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CQAS Final Project
Simulation

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CQAS - DoE
Dr. Parody

GOALS AND OBJECTIVES:

Through the course of this simulation, our primary goal was to aid this company in optimizing its injection molding process. Through the information provided, we were able to identify eight different factors which caused shrinkage in the injection molding process. By identifying these factors, we will be able to aid in reducing the shrinkage metric, thereby making the injection molding process more optimal.

In order to meet our goal, we have identified key objectives to optimize the injection molding process within our 45-run constraint:

- Identify key (significant) variables which play an integral role in causing shrinkage
- Discard variables which do not impact the shrinkage metric
- Pursue the significant variables and analyze which setting (either low or high) they should be manipulated in order to reduce shrinkage

EXPERIMENTAL DESIGN STRATEGY:

From the information provided, we were limited to allotting our design to have a maximum of 45 runs. Seeing how there are 8 key factors which seem to impact shrinkage, it is quite apparent that we cannot conduct a thorough analysis to see which factors clearly affect the shrinkage factor. Due to the lack of runs which we are bound by, we have designed an experiment to help make the process more efficient while also optimizing the amount of information we are able to gather.

In order to proceed in this matter, we have started out by attempting to solely identify which factors impact the shrinkage levels in the injection molding process the most. To start off, we completed a run designed for screening which consisted of 2^{8-4}; or 16 runs total. After running this screening design, we found four main effects to be significant - Pack Pressure (A), Pack Time (B), Mold Temperature (E), Gate Thickness (H), and related interactions. We cannot conclude which interactions are really significant.

This finding was followed by a second run which consisted of a Full Factorial: 2^4 = 16 runs + 4 Centerpoints = 20 total runs to account for the interactions. This run ensured that the four main effects and two two-way interactions AB (Pack Pressure × Pack Time) and EH (Mold Temperature ×Gate Thickness) were significant in the experiment. Based on our results, we were able to set the factors to their optimum levels as depicted in the interaction plots.

We then concluded our experiment with 9 Confirmation Runs, making use of all 45 runs provided.

Run I – Screening – 2^{8-4} = 16 runs

Run Number	Pack Pressure (A)	Pack Time (B)	Injection Speed (C)	Screw Speed (D)	Mold Temp (E)	Flow Length (F)	Feed Throat Cooling Temp (G)	Gate Thickness (H)	Response (Y)
1	150	1	0.5	100	45	170	126	50	**288.9677**
2	450	1	0.5	100	45	240	194	60	**331.6015**
3	150	5	0.5	100	60	170	194	60	**429.7311**
4	450	5	0.5	100	60	240	126	50	**391.6117**
5	150	1	2	100	60	240	194	50	**360.2993**
6	450	1	2	100	60	170	126	60	**419.1819**
7	150	5	2	100	45	240	126	60	**342.7462**
8	450	5	2	100	45	170	194	50	**320.2685**
9	150	1	0.5	200	60	240	126	60	**414.9343**
10	450	1	0.5	200	60	170	194	50	**360.4439**
11	150	5	0.5	200	45	240	194	50	**300.5717**
12	450	5	0.5	200	45	170	126	60	**363.223**
13	150	1	2	200	45	170	194	60	**327.7104**
14	450	1	2	200	45	240	126	50	**288.2325**
15	150	5	2	200	60	170	126	50	**370.7814**
16	450	5	2	200	60	240	194	60	**447.7125**

Run II Full Factorial: 2^4 = 16 runs + 4 Centerpoints = 20 Total Runs

Run Number	Pack Pressure (A)	Pack Time (B)	Injection Speed (C)	Screw Speed (D)	Mold Temp (E)	Flow Length (F)	Feed Throat Cooling Temp (G)	Gate Thickness (H)	Response (Y)
17	150	1	2	200	45	170	194	50	285.8791
18	450	1	2	200	45	170	194	50	285.482
19	150	5	2	200	45	170	194	50	298.51
20	450	5	2	200	45	170	194	50	318.5052
21	150	1	2	200	60	170	194	50	358.7435
22	450	1	2	200	60	170	194	50	358.7687
23	150	5	2	200	60	170	194	50	372.5328
24	450	5	2	200	60	170	194	50	391.5203
25	150	1	2	200	45	170	194	60	328.2187
26	450	1	2	200	45	170	194	60	329.7721
27	150	5	2	200	45	170	194	60	341.3033
28	450	5	2	200	45	170	194	60	360.2767
29	150	1	2	200	60	170	194	60	414.8129
30	450	1	2	200	60	170	194	60	416.5222
31	150	5	2	200	60	170	194	60	427.1512
32	450	5	2	200	60	170	194	60	446.6165
33	300	3	2	200	52.5	170	194	55	359.4373
34	300	3	2	200	52.5	170	194	55	357.0277
35	300	3	2	200	52.5	170	194	55	359.1258
36	300	3	2	200	52.5	170	194	55	357.9599

