ADVANCED DRAINAGE SYSTEMS, INC.

Advanced Drainage Systems

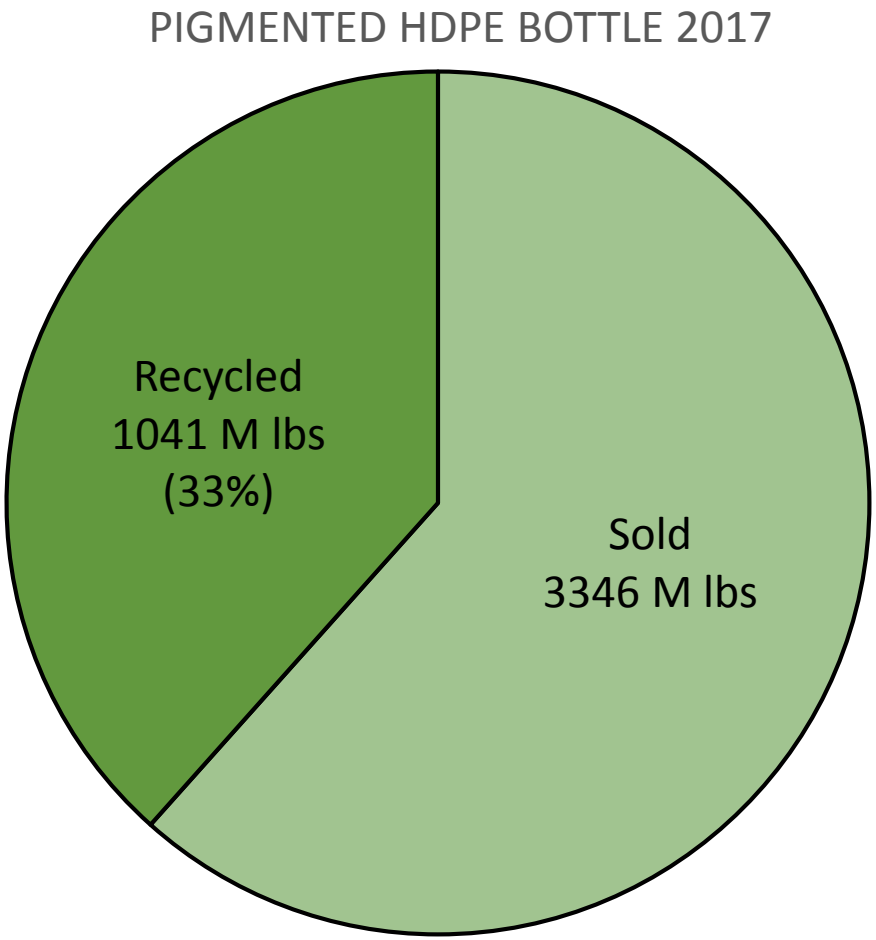
Resin Blending and Variability of HDPE Recycled Materials

January, 2018

Daniel J Figola, PE

- Worldwide HDPE usage 47,980,000 metric tons (2018)
  - Consumer packaging & containers
  - Short life cycle (milk jug <6mo)

