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Comparison of Bioplastics with Conventional Thermoplastics for Consumer Applications

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Abstract

Controversy surrounds the use of plastic products, primarily due to their impact on the environment. Fortunately, bio-based plastics offers a solution by using sustainable resources as starting materials. Our team addressed the task of processing and conducting research on various bio-based plastics that were supplied by an industrial partner and comparing the bio-based plastics to control materials from petrochemical sources. Overall, the goal was to determine which bio-based resin would be the most suitable for use in consumer packaging products. Thermal, mechanical, and chemical properties were analyzed. The control resins used were: Formolene 2610A PP, Ineos Olefins & Polymers PP, and Alathon M5370 HDPE. The bio-based plastics were: Biogrades C5508 and C9550, Terralene PP3509, Terralene HD3505, Terratek SC50 and Terratek BD4015. Samples were injection molded to produce samples for further testing. The resins underwent thermal testing by differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) to determine key thermal transitions and material degradation temperatures to compare control resins to bio-based resins. Mechanical testing included tensile testing, (following ASTM D638) and Izod impact testing (following ASTM D256). Chemical compatibility tests were conducted (following a modified ASTM D543 procedure) with four typical household cleaners to determine the feasibility of the bio-based plastics for practical use. Mechanical data showed the bio-based plastics had overall lower strength than the controls. The Izod impact results of Terralene HD and Terralene PP were similar to that of HDPE and the PP controls. Additionally, the bio-based plastics demonstrated good compatibility to the household cleaners tested.

Introduction

Plastics and other polymeric materials have been in the spotlight for the negative impacts that they have on the environment after they are discarded and not recycled. Most widely used plastics are manufactured from petrochemicals such as petroleum, coal, or natural gas. Petrochemical plastics are not able to readily breakdown in the environment which aggravates the existing problem of pollution. Most petrochemically-based plastic will take up to thousands of years to degrade. Recycling offers a way to manage this problem, but not all communities offer recycling facilities or require that plastic be recycled. As a result, tons of plastic goes into landfills each year. New biobased or biodegradable plastics could be the solution to this problem.

Bioplastics can be derived from renewable sources, including vegetable oils, corn starch, woodchips, and food waste.[1] Bioplastics may also be partially or fully biodegradable so they can be turned into compost by exposure to water, carbon dioxide, and microorganisms.[2] Currently, more than 300 million tons of plastic are produced every year and only 10% of that is recycled. Bioplastic has the potential to have a significant impact on the 90% of plastics that goes unrecycled each year.[3] In 2014, there were 1.7 million metric tons of bioplastics produced and this is expected to grow 20-30% annually.[4] Bioplastics made from 20 percent or more of renewable materials can help reduce the depletion of fossil fuel resources, create a smaller carbon footprint, and can decompose faster compared to petroleum based polymers.[5,6]

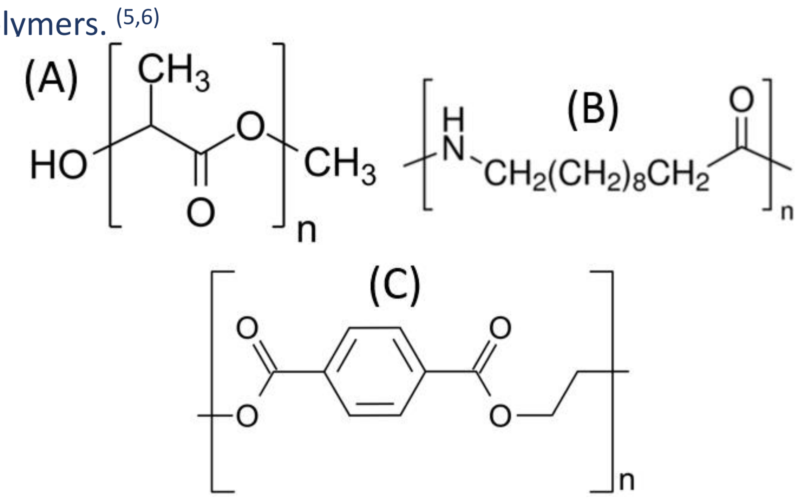


Figure 1. *Examples of Bioplastics*:
A) Poly(lactic acid), B) Nylon 11, and C) Polyethylene Terephthalate.