Run III – 9 Confirmation Runs

Run Number	Pack Pressure (A)	Pack Time (B)	Injection Speed (C)	Screw Speed (D)	Mold Temp (E)	Flow Length (F)	Feed Throat Cooling Temp (G)	Gate Thickness (H)	Response (Y)
37	450	5	2	200	60	170	194	55	420.3842
38	450	5	2	200	60	170	194	55	419.9787
39	450	5	2	200	60	170	194	55	420.3518
40	450	5	2	200	60	170	194	55	418.6844
41	450	5	2	200	60	170	194	55	418.9583
42	450	5	2	200	60	170	194	55	419.363
43	450	5	2	200	60	170	194	55	419.5595
44	450	5	2	200	60	170	194	55	419.2816
45	450	5	2	200	60	170	194	55	419.9381

ANALYSIS AND DISCUSSION:

Run I – Screening – 2^{8-4} = 16 runs

Factorial Fit: y versus A, B, C, D, E, F, G, H

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Estimated Effects and Coefficients for y (coded units)

Term        Effect     Coef
Constant            359.876
A           10.817    5.408
B           21.909   10.955
C           -0.519   -0.260
D           -1.350   -0.675
E           78.922   39.461
F           -0.325   -0.162
G           -0.167   -0.084
H           49.458   24.729
A*B          8.930    4.465
A*C          7.648    3.824
A*D          0.587    0.293
A*E         -0.016   -0.008
A*F         -0.665   -0.333
A*G         -0.388   -0.194
A*H          0.833    0.416
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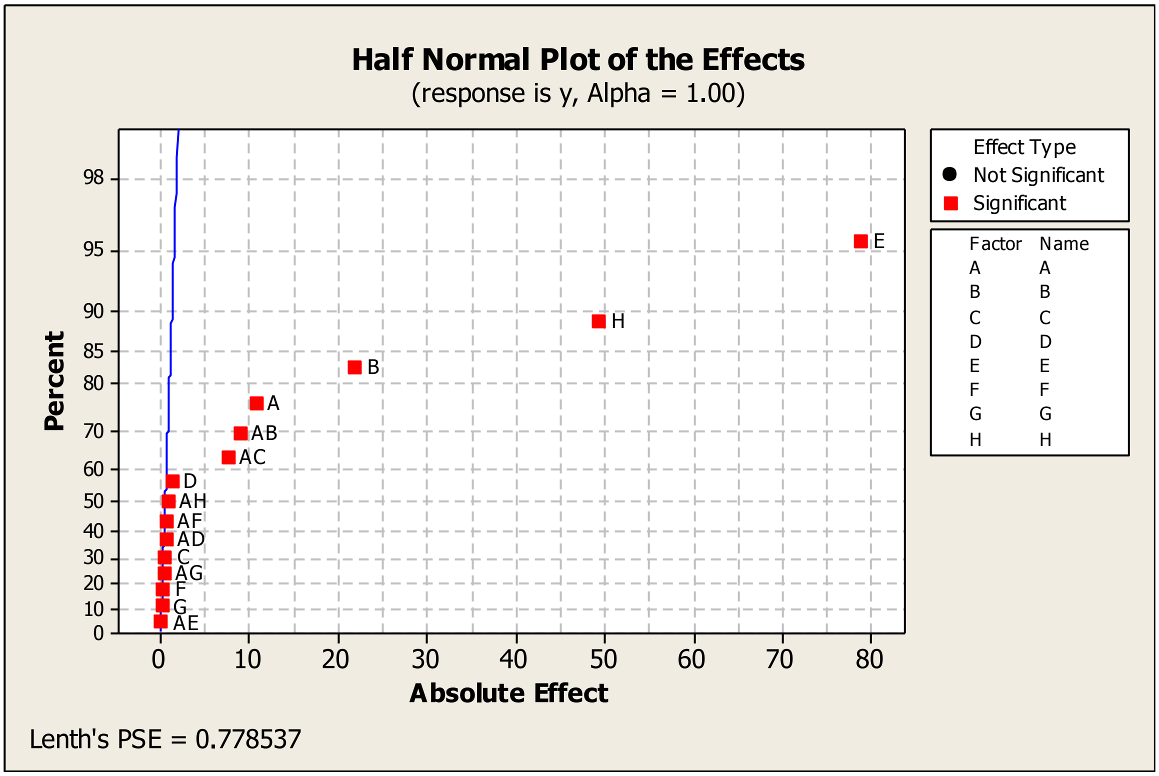


