Natural Zinc Ion-embedded Nylon Non-Wovens for Permanent Antimicrobial Activity and Biofilm Resistance

Novel Technology to Improve the skin contact layer in medical devices

Cristina Acevedo[1], Bliss A. Cunningham[2], Rajib Mondal[1], Vikram Gopal[1], Christopher A. McDevitt[2], and Kimberly Grace[1]

[1]Ascend Performance Materials, Texas, United States

[2]Department of Microbiology and Immunology, The Peter Doherty Institute for Infection and Immunity, University of Melbourne, Victoria, Australia.

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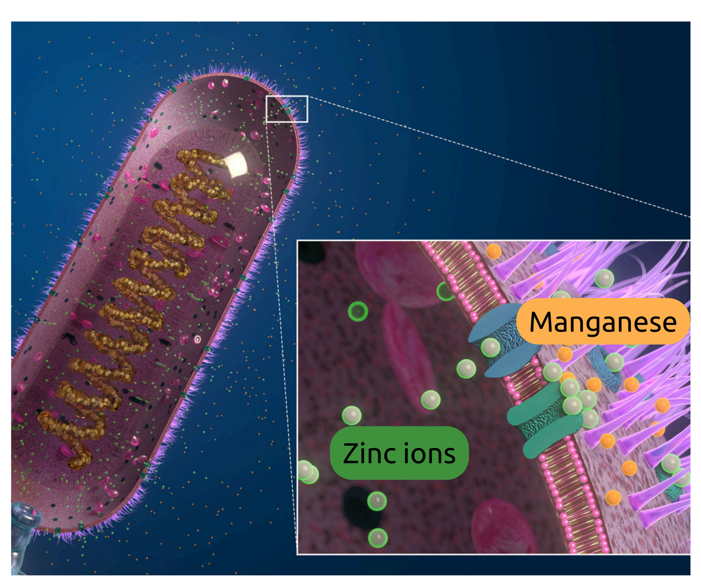
INTRODUCTION

The interface between medical devices and patients is a critical factor in determining both device performance and patient experience. These, in turn, significantly influence compliance and product adoption. The selection of optimal materials, in conjunction with device design, plays a pivotal role in enhancing device functionality. This includes promoting recovery, augmenting lymphatic fluid circulation, regulating moisture and temperature, and providing persistent antimicrobial, antifungal, and/or antiviral properties, as well as skin soothing effects, among others. It is imperative that these performance enhancements do not adversely affect either skin health or the environment. A new technology involving natural zinc ion-embedded nylon, which is easily scalable, has been developed recently. Investigating the antimicrobial activity, biofilm resistance, and cytotoxicity profiles of substrates manufactured using this technology is essential, given its potential applications in advanced wound care products.

Zinc–Effective, yet safe and all-natural antimicrobial option

- Zinc has proven therapeutic benefits and is commonly applied to soothe the skin.
- Zn^{2+} induces Mn^{2+} starvation, resulting in bactericidal behavior[1].
- Active ingredient is labeled GRAS, or Generally Regarded as Safe, by the U.S. FDA.
- Various end-forms demonstrated effective antibacterial and antifungal properties while tested to be non-cytotoxic while exposed to exposing the extract fluid to mouse fibroblast cells.

