Predictive Modeling of LSGT Performance Results for Composition C-4 Utilizing Physical Properties of Input Materials (Abstract # 13893)

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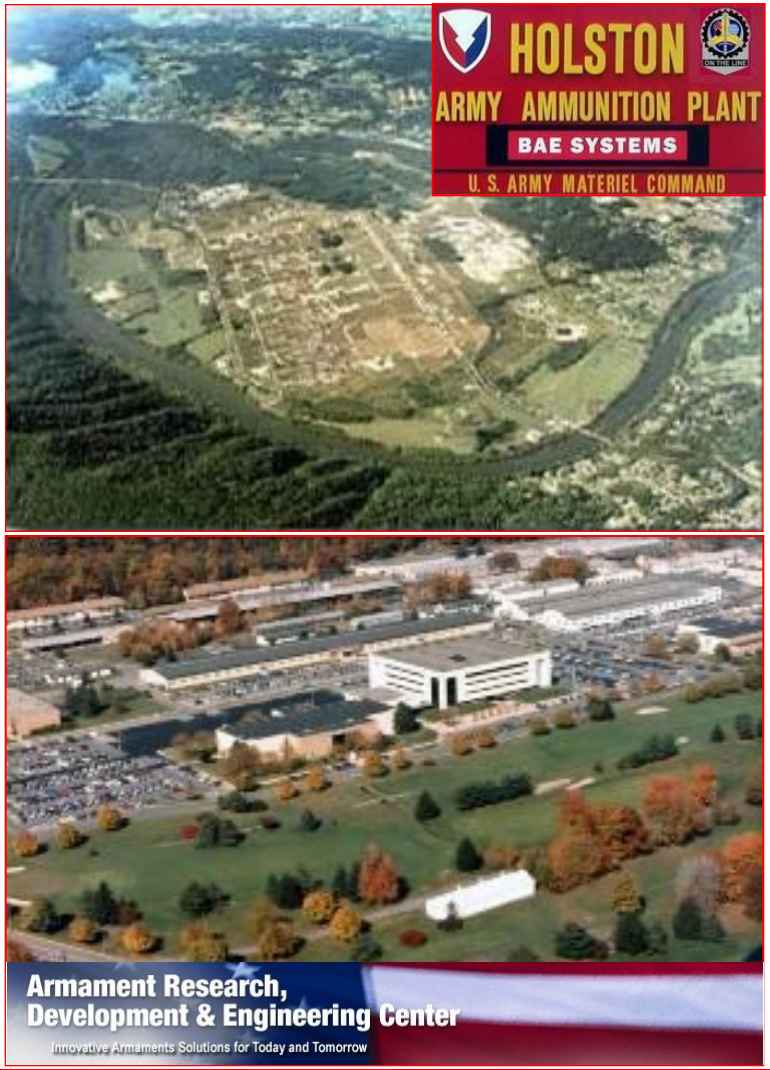


Presentation Outline

- **Predictive Modeling of LSGT Performance Results for Composition C-4 Utilizing Physical Properties of Input Materials**
  - Background
  - Program Objectives
  - Technical Approach
  - Analysis and Evaluation
  - Summary
  - Future Work
  - Conclusion

Composition C-4 - Background

- Composition C-4 is a white plastic-bonded explosive material that can be molded and shaped by hand
- Composition C-4 is a legacy explosive formulation with decades of use.
  - ~ 90.5% RDX
    - Specific ratio of coarse to fine RDX. (3:1, Class 1 to Class 5)
  - ~ 9.5% plastic binder
    - High molecular weight polyisobutylene (PIB)
    - Dioctyladipate (DOA)
    - Lightweight process oil (Oil)

Composition C-4 - Background

- Due to its exceptionally high brisance characteristics, Composition C-4 is mainly used for demolition purposes
  - M112 Demolition Charge
  - M183 Demolition Kit
  - MICLIC
  - M18A1 Claymore Mine
- Composition C-4 is extruded to generate the M112 Demolition Charge
  - The M112 Demolition Charge should be moldable / pliable

