The effect of Extrusion and Casting settings on Stretch Film Properties

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ABSTRACT

A designed experiment was carried out using the Cast2020 stretch film line of SMS Folientechnik GmbH in Vienna. Goal was to determine the effect of the extrusion and casting setting on the stretch film properties using 1-butene based LLDPE under commercial production conditions.

INTRODUCTION

Nowadays more than 80 producers, from small to very large, are producing stretch films in Europe consuming more than 800,000 tons of LLDPE. This volume accounts for 40% of the total LLDPE resin consumption in Western Europe used for film applications.
Stretch films can be produced either by blown or the cast film process. Due to processing advantages (e.g. higher output and speed, better optical properties) cast film clearly dominates the market with an 80% market share.
Butene, hexene, metallocene and octene-based LLDPE's are used to produce multi-layer stretch films - up to 5 layers – for wrapping applications. More than 50% of the total volume used for stretch films is captured by butene and hexene based LLDPE in one of the strongest growing PE film markets in Europe.

In the past already the effect of extrusion and casting conditions on the performance of LLDPE stretch film has been investigated [1]. However this investigation was based on experiments using a lab scale cast film line and a maximum line speed of 305 m/min, which nowadays can be considered bottom line.

Main objective of this designed experiment was to investigate the effect of the melt temperature, chill-roll temperature and vacuum box using a commercial 2m cast stretch film line using commercial outputs and winding speeds.

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MATERIALS AND EQUIPMENT

(a) Materials. The melt-3, density 918kg/m³ 1-butene SABIC® LLDPE 318B was used to run the experiments and a common melt-3 VLDPE as cling material.

(b) Cast Film Extrusion. All films were produced on the Cast2020 stretch film line of SMS Folientechnik GmbH.

Photo: Cast2020 (courtesy SMS Folientechnik GmbH)

This 2meter line consists of two 75mm extruder and one 150mm extruder connected via an A/B/C Cloeren feedblock to a 2750 mm Cloeren Autogauge™ die with a die gap of 0.6mm. Output was 1000 kg/h and the winding speed 500 m/min to produce a 3-layer stretch film with a nominal film thickness of 20µm. Web pinning was done using a dual chamber vacuum box and static edge pinners. Layer distribution was 15/70/15% with SABIC® LLDPE 318B in all three layers using 15% of VLDPE in the cling layer and 25% recycle in the core layer. Film thickness distribution was controlled by the Extrol 6032 line process control system using an automatic film profile control in combination with an NDC NIR thickness gauge.

EXPERIMENTAL

A Box-Behnken design was used to investigate the effect of the melt temperature, chill-roll temperature and the vacuum box on end film properties. The variables were selected via a Pareto analysis. Condition was that the variables should be easily adaptable by converters.

In the design the melt temperature was varied from 250 to 290 °C, the chill roll temperature from 15 to 25 °C and the vacuum box from 2 to 4 cm of water pressure (see table 1). All other settings were fixed (see table 2).

Table 1: Design matrix

Exp Name	T_{MELT}	T_{CR}	Vacuum Box
N1	250	15	3
N2	290	15	3
N3	250	25	3
N4	290	25	3
N5	250	20	2
N6	290	20	2
N7	250	20	4
N8	290	20	4
N9	275	15	2
N10	275	25	2
N11	275	15	4
N12	275	25	4
N13	275	20	3
N14	275	20	3
N15	275	20	3

Table 2: Line settings

Parameter	Unit	Value
Die gap	mm	0.5
Air gap	mm	22
Film thickness	µm	20
Output	kg/h	1000
Winding speed	m/min	500

The films were conditioned during 24 hours in a standard atmosphere (temperature 23 ºC, humidity 50 %). After conditioning the following stretch film properties were determined:

Optical properties

- Gloss according to ASTM D2457, 45º
- Haze according to ASTM D1003-A

Mechanical properties

- Tear resistance – Elmendorf method, according to ISO 6383/2
- Peel cling according to ASTM 5458-95 (2001)
- Elastic Recovery and Stress retention according to ASTM D5459-95 (2001)
- Protrusion Puncture Resistance – ASTM D5748-95 (2001)
- Flaw resistance [2]
- Dart Impact – Free falling dart method, according to ISO 7765-2
- Ultimate pre-stretch test (Highlight Tester)
- Film retention probe test (Highlight Tester)
- Ultimate pre-stretch level using a the Robopac Rotoplat 705 PVS semi-automatic turntable stretch wrapper (400% max. pre-stretch)[1]

All data obtained for the 15 film samples were analysed using the Modde 6 experimental design software package (Umetrics, Sweden). For each dependent variable a model was fitted as a function of the processing and casting unit variables mentioned.