This work seeks to compare six commercially-available bioplastics to three traditional, petrochemically-based plastics. The bioplastics that we evaluated were: Terralene HD 3505, Terralene PP 3509, Terratek BD4015, Terratek SC50, Biograde C5508, and Biograde C9550. These were compared to industrial-grade polypropylene (PP), high-density polyethylene (HDPE), and high-impact polypropylene (HIPP). We compared processability, thermal properties, mechanical properties, and resistance to household chemicals to determine if these six bioplastics can be used in place of traditional petrochemically-based plastics with little to no loss of desired properties.

Objectives

In order to achieve our goals, our study sought to address the following objectives:

- To obtain bio-based resins from an industrial partner,
- To identify control resins,
- To injection mold bioplastic resins and control resins,
- To perform material characterization on controls and bioplastics, and
  - Mechanical testing
    - Izod impact testing
    - Tensile testing
  - Chemical resistance testing
  - Thermal testing
    - Thermogravimetric analysis (TGA)
    - Differential scanning calorimetry (DSC)
- To analyze TGA, DSC, and chemical resistance test data.

Materials and Methods

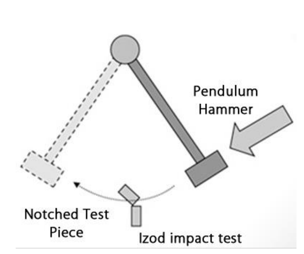
Materials:

Control Resins:

- Polypropylene (PP) (1): Homopolymer Polypropylene H05A-00
- High Density Polyethylene (HDPE) (2): Alathon M5370 HDPE
- High Impact Polypropylene (HIPP) (3): Formolene 2610A high impact copolymer polypropylene
- ***PP and HDPE data shown***

Bioplastic resins:

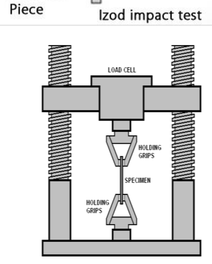
- Terralene PP (4): Terralene PP 3509 PP copolymer blend with biobased HDPE- Biobased carbon content is 33%
- Terralene HD (5): Terralene HD 3505 HDPE blend with Biobased HDPE; Biobased carbon content is 60%
- Terratek BD4015 (6): Blend of natural and synthetic biodegradable polymers
- Terratek SC50 (7): Blend of wheat starch (50% by weight) and polypropylene
- Biograde C5508 (8): Biodegradable compound partially based on renewable resources
- Biograde C9550 (9): Biodegradable compound made partially of renewable resources
- ***Terralene PP and Terralene HD data shown***



Methods:

Mechanical Testing:

Izod Impact Testing
- Five notched samples and five unnotched samples.
- Test performed in accordance with ASTM D256.

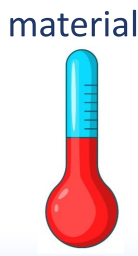


Tensile Testing
- 10 "dog bone" samples were tested for each resin.
- Specimens were pulled at a rate of 50 mm/min.
- Once the sample ruptured, the test was complete .
- Test performed in accordance with ASTM D638.

Chemical Compatibility
- This procedure is a modification of ASTM D543.
- The samples were tested in four household cleaners:
  -Windex, Bleach, Antibacterial hand soap, and Pine Sol.
- Each specimen was submerged for 4 weeks and weighed every 24 hrs.

Thermogravimetric Analysis (TGA):
- TGA was performed on a resin pellet and part of the molded material.
- Material was heated up to 600˚C at a rate of 10˚C per minute.
- The mass was plotted against temperature.
- Temperature at 10% weight loss, 50% weight loss and the percent residue were noted.

