NEW PRODUCT DEVELOPMENT: CONCEPT TO REALITY

Luke Adams, Brady Dore, and Sarah Ross, University of Massachusetts Lowell

Prepared under advisement of Dr. Anne Soucy, University of Massachusetts Lowell, and the Society of Plastics Engineering Blow Molding Division Board of Directors

Abstract

This capstone project identified critical properties, a preferred blow molding process, and an appropriate high-density polyethylene (HDPE) material for rigid bottle packaging of a nutritional dry powder. A process with optimized parameters was established, and bottles were validated according to standard industry quality testing for the application. The costs of all necessary components to bring the product to the market were accounted for, with consideration for producing the bottle at a competitive price point. Upscaling of the process was considered, and the commercialization of the product was presented to blow molding industry professionals.

Introduction

The purpose of this project was to determine the best practices to bring a commercially blow molded product to the market at a competitive price point. The product was designed to hold a nutritional dry powder and has a wide mouth opening for ease of scooping. The bottle needed to protect the powder's integrity which means that the resin of choice needed to have good barrier properties against moisture and gases to prevent degradation of the product. The bottle also needed to be safe for food contact. To ensure that the bottle was safe for food contact, a material that is FDA-approved needed to be selected to ensure that the bottle does not contaminate the product with any harmful chemicals which could lead to negative health effects. The bottle also needs to preserve sensory qualities of the product. This means the material needed to have low organoleptic properties, meaning a low effect on the senses such as taste, smell and sight of the product. The bottle should not affect these properties as it could be detrimental to the product quality. To ensure that the bottle is competitive in industry, the bottle needed to be low cost while achieving the goals presented above.

There were two processes considered for producing a wide-mouth bottle, continuous extrusion blow molding and intermittent extrusion blow molding. Continuous extrusion blow molding is better for large volume production of simple parts because of the high production speeds the machine can attain. Consequently, continuous blow molding is generally cheaper. The continuous blow molding machine at the University of Massachusetts Lowell also has a parson programming feature which allows for the adjustment of wall thicknesses when applicable. Intermittent blow molding is better for complex and small parts. It produces less waste than the continuous blow molding process and is well-suited for parts with non-uniform wall thickness. It was decided that the continuous extrusion blow molding process is better for this bottle because the bottle has a simple design that can be optimized with the parison programming feature. For this project, a continuous extrusion blow molding machine was used.

Materials

To determine an appropriate resin, polyethylene homopolymer and copolymer were initially compared. Homopolymers were found to provide higher crystallinity and rigidity due to greater chain regularity and packing, while sustaining good impact resistance. These types are also generally lower in cost, which was one of the objectives, and present better post-consumer recyclability. On the other hand, polyethylene copolymers have a higher impact resistance and lower modulus from the chain flexibility imparted by the comonomer. These also present better environmental stress cracking resistance and have a wider processing range than homopolymers.

The material selection was narrowed down to two specific grades of FDA-approved Shell Polymers HDPE. Each has a fractional melt index which is required for extrusion blow molding.

The homopolymer HDPE, Shell 63B072, and the copolymer HDPE, Shell 46B035A, were considered for the bottle. The homopolymer has low organoleptic properties when compared to the copolymer. This is because the copolymer is an ethylene hexene copolymer, and there is the potential for residual trapped hexene monomer in the material after polymerization. These low molecular weight olefins and oligomers can cause odors which may affect the integrity of the powder in the bottle. The homopolymer also provides an acceptable toughness and rigidity balance which is needed for the application. The copolymer has an additional antistatic additive which would be beneficial for product appearance. However, because low organoleptic properties and cost are paramount, it was determined that the Shell 63B072 homopolymer would be more suitable for this application. Shell Polymers provided a gaylord of 100% virgin material as well as a gaylord with 40% regrind material incorporated. This allowed for evaluation of processing and property differences between the virgin and regrind materials, and was considered in accounting for the cost savings that industrial regrind can present.

Experimental

A Rocheleau CS-1 continuous extrusion blow molding machine with a 50 mm (2 in) extruder unit and a throughput of 55 kg (120 lbs) per hour HDPE was used to mold the bottles. The first bottles were molded with straight profiles, where the parison programmer was set to a constant die opening, with both the virgin and regrind materials. The screw speed was adjusted to maintain an approximately constant linear velocity out of the die, such that the parisons were all about the same length.

Table 1. Straight Profiles

Die Opening (%)	Screw Speed Setpoint
35	35
50	36
65	37

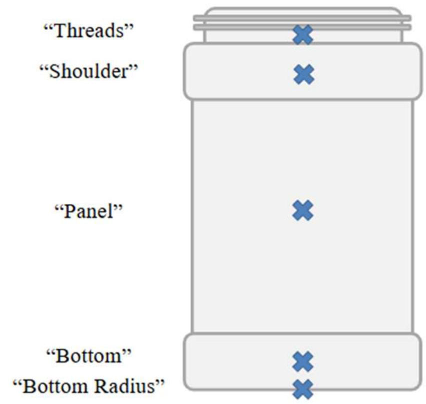
The straight profile groups were named according to the die opening percentage and the material type, 'V' for virgin or 'R' for regrind. For example, group 50R corresponds to the regrind bottles produced with a constant 50% die opening. The parameters used for molding the straight profiles are shown below.

Table 2. Processing Parameters

Parameter	Setpoint
Rear Zone Temp (°F)	360
Center Zone Temp (°F)	365
Front Zone Temp (°F)	370
Head Temp (°F)	375
Nozzle Heat	Off
Mold Temperature (°F)	70
Blow Time (s)	17.0
Blow Pressure (psi)	65
Pre-Blow Pressure (psi)	30
Exhaust Time (s)	2.0
Cycle Time (s)	25.25

The temperatures and exhaust time were held constant throughout all molding trials. When changing between the virgin and regrind materials, the vacuum feed system was turned off and the machine ran until the hopper was mostly empty. Then, the machine was stopped, and the hopper was opened and vacuumed to remove leftover material and dust. Before closing the hopper, a small amount of the new material along with a colorant pellet was added. The machine was run until the color no longer appeared in the bottles, indicating a complete material changeover.