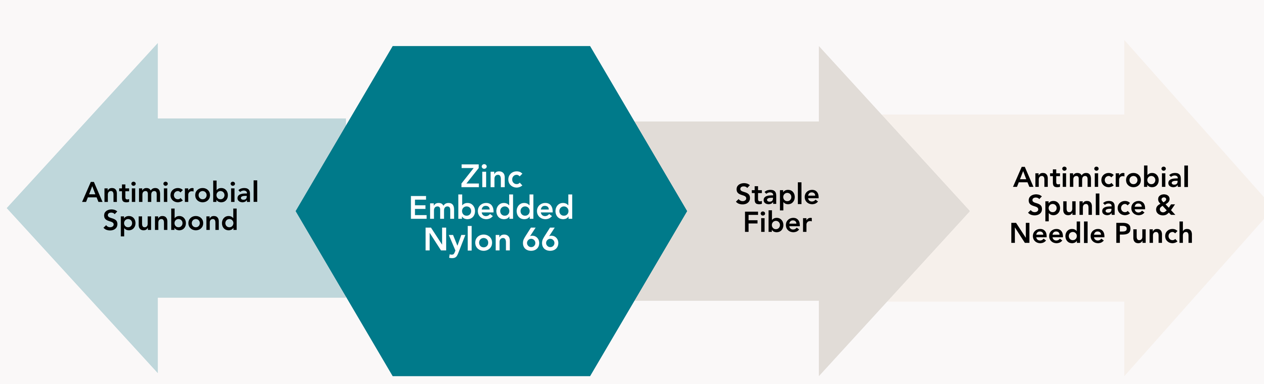


Design flexibility of wound dressings

- Wound dressings are composed of various layers of materials, having different moisture and pressure management properties.
- Desired antimicrobial properties in these layers are typically imparted by topical treatment or by using electroplated fibers/textiles.

Electroplated Fibers and Textiles	Limits dyeability and physical properties: wicking, absorption and abrasion.
Topical Treatment	Applied after dyeing through dye bath, pad, plasma treatment, foams and spray coating. Limited to some end forms.
Novel Zinc Embedded Polymer	Zinc added during the polymerization process, leaving zinc ions disperse at the molecular level. Maintains nylon properties: dyeability, wicking, absorption and comfortability.

Example of simplified antimicrobial non-wovens manufacturing process



METHODS

- Three different types of commonly used wound dressing non-wovens, specifically spunbond, spunlace, and needle punch, were generated with zinc ion-embedded technology using common industrial processes.
- The Minimal Essential Media (MEM) elution test was used to determine the cytotoxicity of extractable substances from spunbond and spunlace with L-929 cells.
- Antibacterial activity of these materials was then evaluated against polypropylene (PP) spunbond control using an adaption of the ASTM E3151-18 standard against three distinct bacterial strains: *Staphylococcus epidermidis* ATCC 35984, *Staphylococcus aureus* Newman and *S. aureus* USA300 (MRSA). This method enables investigation of the planktonic and adherent/biofilm states of the bacterial strains in the presence of the different materials.
- These materials were further analyzed by Scanning Electron Microscope (SEM) following the ASTM E3151-18 protocol using *S. aureus* USA300 (MRSA).

RESULTS

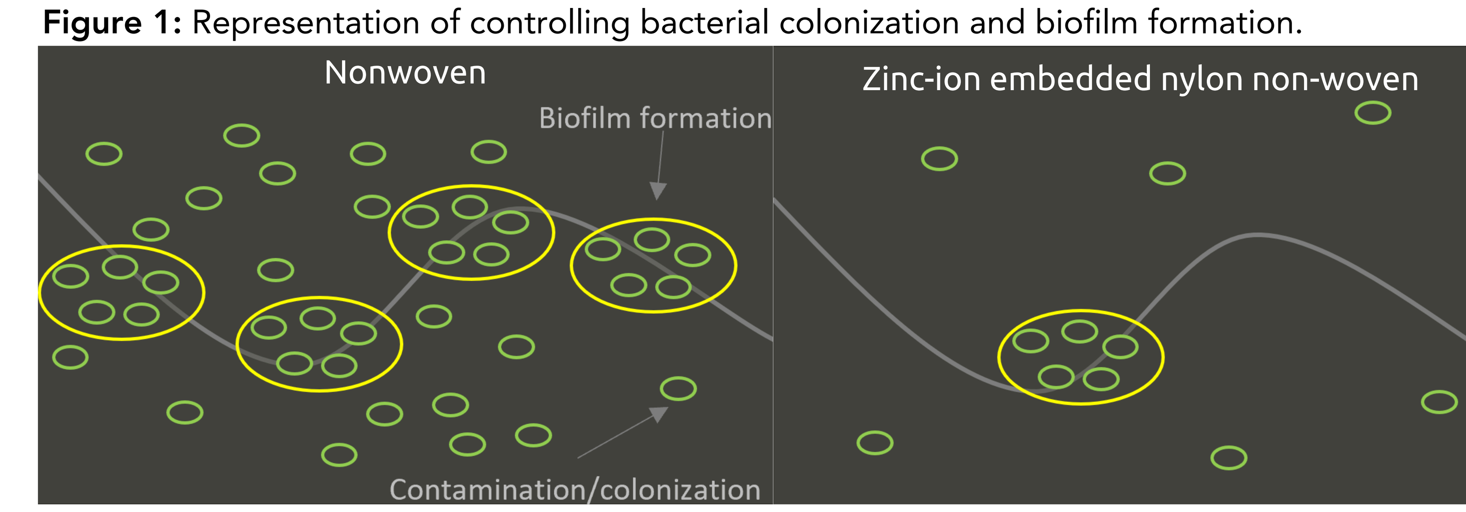
- Antibacterial efficacy and biofilm resistance of these materials are summarized in Table 1.
- Materials tested for cytotoxicity were determined to be non-cytotoxic.
- All zinc ion-embedded non-woven samples were highly efficacious relative to PP spunbond in reducing viable planktonic and adherent bacteria against known biofilm-producing strains of *S. epidermidis* and *S. aureus* Newman.
- The zinc based spunbond and needle punch samples were highly efficacious in reducing viable planktonic and adherent bacteria against *S. aureus* USA300, but slightly lower efficacy was observed with the spunlace, while compared against PP spunbond.

