse macrostructure



SEM showing MFC fibrillar micro and nano structure



# Effect of Morphology: Bonding vs. Bridging

**Bonding:** strength of bonding at particular fibre-fibre joints. Related to **MFC nanostructure**.

**Bridging:** ability of MFC particles to overlap multiple fibres in a sheet. Related to **MFC macrostructure**.

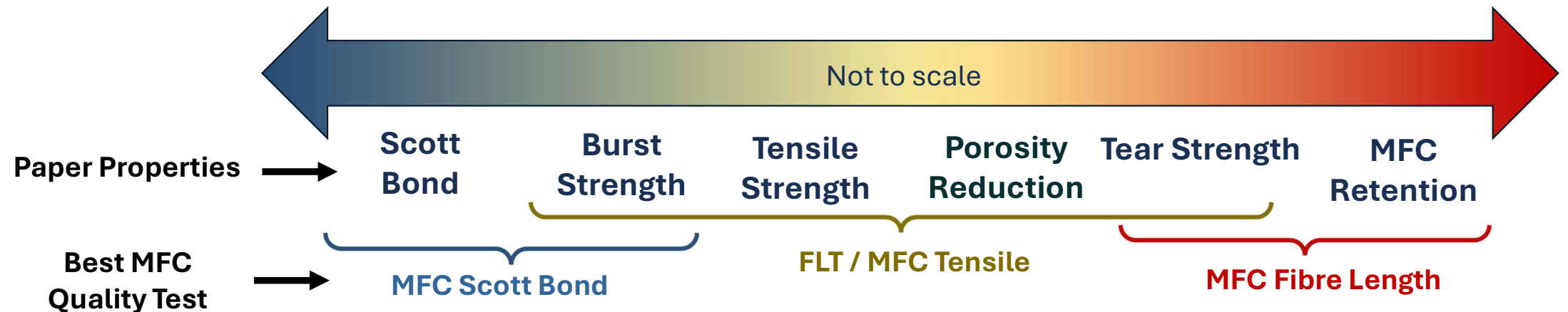
Different paper properties have different dependencies depending on the nature of the failure mechanisms. Improvements in bonding and bridging are **not necessarily mutually exclusive**. One can optimise for both by having a **high degree of fibrillation and a coarse macrostructure**.