Differential Scanning Calorimetry (DSC):
- DSC was performed on a resin pellet and part of the molded material.
- Step 1: Equilibrate at -80˚C,
- Step 2: Heat to 200˚C at a rate of 10˚C per minute,
- Step 3: Cool to -80˚C at a rate of 10˚C per minute, and
- Step 4: Reheat 200˚C at a rate of 10˚C per minute.



Results

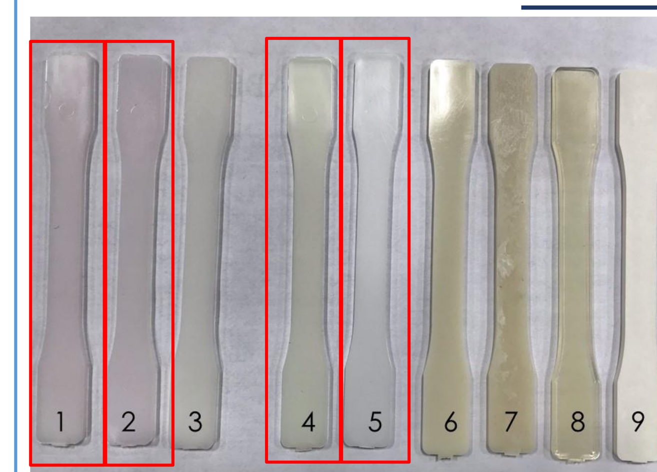


Figure 2. *Injection-molded samples*. Numbers on figure correspond to numbers in the materials list (left). PP, HDPE, Terralene PP, and Terralene HD indicated in red boxes.

Table 1. *Izod Impact Data*:
A) PP, B) HDPE,C) Terralene PP, and D) Terralene HD.

A) Ineos Olefins & Polymers PP

Notched Test			Non-notched		
Trial	Ftlb/in	Break Type	Trial	Ftlb/in	Break Type
1	8.886	Hinge Break	6	43.331	Non-Break
2	9.452		7	41.776	
3	9.061		8	37.398	
4	9.452		9	37.503	
5	9.549		10	38.756	
Avg.	**9.28**		Avg.	**39.7528**	

B) Alathon M5370 HDPE

Notched Test			Non-notched		
Trial	Ftlb/in	Break Type	Trial	Ftlb/in	Break Type
1	1.647	Full Break	6	30.386	Non-Break
2	1.647		7	29.863	
3	1.74		8	29.444	
4	1.555		9	27.877	
5	1.647		10	29.444	
Avg.	**1.6472**		Avg.	**29.4028**	

C) Terralene PP 3509

Notched Test			Non-notched		
Trial	Ftlb/in	Break Type	Trial	Ftlb/in	Break Type
1	0.638	Full Break	6	34.574	Non-Break
2	1.279		7	45.293	
3	1.095		8	36.144	
4	1.004		9	35.306	
5	0.638		10	45.602	
Avg.	**0.9308**		Avg.	**39.3838**	

D) Terralene HD 3505

Notched Test			Non-notched		
Trial	Ftlb/in	Break Type	Trial	Ftlb/in	Break Type
1	1.832	Full Break	6	34.364	Non-Break
2	1.832		7	32.165	
3	1.832		8	31.328	
4	1.925		9	33.841	
5	1.555		10	29.235	
Avg.	**1.7952**		Avg.	**33.1866**	

Table 2. *Tensile Testing Data for PP, HDPE, Terralene PP, and Terralene HD*.

