HPRC
Healthcare Plastics Recycling Council

Flexibles Recyclability Assessment Project
Final Report

EXECUTIVE SUMMARY

The Healthcare Plastics Recycling Council (HPRC) is a private, technical coalition of industry peers across the healthcare, recycling, and waste management industries seeking to improve recyclability of plastic products and packaging within healthcare. This white paper was conceived to help provide our medical device manufacturer, hospital, and recycler partners with shared learnings from our Flexibles Recyclability Assessment Pilot project. The pilot project uncovered that, with the proper controls in place, flexible packaging can be successfully segregated from the OR waste stream without fear of hazardous material contamination, and that a mixed-material stream of flexibles from multiple sources can be processed and pelletized into a resin that could potentially be used in a secondary application.

INTRODUCTION

Healthcare facilities in the United States generate a surprising amount of waste—11,000 to 14,000 tons of waste per day[i,ii]. A common misperception is that this waste is "contaminated" in some manner, when in fact about 85% is free of patient contact and considered non-hazardous.[iii,iv] Of that non-hazardous waste, it's estimated that between 20% and 25% is plastic packaging and plastic products.[v] Tallying it all up, between 2,000 and 3,000 tons a day of high-quality, non-hazardous, medical plastic is entering our municipal waste stream to be incinerated or buried in a landfill.

Participants

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BACKGROUND

Our first step was to understand the current recycling drivers for plastic waste within the healthcare setting. We found that many domestic healthcare systems recognize that setting goals for the recycling of their municipal solid waste stream is an important aspect of an integrated waste program.[vi] These materials enter a developing recycling marketplace where mechanical recycling is the most common option. We performed a literature review of life cycle assessment (LCA) studies[vii] comparing four different disposal methods: 1) mechanical recycling (back to polymers); 2) feed stock recycling (back to monomer); 3) incineration with energy recovery systems (for heating systems or electricity generation); and 4) modern landfill disposal. We concluded that mechanical recycling of waste plastics has a lower environmental impact than other disposal options due to the benefits of avoiding virgin plastic production. Our findings, which indicate mechanical recycling as the preferred waste management option after source reduction and reuse, echo the EPA waste hierarchy guidance[viii]. Considering the rise in the global markets for recycled plastic, HPRC set out to pilot a mechanical recycling methodology for one of the most challenging types--mixed-flexible packaging materials--because they are made from multiple plastic resins and easily confused, visually, with other types of material.

MIXED FLEXIBLE PACKAGING

Waste material recycling programs, including those for corrugated cardboard, newsprint, metal cans, plastic bottles with various resin ID codes, and glass jars are available to a substantial majority (>60%) of US consumers and thus these materials may be marketed as recyclable.[ix] One major class of materials not commonly known as recyclable, yet very common in the healthcare waste stream, is flexible packaging, which includes plastic bags, stretch and shrink film used around pallets piled with case cartons, sterilization wrap, and medical device packaging (i.e. pouches, header bags, and vented bags). These also include a variety of resin types, including polyethylene film (i.e. LDPE), polypropylene and polyethylene non-wovens, plasticized polyvinylchloride, and complex multi-layer/multi-material structures. Due to this lack of a standard composition, and the potential for the presence of multi-materials utilizing different resins across the layers, recovery of these materials is complicated.

MATERIAL COLLECTION

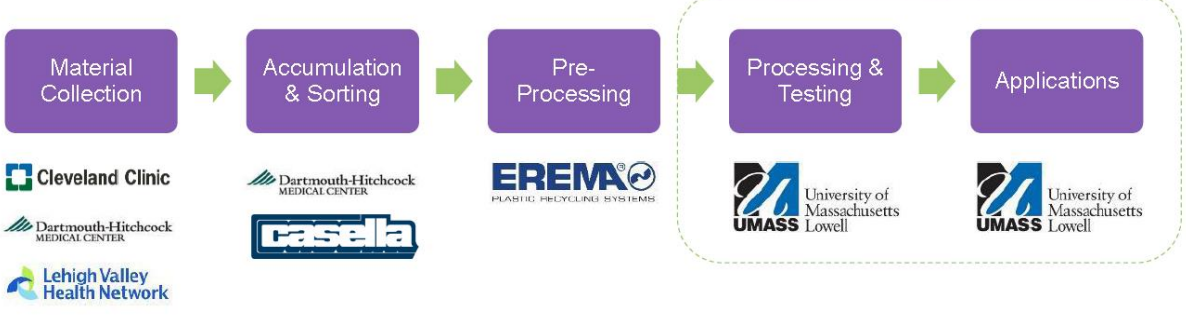


Figure 1: Material collection process

At the start of the project, we recognized that in order to encourage manufacturers to reuse healthcare plastics, we had to combat concerns around the risk of hazardous contamination from hospitals. To accomplish this, we designed a rigorous, facility-specific collection process and put the necessary controls in place to minimize the risk of contamination.