Using a Magna-Mike thickness gauge and a Mettler Toledo balance, the wall thickness and weights were measured for all bottles. The thickness measurements were taken at five locations on one side of the bottle as marked below: the threads, the shoulder, the panel, the bottom rim, and the bottom radius.



The weights of the bottle, the top scrap and the bottom scrap were recorded. The bottles were then subjected to drop impact testing based on ASTM D2463. It was decided to test a sample size of 20 bottles filled with powder and 20 bottles filled with water, since powder is more representative of the application and water was specified in the ASTM procedure. Taking protein powder as the reference nutritional dry powder, the bulk properties were compared to polypropylene powder, corn starch and flour. Bulk density, tapped density, recompressibility, angle of repose, and flowability were assessed based on ASTM D1895 and ASTM D6393, and the polypropylene powder was chosen as a suitable representative powder for use in drop testing. This test was performed using the Bruceton staircase method, where the bottles were dropped initially at 6 feet and if a bottle passed, the drop height was increased by half foot up to a maximum of 8 feet, and if a bottle failed, the drop height was decreased by half foot to a minimum of 5 feet. The bottles were filled with 300 grams of powder or 650 grams of tap water at 59°F and dropped into an enclosure to contain any spillage in the case of a failed test. Any significant deformations and failures were recorded. While performing the water filled drop test, the volumes of the bottles were also measured. This was done by taring a scale with an empty bottle, filling that bottle to the brim with water and weighing it again. The water weight was then converted to volume.

Top load compression testing was performed following the standard ASTM D2659 at a rate of 1 in/min to a deflection of 1 in, using an Instron Universal Testing Machine and a sample size of 10 bottles. A vent was machined into an annular aluminum plate and placed between the bottom of the bottle and the bottom compression plate to allow air to escape from the system during testing. Furthermore, to aid in this, a 3/8" hole was drilled into the bottom of each bottle to allow the air to escape so it did not alter the results of the test. The bottles were tested empty with a cap on, and it was decided to report force vs. displacement instead of stress vs. strain because the bottles did not all yield in the same location, meaning the cross-sectional area was not consistent. The provided technical drawing specified the bottles needed to withstand greater than 70 lbf at a quarter inch displacement, so from 90 to 100 lbf was taken as a goal to include a reasonable safety factor.

After the testing of the straight profile bottles, the optimization trials could begin. However before that, the 25 points on the parison programmer needed to be correlated to locations on the bottle. To do this, the first row (setpoints 1-5) of the uniform program of 50% was raised to 65%, 5 samples were taken, and thickness measurements were recorded. Then, one at a time, each row of the program was raised to 65%, and the thickness measurements were compared to determine where each row affects the bottle. Based on the test results, the first optimization involved removing material from the panel and bottom scrap and adding material to the threads and bottom radius. The parison program was adjusted based on the understanding gained from correlating the points to the bottle. Also, the blow time was decreased from 17.0 seconds to 8.5 seconds, and the screw speed was increased from a machine setpoint of 33 to 40. To ensure the machine continued to run smoothly, the blow time and the screw speed were changed incrementally. The blow time was slightly decreased with a slight increase in screw speed, and this was repeated until the desired values were reached. This resulted in a cycle time reduction from 25.25 seconds to 16.5 seconds. Drop impact and top load compression testing were performed again for the first optimization groups, and based on this data, a second optimization was performed. The focus of this attempt was to reduce the thickness of the threads and the panel, solve the rocker bottom problem, and reduce the dead time in the cycle. The thicknesses were adjusted using the parison program, the bowing issue was solved by increasing the blow pressure, and finally the dead time was reduced by changing the cutter delay, the shuttle delay, and the shuttle and clamp speeds. This further reduced the cycle time from 16.5 seconds to 15.7 seconds. The second optimization groups of virgin and regrind bottles were again measured and validated with drop impact and top load compression testing.

Results & Discussion

The wall thickness and weight measurements from the preliminary straight profile molding are shown in Figures 1 and 2 below. The greatest wall thicknesses were observed at the threads and at the panel for all groups, and the wall was measured to be thinnest at the bottom rim and bottom radius, which was expected based on the bottle geometry and pinch off. The greatest overall wall thicknesses for each location were measured in the groups with a 50% die opening. This indicates that although the die opening was wider at 65%, the additional material caused greater sag, resulting in thinner walls than the 50% groups.