[1] *These measurements were not performed using conditioned samples because this was not possible considering the circumstances.*

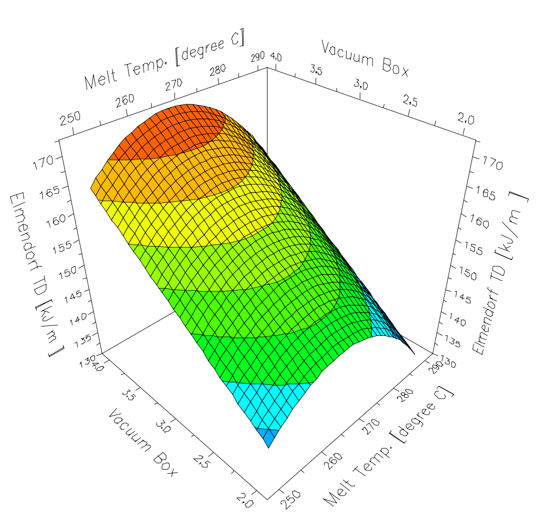
A lack-of-fit test was manually performed for each model using the three center points (replicates).

RESULTS AND DISCUSSION

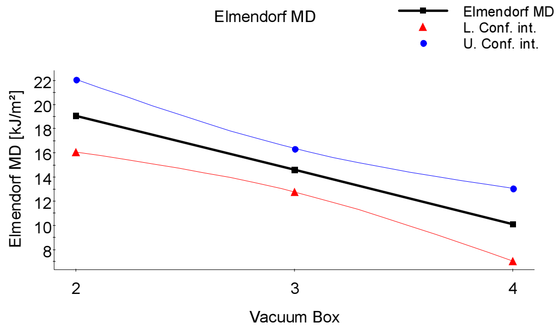
(a) Optical properties. The effect of extrusion and casting variables on the gloss and haze is very small. The gloss level of all experiments was higher than 88 ‰ with a Δ gloss of only 3.7 ‰. The haze levels were all lower than 2.1 mV, which is consistent with the high gloss values (haze and gloss are reverse proportional).
Although the differences between the samples were very small still dependencies with melt temperature and vacuum box could be detected. Most likely is that the higher melt temperature and low vacuum box setting, give more relaxation of the melt and therefore a smoother film surface.

(b) Impact resistance. For the impact resistance the standard deviation of the individual samples was on a level that equals differences between the samples. So there is no significant influence of the melt temperature, vacuum box setting or chill roll temperature on the impact resistance of the stretch film.

(c) TD Tear resistance. The vacuum box setting has the major effect on the TD tear resistance. A smaller, but still significant effect has the melt temperature, which shows an optimum at a melt temperature of 265 to 270°C.



(d) MD Tear resistance. In contrast to the TD Tear resistance there is only an influence of the vacuum box setting on the MD Tear resistance; decreasing the vacuum box setting increases the MD tear.



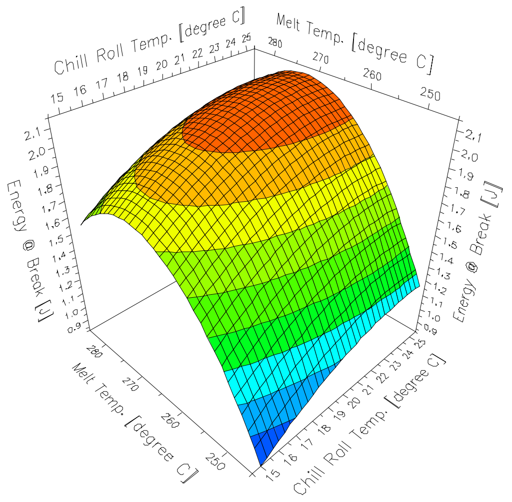
(e) Peel cling. The variation coefficient of the 15 individual samples was below 6%; standard deviation was 0.0035 N/mm on an average of 0.060 N/mm. Several of the standard deviations for the individual samples were higher than the overall standard deviation of the 15 results. It can be concluded that there is no significant influence of the extrusion and casting variables on the peel cling. Question is whether the C_4-LLDPE resin, in combination with the extrusion and casting variables, or the consistency of the cling material (VLDPE) has the major influence on the cling level of the stretch film?

(f) Elastic Recovery. The elastic recovery results range from 49.8 to 53.1% with an average of 51.8% and a standard deviation of 0.9%. This implies a measurement error of ± 1.9% which already covers the full range of the obtained data.

(g) Stress Retention. The stress retention also showed a very small Δ of less than 1.5% on an average of 77.7% (VC is only 0.4%).

(h) Protrusion Puncture Resistance. The protrusion puncture resistance (energy @ break) is a function of the melt temperature, vacuum box setting and chill-roll temperature.

