IMPROVEMENTS TO THE BEVERAGE CAN REDRAW PROCESS USING LSDYNA

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ABSTRACT

In the United States, in the year 2000, over 100 billion aluminum beverage cans were manufactured. Lightweighting of these aluminum D&I beverage cans has been a continuous process for more than 35 years. Aluminum beverage can "ends" have been made progressively smaller over the years in order to reduce costs. Likewise, cost control efforts have resulted in continuous reduction of the net metal requirements for the can body. To reduce the weight and cost of the "bodies", cans with thinner sidewalls, reduced neck diameters and smaller base diameters have been developed. The reduction in cost has been achieved while maintaining functionality, structural performance, and formability of the can. Today, the gauge of can body stock is as low as 0.0098 inches. With small base diameter cans and a sheet thickness that continues to decrease, the likelihood of profile wrinkling during can forming increases, particularly in the redraw process. Redraw wrinkling is influenced by many factors such as mechanical properties of the aluminum sheet, tooling geometry, contact conditions including the effects of lubrication, and process boundary conditions. These factors are readily handled using the finite element method. A numerical technique for calculating the severity of the redraw wrinkling or wrinkle factor from an LSDYNA finite element analysis is employed. Using this wrinkle factor, and a fully parametric input generator, improvements to the beverage can redraw process are developed.

BACKGROUND

In the United States, lightweighting of aluminum drawn and ironed (D&I) beverage cans has been a continuous process for over 35 years. Advances in can manufacturing technology and cost control efforts by aluminum suppliers, canmakers, and fillers have resulted in a consistent reduction of the net metal weight and cost of the beverage can. Since its inception, the gauge of the aluminum D&I can body stock has decreased from approximately 0.0200 inches to today's thickness of 0.0100 inches. This has resulted in a reduction of net can weight from 39 lbs. per 1000 cans to 23 lbs. per 1000 cans. This reduction in weight has been achieved without compromise to the structural integrity or performance of the can. The performance requirements include dome reversal pressure, axial column load, drop resistance, and can growth.

To reduce the weight and cost of the can bodies, cans with thinner sidewalls, reduced neck diameters and smaller base diameters have been developed. With small base diameter cans and light gauge material, the likelihood of wrinkling during can manufacturing increases, particularly in the redraw process. A schematic of the redraw process is provided in Figure 1. A photograph showing typical redraw wrinkling is provided in Figure 2. Manufacturing experience demonstrates that redraw wrinkling is influenced by many factors such as mechanical properties of the aluminum sheet, tooling geometry, contact conditions including the effects of lubrication, and process boundary conditions. The most common wrinkling control techniques include increased redraw sleeve pressure, reduced redraw sleeve radius, reduced redraw die radius, and increased cup diameter. However, all of these methods provide increased resistance to metal flow which can lead to increased thinning and fracture in the sheet metal under the punch nose.

A numerical technique for calculating the severity of the redraw wrinkling or wrinkle factor from an LSDYNA finite element analysis is employed. Using this wrinkle factor, and a fully parametric input generator, improvements to the beverage can redraw process are developed. Effects of punch speed, friction conditions, cup and punch geometry, and material characteristics on formability are investigated. The formability is evaluated by monitoring both wrinkling and localized thinning during the redraw process.

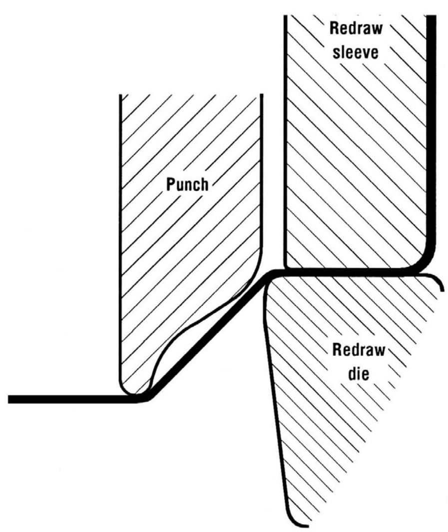

Figure 1. Schematic of cup redraw process.

Figure 2. Photograph of redrawn beverage can showing profile wrinkles.

