Improving Adhesion Strength of Thermoplastic Elastomers (TPEs) Overmolded onto Eastman Tritan™ Renew

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June 12, 2024

A materials innovation company

- Celebrating more than **100 years of vital innovations that enhance people's lives every day**.
- A Fortune 500 company with approximately **14,500 employees and approximately 8.5 billion USD** in revenue
- Dedicated to **enhancing the quality of life in a material way**
- Sustainability strategy commitment to **mitigating climate change, mainstreaming circularity** and **caring for people and society**

Global Commitment

U.S. PLASTICS PACT

ENERGY STAR AWARD 2019 PARTNER OF THE YEAR Sustained Excellence

AMERICA'S MOST JUST COMPANIES Forbes 2017

Responsible Care® OUR COMMITMENT TO SUSTAINABILITY

FAST COMPANY World Changing Ideas 2022

TOP 100 BARRON'S Most Sustainable Companies 2021

WSJ 100 MOST SUSTAINABLY MANAGED COMPANIES 2020

Three simultaneous global crises need solutions

Mechanical and Molecular recycling

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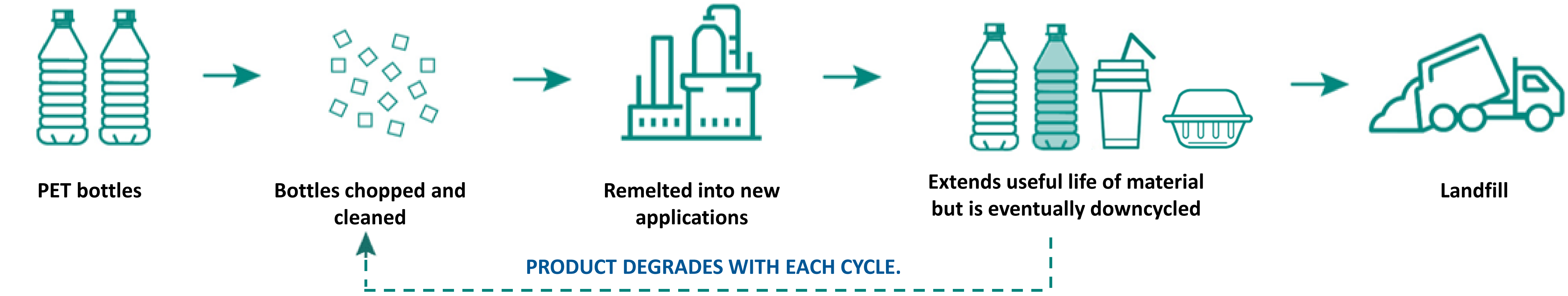
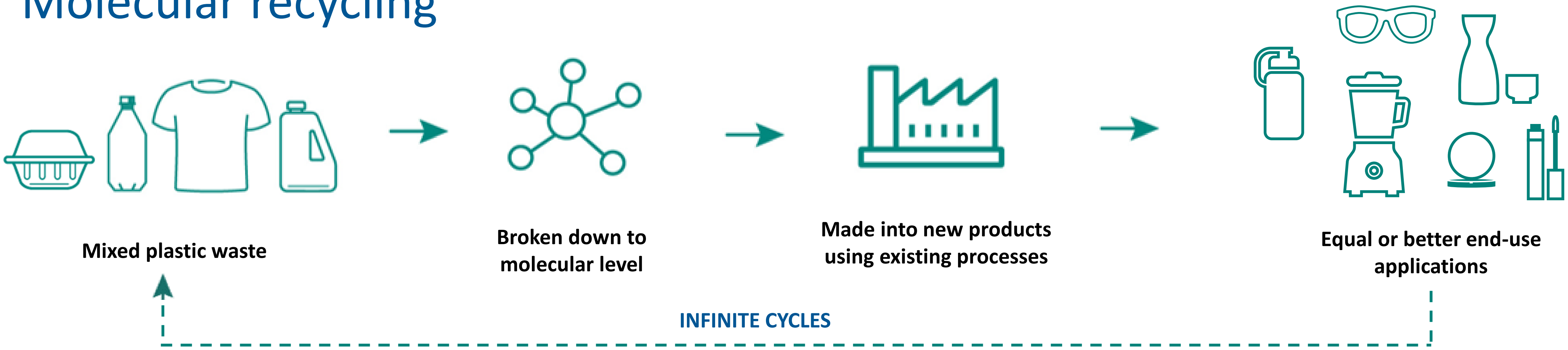
Mechanical recycling



Molecular recycling



The world’s largest molecular recycling facility

Producing on-spec product and generating revenue since March 2024.

The mixed plastics processing plant prepares hard-to-recycle polyester waste converting it to the format needed for depolymerization.

The depolymerization plant converts this material to monomers that feed our existing polymer lines

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Context and Scope

- Overmolding is utilized in myriad markets, such as automotive, consumer electronics and medical due to its inherent ability to join two polymeric materials together.
- While the materials selected for overmolding will depend on the end-use application, in most cases, a soft thermoplastic elastomer (TPE) is overmolded onto a rigid thermoplastic resin.
- As companies introduce new, sustainable materials to the market, adequate bonding between the overmolded materials is required to maintain performance in the end-use application.
- The ambiguity associated with new and sustainable materials has resulted in sub-par product performance in end-use applications. This work was initiated to address this issue.
- There are three main ways to influence the bond strength of overmolded materials:
  - i. Chemistry (Choice of substrate or TPE)
  - ii. Design (cross-sectional area of overmolded, mechanical interlocks)
  - iii. Processing Conditions
- The scope of this work is two-fold:
  1) To understand how the processing conditions impact adhesion strength of 2k overmolded materials.
  2) To highlight how the choice of material impacts adhesion.

Abstract

Abstract

The purpose of this work was to examine how various TPE processing parameters impact the peel strength (adhesion) of TX1501HF overmolded with TPEs via 2K molding. This study was limited to three easy-to-change variables (Mold Temperature, Pack and Hold Time, and Injection Speed) and one hard-to-change variable (TPE Barrel Temperature). Utilizing a Split-Plot DoE, we determined that three variables (Mold Temperature, Pack and Hold Time, and TPE Barrel Temperature) were statistically significant and that the peel strength performance could be increased by optimizing these conditions.

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DoE Variables and Values Examined

Parameter	DoE Designation	Parameter Value	TPE	Thermoplastic Resin
Mold Temp	-1	40 ^oC	Not Identified	Tritan TX1501HF
	0	50 ^oC		
	1	60 ^oC		
TPE Barrel temperature	-1	195 ^oC		
	0	205 ^oC		
	1	215 ^oC		
Pack and Hold Time (TPE)	-1	normal pack and hold time		
	0	normal time plus 10% longer pack and hold		
	1	normal time plus 20% longer pack and hold		
Injection Speed of TPE	-1	normal speed		
	0	normal speed + 10%		
	1	normal speed + 20%		
Barrel Temp (TX1501HF)		270 ^oC		

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DoE Objective: Optimize Conditions for Overmolding onto TX1501HF

Parameter	DoE Designation	Parameter Value	TPE	Thermoplastic Resin
Mold Temp	-1	40 °C	Not Identified	Tritan TX1501HF
	0	50 °C		
	1	60 °C		
TPE Barrel temperature	-1	195 °C		
	0	205 °C		
	1	215 °C		
Pack and Hold Time (TPE)	-1	normal pack and hold time		
	0	normal time plus 10% longer pack and hold		
	1	normal time plus 20% longer pack and hold		
Injection Speed of TPE	-1	normal speed		
	0	normal speed + 10%		
	1	normal speed + 20%		
Barrel Temp (TX1501HF)		270 °C		

- TPE was held constant for DoE study.
- Thermoplastic resin (TX1501HF) and processing conditions thereof were held constant for DoE.
  - Temperature of the thermoplastic resin (substrate) not examined.

This design will estimate main effects (linear terms), two-factor interactions and quadratic terms.

