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Title: Thermoformed Packaging from Soy Protein Isolate Resin

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ABSTRACT

Prototype thermoforming trials of a soy protein isolate based sheet material are conducted to evaluate the effect of moisture level, draw ratio, plug-assist, and vacuum rates on the forming of cup-shaped containers. The forming behavior of the soy sheet is compared to PVC and PP materials. Cycle time and draw ratio comparisons are made.

Thermoformed Packaging from Soy Protein Isolate Resin

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Abstract

Prototype thermoforming trials of a soy protein isolate-based sheet material are conducted to evaluate the effect of moisture level, draw ratio, and plug-assist on the wall thickness distribution of cup-shaped containers. The forming behavior of the soy protein isolate sheet is compared to PVC and PP materials. Cycle time and draw ratio comparisons are made.

Introduction

There has been much interest in the development of sustainable packaging materials in recent years. Most notable has been the development of NatureWorks® PLA by Cargill [1], which is based upon polymerized lactic acid derived from corn. Research to date involving the use of soy-based resins has focused primarily upon compression molding applications of either soy-based polyesters or soy protein isolate [2, 3]. The motivation for this work stems from the mission articulated by Brown [4] calling for sustainable packaging applications through thermoforming. Soy protein isolate offers promise as a more water resistant foam material than corn starch and in a non-foamed form can exhibit mechanical properties similar to high impact polystyrene.

In this paper, the use of soy protein isolate resins for thermoforming is examined. The soy protein isolate formulation used in this study is comprised of all biodegradable, renewable materials. As a bio-based and biodegradable material, it meets the "ecoefficient" requirement outlined by Narayan [5]. This study is one step in a process to design bio-based packaging materials and appropriate applications. The thermoforming applications for packaging that directly relates to this study include disposable cups, bowls and trays. Other formulations of soy protein isolate may be appropriate for closures such as drink lids and clam shell containers.

As with many bio-based polymers, the effect of moisture on the mechanical properties of the resins is significant. Variable humidity conditions may affect the processability of the stock material, as in the case of extruding sheet into rolls and later forming containers. Another parameter critical to thermoforming is the draw ratio possible for a material based upon the hot melt strength at forming temperatures. Some materials exhibit excessive thinning during forming due to poor hot melt strength. Plug-assist forming is one way to accommodate deeper draws while yielding a more uniform wall thickness distribution. Thus, the effect of draw ratio on the wall thickness will be examined as well as the benefit of plug-assist.

The height to diameter ratio of the container is used to characterize the draw ratio as this parameter is often used to describe the formability of plastics for cup shapes.

Experimental Procedure

To scope of this study involves forming soy protein isolate sheet stock into cup-like containers. The effect of three process variables on the wall thickness distribution is studied:

1. draw ratio (H:D) from 0.44 to 0.60,
2. use of plug-assist,
3. change of moisture content (from as extruded 15% by weight to as dried for 12 hours at 10% by weight).

In addition, the thickness distribution resulting from changes in draw ratio and the use of plug-assist on two common packaging materials, polypropylene (PP) and polyvinyl chloride (PVC), is assessed and compared to the results obtained for the soy protein isolate (SPI) sheet.

The soy protein isolate sheet contains water and glycerol as plasticizers and potassium sorbate and organo clay additives. The sheet material was provided by the Soy Works Corporation and is based upon work done by Mungara, *et al*. [6].

The forming trials are done on a MAAC ASP shuttle-type forming machine. The moisture levels are evaluated with a MAX 50 Moisture Analyzer by Arizona Instruments. Sheet material is cut into approximately 2 mm square pieces and 14 grams are placed on the specimen pan for evaluation. The sheet temperatures are measured with Raytek MID infrared pyrometers. The sheet temperatures are recorded after the sheet has exited the oven and held over the forming area.