WRINKLE FACTOR CALCULATION

Finite element models were assembled to investigate the severity of wrinkling during the redraw process. All input data files for the fully parametric LS-DYNA models were generated using the LS-INGRID pre-processor. A list of the baseline parameters for the redraw simulations is provided in Table 1. The nomenclature used for the redraw tooling parameters is depicted in Figure 3. All the models employ 1/4 symmetry. The modeled tooling consists of the punch, redraw sleeve, and redraw die. The cup geometry is idealized and has uniform metal thickness. No history of cup forming is accounted for in the redraw model. The material model used is an elastic-plastic von Mises material with isotropic hardening. Young's modulus is 10 million psi and Poisson's ratio is 0.33. Sliding interfaces (type 10) are used to model the contact between the cup profile and rigid tooling. A coefficient of friction of 0.05 was used for all contact interfaces between the rigid tools and the deformable cup. A total punch displacement of 0.9 inches was applied in 0.025 seconds resulting in a maximum punch speed 40.0 inches/sec. A constant redraw sleeve force of 2500 lbs. was applied.

The initial cup geometry and typical deformed shape of a partially redrawn cup are provided in Figure 4. A radial coordinate contour plot of the wrinkled profile of the cup is shown in Figure 5. The plot shows the radial distance and circumferential position for each ring of nodes in the wrinkled region of the cup profile. The wrinkle factor is calculated as the percentage of the maximum normalized arc length relative to the unit length calculated from each contour in the radial coordinate plot data. A wrinkle factor of zero indicates no wrinkling. The wrinkle factor for the redrawn cup shown is 5.12. Predicted wrinkle factors and percent thickness reduction for all cases studied in the paper are provided in Appendix A.

Table 1
Cup Redraw Model - Baseline Conditions
(inches)

Punch Dimensions	
Base Diameter	*1.866*
Punch Diameter	*2.603*
Inside Nose Radius	*0.060*
Outside Nose Radius	*0.060*
Profile Radius	*0.120*
Lower Body Radius	*0.200*
Profile Height	*0.365*
Lower Transition Length	*0.350*
Thinwall Length	*0.500*
Outside Nose Angle (degrees)	*65.000*
Lower Body Angle (degrees)	*28.000*
Redraw Sleeve Dimensions	
Sleeve Inside Diameter	*2.650*
Sleeve Outside Diameter	*3.592*
Sleeve Inside Corner Radius	*0.030*
Sleeve Outside Corner Radius	*0.075*
Sleeve Taper Length	*0.500*
Sleeve Height	*1.500*
Sleeve Taper Angle (degrees)	*0.000*
Alcoa Redraw Die Dimensions	
Die Inside Diameter	*2.635*
Die Outside Diameter	*4.100*
Die Radius	*0.090*
Die Finish Radii	*0.040*
Landing Offset	*0.105*
Landing Length	*0.025*
Die Height	*0.750*
Die Entry Angle (degrees)	*8.000*
Die Relief Angle (degrees)	*8.000*
Cup Dimensions	
Cup Inside Diameter	*3.598*
Cup Corner Radius	*0.078*
Cup Height	*1.500*
Cup Thickness	*0.0108*
Material Constants	
Voce Constant - A (psi)	*48328*
Voce Constant - B (psi)	*6978*
Voce Constant - C	*34.67*
Friction, Loads, Motion	
Punch Friction (μ)	*0.050*
Sleeve Friction(μ)	*0.050*
Die Friction(μ)	*0.050*
Redraw Sleeve Force (lbs)	*2500*
Punch Displacement	*0.900*
Duration Time	
Cycle Time (ms)	*0.025*

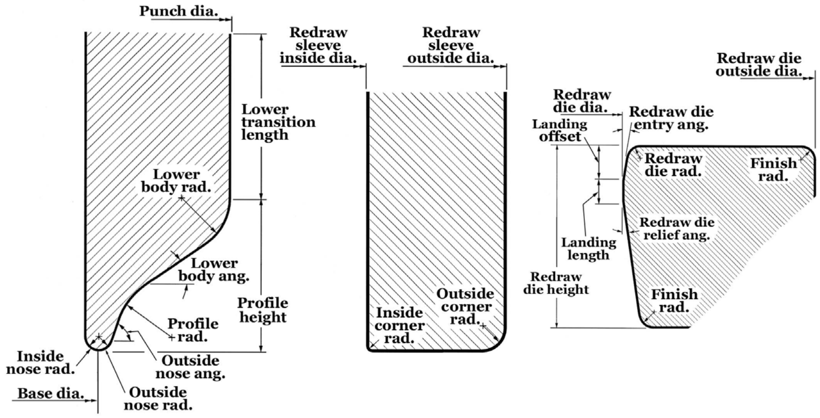

Figure 3. Nomenclature for redraw tooling.