## Improved by Bonding

MFC with **high fibrillation surface area** desirable

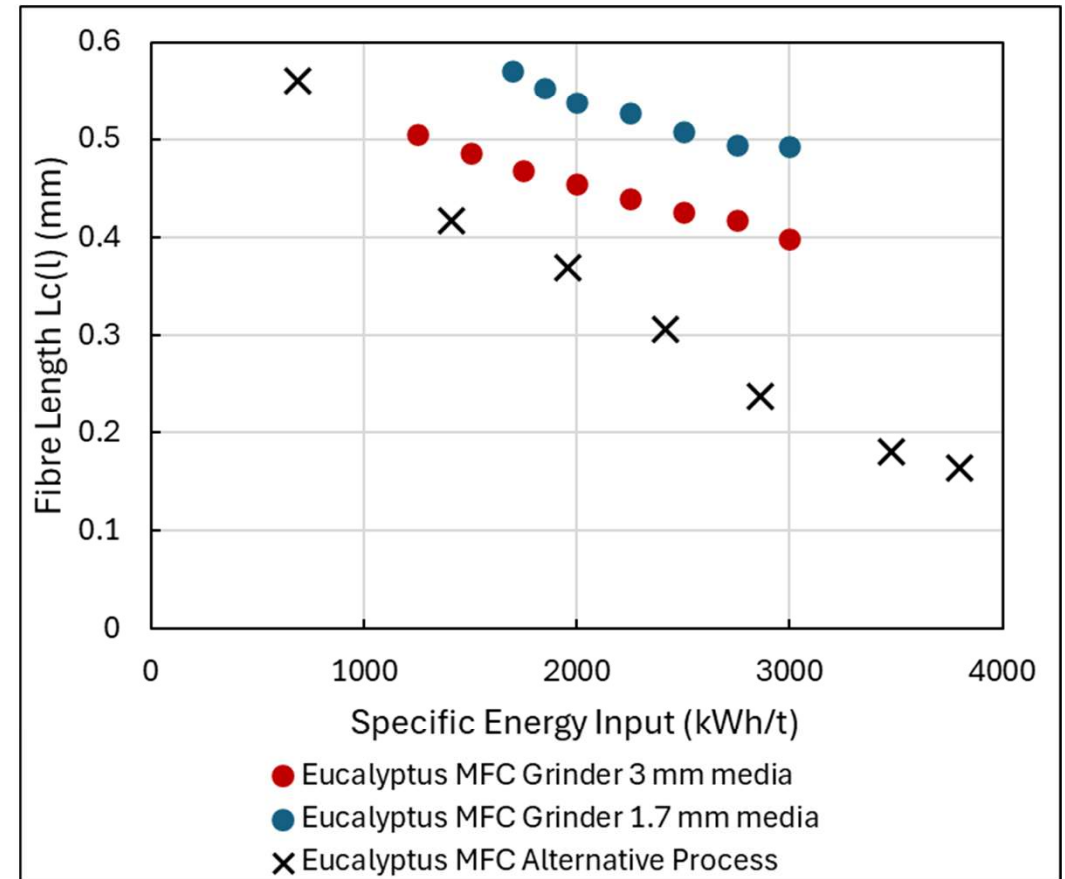
## Improved by Bridging

MFC with **Coarse macrostructure** desirable



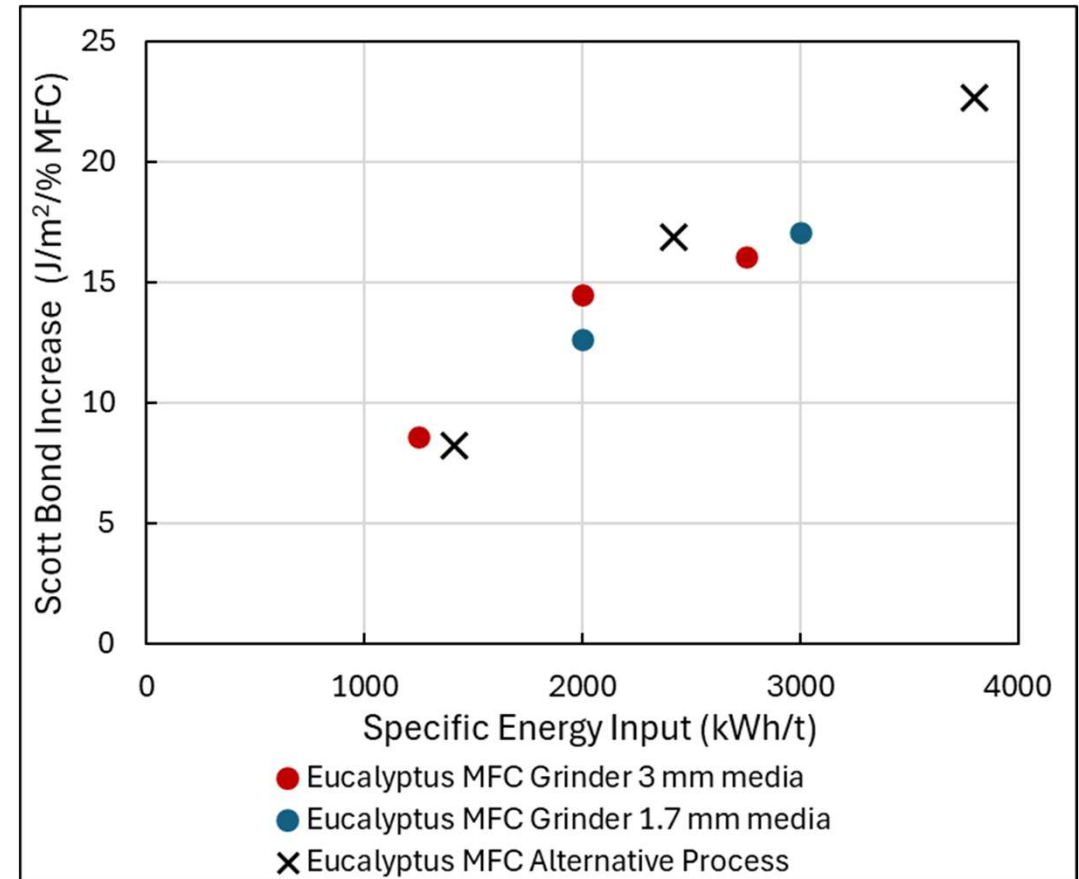
# Grinder MFC 'Size' vs. Alternative MFC

- **Grinder MFC** optimised for general improvements in paper properties **retains a coarse macrostructure whilst comprising fine and high quality microfibrils.**
- Shown is a comparison of fibre lengths of such grinder products versus an alternative MFC production method.
- **The alternative method is much more effective at fibre breakage / size reduction.**



# Performance of MFC in Paper: Scott Bond

- Small amount of MFC added to paper furnish in handsheet study.
- Scott Bond is measurement of *bonding* (i.e. nanostructure).
- Not strongly affected by *bridging* (i.e. insensitive to macrostructure).
- In this example, grinder MFC and alternative method **are equivalently efficient at generating bonding-capable nanostructure.**