M18A1 Claymore

Composition C-4 Phase I – Program Objectives

- Composition C-4 Phase I Production Process Analysis and Optimization Design of Experiments (DOE) was conducted to identify the sources of variability in bulk Composition C-4 and define the process inputs, procedures and metrics that can predict and produce repeatable and consistent bulk Composition C-4 for M112 Demolition Charge extrusion rate
- Analyses of the Phase I data results and in-process record sheets were conducted by the Six Sigma team members to determine the factors and levels for the Phase II Six Sigma C-4 Optimization DOE

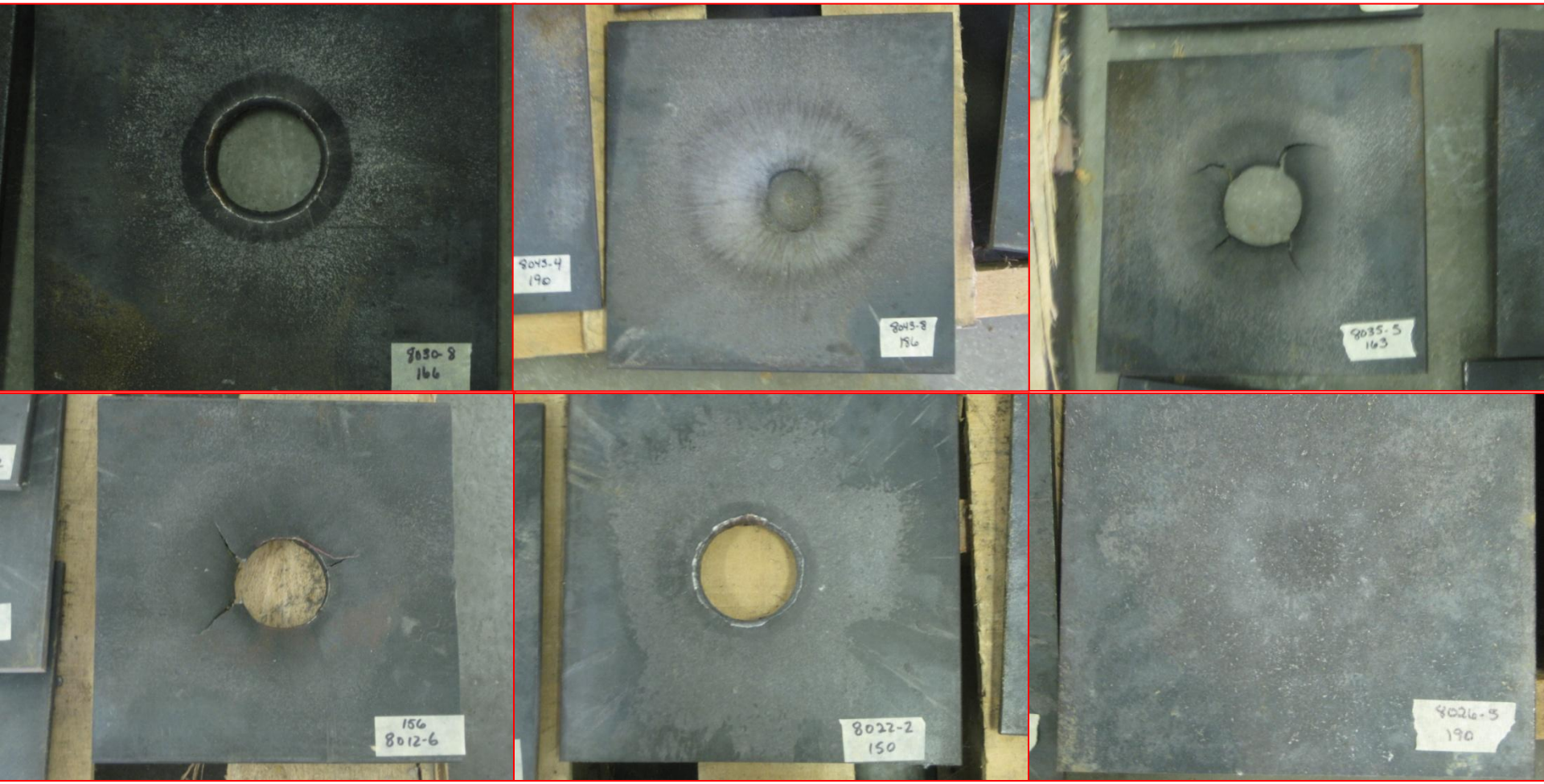
Composition C-4 Phase II – Program Objectives