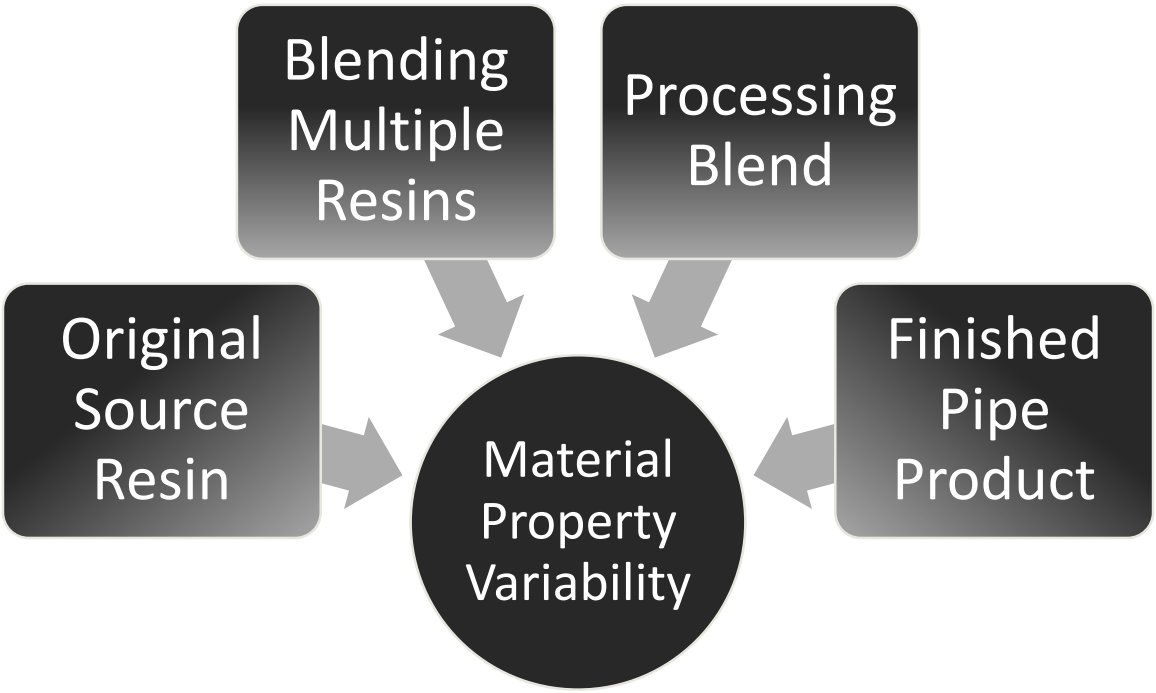
Domestic Recycling



The Perfect Outlet

- Drainage pipe is the ideal outlet for recycled HDPE
  - Colored flake can be used since end product is black
  - Blending allows for use of materials with a wide range of properties
  - Odors remaining in the plastics are not a concern
  - Short service life products are removed from a closed tight loop recycling chain and put it into service for 50-100 years

Project Goals



Nomenclature

- Post-Consumer HDPE
  - General public recycling
  - Milk jug, detergent containers, food & product packaging
  - Includes commercial and industrial products that have served its purpose
- Post-Industrial HDPE
- Flake
- Salt & Pepper Blending
- Pellets & Pelletizing

Recycled HDPE Bales

Nomenclature

- Post-Consumer HDPE
- Post-Industrial HDPE
  - Excess or rejected bottles, crates, drums dunnage
- Flake
- Salt & Pepper Blending
- Pellets & Pelletizing

Post-Industrial HDPE

Nomenclature

- Post-Consumer HDPE
- Post-Industrial HDPE
- Flake
  - Original production, shredded plastic; washed
- Salt & Pepper Blending
- Pellets & Pelletizing

Recycled HDPE Flake

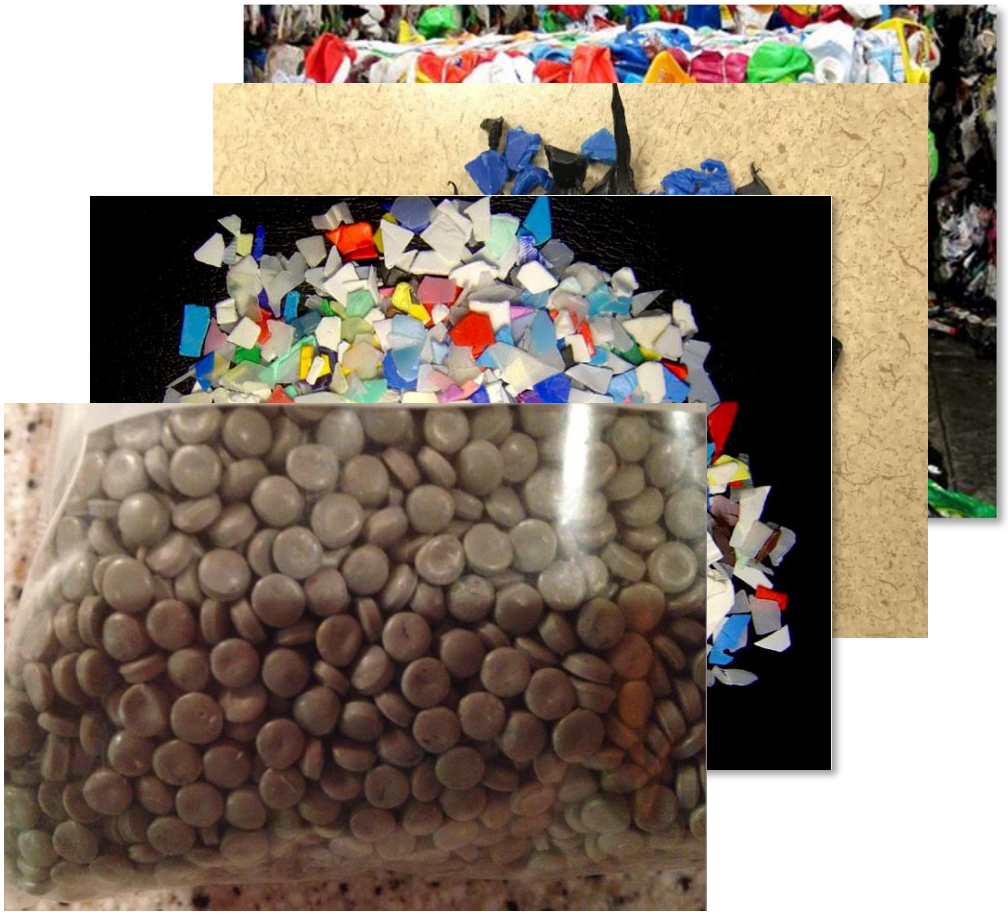
Nomenclature

- Post-Consumer HDPE
- Post-Industrial HDPE
- Flake
- Salt & Pepper Blending
  - Mechanical blending of 2+ components
- Pellets & Pelletizing

