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Design Optimization Of Disposable Coffee Cups

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Abstract

In 2014, Starbucks made a change in the lids used for their disposable hot coffee cups. Since this change, customers have noticed an excessive amount of drip originating from the interface of the coffee cup lid and the paper cup rim. The flaw occurs when the Starbucks disposable hot coffee cup is filled with coffee, and the cup is tilted to drink. Due to the seam created during the paper cup manufacturing process, the hot beverage saturates the seam of the paper cup and travels up to the rim of the cup where residual amounts of coffee collect. Upon meeting the lid, the coffee then drips down the side of the cup and on to the consumer. This research aims to provide a solution to the described design flaw in the lid-rim interface of the Starbucks coffee cup. To further analyze this problem, the coffee drip was replicated in a series of experiments using cups from various manufacturers to determine the cup-lid combinations that minimized the issue. Using this design information, optimal coffee cup designs were modeled with computer-aided-design (CAD) software. Physical three-dimensional (3D) prototypes of the new coffee cup designs were printed using additive manufacturing (AM) to test the effectiveness of the designs.

Keywords: additive manufacturing, Starbucks, coffee cup

1. Introduction

1.1 Leakage In Disposable Hot Beverage Cups

The Starbucks Coffee Company was previously known to use the Solo® Traveler beverage lid, shown in Figure 1, for their disposable hot coffee cups. Around 2014, the company made a change from the Solo lids to a new, unmarked coffee cup lid, shown in Figure 2.

Figure 1. Solo® traveler dome hot cup lid, 2010[1]

Figure 2. New unmarked Starbucks lid, 2016

This change in disposable hot cup packaging was simple, and the exact reason behind it is unknown. It is possible that cost, contract negotiations, or environmental concerns were motivators for this change. Regardless, after the switch, Starbucks customers started noticing a difference in their disposable cup drinking experience. Since 2014**,** there have been loosely documented personal accounts of leakage from the rim of the Starbucks' hot beverage cup on blogs and social media. Another source of customer complaints can be found on Starbucks' platform, *My Starbucks Idea*, where customers are encouraged to vote, share, and discuss their ideas with the purpose of developing useful suggestions for Starbucks to implement in-store[2, 3, 4]. Concerned customers have attributed these leaks to the seepage of liquid in the seam of the paper cup, while others believed the problem was due to Starbucks' change in lid manufacturers. Further analysis of these leaks reveals that as a filled disposable coffee cup is tilted to drink, hot coffee saturates the seam of the paper cup and travels up to the rim of the cup. This saturation encourages the liquid to leave residual amounts of the beverage on the rim. Upon meeting the lid, the coffee then drips down the side of the cup and on to the consumer, as shown in Figure 3 below.

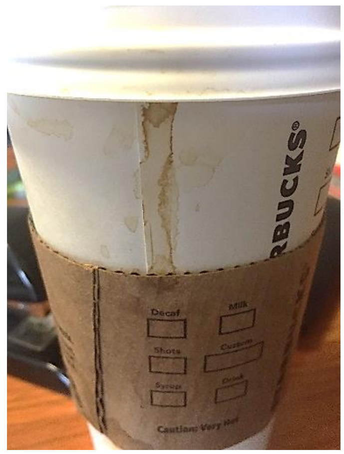

Figure 3. Residual drip stain on Starbucks disposable hot coffee cup[5]

The purpose of this research is to investigate the drip problem in the Starbucks disposable hot coffee cup, and modify the existing lid-rim interface of the cup. The overall goal is to ultimately optimize user drinking experience by minimizing the observed drip. To understand the function of cups and lids in this problem, the beverage drip was replicated using hot coffee and four different paper cups from various manufacturers. These experiments answered questions about the importance of the cup seam and the effectiveness of each lid design. After collecting relevant design and material information, optimal coffee cup designs were modeled using CAD software and functional prototypes were 3D printed to test against the Starbucks cup design.