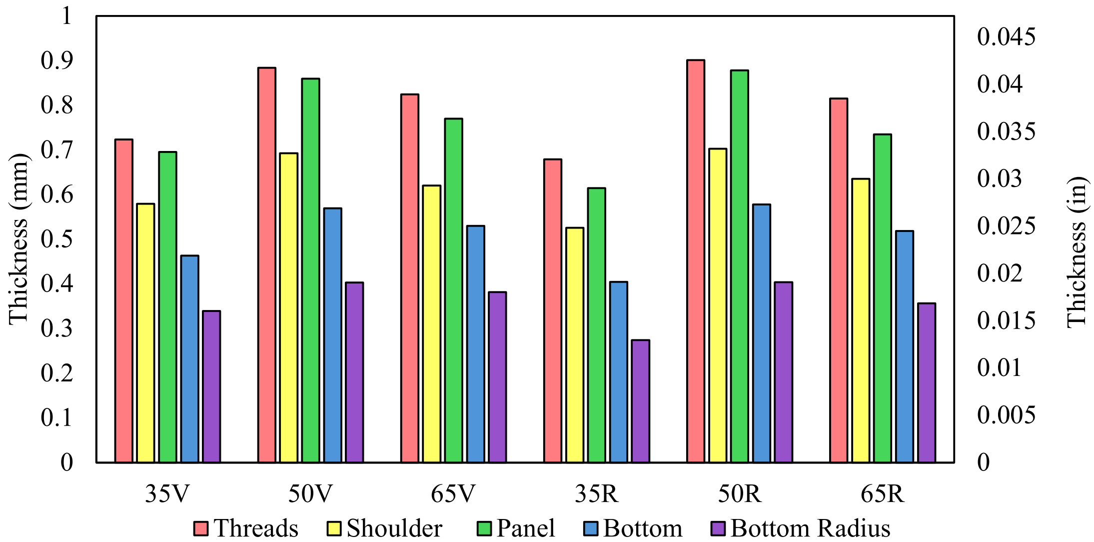


Figure 1. Straight Profiles Wall Thickness

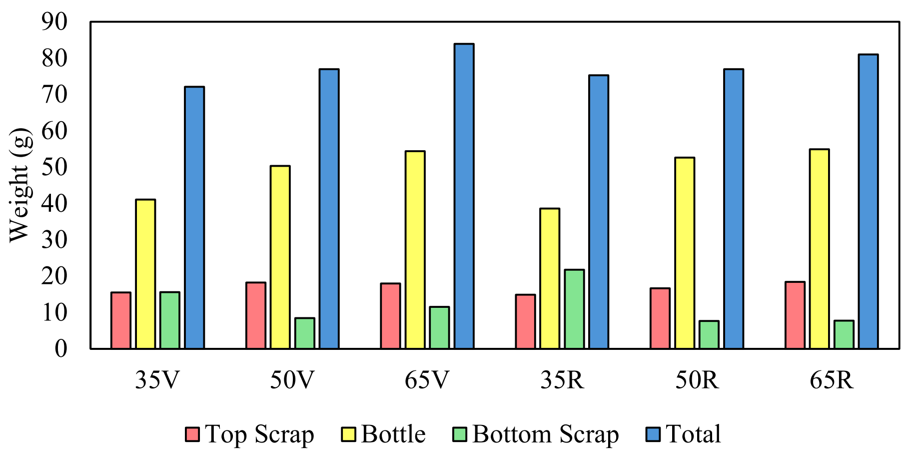


Figure 2. Straight Profiles Weights

The total weight was seen to increase with increasing die opening percentage, which was expected since the parisons were approximately the same length with increasing thickness. Greater bottom scrap was observed for the groups with a die opening of 35%, which was attributed to the parison being slightly longer with this opening. The screw speed setpoint is incremented by 1 unit, and it was adjusted to produce parisons of approximately the same length for each die opening percentage, but this resulted in a slightly longer parison for these groups.

Table 3 shows the results of drop testing the straight profile bottles with powder and water, as well as their volumetric measurements.

Table 3. Straight Profiles Drop Impact

Group	Bottom Radius (mm)	Bottom Radius (in)	%Pass, Powder	%Deformed, Powder	%Pass, Water	%Deformed, Water	Avg. Volume (mL)
35V	0.339	0.0133	100	85.0	100	90.0	858.3
50V	0.403	0.0159	100	55.0	100	45.0	849.6
65V	0.381	0.0150	100	40.0	100	95.0	844.0
35R	0.273	0.0108	100	90.0	90	80.0	858.5
50R	0.404	0.0159	100	60.0	100	85.0	847.7
65R	0.356	0.0140	100	70.0	95	75.0	843.3

No failures were observed when dropping the bottles filled with powder, but the greatest deformation was observed with the 35R and 35V groups. Failures were noted for the bottles filled with water from groups 35R and 65R. It was observed that deformation or failure occurred at the bottom radius of the bottle, and greater wall thicknesses at the bottom radius were seen to correlate with superior impact performance. Additionally, bottle volume was seen to increase with decreased wall thickness, which suggests that the thinner walls achieved superior cooling so these bottles underwent less shrinkage.

When subjected to top load compression, the straight profile bottles were observed to yield first at the threads/shoulder interface and then transfer the load to the panel, where a second yield was noted. This is shown by two yield peaks on the representative top load compression curves in Figure 3 below.

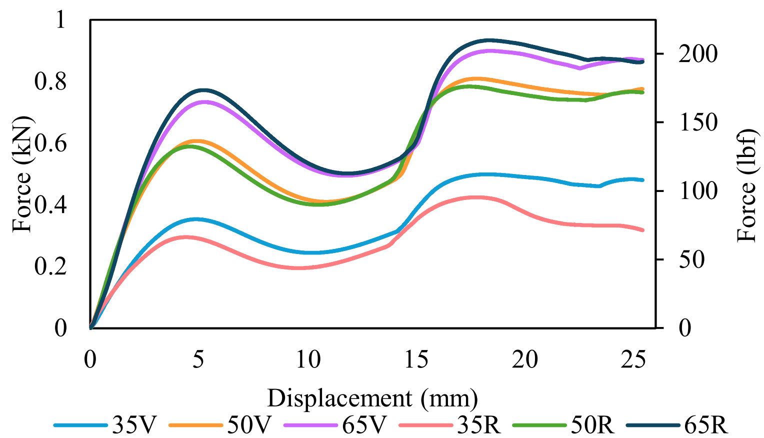


Figure 3. Straight Profiles Compressive Force v. Displacement

Yield force was seen to increase with increasing die opening percentage, and little variation was seen between the virgin and regrind groups with the same die opening. The force at yield and the force at a quarter inch displacement are tabulated in Table 4, and the force was seen to correlate with the thickness at the bottle threads.