Run#	Extrusion Day	Whole Plots	TPU BarrelTemp	Mold Temp	Pack & Hold	Injection Speed
1	1	1	-1	-1	0	-1
2	1	1	-1	0	1	0
3	1	1	-1	1	0	0
4	1	1	-1	0	0	1
5	2	2	0	-1	1	-1
6	2	2	0	-1	-1	0
7	2	2	0	1	1	1
8	2	2	0	0	-1	-1
9	3	3	-1	0	0	0
10	3	3	-1	0	0	0
11	3	3	-1	-1	-1	1
12	3	3	-1	1	-1	-1
13	4	4	1	1	0	-1
14	4	4	1	1	1	1
15	4	4	1	0	-1	1
16	4	4	1	-1	1	0
17	5	5	0	1	1	-1
18	5	5	0	-1	1	1
19	5	5	0	0	0	0
20	5	5	0	1	-1	1
21	6	6	1	-1	0	1
22	6	6	1	-1	-1	-1
23	6	6	1	0	1	-1
24	6	6	1	1	-1	0

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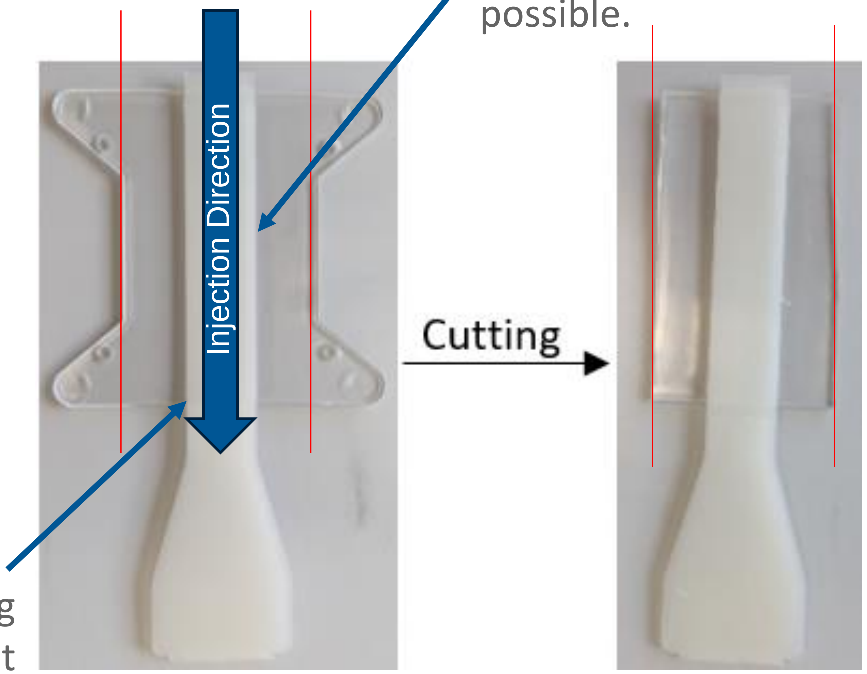
Injection Molding Machine and Sample Generation

Engel E Victory 220

Clamping Force = 2200 kN

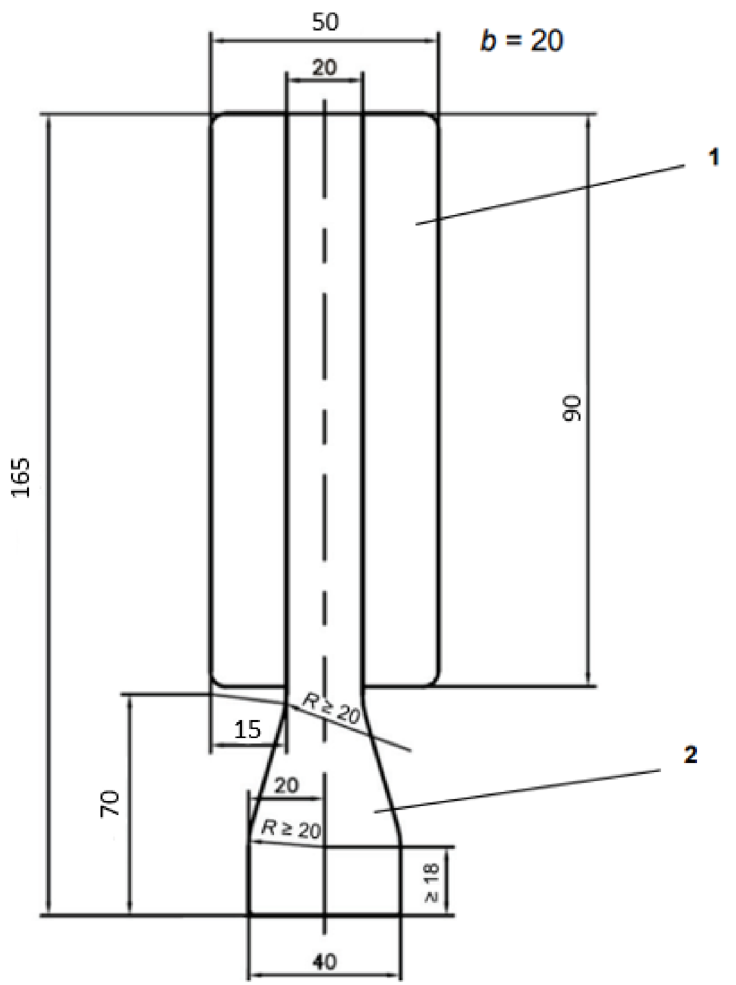
Dual Barrel Molding Machine



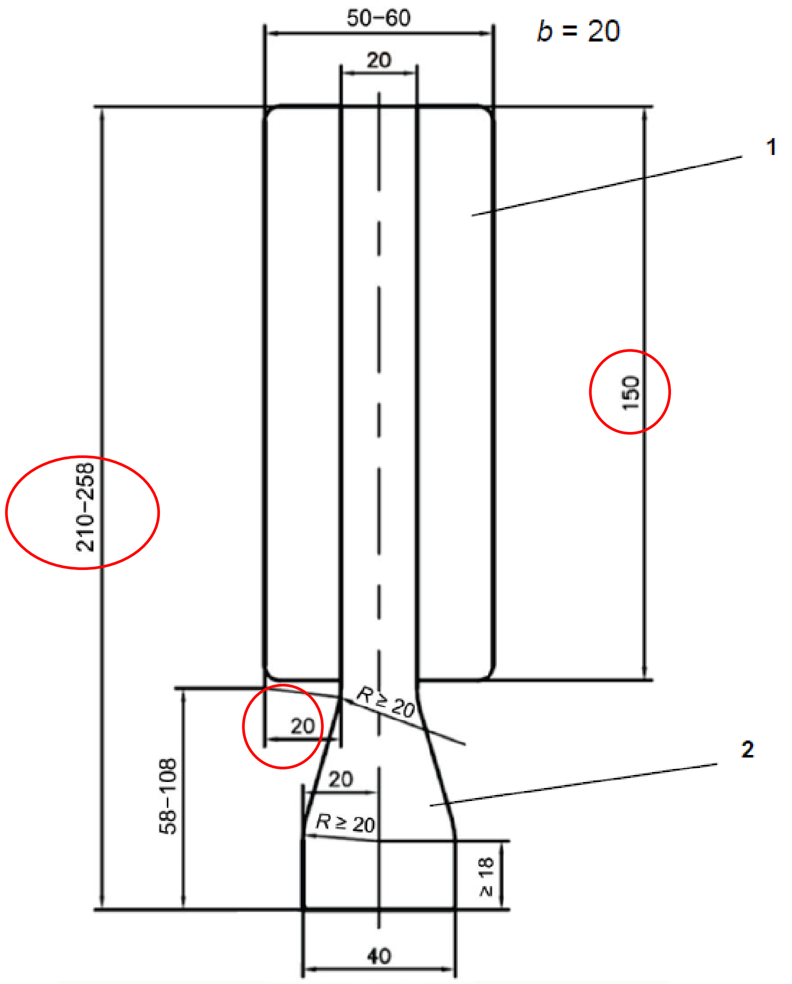
- Samples generated via 2k injection molding process using Engel E Victory220.
- Samples were stored for at least 24 h at 23 ^{o}C and 50% RH.
- Samples then had all four corners removed to fit into the specimen holder.