Based on the 2^{8-4} screening design which occupied 16 runs, the results alluded to variables Pack Pressure (A), Pack Time (B), Mold Temperature (E), and Gate Thickness (H), as being significant. Based on this output, we decided to run a 2^4 design with these same four factors (A, B, E, and H). In addition, the inclusion of 4 centerpoints was placed in the design to help test for curvature.

Although as shown above in the half-normal plot and the corresponding coefficient values that AC is significant; we are assuming that this two-way interaction is being strongly affected by variable A (Pack Pressure), which proved to be significant while variable C (Injection Speed) was not. Due to this anomaly, we are assuming that this two-way interaction is not impacting the model as strongly as the other variables, and therefore justify this idea by not including variable C into our reduced model.

Since the other factors were not significant, the decision was made to keep Injection Speed (C) and Screw Speed (D) at the high levels, and Spiral Flow Length (F) at the low level, in order to increase the production rate. The variable Feed Throat Cooling Temperature (G) was also kept at the high level for the free flow of the fed plastic, once again increasing the production rate.

Run II Full Factorial: 2^4 = 16 runs + 4 Centerpoints = 20 Total Runs

Factorial Fit: Y versus A, B, e, h

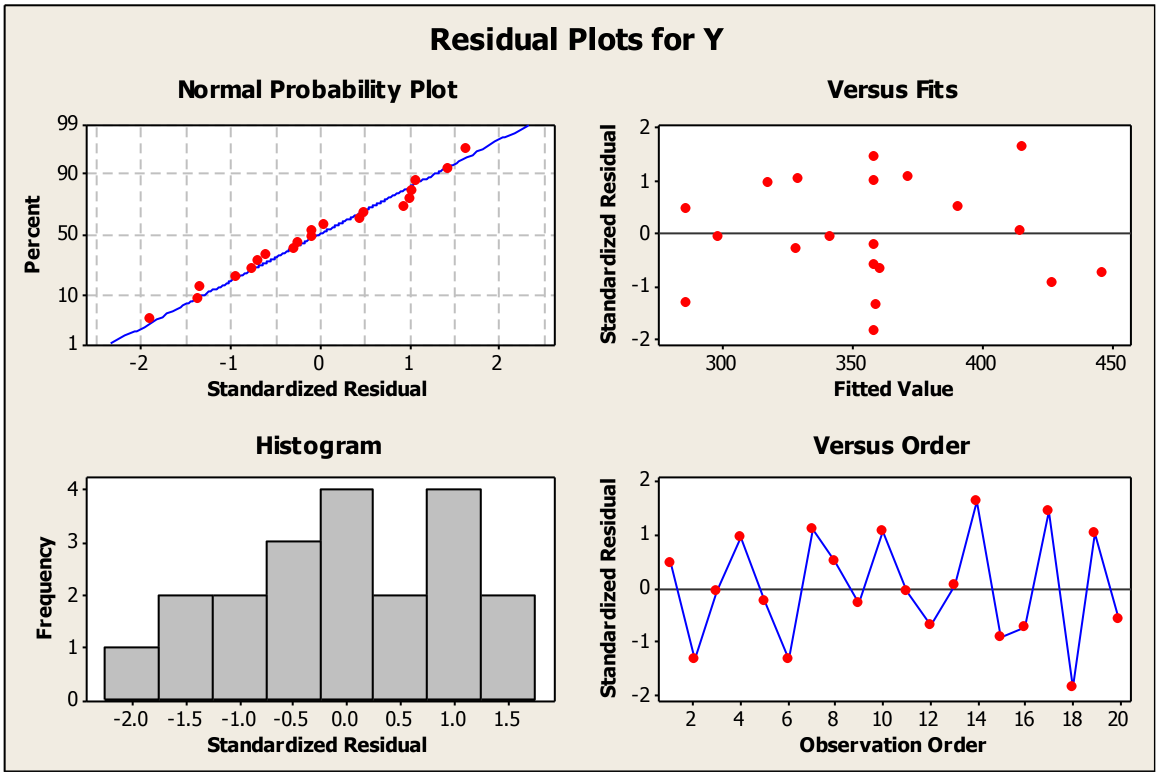
Estimated Effects and Coefficients for Y (coded units)

