PEELABLE SEAL FILMS WITH ENHANCED MOISTURE BARRIER PROPERTIES FOR FLEXIBLE PACKAGING APPLICATIONS

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Abstract

Most cereal and cracker packages are designed to have the seal layer peel apart while being opened. Unfortunately, opening these packages often results in catastrophic failure of the film and spillage of the contents. In this study, various types of peelable seal layers were investigated. In addition, a new high moisture barrier sHDPE was evaluated.

2.0 Background

Peelable Seals

Many consumer foods require the package to be easy-open in order to access the contents. Unfortunately, consumer experience has shown that many products sold in "easy-open" packages are actually difficult to open and often result in the catastrophic destruction of the bag. Consumer Reports magazine (1) rated cereal bags as one of the five worst consumer packages due to problems with opening. The article showed that 75% of the bags tested tore while their examiner attempted to peel the bags open.

The need for an easy-open, peelable seal package has been studied previously. Various polymer technologies have been reported in the literature (2)(3)(4)(5)(6)(7). There are three generally accepted easy open, peelable seal failure modes: interfacial separation, delamination, and cohesive failure (4) (Figure 1-4).

- **Interfacial Separation:** The separation occurs at the seal interface. The seal strength is dependent on the sealing temperature

- **Delamination:** The seal separates at an internal interface (between internal layers or between the inside layers). Sealing temperature is one of the significant variables in determining seal strengths; however, the thickness of the internal layer and adhesion between the internal layers also play major roles.

- **Cohesive Failure:** The structure separates within the seal layer. The peel seal material's inherent strength determines the strength of the seal.

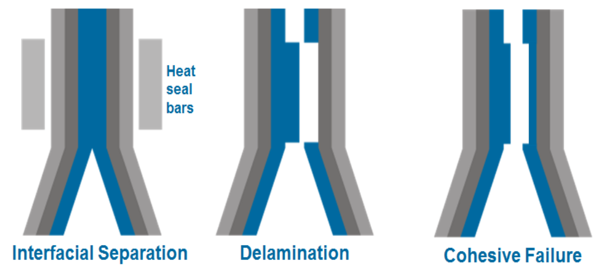

Figure 1: Fundamentals of Peelable Sealing (4)

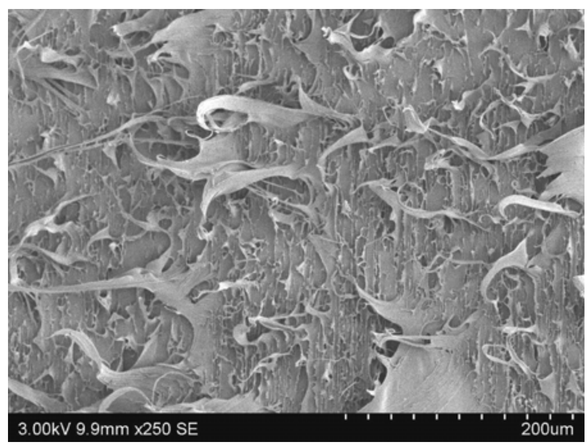

Figure 2: Interfacial Separation

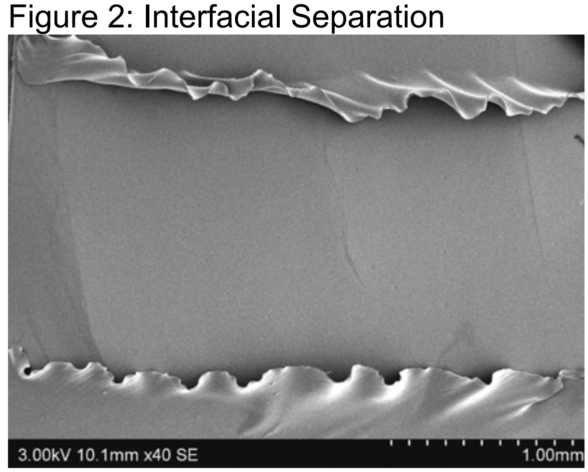

Figure 3: Delamination

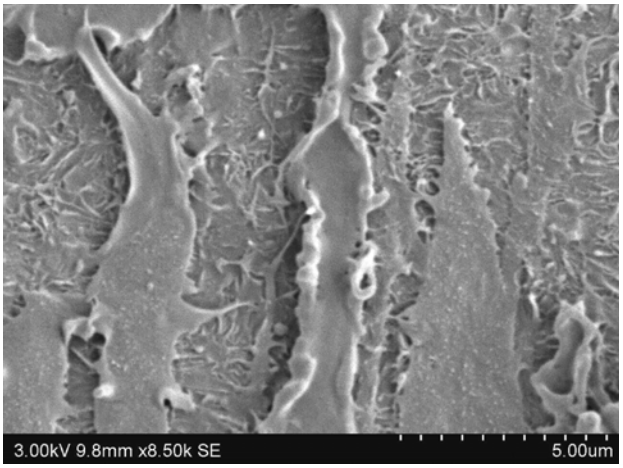

Figure 4: Cohesive Failure

Is this study films having peelable seal properties were studied along with a sHDPE having excellent moisture resistant properties. As previously stated, cohesive peel seal systems peel within the film layer while delamination fails at the internal interface. The cohesive seal results in a smooth, clean peel surface and offers “whitening” of the seal with added built in tamper evidence (5)(8) (Figure 5).

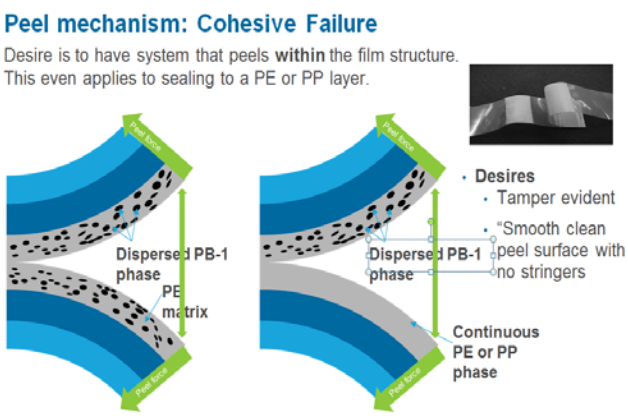

Figure 5: PB-1 Peel mechanism: Cohesive Failure

Three types of polymeric resin systems were used for peelable seal applications in this paper: polybutene-1 (PB-1), commercial ethylene propylene peel polymers (EP) and an ionomer specific to peel seal applications. The following is a brief background describing the performance of each of these resins.

Polybutene-1

PB-1 is a semi-crystalline, highly isotactic thermoplastic made from the polymerization of butene-1 using a Ziegler-Natta type catalyst. It works by being incompatible with polyethylene. In the seal layer, it creates a layer with PB-1 islands in the PE matrix as per Figure 5 & 6 and results in cohesive failure of the seal.

PB-1 is typically blended with 55% LDPE and 30% low seal initiation LLDPE. The PB-1 has more incompatibility with the LDPE than the LLDPE, hence the LLDPE should be chosen based on economics and seal initiation temperature desired. Slip and antiblock may are also required.

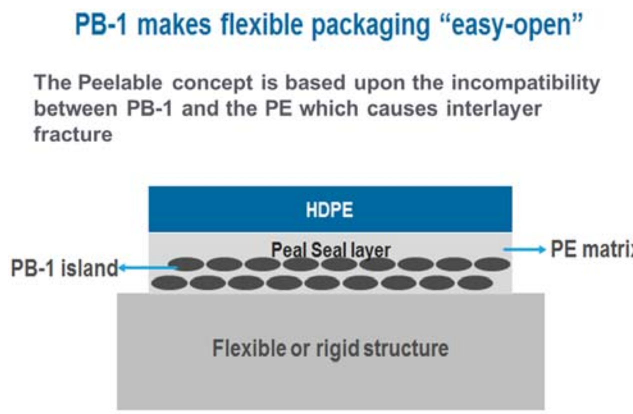

Figure 6: PB1 -How it works (5)

Ethylene Propylene Peel Polymers

The ethylene propylene peel polymer (EP) is a fully formulated copolymer (EP) that is commercially available. Seal failure may occur in a few ways: At lower temperatures, interfacial separation occurs at the seal / seal interface. At higher temperatures, the two seal layers “lock up” and failure occurs when the seal delaminates from the core layers. The strength of the bond at the HDPE / seal interface is significantly high enough that care must be taken on the packaging line to use enough heat to “just seal” the package.

Ionomer

Ionomers, are partially crosslinked acid copolymer resins. Ionomers can be formulated with PB-1 to fail cohesively or used alone in a delamination style peel seal where failure occurs between the ionomer sealant and the HDPE layer (8). Much like the EP peel polymer, care must be taken to not seal at too high of temperature as seal lock-up is expected to occur.

Low Moisture Vapour Transmission Rate (MVTR) Film

A film that has low MVTR is a requirement for dry good packages, such as cereal and crackers, in order to maximize the shelf life of the product. Most cereal and cracker films are three-layer coextruded blown films that are comprised of a peelable seal layer and an HDPE core layer. The thickness of the HDPE typically determines the MVTR of the film. In this study, the MVTR properties of a high moisture barrier sHDPE (sHDPE) are compared to a conventional HDPE.

This study was done to:

1. Evaluate a number of different peelable seal formulations
2. Evaluate high moisture barrier sHDPE vs standard HDPE for moisture resistance

3.0 EXPERIMENTAL METHODS

Previous studies have limited the qualitative measurement of peelability to the laboratory cold seal strength test. Traditionally, 25.4mm (1") wide samples were cut from the film and heat sealed in the transverse (TD) direction. The sealed samples were then pulled using a tensile tester to determine the seal strength vs. seal temperature. In this study, we used a combination of heat sealed film, hottack strength, and performance in a vertical form fill and seal (VFFS) machine.

Film Fabrication

Table 1 shows the resins used to make the 12 film structures shown in Table 2 (in Appendix). The films were fabricated using the 3 layer Brampton Coex line at NOVA Chemicals Centre for Performance Applications. The extrusion conditions were: 2.5:1 BUR, 10 cm (4") die, 35-mil die gap, 45 kg/h (100 lbs/h) output rate, standard temperature profile, and a barrier screw with Maddock mixing head.

Name	Type	Melt Index dg/min	Density g/cc
PB-1	Polybutene-1	28	0.906
LDPE	LDPE	0.75	0.920
LLDPE	C8-LLDPE	1.00	0.920
sLLDPE	C-8 Single Site LLDPE	0.65	0.916
EP	EP copolymer	3.80	0.895
Ionomer	Zn - Ionomer	4.00	0.940
sHDPE	barrier HDPE	1.20	0.966
HDPE	HDPE	0.95	0.958

Table 1: Resins Used

All physical properties were tested at NOVA Chemicals Centre for Performance Applications. Test results were converted into absolute values for the purpose of comparing films of different thicknesses.

The films were subjected to the following physical tests to determine their various properties:

- MVTR, using Mocon test unit 100% RH
- Dart Impact, using ASTM D1709, Method A;
- Film Tear, using ASTM D1922;
- Puncture, using NOVA Chemicals Method
- 1% and 2% Secant Modulus, using ASTM D882;
- Tensiles, using ASTM D882;
- Hot Tack Strength; using method described below;
- Heat Seal Strength, using method described below;
- Vertical Form Fill and Seal (VFFS) described below;

Hot Tack Strength Test Method

The hot tack strength of the sample films were measured using the "J&B Hot Tack test method" which measures the force required to separate a heat seal before the seal has had a chance to fully cool. This simulates the filling of material into a pouch or bag before the seal has had a chance to cool.

The "J&B Hot Tack test method" used the following conditions:

Specimen Width:	25.4 mm
Sealing Time:	0.5 seconds
Sealing Pressure:	0.27 /mm/mm
Delay Time:	0.5 seconds
Peel Speed:	200 mm/seconds

Number of Samples/Temperature	5
Temperature Increments:	5°C
Temperature Range:	75°C - 150°C

Film Heat Seal Strength Test Method

The heat seal strength of the sample films measures the force required to separate a seal after the material has cooled to 23°C. In this study, the sealed samples were allowed to age for two weeks prior to testing. Aging is a significant issue with some peel seal technologies, especially PB-1 blends.

Samples were tested using the following conditions:

Specimen Width:	25.4 mm
Sealing Time:	0.5 seconds
Sealing Pressure:	0.27 /mm/mm
Number of Samples/Temperature	5
Temperature Increments:	5°C
Temperature Range:	75°C - 150°C

The seal strengths were then determined using a Tensile Tester model according to the following test conditions:

Direction of Pull:	90° to seal
Crosshead Speed:	300 mm/minute
Full Scale Load:	5 kg

Vertical Film Form and Seal (VFFS)

The Rovema VFFS machine used in this study was a model VPI 260 with a Bozn DCS-3BC Auger Filler. It had a 165 mm forming set and TEFLON® tape on both the vertical and cross sealing bars (Figure 7).

Figure 7: Rovema Vertical Form Fill and Seal Machine

19 cm x 16.5 cm pouches (seal to seal) were produced with no gusseting. The pouches were filled with 500 g of HDPE pellets to simulate the packaging of product in commercial applications. The 500 g of pellets only half filled the pouches so that they could be tested in the leak detector test.

A temperature window was selected using the hand squeeze method described below. All films were run from low temperature (where the seal easily opens) to a temperature where burn through occurred. Pellet filled pouches were submitted for leak testing while other pouches were emptied of the pellets aged for two weeks. Sample strips 25.4 mm (1") were cut from the seal area and tested using a tensile tester.

Haug Pack-Vac Leak Detector Test

The purpose of this test is to evaluate the seal strength and general packaging integrity of pouches produced on the VFFS. A pouch was placed underwater in the leak detector tank and a vacuum was applied. If the seals fail then air from inside the pouch escapes through the failure and bubbles are noticed in the tank. Results from this test can be used to compare and rank different film structures at different equipment seal bar settings. Testing conditions were:

- Pouch volume filled 50% with pellets
- Line speed 20 bags / minute
- Replicates per temperature – 5
- Once good seals were achieved temperature increments were adjusted by 10°C increments
- Vacuum setting 20 inHg
- Hold for 30 seconds once targeted vacuum setting is reached

The Figure 8 & 9 illustrates pouches that have seal failure and burn through.

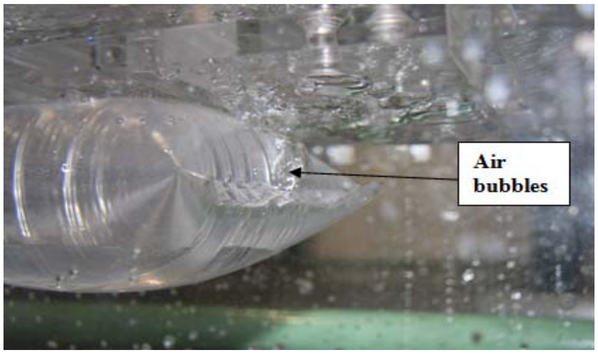

Figure 8: Seal Failure


Figure 9: Burn Through

Drop Test

10 pellet-filled pouches were made at each temperature and then dropped from a height of 1.8m (6') to simulate the packaging operation.

Compression Test

Five air-filled pouches were made at each temperature then tested under compression using a tensile tester to determine the load that the end seal failed at.

Pouch End Seal Strength

Five pellet-filled pouch samples were made at each temperature. The pellets were emptied and 25.4mm (1") wide samples were cut from the same seal region on each pouch and pulled using an Instru-Met 5-Head tensile tester.

4.0 RESULTS AND DISCUSSION

1) Commercial Film

Prior to the start of the project, samples of a commercial cereal liner were purchased at a local grocery store and tested to determine typical film properties. The analysis (Figure 10-12) indicates that the film was a three layer co-ex with EP peel polymer in the seal layer and two HDPE layers. Physical properties of the film have been added to analysis of this study (Table 3). No VFFS work was done with the competitive due to the small sample size.

The heat seal curve of the film shows the classic curve expected for EP peel polymers. Note the dramatic increase in seal strength at the higher temperatures as the seal "locks up" into cohesive failure (Figure 13).

