The use of minerals in fiber-based packaging and pulp molding

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ABSTRACT: Minerals are widely used in the pulp and paper industry for aiding the processing, economics, and final quality of fiber-based products. Among these, calcium carbonate, talc, and kaolin are widely used as fillers, and these can have varying brightness, particle size distributions, and aspect ratios. For the molded fiber area, these minerals can raise the solids content of the pulp mixture and improve throughput and lower energy requirements for drying. Talc is also widely used as a process control agent, picking up pitch and stickies and improving productivity by lowering machine cleaning time.

The replacement of single use plastic with fiber-based replacements is a global trend; however, it does come with some significant challenges, such as grease and moisture proofing. Previously, per- and polyfluoroalkyl substances (PFAS) have been used to provide functions such as water and grease repellency, but regulatory demands have seen its demise in the packaging industry. Therefore, water holdout is now generally achieved by addition of alkyl ketene dimer (AKD) sizing. Wax additives are being developed and tested as PFAS replacements for oil and grease resistance. Rather than strongly repelling lipids from the fiber surface, these PFAS alternatives restrict flow pathways and react with food oils to alter their flow characteristics to prevent penetration through the substrate. During studies incorporating both PFAS substitutes and minerals, no detrimental interactions were observed.

This paper addresses the different needs of the molded fiber market by including mineral fillers in molded fiber articles and will be presented as a series of different case studies. In all studies, we show that the trends observed when mineral filler is added to molded fiber are broadly similar to those seen in conventional paper and paperboard applications. Mineral addition in all studies gave improvements in productivity and optical appearance. With its organophilic surface, hydrophobic talc had the additional advantage of pitch and sticky control, and although a small decrease in strength was always observed when filler was added, the final articles still retained sufficient strength for their particular application. This small strength reduction should be balanced against the productivity gains.

Application: Molded fiber products have attracted increasing attention due to their sustainable advantages. Minerals, when added as a filler to these molded fiber articles, can bring additional benefits for the molded fiber producers, including, but not limited to, significant productivity gains.

The molded fiber packaging market is gaining in importance and market share, fueled by consumer drive and a growing preference for recyclable and ecofriendly materials [1]. Recently, regulations restricting the use of single use plastics gave another boost to growth opportunities [2]. An excellent review by Zhang et al. [3] provides an overview for the potential of molded fiber products as sustainable alternatives to plastic. The global molded pulp packaging market size is projected to be worth around US$5.89 billion by 2027, according to information published by Vision Research Reports [4]. They also projected a compound annual growth rate (CAGR) for this market of 5.3% over the period of 2020-2027. Wood pulp as raw material accounts for > 90% (by revenue). However, several molded fiber producers are looking at nonwood fibers such as bagasse. The transfer molded fiber segment accounted for the highest market share in 2018. However, the thermoformed molded segment is expected to have the highest growth rate owing to its potential to be used in foodservice and packaging for electronics industries.

The four key market areas for molded fiber as suggested by the International Molded Fiber Association (IMFA) are [5]:

- Food related (clam shell, cups, bowls, serving trays, fruit punnets, and egg trays, which accounted for around 75% market share in 2020).
- Industrial or engineered packaging (electronics, cell phones, industrial products, tools, plumbing, vehicle parts, and household items like furniture).
- Single-use medical (bedpans and washbowls).
- Horticultural trays and pots.

It is widely understood that the carbon dioxide (CO_2) footprint of the food packaging is small compared to that of the food it protects. For example, Huhtamaki [6] suggests that packaging generally represents some 5% of the total carbon footprint of the food product, while 80% is caused by growing and preparing the food, and 15% is caused by transport. However, the carbon footprint of the packaging material itself and its ability to be reused, recycled, or composted is still of great importance. This opens up the potential for molded fiber to be used as a replacement for single-use plastic and polystyrene packaging.