Mold Geometries

Three thermoforming molds are used to evaluate the effect of draw ratio on thickness distribution. Section views of the mold geometries are shown in Figure 1 for the three shapes of cup containers. The first two shown in Figure 1 are nominally 75 mm (3 inches) in diameter with depth to diameter ratios (H:D) of 0.44 and 0.60. The third mold is a nominal 100 mm (4 inches) diameter cup with an H:D of 0.44. It represents a "bowl" geometry as opposed to a "cup" geometry. Since the "bowl" has a draw ratio similar to one of the "cups" it is expected that the thickness distributions will be similar. The molds are fabricated with acrylonitrile butadiene styrene (ABS) filament through a fused deposition modeling rapid prototyping process. The molds have no cooling.

The wall thickness variation is measured with a veneer caliper at six locations along a center-section cut of the product as illustrated in Figure 2. Repeatable measurement locations are made with the aid of a template. Plug-assist is achieved with a spherical plug that pushes the sheet material to within 8 mm (5/16 inches) of the bottom of the mold cavity prior to vacuum forming. A schematic of the plug-assist geometry for one cavity is shown in Figure 3.

Forming Trials

The nominal gage, heating time, and recorded sheet temperature prior to forming are summarized below:

PP sheet
- Nominal gage 0.56 mm (0.022 in.)
- Heating time 25 seconds
- Forming sheet temperature 129°C

PVC sheet
- Nominal gage 0.22 mm (0.0085 in.)
- Heating time 10 seconds
- Forming sheet temperature 132°C

SPI (soy protein isolate) sheet
- Nominal gage 1.09 mm (0.043 in.)
- Heating time 25 seconds
- Forming sheet temperature 110°C

During the forming trials four to five samples of each trial set point were collected. Six measurements were made on each sample and the averages from all the samples are used to evaluate the effect of processing on the thickness distribution. Replicates of some of the SPI forming were performed on different days. Twenty four forming conditions were evaluated. A trial ID is used to denote the conditions of each trial. The syntax for the ID is: Material(H:D, plug assist?, moisture level). "PA" denotes plug-assist used, "va" denotes straight vacuum. Moisture level is only appropriate for the SPI: "H" denotes 15% and "L" denotes 10% moisture by weight.

Results and Discussion

The thickness measurement data obtained during the forming trials is normalized by the initial sheet thickness of the material. This way wall thickness distribution data from different sheets can be compared. A table of the average normalized thickness data for the trial set points is presented in Figure 4. The trial ID denotes the forming conditions: material used, draw ratio, plug-assist, and moisture level (as appropriate). The table also indicates the number of samples used to compute the averages shown under the measurement locations.

Before comparisons can be made regarding the significance of the parameters on the outcomes, a view of the experimental noise must be made. Figure 5 illustrates the measurement outcomes for PP in the 100 mm bowl geometry. Notice the values have a spread of approximately 10 percent at any one measurement location. Similarly, the data shown in Figure 6 for the SPI data exhibits a similar spread. Thus, outcomes that are within 10 percent of each other are for practical purposes not significantly different. More forming data would be needed to conduct a detailed statistical analysis of the differences between two treatments. Graphs of only a subset of the data in Figure 4 are presented to highlight important observations.

Expected trends do appear as in the case of the reduction in wall thickness at the bottom of a high draw ratio container as shown in Figure 7 for PP and Figure 8 for SPI. The data in Figures 9 and 10 indicate that SPI exhibits similar forming behavior to PP and PVC under similar draw ratios.

The most notable outcome is seen in Figures 11 and 12. The SPI resin does not exhibit any improvement in thickness distribution with the use of plug-assist, unlike the PP and PVC materials. The data in Figure 13 makes this clear that the outcomes for plug-assist and straight vacuum are nearly identical.

Finally, the effect of a 5% reduction in moisture resulting from drying for 12 hours under ambient conditions is not significant. Results shown in Figures 14 and 15 illustrate no significant effect. This has positive implications for the logistics of forming SPI sheet material in a production environment.