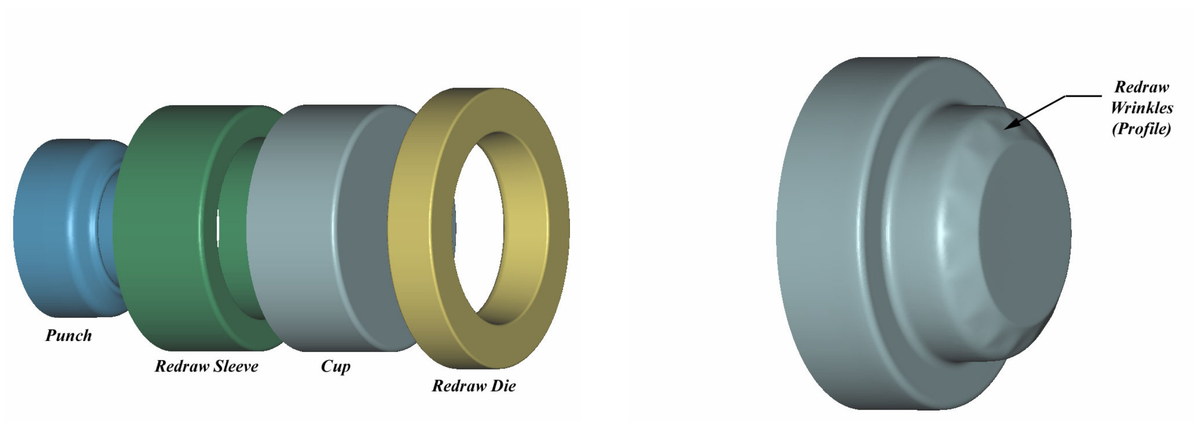

Figure 4. Initial geometry and partially redrawn cup showing wrinkles.

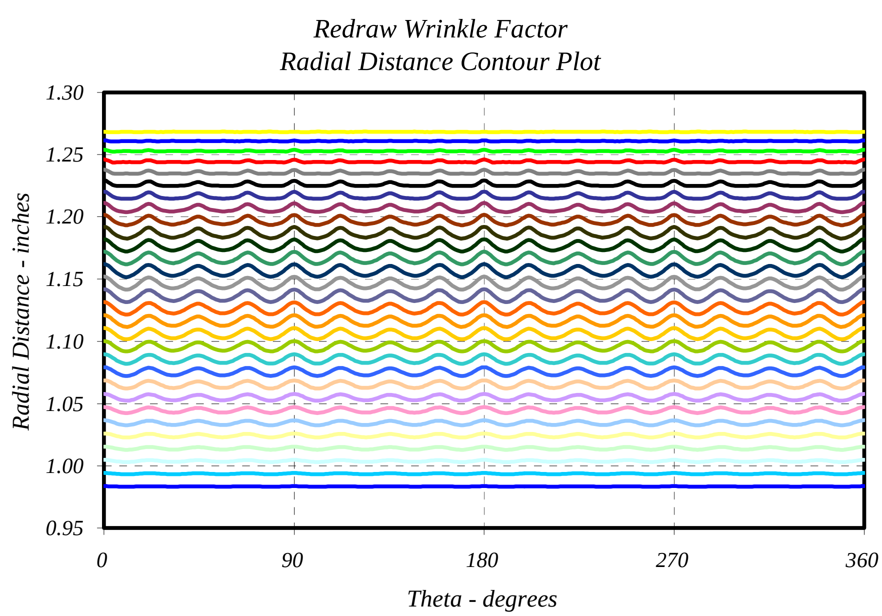

Figure 5. Radial distance contour plot for partially redrawn cup.

PUNCH SPEED

Analyses were performed to determine the influence of maximum punch speed on the predicted wrinkling factor. The total punch displacement of 0.9 inches was applied at time periods ranging from 0.010 seconds to 0.150 seconds using a smoothed load curve. The resulting maximum punch speeds range from 100.0 inches/sec to 6.67 inches/sec. The results are provided in Figure 6 and indicate that as the punch speed increases, the severity of wrinkling decreases.