Sample Comparison (Eastman Technology Center vs VDI)

Eastman Technology Center (Ghent)



VDI 2019



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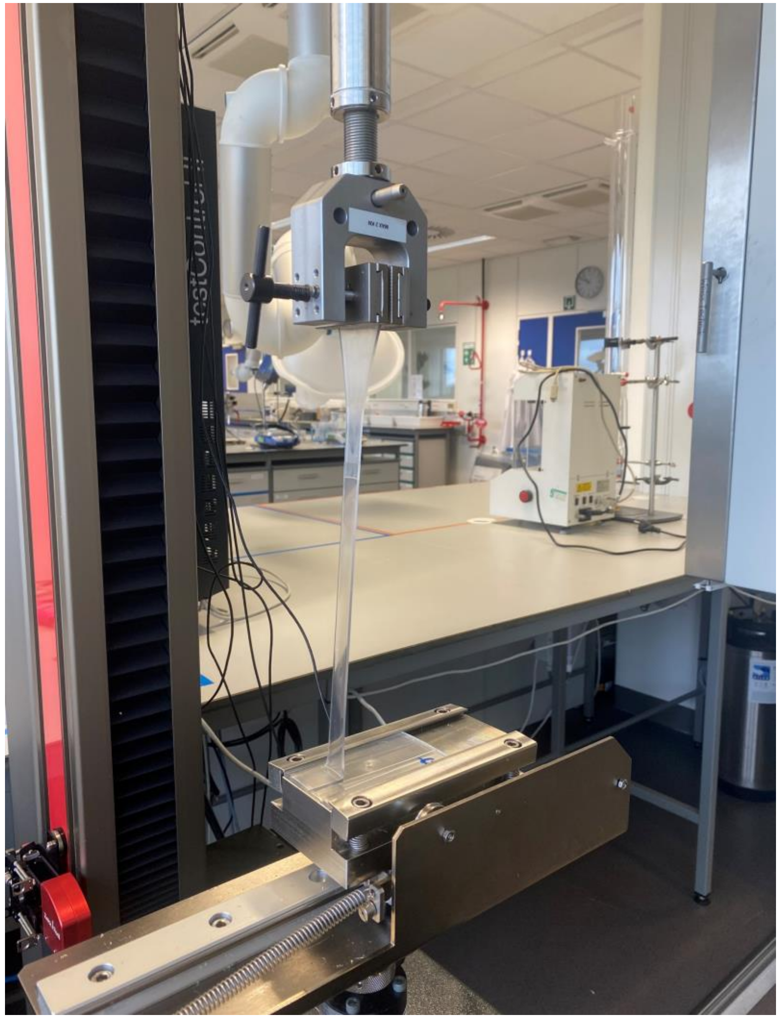
Sample Measurements and Methodologies

- Samples were tested on a Zwick Roell Z010 Machine equipped with a 90º peel test kit. This kit aligns with ASTM D6862 and ISO 913.
  - Carriage tracks at crosshead speed enabling exact observance of 90º peel angle.
  - Force required to advance carriage is not transmitted to the specimen.

- Samples were tested at 23 ºC and 50% RH at a peeling speed of 100 mm/s. (Minimum of 10 samples tested for each DoE Run.)



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Values Reported as Described by VDI Method (ISO: 6133)

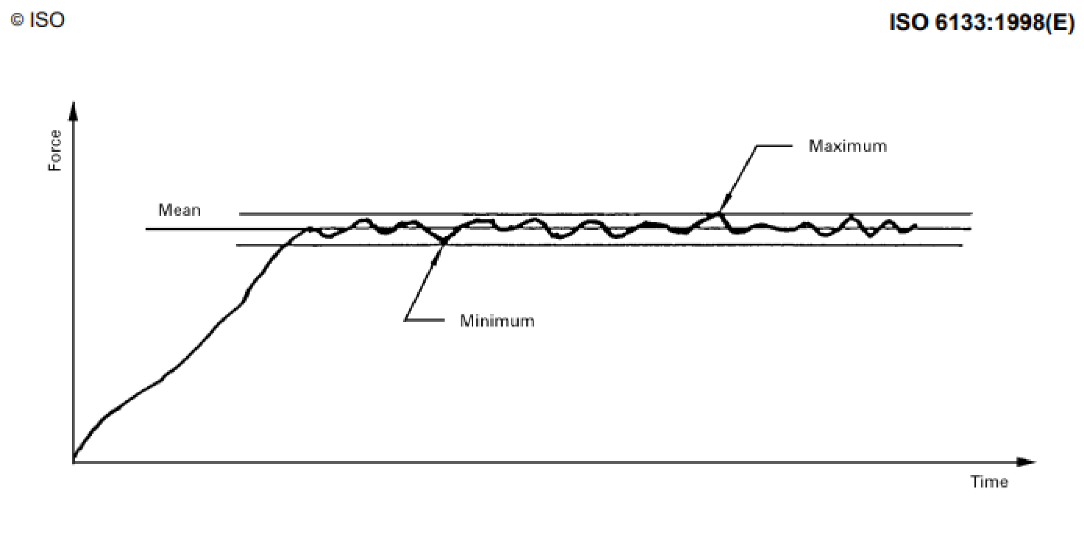
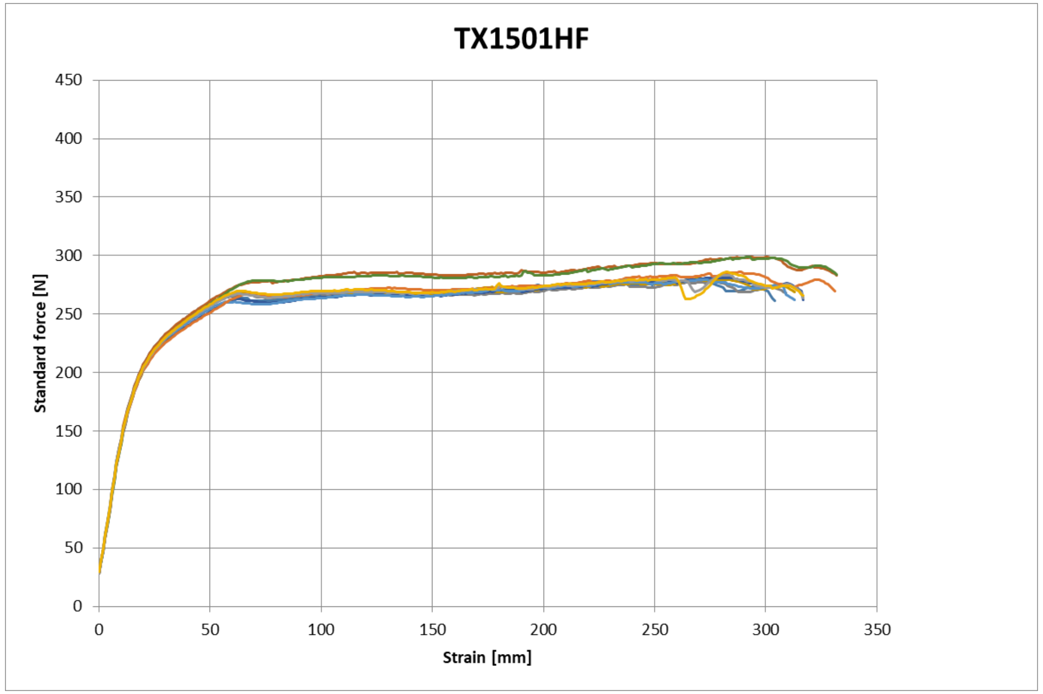


Figure 3 – Analysis of an undulating trace (range or median of no significance)

- Ignore initial rise at the start of the test.
- Report:
  - For Undulating curves, report arithmetic mean.

- ASTM D6862
  - Disregard the first 25 mm of test.



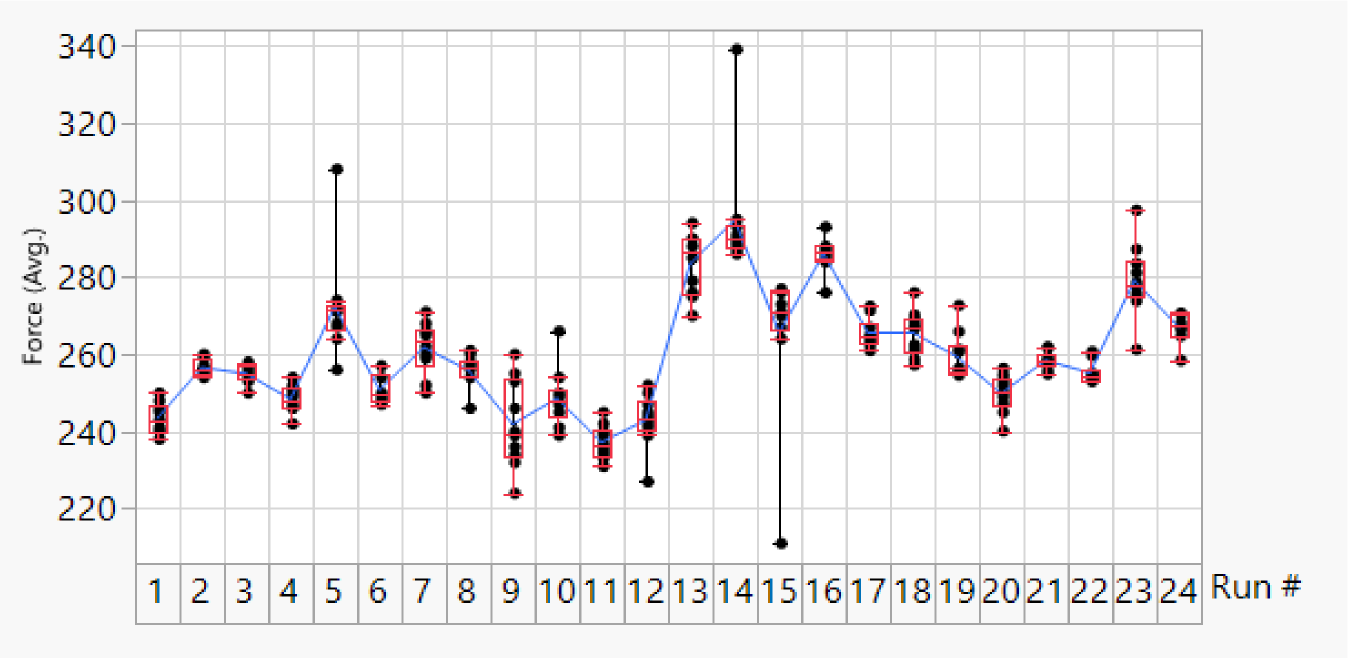
- Ignored initial rise at the start of the test.
  - Left first 20% out of calculation
  - Left last 5% out of calculation