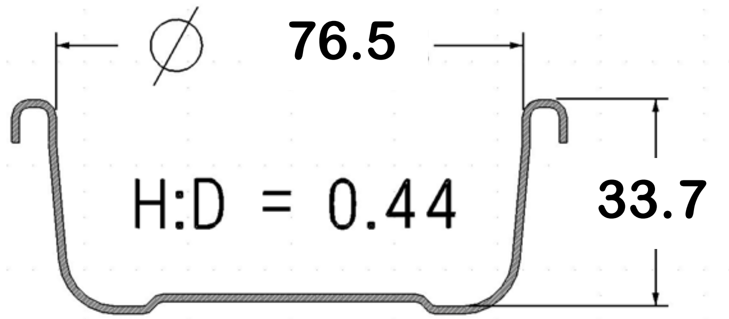
Conclusion

These forming trials document the following trends

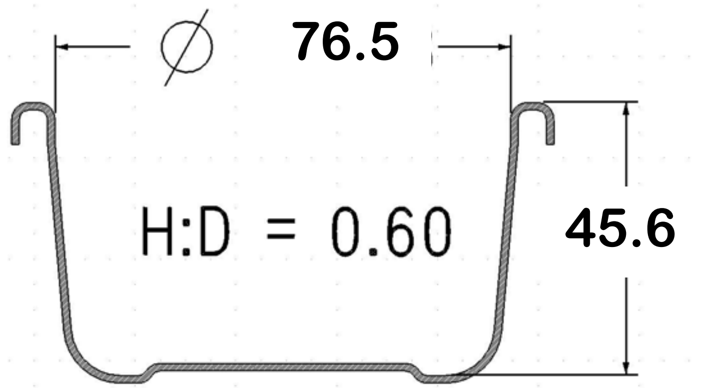
1. soy protein isolate sheet material exhibits similar thickness reductions to PP and PVC for comparable draw ratios,
2. plug-assist forming does not improve the wall thickness reduction of soy protein isolate as it does for PP and PVC,
3. the effect of moisture change, from a high of 15% (as extruded) to 10% (twelve hours exposure to low humidity), does not significantly affect the forming behavior of soy protein isolate sheet material.

References

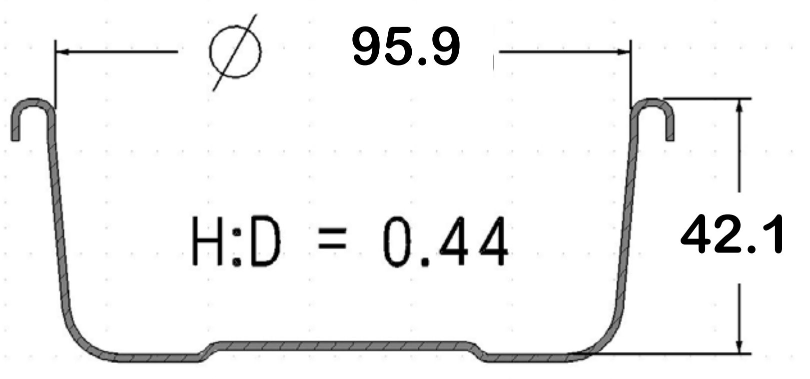
1. Glasbrenner, B., "NatureWorks® PLA–Commercial Development of Biopolymers on a World Scale", GPEC 2005.
2. Maas, B. J., "Renewable Resources in Composite Materials", GPEC 2004.
3. Ralston, B., and Osswald, T.A., "Formulation, Processing and Properties of Compression Molded Soy Protein Based Plastics: A Review", GPEC 2005.
4. Brown, M., "Meeting Sustainability Goals and Environmental Mandates Using Thermoformed Packaging", GPEC 2005.
5. Narayan, R., "Rational and Design for Biodegradable Plastics", GPEC 2002.
6. Mungara, P., et al., "Soy Protein-Based Bio-degradable Plastics", GPEC 2002.



(A) 75 mm round with H:D of 0.44



(B) 75 mm round with H:D 0.60



(C) 100 mm round with H:D of 0.44

Figure 1. Critical dimensions (mm) of the three cup mold geometries

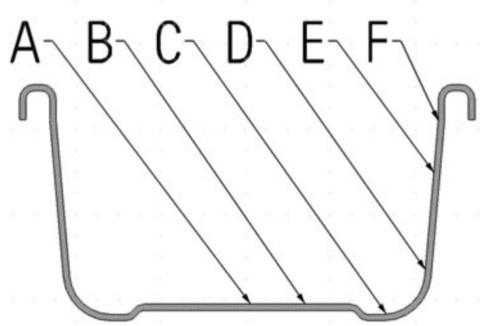


Figure 2. Schematic of wall thickness measurement locations.