The collection process at the facilities was based upon both the HPRC's Hospicycle guidance and their site-specific programs for collection for other materials and products. With these partners we focused the collection point to operating rooms since they have well-defined controls established to minimize end-use contamination, making the operating room a desirable collection point. To eliminate the primary risk of patient contact, the collection of these materials was limited to the set up and preparation for a surgical case prior to the patient entering the operating room.

During the set-up process, nursing personnel removed products from their packages and staged the products in the sterile operating field. If the product was packaged in a flexible plastic, it was disposed of by the nursing staff in a collection bag dedicated to the pilot materials. Once set up for the procedure was complete, the bags were tied off and removed to eliminate the risk of any post-op materials being placed inside.

After addressing concerns about material stream contamination, the second issue we faced was making sure that flexible plastics were the only pre-op packaging materials being placed in the dedicated bags. To help the nursing staff correctly segregate packing materials, we provided them with packaging identification training. Being a mixed-material study, hospital personnel were simply instructed to collect plastic packaging which was flexible by touch. The collected packages included pouches, header bags, vented bags, Tyvek®, and blue wrap. If a package had an adhered label of any material type (paper or plastic), it was still included in the study. Through this defined methodology and training we were able to establish a collection process that resulted in a consistent stream of mixed-flexible materials from the participating facilities.

ACCUMULATION AND SORTING

Although the operating room collection process provided segregation of the plastics coming out of the healthcare facilities, we set up an additional post-OR segregation step at a central sorting facility near Dartmouth-Hitchcock hospital. We did this for several reasons: the additional sorting allowed us to evaluate the success of the OR segregation activities, obtain information on what types of materials were being generated in OR settings, and segregate the materials further for processing. This post-hospital segregation step also allowed us to request different waste streams from the participating hospitals to evaluate the impact of different flexibles on the final output. Lehigh Valley and Cleveland Clinic were instructed to collect both flexible packaging and sterilization wrap, which is commonly referred to as blue wrap within hospitals, and Dartmouth-Hitchcock was instructed to collect flexible packaging only. Our secondary sorting operation identified several common flexible packaging types that were being generated by the hospitals; pouches, header bags, vented bags, formed packages, film/tear bags (non-porous), and Tyvek®.

Figure 2: Common flexible packaging types

Some additional characteristics and observations of the waste stream:

- All pouches, header bags, and vented bags were two-dimensional packages constructed from a non-porous film and a porous non-woven material (i.e. Tyvek®).
- A small percentage of the collected packages were constructed with medical grade paper; these were removed from the all plastic material stream prior to processing.
- Packages with a "form" within which a device could be nested were three-dimensional and could be either all-film or a combination of film and porous material.
- Film packages (also referred to as pouches or bags) were solely constructed from non-breathable films.
- A variety of loose Tyvek® material was encountered, which we speculated came from rigid trays or had been separated from a pouch, header bag, or vented bag during the collection process.

The weights of the various flexible plastic types that made up the combined blue wrap and flexible plastic packing waste stream were evaluated as well. We did this to get a better understanding of the ratio of the types of packages that make up the material stream. Out of an approximately 165-pound aliquot, the constituent weights were as follows:

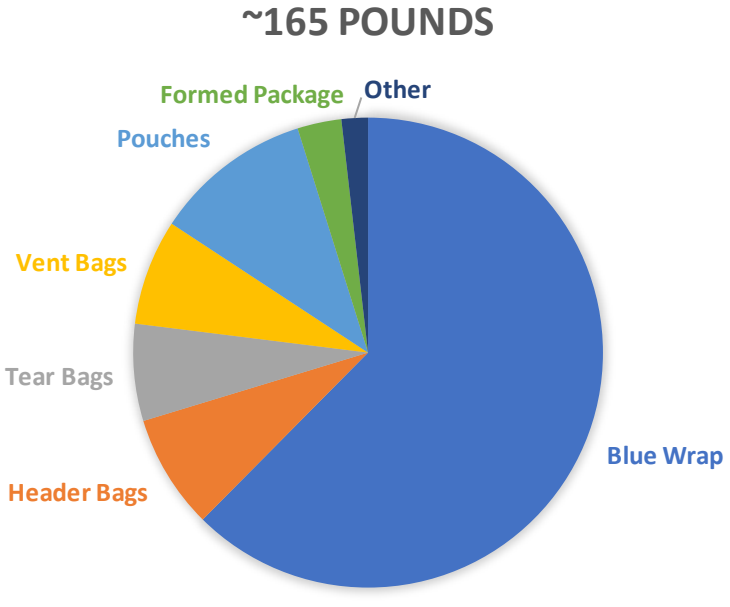


Figure 3: Weight distribution of Stream 1 with blue wrap and flexible packaging

We also evaluated an approximately 90-pound aliquot from the stream without blue wrap, which had the following constituent weights:

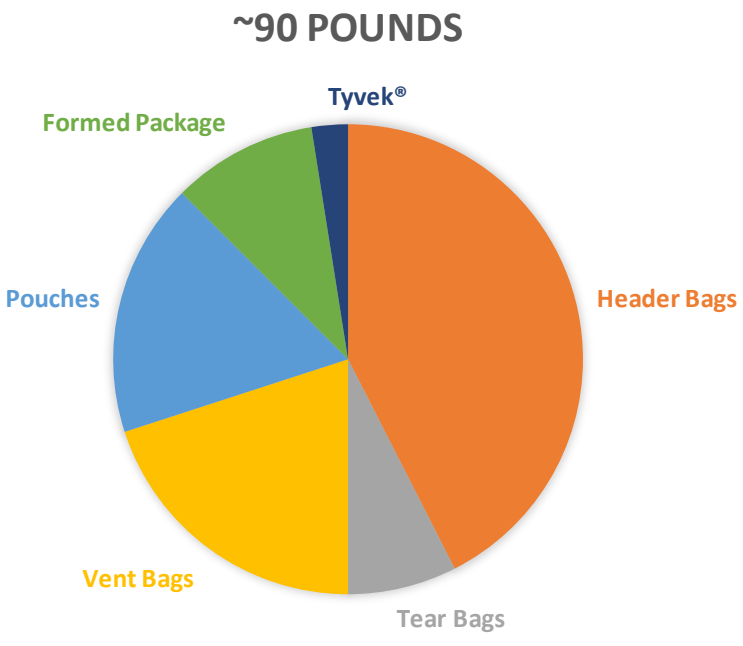


Figure 4: Weight distribution from Stream 2 with no blue wrap

A small percentage of other/unwanted materials were also found during the sorting process, including loose paper, foil or foil laminates, large pieces of packing tape, and a few rigid trays. While this was not ideal, we anticipated some amount of undesired material would be collected given the project's pilot status. Following the sorting and characterization activities, the material was sent for mechanical recycling.

RECYCLING PROCESS

Figure 5: Material processing machine from EREMA

The materials were processed at EREMA's North America headquarters in Ipswich, MA. The processing included eight steps:

- **Feeder**: Materials were removed from their plastic bags and added to a conveyor system. A primary component of this conveyor system was a metal detector to help screen out any metallic films not identified during the preceding visual segregation activities.
- **Preconditioning unit**: The material fed into the machine was cut, mixed, heated, dried, pre-compacted, and buffered.
- **Extruder screw:** The material was plasticized and degassed. At the end of the plasticizing zone, the melt was directed out of the extruder.
- **Melt filter:** The material being extruded was cleaned and returned to the extruder again.
- **Melt homogenization:** The material went through one final melt homogenization.
- **Degassing zone**: Once the melt had been filtered and homogenized, it was degassed.
- **Discharge zone**: The melt in its final form was conveyed to the end of the machine and to the pelletizer tool being used for output.
- **Pelletizer**: The melt was cooled and pelletized at extremely low pressure.