Table 4. Straight Profiles Top Load Compression

Group	Threads (mm)	Threads (in)	Force @ 0.25" Disp. (kN)	Force @ 0.25" Disp. (lbf)	Force @ Yield (kN)	Force @ Yield (lbf)
35V	0.723	0.0285	0.321	72.3	0.343	77.1
50V	0.883	0.0348	0.576	129.4	0.616	138.5
65V	0.824	0.0324	0.722	162.2	0.745	167.5
35R	0.679	0.0267	0.257	57.9	0.299	67.2
50R	0.900	0.0355	0.563	126.6	0.608	136.7
65R	0.815	0.0321	0.651	146.4	0.698	156.9

Many of the groups achieved a force at a quarter inch displacement much greater than the minimum 70 lbf, but the 35R group did not, and some of the 35V did not. Based on the impact and compression results, it was determined that the non-critical locations, like the panel, should match the 35% die opening, but the property-determining shoulder and bottom radius should match the 50% die opening groups. Consequently, in the first optimization of the virgin material, the parison programmer was used with the goal of adding material to the threads and bottom radius while lightweighting the panel and reducing the scrap weight, producing group V-1. For group V-2, the wall thicknesses were maintained and the blow time was reduced from 17 seconds to 8.5 seconds, increasing the screw speed setpoint from 33 to 40, accordingly. This resulted in a decrease in cycle time from 25.25 seconds to 16.5 seconds. The resulting dimensions and weights are shown below in Figures 4 and 5.

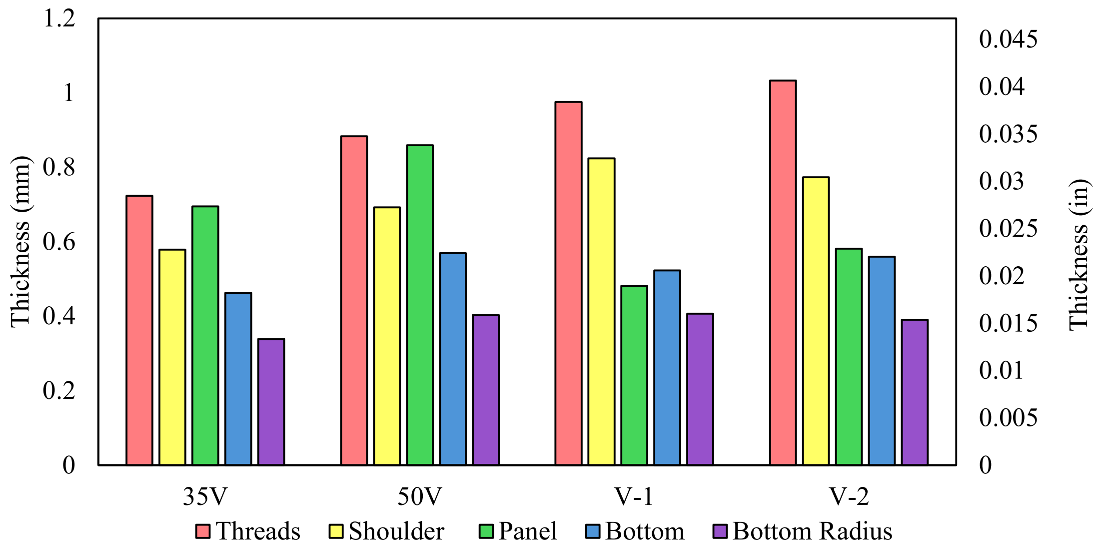


Figure 4. Optimization #1 Virgin Wall Thickness

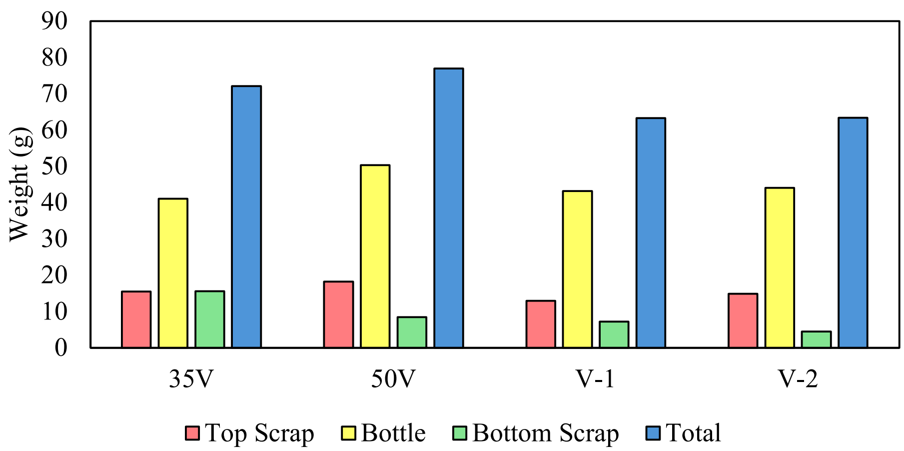


Figure 5. Optimization #1 Virgin Weights

Figure 4 shows that the thickness at the threads and bottom radius were successfully increased in V-1 compared to 35-V, and that the panel thickness was reduced. The approximate dimensions were successfully maintained with the blow time reduction in V-2. It was observed that these changes were effective in also reducing the weight of the bottle and the scrap compared to 50V, and the blow time reduction in V-2 aided in reducing the bottom scrap since there was less time for the parison to sag. The same effects were achieved with the regrind material, as shown in Figures 6 and 7.