2) Fabricated Film Physical Properties

Table 3 and Figures 14 to 34 show the film physical properties, all of which can be found in the appendix.

<u>Film Properties</u>

1) MVTR (Figure 14)

The use of sHDPE was found to dramatically lower the MVTR of the films. As expected, thicker films were also found to have lower MVTR. The commercial film had MVTR properties similar to the films having conventional HDPE in the core.

2) Dart Impact (Figure 15)

Not enough sample was available to determine the dart impact properties of the commercial film.

The films with sHDPE in the core had slightly lower dart impact properties than films made with HDPE. Overall, films with the ionomer had the highest impact resistance.

3) Film Tear

3.1) TD Tear (Figure 16)

The films with EP peel polymer and ionomer had TD tear values that were less than half of the commercial film and films with PB-1. TD tear is not expected to play a significant role in this application.

The use of sHDPE resin did not appear to have an effect on the TD tear properties.

3.2) MD Tear (Figure 17)

In cereal bag applications, high machine direction (MD) tear resistance is a very desirable attribute once the bag is opened. Figure 17 shows the MD tear for the films tested. All of the films tested had higher MD tear resistance than the commercial film. The ionomer films had the highest tear resistance, about double the commercial film.

4) Puncture (Figures 18 & 19)

There was not enough commercial film available to test puncture resistance. Overall, the films had similar puncture resistance when comparing normalized results

5) 1% and 2% Secant Modulus (Figures 20 & 21)

High film stiffness is a desirable attribute for these films for faster packaging speeds. Figures 20 and 21 show that films made with sHDPE in the core had higher 1% and 2% secant modulus. This was expected since the HDPE had a density of 0.958 g/cc vs. 0.966 g/cc for the sHDPE. The results were almost 20% higher than the commercial film. Higher stiffness could allow the film to be downgauged while still maintaining stiffness relative to the competitive film. It may also allow the packaging line to run at a faster rate.

6) Tensile (Figure 22 to 24)

No significant differences were seen with the tensile properties except the 2.3 mil commercial film had lower elongation than the other films tested.

7) Hot Tack (Figure 25)

Three distinct groupings were seen in the testing. The ionomer films had the lowest hot tack initiation temperature along with a broad, flat profile. EP films initiation temperature was only slightly higher than the Ionomer but rose quickly to the highest hot tack strength and the narrowest profile. PB-1 hot tack initiation temperature was approximately 25°C – 30°C higher than the other two types of sealant.

8) Film Heat Seal Strength (Figure 26)

Three distinct groupings were also seen with the films tested. The ionomer films had a sharp rise in seal strength in the interfacial separation phase followed by a drop in strength in the delamination phase. The maximum strength at higher temperatures was lower than the commercial films which appeared to "lock-up" beyond 130°C. EP film had a wide, flat sealing profile. Testing was stopped at 155°C.

PB-1 had the highest sealing initiation temperature of the films tested and the narrowest sealing window. The seal strength continued to increase as the sealing temperatures increased. Unlike the other films, no plateau was observed.

As expected, the PB-1 films made with higher levels of LDPE had lower overall seal strengths. As previously stated, LDPE is more incompatible with the PB-1 than LLDPE.

<u>VFFS</u>

1) Hand Squeeze Test

In this study, the VFFS processing window was determine by hand squeezing the pouches. The seal initiation temperature (SIT) was defined first by the dry fill staying in the pouch once the seal bars opened, then the pouches were lightly squeezed by hand. The SIT was defined when the pouches retained internal pressure (no sign of leaks). The end processing temperature was determined by hand squeezing of the pouches again but this time, failure occurred when burn through of the end seal was observed.

2) Haug Leak Tester

All pouches produced that retained the dry fill (pellets) passed at 10 in.Hg, but leaked at 13 to 15 in.Hg. This off-line test did not differentiate the different film structures and temperature profile (same results from initial seal to burn thru seal). The commercial cereal packages all failed at 5 in.Hg. A small individual sized cereal package failed @ 1 in.Hg.

Based on these results, the Haug test does not appear to be a reliable test for this application.

3) 6' Drop Test

The 6' drop test also did not provide any conclusive data to differentiate between film structures and temperature profile. Dry fill (pellets) were found to cause pin-holes failures on the side on the pouch when dropped giving a false positive.

4) Pouch End Seal Strength (Figures 27 to 32)

25.4mm (1”) wide samples were cut from the end seals and allowed to age two weeks before testing. Similar to the film heat seal strength test, three groupings were also seen (Figure 27).

4.1) PB-1

Figure 28 depicts two different groupings of seal curves. The difference between the two groups is the amount of LDPE used in the blend. The higher heat seal strength grouping contained 30% LDPE vs 55% LDPE for the stronger seal group. The PB-1 producer reports that the amount of LDPE plays a critical role in the peel seal strength (5).

The PB-1 films all had higher heat seal initiation temperatures and lower overall seal strength of the films tested.

4.2) Ionomer

Three distinct phases of sealing can be seen in Figure 29. At lower temperatures, interfacial separation occurred wherein the seal simply peeled apart. From about 95°C to about 130°C delamination occurred where the seal pulled away from the HDPE layer. Cohesive failure occurred from 130°C to 150°C.

4.3) EP Peel Polymer

The samples were tested after two weeks. The resin manufacturer claimed that with time, the seal strength decreases when the EP peel polymer is used in the seal layer (9). Figure 30 shows a classic seal curve with the 2.25 mil film having higher heat seal strength.

4.4) Comparison of Film Heat Seal Strength to VFFS Pouch Heat Seal Strength

Figures 31 & 32 compare the measured film heat seal strength to the measured strength of the pouch end seal. The figures show a significant correlation between the two. Heat seal initiation and burn through were almost identical. This indicates that the film heat seal strength test should be a suitable laboratory test method to predict performance in a VFFS unit.

5) Compression Test (Figure 33 to 36)

Five pouch samples from each temperature were tested under compression using a tensile tester. Overall, the pouch seal performance under compression correlated with the pouch end seal testing.

5.1) PB-1 (Figure 34)

PB-1 seal initiation temperature was significantly higher than either the ionomer or EP peel polymers. Seal strength also continued to increase until cohesive failure was observed.

Lower compression strength was also observed with LDPE blends.

5.2) EP Peel Polymer (Figure 35)

The end seal strength with the EP peel polymer increased with temperature until cohesive failure occurred. In the cohesive failure region, the film was observed to fail vs. the seal peeling apart.

5.3) Ionomer (Figure 36)

Like the pouch end seal strength, the ionomer films showed three distinct regions; interfacial separation, delamination and cohesive failure (Figure 32). It was noted that during cohesive failure, the film failed vs. the seal peeling. The ionomer films had a very low and flat strength curve until cohesive failure.

5.0 CONCLUSIONS

1) The sHDPE significantly decreased the MVTR versus a conventional HDPE. It also resulted in films with the highest 1% and 2% secant modulus (20% higher than a commercial film).
2) Films made with ionomer in the seal layer had the best overall physical properties.
3) Ionomer was also found to have broadest peel seal window along with the lowest peel force.
4) EP peel polymers produced films with the highest hot tack strength.
5) Seal layer thickness did not appear to have a significant impact on the properties of the films tested.
6) The amount of LDPE blended with the PB-1 was found to affect the end seal strength of the films. Higher amount of LDPE resulted in lower seal strengths.

Overall, films made with either the Ionomer or EP Peel Polymer in the seal layer and a barrier HDPE would produce an effective peelable seal film with enhanced barrier properties. Also, the higher film stiffness with a barrier sHDPE would allow downgauging of the film.

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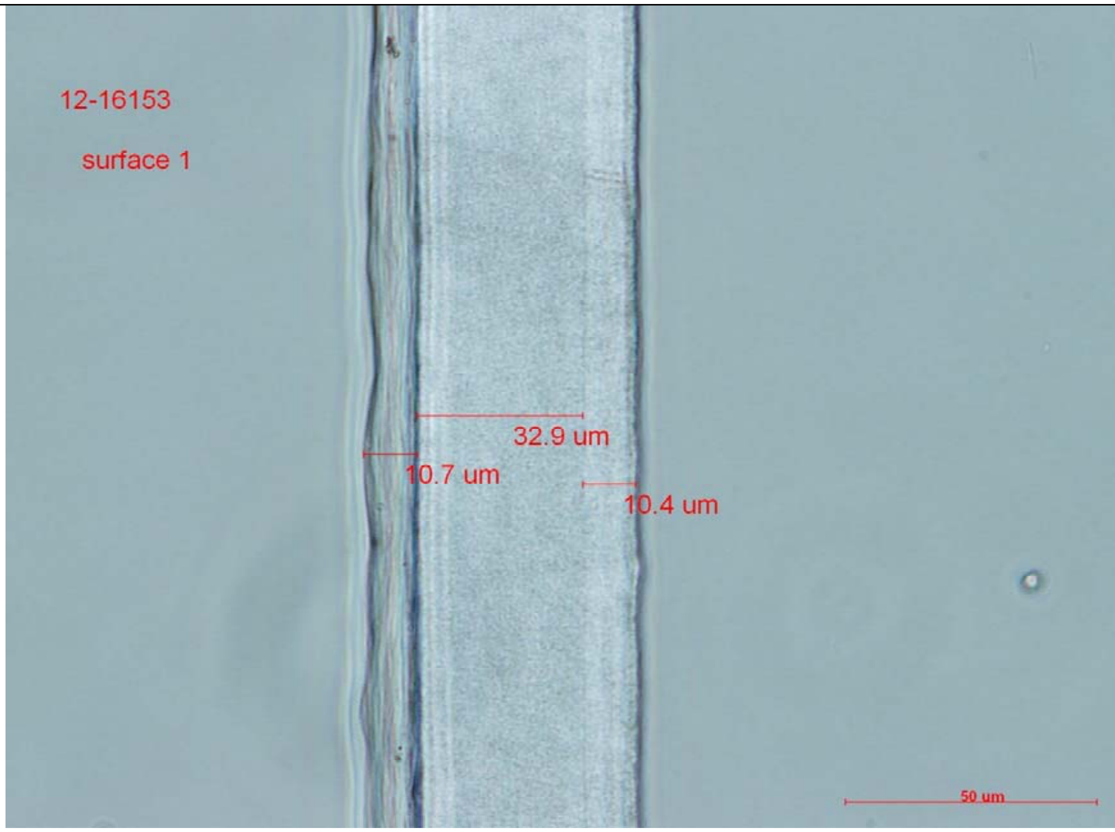
Trademarks

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12
	1.75 PB-1 sHDPE 20% Skin	2.25 PB-1 HDPE 20% Skin	2.0 EP sHDPE 15% Skin	2.0 EP HDPE 15% Skin	2.25 EP HDPE 15% Skin	2.0 Ionomer sHDPE 15% Skin	2.0 Ionomer HDPE 15% Skin	2.25 Ionomer HDPE 15% Skin 15% Skins	2.0 10% PB-1 HDPE 20% Skin	2.0 15% PB-1 HDPE 20% Skins	2.0 Ionomer HDPE 10% Skins	2.0 EP + sHDPE LLDPE 15% Skins
Thickness, mil	1.8	2.3	2.0	2.0	2.3	2.0	2.0	2.3	2.0	2.0	2.0	2.0
Skin -												
PB-1	15%	15%							10	15		
LDPE	55%	55%							30	30		
sLLDPE	30%	30%							60	55		
EP			100%	100%	100%							100%
Ionomer						100%	100%	100%			100%	
Core												
sHPDE	100%		100%			100%						80%
HDPE		100%		100%	100%		100%	100%	100%	100%	100%	
LLDPE												20%
Skin												
HDPE	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 2: Film Structures

Table 3: Physical Test Results

		Commercial	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12
		2.3mil Commerical	1.75mil PB-1 + sHDPE 20% Skin	2.0mil 10% PB-1 HDPE 20% Skin	2.0mil 15% PB-1 HDPE 20% Skins	2.25mil 15% PB-1 HDPE 20% Skin	2.0mil EP sHDPE 15% Skin	2.0mil EP HDPE 15% Skin	2.25mil EP HDPE 15% Skin	2.0mil Ionomer sHDPE 15% Skin	2.0mil Ionomer HDPE 15% Skin	2.25mil Surlyn 19C 15% Skins	2.0mil Ionomer HDPE 10% Skins	2.0mil EP sHDPE + 20% LLDPE 15% Skins
Thickness	mil	2.3	1.8	2.0	2.0	2.3	2.0	2.0	2.3	2.0	2.0	2.0	2.0	2.0
PROPERTY	UNITS													
BARRIER H20 FILM	G/100IN2/DAY	0.205	0.087	0.199	0.195	0.187	0.0638	0.2066	0.1691	0.0602	0.216	0.1953	0.2051	0.079
FILM THICKNESS 2	MIL	2.3	1.6	2.0	2.1	2.2	2.0	2.0	2.4	2.0	2.1	2.2	2.0	2.0
Dart	G/MIL	Not Tested	37	44	42	39	23	44	46	36	59	55	58	27
Dart	G		64.8	88.0	84.0	87.8	46.0	88.0	103.5	72.0	118.0	123.8	116.0	54.0
1% Secant Mod MD	MPA	576	893	713	668	694	958	693	723	928	723	654	763	725
1% Secant Mod MD	lb	0.91	1.08	0.98	0.92	1.08	1.32	0.96	1.12	1.28	1.00	1.01	1.05	1.00
2% Secant Mod MD	MPA	463	675	570	538	543	738	553	569	717	564	522	588	570
2% Secant Mod MD	lb	0.73	0.81	0.79	0.74	0.84	1.02	0.76	0.88	0.99	0.78	0.81	0.81	0.79
1% Secant Mod TD	MPA	840	1152	904	869	886	1182	920	924	1117	874	868	923	883
1% Secant Mod TD	lb	1.33	1.39	1.25	1.20	1.37	1.63	1.27	1.43	1.54	1.21	1.35	1.27	1.22
2% Secant Mod TD	MPA	671	892	707	692	689	911	722	725	867	675	672	728	700
2% Secant Mod TD	lb	1.06	1.08	0.98	0.95	1.07	1.26	1.00	1.13	1.20	0.93	1.04	1.00	0.97
Tear MD	G/MIL	16	28	26	24	25	27	23	24	36	32	43	44	28
Tear MD	g	36.8	49.0	52.0	48.0	56.3	54.0	46.0	54.0	72.0	64.0	96.8	88.0	56.0
Tear TD	G/MIL	814	203	278	277	283	78	120	69	152	120	109	129	80
Tear TD	g	1872.2		556.0	554.0	636.8	156.0	240.0	155.3	304.0	240.0	245.3	258.0	160.0
Tensiel Break MD	MPA	42.5	32.3	42.2	41.4	38.2	35.6	40	44.3	34	36.7	39.8	40.9	36.7
Tensiel Break MD	lb	0.067	0.039	0.058	0.057	0.059	0.049	0.055	0.069	0.047	0.051	0.062	0.056	0.051
Tensiel Elong MD	%	600	613	689	687	718	722	728	786	738	737	832	785	735
Tensiel Yield MD	MPA	20.2	26.8	23.6	23.3	22.9	26.8	23.8	24.4	27.8	24.3	23.2	24.9	24.7
Tensiel Yield MD	lb	0.032	0.032	0.033	0.032	0.036	0.037	0.033	0.038	0.038	0.034	0.036	0.034	0.034
Tensiel Break TD	MPA	20.9	28.7	36.6	35.9	36.2		41.7	38.2	28.3	40	38.3	42.2	35
Tensiel Break TD	lb	0.033	0.035	0.050	0.050	0.056		0.058	0.059	0.039	0.055	0.059	0.058	0.048
Tensiel Elong TD	%	459	751	786	795	855		873	835	755	848	829	871	837
Tensiel Yield TD	MPA	20.2	25.3	24.7	25.3	25.6	Not tested	28.4	26.6	28.4	27.3	26.4	27.2	26.3
Tensiel Yield TD	lb	0.032	0.031	0.034	0.035	0.040		0.039	0.041	0.039	0.038	0.041	0.038	0.036
Tensiel Break TD	MPA	23.4	25.3	24.7	25.3	25.6		28.4	26.6	28.4	27.3	26.4	27.2	26.3
Tensiel Break TD	lb	0.037	0.031	0.034	0.035	0.040		0.039	0.041	0.039	0.038	0.041	0.038	0.036
Puncture	J/MM	Not Tested	23	22	21	23	19	22	20	23	22	22	24	20
Puncture	J		40.3	44.0	42.0	51.8	38	44	45	46	44	49.5	48	40.0