- From the knowledge gathered during the first phase of the Six Sigma Composition C-4 Optimization DOE, the DOE team determined the three critical parameters in the C-4 manufacturing process
- The Phase II Composition C-4 Process DOE was based on a full factorial design and takes into account the three critical parameters affecting extrusion rate; Drying Cycle Drop Point, RDX particle size, and Virgin / Recovered RDX
- Previous knowledge from BAE Systems and ARDEC indicated the likely major factors affecting the Large Scale Gap Test (LSGT) sensitivity are as follows:
  - RDX particle size
  - RDX particle shape and morphology
  - Binder coating on RDX particles
  - Air gaps in LSGT Sample
  - Impurities in RDX from HMX
  - Density of LSGT Sample

Composition C-4 LSGT – Technical Approach

- The LSGT is the standard test method to evaluate the shock sensitivity of energetic materials.
- Procedure: The test is conducted where a polymethyl-methacrylate (PMMA) attenuator is placed between a donor explosive (pentolite; 50% PETN/50%TNT) and an acceptor explosive (Composition C-4). The attenuator (card) gap is varied following a modified Bruceton Staircase technique until detonation is achieved in a 50% probability. The thickness of the card gap at that point can be translated into shock pressure. The lower the 50% card gap, the lower its shock sensitivity.
- The testing at HSAAP utilizes a witness plate support structure that consists of a 6” long, 7” OD, 1” thick steel tube that is buried in the sand/soil floor on top of a thick steel plate in a covered test area at an outdoor range. A 9” witness plate is approximately centered on the steel support tube. This presents a 3” stand off from the floor to the witness plate with the witness plate supported 360 degrees.

Composition C-4 LSGT - Testing Pictures



Composition C-4 Modeling – Analysis and Evaluation

- During analysis, a large variation in the LSGT result was noticed – 150.0-177.5 card gap difference
  - Looked into the reasoning why
- Initial Development:
- Weight-averaged particle size distribution for the RDX used in Composition C-4 and the results of the LSGT analysis
  - Using only the screen analyses for the RDX inputs and crossed effects of the screen analyses
  - Ignoring all processing variables from the production process
  - The 50 screen, 100 screen, and 200 screen and their crossed effects were used to develop a regression model
- **Looking for:**
  - **R^2 value > 80 %**
  - **Regression P-value < 0.05**

Regression Equation

LSGT^2 = A+B*(50)+C*(100)+D*(200)+E*(50x50)+F*(50x100)+G*(50x200)+H*(100x100)+J*(100x200)
+K*(200x200)

Coefficients

Term	Coef	SE Coef	T	P
Constant		73678.1	1.12387	0.463
50		2391.5	-0.46326	0.724
100		7803.5	0.67521	0.622
200		12708.7	-0.65920	0.629
50 x 50		27.3	0.98190	0.506
50 x 100		27.2	-2.34988	0.256
50 x 200		147.5	0.12072	**0.924**
100 x 100		75.3	1.39333	0.396
100 x 200		398.4	-0.77882	0.579
200 x 200		371.6	0.83027	0.559

Summary of Model

S = 1443.42 R-Sq = 96.95% R-Sq(adj) = 69.50%
PRESS = 13601677139 R-Sq(pred) = -19813.41%

Composition C-4 Modeling – Analysis and Evaluation

- Second Development:
- Remove the component with the highest P-value (so long as it is above 0.05) and re-running the regression model
- This iterative process is repeated until all components have a P-value less than or equal to 0.05
- **R^2 value - 89.7 %**
- **Regression P-value < 0.05**
- Four data points in the model stand out as being different and having an assignable cause. (Higher negative residual)
  - Dried to higher temperature than normal (DOE Variable)

Regression Equation

LSGT^2 = A+B*(50x50)+C*(50x100)+D*(100x100)