1.2 Disposable Paper Cups And Polystyrene Lids

For current disposable hot beverage containers, Polyethylene (PE) paper cups are a popular choice due to their material composition: an outer processed paper layer and an inner lining of heat-resistant polyethylene plastic[6]. The process of manufacturing these paper cups involves forming processed paper into pre-cut paperboard blanks that are loaded into the hopper of a cup forming machine. In this machine, the blanks are folded and rolled in an overlapping spiral to form a standard coffee cup[7]. This process creates a seam closure on the paper cup, which is vulnerable to leaks by design.

When analyzing the disposable hot coffee cup lids, it is important to note that a large majority are composed of polystyrene, a material chosen because of its ability to contain hot beverages[8, 9]. Since 1934, there have been many individually patented drink-through coffee cup lids and by far, the most popular of these lids is the Solo® Traveler Lid, previously used by Starbucks[8, 10, 11]. This Solo lid is a 'pucker' lid type, named after the lip motion used to sip from this cup style[8, 9]. This lid has been praised because of its accommodation for the facial features of the lid users for a more comfortable drinking experience[8, 10]. Other cup lids have been designed to target issues in the drinking experience, but so far no design has emphasized a solution to the observed drip problem.

2. Methodology

To pinpoint the design flaws in the hot coffee cup, four samples of PE-Paper cups and their corresponding polystyrene lids were collected from various coffee shops. Information for each cup can be reviewed in Table 1 below. Using these cups, three separate drip tests were performed to provide information on the drip effect.

Table 1. Comparison chart of coffee cups used in drip experiments

Cup/Lid Brand	Weight (oz.)	Cup Volume (oz.)	Lid Type [8, 9]	Presumed Manufacturer
Starbucks	0.50/0.60	12/16	Pucker	International Paper[6]
Dunkin Donuts	0.45	10	Peel	Unknown
Colectivo	0.55	12	Pucker	Solo® Cup Company / Dart Container Corporation
Dixie	0.50	12	Pucker	Georgia Pacific

2.1 Tilt Test

The tilt test was performed to determine whether the drip effect existed solely in Starbucks cups. A volume of 9.15 ounces was the chosen amount of coffee placed in each cup. This was chosen because each cup became full with this amount. "Full" was determined to be within a half inch from the top of the cup. A temperature range of 70-80° Celsius was determined by brewing one pot of coffee and using a thermometer to measure the temperature of the coffee as it was steaming. After being filled, each cup was weighed, and the lid was placed so that the opening of the lid was in line with the seam of the paper cup, as observed in the original problem. The covered cups were then plugged with a stopper in the lid opening. A tilt angle of 40° was determined by first using a three-pronged beaker stand to hold a Starbucks coffee cup at 90°. Then, the cup was tilted in 10° increments away from the 90° angle until the drip was successfully replicated at the previously mentioned 40°. Each tilt test was observed for one full minute, and each cup was weighed again to determine the change in volume during the test. For every cup and lid combination, the tilt test was performed three times, averaged, and the standard deviation of each combination was calculated.

2.2 Seam Test

The seam test was performed to study the occurrence of coffee drip when the lid opening of each cup was turned 180° from the seam of the paper cup. In this experiment, each coffee cup was filled with 9.15 oz. of coffee ranging from 70-80° Celsius and weighed. The covered cups were then plugged with a stopper in the lid opening and held at a 40° angle while the drip was observed for one full minute. Finally, the cups were weighed a second time to determine the change in volume. For every cup and lid combination, the seam test was performed three times, averaged, and the standard deviation of each combination was calculated.

2.3 Lid Test

Based on the results from the previous two experiments, the lid test was completed to analyze the performance of cup and lid interfaces in different combinations. Each cup and lid was swapped for testing, except for the Dunkin Donuts design, because the 10 oz. size did not universally fit the other cups. Also, the 12 oz. Starbucks hot cups used in the two previous tests were not universally sized to fit the 12 oz. Colectivo and Dixie cups. However, the Starbucks 16 oz. cup could fit with the 12 oz. Colectivo and Dixie cups. Upon discovering this, the cups chosen for this experiment were the Colectivo 12 oz., the Dixie 12 oz., and the Starbucks 16 oz., for a total of 9 combinations of cups and lids. Each coffee cup was filled with 9.15/12.2 oz. of coffee ranging from 70-80° Celsius, weighed, and placed so that the opening of the lid was in line with the seam of the paper cup. The covered cups were then plugged with a stopper in the lid opening, held at a 40° angle, observed for one full minute, and weighed a second time. For every cup and lid combination, the lid test was performed three times, averaged, and the standard deviation of each combination was calculated.