- For DoE, Samples were tested until sample failure (break) or material was fully peeled off (~300 mm).

Individual F_{Avg} versus Run#

This design will estimate main effects (linear terms), two-factor interactions and quadratic terms.

Run#	Extrusion Day	Whole Plots	TPU BarrelTemp	Mold Temp	Pack & Hold	Injection Speed
1	1	1	-1	-1	0	-1
2	1	1	-1	0	1	0
3	1	1	-1	1	0	0
4	1	1	-1	0	0	1
5	2	2	0	-1	1	-1
6	2	2	0	-1	-1	0
7	2	2	0	1	1	1
8	2	2	0	0	-1	-1
9	3	3	-1	0	0	0
10	3	3	-1	0	0	0
11	3	3	-1	-1	-1	1
12	3	3	-1	1	-1	-1
13	4	4	1	1	0	-1
14	4	4	1	1	1	1
15	4	4	1	0	-1	1
16	4	4	1	-1	1	0
17	5	5	0	1	1	-1
18	5	5	0	-1	1	1
19	5	5	0	0	0	0
20	5	5	0	1	-1	1
21	6	6	1	-1	0	1
22	6	6	1	-1	-1	-1
23	6	6	1	0	1	-1
24	6	6	1	1	-1	0



- The individual average force values are plotted for each run in the DOE.
- The average force values calculated for each run are displayed by the connected blue line.
  - The impact of outliers can be eliminated by calculating the median force values (middle line in box plot).

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Average F_{Avg} Model Statistics

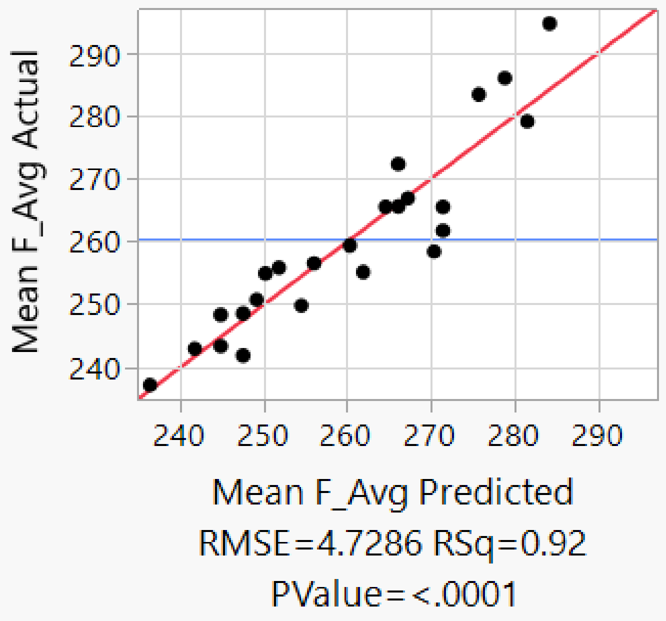
The experimental values plotted vs the model's predicted value show good agreement.

- Specifically, the R-Square and Adjusted R-Squared statistics are 0.92 and 0.91, respectively.

The parameter tests table shows that **<u>TPE melt temperature, mold temperature and pack and hold time are all statistically significant at the 95% confidence level</u>**. The effect of injection speed was not significant and removed from the model.

The parameter estimates can be used to predict the average of the average force within the ranges of the process factors studied.

Actual by Predicted Plot



Summary of Fit

RSquare	0.924469
RSquare Adj	0.91314
Root Mean Square Error	4.728619
Mean of Response	260.2251
Observations (or Sum Wgts)	24

Parameter Estimates

Term	Estimate
Intercept	-23.66052
TPE Melt Temp	1.2785294
Mold Temp	0.2681375
Pack & Hold	0.8491985

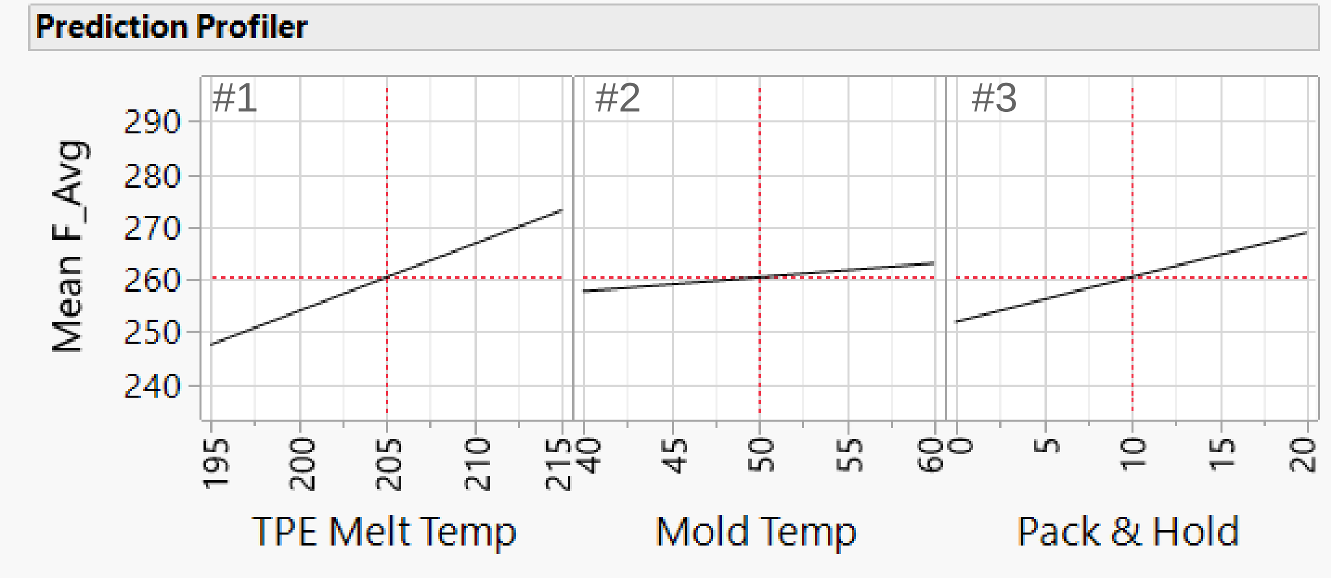
Parameter Tests

Term	Prob>|t|
Intercept	<.0001*
TPE Melt Temp(195,215)	0.0056*
Mold Temp(40,60)	0.0387*
Pack & Hold(0,20)	<.0001*

Average F_{Avg} Model Trends

The profile plot to the right shows the trends of average force average vs each of the process variables in the model.

- Plot #1 shows force increases as TPE Melt Temperature increases.
- Plot #2 shows force increases as Mold Temperature increases.
- Plot #3 shows force increases as Pack & Hold increases.



