PacifiCan-MMRI Accelerating Circular Economy (ACE) TechBrief Report

THE UNIVERSITY OF BRITISH COLUMBIA

Materials & Manufacturing Research Institute

Project title: Towards Development of a Biodegradable Polymer for Use in Single-Use Surgical Gloves

Industry partner(s): FEED Engineering Inc.

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Introduction & Background:

Recent trends in global plastics consumption have led to a proliferation of studies focusing on biodegradable resources as a replacement for conventional plastic products. Next to synthesizing new biodegradable plastics, recent studies have focused on biodegradable elastomeric materials based on nitrile, butadiene nitrile, and natural rubber [1]. Specifically, since the SARS-CoV-2 pandemic, there has been a sharp increase in the demand for rubber-based personal protective equipment (PPE), which also revealed that we are in imperative need of developing more sustainable and environmentally friendly rubber-based disposable PPE. An environmentally friendly rubber material can be achieved by using biopolymers in blends with rubber [2,3], to impart biodegradable properties. This research has aimed to develop novel, biodegradable nitrile-based blends, towards scaling-up production for commercialization. The objectives of this research were to design, manufacture and test FEED's proprietary nitrile rubber - pectin-based biopolymer (NBR-NGP) blend, under mechanical requirements tested in an Instron 5969 50kN load frame, of tensile strength and modulus (ASTM D412), puncture resistance (ASTM F1342), tear resistance (ASTM D624), as well as using a RSA PF8000 online respirometer to asses anaerobic biodegradability (OECD 301F) and aerobic biodegradability (ASTM D6400), complemented by thermogravimetric analysis (TGA, TA Instruments TGA550), Fourier-transform infrared spectroscopy (FTIR, Thermo Scientific Nicolet iS20) and scanning electron microscopy (SEM, TESCAN MIRA3) to assess the blend's miscibility.

Relevance to Circular Economy:

This research represents an important step towards imparting circular supply chains in single-use medical PPE. The circular model targets downcycling strategies such as "waste to energy", where spent gloves will be used as feedstock in e.g. composting facilities to produce downstream valorization. This is the first step towards further refining this technology towards true circularity.

Methodology:

This research was guided by ASTM 5250-19, "Standard Specification for Poly(vinyl chloride) Gloves for Medical Application", towards the long-term goal of commercialization. To this end, a series of specimens were manufactured for a subset of the required tests, where NBR was used as the base material for the specimens. NBR was initially obtained from two different sources (for comparison and final selection purposes in the present blending application): Kumho Petrochemical (KP) (South Korea) with 35% acrylic content, and Nitriflex (NF) (SP, Brazil) with 33% acrylic content. For the NGP-blended NBR, NGP-additive as a biopolymer composing pectin was dispersed in a solvent (water/alcohol), which is compatible with these monomers. Then, the dispersion solution was processed to be evaporated. Following, the dispersed NGP was added to NBR and cured at 160-170°C, with a 10% NGP and 90% NBR mass ratio. The test samples were prepared in the form of thin films (< 2 mm thick) by the casting process. These films were then cut into specimens as required by each ASTM standard. All experiments were conducted in triplicates. Table 1 below summarizes the different blends analyzed, Figure 1 shows the polymerization, and Figure 2 the test workflow.

Table 1: Summary of NBR-NGP blends, used for downstream testing.

Blend	NBR content (% mass)	NGP content (% mass)	NBR supplier
1	100	0	KP
2	90	10	KP
3	100	0	NF
4	90	10	NF

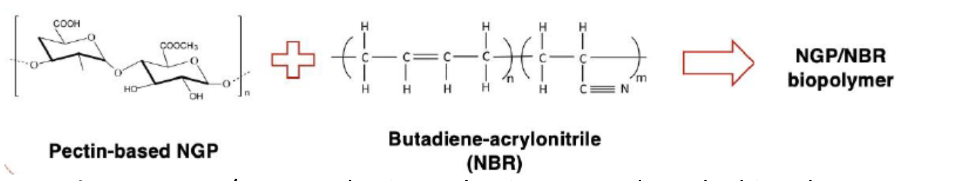

Figure 1: NBR/NGP synthesis mechanism to produce the biopolymer.

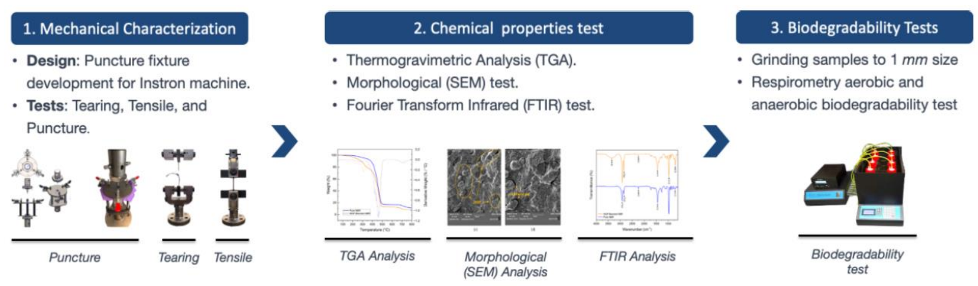

Figure 2: Summary of mechanical (guiding performance requirements for use in the medical industry), chemical (towards ensuring miscibility) and biodegradability (ensuring target circularity performance) tests conducted within this study.