Sample	Mean Tensile Stress (MPa)	Mean Tensile Strain (mm)
PP Control	26.57964	4.93231
HDPE Control	25.96827	7.83432
Terralene PP	30.64462	8.19856
Terralene HD	29.98896	8.41417

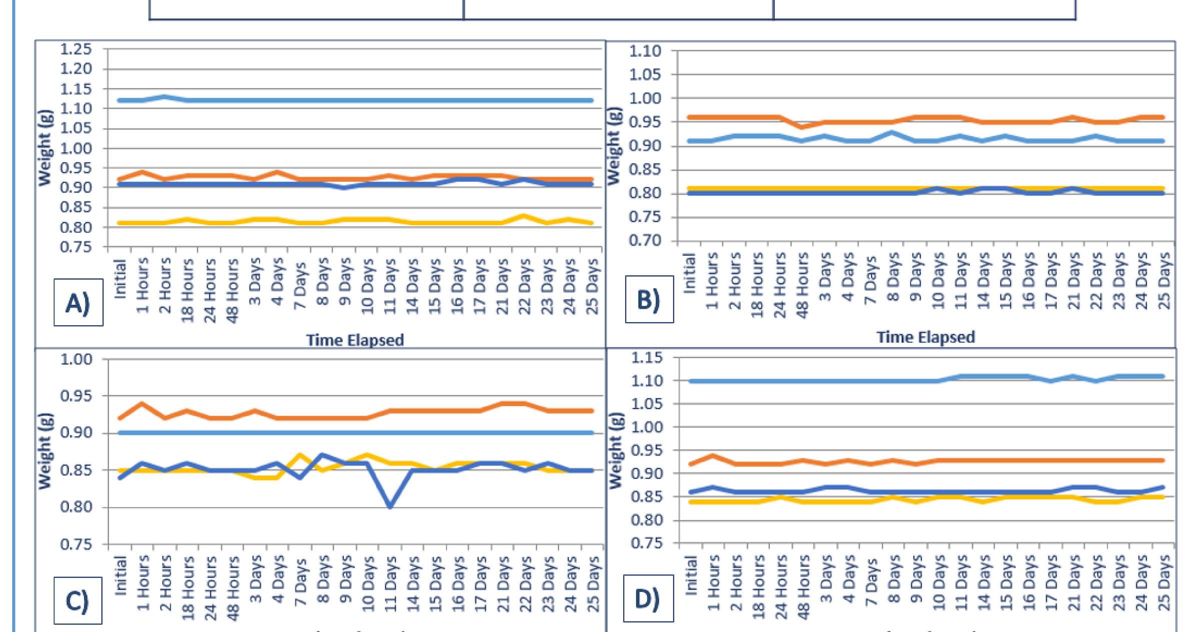


Figure 3. *Chemical Compatibility*:
A) Windex , B) Bleach, C) Hand soap, and D) Pine Sol.
PP (—), HDPE) (—), Terralene PP 3509 (—), and Terralene HD 3505 (—).

Table 2. *Thermogravimetric Data for PP, HDPE, Terralene PP, and Terralene HD*.

Sample	Temperature @ 10% Weight Loss (°C)	Temperature @ 50%Weight Loss (°C)
PP Control Pellet	382	410
PP Control Part	335	382
HDPE Control Pellet	428	450
HDPE Control Part	417	447
Terralene PP Pellet	339	385
Terralene PP Part	339	391
Terralene HD Pellet	344	395
Terralene HD Part	346	397

All resins had 0% residue after analysis.

Results (continued)