It has been extensively reported that the inclusion of fillers into paper and paperboard products has the potential to increase the drainage and drying rate and improve productivity [7,8]. Fillers such as kaolin, calcium carbonate, and talc are often combined with fiber to impact final properties. Each mineral can differ in their particle size distribution (average size and range of particle sizes), state of aggregation, brightness, particle shape, color (light absorption coefficient *K*), and surface charge. In a similar manner to the paper industry, the different particles can also have various influences on the optical properties, strength, bulk, drainage, and drying times in molded fiber products. Functional fillers, added in small concentrations, could also be used to control process parameters such as pitch and sticky buildup. There are some challenges with using high filler loading, including loss of sheet strength [9] and bulk and alteration of the chemistry of the papermaking process, including increased size consumption [10-13]. However, it was reported by Poraj-Kozminski that alkyl ketene dimer (AKD) size consumption was driven by interactions between the fiber fines and AKD (covalent bonds forming with the cellulose) and was not impacted by filler addition, such as calcium carbonate [14]. However, there are other levers that can be used to optimize the product value/performance and help mitigate these challenges. The mechanical performance and the value/price of molded pulp products is influenced by fiber sources (virgin fiber vs. recycled fibers), molding processes (especially drying processes), and different post-treatments. The wide range of applications using this technology necessitates an investigation into the strength requirements for each specific case. Measurements of tensile and compressive strength, bending stiffness, etc., can be used in the assessment of the strength of the product. An example of this type of work has been reported by Morimanno [15], who showed that addition of ground calcium carbonate (GCC) to molded fiber gave improved surface finish and brightness and reduced energy consumption on drying. Also, although this research showed reduction in strength, minerals did not appear to adversely impact the rigidity.

In this paper, a series of case studies is presented where mineral addition is used to modify process and quality parameters in molded fiber products.

MATERIAL AND METHODS

We present three case studies where minerals have been included as fillers in molded fiber articles. Each study will highlight different aspects of mineral benefit in molded fiber. Details of the three case studies are found in the following sections.

Case study 1: Kiefel plant trial

The Natureformer KFT lab machine at Kiefel in Freilassing, Germany, was used to produce thermoformed cups. Fine and ultrafine talcs were added to bagasse pulp that had been prepared by dispersion in water but with no refining. One aspect of bagasse pulp is its propensity to stick to the mold due to residual sugar from the pulp. Therefore, the sticking and release of the cup from the heated dryer mold was assessed, as well as the dry content of the article after pressing. The fillers were added at dose rates of 20% to the furnish mix at the pulp disintegration stage, followed by 0.1% retention polymer. The thermoformer parameters used included: suction time of 0.5–1.0 s, press time of ~7 s, drying time of 10–15 s at 200°C. Pigment parameters were:

a. Fine talc: average particle size (d50) = 3.5 µm (as measured by SediGraph; Micromeritics; Norcross, GA, USA); whiteness = 70%Y.
b. Ultrafine talc: average particle size (d50) = 1.1 µm (as measured by SediGraph); whiteness = 91%Y.

Case study 2: University of Maine laboratory study

Again, the Kiefel Natureformer lab machine was used but this time at the University of Maine (Orono, ME, USA). The formed article was a shallow food tray. A blend of unrefined (550 mL CSF) and refined (310 mL CSF) bleached hardwood pulp was used. Fillers were added at 5%, 10%, and 15% dose levels. The wet-end chemistry involved using a commercially available PFAS-free system: biobased wax at 8.5% addition, AKD sizing agent at 1.0% addition, cationic retention aid at 0.2% addition, and anionic retention aid at 0.1% addition. There was a hold time of 1 min after each filler or additive addition to allow the process to stabilize. Observations made included:

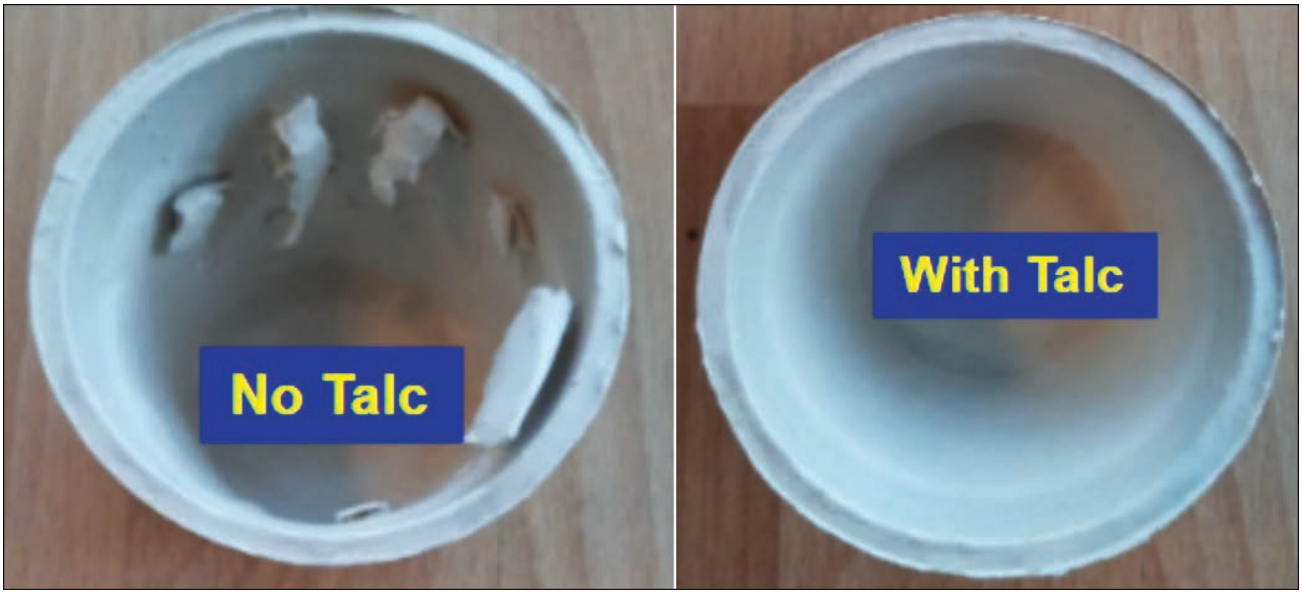
- Runnability.
- Brightness, using Technidyne ColorTouchX, source C, illumination/observer C/2 (Technidyne; New Albany, IN, USA).
- Oil barrier performance, measured by oil weight absorption (hot oil at 60°C in contact with the tray for 30 min). Samples were conditioned and tested in accordance with TAPPI Standard Test Method T 402 “Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products."
- Stain rating (5 = no interior stain; 4 = interior stain, no show through; 3 = minor show through (spotting); 2 = show through < 50% of backside surface area; 1 = show through > 50% of backside surface area, 0 = show through complete saturation).

Pigment parameters were:

a. Coarse GCC: average particle size (d50) = 12 µm (as measured by SediGraph); brightness Hunter Y = 93.
b. Coarse kaolin: average particle size (d50) = 3.1 µm (as measured by SediGraph); brightness = 89%Y.

Case study 3: Molded fiber producer

A molded fiber producer in Belgium produced a range of food service trays (weight ~28 g, ~17 cm x 22 cm x 3 cm in



1. Benefit from the talc, which allows easier release of the article from the mold.

dimension). The intended use of the trays was food service with a shelf life of up to 12 months. A mix of long and short fiber chemithermomechanical pulp (CTMP) was used at 1% solids, with a drying time of around 30 s at 250°C. An undisclosed amount of a proprietary sizing agent was added to create the desired water resistance. Both kaolin and talc pigments (with the following specifications) were added directly to the pulp in the storage tank:

a. Kaolin: average particle size (d50) = 1.9 µm (as measured by SediGraph); brightness = 92%Y.
b. Talc: average particle size (d50) = 9.8 µm (as measured by SediGraph); whiteness = 86%Y.

The wt% solids of the articles were determined after the press. Visual observations of the boards were made, and strength testing was conducted using a Tinius Olsen Compression tester with 10kN load cell (Tinius Olsen; Redhill, UK).

RESULTS AND DISCUSSION

Case study 1: Kiefel plant trial

The study in conjunction with Kiefel in Germany showed that fine and ultrafine talc added to the production run of thermoformed cups improved the dry content after pressing. Using ultrafine talc, the dry content after pressing was raised by 4% (32% to 36%), while use of fine talc raised the dry content after pressing by 2% (34% to 36%). Approximately 9% of filler reduced the drying energy by ~ 15%. As a further benefit, the talc allowed easier release of the article from the mold (**Fig. 1**) when using harder to process bagasse fiber. Bagasse is the fibrous byproduct that remains after crushing sugarcane for the sugar and alcohol industries. It has a propensity to stick to the mold in the thermoforming process due to residual sugar from the pulp. In this trial, just 2% talc was added to achieve the improved release.