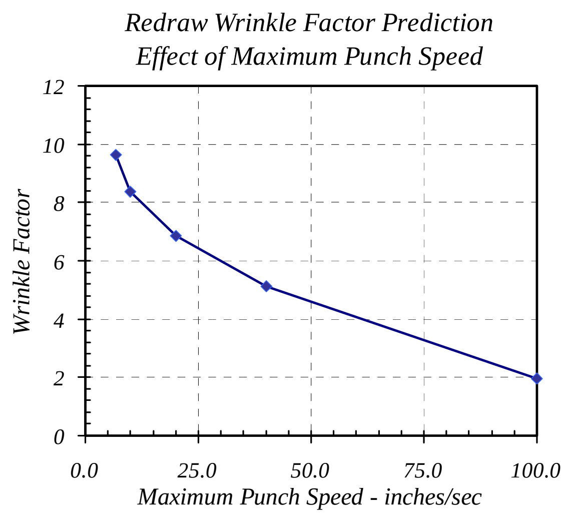

Figure 5. Effect of punch velocity on the predicted redraw wrinkling factor.

FRICTION

Friction is controlled commercially through the application of lubricants. Coefficient of friction values were varied from a nearly frictionless condition of 0.001 to a value of 0.1. The influence of coefficient of friction between the rigid tools and the cup is shown in Figure 7. The data shows a significant increase in the wrinkle factor as a frictionless condition is approached. Also, as friction increases the restraining forces on the cup increases leading to increased thinning in the metal under the punch nose. High coefficients of friction can lead to dome fractures or "punch-outs".

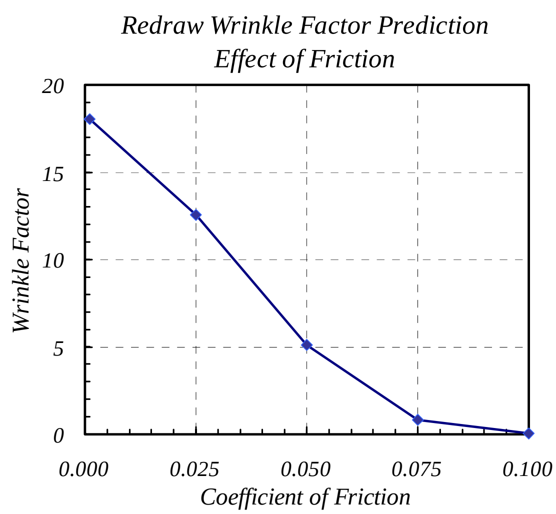

Figure 7. Influence of coefficient of friction on the predicted redraw wrinkle factor.

CUP GEOMETRY

The influence of the cup geometry was examined by varying the cup diameter and cup thickness. The cup diameter ranged from 3.498 inches to 3.798 inches. The metal thickness varied from 0.0096 inches to 0.0114 inches. The results are summarized in Figure 8. The data indicates that as both the cup diameter and thickness increase, the severity of wrinkling decreases.

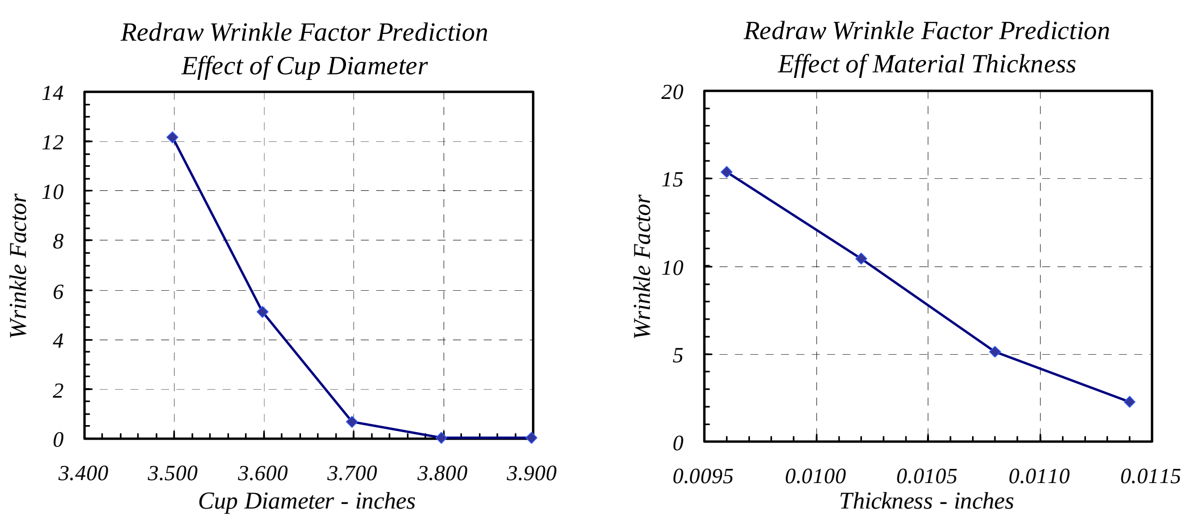

Figure 8. Effect of cup diameter and metal thickness on the predicted redraw wrinkle factor.