EP copolymer / PE / PE

Figure 10: Commercial Cereal Film Micrograph

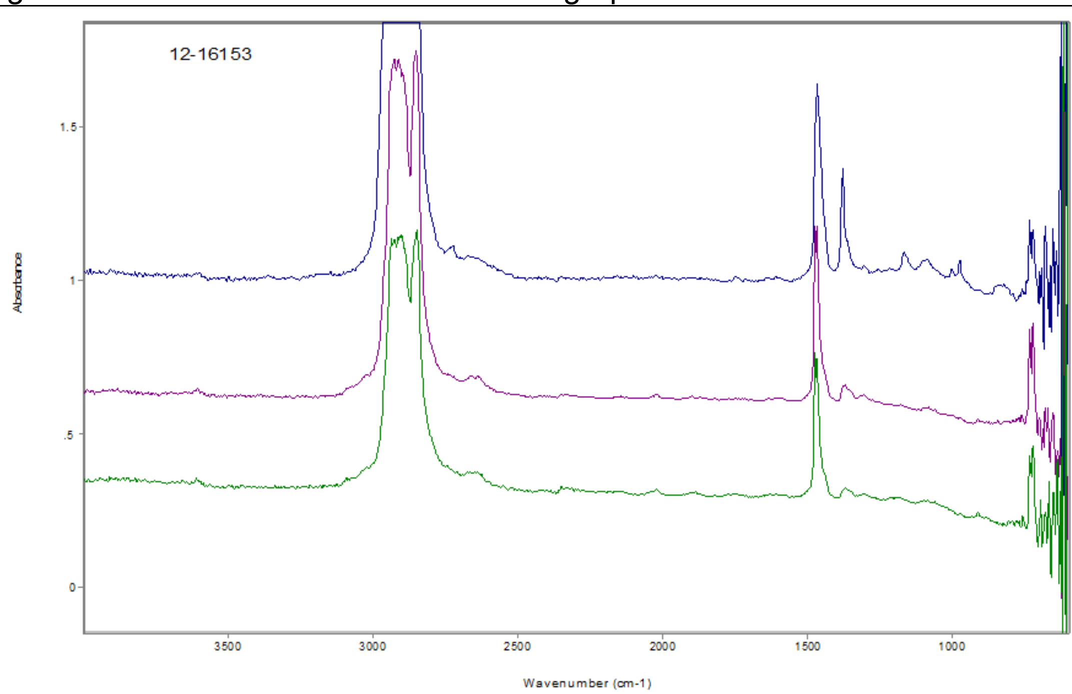


Figure 11: FTIR scan of all three layers indicating EP Peel Polymer in the seal layer