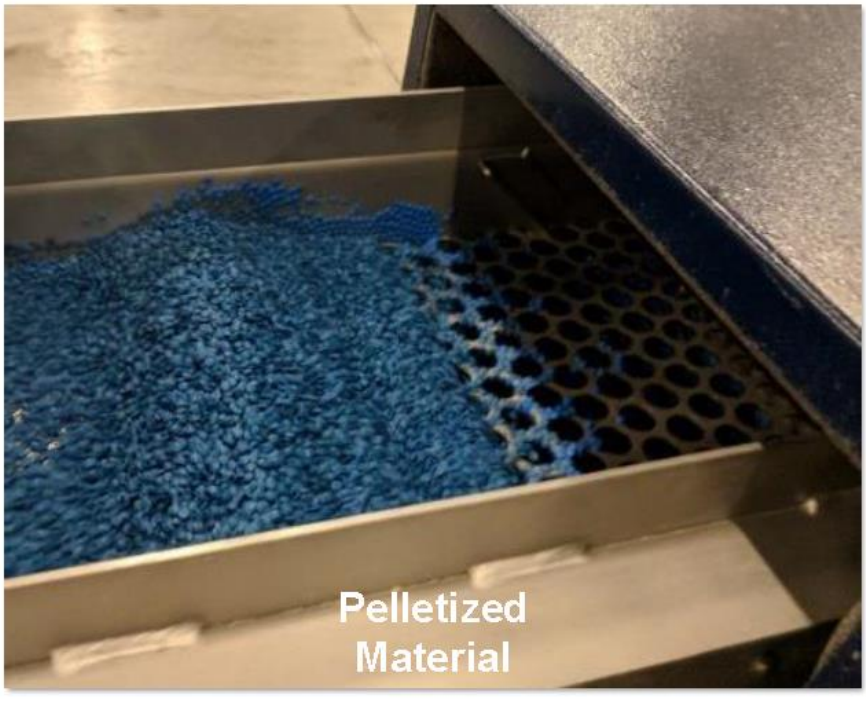


Figure 6: Pelletized material

MATERIAL TESTING

Following the EREMA processing, the pelletized material was package and shipped to the University of Massachusetts Lowell for analysis and testing. Once at the University of Massachusetts, the recycled pellets were compounded with two different compatibilizers to investigate their effects on performance. Both compatibilizers, detailed below, were produced by the Dow Chemical Company:

- Compatibilizer 1 is INTUNE™ from Dow, an olefin block copolymer, designed to improve the compatibility between PE and PP.
- Compatibilizer 2 is Retain™ 3000, targeted to enhance the dispersion of polar polymers to olefin matrix.

The compatibilizers were applied to the recycled pellets at three different concentrations: 0.5, 2, and 5%. One sample was prepared without compatibilizer to use as a control in the study. Additionally, the recycled pellets were segregated based on their waste stream. Stream 1 was the flexible packaging without blue wrap whereas Stream 2 included blue wrap.

	Base Material					
	Waste Stream 1			Waste Stream 2		
Compatibilizer 1	0.5%	2%	5%	0.5%	2%	5%
Compatibilizer 2	0.5%	2%	5%	0.5%	2%	5%
Control	0			0		

Table 1. Material compositions

The recycled pellets were compounded with the compatibilizers at the designated concentrations using a Technovel® twin-screw extruder. The strands from the extruder were cooled in a water batch and then pelletized. During the extrusion, the screw speed was 435 rpm; the melt temperature was about 235 C, and the residence time of the material in the extruder was around one minute.

Figure 7: Screw configuration in extrusion compounding

The pellets from extrusion compounding were molded into ASTM standard specimens using a Toyo Injection Molding Machine for tensile and impact testing. The figure below shows the molding process parameters, a picture of injection molding machine, and the molded ASTM standard specimens.

Molding Process Settings		
Parameters	Value	Unit
Injection speed	0.65	[in/s]
Melt temperature	210	[°C]
Resident time	1	[min]
Holding time	11	[s]
Cooling time	30	[s]

Table 2. Molding process settings

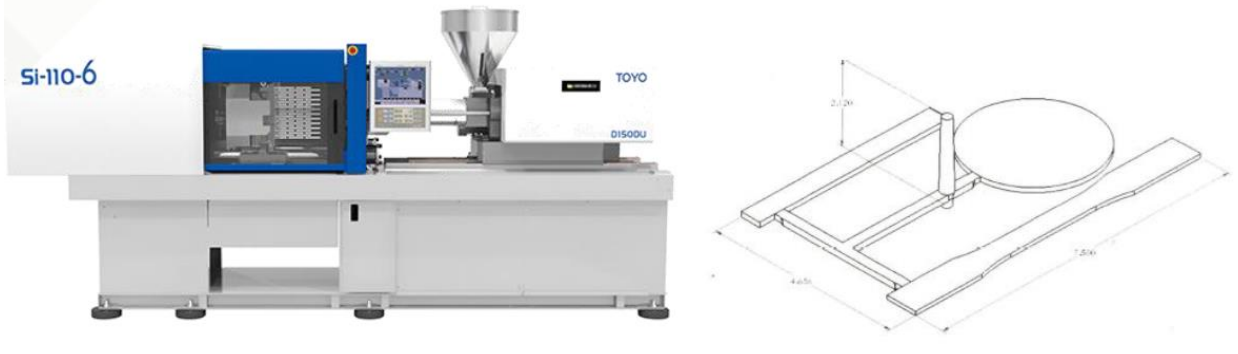


Figure 8: Injection molding machine and molded ASTM standard specimens

TESTING RESULTS

Melt Flow Index

The Melt Flow Index (MFI) is a measure of the flowability of melted plastics (a high MFI signals high melt flowability). Units of MFI are expressed in gram/10 min., and in the study, MFI was determined from testing of the samples at a temperature of 230 C and 2.16 kg weight. For each group, there were six replicates to ensure consistency of the results. The figures below show the instrument used in the MFI measurement as well as the MFI test results.