PUNCH GEOMETRY

The influence of punch geometry on the predicted wrinkling factor was investigated by varying the profile height which ranged from 0.355 inches to 0.385 inches. While many factors could be adjusted, the profile height is considered to be the one of the most critical. The results are plotted in Figure 9 and show increased wrinkling with increased profile height.

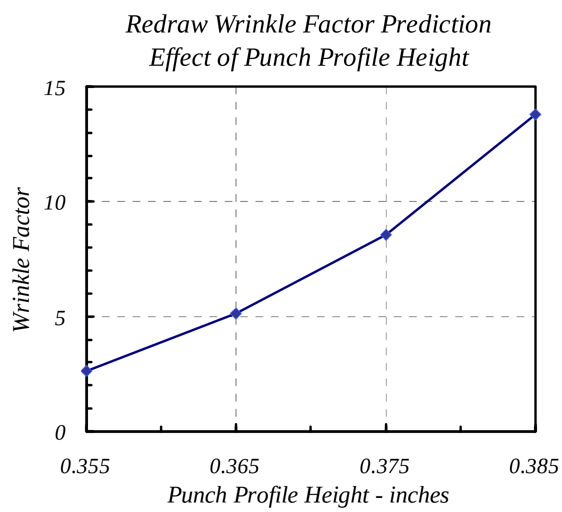

Figure 9. Effect of punch profile height on the predicted redraw wrinkle factor.

MATERIAL

The effects of material characteristics were evaluated by modifying yield stress, strain hardening, and strain hardening rate. The material flow stress was described using the Voce equation:

$$\sigma = A\text{-}B \cdot exp(-C\varepsilon) \qquad (1)$$

which may be re-written as:

$$\sigma = A\text{-}(A\text{-}YS) \cdot exp(-C\varepsilon) \qquad (2)$$

where σ is the true stress, ε is the true plastic strain, A, B, C are the Voce material constants and YS is the yield strength. The complete experimental design is given in Table 2. The range of values chosen is considered typical of *as-rolled* properties for existing body stock alloys. Runs 1-15 are a central-composite design at three levels of yield strength (A-B), asymptote or tensile strength (A), and strain hardening rate (C) as shown in Figure 10. This design allows the estimation of quadratic and interaction effects. Run 18 augments run 16 with low rate (low asymptote, mid-yield strength) while run 19 augments run 17 with low rate (high asymptote, higher strength).

Table 2
Voce Material Coefficients

Run ID	A (psi)	B (psi)	C	YS (psi)	Wrinkle Factor	%Thick Reduction
1	48328	6978	17.335	41350	4.650	5.17
2	48328	6978	34.67	41350	5.116	5.23
3	48328	7633	26.0025	40695	4.335	5.05
4	48328	8288	17.335	40040	3.585	4.98
5	48328	8288	34.67	40040	3.915	5.07
6	50479	9129	26.0025	41350	4.157	4.97
7	50479	9784	17.335	40695	3.364	4.98
8	50479	9784	26.0025	40695	3.684	4.94
9	50479	9784	34.67	40695	4.037	5.00
10	50479	10439	26.0025	40040	3.052	5.00
11	52630	11280	17.335	41350	3.645	4.99
12	52630	11280	34.67	41350	3.983	5.19
13	52630	11935	26.0025	40695	3.190	5.20
14	52630	12590	17.7	40040	2.422	5.15
15	52630	12590	34.67	40040	2.959	5.32
16	45587	4892	34.67	40695	5.172	5.41
17	54479	9784	34.67	44695	6.869	5.16
18	45587	4892	17.335	40695	4.979	5.50
19	54479	9784	17.335	44695	6.517	5.02

The results show that only linear terms were statistically significant with no significant curvature or interactions over the range of parameters studied. The fitted equation is given by:

$$\boldsymbol{wf} = -23.61 - 2.55\text{E-}04 \cdot \boldsymbol{A} + 2.39\text{E-}02 \cdot \boldsymbol{C} + 9.74\text{E-}04 \cdot \boldsymbol{YS} \quad (3)$$

where *wf* is the predicted redraw wrinkle factor. This implies that redraw wrinkling is minimized when the yield stress is low, the asymptote is high, and the hardening rate is low. Lowering the yield stress provides the greatest reduction on wrinkling followed by increasing the asymptote or tensile strength and then decreasing the hardening rate.