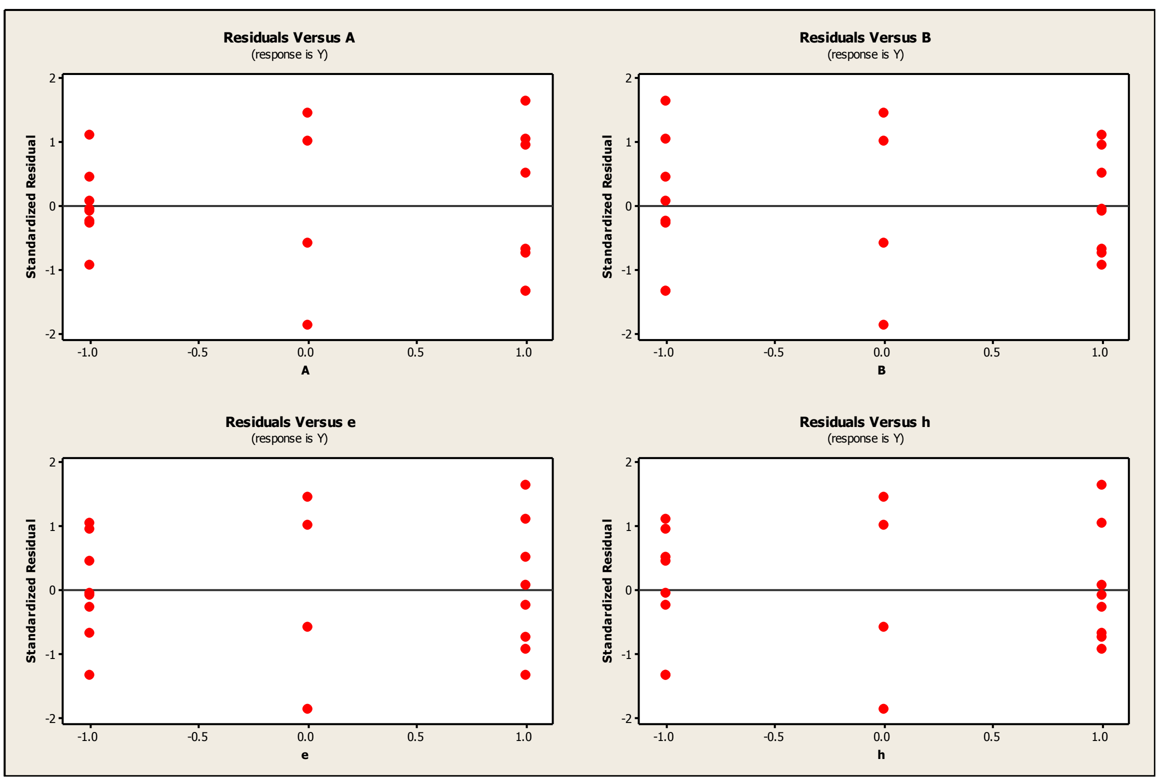
Term	Effect	Coef	SE Coef	T	P
Constant		358.413	0.2769	1294.60	0.000
A	**10.039**	**5.020**	**0.2769**	**18.13**	**0.000**
B	**22.277**	**11.139**	**0.2769**	**40.23**	**0.000**
e	**79.840**	**39.920**	**0.2769**	**144.19**	**0.000**
h	**49.341**	**24.671**	**0.2769**	**89.11**	**0.000**
A*B	**9.316**	**4.658**	**0.2769**	**16.83**	**0.000**
A*e	0.008	0.004	0.2769	0.01	0.990
A*h	0.386	0.193	0.2769	0.70	0.536
B*e	-0.034	-0.017	0.2769	-0.06	0.955
B*h	-0.772	-0.386	0.2769	-1.39	0.258
e*h	**6.543**	**3.271**	**0.2769**	**11.82**	**0.001**
A*B*e	-0.137	-0.068	0.2769	-0.25	0.821
A*B*h	-0.522	-0.261	0.2769	-0.94	0.415
A*e*h	0.154	0.077	0.2769	0.28	0.799
B*e*h	-0.255	-0.128	0.2769	-0.46	0.676
A*B*e*h	0.221	0.110	0.2769	0.40	0.717
Ct Pt		-0.026	0.6191	-0.04	0.969