Recycled HDPE Flake

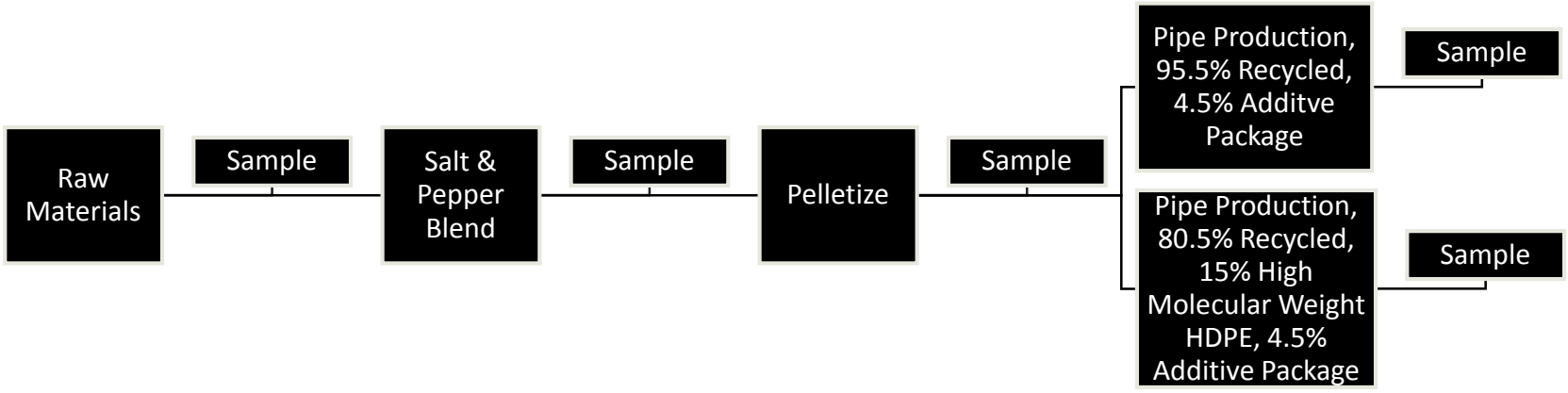
Nomenclature

- Post-Consumer HDPE
- Post-Industrial HDPE
- Flake
- Salt & Pepper Blending
- Pellets & Pelletizing
  - Melt, blend, filter process
  - Extruded into thin, cylindrical pellets



Recycled HDPE Pellets

Experiment


Raw Materials
Sample
Salt & Pepper Blend
Sample
Pelletize
Sample
Pipe Production, 95.5% Recycled, 4.5% Additve Package
Sample
Pipe Production, 80.5% Recycled, 15% High Molecular Weight HDPE, 4.5% Additive Package
Sample

Experiment

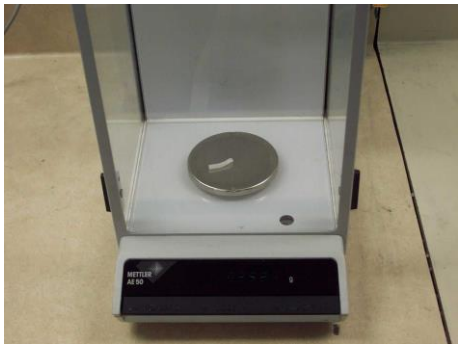
- 45,000lbs total material
  - 45% “Z” (post-industrial flake)
  - 25% “6” (post-consumer flake)
  - 15% “X” (post-industrial blow molding flake)
  - 10% “V” (post-industrial film)
  - 5% “Y” (post-industrial pellet)
- 95.5% recycled content, 4.5% additive to meet ASTM F2648 requirements
- 80.5% recycled content, 15% high molecular weight HDPE, 4.5% additive to meet AASHTO M294 requirements

Tested Properties

- Melt Index, per ASTM D1238
  - Processability of material

Standard Specification	Melt Index [ASTM D1238]	NCLS [ASTM F2136], hrs	UCLS [ASTM F3181], hrs
ASTM F2648 Private land drainage	<0.15	Avg >16, Min >12	N/A
AASHTO M294 Surface and subsurface drainage	<0.15	Avg ≥24	Avg >34, Min >18