Coefficients

Term	Coef	SE Coef	T	P
Constant		775.458	28.6955	0.000
50 x 50		5.407	4.6508	0.002
50 x 100		14.830	-4.3713	0.003
100 x 100		10.059	4.1880	0.004

Summary of Model

S = 1002.67 R-Sq = 89.70% R-Sq(adj) = 85.28%
PRESS = 18139486 R-Sq(pred) = 73.44%

Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	61266661	61266661	20422220	20.3135	0.0007839
50 x 50	1	24185508	21745869	21745869	21.6301	0.0023396
50 x 100	1	19448051	19210499	19210499	19.1082	0.0032689
100 x 100	1	17633102	17633102	17633102	17.5392	0.0040963
Error	7	7037465	7037465	1005352		
Total	10	68304125				

Fits and Diagnostics for All Observations for Transformed Response

Obs	LSGT^2	Fit	SE Fit	Residual	St Resid
1	27722.3	26639.0	635.962	1083.28	1.39745
2	23562.3	23030.1	463.996	532.18	0.59873
3	26406.3	26157.7	939.127	248.58	0.70765
4	24492.3	23539.7	510.341	952.56	1.10368
5	**26732.3**	**27034.6**	**601.097**	**-302.34**	**-0.37674**
6	**23104.0**	**24531.5**	**401.426**	**-1427.51**	**-1.55365**
7	**23409.0**	**24255.8**	**630.881**	**-846.77**	**-1.08654**
8	**22500.0**	**23574.1**	**416.245**	**-1074.10**	**-1.17750**
9	24964.0	24737.1	373.626	226.89	0.24385
10	24492.3	23755.1	383.568	737.12	0.79568
11	31506.3	31636.1	937.448	-129.89	-0.36513

Composition C-4 Modeling – Analysis and Evaluation

- Third Development
- Use **'Drying Type'** as a categorical component in the evaluation
- Eliminate all components that have a P-value less than or equal to 0.05
- **R^2 value - 99.1 %**
- **P-value < 0.05**
- Four components were found as being significant factors
  - 50 screen X 50 screen
  - 100 screen X 100 screen
  - 50 screen X 100 screen
  - Drying type

Regression Equation

Drying Type
Normal LSGT^2 = A+B*(50x50)+C*(50x100)+D*(100x100)

Overdry LSGT^2 = E+F*(50x50)+G*(50x100)+H*(100x100)

Coefficients

Term	Coef	SE Coef	T	P
Constant		261.330	82.7638	0.000
50 x 50		1.910	9.8872	0.000
50 x 100		5.246	-9.0560	0.000
100 x 100		3.559	8.5306	0.000
Drying Type				
Normal		111.696	7.8664	0.000