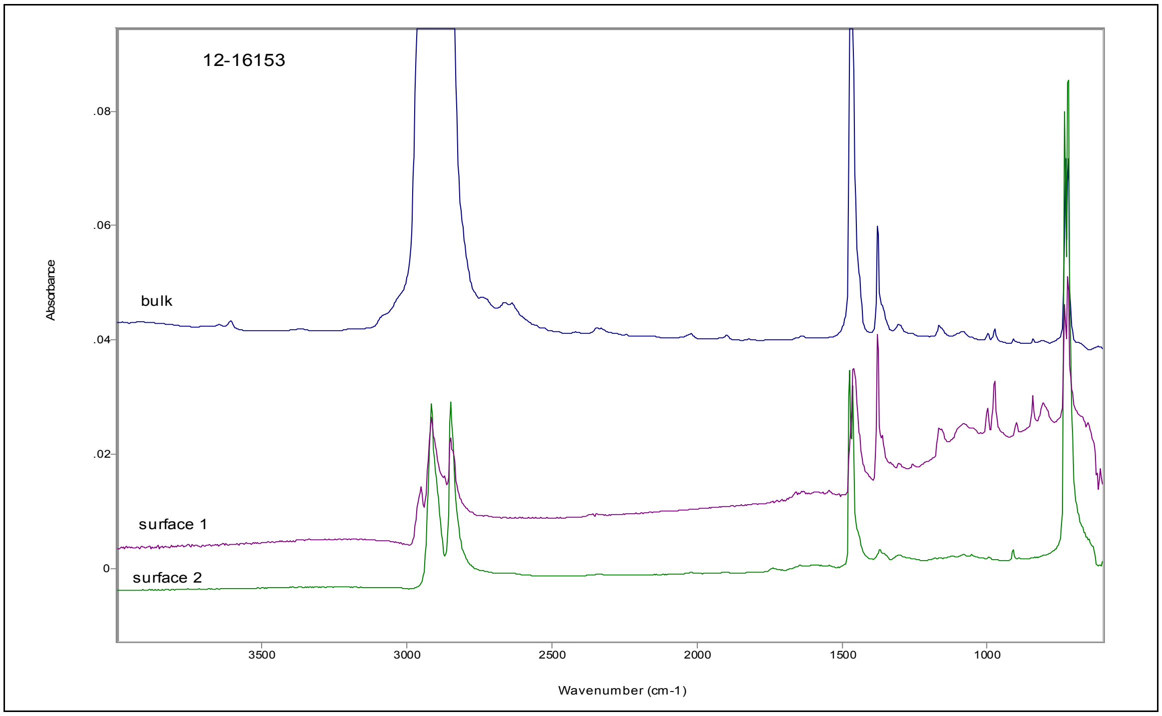


Figure 12: FTIR of seal layer

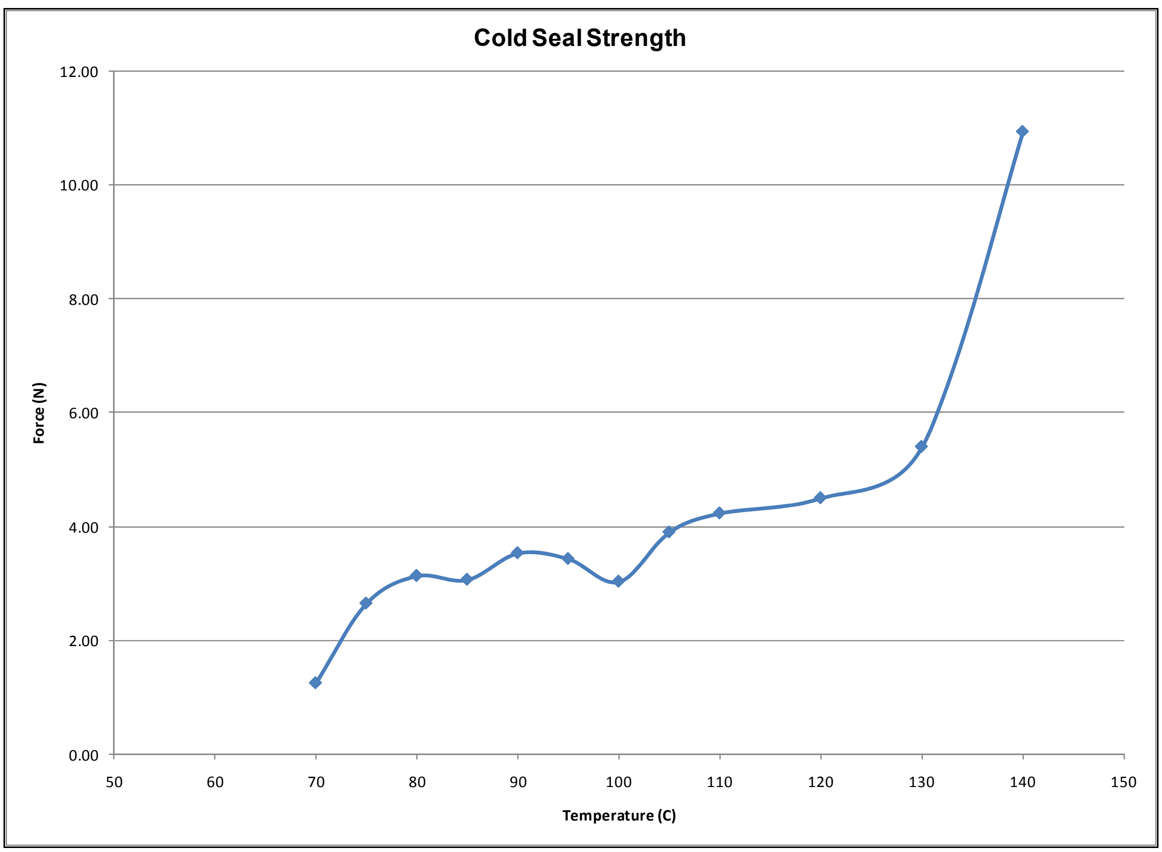


Figure 13: Commercial Cereal Film - Heat Seal Strength

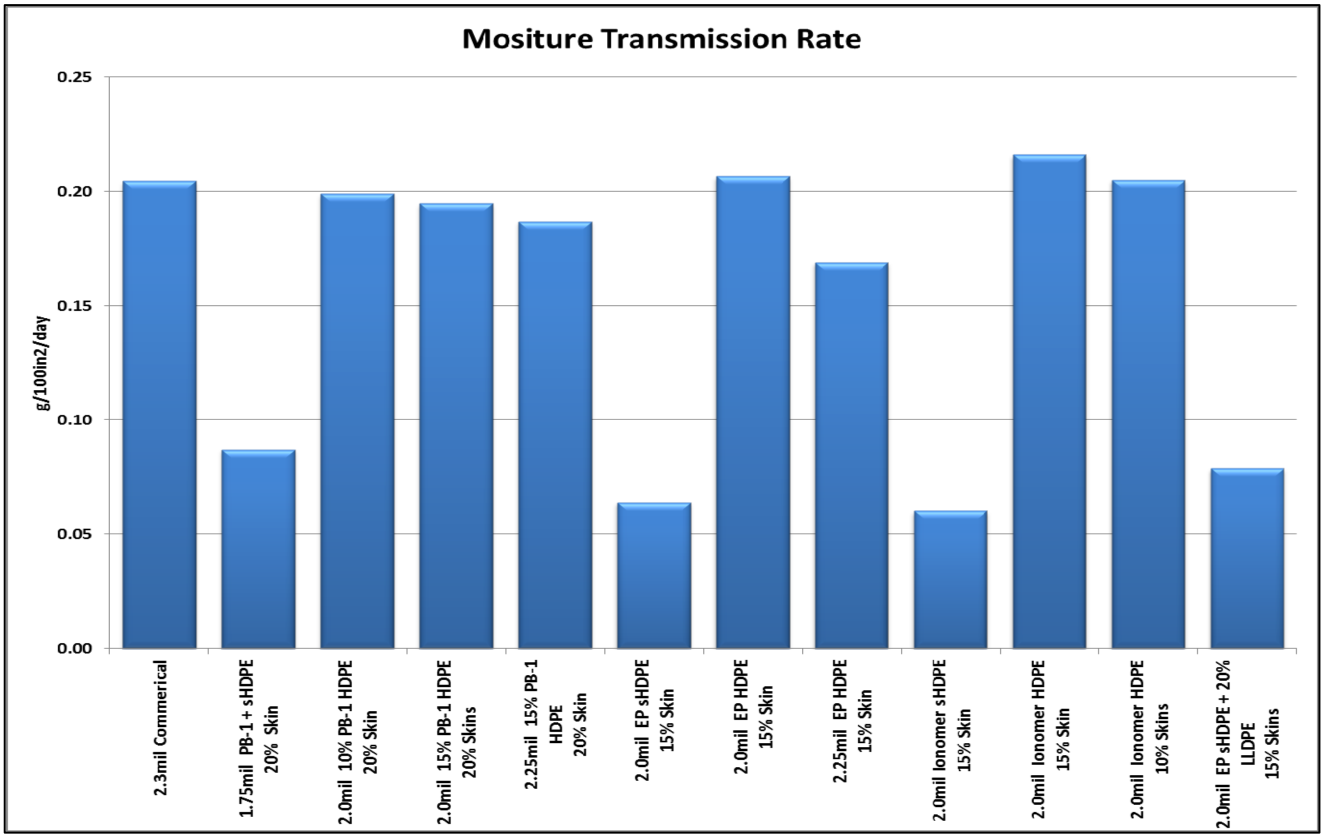


Figure 14: Mositure Vapour Transmission Rate

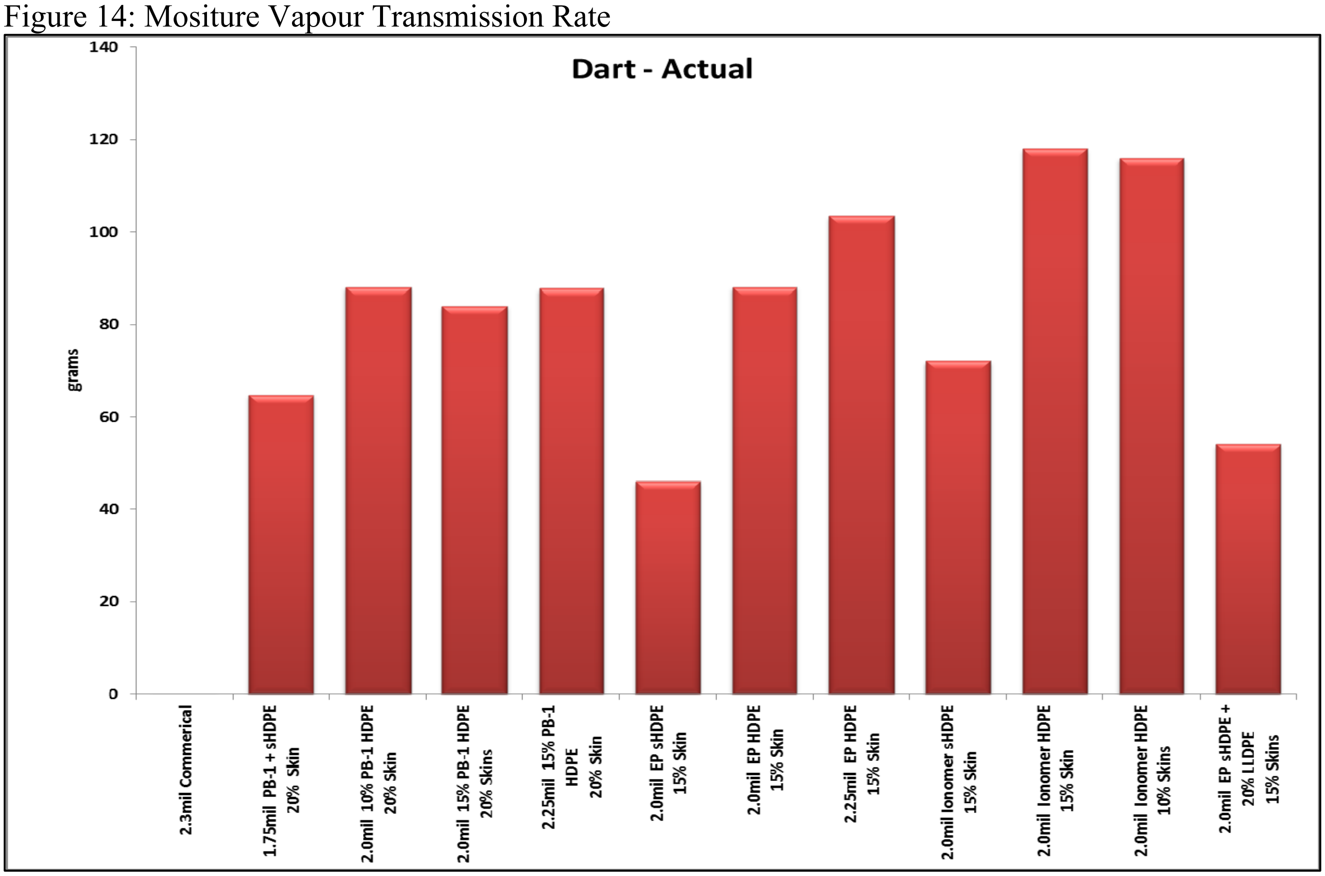


Figure 15: Dart Impact

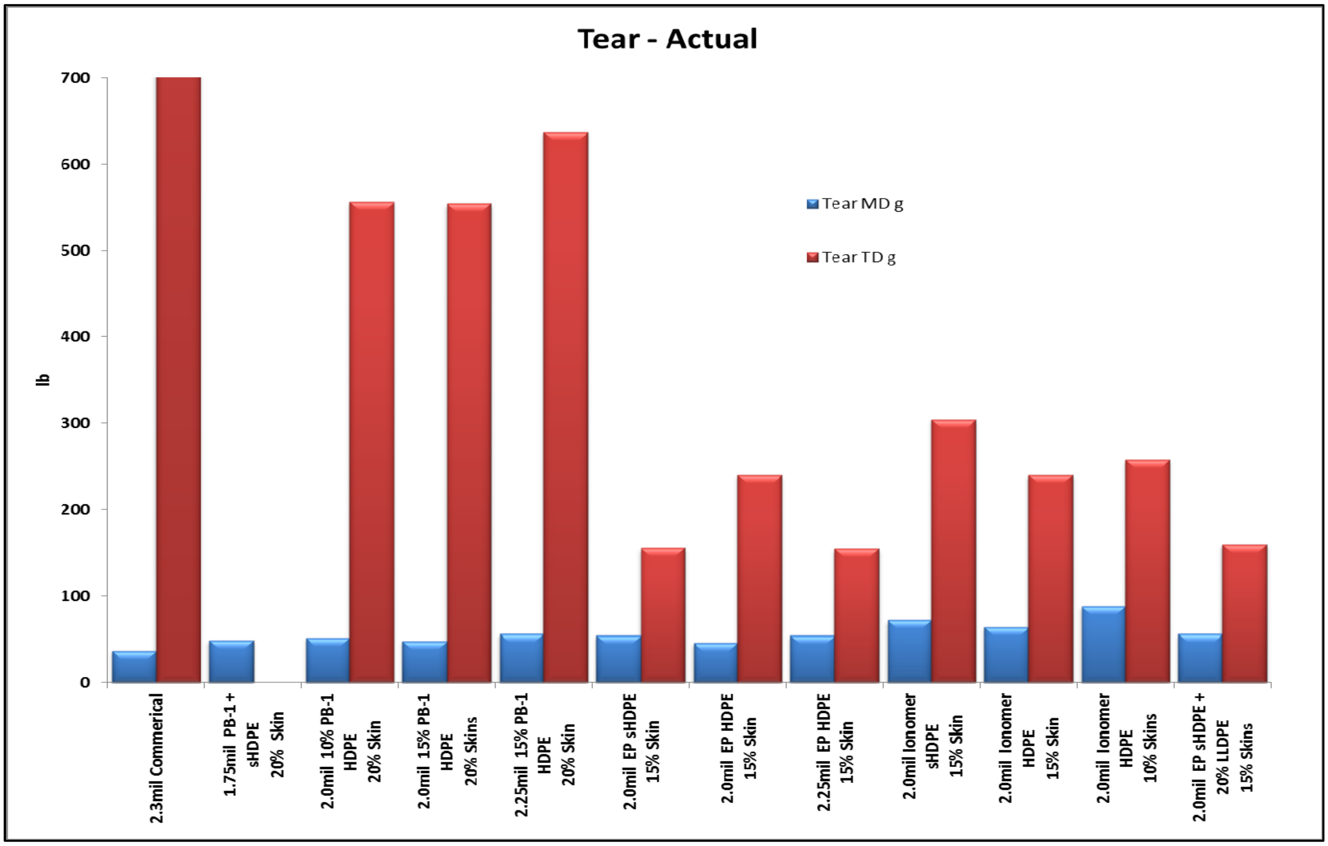


Figure 16: Elmendorf Tear

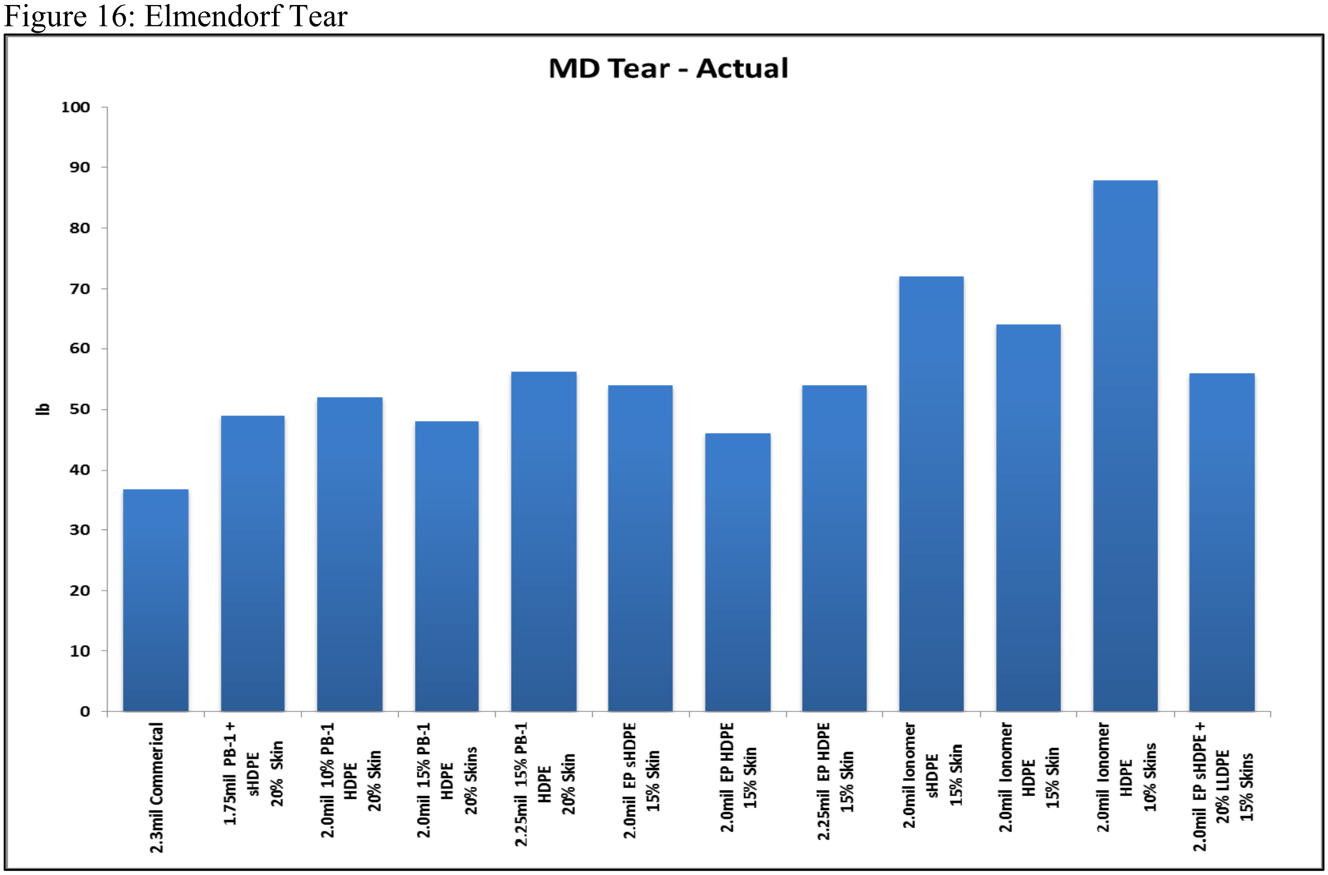