Figure 9: Melt flow indexer

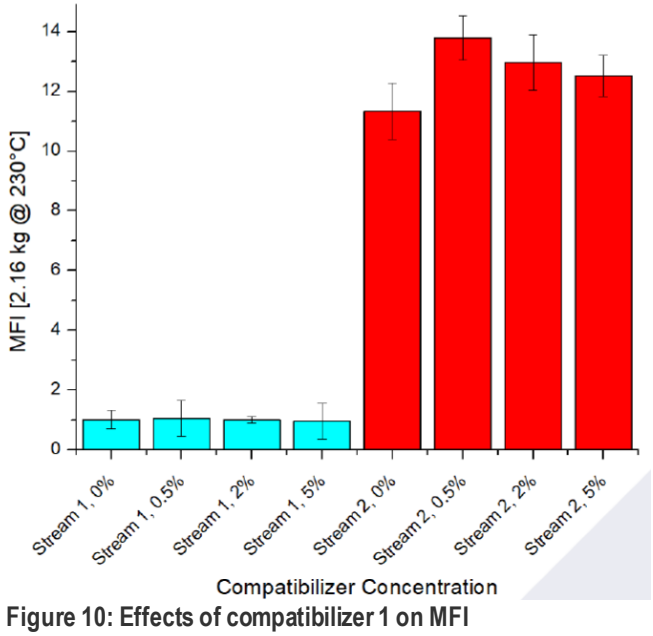


Figure 10: Effects of compatibilizer 1 on MFI

As shown, Stream 2 (blue wrap included) had a higher MFI than Stream 1 (blue wrap excluded), implying Stream 2 had a higher flowability. This is likely the result of the blue wrap, which has a lower viscosity than PE and thus reduces the viscosity of the system. For Stream 1, there was no direct relationship between MFI and the concentration of the compatibilizer 1. The average MFI remained nearly the same with increasing concentrations of compatibilizer. On the other hand, the MFI of Stream 2 changed with the compatibilizer, indicating that the concentration of the compatibilizer could have increased the flowability of the Stream 2.

Tensile Test

The tensile test was used to evaluate the relation of stress versus strain of the test specimen under uniaxial tension. In the current project, the tensile test followed ASTM D638-14; the test speed was 100 mm/min and 12 specimens per condition were tested. The figure below shows the progress of a specimen under tensile test as well as the results of the testing.