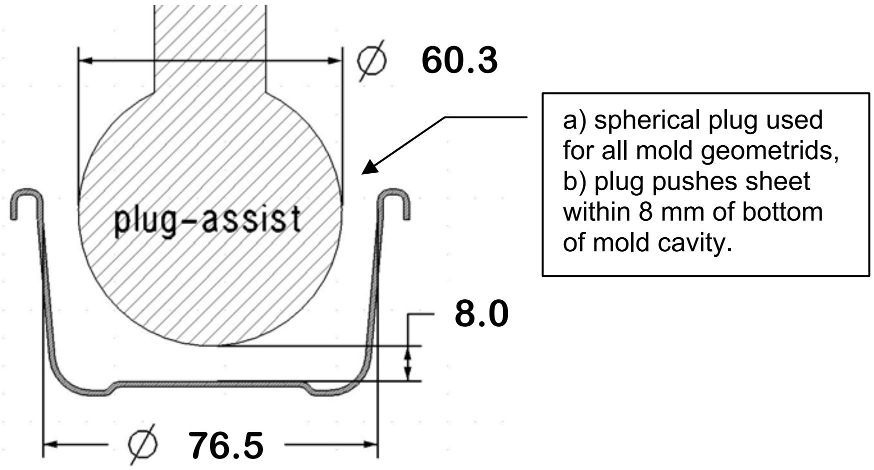


Figure 3. Schematic of plug-assist geometry (dimensions in mm)

		Measurement Location					
# Samples	Trial ID	A	B	C	D	E	F
4	PP(.44,PA)	**69**	**63**	**49**	**35**	**53**	**70**
3	PP(.44,va)	**44**	**39**	**23**	**27**	**48**	**62**
4	PP(.60,PA)	**57**	**56**	**31**	**34**	**41**	**68**
3	PP(.60,va)	**20**	**16**	**9**	**26**	**49**	**75**
5	PP(100,PA)	**70**	**64**	**40**	**32**	**45**	**66**
4	PP(100,va)	**40**	**36**	**23**	**30**	**51**	**68**
4	PVC(.44,PA)	**54**	**50**	**29**	**31**	**47**	**59**
3	PVC(.44,va)	**53**	**45**	**29**	**40**	**54**	**57**
4	PVC(.60,PA)	**51**	**51**	**31**	**30**	**26**	**65**
3	PVC(.60,va)	**27**	**25**	**14**	**35**	**49**	**67**
4	PVC(100,PA)	**57**	**46**	**32**	**22**	**43**	**60**
4	PVC(100,va)	**38**	**31**	**20**	**24**	**44**	**60**
4	SPI(.44,PA,H)	**54**	**48**	**31**	**35**	**58**	**75**
5	SPI(.44,va,H)	**48**	**38**	**25**	**36**	**57**	**80**
3	SPI(.44,va,H)	**39**	**37**	**25**	**32**	**56**	**81**
3	SPI(.44,va,H)	**55**	**45**	**27**	**37**	**53**	**76**
5	SPI(.44,va,L)	**41**	**39**	**27**	**34**	**62**	**80**
4	SPI(.60,PA,H)	**38**	**32**	**20**	**28**	**48**	**75**
4	SPI(.60,va,H)	**26**	**23**	**15**	**19**	**46**	**83**
3	SPI(.60,va,H)	**30**	**27**	**17**	**23**	**48**	**70**
2	SPI(.60,va,L)	**23**	**23**	**15**	**28**	**55**	**84**
5	SPI(100,PA,H)	**34**	**33**	**25**	**33**	**59**	**87**
5	SPI(100,PA,L)	**39**	**35**	**27**	**41**	**60**	**80**
5	SPI(100,va,H)	**37**	**33**	**27**	**27**	**54**	**83**
4	SPI(100,va,L)	**37**	**32**	**24**	**30**	**52**	**74**

Figure 4. Table of forming trials and normalize thickness distribution data.

