Application note

Uncovering the microstructure of milk packaging with scanning electron microscopy

Authors

Marc Liu, ThermoFisher Scientific and George Lv, Phenom China Scientific

Introduction

Milk undergoes various essential stages from collection to consumption, including sterilization, packaging, transportation, and storage. The milk packaging protects it against external contaminants, safeguarding it from bacterial pollution and preventing spoilage, ultimately ensuring that the milk is delivered to consumers in optimal condition. Within milk packaging, two primary categories exist: shelf-stable milk and refrigerated milk. Shelf-stable milk is typically stored at room temperature, offering a longer shelf life ranging from several months to a year. Refrigerated milk is commonly stored in environments between 2–6°C, with a relatively short shelf life of a few weeks. The longevity of each type is intricately linked to a number of factors such as sterilization methods and chosen packaging techniques. This application note employs a Thermo Scientific™ Phenom™ XL G2 Desktop Scanning Electron Microscope (SEM) to investigate the microscopic characteristics of these two types of packaging and how they impact shelf life.

Microscopic analysis using scanning electron microscopy

To uncover the hidden intricacies of milk packaging, cross-sectional samples of conventional carton packaging were obtained from two sections of the carton. The first sample was taken from the filling area of the carton, which undergoes a series of standardized operational steps during the carton production process. This sample represents the typical conditions within the milk carton. The second sample was taken from the carton seam, a section often considered one of the most delicate parts of the packaging. This sample aids in evaluating the sealing effectiveness and material stability of the seam area.

Since most packaging is made of non-conductive materials, the low-vacuum mode of the Phenom XL G2 Desktop SEM was utilized to minimize charging effects and directly capture sample SEM images. The Phenom Auto Image Mapping (AIM) plugin was used to image a substantial area around the carton's seam and to stitch the images together. Additionally, energy-dispersive X-ray spectroscopy (EDS) was used to determine the elemental composition of various layers within the packaging material.

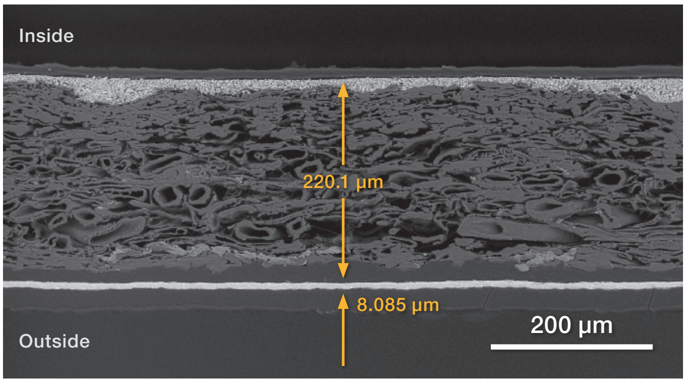
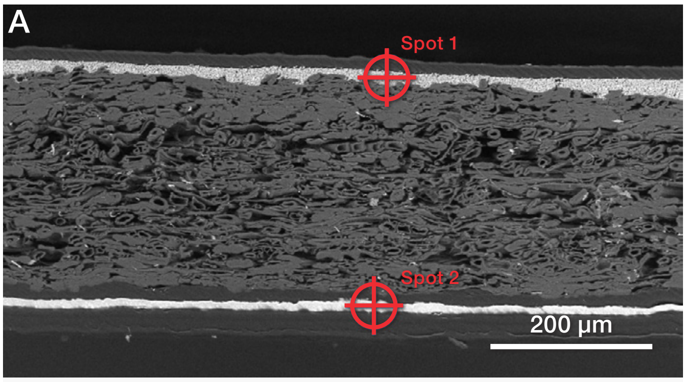
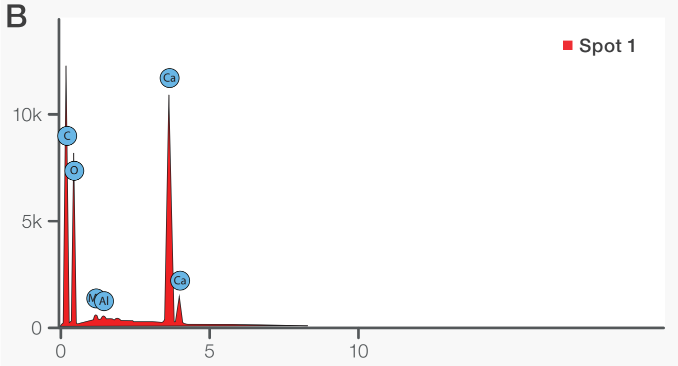
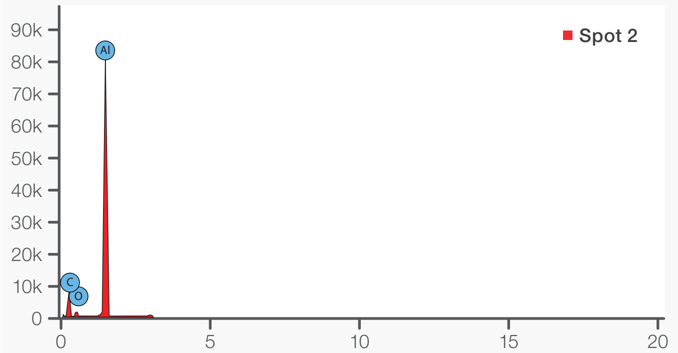