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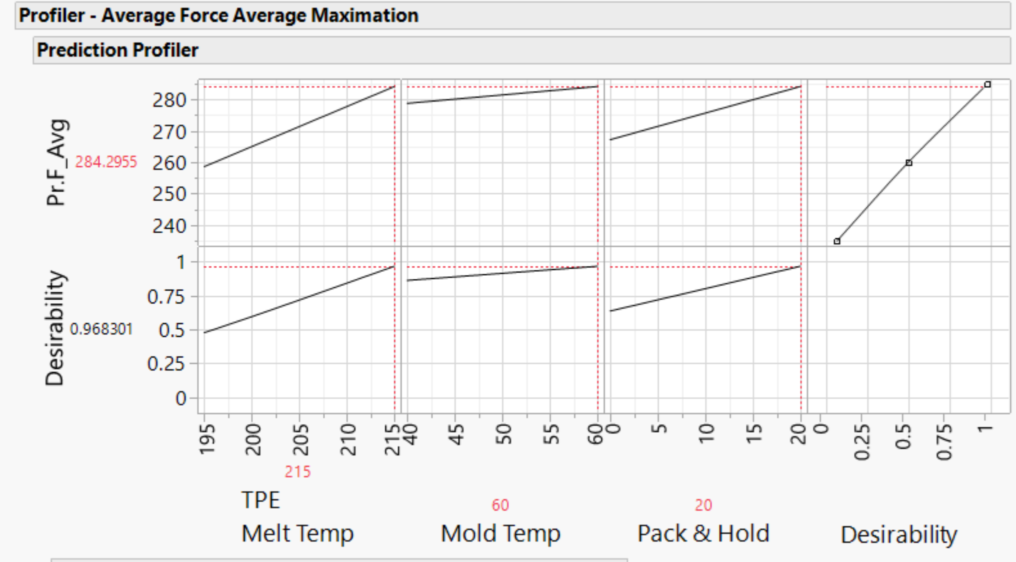
Average F_{Avg} Maximization

The profiler to the right shows that optimizing the process settings to generate the maximum peel force predicts a value of **284 N**.

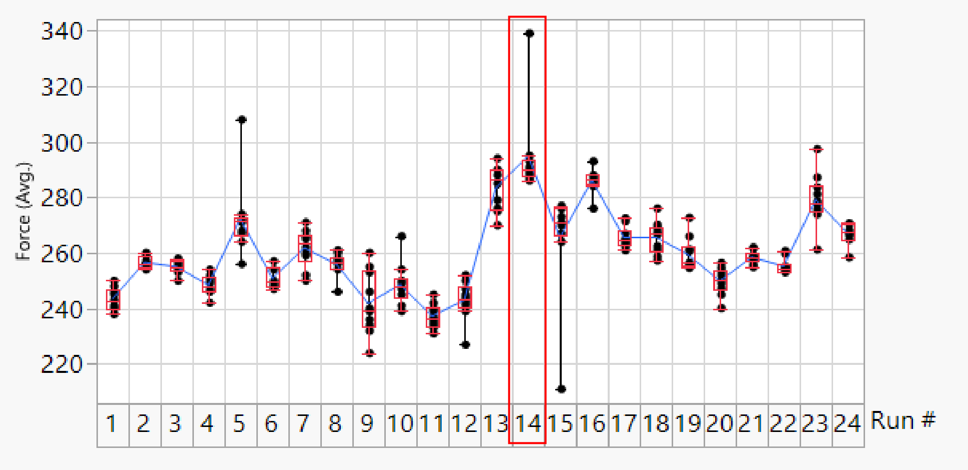
- TPE Melt Temperature should be set hot (215 ^{O}C).
- Mold Temperature should be set hot (60 ^{O}C).
- Pack and Hold should be set at the high level (normal time plus 20% longer pack and hold).
- The Injection Speed of the TPE is not in the model and could be set at any level within the range studied (normal speed to normal speed +20%)



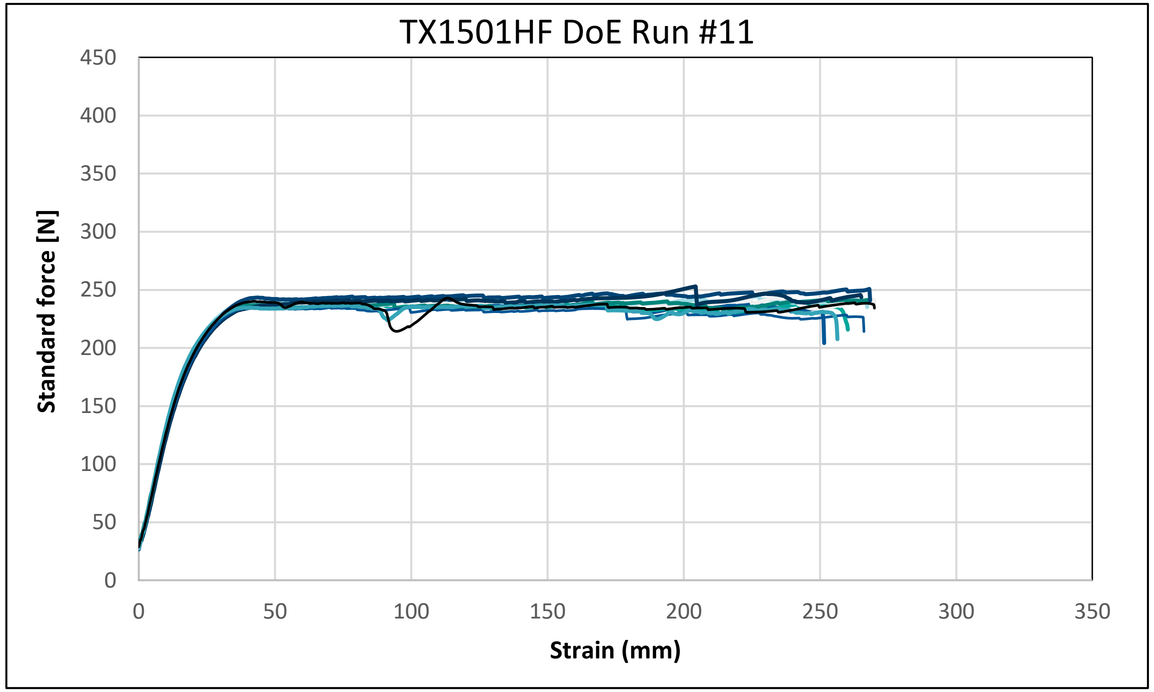
Remembered Settings

Setting	TPE Melt Temp	Mold Temp	Pack & Hold	Pr.F_Avg	Desirability
Optimal	215	60	20	284.29552	0.968301

Reflecting on the DoE, run 14 utilized the optimized settings noted above and obtained an average value of **294 N.** This peel strength is indeed the highest value obtained.



Comparison of Adhesion Strength Utilizing Optimized Molding Conditions vs Non-Ideal Conditions



DoE Experiment	Mean	Std Dev	Lower 95%	Upper 95%	Median
Run #[11]	237.2	4.315347	234.113	240.287	236.5

Average Peel Strength: ~237 N

Molding Conditions:
Injection Speed: Normal Injection Speed + 20%
Barrel Temperature: 195 ºC
Mold Temperature: 40 ºC
Pack and Hold: Normal Pack and Hold Time

DoE Experiment	Mean	Std Dev	Lower 95%	Upper 95%	Median
Run #[14]	294.8	15.76071	283.5255	306.0745	290

Average Peel Strength: ~294 N

Molding Conditions:
Injection Speed: Normal Injection Speed + 20%
Barrel Temperature: 215 ºC
Mold Temperature: 60 ºC
Pack and Hold: Normal Pack and Hold Time + 20% Longer Time