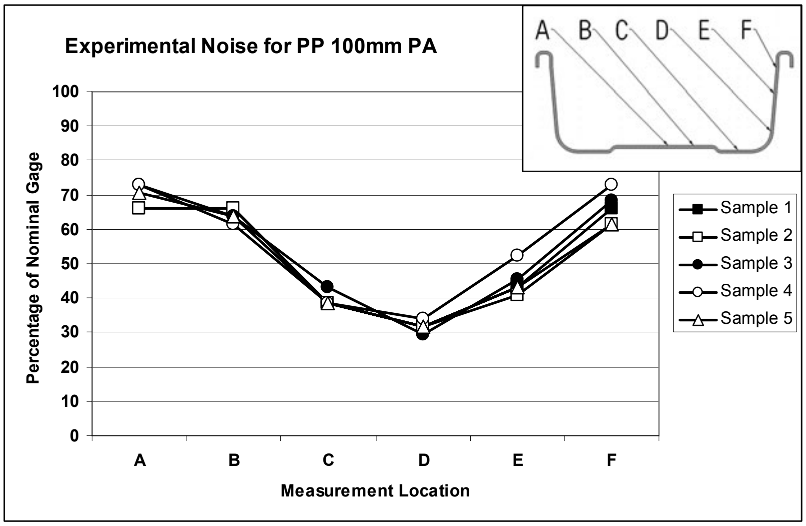


Figure 5. Measurement results for five samples of same trial set point

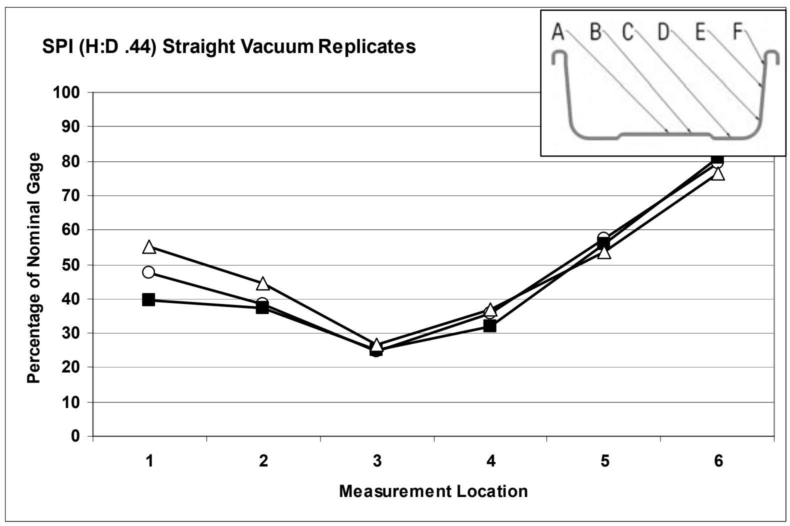


Figure 6. Measurement results for replicated trial set points using SPI resin

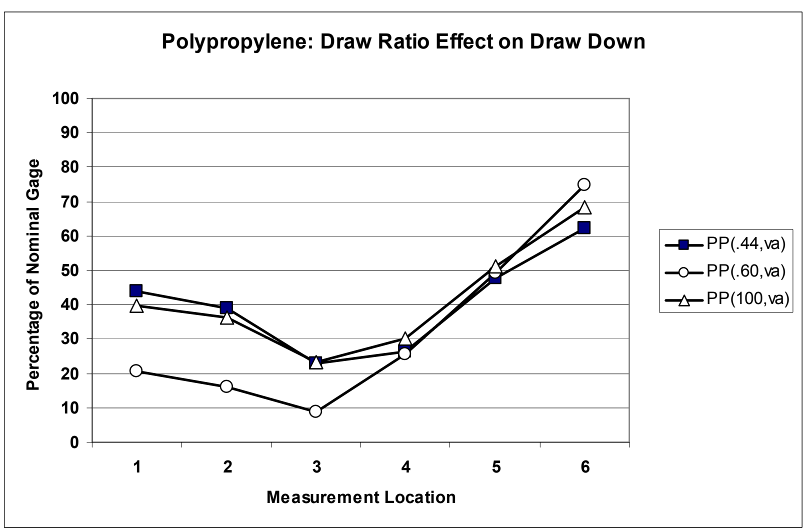