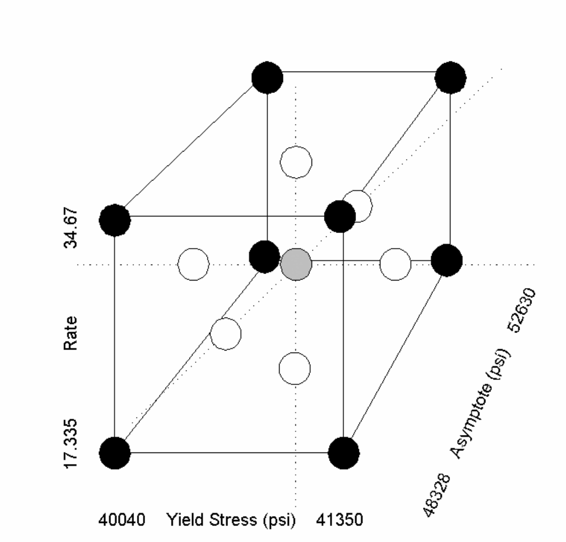

Figure 10. Experimental Design (15 Central-Composite Runs Only)

SUMMARY

Software tools have been developed to quantify the magnitude and frequency of wrinkles in the cup redraw process. These tools can be used to evaluate the effects of tooling geometry, material characteristics (anisotropy, yield strength and work hardening), and boundary conditions (redraw sleeve force and friction) on redraw wrinkling. The results presented confirm the trends based on manufacturing experience. The analysis of loading rate demonstrated that increased punch velocity reduced the amplitude of redraw wrinkling. The study of friction indicated the effects of friction are significant in the prevention of redraw wrinkling and the severity of wrinkling increases as the coefficient of friction decreases. The amount of localized thinning also increased with increased friction. It was concluded the effects of lubrication must be balanced between wrinkling prevention and localized thinning. The examination of cup geometry demonstrated that increased cup diameter and increased thickness reduce redraw wrinkling. However, to minimize costs, increasing metal gauge is generally not feasible. Punch design changes, such as reduced profile heights, can also minimize redraw wrinkling. Lower profile heights can reduce wrinkling but produce domes with decreased dome reversal pressures and increased can growth. Finally, the study on material characteristics indicated that when yield stress is low, the tensile stress is high, and the hardening rate is low, redraw wrinkling is minimized. The most significant material factor affecting redraw wrinkling is the as-rolled yield stress.

There is a trade-off between wrinkling and structural performance. Factors that control or reduce wrinkling may also affect localized thinning or structural performance. An acceptable solution must balance formability and structural performance requirements.

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Appendix A

Summary Table.
Wrinkle Factors and Percent Thickness Reduction

Identification	Wrinkle Factor	% Thickness Reduction
SPEED1(100 inches/sec)	1.96	5.62
SPEED2 (40 inches//sec)	5.12	5.23
SPEED3 (20 inches/sec)	6.85	5.31
SPEED4 (10 inches/sec)	8.36	5.44
SPEED5 (6.67 inches/sec)	9.65	5.45
FRICTION1 (μ=0.001)	18.05	5.29
FRICTION2 (μ=0.025)	12.55	5.24
FRICTION3 (μ=0.050)	5.12	5.23
FRICTION4 (μ=0.075)	0.80	5.44
FRICTION5 (μ=0.100)	0.04	6.04
CUPSIZE1 (3.498)	12.18	5.70
CUPSIZE2 (3.598)	5.12	5.23
CUPSIZE3 (3.698)	0.67	6.42
CUPSIZE4 (3.798)	0.04	7.31
CUPSIZE5 (3.898)	0.04	7.78
THICKNESS1 (0.0096)	15.36	4.95
THICKNESS2 (0.0102)	10.42	5.18
THICKNESS3 (0.0108)	5.12	5.23
THICKNESS4 (0.0114)	2.25	5.54
PHEIGHT1 (0.355)	2.64	5.22
PHEIGHT1 (0.365)	5.12	5.23
PHEIGHT1 (0.375)	8.56	5.64
PHEIGHT1 (0.385)	13.78	6.29