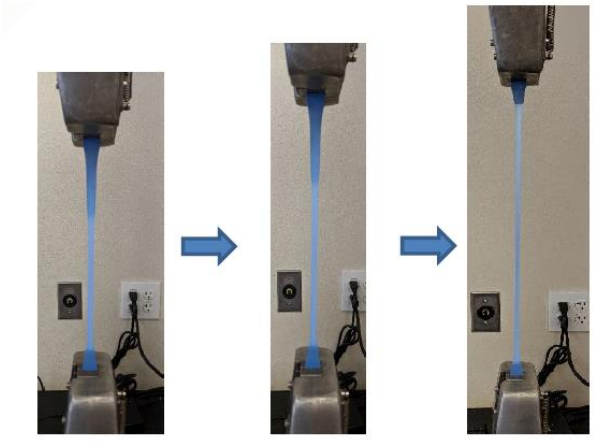


Figure 11: Progress of tensile bar under test

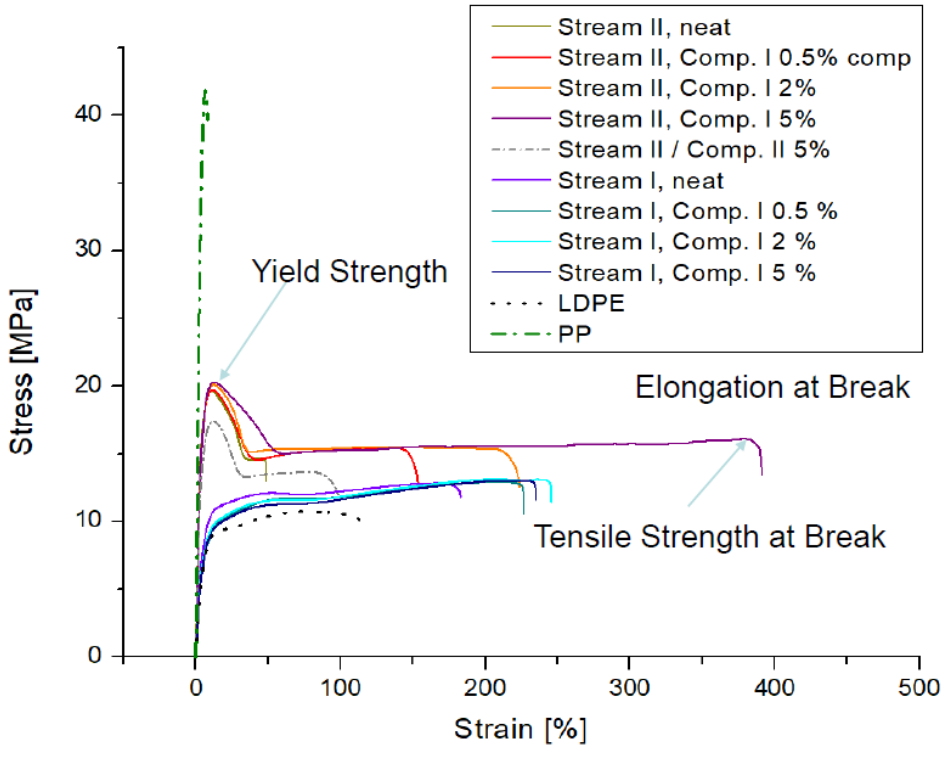


Figure 12: Summary of samples under tensile test

The results of the test show that the effect of compatibilizer 1 on Stream 1 was small; on the other hand, compatibilizer 1 increased the tensile strain at break for Stream 2. This was likely due to the fact that compatibilizer 1 is an olefin-based copolymer, improving the compatibility between PE and the PP non-woven blue wrap. This trend is consistent with the observation in the MFI test. For comparison purposes, two commercially available resin grades, LDPE and PP, were added into the tensile curve plot. Stream 1 can be close to LDPE grade and Stream 2 is similar to PP grade, based on tensile performance.

The following figure summarizes the tensile test results including tensile force, tensile strain and stress at break, force at yield, and tensile modulus. Stream 1 shows consistent properties with different compatibilizers. Stream 2 has a higher modulus and force at yield, but also has a higher statistical variation. The higher modulus and force at yield implies that Stream 2 is more rigid than Stream 1. This is likely related to the ingredients in the streams. The blue wrap in Stream 2 is

a PP based material, which has a higher rigidity than PE in the streams. The higher statistical variation in Stream 2 can likely be attributed to the dispersion of PP in the PE matrix, including variations in the amount of PP and dimension of the PP domain. Compatibilizer 2 has a lower impact on Stream 2 properties than Stream 1, implying a lower concentration of polar polymers in the waste stream.

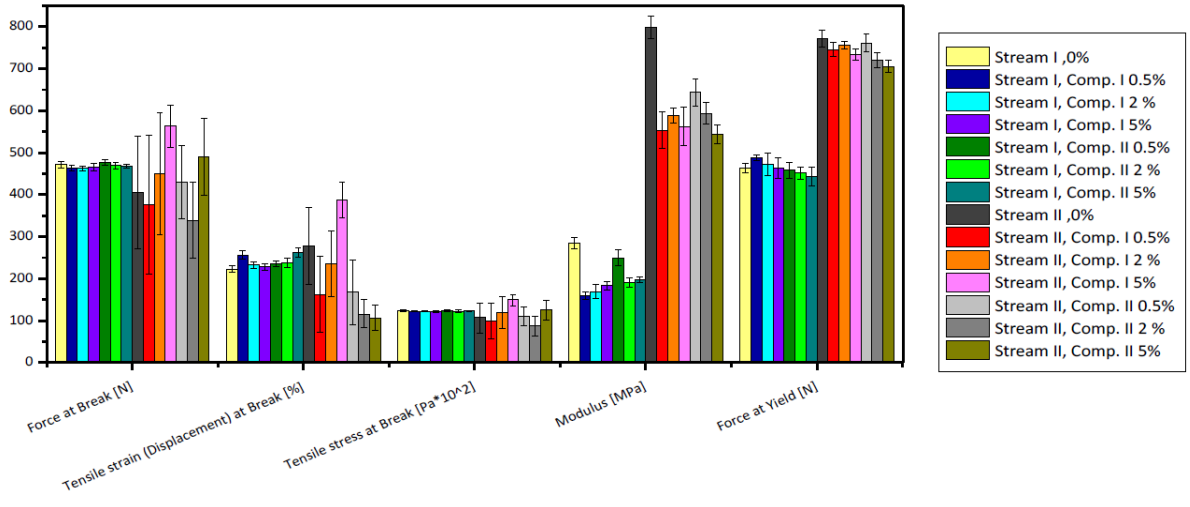


Figure 13: Summary of tensile test results, force, tensile strain and stress at break, modulus and force at yield

Izod Impact Test

The Izod impact test was conducted to evaluate the impact resistance of samples. Figures below show the impact testing set and test results. Stream 1 shows no break (bending), while the testing caused hinged breaks of Stream 2 during the test. This indicates that Stream 1 has a better impact resistance than Stream 2. Again, this is related to the composition difference between Stream 1 and 2. Both compatibilizers show minor effects on the streams' impact properties.