Finished pipe requirements; not raw material

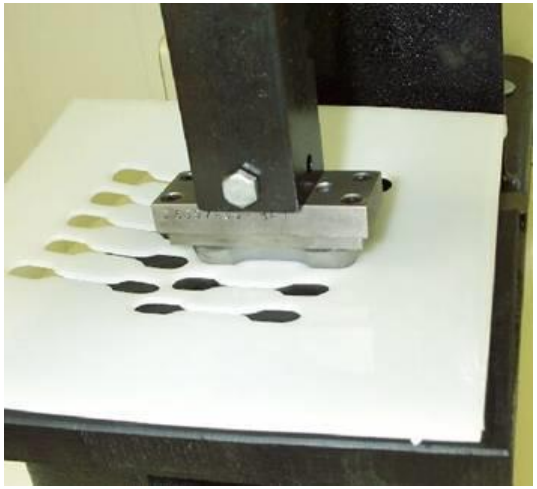


Tested Properties

- Notched Constant Ligament Stress, per ASTM F2136
  - Initiated crack, time to failure
  - Stress crack resistance

Standard Specification	Melt Index [ASTM D1238]	NCLS [ASTM F2136], hrs	UCLS [ASTM F3181], hrs
ASTM F2648 Private land drainage	<0.15	Avg >16, Min >12	N/A
AASHTO M294 Surface and subsurface drainage	<0.15	Avg ≥24	Avg >34, Min >18

Finished pipe requirements; not raw material

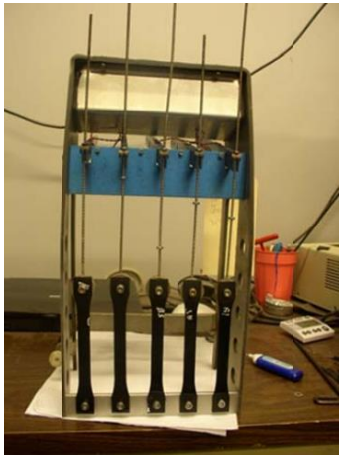


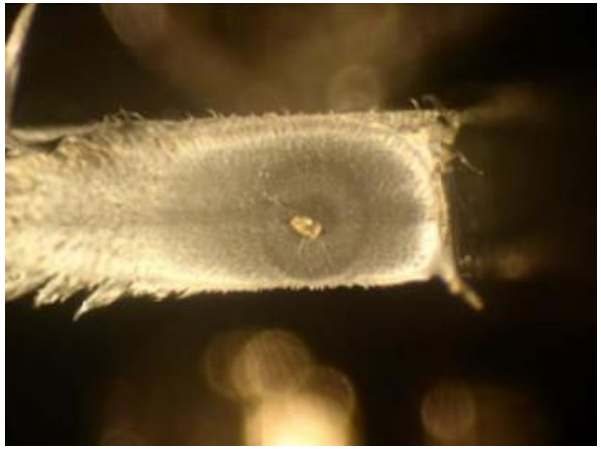
Tested Properties

- Un-notched Constant Ligament Stress, per ASTM F3181
  - Crack propagation, time to failure
  - Presence of contaminant

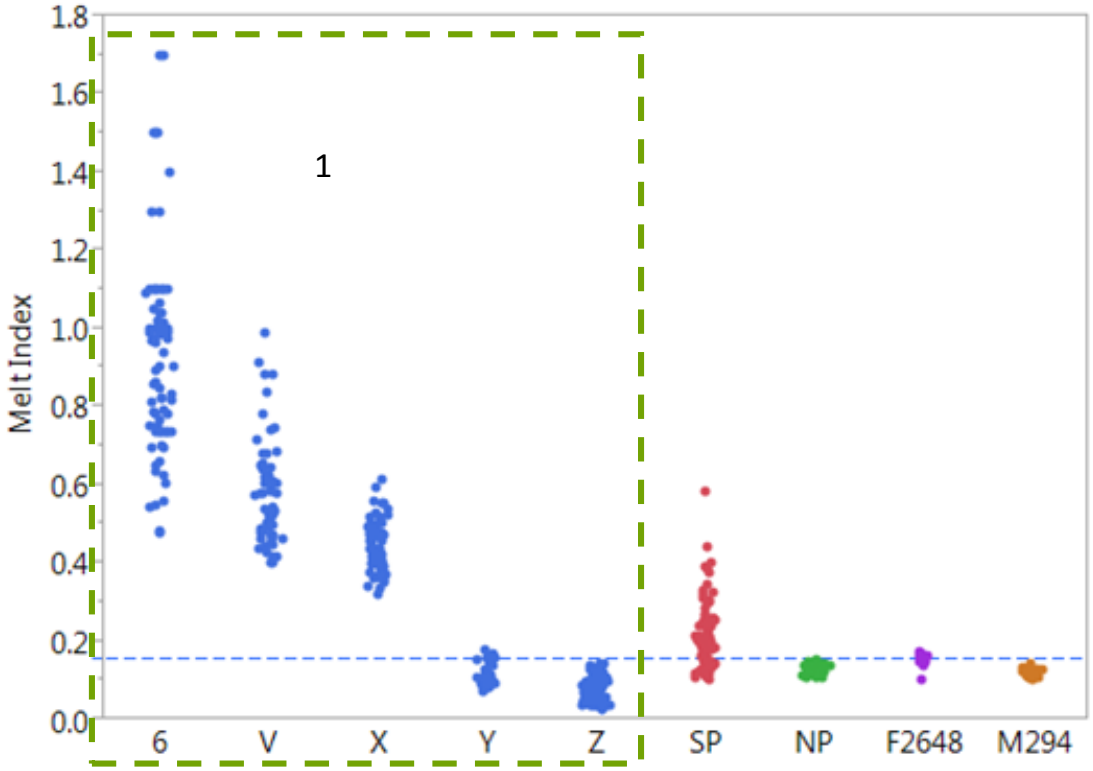
Standard Specification	Melt Index [ASTM D1238]	NCLS [ASTM F2136], hrs	UCLS [ASTM F3181], hrs
ASTM F2648 Private land drainage	<0.15	Avg >16, Min >12	N/A
AASHTO M294 Surface and subsurface drainage	<0.15	Avg ≥24	Avg >34, Min >18