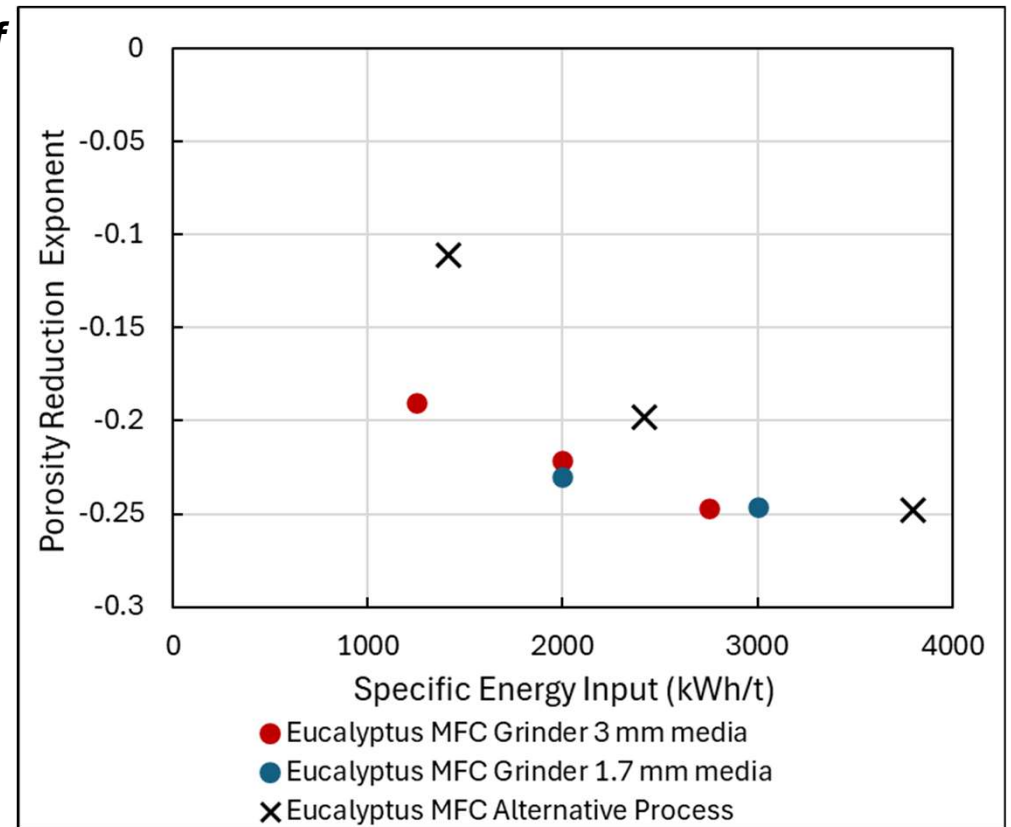
# Performance of MFC in Paper: Porosity

- **Sheet porosity is sensitive to the bridging ability of MFC to close up pores in the sheet.**
- Porosity shows an exponential decay relationship with MFC addition. Graph plots the value of this exponent. **More negative value means more efficient porosity reduction.**
- By maintaining a coarse macrostructure, **grinder MFC is more efficient at reducing porosity** than the alternative method, despite similar bonding ability.

Note: Porosity has an inverse exponential relationship with MFC dose:

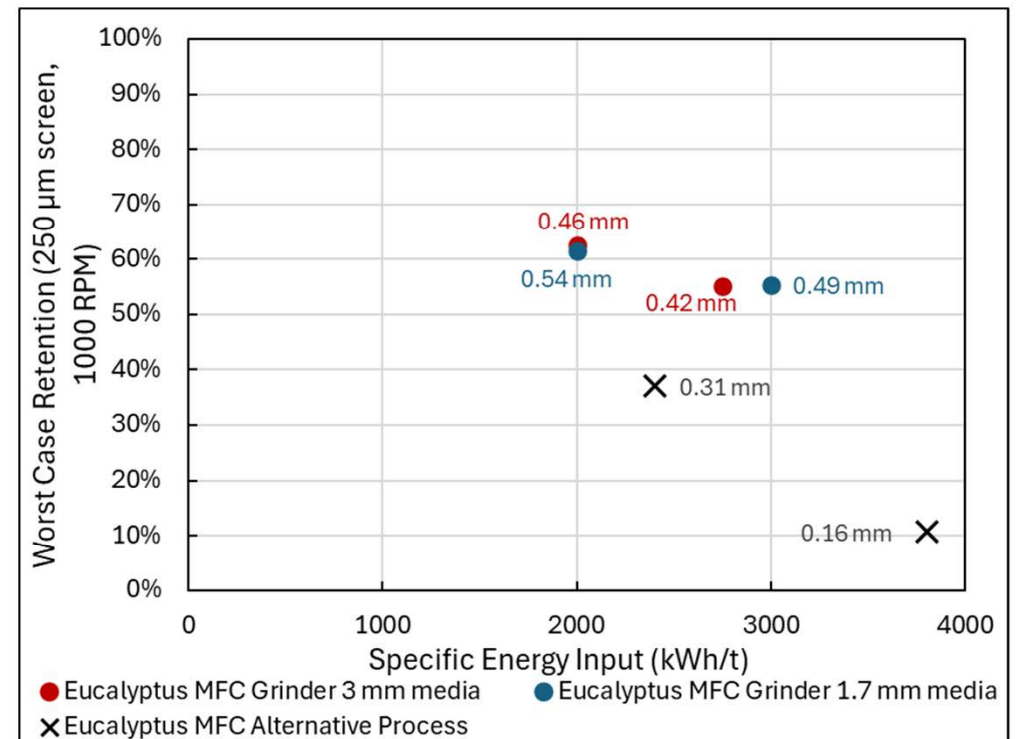
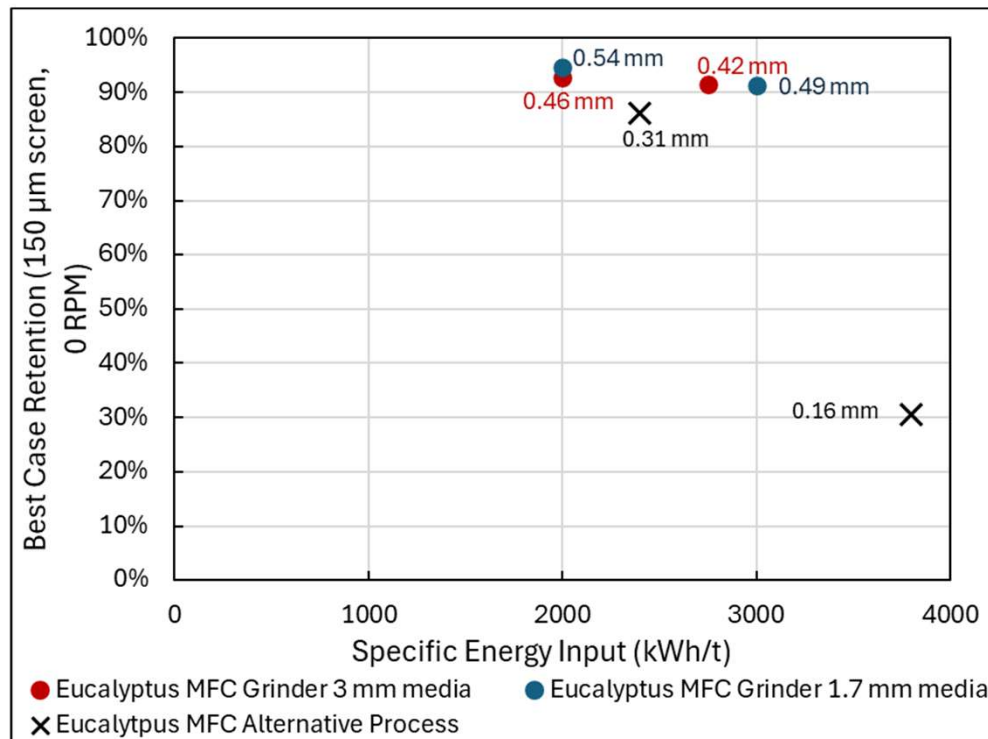
$$\text{Bendtsen Porosity} = Ae^{kd}$$

A = porosity with zero MFC,  $d$  = MFC dose (%),  $k$  = **porosity reduction exponent** (more negative = more effective at reducing porosity).