Figure 17: Elmendorf Tear – Machine Direction

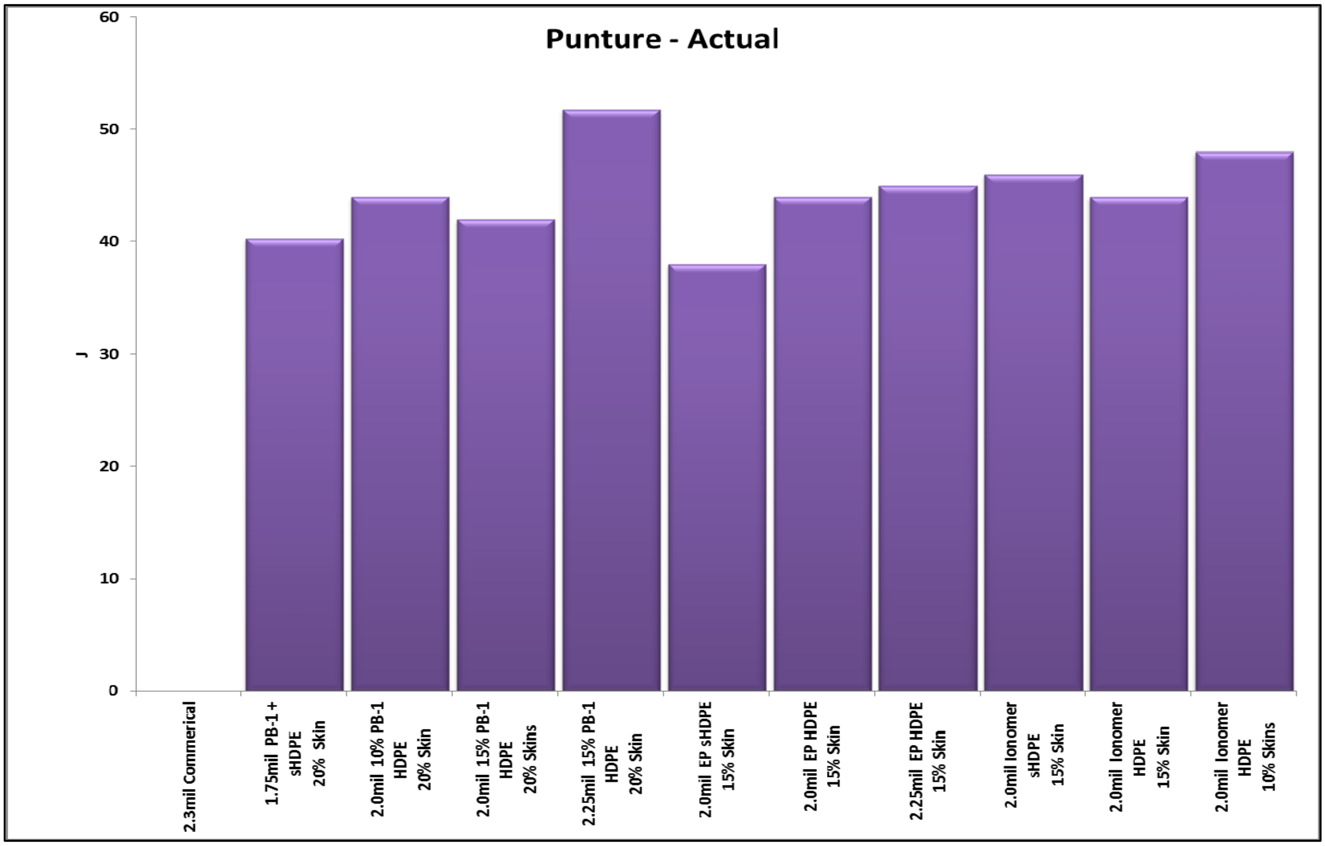


Figure 18: Puncture Resistance

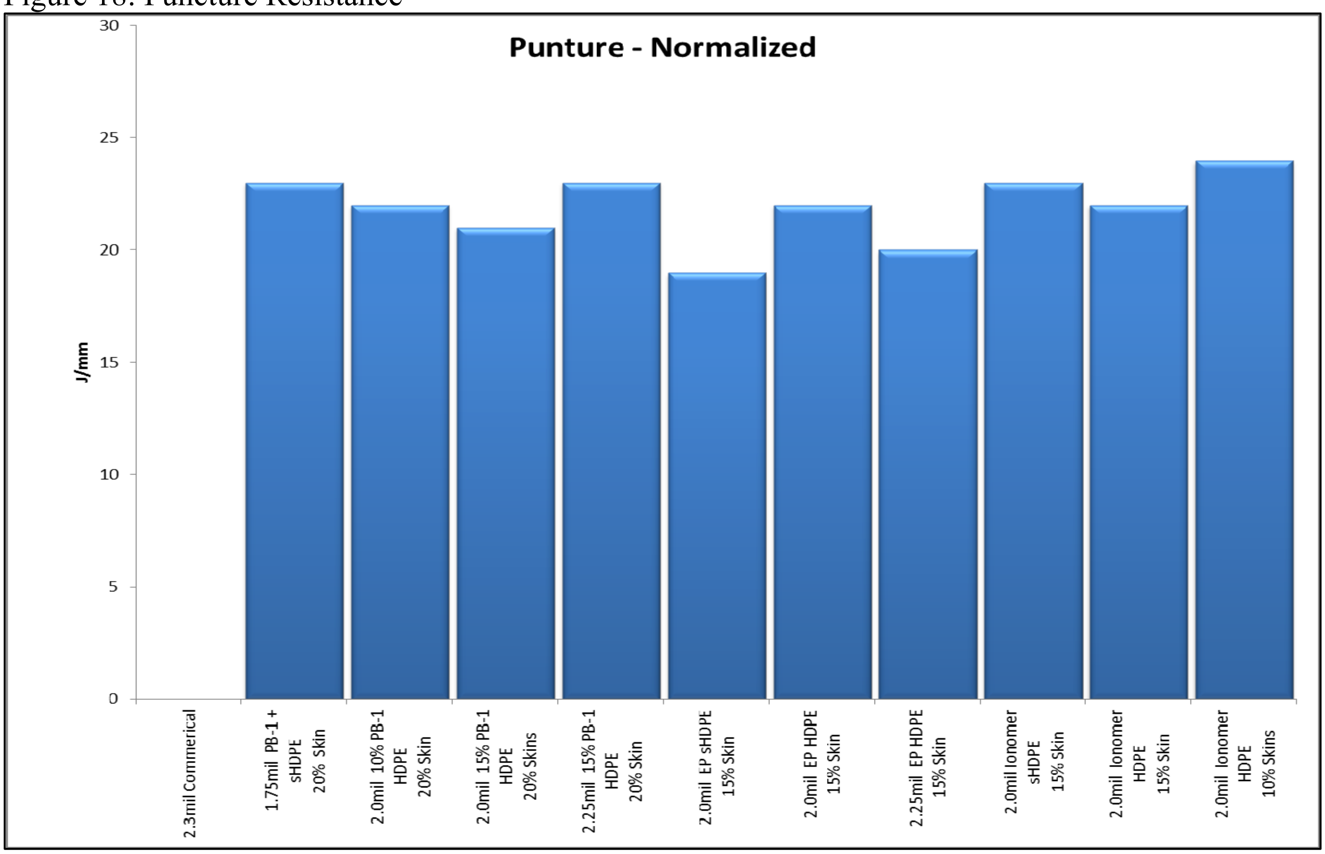


Figure 19: Normalized Puncture Resistance

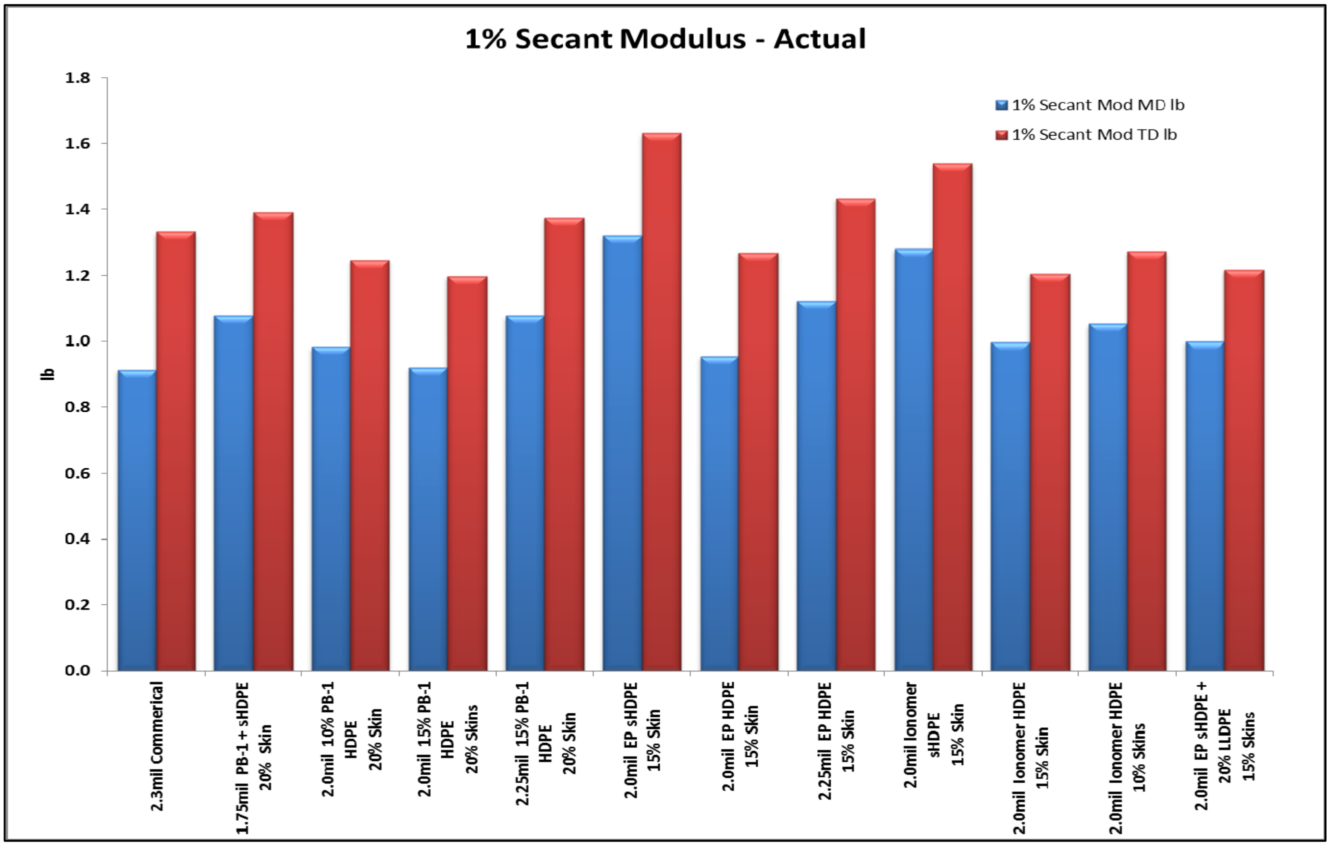


Figure 20: 1% Secant Modulus

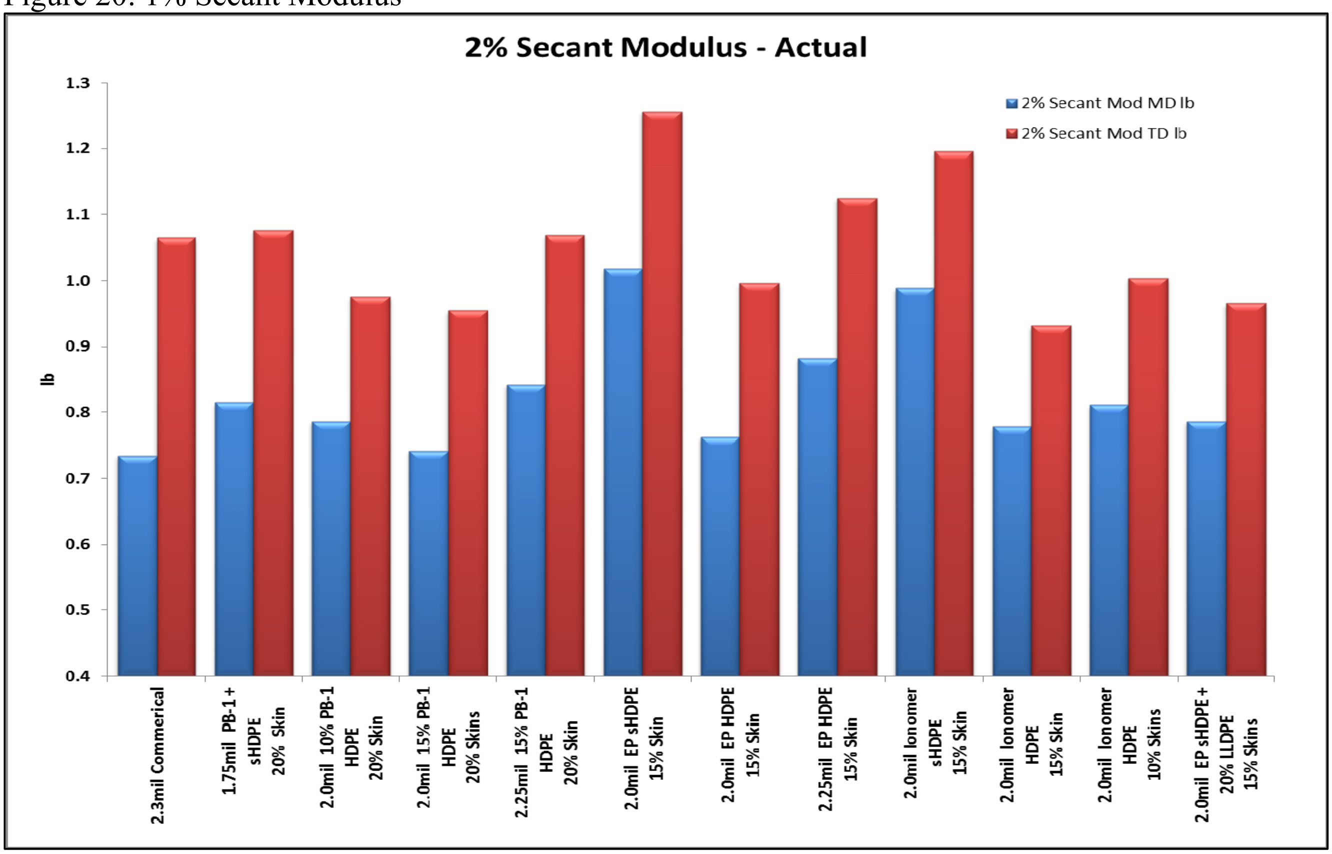


Figure 21: 2% Secant Modulus

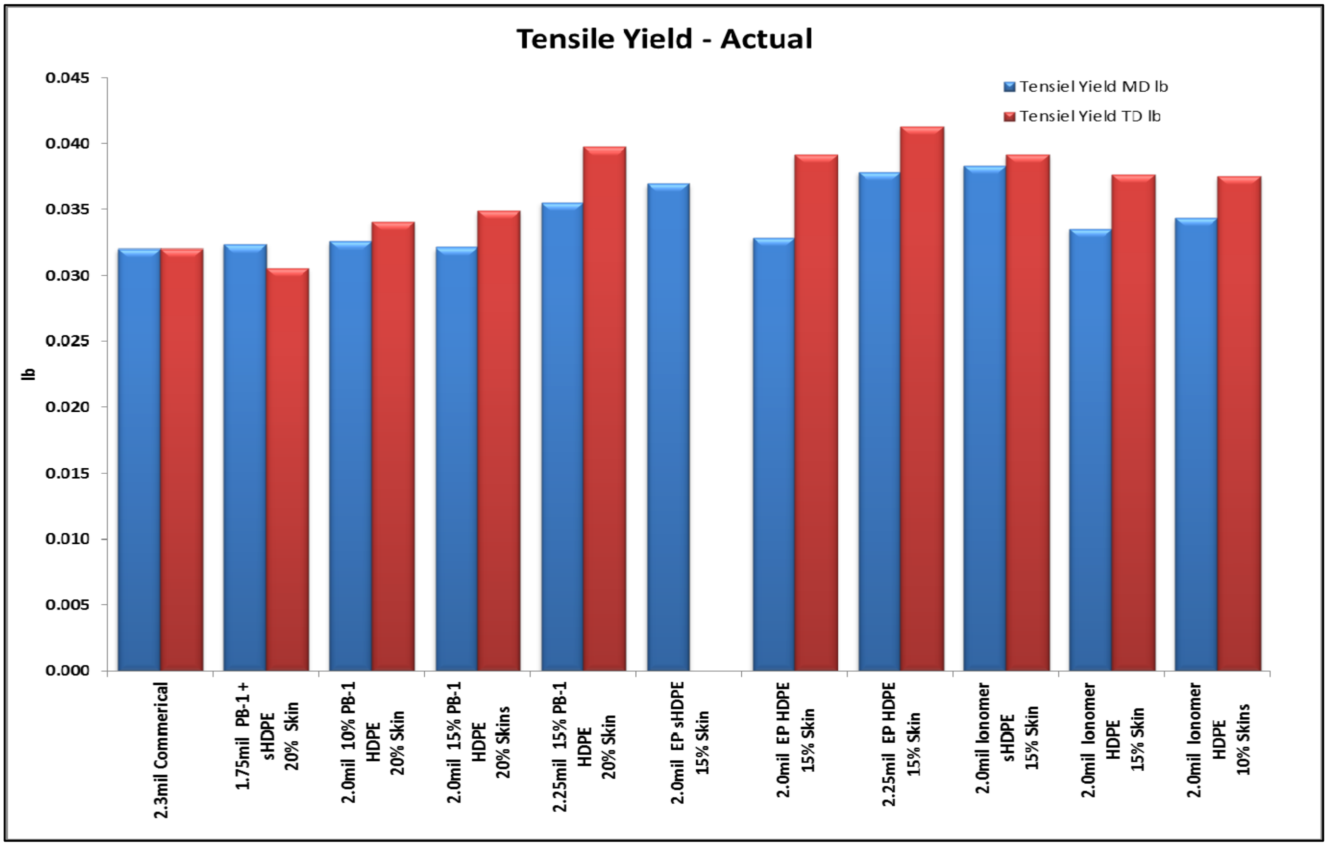