Finished pipe requirements; not raw material





Results

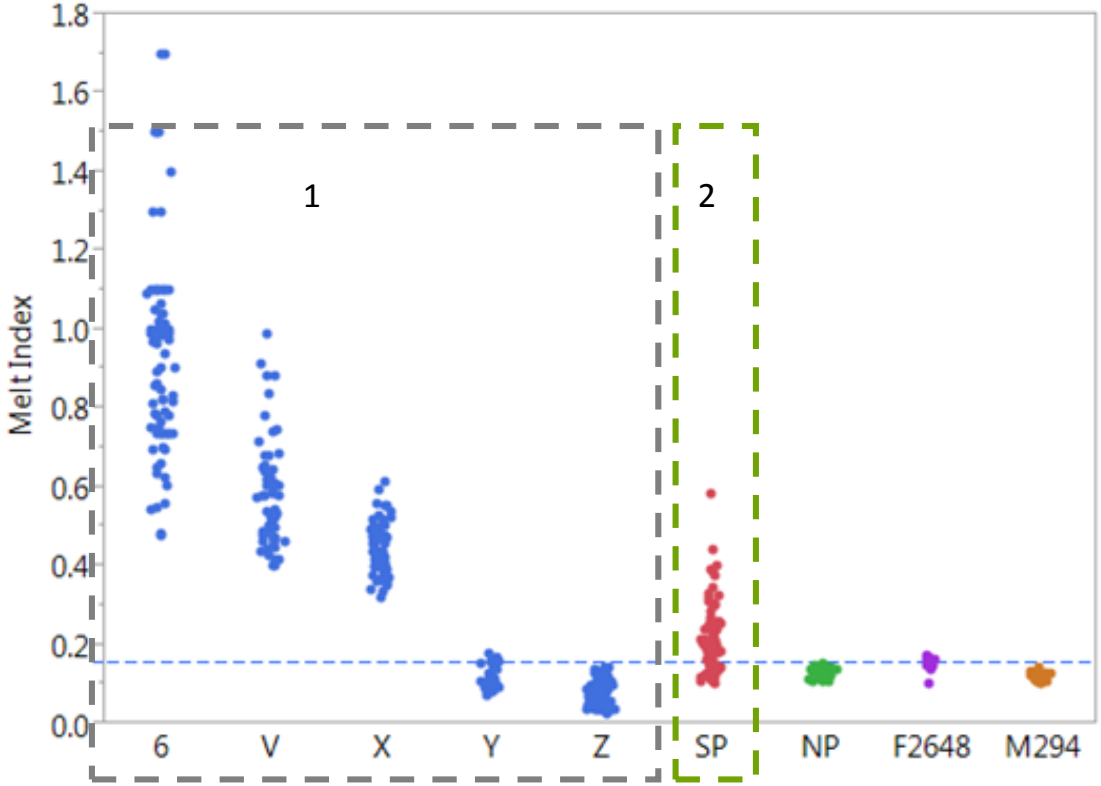


Melt Index

1. Raw material wide distribution

Dashed line is maximum threshold per ASTM F2648 and AASHTO M294

Results

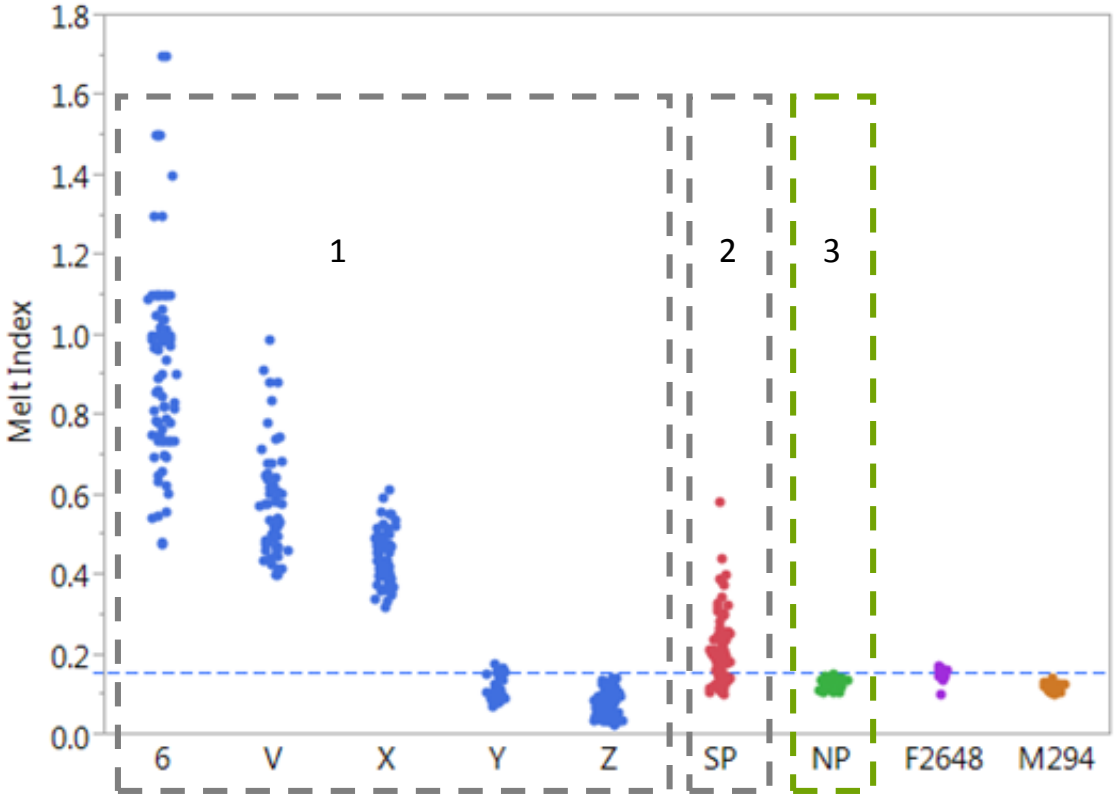


Melt Index

1. Raw material wide distribution