Case study 2: University of Maine laboratory study

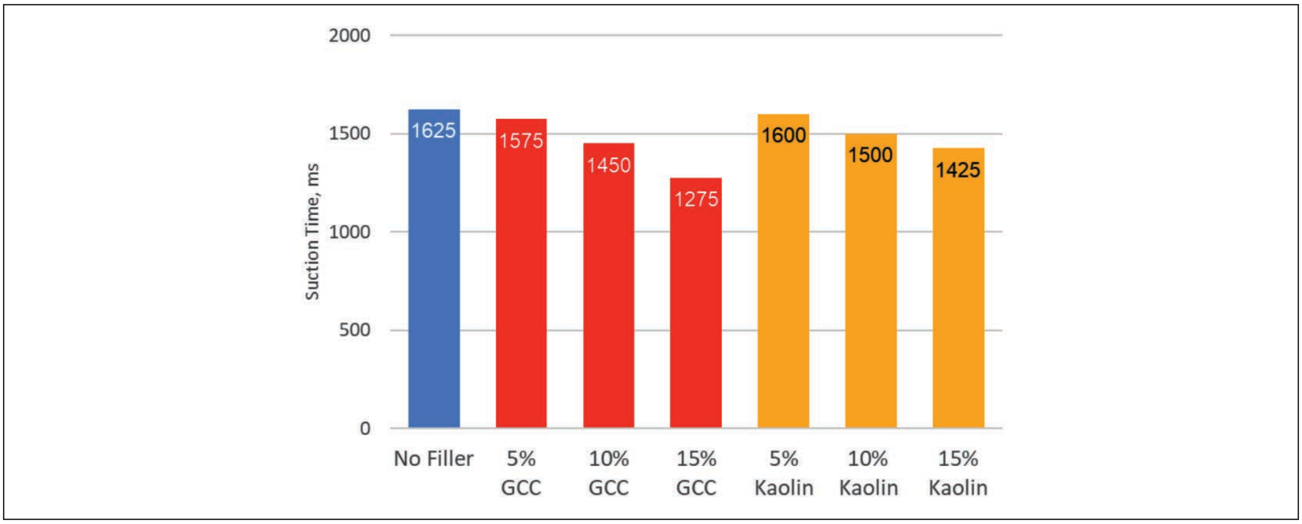
In the second study using the Kiefel former at the University of Maine Process Development Center, the added filler reduced the required suction time (Fig. 2), suggesting less water was present that needed to be removed to improve drainage. We also observed reduced cycle time, but University personnel indicated that several additional factors could influence measurement of cycle time.

We observed an improvement in brightness with addition of kaolin but a slight decrease with addition of coarse GCC (**Fig. 3**). Even though the pigment brightness of the coarse GCC is higher, its large particle size resulted in lower scatter, and hence, lower brightness.

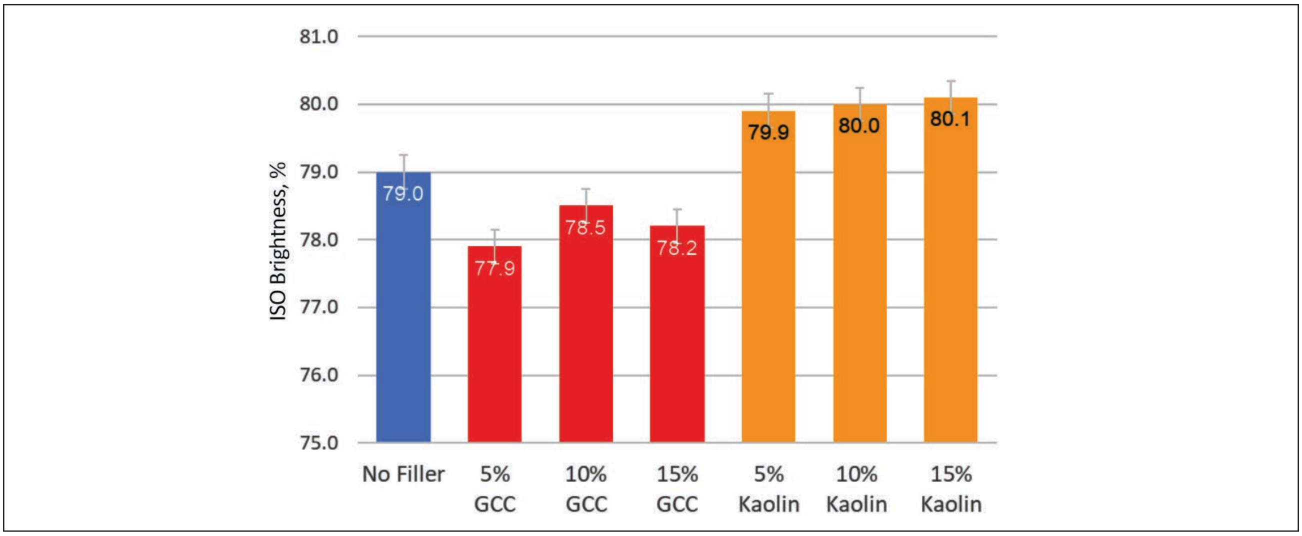
Filler loadings of 5% and 10% had lower-to-equal oil absorption, while oil absorption increased at 15% target loading for both mineral fillers, as shown in **Fig. 4**. Articles containing kaolin had improved stain rating (rating 5 at 5% and 10% loading) compared to the control without filler (rating of 3) and those containing 5% and 10% GCC (ratings of 4 and 3, respectively). This suggested that the platy nature of kaolin provided improved holdout properties vs. the blocky nature of the GCC. All results suggested no negative impact, once mineral level is optimized, on the oil barrier performance imparted by the waxy PFAS substitutes used in the study.