Figure 1. Cross-sectional SEM image of shelf-stable milk packaging. The back-scattered electron detector is clearly displaying the different layers, which can easily be measured.





Element symbol	Atomic conc.	Weight conc.
C	38.213	25.00
O	45.320	39.500
Mg	0.302	0.400
Al	0.272	0.400
Ca	15.893	34.700



Element symbol	Atomic conc.	Weight conc.
C	55.482	36.400
O	3.318	2.900
Al	41.200	60.700

Figure 2. a) SEM image indicating positions on the milk carton cross-section where EDS data was collected. b) EDS analysis of the shelf-stable milk packaging.

Results and discussion

Microscopic analysis of shelf-stable milk packaging

The multi-layer structure of the shelf-stable milk packaging is shown to consists of six layers (Figure 1). EDS analysis, along with publicly available information from packaging material suppliers, reveal that the outermost layer is a polymer designed to repel water vapor. The second layer is a pattern printing layer with a high concentration of calcium, depicted as a granular material in the SEM image. The third layer, with a thickness of approximately 220 µm, is a cardboard composed of hollow fibers; this constitutes the majority of the packaging and provides it with strength and hardness. As verified by EDS, the fourth layer bonds the cardboard to a roughly 8 µm-thick aluminum foil. This layer is crafted from highly pure aluminum and acts as a barrier against light and oxygen. The innermost layer is a polymer used to seal the milk and isolate it from the other packaging materials.

Seam of the container

Sealing is a crucial aspect of packaging, preventing milk leakage and maintaining structural integrity during transportation. Note that sealing in this context refers to the seal line on the packaging body, not the seals at the top and bottom after filling. Figure 3 showcases two different sealing techniques employed by packaging companies. The first method (Figure 3A) involves overlapping edges with an additional inner sealing layer, preventing milk from coming into contact with the seam. The second method (Figure 3B) employs a folding approach that removes material from outside the cardboard layer, potentially facilitating folding. The inner walls are adhered, eliminating the need for additional isolating materials.