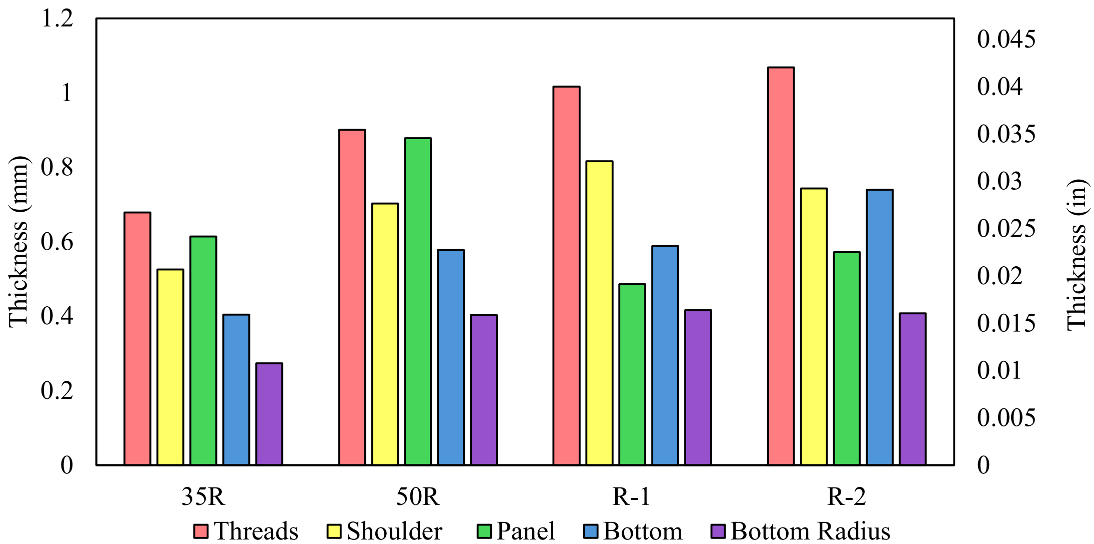


Figure 6. Optimization #1 Regrind Wall Thickness

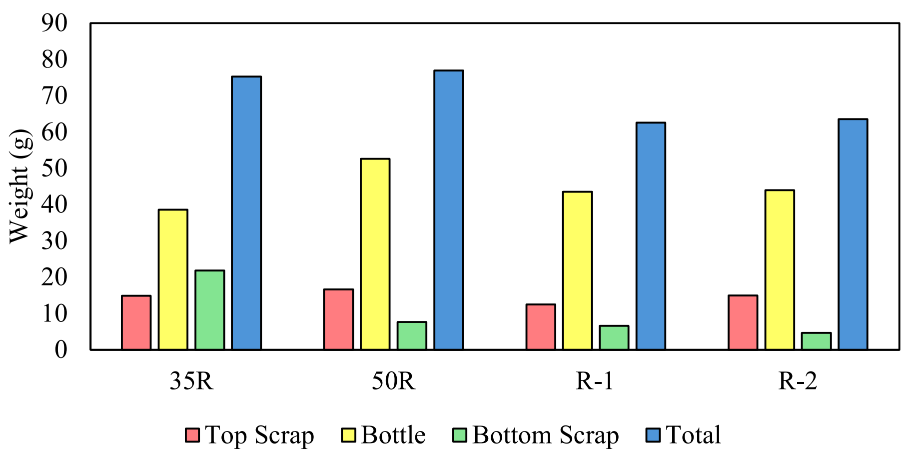


Figure 7. Optimization #1 Regrind Weights

With parison programming, a similar increase in the thickness of the threads and bottom radius was achieved in R-1, and the panel thickness was decreased. Additionally, the blow and pre-blow pressures were reduced from 65 to 50 psi and 30 to 10 psi, respectively. The blow pressure was reduced to reduce process energy consumption, while the pre-blow pressure was reduced to reduce the pre-stretch on the top of the parison. It was determined that this pre-stretch resulted in thinner walls at the bottom rim and bottom radius, so reducing the pre-blow pressure aided in increasing these thicknesses. The reduction in blow time caused inferior contact and cooling of the parison against the mold, resulting in a rocker bottom defect which needed to be addressed in the final optimization. The blow time and consequently cycle time were likewise reduced for group R-2, again showing a reduction in bottom scrap weight. The effect of this first optimization on the drop impact performance is shown in Table 5.

Table 5. Optimization #1 Drop Impact

Group	Bottom Radius (mm)	Bottom Radius (in)	%Pass, Powder	%Deformed, Powder	%Pass, Water	%Deformed, Water	Avg. Volume (mL)
35V	0.339	0.0133	100	85.0	100	90.0	858.3
50V	0.403	0.0159	100	55.0	100	45.0	849.6
V-1	0.407	0.0154	100	35.0	100	75.0	855.1
V-2	0.391	0.0164	100	53.3	100	100.0	844.9
35R	0.273	0.0108	100	90.0	90	80.0	858.5
50R	0.404	0.0159	100	60.0	100	85.0	847.7
R-1	0.416	0.0161	100	20.0	95	70.0	861.1
R-2	0.408	0.0165	100	40.0	95	90.0	845.6

The improvements in bottom radius thickness were found to be effective in reducing the powder deformation rate, but failures were still noted for the regrind groups dropped with water. This indicated that the bottom radii of the regrind groups required additional fortification in the final optimization. Additionally, the blow time reduction was seen to reduce the bottle volume, demonstrating that the walls cooled less with less time against the mold, resulting in more post-mold shrinkage.

The impact of the first optimization on the compression properties is shown in Figure 8 and Table 6 below.

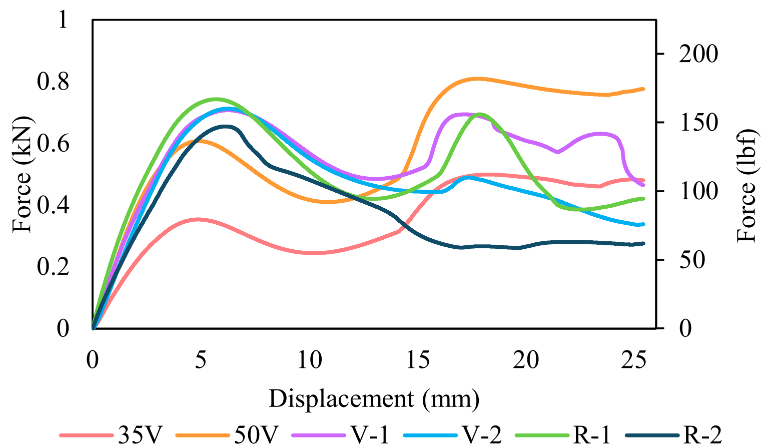


Figure 8. Optimization #1 Compressive Force v. Displacement

With the increased threads thicknesses, the yield location was observed to shift into the panel region and then some groups showed a second yield in the threads. This means that the thicker threads were strong enough to withstand and transfer the initial force.