Case study 3: Molded fiber producer

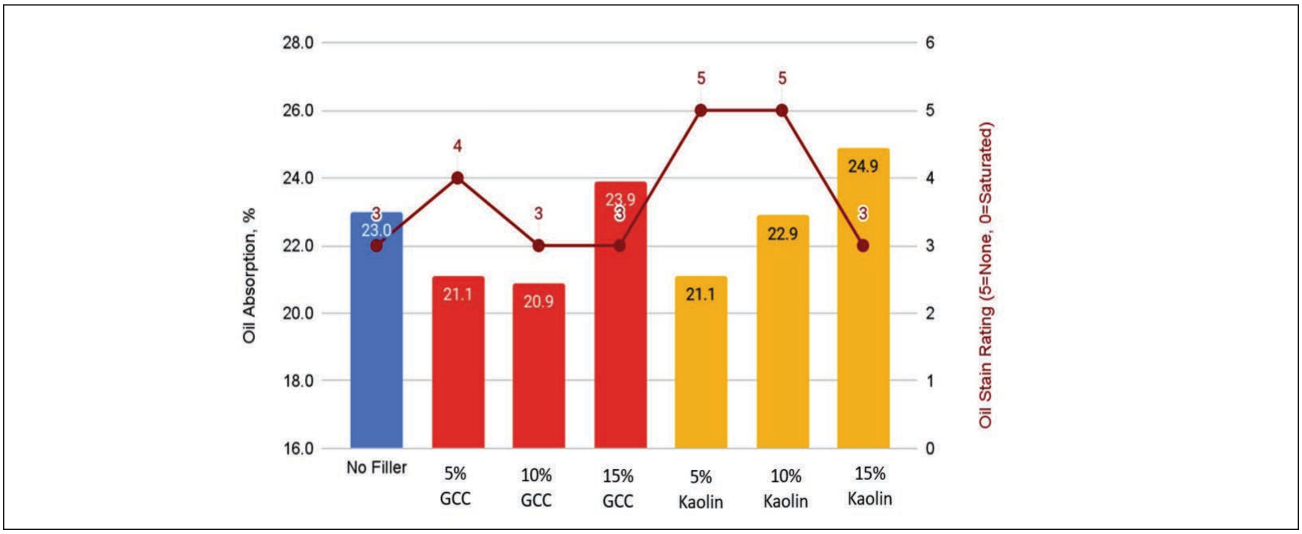
Finally, a plant trial at a mill in Belgium was used to produce a range of food service trays, and in this case coarse kaolin and talc were added directly to the pulp (**Table I**).