# MFC Retention

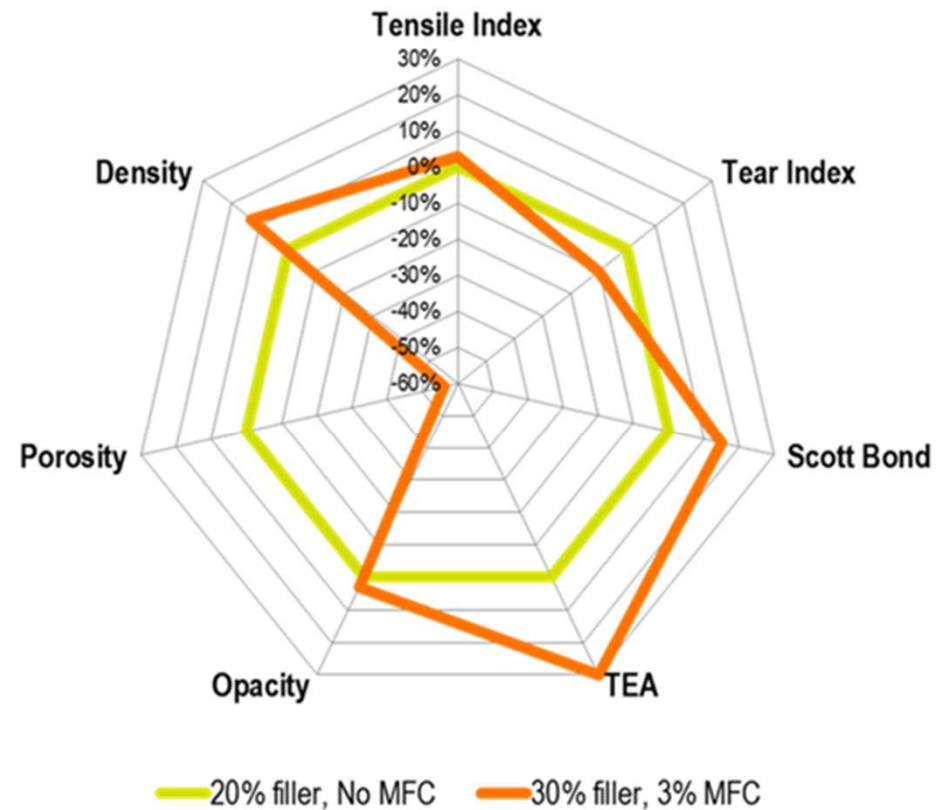
- Graphs show dynamic drainage jar results, data points annotated with Lc(l) fibre length.
- Due to coarser macrostructure size, grinder-produced MFC is better at MFC retention than MFC made by the alternative method at equivalent energy input, despite equivalent bonding ability.



# Grinder-Produced MFC: In paper performance

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

- Improved performance stability.
- 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).
- A smoother sheet.
- Improved coating hold out.
- Loss of bulk and slower drainage are negatives but can be managed.



# MFC Applications 1: In-furnish application

Use of grinder MFC as a furnish component has shown benefits in many applications:

- **Graphic Paper** – filler increase / softwood reduction.
- **Folding box board** – chemical pulp reduction in outer layers.
- **White top liner** – fibre reduction, improved optical properties from formation improvement and filler increase.
- **3D Moulded Objects** – fibre reduction by light-weighting, improved formation, reduced porosity. Potential ~30% weight reduction.
- **Tissue** – fibre reduction by light-weighting.
- **Specialty papers** – various (e.g. low porosity improves coating holdout; significant increases in wet web strength enables low GSM papers).

# MFC Applications 2: Surface application

Use of grinder MFC as a coating layer has also shown benefits applications including:

- **White liner** - Upgrade brown boxboard to WTL with minimal capex.
- **Barriers** – MFC can form a layer which greatly improves oil and grease resistance and oxygen barrier properties for food packaging. MFC can also form a suitably smooth surface for water barrier application.

# MFC Applications: Example 1 – White Top liner

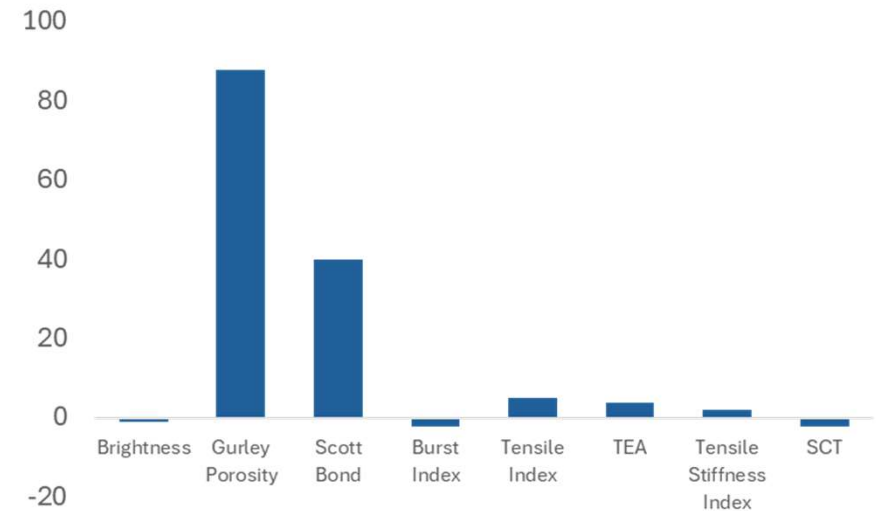
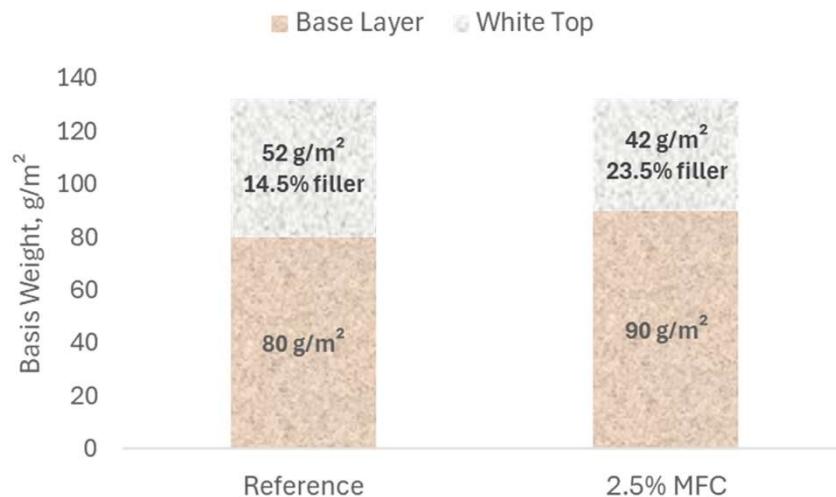
## Case Study – Filler Increase & Lightweighting (White Layer)