2. Mechanical blending some homogenization

Dashed line is maximum threshold per ASTM F2648 and AASHTO M294

Results

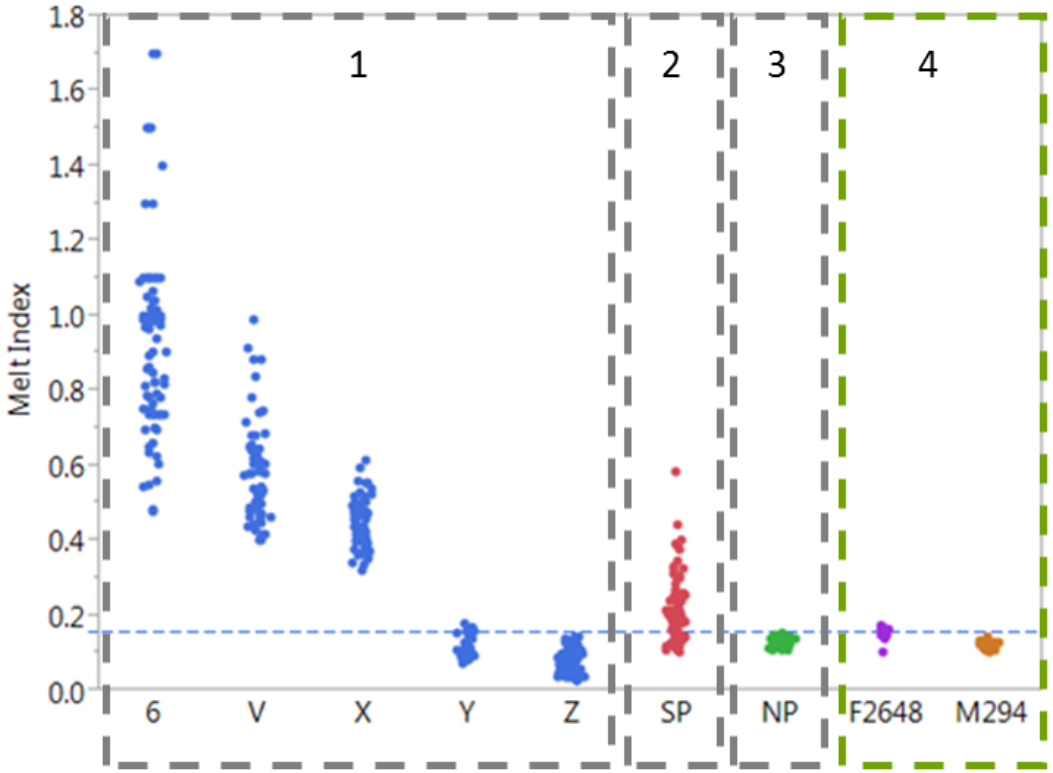


Melt Index

1. Raw material wide distribution
2. Mechanical blending some homogenization
3. Pelletizing (melt-filter) further homogenization