2. Suction time measurements (GCC: ground calcium carbonate).



3. ISO brightness measurements.



4. Barrier performance measured by absorption and stain rating.

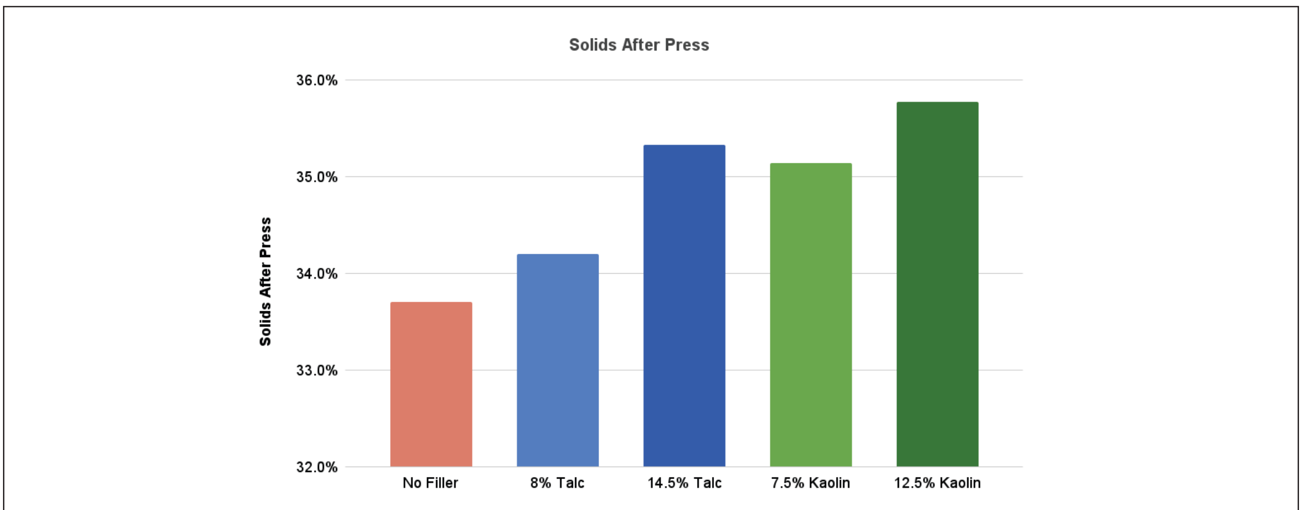
The wt% solids of the articles were determined after the press, and it was shown that the measured dry content after pressing increased between 0.5% and 2.1% (**Fig. 5**).

Optical appearance of the trays was improved with the inclusion of minerals. Looking against daylight (**Fig. 6**), one can see that both talc and kaolin significantly increased the opacity compared to the tray without any filler added (middle).

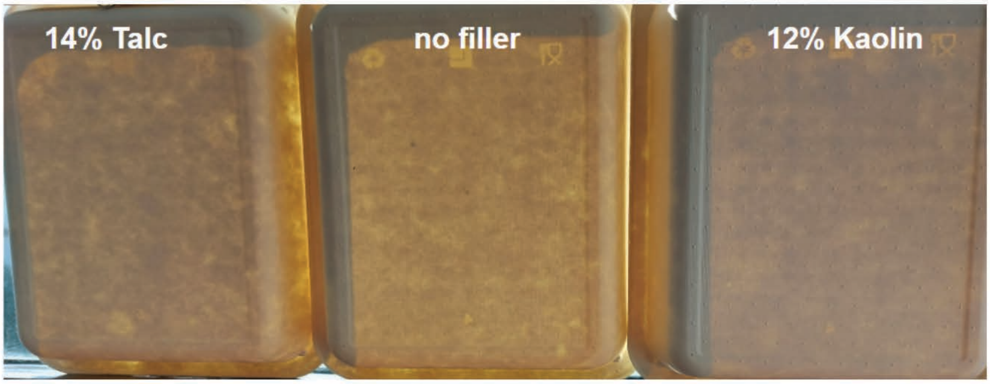
Cross sections of the trays and mapping of the filler distribution within the cross section (**Fig. 7**) showed that the minerals are evenly distributed throughout the tray. The finer kaolin particles provided additional light scattering

Ash content	Sample	No Filler		10% Talc		20% Talc		10% Kaolin		20% Kaolin	
	Ash %	0.6%		8.0%		14.5%		7.5%		12.5%	
	Retention %			74%		70%		69%		60%	
Optical properties		Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
	Y %	81.8	81.8	82.8	81.9	83.2	82.4	83.8	83.1	84.5	84.2
	Ry %	70.4	69.3	71.3	69.5	72.4	70.7	72.1	70.4	73.4	72.8
	L	92.5	92.5	92.9	92.6	93.1	92.7	93.4	93.0	93.7	93.6
	a	-0.5	-0.7	-0.6	-0.7	-0.6	-0.6	-0.8	-0.8	-0.8	-0.7
	b	10.3	11.3	10.2	11.2	9.6	10.6	10.4	11.4	0.8	10.1
Porosity	Bendtsen average, mL/min	40	38	51	51	43					
	Bendtsen standard deviation	9	9	7	19	12					
	Gurley average, s	315	329	237	273	304					
	Gurley standard deviation	72	73	32	116	102					
Thickness bottom, µm		Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2
	Average, µm	710	772	750	735	752	734	693	754	770	732
	Standard deviation, µm	7	7	10	9	6	13	10	4	7	23