Summary of Model

S = 321.984 R-Sq = 99.09% R-Sq(adj) = 98.48%
PRESS = 2345731 R-Sq(pred) = 96.57%

Analysis of Variance

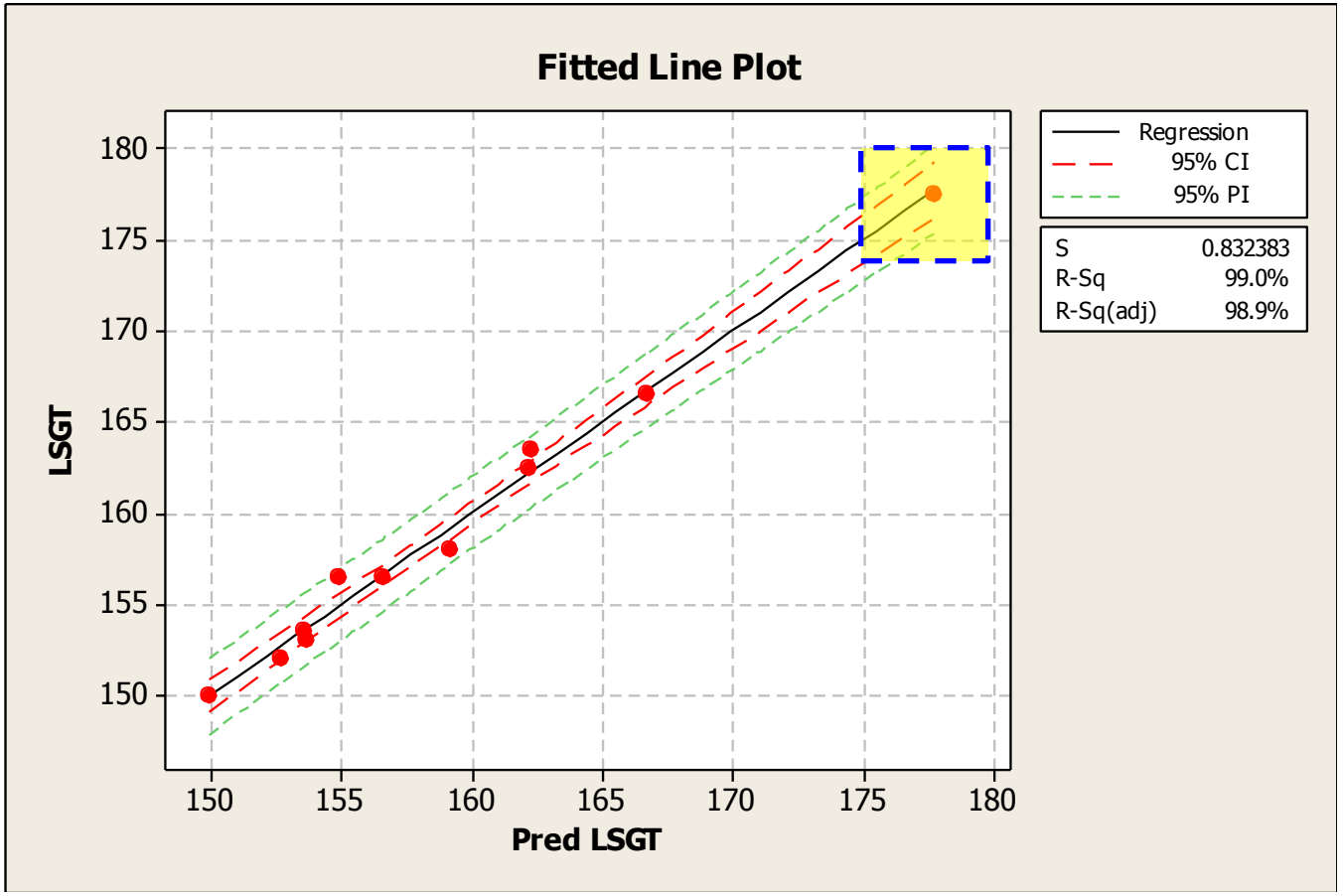
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	67682084	67682084	16920521	163.210	**0.0000030**
50 x 50	1	24185508	10134774	10134774	97.757	**0.0000618**
50 x 100	1	19448051	8502308	8502308	82.010	**0.0001017**
100 x 100	1	17633102	7544457	7544457	72.771	**0.0001422**
Drying Type	1	6415423	6415423	6415423	61.881	**0.0002234**
Error	6	622041	622041	103674		
Total	10	68304125				

Fits and Diagnostics for All Observations for Transformed Response

Obs	LSGT^2	Fit	SE Fit	Residual	St Resid
1	27722.3	27797.4	251.779	-75.135	-0.37436
2	23562.3	23598.1	165.576	-35.841	-0.12979
3	26406.3	26316.4	302.252	89.804	0.80918
4	24492.3	24010.8	174.483	481.459	1.77917
5	26732.3	26342.9	212.109	389.305	1.60706
6	23104.0	23319.2	200.921	-215.160	-0.85515
7	23409.0	23604.6	218.851	-195.605	-0.82822
8	22500.0	22478.5	193.036	21.459	0.08327
9	24964.0	25328.5	141.590	-364.519	-1.26052
10	24492.3	24515.5	156.575	-23.284	-0.08276
11	31506.3	31578.7	301.127	-72.484	-0.63582

Composition C-4 Modeling – Analysis and Evaluation

- Predicted LSGT result versus the observed LSGT result
- One data point at a higher LSGT result that may be driving the regression model