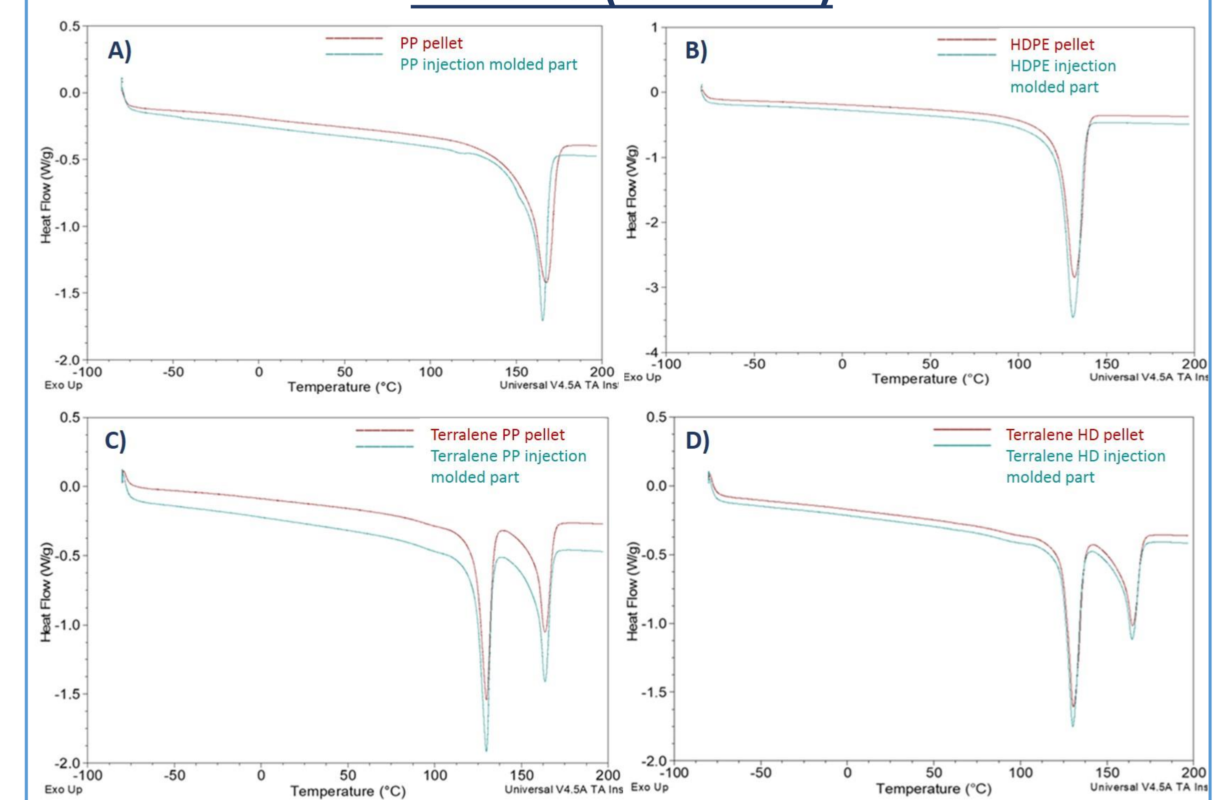


Figure 4. *Differential Scanning Calorimetry*:
A) PP, B) HDPE, C) Terralene PP 350, and D) Terralene HD 3505.

Conclusions

Terralene HD and Terralene PP bioplastics perform most similarly to the control PP and HDPE resins.

Impact testing:
- PP control samples produced hinge-break when notched
- Terralene HD produced highest notched ftlb/in.
- Terralene PP produced highest non-notched ftlb/in.
- Overall, bioplastics produced similar results to their respective controls.

Tensile testing:
- Terralene HD produced highest mean tensile strain.
- Terralene PP produced highest mean tensile stress.

Chemical compatibility:
- Most resins performed well against the cleaners.
- Terralene PP had noticeable weight loss after 11 days in soap.

Thermals Analysis
- TGA Analysis: Resin pellets and injection molded parts had similar degradation temperatures.
- DSC Analysis: Slight temperature differences between pellets and injection molded parts; Most noticeably for Terralene PP.

Future Work

As an extension of this work we would like to further explore:
- Comparison of the mechanical, chemical, and physical effects of adding colorants to bioplastics to those of petrochemical plastic controls.
- Using the same experimental bioplastics, creation of actual parts and test their durability during the part's life cycle.
- Finding ***biodegradable*** plastics and comparing their mechanical, chemical, and physical affects to ***biobased*** plastics and petrochemical plastics.

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