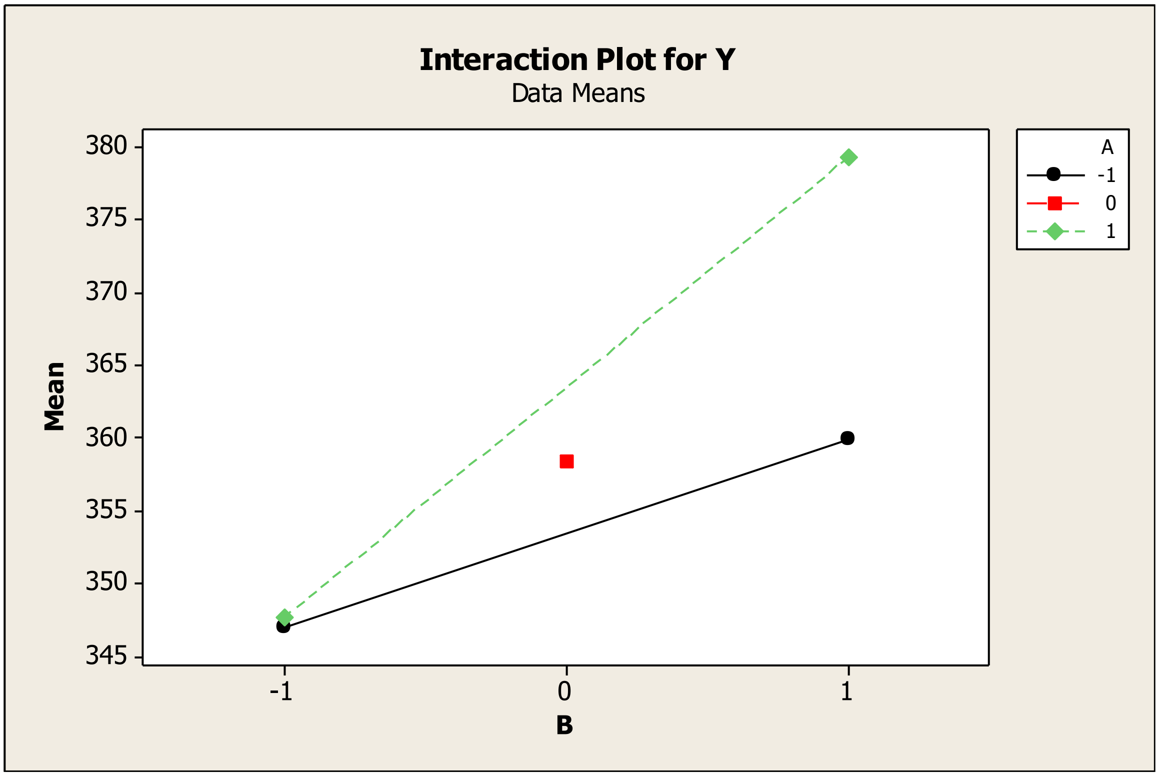
S = 1.10741 PRESS = *
R-Sq = 99.99% R-Sq(pred) = *% R-Sq(adj) = 99.94%