Composition C-4 Modeling – Analysis and Evaluation

- Investigate if the higher data point has a significant effect on the overall model
- **After Removal of data point from data set and repeat of regression analysis:**
  - **R^2 value - 97.8 %**
  - **P-value < 0.05**

Regression Equation

Drying Type
Normal LSGT^2 = A+B*(50x50)+C*(50x100)+D*(100x100)

Overdry LSGT^2 = E+F*(50x50)+G*(50x100)+H*(100x100)

Coefficients

Term	Coef	SE Coef	T	P
Constant	276.466	78.2284	0.000	
50 x 50	4.213	5.0100	0.004	
50 x 100	11.223	-4.7557	0.005	
100 x 100	7.420	4.6097	0.006	
Drying Type				
Normal	118.405	7.3824	0.001	

Summary of Model

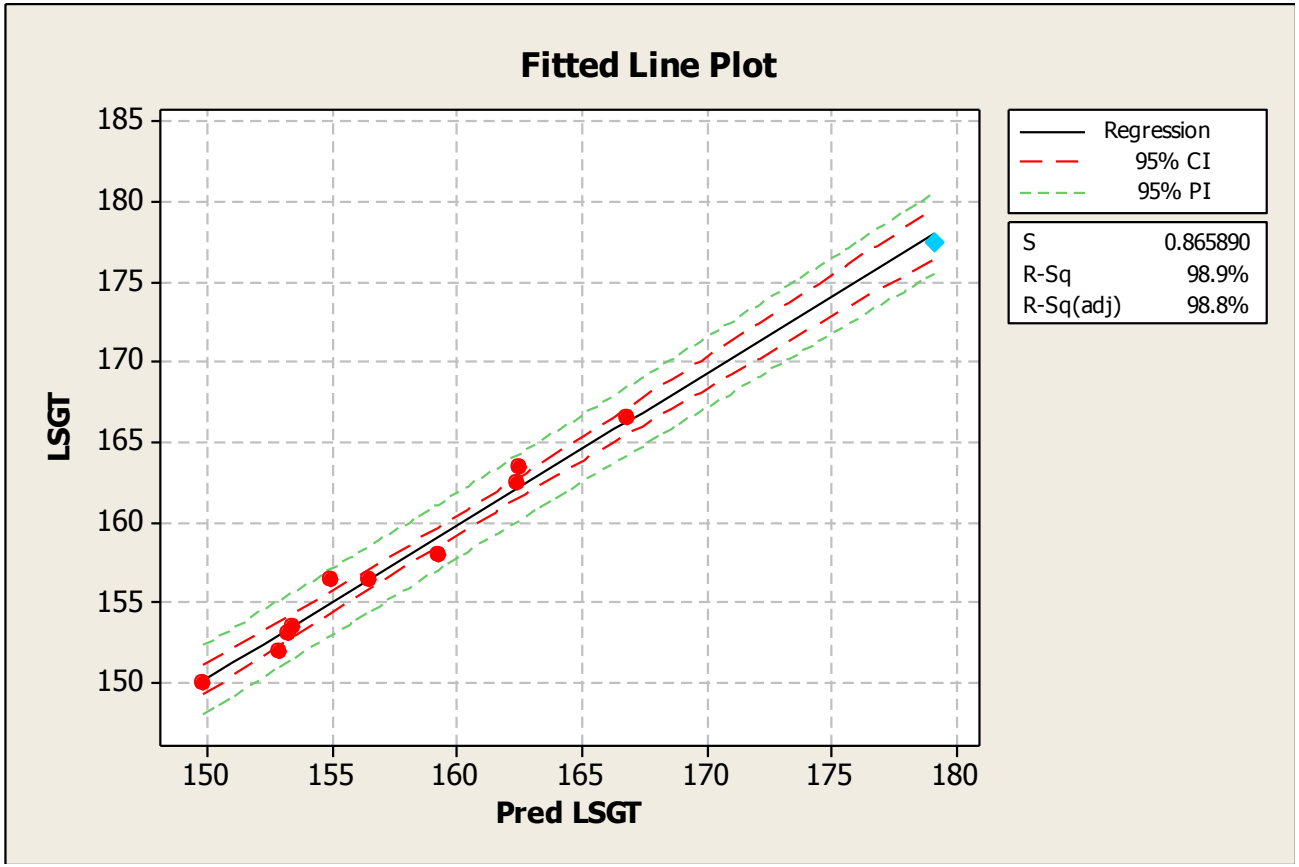
S = 340.626 R-Sq = 97.82% R-Sq(adj) = 96.08%
PRESS = 3621879 R-Sq(pred) = 86.42%

Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	26084799	26084799	6521200	56.2047	0.0002406
50 x 50	1	12305793	2912208	2912208	25.0997	0.0040699
50 x 100	1	2033469	2624080	2624080	22.6163	0.0050789
100 x 100	1	5422234	2465517	2465517	21.2497	0.0057889
Drying Type	1	6323303	6323303	6323303	54.4991	0.0007170
Error	5	580129	580129	116026		
Total	9	26664928				

Composition C-4 Modeling – Analysis and Evaluation

- Predicted LSGT result versus the observed LSGT result
- The data point at 177.5 cards falls within the predictive model developed without that data point. Therefore, it is acceptable to include this data point in developing the regression model because it does not have an influence that manipulates the results



Composition C-4 Modeling – Analysis and Evaluation

- Two evaluations are conducted to determine if the regression model is skewed at any data level.
  - Performed an **Anderson – Darling** analysis to determine if the residuals are normally distributed
    - P-value must be > 0.05
      - Resulted with Anderson-Darling P-Value of 0.216
  - **Fitted Line Plot** of the residual versus the observed LSGT result
    - P-value must be > 0.05
      - Resulted with P-Value of 0.741

Composition C-4 Modeling – Summary

Predictive Model Equation:

$$LSGT_{PRED} = \sqrt{\text{A+B*(50x50)+C*(50x100)+D*(100x100)}}$$

This equation can be utilized for prediction of LSGT results for Composition C-4 that has been dried in a “normal” fashion at HSAAP. This model was based exclusively on Composition C-4 made with Vistanex PIB binder.

Composition C-4 Modeling – Summary

Actual vs. Predicted using Predictive Modeling Equation

Batch	50	100	200	LSGT	Drying Type	Pred LSGT	Residual
C403-7921				166.5	Normal	166.7	-0.2
C403-R7923				153.5	Normal	153.6	-0.1
C403-R7929				162.5	Normal	162.2	0.3
C403-7932				156.5	Normal	155.0	1.5
C403-7920				163.5	Overdry	162.3	1.2
C403-R7922				152.0	Overdry	152.7	-0.7
C403-R7930				153.0	Overdry	153.6	-0.6
C403-7931				150.0	Overdry	149.9	0.1
C403-R7999				158.0	Normal	159.1	-1.1
C403-8012				156.5	Normal	156.6	-0.1
C403-8014				177.5	Normal	177.7	-0.2

Composition C-4 Modeling – Future Work

- Future Composition C-4 will be made with Oppanol PIB binder vs. Vistanex PIB
- Repeat the Modeling development for Composition C-4 made with Oppanol PIB binder
- Utilize the process/parameters in Phase I and II of the six sigma project to predict how Composition C-4 will extrude
- Analyze how other likely major factors may influence the LSGT Results
  - RDX Particle Size
  - Particle Morphology
  - Binder coating on RDX particles
  - Air gaps in LSGT Sample
  - Impurities in RDX from HMX
  - Density of LSGT Sample

Conclusion

Successfully demonstrated that the LSGT can be predicted for Composition C-4 based on:

RDX Particle Size

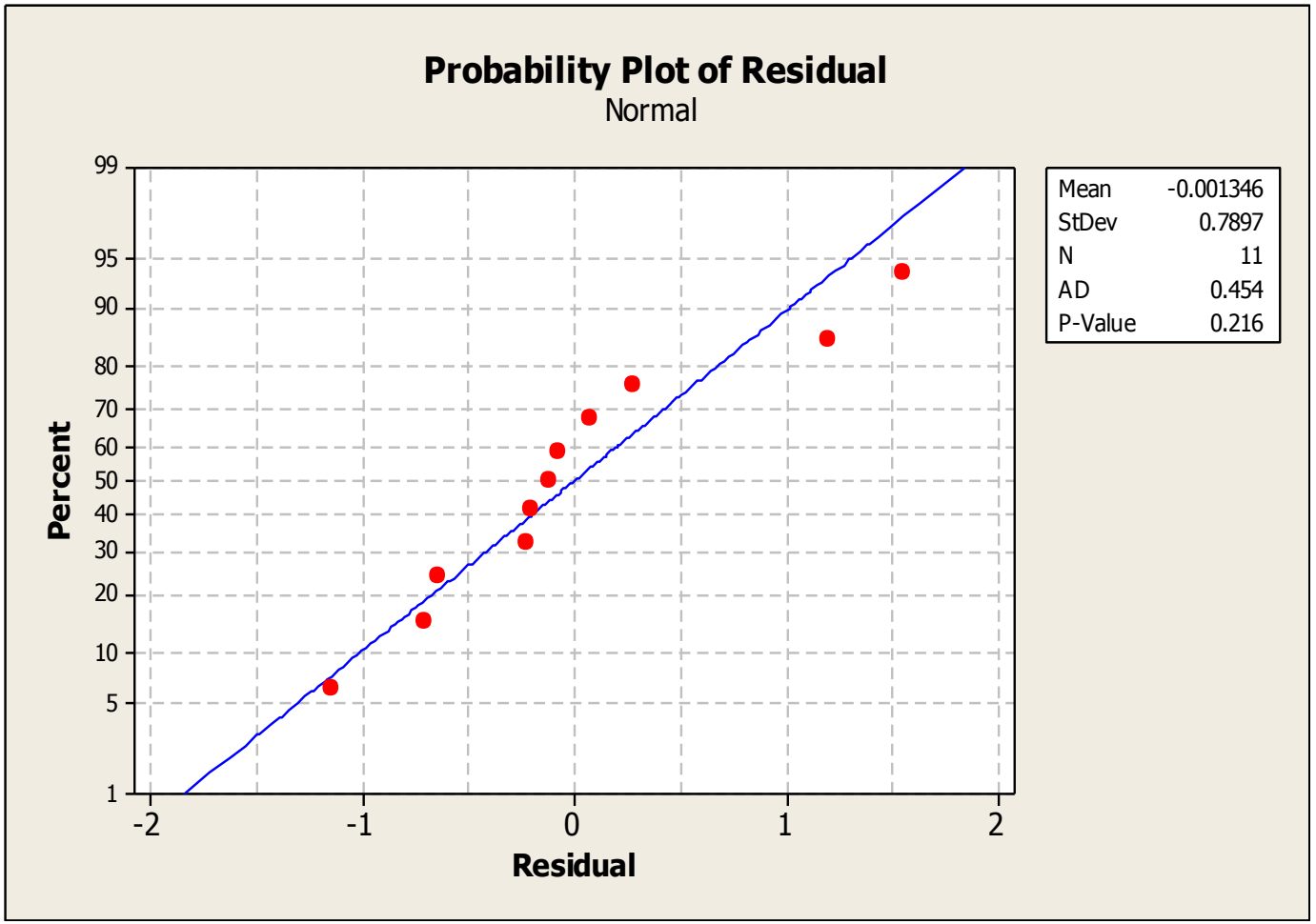
with

R^2 value - 97.8 %

Questions?

Composition C-4 Modeling – Analysis and Evaluation

- Anderson-Darling Analysis
- The normality of the residuals (defined as the observed LSGT result minus the predicted LSGT result) for the predicted LSGT results compared to the Observed LSGT results
- P-value > 0.05, therefore the residuals are normally distributed



Composition C-4 Modeling – Analysis and Evaluation

- Fitted Line Plot
- Determine if the regression model is skewed at any data level is the fitted line plot of the residual versus the observed LSGT result
- No statistical trend seen in the residual of the Predicted LSGT result when plotted against the observed LSGT result.
- P-value > 0.05