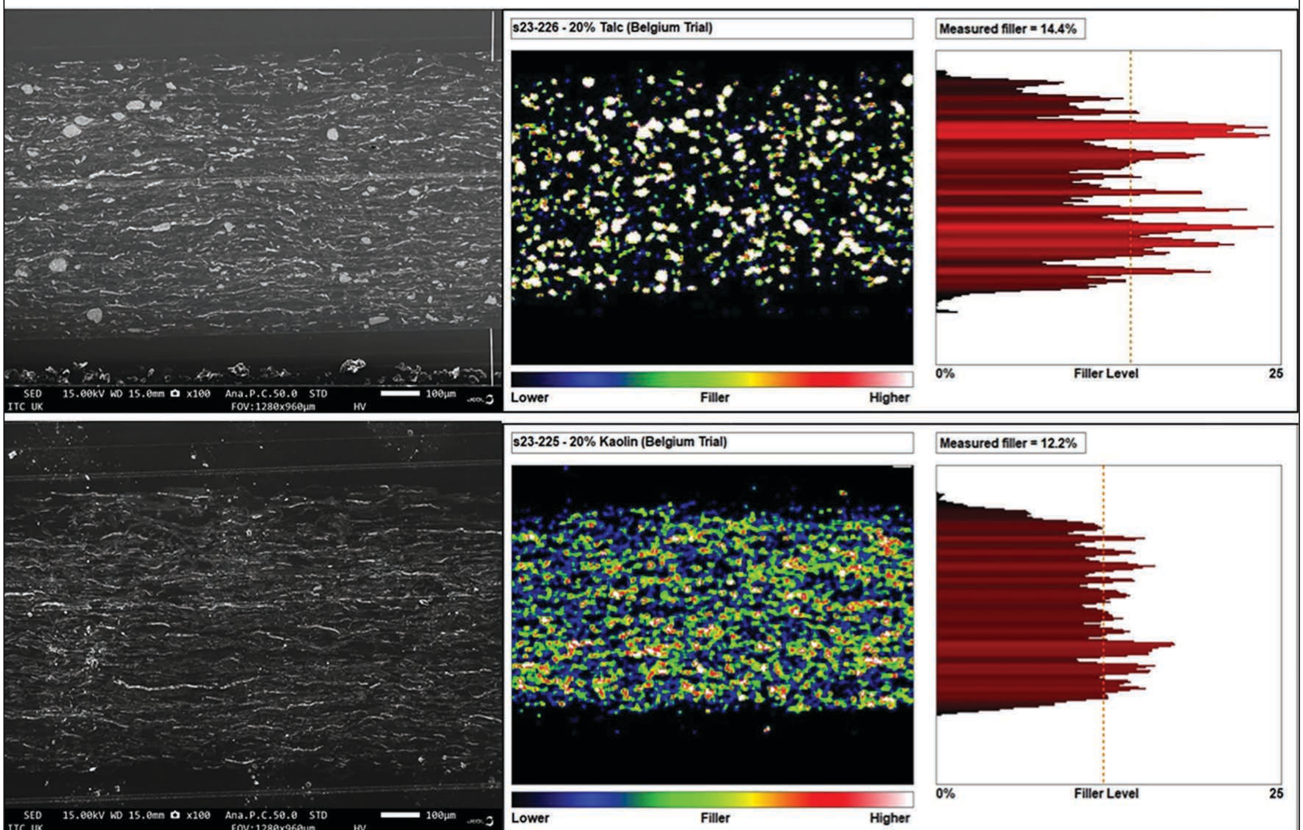
I. Measured properties of the produced samples