2.4 Designing Improved Cup And Lid Models

Based on the results found in section 3, the new designs for a functional, disposable coffee cup and lid were sketched using Autodesk Inventor CAD software. One cup and two lid designs were generated as 3D models and sent to the MSOE Rapid Prototyping Center to be additively manufactured into physical models. From the three previous tests, it was determined that:

- The lid designs would be modifications of the 'pucker' lid type - as no other lid type was fully analyzed
- The Starbucks lid structure is thinner, has less surface area for liquids to splash, and features a weak lid-rim interface due to the little curvature on the cup lid.

These design conclusions were expanded upon to generate alternative designs.

The first design improvement involved a modification of the Starbucks PE-paper coffee cup. A model was produced using measurements from a Starbucks coffee cup, and then altered to fit the minimum size requirements for stable 3D printing. Modifications on to this coffee cup feature two 0.018 inch rectangular cuts that are swept around the exterior of the cup. These cuts are shown in Figure 4, and were designed to mitigate the leakage in PE-Paper cups by catching any dripping coffee before the liquid were to reach a drinker's hand.

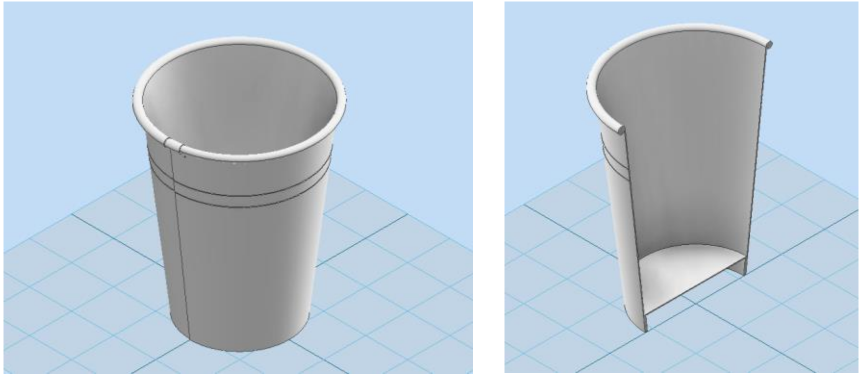

Figure 4. The improved coffee cup design featuring two rectangular cuts around the cup exterior

The next design was a lid modification inspired by the interface of the Solo® Traveler lid. After testing, it was thought that an overall increase in the surface area of the lid would help to prevent excess liquid from leaving the cup. To demonstrate this, the lid height was increased and more pronounced curvature was introduced where the lid would meet the cup's rim, as shown in Figure 5 below. This design was also altered to fit the minimum wall thickness for 3D printing.

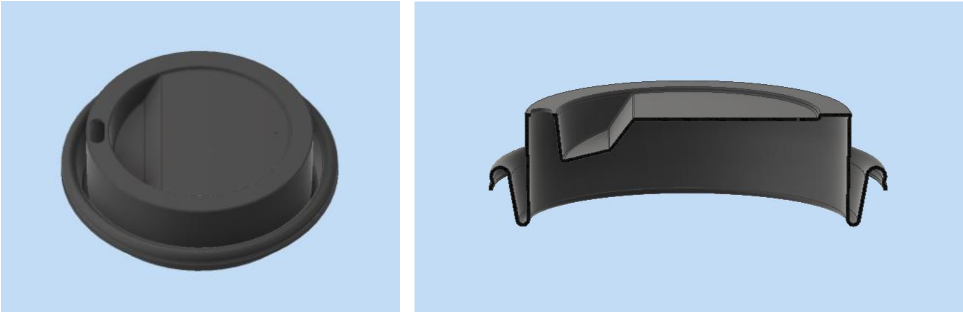

Figure 5. Coffee lid design 1 (featuring a lengthened lid height, and increased curvature at lid-rim contact point)

The final design was another lid modification inspired by the O-rings used in re-usable coffee tumblers. Figure 6 below shows the 0.070 inch circular cut added to the bottom of the lid to accommodate a small sealing ring to prevent liquid from leaking. This design also features an increased lid height was and more pronounced curvature where the lid meets the cup's rim, and was altered to fit the minimum specifications for 3D printing.