Table 6. Optimization #1 Top Load Compression

Group	Threads (mm)	Threads (in)	Force @ 0.25" Disp. (kN)	Force @ 0.25" Disp. (lbf)	Force @ Yield (kN)	Force @ Yield (lbf)
35V	0.723	0.0285	0.321	72.3	0.343	77.1
50V	0.883	0.0348	0.576	129.4	0.616	138.5
V-1	0.975	0.0384	0.722	162.4	0.724	162.8
V-2	1.033	0.0407	0.700	157.5	0.701	157.6
R-1	1.016	0.0400	0.683	153.5	0.719	161.6
R-2	1.068	0.0421	0.645	145.0	0.666	149.7

The virgin and regrind groups from optimization #1 achieved both a greater force at a quarter inch displacement and an overall reduction in weight, indicating that the changes were successful in terms of top load compression. However, the force at a quarter inch displacement was greater than double the minimum 70 lbf for all groups, indicating that these groups were overdesigned and that further optimization should find a middle ground with sufficient strength but less material.

For the second optimization, the threads and panel thicknesses were reduced, the cutter delay and shuttle delay times were reduced, and the shuttle and clamp speeds were increased. In reducing these dead times and increasing the speeds, the cycle time was again reduced from 16.5 seconds to 15.7 seconds. Additionally, the blow pressure was increased back to 65 psi from 50 psi, which successfully eliminated the rocker bottom defect. The measurements for the final optimized virgin group, V-3, are found in Figures 9 and 10.

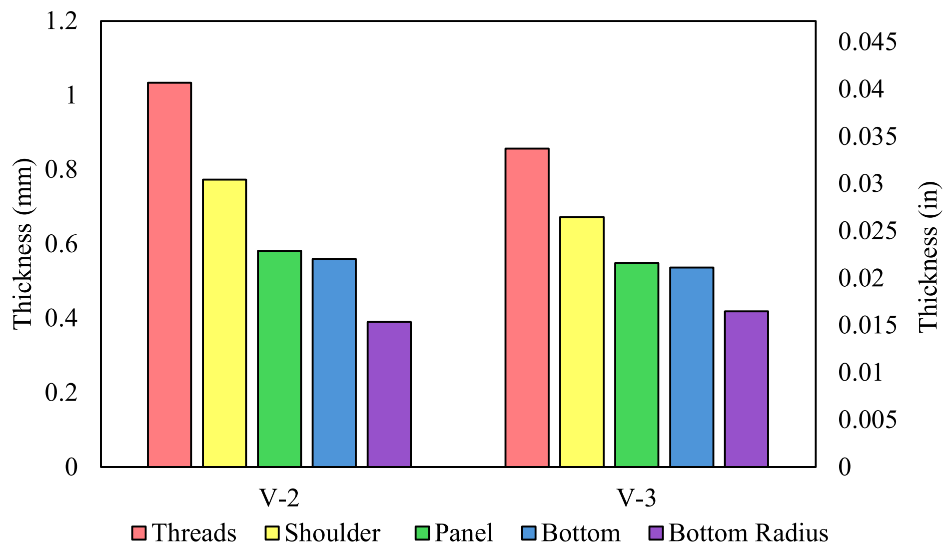


Figure 9. Optimization #2 Virgin Wall Thicknesses

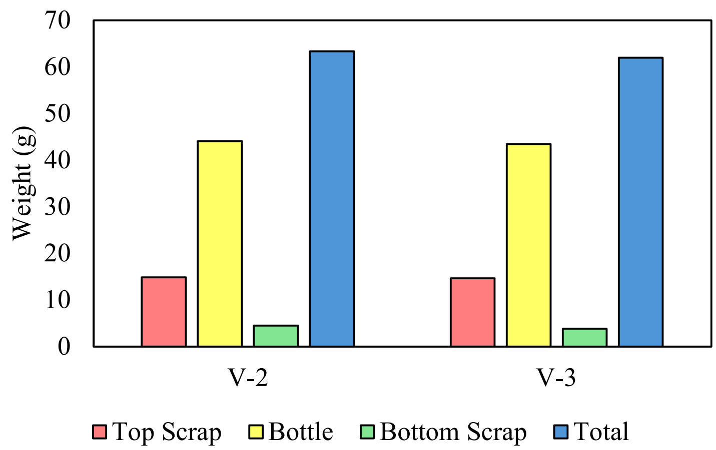


Figure 10. Optimization #2 Virgin Weights

Similarly, the threads and panel were reduced for the regrind group, R-3, and additional reinforcement was added to the bottom radius to improve the water drop performance, as shown in Figure 11. Figure 12 shows that the bottle and scrap weights were also slightly reduced.