Figure 22: Tensile Yield

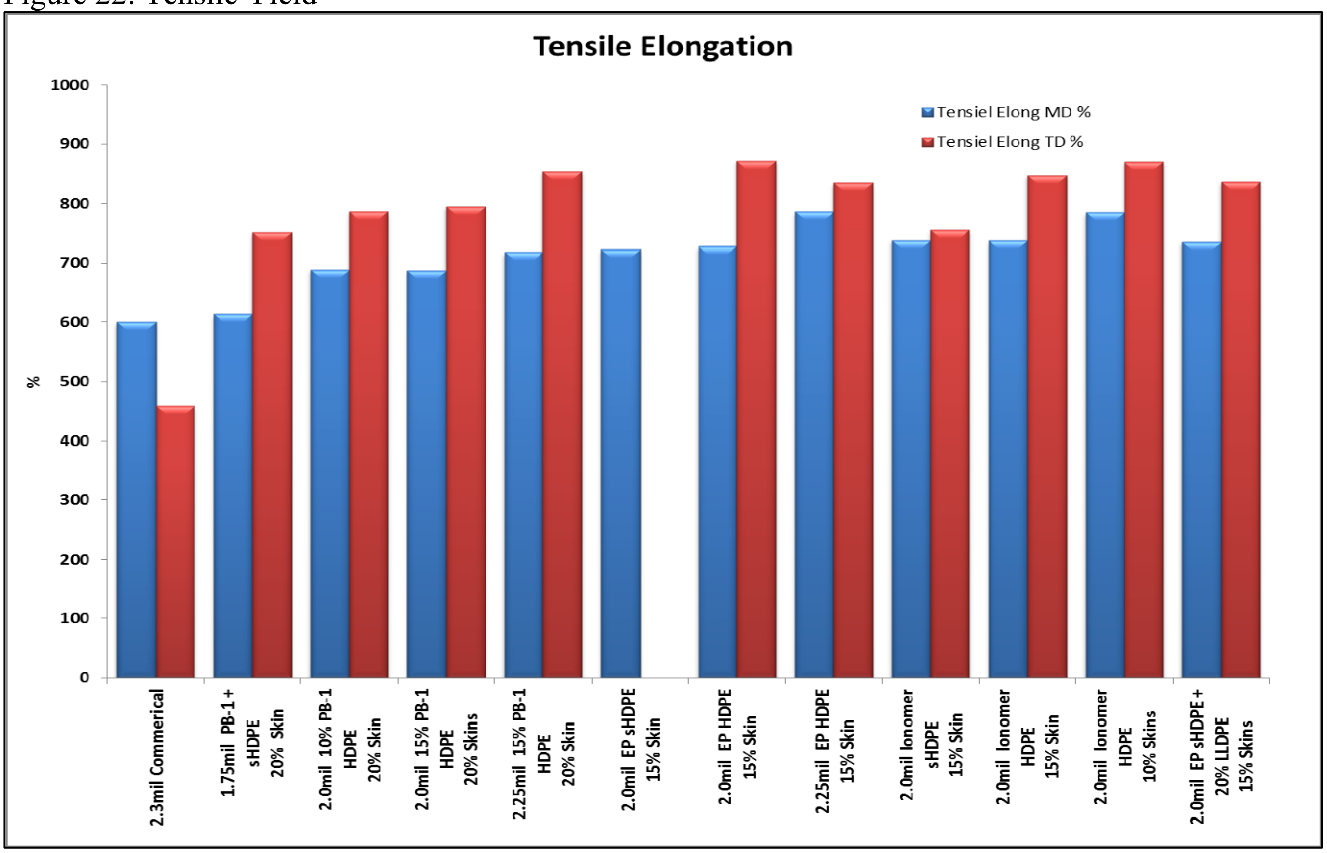


Figure 23: Tensile Elongation

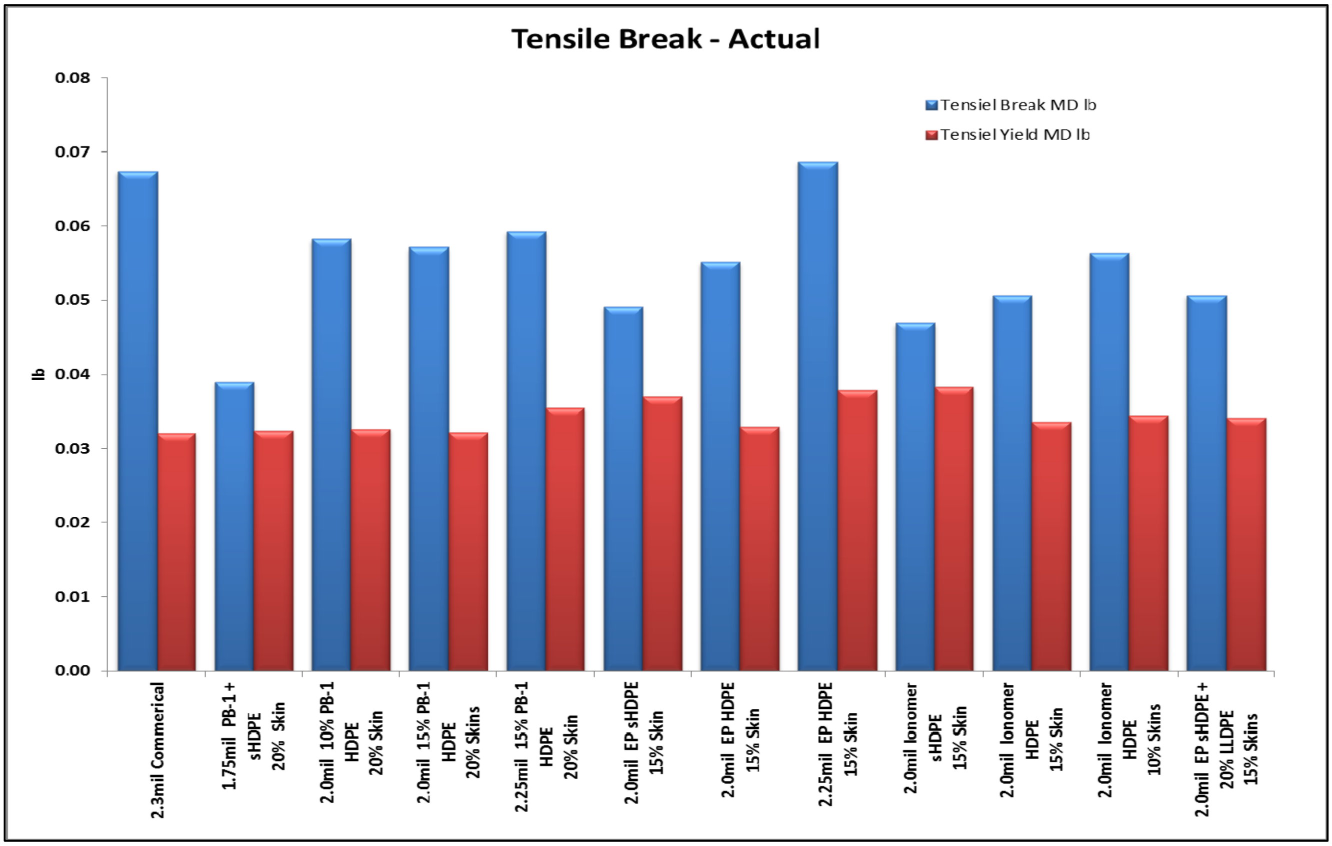


Figure 24: Tensile Break

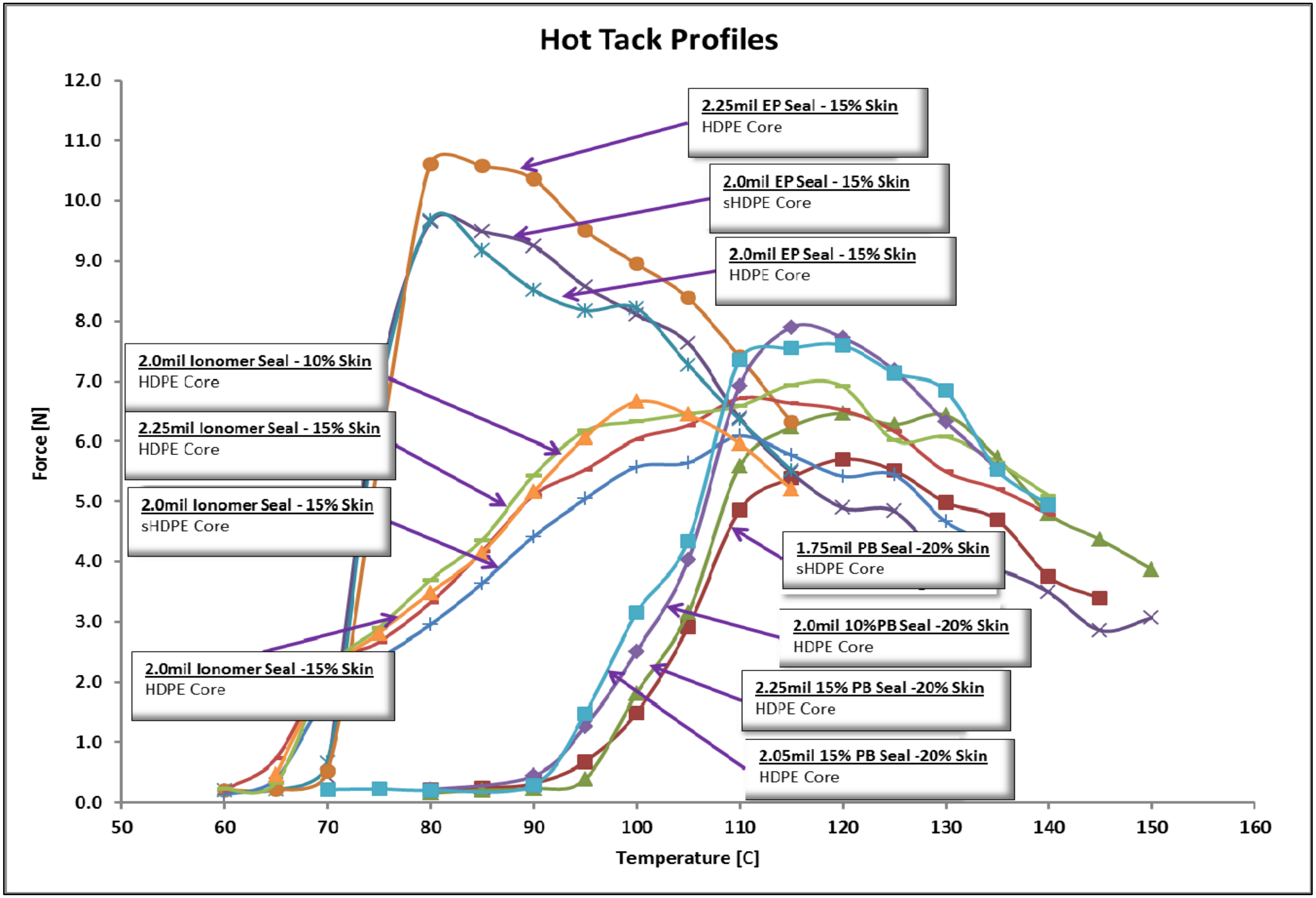


Figure 25: Hot Tack Strength

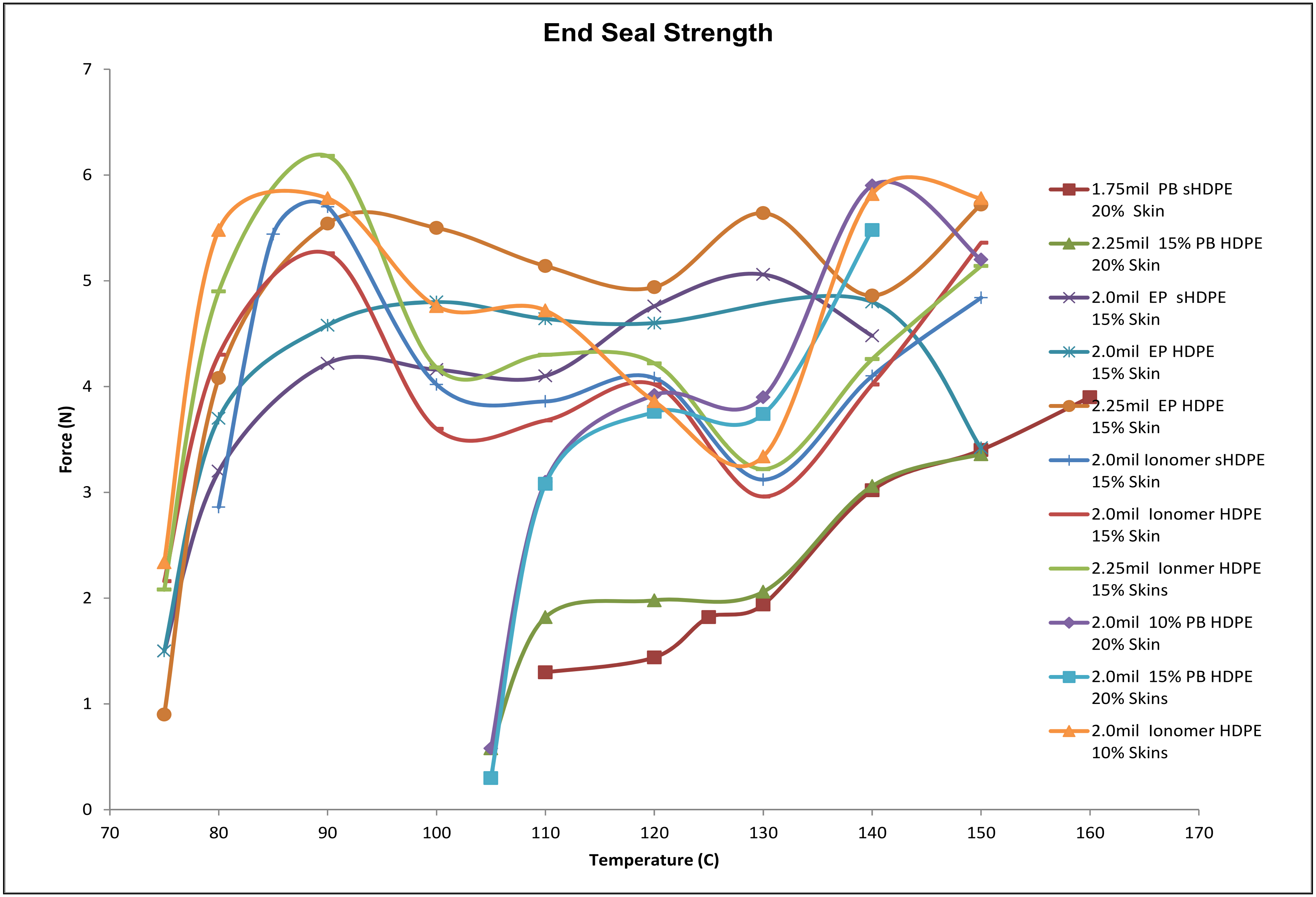


Figure 26: Film Heat Seal Strength - All after two weeks

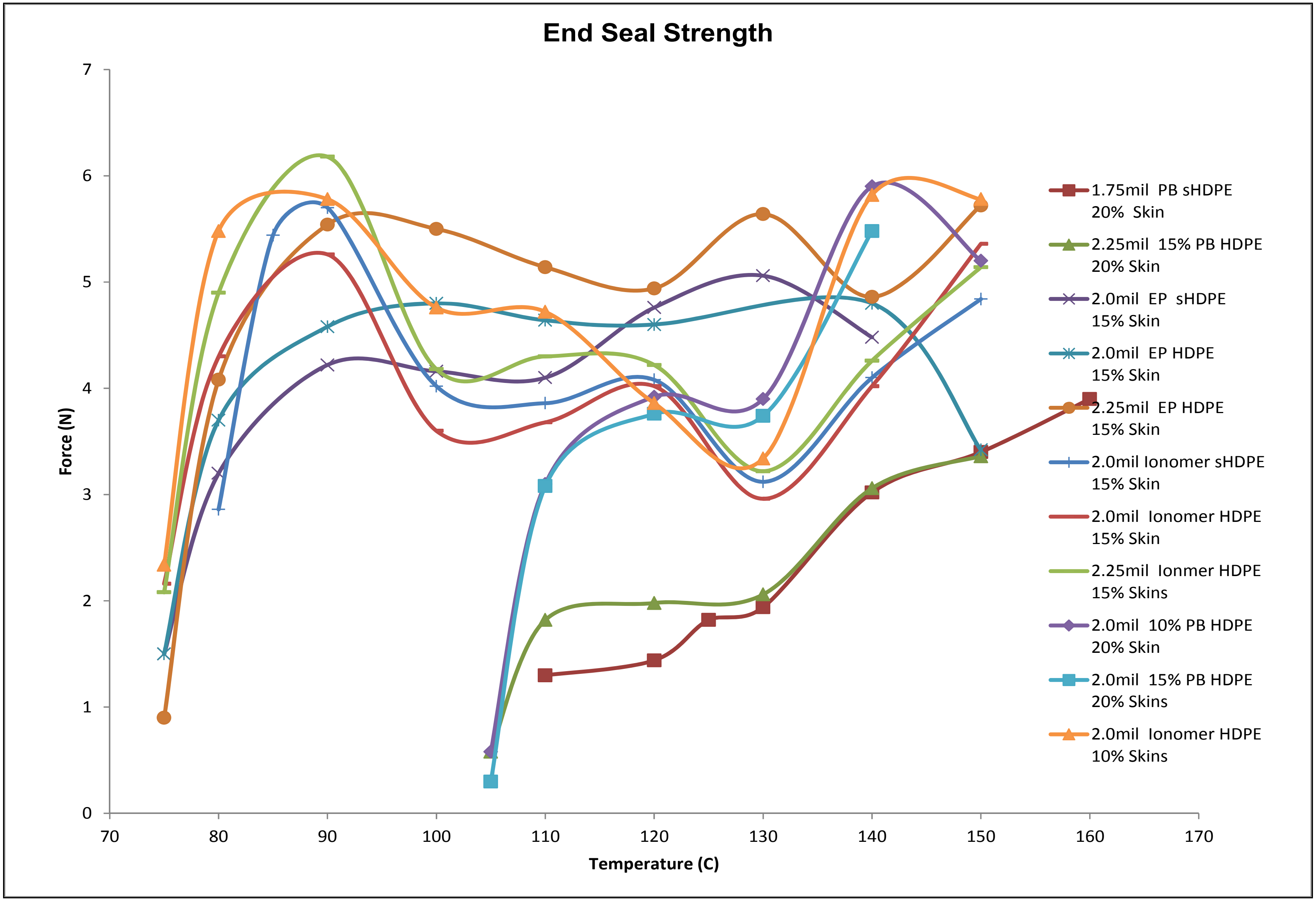


Figure 27: Pouch End Seal Strength - All after two weeks