### Trial Outcomes:

- 2.5% MFC in white layer.
- +9% filler in the white layer.
- 10 g/m<sup>2</sup> of top layer replaced by brown layer.

### Benefits:

- ✓ **28% reduction of white layer fibre consumption.**
- ✓ Same specification at lower cost.
- ✓ Conditions chosen to maintain brightness.
- ✓ Machine speed and runnability maintained.
- ✓ Maintained filler retention.



# MFC Applications: Example 2 - Moulded objects

Bleached NBSK unrefined: Pilot study



(0% MFC)

(10% MFC)

(17% MFC)

KIT = 0 out of 12

KIT = 0 out of 12

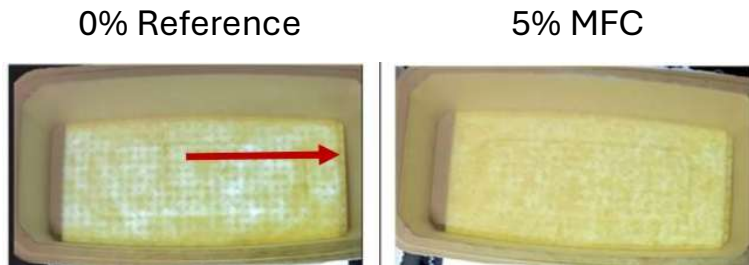
KIT = 4 out of 12

MFC Content (%)	Tray Basis Weight (g/m <sup>2</sup> )	Tensile stiffness index (N m g <sup>-1</sup> )	Tensile strength index (N m g <sup>-1</sup> )	Tensile stiffness (N m <sup>-1</sup> )	Tensile strength (N m <sup>-1</sup> )	Bendtsen Porosity (ml min <sup>-1</sup> )
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.**

# MFC Applications: Example 2 - Moulded objects

## Commercial trial results, 5% grinder 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.

# MFC as a coating: Example 3 - Wet-end coating



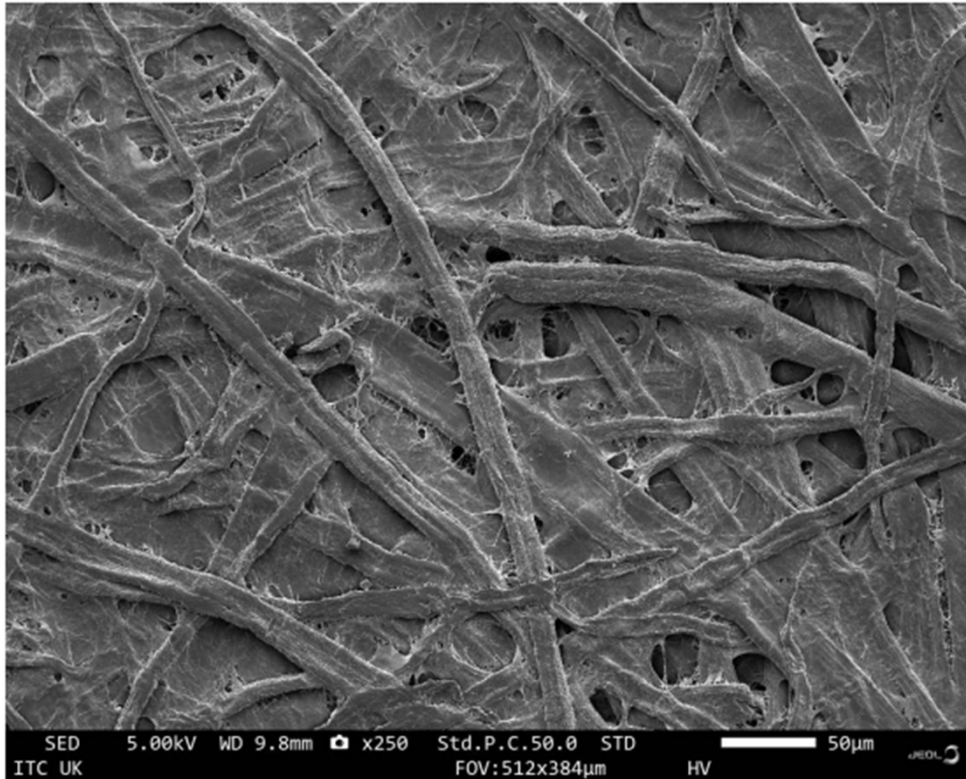
**MFC is applied during the paper making process using surface applicator**