Figure 6. Coffee lid design 2, featuring the O-ring design

2.4.1 *additive manufacturing*

Additive manufacturing (AM) is the process in which physical objects are fabricated by converting computer aided designs (CAD) into physical, 3-Dimensional (3D) models by depositing material in consecutive 2-Dimensional (2D) layers over a period of time. This technology has become useful in multidisciplinary studies and the creation of complex geometries, as no molds or forms are required to create functional parts[12]. Many AM technologies exist today and are used based on the material, details, production time and cost that a specific design requires. The CAD drawings for this project were saved as a high resolution STL files appropriate for AM and sent to the Rapid Prototyping Center to be printed using Selective Laser Sintering (SLS) technology. The SLS printing process was selected for this project due to its ability to produce realistic prototypes, form complex geometries without supports, and produce heat and chemical resistant materials[13]. The material chosen for this project was DuraForm PA, a powdered nylon material used for snap fit designs and low moisture absorption projects, especially after being treated with an infiltrate glue; these characteristics were suitable for testing in drip experiments[14].

2.4.2 *prototype testing*

To test the effectiveness of the prototypes, visual drip tests were performed to determine if the designs functioned as expected. From these tests, it was determined that the SLS printed cup did not perform as predicted due to the thin structure of the additively manufactured cup walls; the channels were too small to hold any liquid. Next, drip tests were performed using the SLS printed lids and the 16oz Starbucks cups. Each coffee cup was filled with 12.2 oz. of coffee ranging from 70-80° Celsius, weighed, and the lid was placed so that the opening of the lid was in line with the seam of the paper cup. The covered cups were then plugged with a stopper in the lid opening, held at a 40° angle, observed for one full minute, and weighed a second time. For every cup and lid combination, the prototype test was performed three times, averaged, and the standard deviation of each combination was calculated.

3. Results

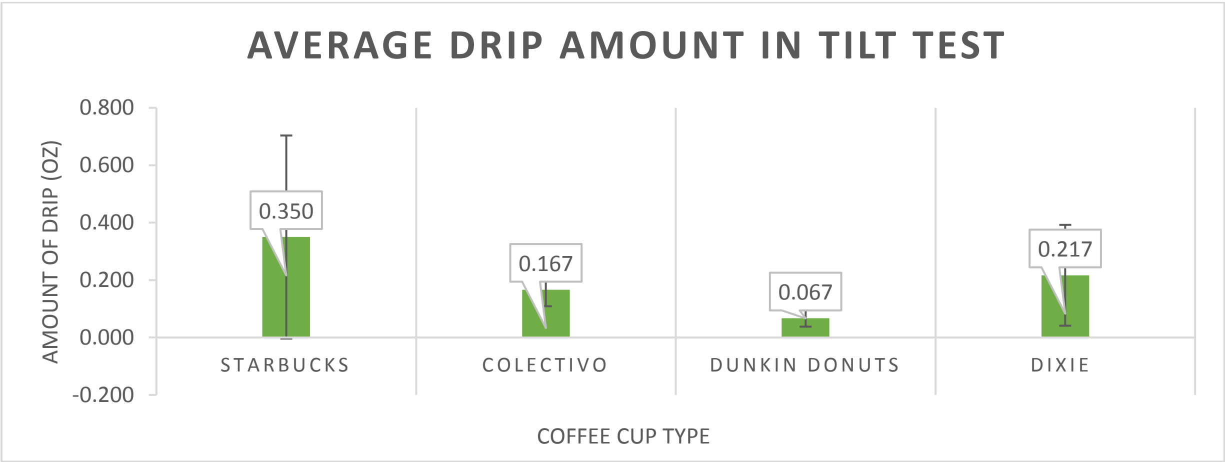

Figure 7. Average drip amount in tilt test

Figure 7 shows that although the Starbucks cup was not the only disposable hot coffee cup with leaks, it was the cup that consistently produced the highest amount of drip with the most standard deviation when the lid opening is lined up with the cup seam.