Dashed line is maximum threshold per ASTM F2648 and AASHTO M294

Results

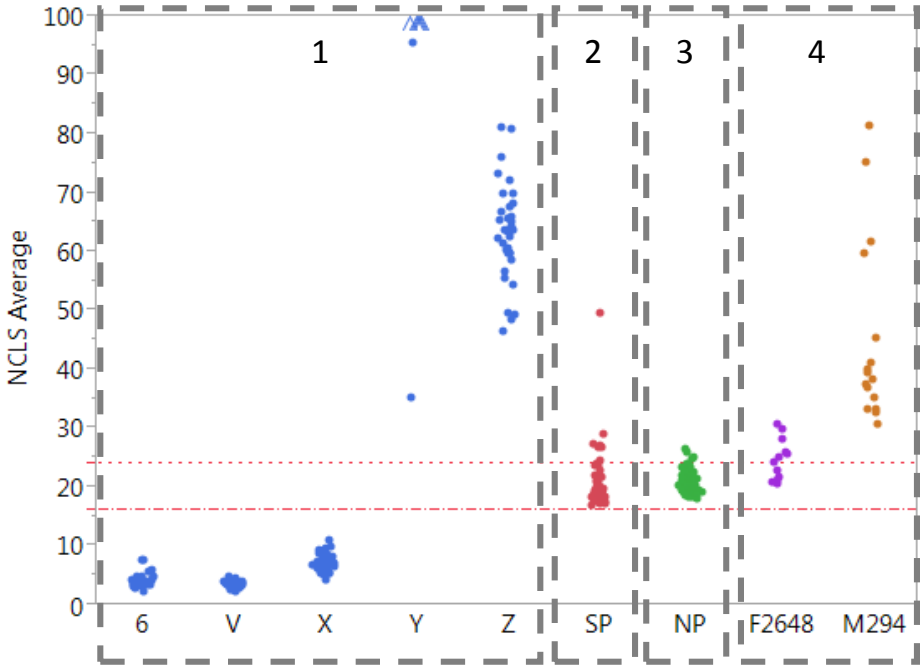


Melt Index

1. Raw material wide distribution
2. Mechanical blending some homogenization
3. Pelletizing (melt-filter) further homogenization
4. Pipe product extrusion

Dashed line is maximum threshold per ASTM F2648 and AASHTO M294

Results

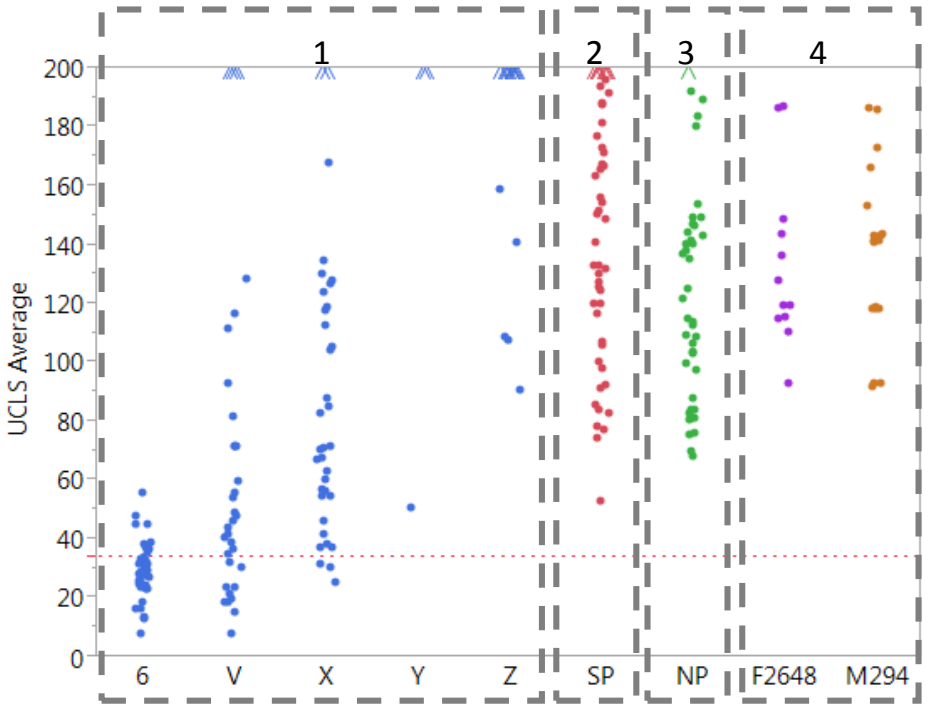


NCLS

1. Raw material wide distribution
2. Mechanical blending some homogenization
3. Pelletizing (melt-filter) further homogenization
4. Pipe product extrusion
    1. Addition of virgin HDPE increased failure time