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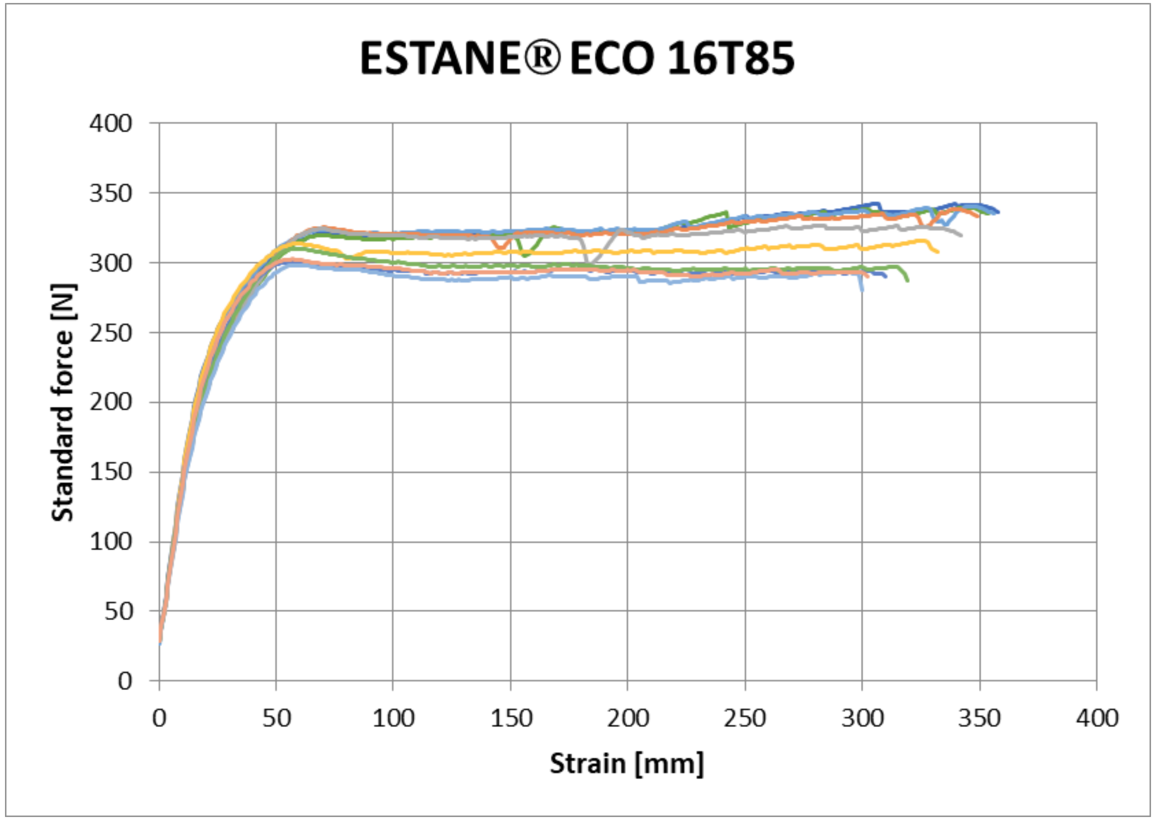
Examining the Performance of Various TPEs using Optimized Processing Conditions

Lubrizol 16T85 TPU Examined Utilizing Optimized Molding Conditions

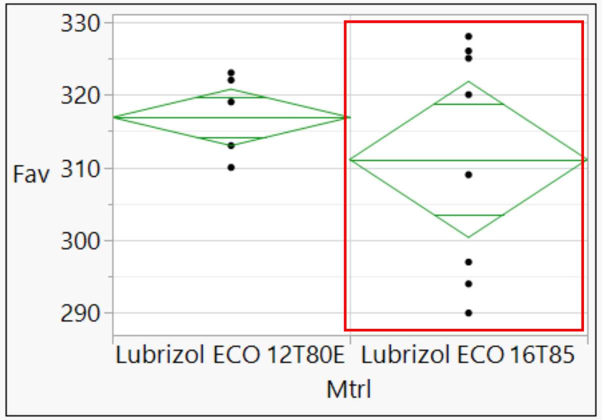


TPU Processing Conditions

		TEMPERATURES								
TPU	UNIT 1	Barrel 1	Nozzle	Flange	Zone 3	Zone 2	Zone 1	Feed Throat	Mold Temp	
		Set value (°C)	200	200	200	190	180	40	40	
		Holding Pressure								
		Time (s)	8.00	4.5	2.5	0				
		Pressure (Bar)	50	100	500	500				
Thermoplastic Resin	UNIT 2	Barrel 2	Nozzle	Flange	Zone 5	Zone 4	Zone 3	Zone 2	Zone 1	Feed Throat
		Set value (°C)	255	270	270	270	270	270	270	80

- Note, the learnings from the DoE were utilized while ensuring that the conditions used for specimen generation resulted in acceptable parts.

Oneway Analysis of Fav By Mtrl



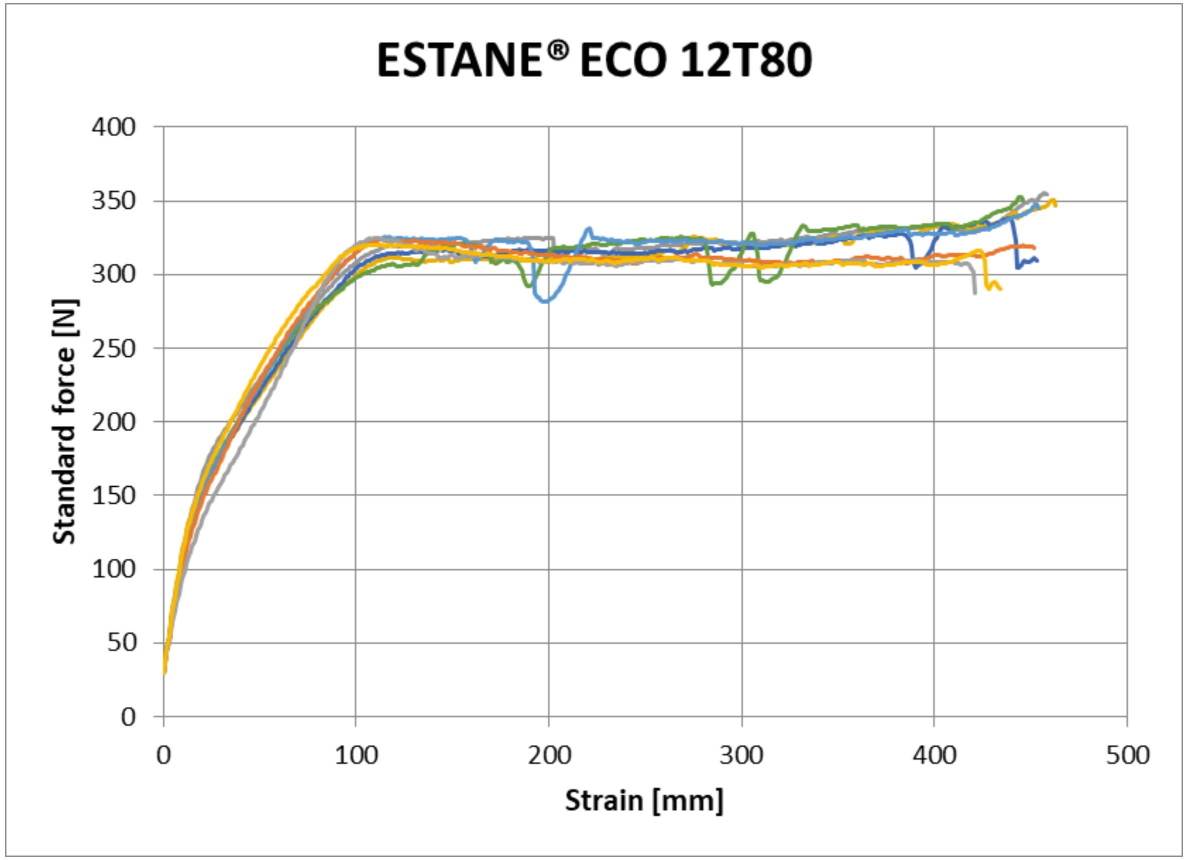
Connecting Letters Report

Level		Mean
Lubrizol ECO 12T80E	A	316.87500
Lubrizol ECO 16T85	A	311.10000

Levels not connected by same letter are significantly different.

Average Peel Strength:
311 N

Lubrizol 12T80 TPU Examined Utilizing Optimized Molding Conditions

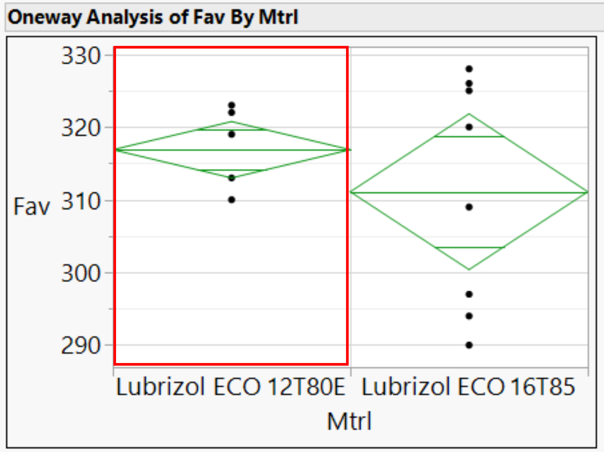


- Note, the learnings from the DoE were utilized while ensuring that the conditions used for specimen generation resulted in acceptable parts.