*Image: 3-meter wide surface applicator operating on a paper machine running at 500 m/min*

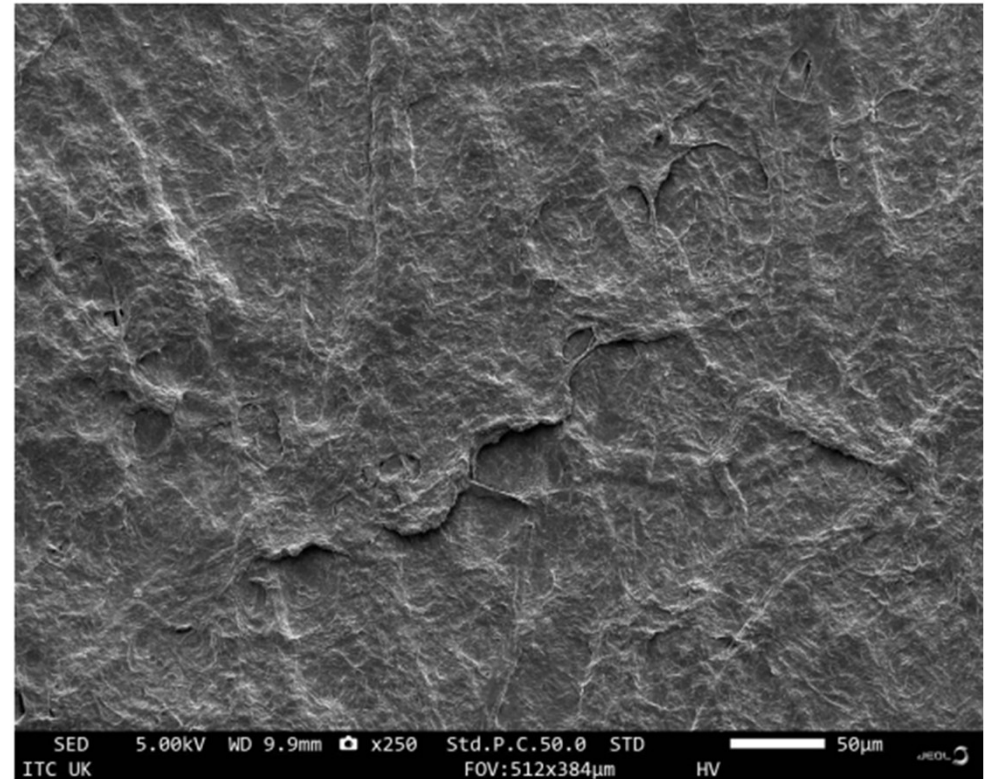
- Specifically designed for application of optimized MFC with jet speed similar to wire speed, i.e., at high-shear conditions. Gradual shear-thinning of MFC through the approach flow system and applicator with maintained laminar flow.
- Low cost and light weight, for easy mounting across paper machine.
- Working with a major coating equipment manufacturer to provide the engineering, fabrication and servicing of these applicators.