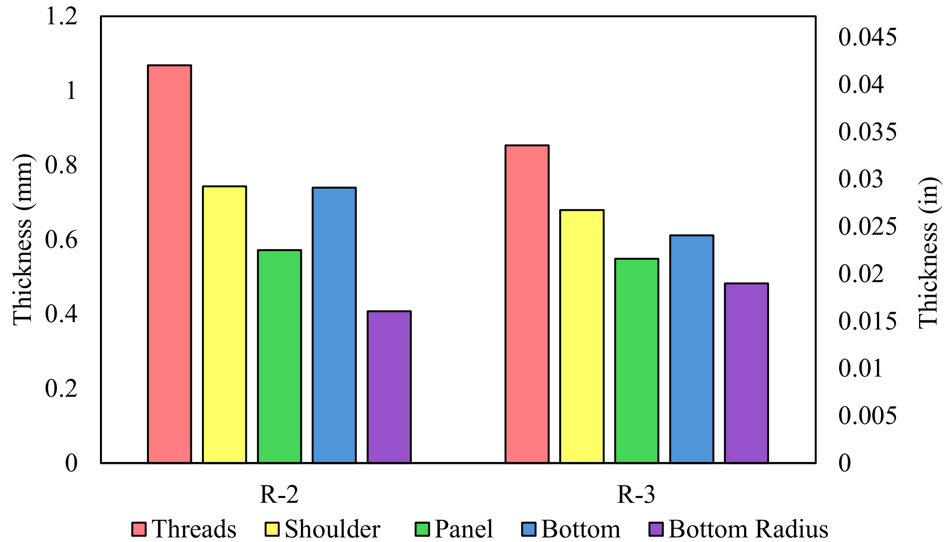


Figure 11. Optimization #2 Regrind Wall Thicknesses

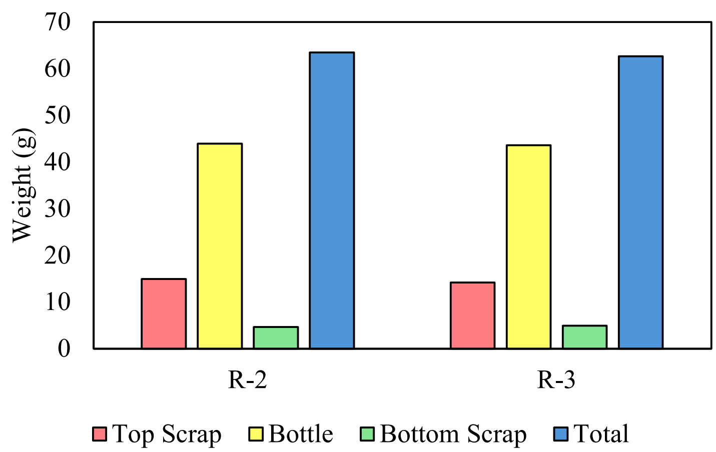


Figure 12. Optimization #2 Regrind Weights

The drop impact performance for the second optimization V-3 and R-3 are shown below.

Table 7. Optimization #2 Drop Impact

Group	Bottom Radius (mm)	Bottom Radius (in)	%Pass, Powder	%Deformed, Powder	%Pass, Water	%Deformed, Water	Avg. Volume (mL)
V-2	0.391	0.0154	100	53.3	100	100	844.9
V-3	0.419	0.0165	100	15.0	100	100	851.2
R-2	0.408	0.0161	100	40.0	95	90	845.6
R-3	0.483	0.0190	100	5.0	100	100	854.4

The reinforcement of the bottom radius of R-3 was successful in reducing the powder deformation and passing the water drop test. Although high deformation rates remain with the water drop, the impact properties of V-3 and R-3 are considered sufficient since water is much heavier that the nutritional dry powder product the bottles would actually hold. Also, the customer expects that it they drop their bottle, it will not fracture. With the increase in blow pressure, the volume was seen to increase, which was attributed to better contact with the mold improving heat transfer so that the walls cooled more in the mold and experienced less shrinkage out of the mold.

In reducing the threads thickness to a moderate value, a yield at the threads followed by a yield at the panel was again observed, as shown by the two local maxima in Figure 13.

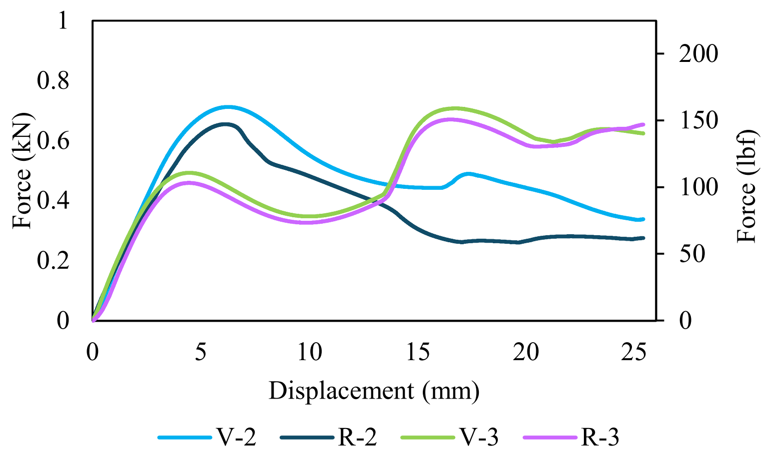


Figure 13. Optimization #2 Compressive Force v. Displacement

Table 8. Optimization #2 Top Load Compression

Group	Threads (mm)	Threads (in)	Force @ 0.25" Disp. (kN)	Force @ 0.25" Disp. (lbf)	Force @ Yield (kN)	Force @ Yield (lbf)
V-2	1.033	0.0407	0.700	157.5	0.701	157.6
V-3	0.856	0.0337	0.440	99.0	0.490	110.2
R-2	1.0682	0.0421	0.645	145.0	0.666	149.7
R-3	0.853	0.0336	0.412	92.6	0.471	105.9

The second optimization resulted in sufficient force at a quarter inch displacement while avoiding excess material use, as shown in Table 8. In achieving forces of 99.0 lbf and 92.6 lbf at a quarter inch displacement, respectively, both the virgin and regrind optimized groups achieved the desired top load compression properties. It was concluded that groups V-3 and R-3 are acceptable according to drop impact and top load compression standards.