Figure 7. Measurement results for replicated trial set points using SPI resin

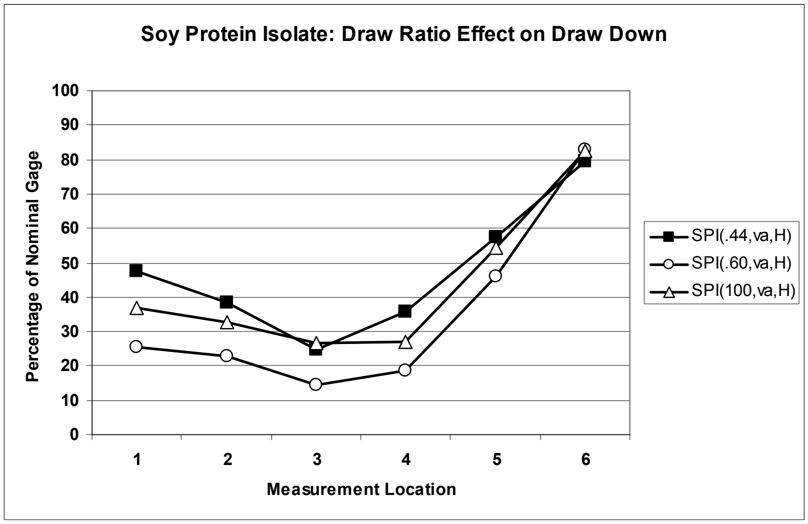


Figure 8. Measurement results for replicated trial set points using SPI resin

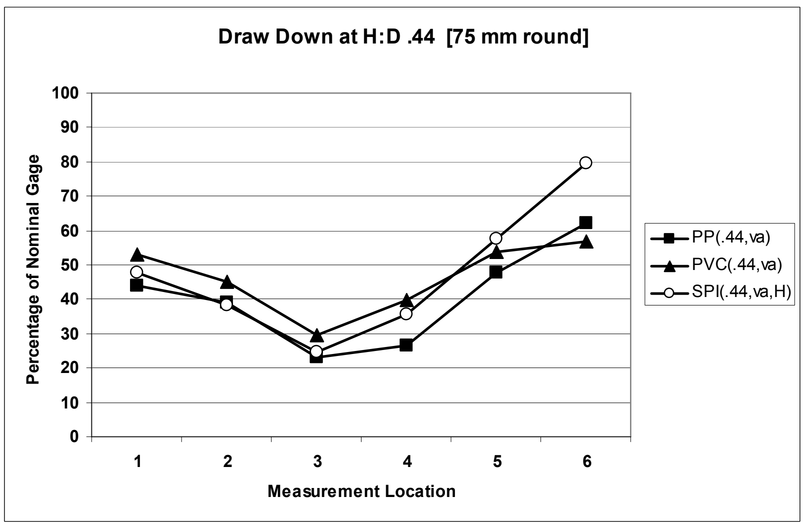


Figure 9. Measurement results for replicated trial set points using SPI resin