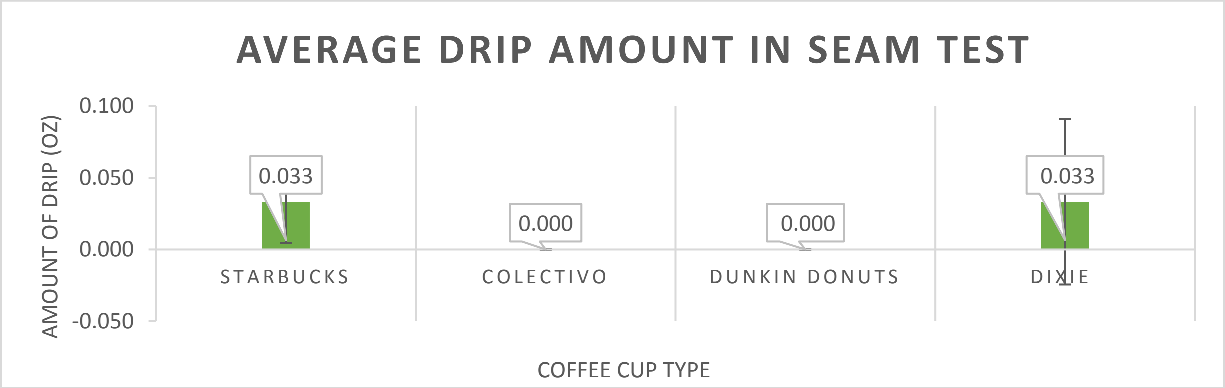

Figure 8. Average drip amount in seam test

Figure 8 shows the significance of the cup seam in the drip problem. It is important to note that when the lid opening was 180° from the cup seam, the amount of drip was roughly $1/10^{th}$ of the drip amount observed the tilt test. These test results demonstrate the importance of the cup seam in creating the drip problem in PE-paper cups.