The differences in processing and properties between the virgin and regrind materials were observed throughout the project. The regrind material has gone through additional thermal processing and therefore greater thermo-oxidation, which results in chain scission and can change chemical moieties. Because of this, regrind resin often has an increase in melt flow rate and molecular weight distribution. The regrind material showed greater variation in the bottom scrap weight due to reduced and variable melt strength. While processing the regrind material, the mix of pellets and flakes fed more easily compared to the virgin pellets through the vacuum feed system since the irregular shapes resulted in more air between the pieces. While compression testing the bottles, little difference between the results of regrind and virgin groups was observed, rather the compression properties were dictated by the threads thickness. With the regrind groups, a greater propensity to deform during drop testing was noted possibly due to the effective reduction in molecular weight which increased molecular mobility. Project time limitations did not allow for characterization of the differences between the two HDPE resins with mechanical and rheological testing.

To account for the costs associated with bringing the bottle to the market, a provided Radius Packaging cost estimation Excel sheet was utilized. Variables regarding capital machinery, production capabilities, labor, material, and electrical operation were adjusted. Quotes were requested for an extrusion shuttle blow molding machine that can provide between 100 and 120 kg/hr throughput of HDPE with a six-cavity mold, spin dome trimmer, and a tail puller, as well as a spare mold, screw, heater bands, and thermocouples to minimize maintenance down time. The Bekum H-155 and Magic ME-T18-800S systems were identified as suitable for the expected production. The Bekum H-155 provides 106 kg/hr output with three parisons and twin mold stations, allowing for a faster cycle since one mold can capture the parisons while the parisons in the other mold are being blown. The Magic ME-T18-800S is a fully electric machine that provides 140 kg/hr output with a six-parison manifold and one mold. Based on the plan to produce only one type of product, it was decided that only one machine type would be chosen and therefore only one type of spare parts would have to be inventoried and training would be simplified. In the event of future expansion, having two different types of machines would provide the advantage of minimizing potential supply chain challenges that could come with a single machine source. Downstream equipment such as an ALPS Inspection Quick Check Single-Station Indexing Conveyor Leak Tester, resin handling system, grinder and blender for regrind incorporation, bottle conveying system, palletizer, strapper, stretch wrapper, and testing equipment was accounted for, as well. The cost of a forklift was included, and it was assumed that machining needs would be outsourced. Production calculations were made assuming a 24-hour, 5-day schedule with 80% overall efficiency. This provides the option to run on weekends with overtime pay if needed to catch up on production targets based on demand and contracts. The plant location was based on the location of the nutritional dry product producer to minimize transportation costs, and was assumed to be in New England for labor and electricity rates. Given a monolayer HDPE bottle and annual production capabilities requiring 500,000 to 1,000,000 pounds of resin per year, a cost of $0.75/lb was considered for virgin material. Scrap material cost is accounted for in the virgin bottle, so reusing that scrap as regrind is estimated to reduce the average resin cost to $0.6375/lb at the 40% regrind loading level. For this annual volume, resin delivery by bulk truck every 3-4 weeks is anticipated.

Optimizations which resulted in bottle weight, scrap weight, and cycle time reductions were seen to reduce the estimated bottle cost, as shown in Table 9. The ratio of the total material weight to the bottle weight is considered as the "flash factor", so a decreasing flash factor indicated a scrap reduction relative to the bottle weight. The costs of the most optimized parameter groups from each round of molding are compared below.

Table 9. Bottle Cost by Group

Group	50V	50R	V-2	R-2	V-3	R-3
Bottle Weight (g)	50.32	52.61	44.04	43.91	43.47	43.58
Flash Factor	1.528	1.462	1.439	1.446	1.424	1.438
Cycle Time (s)	25.25	25.25	16.50	16.50	15.70	15.70
Cost/Bottle ($)	0.2587	0.2480	0.1927	0.1798	0.1866	0.1744

Although bottle and scrap weight reductions were effective, cycle time was observed to be the dominant cost factor. Thus, the greatest cost reduction was observed in going from 50V and 50R to V-2 and R-2, which correlated to a 8.75 second cycle time reduction. Across all the molding trials, using the 40% regrind material produced a cheaper bottle due to the effective reduction in resin cost with scrap incorporation.

Conclusions

For food-grade HDPE packaging of a nutritional dry powder, critical properties, a suitable material, and a preferred processing method were identified. A continuous extrusion blow molding process was established for a wide mouth 28.6 FL OZ bottle mold, and optimization trials were performed. Standard industry testing methods were used to validate the molded bottles, and it was concluded that an acceptable product was successfully molded, and the optimizations significantly improved the characteristics of the bottle and the cycle time of the process. Further optimization could have been accomplished by fine tuning the wall thicknesses to reduce overdesign, removing more weight from the bottle and scrap, and continuing to minimize cycle time. With additional project time, the comparison of the virgin and regrind materials could be improved with rheological characterization, tensile testing, and statistical analysis to identify any significant differences. From the cost accounting estimations, it was shown that this bottle could be brought to the market at a reasonable price point and would satisfy customer expectations.

References

Bart, J. C. J. (2006). Organoleptic Product Quality. In Polymer Additive Analytics: Industrial Practice and Case Studies (pp. 219–248). Firenze University Press. https://media.fupress.com/files/pdf/16/740/2412

Dry Powder Packaging: The Complete FAQ Guide In 2024 – AIPAK. (n.d.). Retrieved December 14, 2024, from https://www.icapsulepack.com/important-knowledge-about-dry-powder-packaging/

Extrusion Blow Molding (EBM) – Definition, Process, Types, Machines, Advantages and Disadvantages - Topgrid. (n.d.). Retrieved December 14, 2024, from https://www.topgrid.co/extrusion-blow-molding-ebm-definition-process-types-machines-advantages-and-disadvantages/

Laboratory Manual for PLAS.3160: Plastics Process Laboratory IV. (2025)