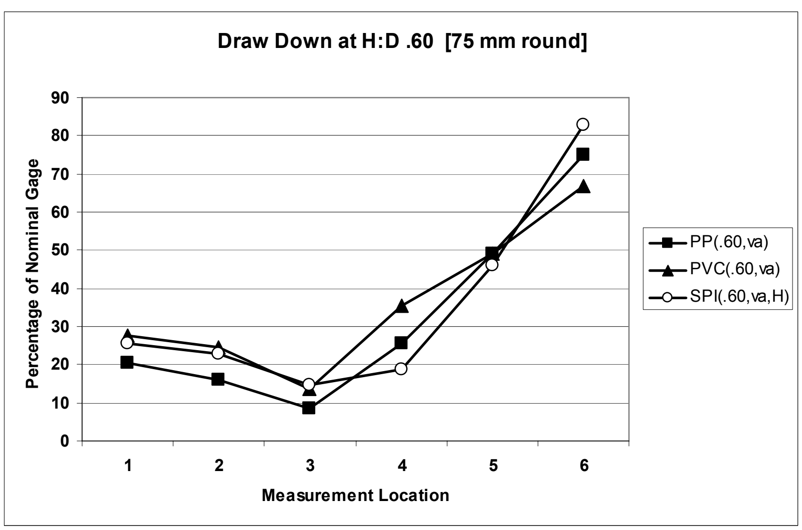


Figure 10. Measurement results for replicated trial set points using SPI resin

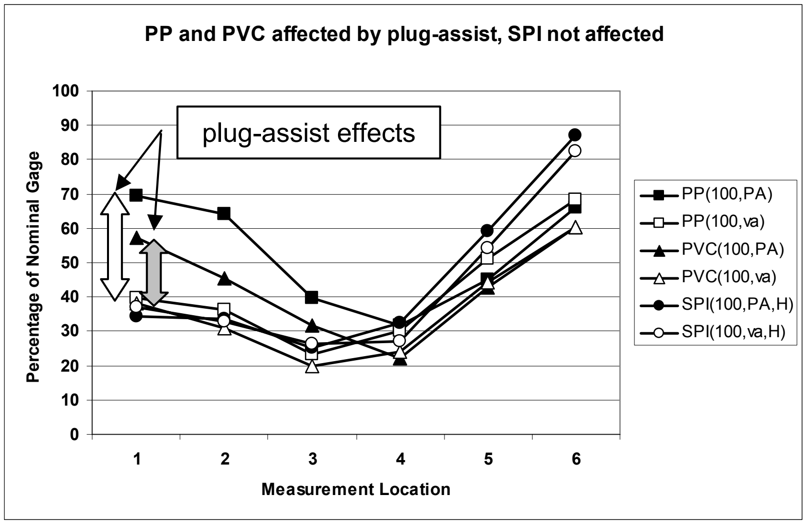


Figure 11. Plug-assist affects thermoplastics thickness distribution, but not SPI