5. The wt% solids of the food service trays determined after the press.



6. Photographs of food trays, looking against daylight.



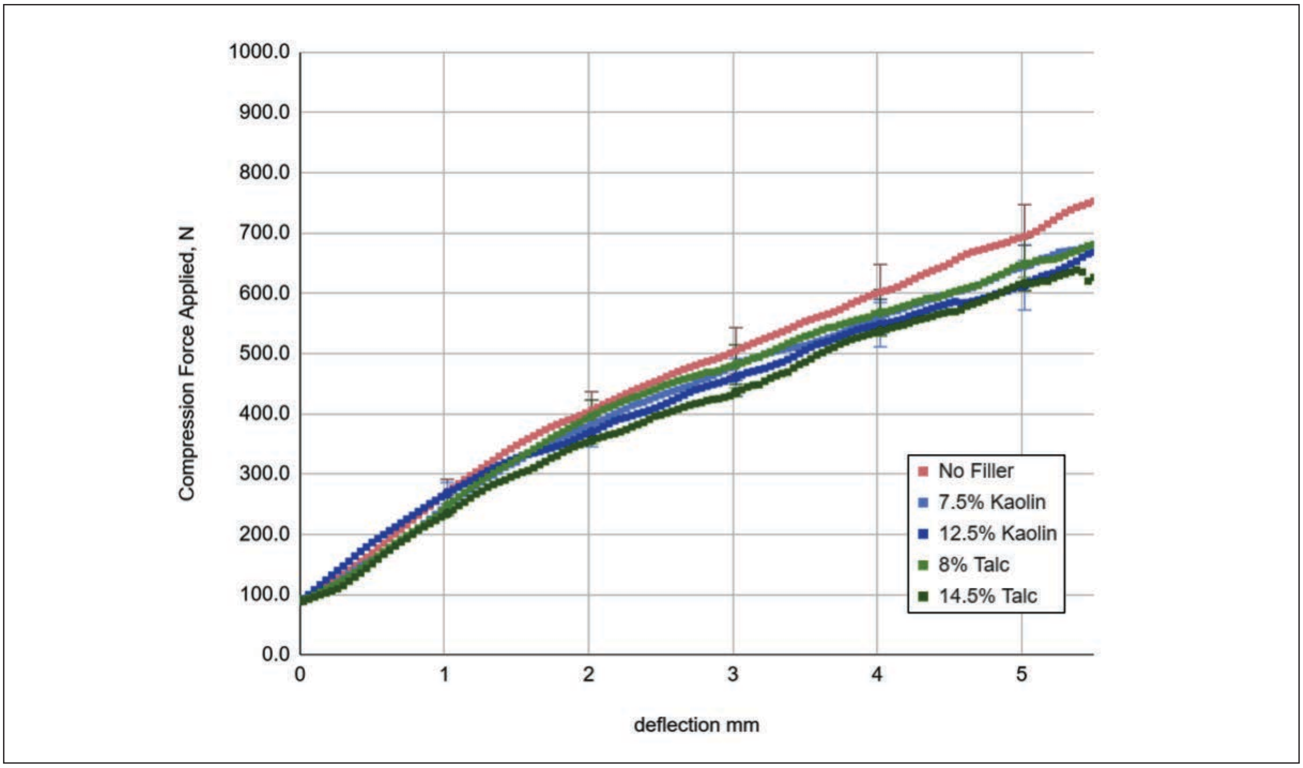
7. Cross of the trays and mapping of the filler distribution within the cross section.

points and increased the opacity compared to the talc, which reduced the "cloudiness" of the trays.

Compression testing on these trays indicated a small decrease in strength with increased mineral loading (**Fig. 8**). As illustrated in the photos shown in **Fig. 9**, the trays only showed a small buckling of the corners/edges under high compressive force. However, "sufficient strength" for the particular application should be balanced against the productivity gains.

CONCLUSION

This work showed that the trends observed when mineral filler is added to molded fiber are broadly similar to those seen in conventional paper and paperboard applications. In all of the trial work, filler addition to molded fiber gave an improvement in productivity, with a higher solids content and a lower amount of water required to be removed by evaporation. In addition, the hydrophobic talc modified the surface, allowing easier release from the mold, and due to its organophilic surface, it is also



8. Compression testing results.

9. Photographs of food trays after compression testing.

likely to have the advantage of pitch and sticky control.

The work carried out at University of Maine confirmed that addition of filler had no negative impact on the barrier performance imparted by PFAS substitutes. A small decrease in strength was observed when filler was added, but the final molded fiber articles still retained more than sufficient strength for the particular application. This small strength reduction should also be balanced against the significant productivity gains. **TJ**

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About this journal

ABOUT THE AUTHORS

We conducted this research to expand our application of minerals to the molded fiber market. This work verified the concepts we know for applications of filler in more conventional papermaking markets and extended these concepts to the molded fiber market.

The most difficult aspect of this research was determining a proper filler retention system. This was accomplished through partnerships with retention aid manufacturers and the producing mill.

It was interesting to discover the many types of molded fiber articles and the various processes used in production. We learned that the addition of fillers at 5%–10% substitution level did not cause detrimental interactions with PFAS replacement chemistries.

Addition of fillers at 5%–10% substitution level will allow molded fiber producers to reduce raw material costs, as well as gain improvements in productivity, smoothness, and appearance. Our next step is to continue to partner with molded fiber producers and provide benefits through filler addition.

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