Results & Discussion:

On average, an 11% improvement in the ultimate strength and 15% improvement in the tearing resistance was noted for the NGP-blended NBR, compared to the pure NBR, shown in Figure 2. However, given the large deviations in the tensile tests repeats after ~250% strain (i.e., towards ultimate strength points), the statistical significance levels were above 5%. In terms of the ultimate puncture resistance, there was a significant reduction (13%) in the maximum puncture force of the NGP-blended NBR compared to the NBR. To further analyze the difference in the materials characteristics, the surface roughness parameters were also calculated. The NGP-blended NBR showed a higher surface roughness (Ra) as compared to the pure NBR. This could partly explain the difference in puncture force resistance between the two materials. However, it can be influenced by various other factors, such as other surface parameters, the material properties, as well as the geometry of the penetrating object. The elongation (tensile strain%) at break was significantly higher in NGP-blended (506%) compared to NBR (358%), suggesting more stretchability when used e.g., in a PPE such as protective glove. Considering the same moderate level of target strain (e.g., up to 250%), the pure NBR outperformed the NGP-blended NBR, and both materials in this range have shown excellent relatability. A comparable elastic modulus was also seen for the two materials. At higher strain values close to breaking, however, the NGP-blended NBR revealed a more robust behavior. Both NBR and NGP-blended NBR were found to cause cytotoxicity on aerobic microorganisms, making them to be non-biodegradable in aerobic conditions (Figure 3a). On the other hand, in anaerobic conditions, NGP addition to NBR increased biodegradability from 2% to 12% (Figure 3b).

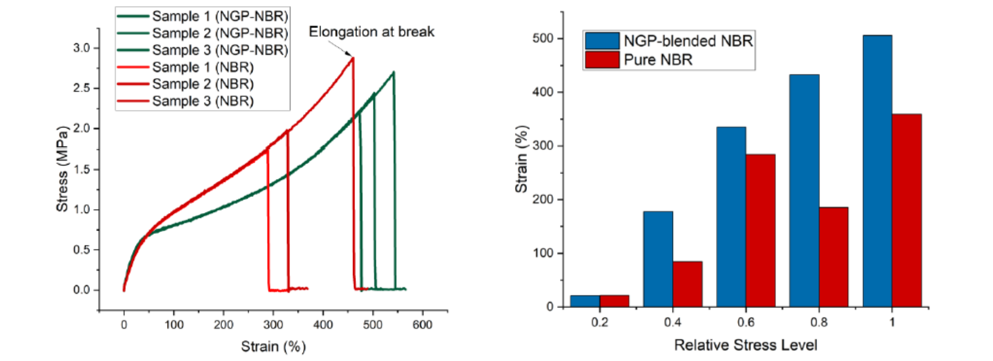

Figure 3: (Left) Stress-stain plot of the KP-sourced NBR-NGP blends. (Right) Strain-to-failure results, normalized to stress.

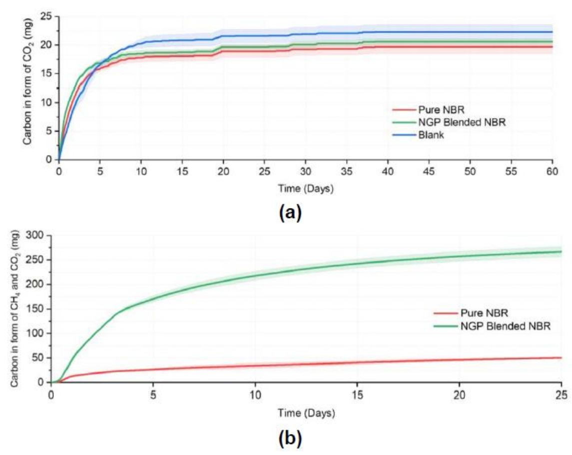

Figure 4: (a) Plot of carbon in CO2 form, measured from aerobic biodegradation. All blends exhibited cytotoxicity that resulted in limited degradation. (b) Plot of carbon in CO2 and CH4 form, measured from anaerobic biodegradation. Significant improvements were seen in the NBR-NGP blend (2% to 12%).

Conclusion & Next Steps:

Blends of synthetic polymers/bio-polymers are gaining popularity in industries, because of their superior combination of mechanical performance and biodegradability characteristics. In this work, a new NGP/NBR blend was manufactured and tested, with the results demonstrating that the mechanical characteristics of the NGP-blended NBR are overall favorable to those of pure NBR. The company partner is working towards upscaling manufacturing and commercializing the material in end-use applications.

References:

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Further reading: N. Akbarian, I.A. Basar, O.H. Margoto, N. Abdollahi, B. Crawford, B. Magel, M. Gharibnavaz, C. Eskicioglu, A.S. Milani, 'Characterization of the Mechanical, Biodegradation, and Morphological Properties of NBR/Biopolymer Blend, Integrated with a Risk Evaluation', American Chem. Soc., vol. 9 (8), pp. 9256-9268 (2024).

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