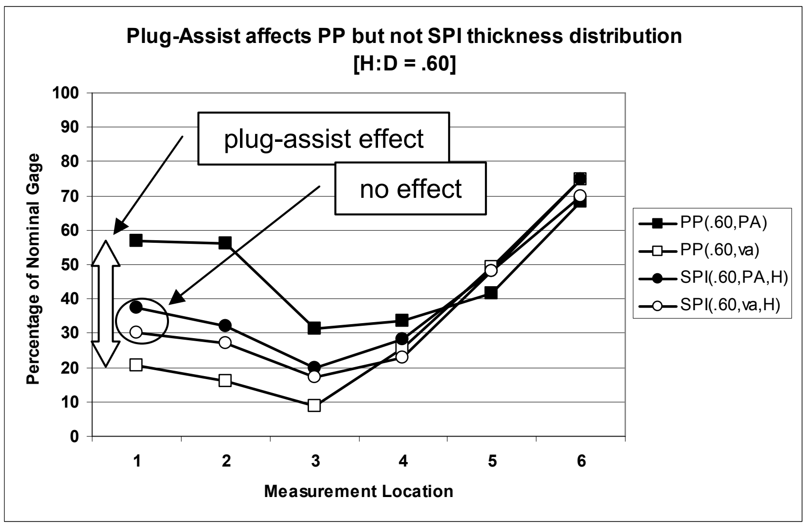


Figure 12. Confirmation of plug-assist at higher draw ratio

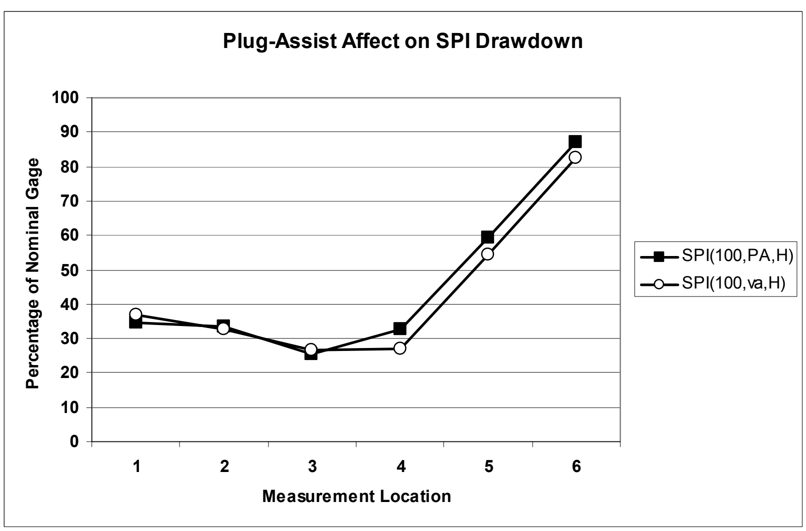


Figure 13. Plug-assist has no effect on wall thickness distribution for SPI

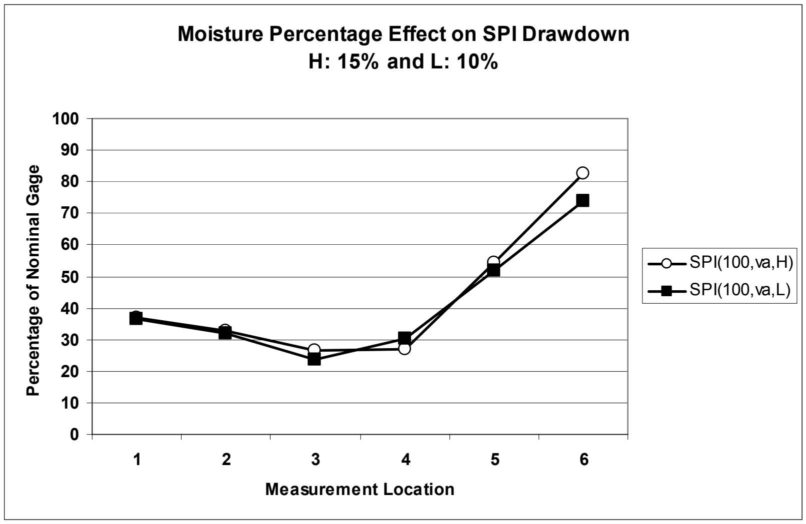


Figure 14. Change in moisture content has no effect on thickness distribution

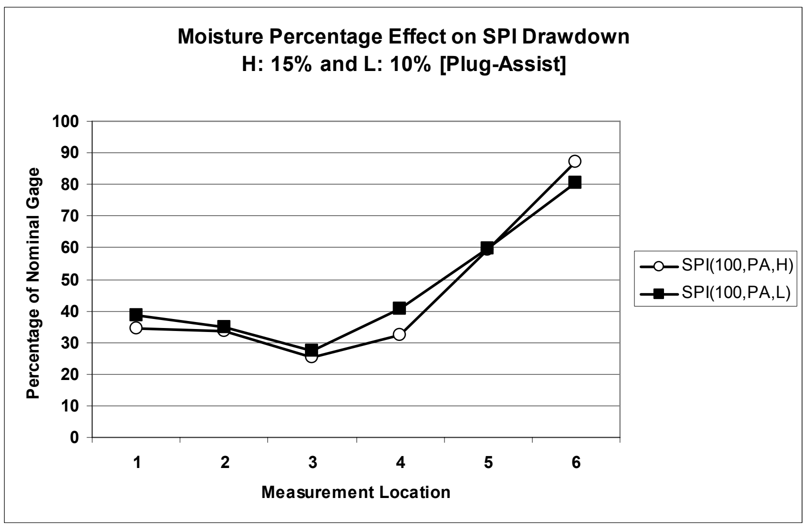


Figure 15. Moisture change from 15 to 10% has no effect on wall thickness