Energy @ Break

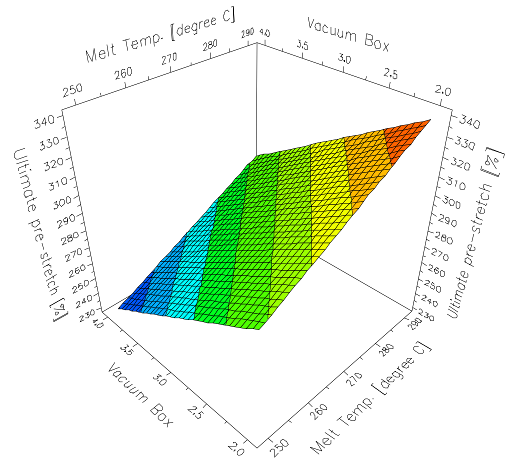


Flaw Resistance. Dow Chemical Company introduced the flaw resistance in 1993 [2] to predict the Ultimate Stretch level that can be obtained with a film using a high-speed pallet wrapper. The measurement is based on the standard tensile test and can be quantified by the elongation at break of intentionally flawed film specimens.
Dow obtained a good correlation (R^2=0.96, 8 observations) between the Flaw Resistance and the stretch performance. In 1999 Equistar [3] used the same test to check the ultimate stretch level of stretch films and confirmed the correlation between the flaw resistance and the ultimate stretch level but with a much worse correlation (R^2=0.7789, 11 observations). Our investigation even indicated a very poor correlation (R^2=0.5995, 15 observations. It therefore can be concluded that the flaw resistance is not a suitable measurement to give a reliable estimation of the ultimate pre-stretch level of a stretch film. However despite the very poor correlation there is a trend indicating a higher ultimate pre-stretch level with a higher flaw resistance.

(i) Dart Impact. For the impact resistance the standard deviation of the individual samples was on the same level as the differences between the samples.

(j) Ultimate Pre-stretch Test. The effect of the melt temperature and vacuum box setting on the ultimate pre-stretch level is shown in the figure below.

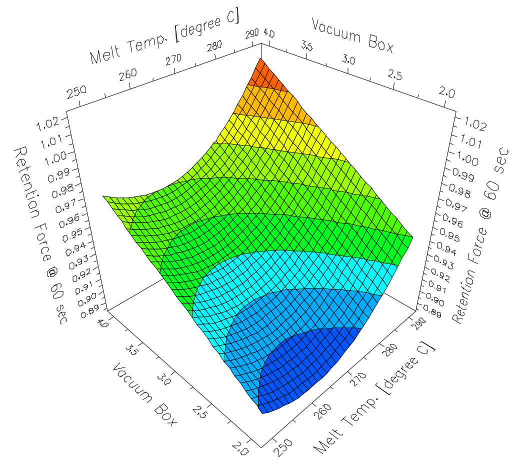
Ultimate pre-stretch



Higher melt temperatures in combination with lower vacuum box settings are increasing the ultimate pre-stretch dramatically. These settings stand for a relatively long a hot melt curtain, which most probably promotes the relaxation of the melt, boosting the pre-stretch potential of the film.

(k) Film retention probe test. The HighLight measurement, determined after 60s, is more or less comparable with the stress retention measurement performed with a tensile tester.

Retention Force @ 60 sec



However in contrast to the stress retention measurement the HighLight results are showing a good fit.
The retention force is a function of the melt temperature and vacuum box setting and can be maximised by using a high vacuum box setting and a high melt temperature. Stretch film will exhibit the highest retention force at a high orientation level in MD and a high vacuum box setting is preventing relaxation of the film and most probably the high melt temperature is maximising the degree of orientation in the melt.

(I) Robopac ultimate pre-stretch.

Exp.	*Max. Pre-stretch [%]*	*Remarks*
N1	400	-
N2	230	-
N3	400	-
N4	280	Many holes
N5	400	-
N6	150	2 holes
N7	160	several holes
N8	150	-
N9	270	-
N10	400	50 on the corners
N11	400	Some holes
N12	400	Big holes
N13	250	-
N14	240	several holes
N15	350	Some holes

It was not possible to model the results because several film rolls (7 out of 15) achieved a pre-stretch level of 400%, which was the maximum. This was definitely beyond the expected.

SUMMARY AND CONCLUSIONS

Based on the results of this investigation it can be concluded that:

- The stretch film performance can be improved by changing the melt temperature and vacuum box setting.
- The protrusion puncture resistance is the only film property affected by the chill roll temperature
- Pre-stretch levels of 400% are achievable with butene-based LLDPE's.
- The cling behaviour of the stretch film is not affected by the melt temperature, vacuum box setting or chill roll temperature; most likely the consistency of the used cling material and the blend ratio are the primary "variables".
- The impact resistance of the stretch film is not affected by the melt temperature, vacuum box setting or chill roll temperature.
- The elastic recovery measurement according to ASTM D5459-95 is not sensitive enough to detect the influence of processing and casting variables.
- The Flaw resistance is not a suitable measurement to give a reliable estimation of the ultimate pre-stretch level of a stretch film.

This investigation showed that even C_4-LLDPE, which is considered to be the low-end material in the stretch film market, has more potential than imputed. Adapting extrusion and casting settings can improve stretch film properties.

REFERENCES

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