Table 1: Evaluation of the antibacterial efficacy of zinc ion-embedded nylon non-wovens against *S. epidermidis* and two strains of *S. aureus*, using an adaptation of ASTM E3151-18 standard.

Sample	Basis Weight (gsm)	Bacterial Strain	Biofilm Resistance (Adherent Bacterial Count)		Antimicrobial Activity (Planktonic Bacteria Counts)	
			Avg Bacteria Recovered (CFU/Sample) at 24h	Avg % Reduction	Avg Bacteria Recovered (CFU/Sample) at 24h	Avg % Reduction
Control (PP Spunbond)	25	*Staph. epidermidis*	2.80E+04	-	5.50E+04	-
		Staph. aureus Newman	4.04E+04	-	2.95E+06	-
		Staph. aureus USA300	9.08E+05	-	1.86E+07	-
Spunbond	34	*Staph. epidermidis*	3.00E+01	99.89%	5.00E+01	99.91%
		Staph. aureus Newman	1.25E+02	99.69%	1.63E+03	99.94%
		Staph. aureus USA300	1.25E+02	99.99%	1.63E+03	99.99%
Spunlace	75	*Staph. epidermidis*	1.00E+02	99.64%	1.00E+02	99.82%
		Staph. aureus Newman	1.25E+02	99.69%	1.63E+03	99.94%
		Staph. aureus USA300	7.20E+03	99.21%	2.15E+05	98.84%
Needle punch	133	*Staph. epidermidis*	9.17E+01	99.67%	5.00E+01	99.91%
		Staph. aureus Newman	2.74E+02	99.32%	4.12E+03	99.86%
		Staph. aureus USA300	2.06E+02	99.98%	5.27E+03	99.97%