TPU Processing Conditions

TPU	UNIT 1	TEMPERATURES							
		Barrel 1	Nozzle	Flange	Zone 3	Zone 2	Zone 1	Feed Throat	Mold Temp
		Set value (°C)	195	205	200	190	180	40	40
		Holding Pressure							
		Time (s)	8.00	4.5	2.5	0			
		Pressure (Bar)	50	100	500	500			

Thermoplastic Resin	UNIT 2	Barrel 2	Nozzle	Flange	Zone 5	Zone 4	Zone 3	Zone 2	Zone 1	Feed Throat
		Set value (°C)	255	270	270	270	270	270	270	80



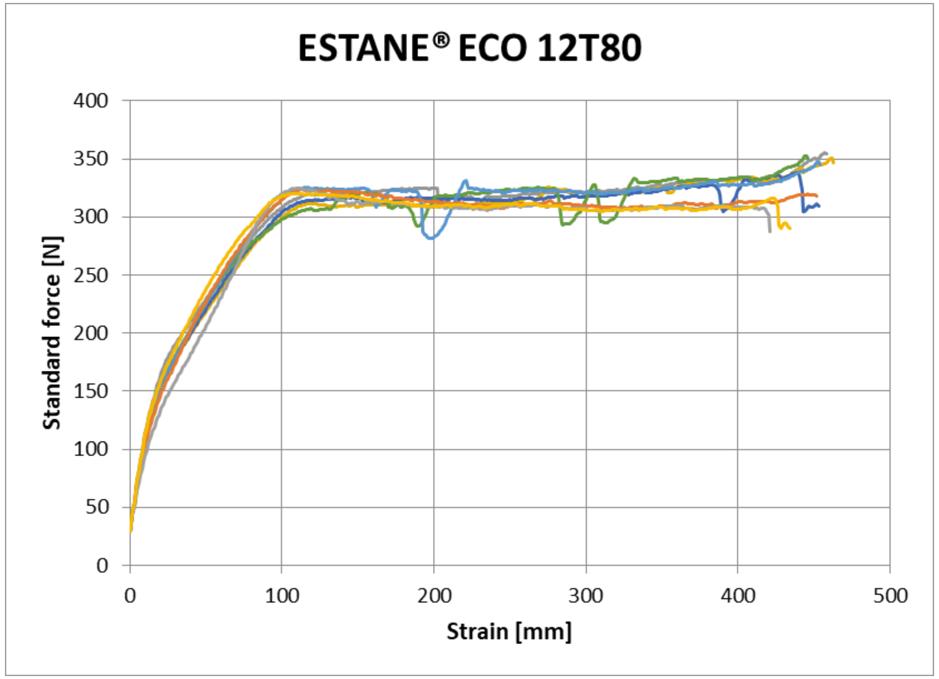
Connecting Letters Report

Level		Mean
Lubrizol ECO 12T80E	A	316.87500
Lubrizol ECO 16T85	A	311.10000

Levels not connected by same letter are significantly different.

Average Peel Strength: 316 N

Comparison of Adhesion Strength Utilizing Optimized Molding Conditions and Various TPEs/TPUs



Average Peel Strength: ~316 N

Molding Conditions:
Injection Speed: Normal Injection Speed + 20%
Barrel Temperature: 195 ºC
Mold Temperature: 40 ºC
Pack and Hold: Normal Pack and Hold Time

Average Peel Strength: ~294 N

Molding Conditions:
Injection Speed: Normal Injection Speed + 20%
Barrel Temperature: 215 ºC
Mold Temperature: 60 ºC
Pack and Hold: Normal Pack and Hold Time + 20% Longer Time

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Conclusions and Recommendations

Results from the DoE suggests that TPE Barrel Temperature, Mold Temperature, and Pack and Hold Times should be maximized to maximize performance.

- Additionally, mass production cycle times may limit one's ability to maximize variables such as Pack and Hold Times. (Cooling time also should be maximized for smooth demolding). While limitations on what variables can be "maxed-out" are expected, the general suggestion to molders should be to maximize the parameters listed below within their limits to obtain the best overmolding performance.

TPE Overmolding Recommendations:

- TPE Melt Temperature: **Maximize.** (Go as high as possible while avoiding degradation.)
- TPE Pack and Hold Time: **Maximize.** (Go as long as possible within the cycle time limitations.)
- Mold Temp: **Maximize**. (Go as high as possible while still maintaining injection over full part.)
- Cooling Time (after second, TPE, shot): **Maximize**. (Go as long as possible within the cycle time limitations.)
  - Note, if sticking at high mold temp is observed, extend cooling time first prior to lowering mold temperature.
- Injection Speed: **No specific recommendation but** utilize values that generate stable production of part.

Lubrizol

By the Numbers

95+Years

of history and opportunity, founded in 1928

8,000+

Employees Globally

100+

Countries Served

50+ Manufacturing Sites
29 R&D Labs (excl. QA)
48 Commercial Offices

7,150

Products

3,500

Patents

Backed by deep chemistry, formulation, application expertise

Lubrizol

An Enduring History of Sustainable Solutions

Since 1928, Lubrizol has provided solutions to our customers' greatest sustainability challenges – in our next century we will build upon our history of collaboration to empower the technology and innovation that is advancing a more sustainable world.

Engine Oil and Fuel Additives

Extending engine mileage from 3,000 miles in 1928 to more than 150,000 miles today; reducing CO2 emissions

Fermentation Derived Ingredients

Preserving biodiversity while delivering nature-based active ingredients for personal care applications

Low Global Warming Potential Cooling

Enabling efficient cooling and refrigeration technology without harmful emissions

Bio-based Polymers and Resins

Renewable-sourced thermoplastic polyurethane for sports, footwear and other key applications

Thermal Management Fluids

Increasing range, reducing charging time for EVs; enhancing energy and water efficiency for server farms

Lubrizol

How sustainability initiatives can work together

Sustainability

- Lubrizol first to offer TPUs made from bio-based raw materials focusing on soft grades
- Eastman offers PCR solution with molecular recycling for material substrates
- Combination of benefits of PCR material being close to virgin material & combination with ESTANE ECO grades that have improved adhesion compared to traditional TPUS. Best in class