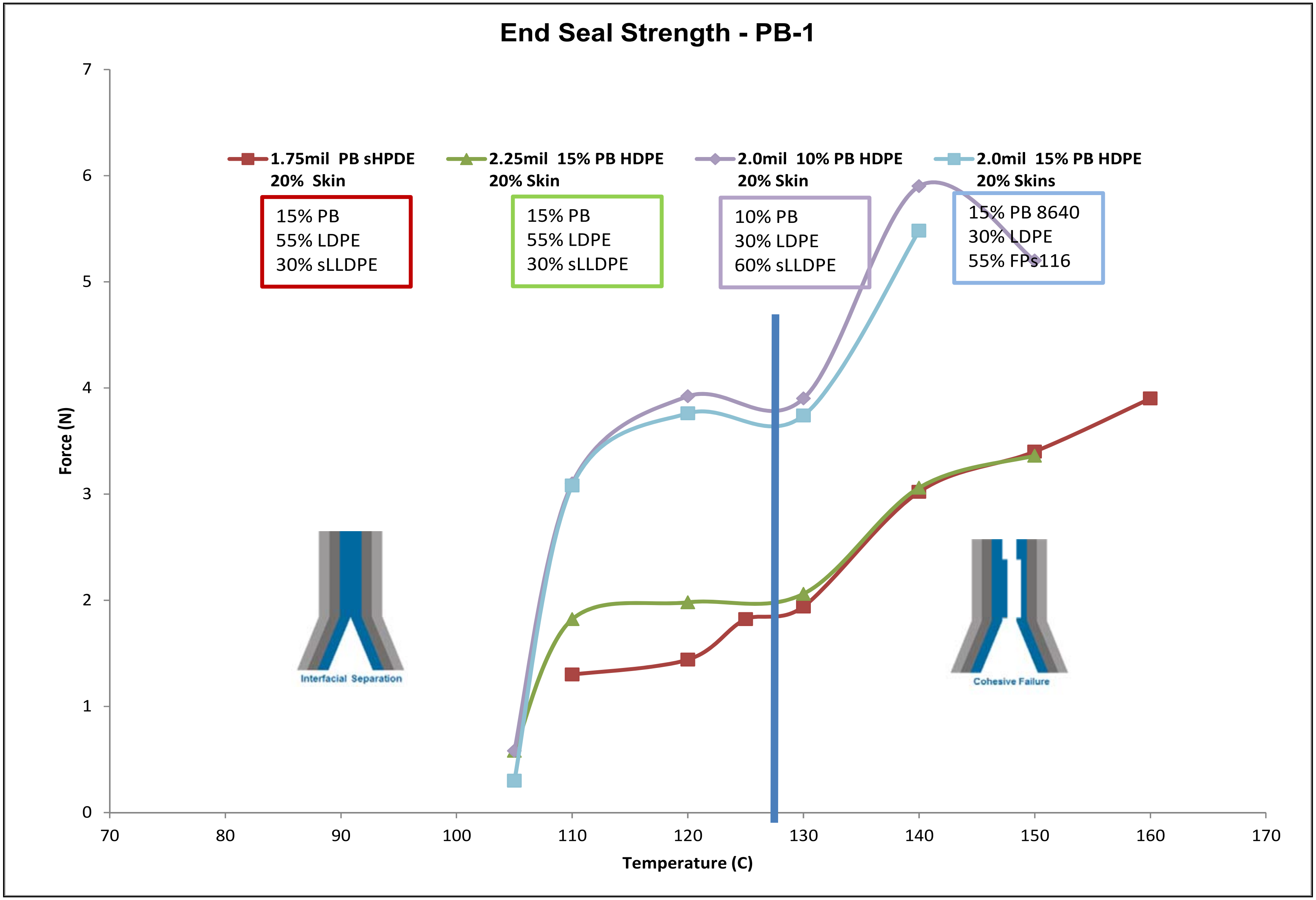


Figure28: Pouch End Seal Strength – PB-1

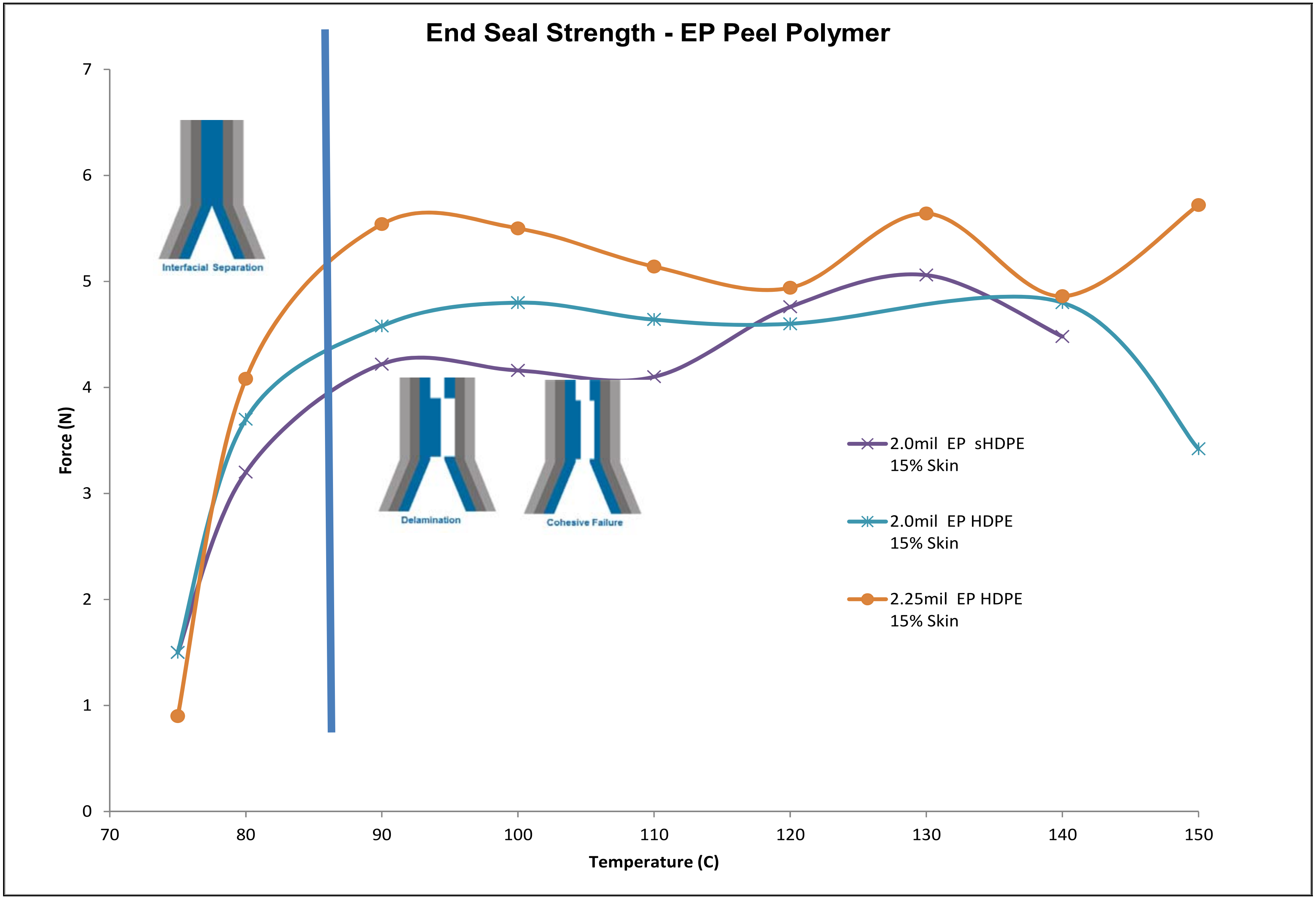


Figure 29: Pouch End Seal Strength – EP Peel Seal Polymer

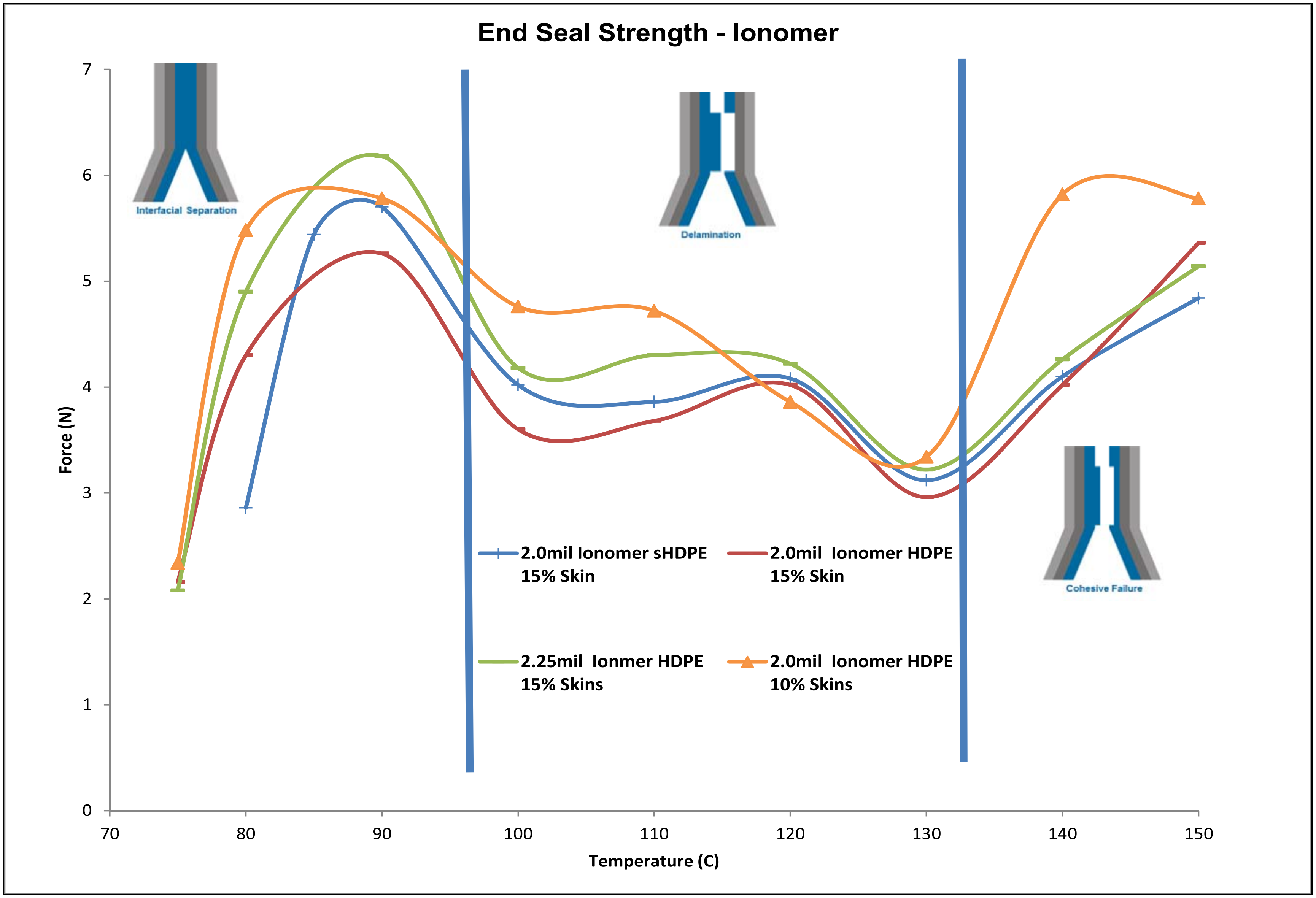


Figure 30: Pouch End Seal Strength - Ionomer

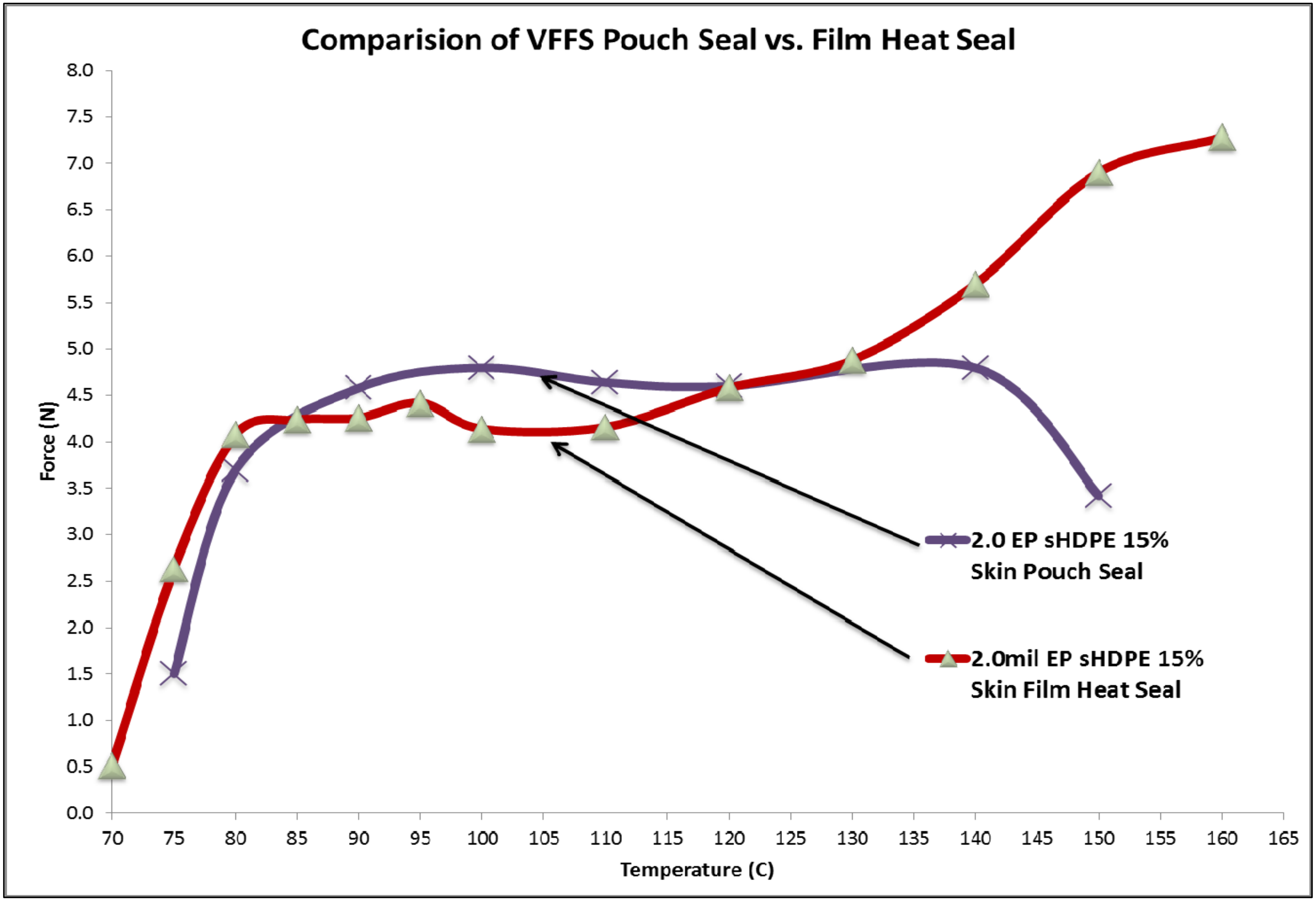


Figure 31: Pouch End Seal Vs Laboratory Heat Sealed Film

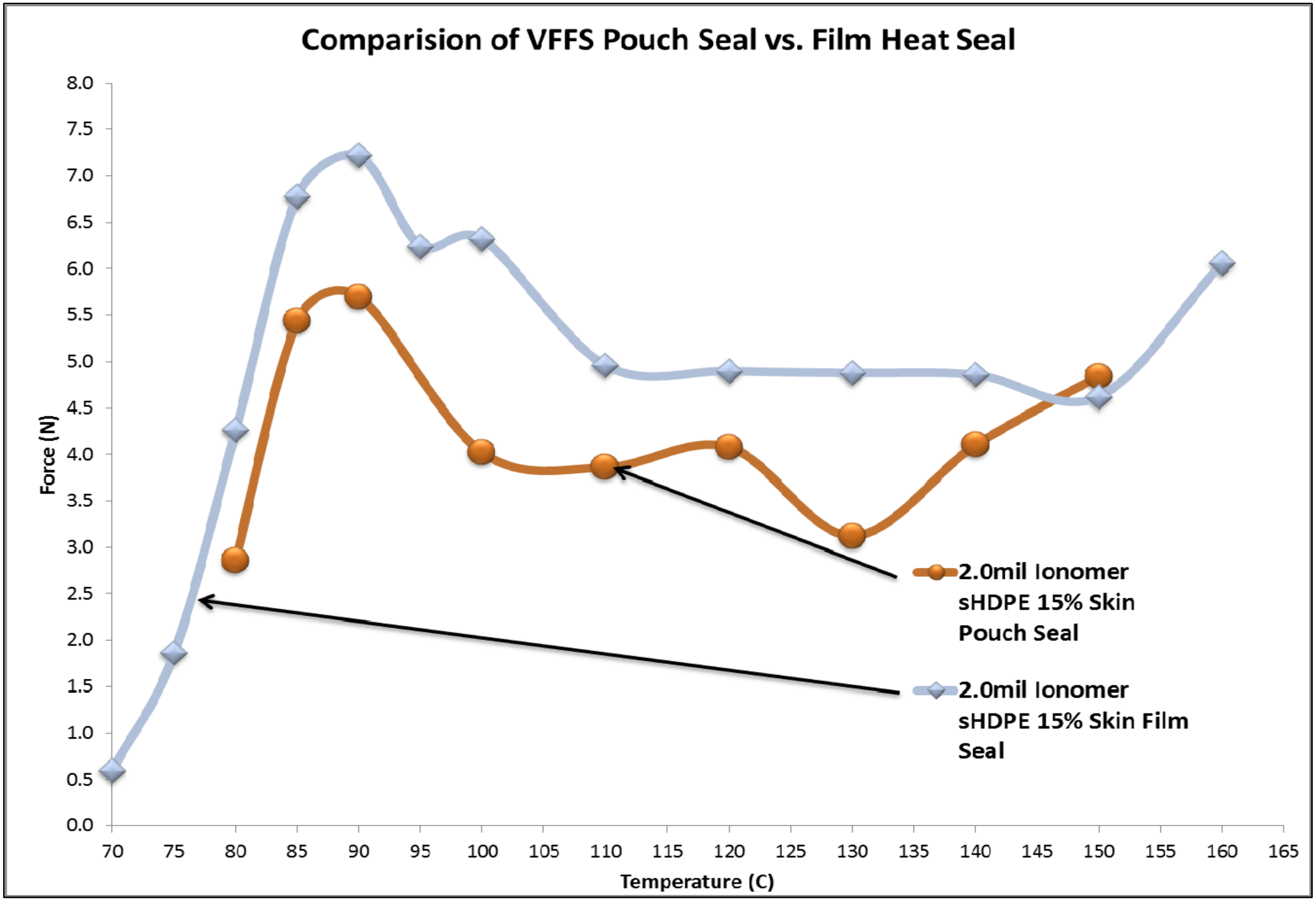