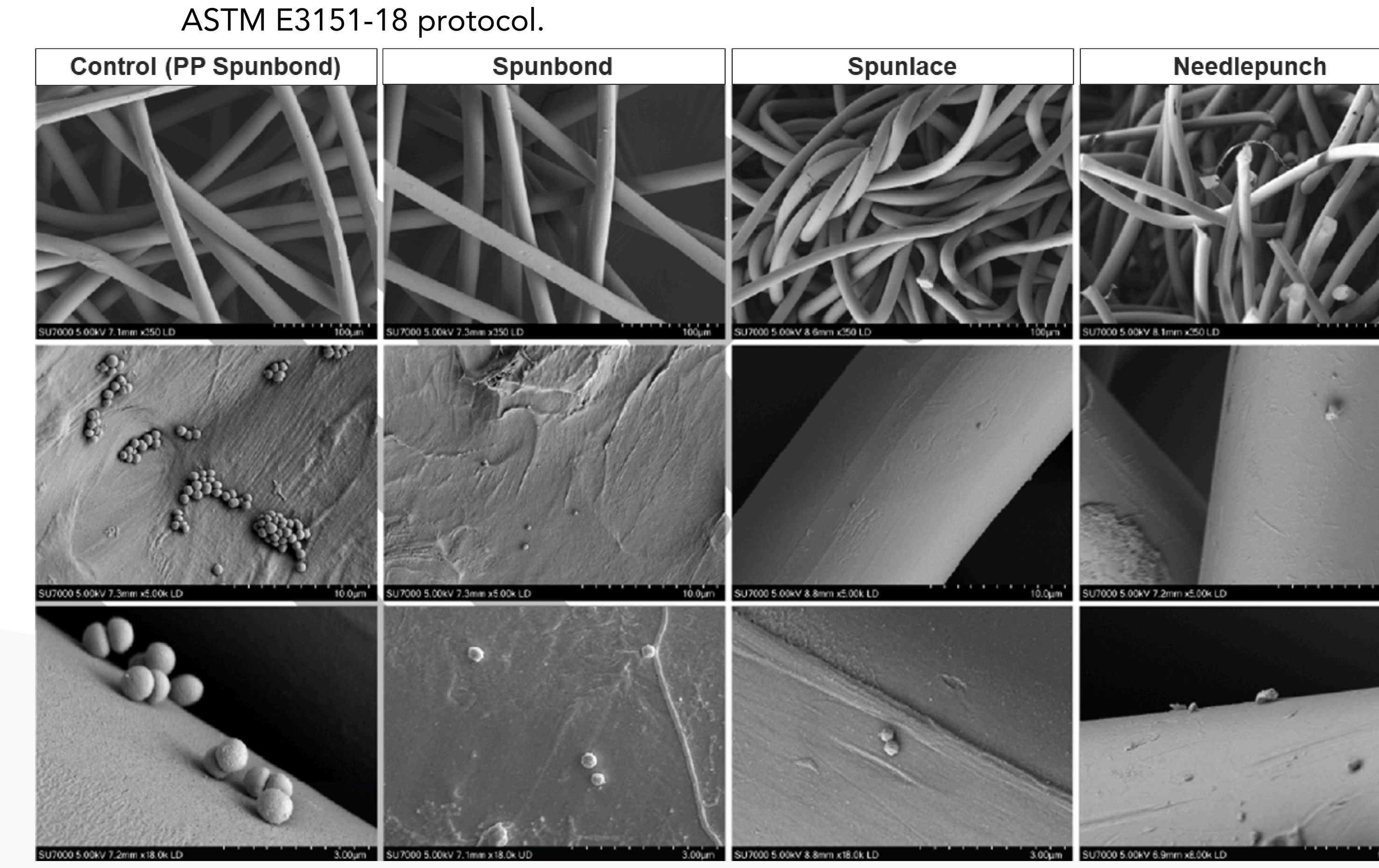
RESULTS CONT'D

Figure 1: Representation of controlling bacterial colonization and biofilm formation.



The samples with zinc ion-embedded nylon appear to show more isolated cells rather than clusters observed in the PP spunbond (Fig 2). Further, cell debris was more frequently observed with zinc ion embedded samples, in addition to morphological changes for cells on these materials. Collectively, these observations indicate that there is not only an inhibition of growth, but also stress and subsequent cell lysis when exposed to substrates made with zinc ion-embedded nylon.

Figure 2. SEM images of adherent *S. aureus* USA300 (MRSA) on non-woven samples following ASTM E3151-18 protocol.



CONCLUSION

In conclusion, this natural zinc ion-based nylon technology was found to be non-cytotoxic while effective against bacterial strains in both planktonic and adherent/biofilm states. This is a scalable and permanent antibacterial solution that can be incorporated to design advanced wound dressings and other medical devices.

REFERENCE

1. McDevitt CA, Ogunniyi AD, Valkov E, Lawrence MC, Kobe B, McEwan AG, Paton JC. A molecular mechanism for bacterial susceptibility to zinc. PLoS Pathog. 2011 Nov;7(11):e1002357.