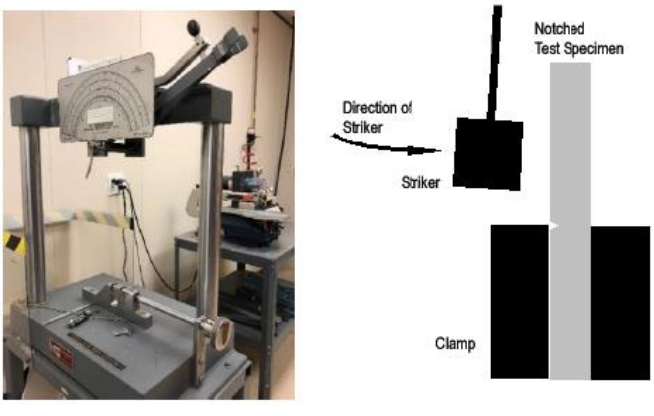


Figure 14: Izod impact test

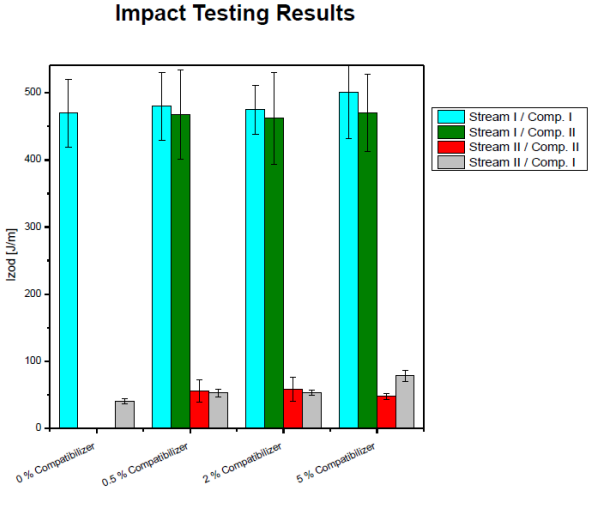
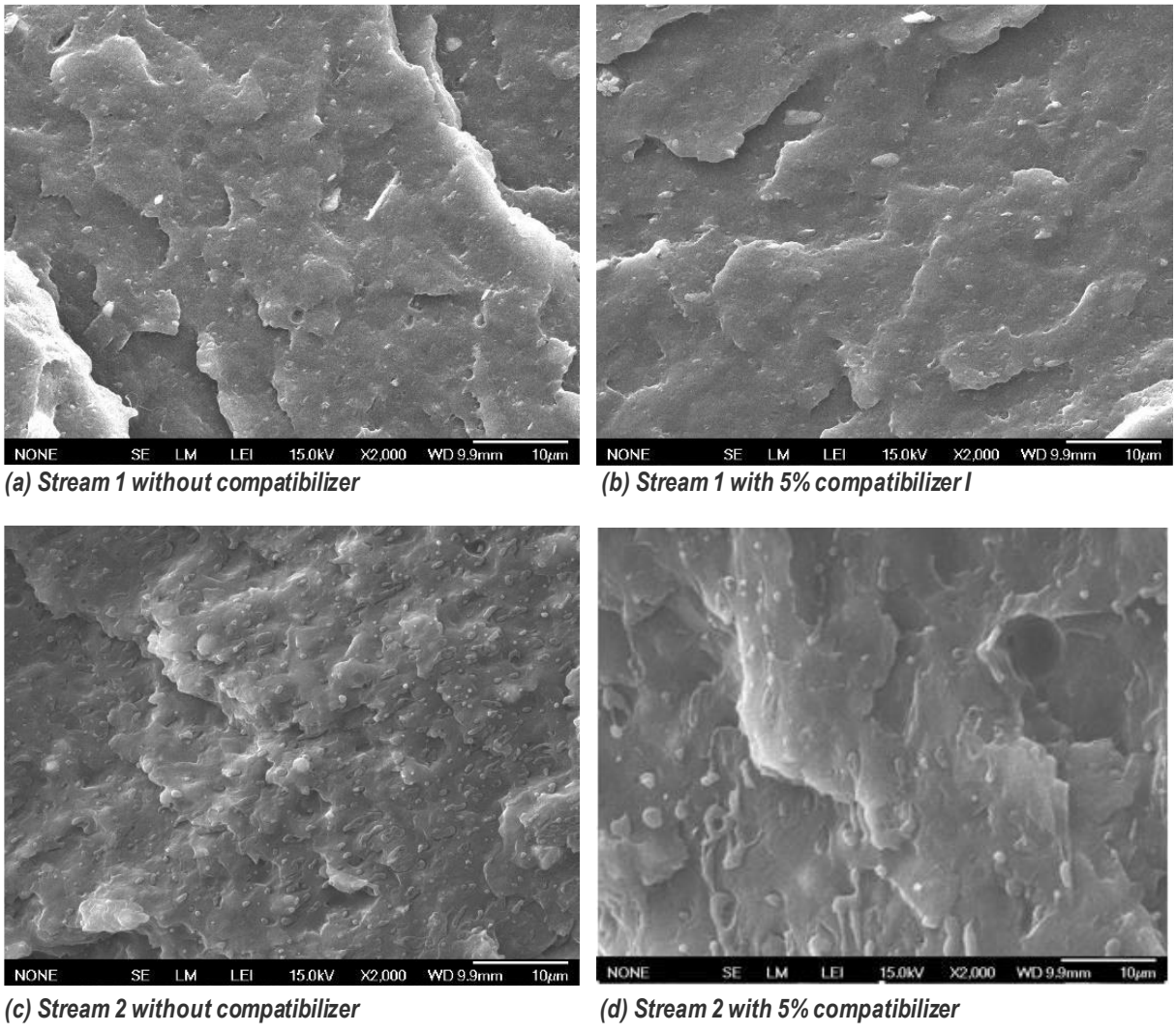