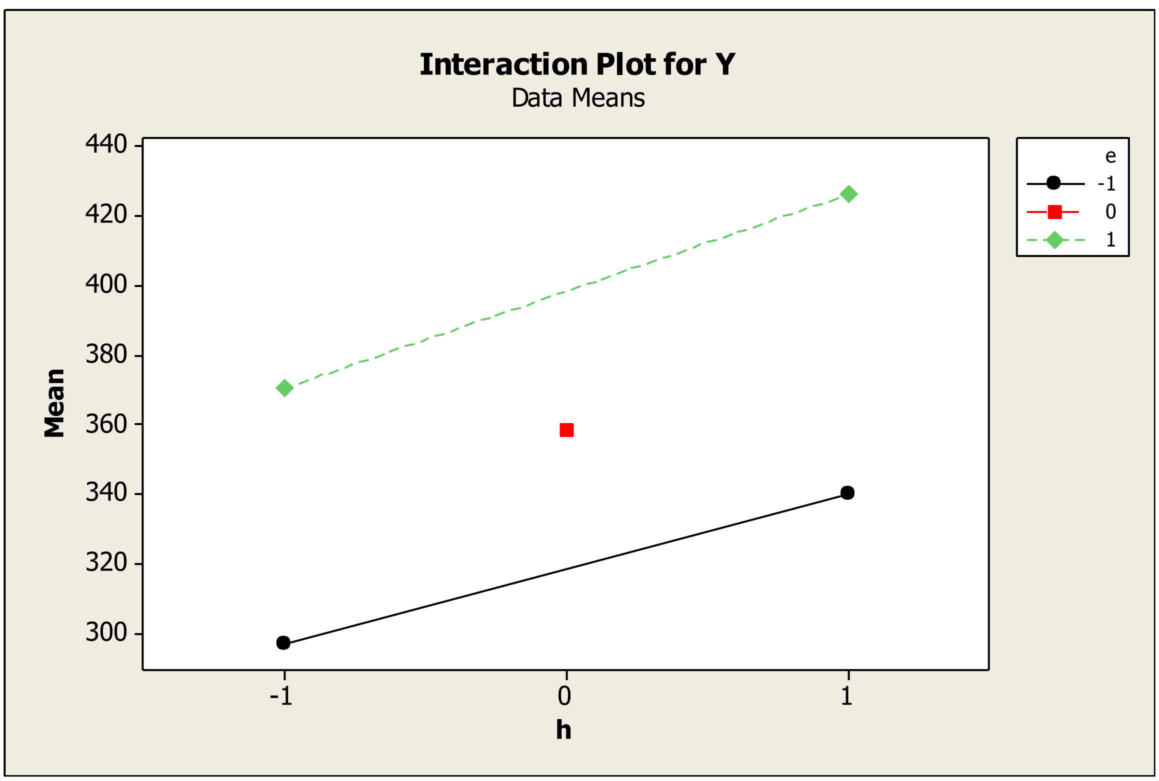
Analysis of Variance for Y (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	37624.3	37624.3	9406.1	7669.95	0.000
A	**1**	**403.1**	**403.1**	**403.1**	**328.72**	**0.000**
B	**1**	**1985.1**	**1985.1**	**1985.1**	**1618.68**	**0.000**
e	**1**	**25497.8**	**25497.8**	**25497.8**	**20791.52**	**0.000**
h	**1**	**9738.3**	**9738.3**	**9738.3**	**7940.88**	**0.000**
2-Way Interactions	6	521.4	521.4	86.9	70.86	0.003
A*B	**1**	**347.2**	**347.2**	**347.2**	**283.10**	**0.000**
A*e	1	0.0	0.0	0.0	0.00	0.990
A*h	1	0.6	0.6	0.6	0.49	0.536
B*e	1	0.0	0.0	0.0	0.00	0.955
B*h	1	2.4	2.4	2.4	1.94	0.258
e*h	**1**	**171.2**	**171.2**	**171.2**	**139.63**	**0.001**
3-Way Interactions	4	1.5	1.5	0.4	0.31	0.856
A*B*e	1	0.1	0.1	0.1	0.06	0.821
A*B*h	1	1.1	1.1	1.1	0.89	0.415
A*e*h	1	0.1	0.1	0.1	0.08	0.799
B*e*h	1	0.3	0.3	0.3	0.21	0.676
4-Way Interactions	1	0.2	0.2	0.2	0.16	0.717
A*B*e*h	1	0.2	0.2	0.2	0.16	0.717
Curvature	**1**	**0.0**	**0.0**	**0.0**	**0.00**	**0.969**
Residual Error	3	3.7	3.7	1.2		
Pure Error	3	3.7	3.7	1.2		
Total	19	38151.1				