Figure 32: Pouch End Seal Vs Laboratory Heat Sealed Film

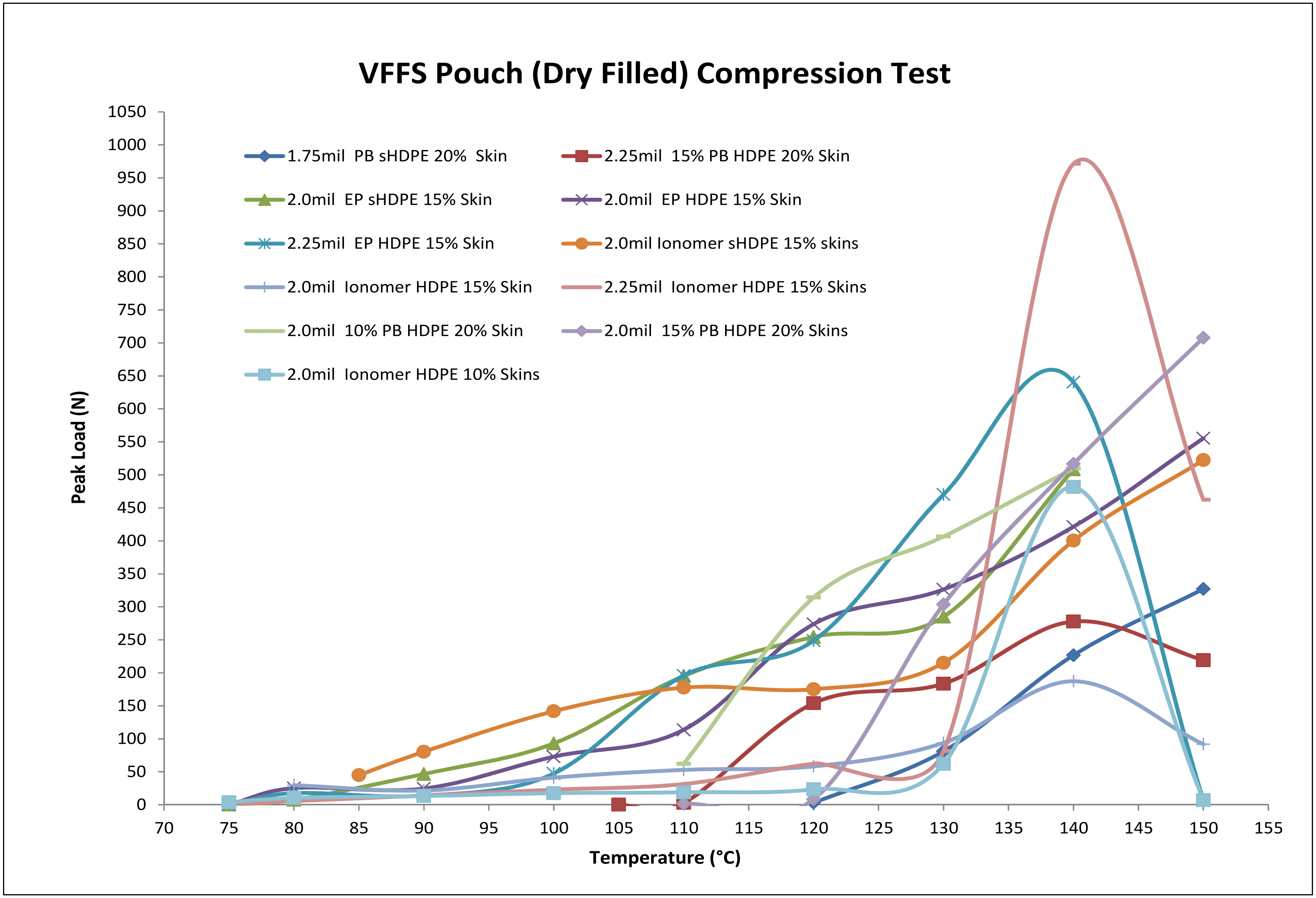


Figure 33: VFFS Pouch Compression Test

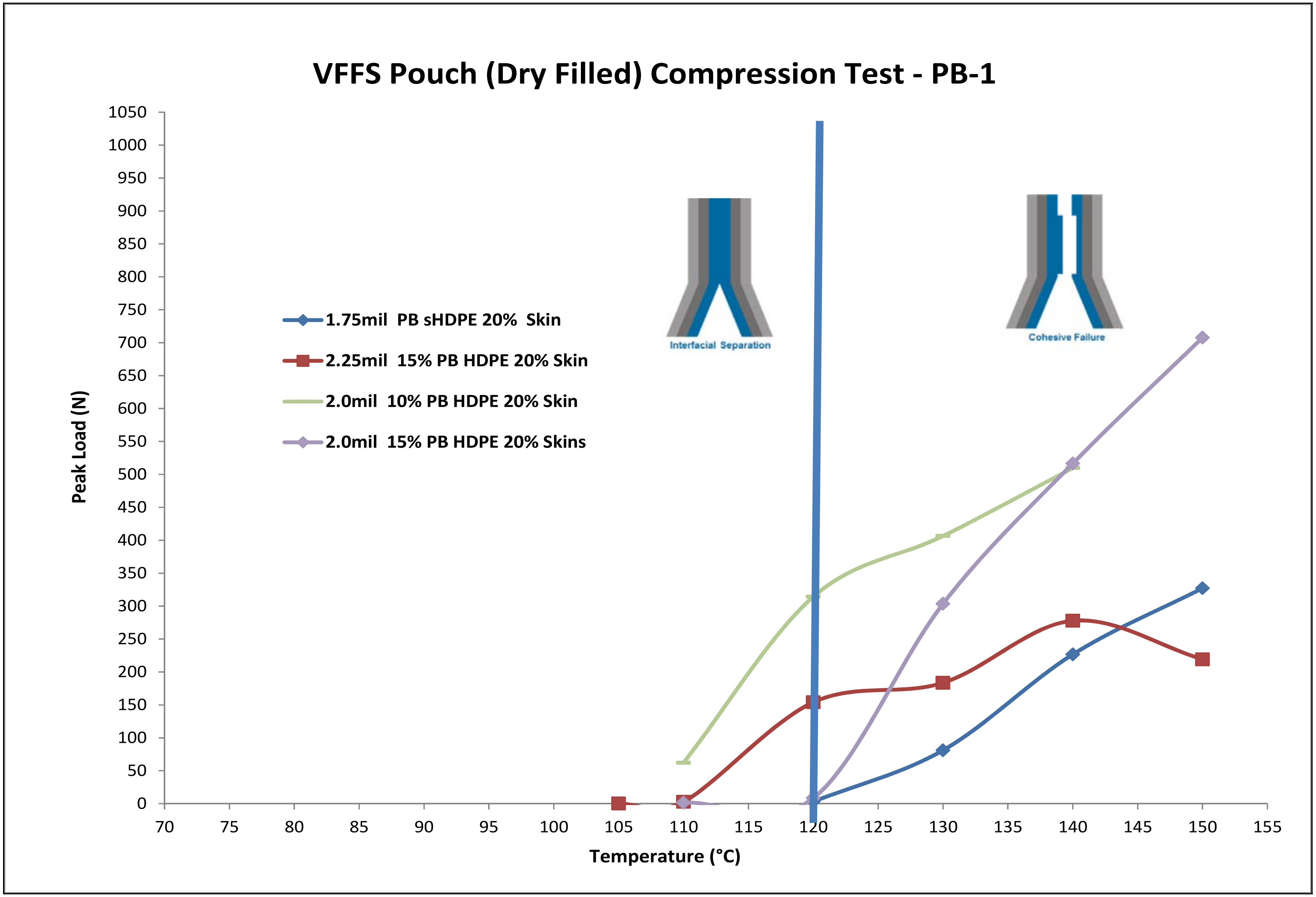


Figure 34: VFFS Pouch Compression Test – PB-1

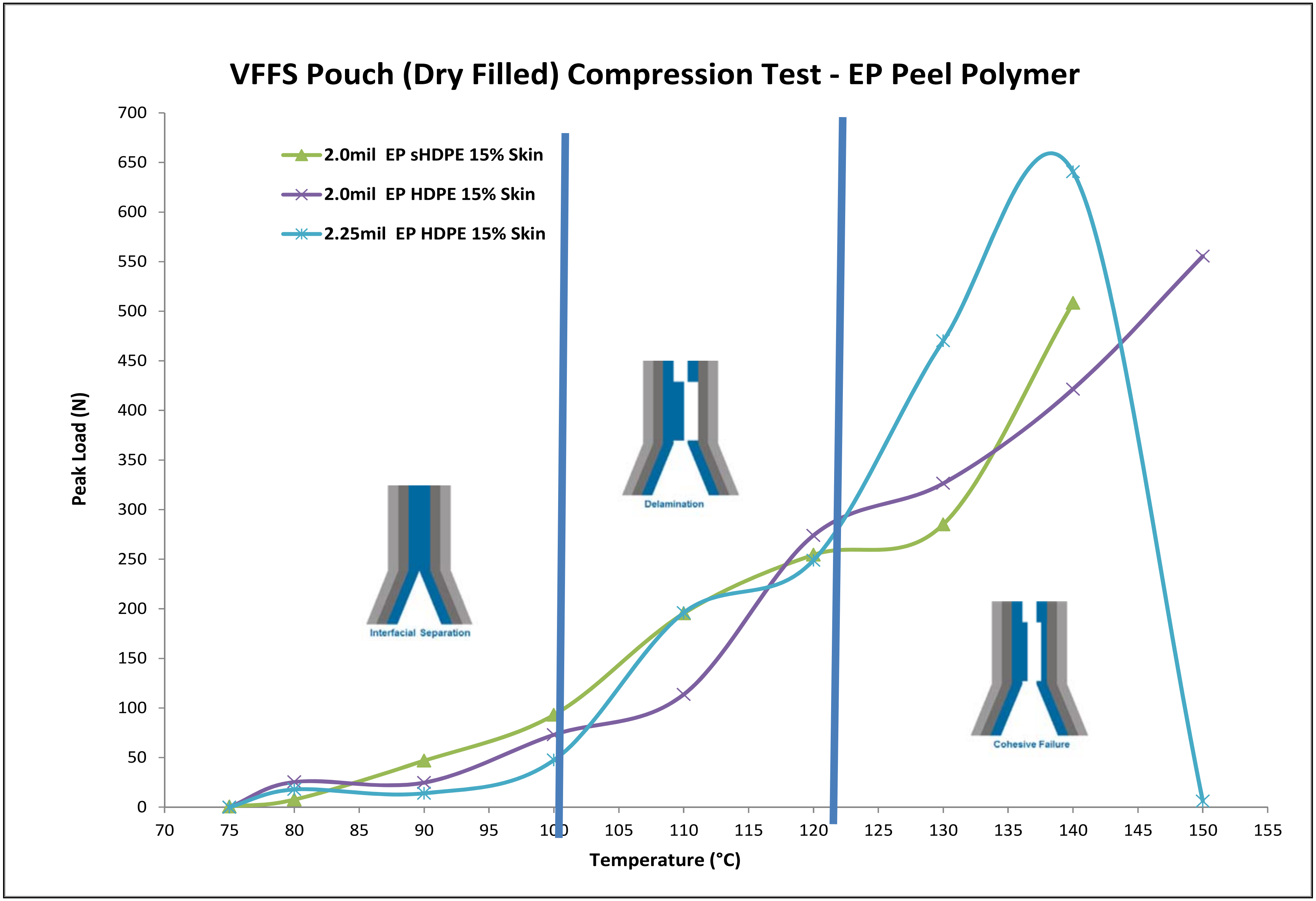


Figure 35: VFFS Pouch Compression Test - EP Peel Polymer

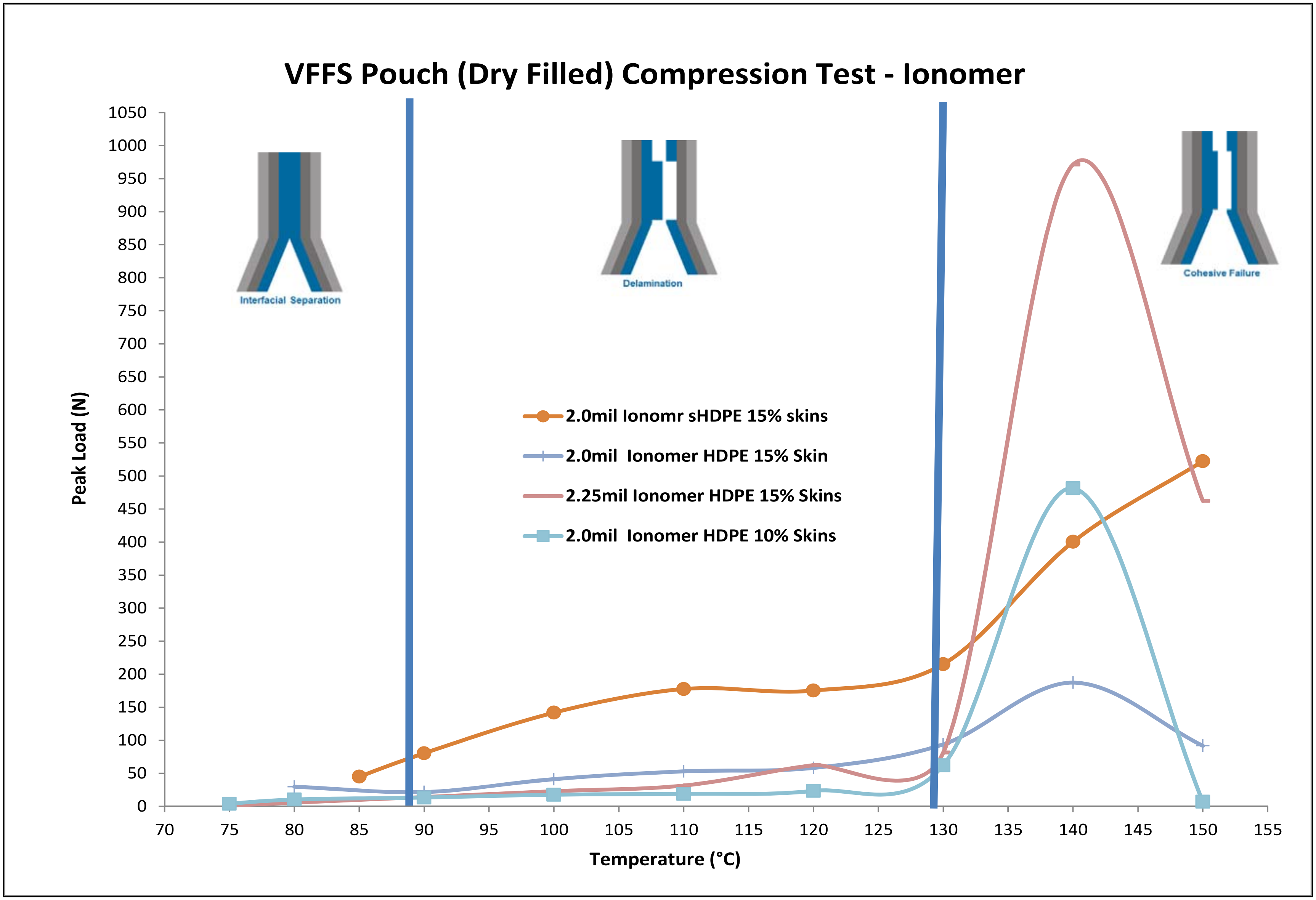


Figure 36: VFFS Pouch Compression Test - Ionomer