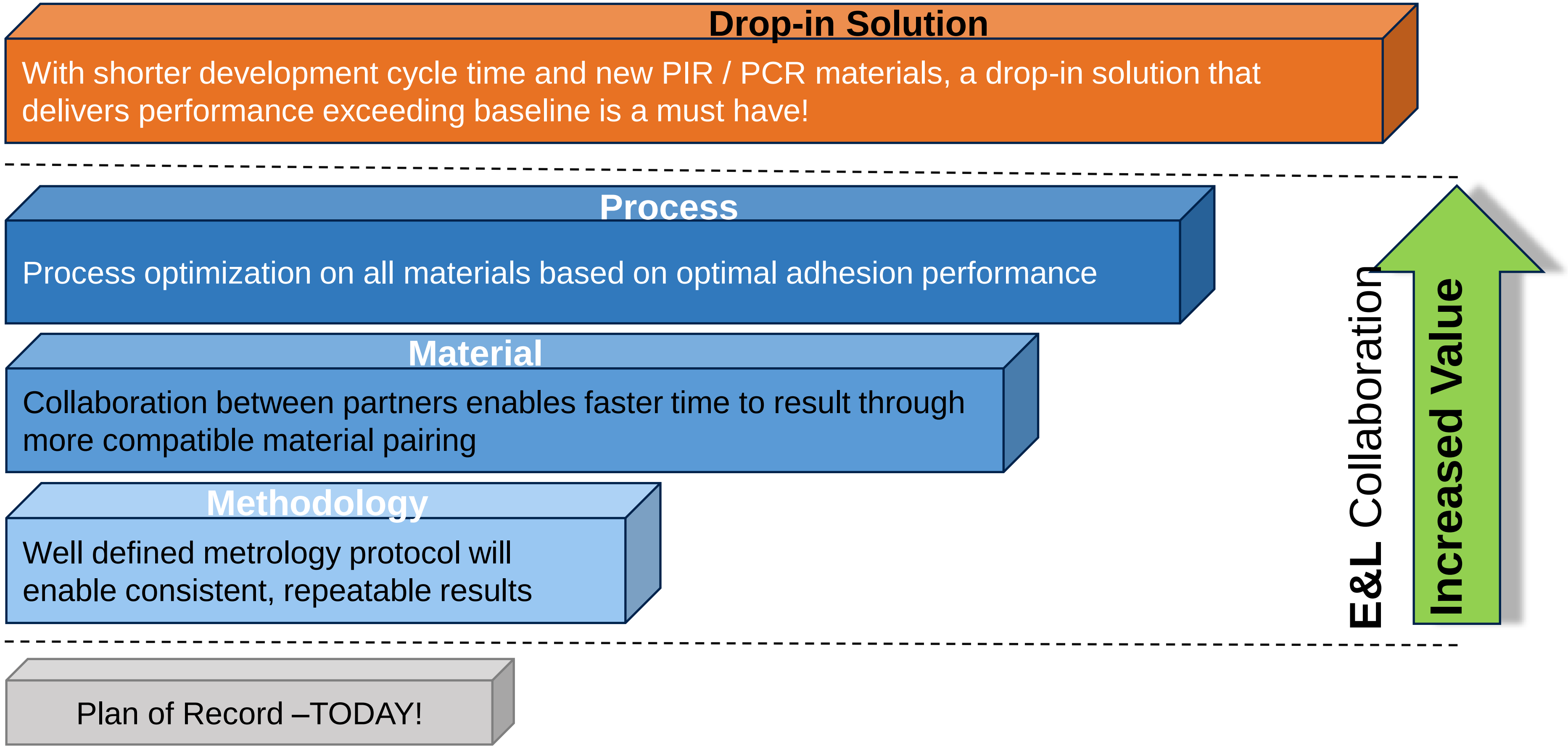
Lubrizol

Benefits of Lubrizol TPU & Eastman Collaboration

- TPUs inherently good for adhesion and overmolding across different applications
  - Long history in multiple application segments since invention in 1959
  - Multi-functional chemistry promotes adhesion on a wide variety of substrates
- The partnership with Eastman is valuable to provide a solution-based approach to application development
- Unique combination brings value to variety of markets
- Significant team learnings on how to improve adhesion properties, opening up new markets w/ this new solution
  - Power tools – where the durability of the substrate combined with haptics and fatigue resistance of overmold is critical
  - Automotive applications - where the combination of strength & soft-touch needed

Lubrizol

Value of Collaboration



Lubrizol

Key takeaways:

1. TPE Barrel Temperature, Mold Temperature, and Pack and Hold Times should be maximized to maximize adhesion performance.

2. Choice of thermoplastic resin and TPE/TPU impact adhesion performance.

3. "Supplier collaborations may enable customer innovations and expand the limits of consumer product experiences." – Vince Haas, Lubrizol's Engineered Polymers Sr. Business Director

Thank you! **Questions?**

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Scan this QR code for the
press release and white paper

Find more resources at Eastman.com/circular

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Links

White paper link Eastman TPE overmolded onto Eastman Tritan TX1501HF

Press Release link Lubrizol to Enhance TPE Overmold with Eastman Tritan Renew

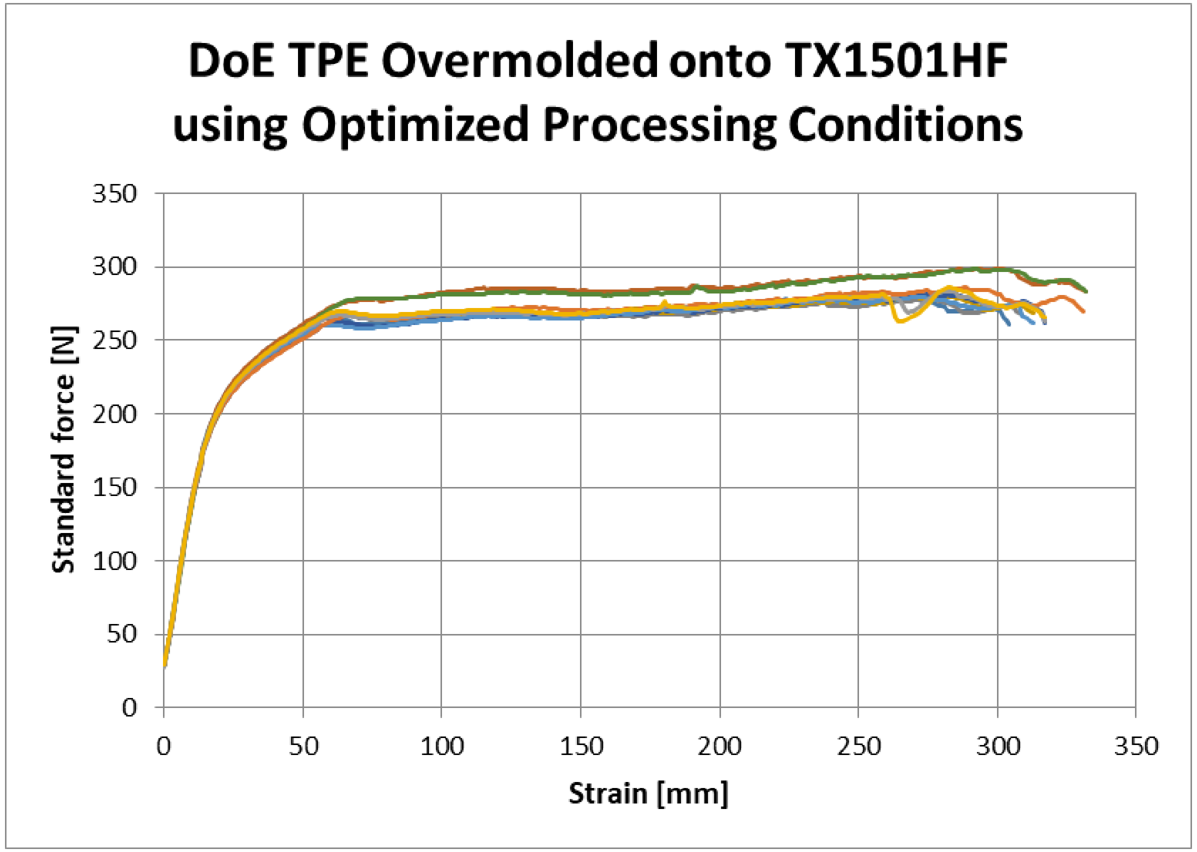
Eastman link www.eastman.com

Lubrizol link www.Lubrizol.com

Eastman Appendix

Additional Sample Generation with DoE Run 14 Settings

Adhesion strength traces of the DoE TPE (not identified) overmolded onto Tritan™ TX1501HF using the optimized settings identified by the DoE profiler. The average adhesion strength value calculated from this data was found to be 274 N, which is within one standard deviation of the adhesion strength value predicted by the profiler.



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The Mean, Standard Deviation, Lower 95%, Upper 95% and Median values for each DoE run.

DoE Experiment	Mean	Std Dev	Lower 95%	Upper 95%	Median
Run #[1]	243.4	3.835507	240.6562	246.1438	243
Run #[2]	256.6	2.1187	255.0844	258.1156	256
Run #[3]	255	2.44949	253.2477	256.7523	255
Run #[4]	248.4	3.50238	245.8945	250.9055	248
Run #[5]	272.4	13.58267	262.6835	282.1165	271.5
Run #[6]	250.8	3.794733	248.0854	253.5146	249.5
Run #[7]	261.8	6.729702	256.9859	266.6141	263.5
Run #[8]	255.9	4.148628	252.9323	258.8677	256.5
Run #[9]	241.9	11.38664	233.7545	250.0455	239.5
Run #[10]	248.6	7.560129	243.1918	254.0082	248
Run #[11]	237.2	4.315347	234.113	240.287	236.5
Run #[12]	243	6.896054	238.0669	247.9331	243.5
Run #[13]	283.5	7.947746	277.8145	289.1855	286.5
Run #[14]	294.8	15.76071	283.5255	306.0745	290
Run #[15]	265.6	19.61972	251.5649	279.6351	271
Run #[16]	286.1	4.306326	283.0194	289.1806	286.5
Run #[17]	265.5914	3.707784	262.939	268.2438	264.8283
Run #[18]	265.668	5.77235	261.5387	269.7973	267.1333
Run #[19]	259.4342	5.895016	255.2171	263.6512	256.5069
Run #[20]	249.8719	4.834016	246.4138	253.3299	250.4251
Run #[21]	258.4683	2.237853	256.8674	260.0692	258.2774
Run #[22]	255.2045	2.741512	253.2433	257.1657	254.4993
Run #[23]	279.1933	9.386007	272.479	285.9077	277.9953
Run #[24]	266.9719	3.751265	264.2884	269.6554	267.5429
Force (Avg.)	260.2251	16.35498	258.1455	262.3048	257.1141

EASTMAN

Lubrizol Appendix