Residual Plots for Y
Normal Probability Plot
Percent
99
90
50
10
1
-2
-1
0
1
2
Standardized Residual
Versus Fits
Standardized Residual
300
350
400
450
Fitted Value
Histogram
Frequency
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Standardized Residual
Versus Order
Standardized Residual
Observation Order


Residuals Versus A
(response is Y)
Standardized Residual
A
Residuals Versus B
(response is Y)
Standardized Residual
B
Residuals Versus e
(response is Y)
Standardized Residual
e
Residuals Versus h
(response is Y)
Standardized Residual
h


Interaction Plot for Y
Data Means
Mean
380
375
370
365
360
355
350
345
-1
0
1
B
A
-1
0
1


Interaction Plot for Y
Data Means
Mean
440
420
400
380
360
340
320
300
-1
0
1
h
e
-1
0
1

First, we must check our model assumptions by analyzing the residuals. First, we can begin by checking the model for independence. Since we know the run order in which this design took place, we can utilize the versus order plot to see that there are no discernible patterns or trends within the plot.

The next model assumption we must check is constant variance. The residuals versus variables plots above shows that each of our factors displays a fairly different variance between levels. Once again, there are no funnels or discernible patterns, so the constant variance assumption is clear.

Additionally, the residuals plotted against their fitted values plot depicts how the residuals fall randomly around the zero line and do not display any discernible pattern. This indicates no evidence of non-homogeneity of variance in our quadratic model.

Lastly, we must check our errors for normality. The best way to do this is by using a normal probability plot displayed below. The normal probability plot for our quadratic model exhibits roughly a straight line indicating no departures from normality.

Overall, it is safe to conclude that our residual analysis did not portray any particular violation of our model assumptions.

Based on the above for the 2^4 design with 4 centerpoints, which occupied a total of 20 runs, the results alluded to variables Pack Pressure (A), Pack Time (B), Mold Temperature (E), and Gate Thickness (H), as being significant. In addition to these main effects, two two-way interactions (AB, EH: Pack Pressure $\times$ Pack Time and Mold Temperature $\times$ Gate Thickness) were also significant with p-values $< \alpha$. Based on this output, we decided to run confirmation runs with the remaining 9 runs to test these four factors (A, B, E, and H). In addition, seeing how the curvature statistic was non-significant (p=0.969 > 0.05=α), we will proceed with using a linear model, and would not consider using a quadratic model to fit the data.

Furthermore, the interaction plots provided above show the optimal levels for our experiment. These plots indicate that Pack Pressure (A), Pack Time (B), and Mold Temperature (E), should be set at a high level to increase shrinkage; and variable Gate Thickness (H) should be set at a midpoint value to increase shrinkage.*

Run III – 9 Confirmation Runs

Based on the responses for the final 9 runs, all of them fell within the range of 418.6844 to 420.3842. In order to ensure that these confirmation runs fell within the scope of our experimental design, we calculated the confidence and prediction limits for these values. The confidence limit for our design was (417.973, 420.6297), and the prediction limit was (416.331, 422.2717). Seeing how all of our 9 confirmation run points fell within the scope of both the confidence and predictions limits, we can ensure that our experimental design is one which fits the model well.

During the course of our experiment, we mistook the stated goal and ran our process by setting the variables to yield an increased shrinkage response.

CONCLUSIONS/RECOMMENDATIONS:

Based on the analysis we conducted, we have found that four of the eight variables, heavily impact the shrinkage within the injection molding process. These significant variables, as seen above, are Pack Pressure (A), Pack Time (B), Mold Temperature (E), and Gate Thickness (H). In addition to these main effects, two two-way interactions – AB (Pack Pressure × Pack Time) and EH (Mold Temperature ×Gate Thickness), also seem to be significant.

*****As a result, we can conclude that three of the four (A, B, E) variables seems to impact shrinkage in a positive regard (as these variables are set on the high level, shrinkage within the injection molding process increases). The fourth variable, H, should be set at its midpoint level in order to maximize the response of shrinkage.

With this finding, we can recommend that four variables – A, B, E, and H – be set to a low level when the process is running. The variables set to these levels will minimize the amount of shrinkage which occurs within the system.