Dotted line is minimum average failure time per AASHTO M294
Dashed line is minimum average failure time per ASTM F2648
Arrows at top of chart indicate results exceeding the scale shown

Results



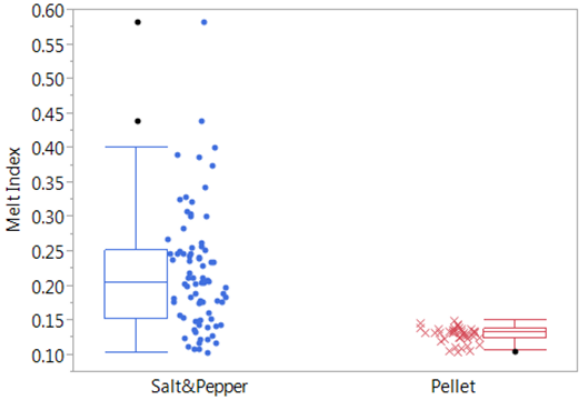
UCLS

1. Raw material wide distribution
2. Mechanical blending some homogenization
3. Pelletizing (melt-filter) some homogenization
4. Pipe product extrusion

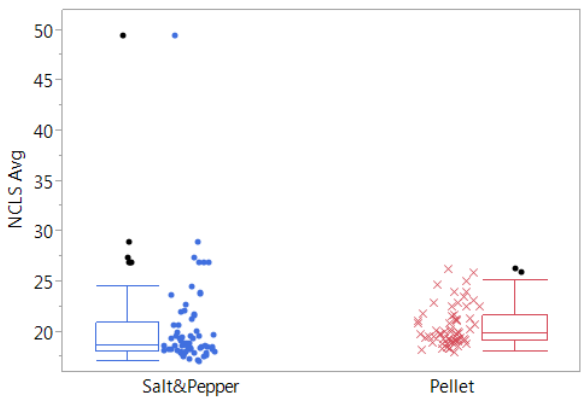
Dotted line is minimum average failure time per AASHTO M294
Arrows at top of chart indicate results exceeding the scale shown

Significance of Pelletizing to Variability

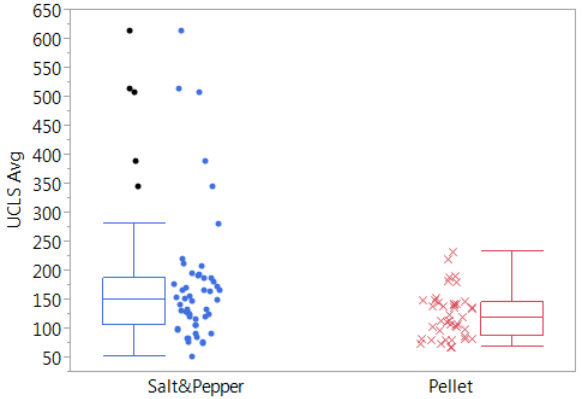
Melt Index



NCLS



UCLS



https://www.ads-pipe.com/

Significance of Pelletizing to Variability

Physical Property	Statistically Significant?	Magnitude of Significance	Significant Reduction to Mean?
Melt Index	Yes	88%	Yes
NCLS Avg. Failure Time	Yes	57%	No
UCLS Avg. Failure Time	Yes	65%	Yes

- Quantify significance variability reduction from Salt & Pepper to Pellet
- Levene Test to test for equal variances
- T-test for change in mean
- Alpha of 0.05 ($P<0.05$) threshold for significance

Conclusions

- Raw material testing alone does not predict final product performance
- Mechanical blending facilitates homogenizing the blend
- Statistically significant reduction in variability with pelletizing salt & pepper (mechanical) blend
- Significant increase in stress crack resistance with 15% high molecular weight HDPE addition to meet AASHTO M294
- Recycled-content HDPE for corrugated pipe production is viable and will meet performance & service life requirements

Special Thanks!

Co-authors from ADS and Battelle for completing the joint research

ADS plant production and laboratory personnel

Crista K. McNish, P.E.
Advanced Drainage Systems, Inc.
Vancouver, WA, USA

Joe Babcanec, P.E.
Advanced Drainage Systems, Inc.
Hilliard, OH, USA

Rachel M. Thurston
Battelle
Columbus, OH, USA

Zacharias Obermeyer
Advanced Drainage Systems, Inc.
Hilliard, OH, USA