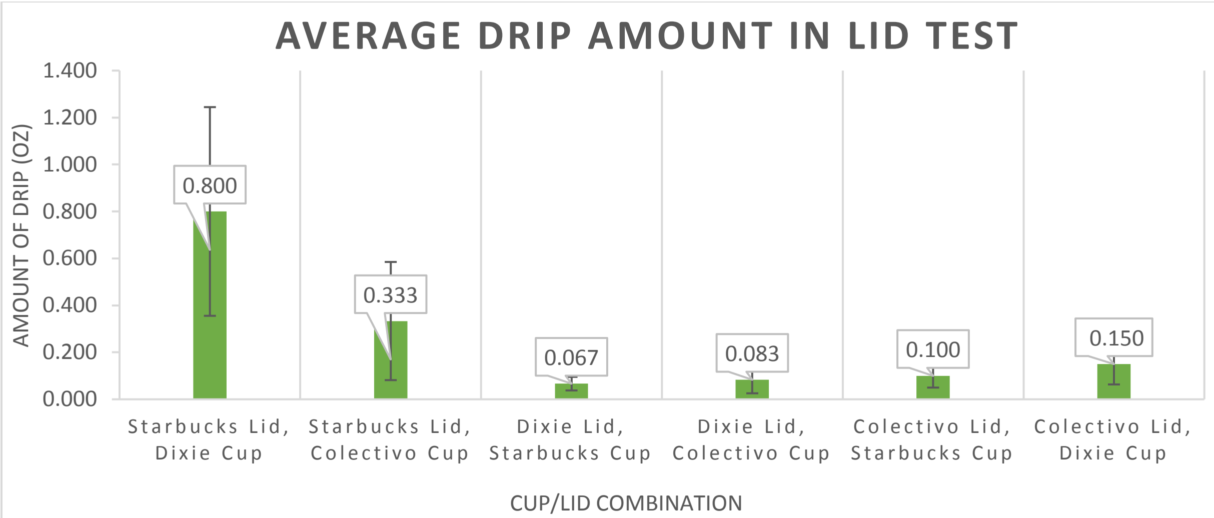

Figure 9. Average drip amount in lid test

The graph in Figure 9 shows that the Starbucks coffee cup lids produce more drip than their counterparts, even when paired with coffee cups from various manufacturers. Here, the Dixie and Colectivo (Solo) coffee cup lids produce less drip; this can be attributed to the sturdy structure of the lids in comparison to Starbucks' design.

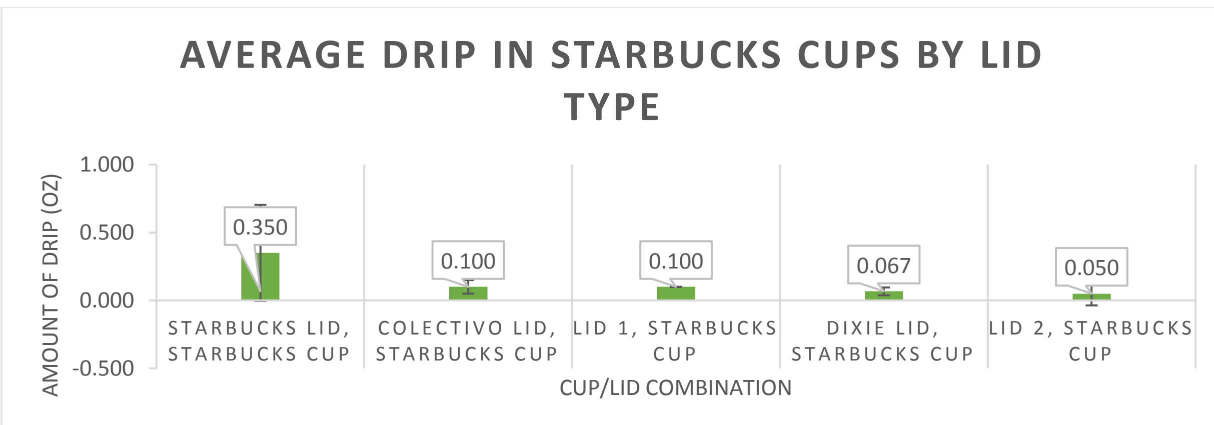

Figure 10. Average drip amount in Starbucks cups by lid type

Figure 10 shows a comparison of each cup lid used in the previously mentioned tests along with the SLS printed cups, and these lids are all paired with Starbucks cups. Once again, the Starbucks lid produces the highest amount of drip, but here the SLS printed lids perform on par with the coffee cup lids that produce less drip. Lid 1 is a modification of the Solo cup lid, so it is assumed that they would perform similarly. Lid 1 has little to no standard deviation as indicated by the error bars, and therefore performed better than the original Solo cup lid. Lid 2 shows an average that closely competes with the Dixie cup lid, although the higher standard deviation is a factor that can be considered when comparing the two models.

4. Discussion & Conclusion

Overall, this is both a lid and a cup problem. Due to the seam created in the cup manufacturing process, paper cups are already vulnerable to leakage. The Starbucks' case involves a mixture of the paper cup design flaw and a less-sturdy lid with a weak lid-rim interface. Given the popularity of disposable coffee cups, it is important to continue to improve this issue to optimize the consumer experience over time. In future work, designs can be replicated using polystyrene plastic to form the lids. These lids would then be used in additional drip tests to determine how the material choice changes the effectiveness of the design. Next steps would also involve analyzing other lid systems, such as the Dunkin Donuts peel lid, to gather more information about which lid performs best by form and function. Outside of drip tests, it would be beneficial to perform both a cost and sustainability analysis to determine the feasibility of these designs. Based on the economic analysis, further optimization of the lid designs would be required.

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