Figure 15: Impact test results

Scanning Electron Microscope (SEM)

The SEM was used to evaluate the morphology of the streams. The fracture surface used in the SEM analysis was generated from freeze fracture techniques. Small domains were identified in the samples, which can be seen in the photos

below. Stream 2 had more voids and spherical structures. This is likely due to the different composition of the streams; in other words, Stream 2 had high concentration of PP. The amount of dispersed domain appears to be comparable in Stream 1 with the presence of the compatibilizer, but it seems to decrease in Stream 2. This is consistent with the previous observation that compatibilizer 1 improves the compatibility in Stream 2.



(a) Stream 1 without compatibilizer *(b) Stream 1 with 5% compatibilizer I*

(c) Stream 2 without compatibilizer *(d) Stream 2 with 5% compatibilizer*

Figure 16: SEM picture of Stream 1 and Stream 2

CONCLUSIONS

This pilot project helped highlight some of the key opportunities and barriers associated with recycling flexible packaging derived from healthcare settings. We demonstrated that, with the proper controls in place, flexible packaging can be successfully segregated from the OR waste stream without fear of hazardous material contamination, and that a mixed-material stream of flexibles from multiple sources can be processed and pelletized into a resin that could potentially be used in a secondary application.

Specifically, based on the testing results, the resin produced from Stream 1 (no blue wrap), which is composed mainly of header bags, vent bags, Tyvek, formed package, and tear bags, demonstrated similar tensile performance to LPDE, and could be a potential candidate for applications that use LPDE resin. For example, the resin could be utilized in the creation of plastic bags, thus “closing the loop” on the waste stream. The resin from Stream 2, which contains about 60% blue wrap

and 40% of Stream 1, demonstrated properties that could make it a replacement for some PP-like resins. We also demonstrated the efficacy of compatibilizers in improving the compatibility of waste streams that include both blue wrap and mixed flexible films.

On the other hand, we uncovered a number of barriers that would need to be resolved to properly scale the pilot. Metallic films were difficult to distinguish in the OR and needed to be removed by hand from the waste streams prior to processing, adding a time-intensive additional step. Additionally, while coordinating the waste streams from four hospitals for the pilot project was manageable, adding the requisite number of additional hospitals to scale the effort would add additional logistical challenges. Lastly, to make the recycling efforts financially viable we would need to develop a market for these new recycled resins. That would require developing a process to add some level of homogenization and consistency to the waste stream.

While overcoming these barriers may seem daunting, we are not alone in trying to tackle the problem. Private industry, public entities, and NGOs around the world are working together to drive solutions to mixed flexible recycling. With this in mind, and HPRC's continued efforts on this front, we believe a sustainable solution for flexible plastics recycling is on the horizon.

ACKNOWLEDGEMENTS

We would like to thank BD, DuPont, Medtronic, Ravago, Dartmouth-Hitchcock Hospital, Lehigh Valley Hospital, and Cleveland Clinic for their contributions to this study. We would also like to recognize our other HPRC and Healthcare Facility Advisory Board (HFAB) members for their support. Special thanks to EREMA and UMass-Lowell for their external assistance as well.

HPRC Members:

Healthcare Facility Advisory Board:

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