# MFC as a coating: Example 3 - Wet-end coating

SEM – Surface imaging

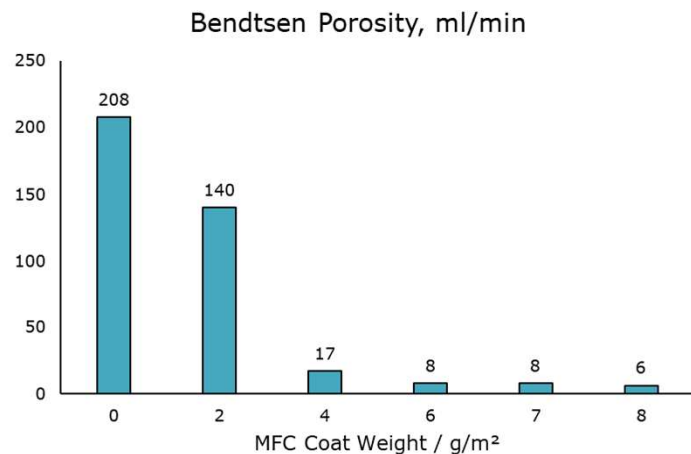
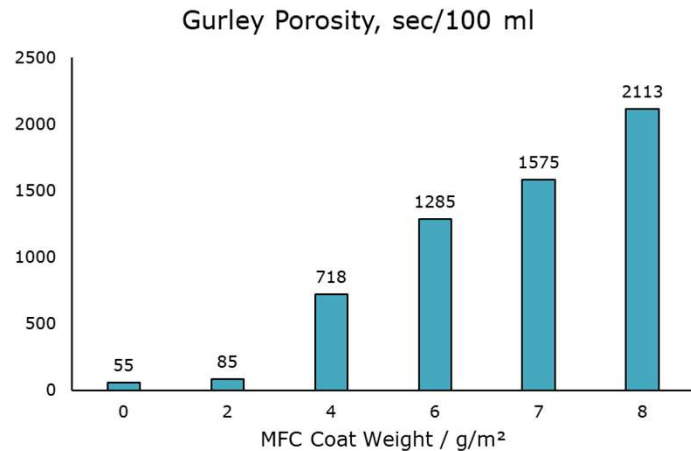


Base paper reference 45 g/m<sup>2</sup> (0 g/m<sup>2</sup> MFC)

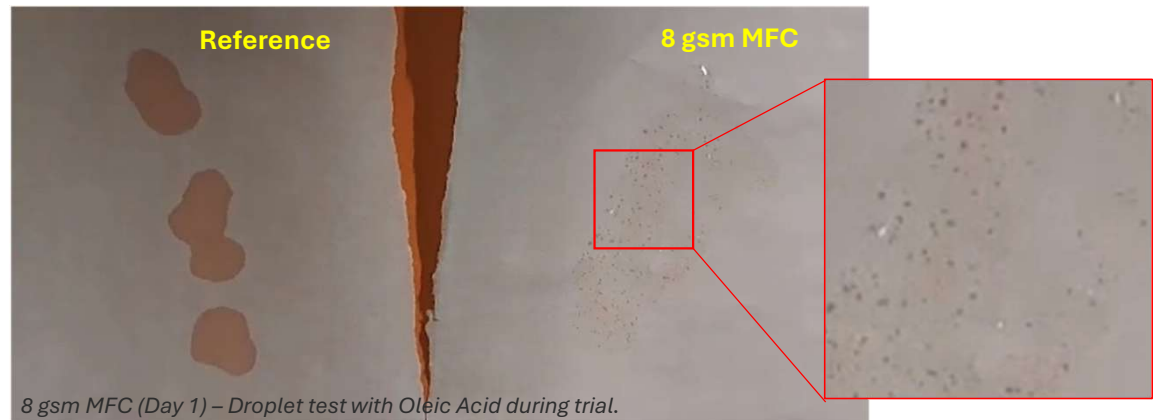


MFC coated paper 45 g/m<sup>2</sup> (+6 g/m<sup>2</sup> MFC)

# MFC as a coating: Example 3 - Wet-end coating



- Significant closure of the sheet was observed through the application of MFC.
- Pinholes were visible in oil draw down tests, so the surface was not yet “completely closed” to a point where barrier properties could be achieved.
- Nonetheless, the significantly lower permeability should enable improved performance of topcoats applied or enable a reduction in topcoat weight to achieve a target performance.
- **Post trial addition of starch coating by customers resulted in chemical free-mid level grease resistant paper for fast food wrap.**



# Summary

- Wet-stirred media grinders are an efficient and high throughput method for producing MFC.
- High quality MFC can be produced from a wide range of feed fibres with little to no equipment modification.
- 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 wet-stirred media grinders allows lighter products, reducing transport related emissions and supports recyclability and the circular economy by enabling plastic replacement in packaging.
- Use of MFC in paper and board leads to enhanced mechanical properties and reduced porosity sheets.
- Hence, offers opportunities for considerable cost savings in many specialty paper and board segments.
- Use of MFC both “in” and “on” moulded objects offers opportunities for lightweighting and property improvement.
- Implementation of wet-stirred media grinders is well established.



# Thank you for your attention

[david.skuse@fiberlean.com](mailto:david.skuse@fiberlean.com)

[www.fiberlean.com](http://www.fiberlean.com)