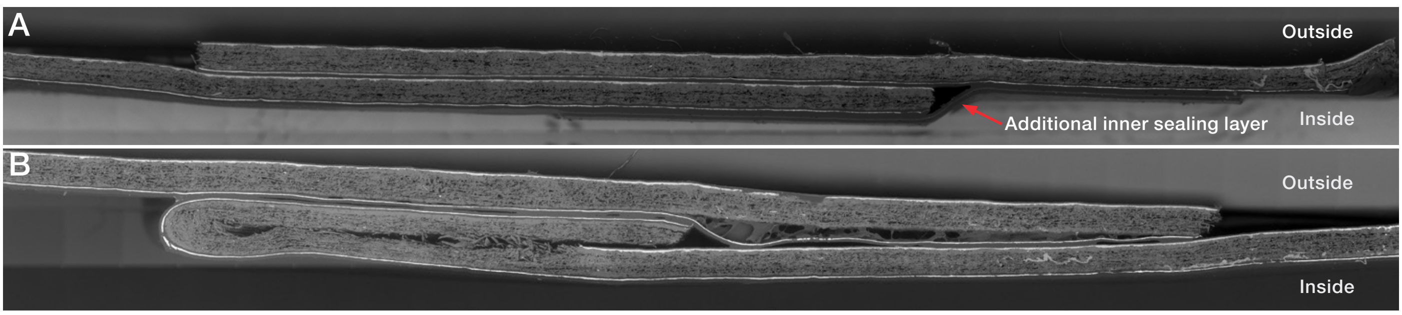


Figure 3. Stitched SEM images of shelf-stable milk packaging taken at the seam position, showcasing two different sealing techniques. Composite images were generated by the Phenom Auto Image Mapping plugin.

Microscopic analysis of refrigerated milk packaging

Unlike shelf-stable milk packaging, refrigerated milk packaging omits an aluminum foil layer (Figure 4). It has a sandwich-like structure, featuring a thicker central cardboard layer of approximately 400 µm. This reinforced central layer is likely used to enhance the packaging's insulating properties, shielding the milk from external temperature fluctuations. Figure 5 showcases the seam of these cartons, illustrating that sealing is accomplished through overlapping edges without extra material isolation between the milk and the seam.

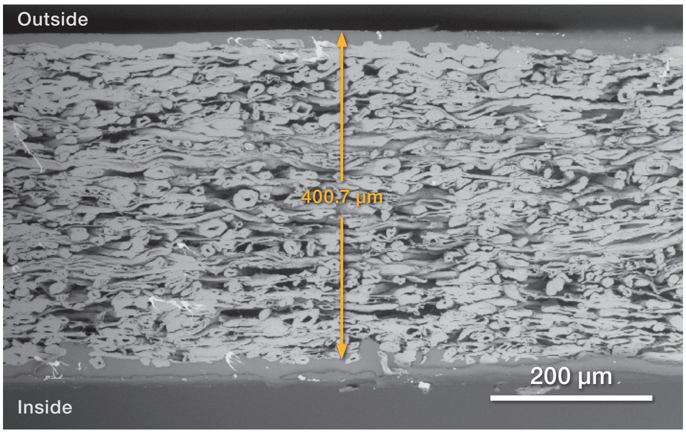


Figure 4. Cross-sectional SEM image of refrigerated milk packaging.

Sustainability considerations for packaging materials

While the aluminum foil layer in shelf-stable milk packaging is crucial for quality and safety, it poses recycling challenges. As it is only 8 µm thick (thinner than a human hair), this complicates separation during recycling and elevates costs. This has prompted packaging material suppliers to explore more sustainable alternatives.

Conclusions

The Phenom XL G2 Desktop SEM was used to analyze the microstructure and sealing methods of milk packaging through a combination of low-vacuum imaging, automated image stitching, and EDS elemental analysis. This has illuminated the connection between a milk carton's preservation capabilities and its microstructure. Such analysis enhances our understanding of the packaging's role in maintaining milk quality and safety while also underscoring the challenges of milk package recycling. This application note highlights the intricate interplay between the packaging materials, milk preservation, and environmental consciousness.

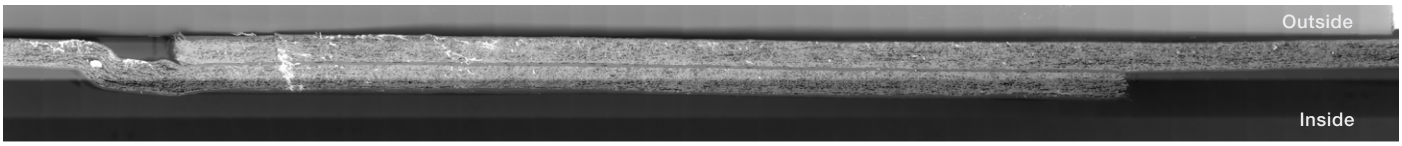


Figure 5. Stitched SEM image of refrigerated milk packaging taken at the seam. The composite image was generated by the Phenom Auto Image Mapping plugin to provide a large field of view.

Learn more at **thermofisher.com/phenom-xl**

For research use only. Not for use in diagnostic procedures. For current certifications, visit thermofisher.com/certifications