Design of experiments

A Project Report

On

Determining how to optimize the settings for optimal surface finish in a sand - blasting experiment

Submitted By,

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Introduction :

Surface finishing is an important factor in engineering applications as it determines how an object will interact with its environment. Statistical descriptor Ra is one of the most common and effective measures used to measure the surface finishing in most of the engineering applications. Ra is the arithmetic average of surface heights measured across a surface. Our team is conducting an experiment related to sand blasting surfaces using a new piece of equipment and the goal of our experiment is to minimize the surface finish (Ra) to be less than 10μm. Our project manager has allocated enough resources for 64 runs. We had 4 lab days to complete the experiment and the maximum number of runs we could complete in a day is 32.

For our project Ra is the response variable and we have considered eight potential factors each having two levels: a high and a low.

The factor and their levels considered for this experiment are given below.

Factors	**Low Level**	**High Level**
Grit Size (A)	20	100
Pressure (psi) (B)	50	100
Distance from Surface (inches) (C)	6	18
Number of Passes (D)	1	9
Nozzle Size (inches) (E)	0.125	0.5
Nozzle Shape (F)	Shape 1	Shape 2
Speed (mm/sec) (G)	50	150
Surface Area (sq. feet) (H)	1	3

Table 1: Table of Factors with their levels

Choice of Design:

Our team decided to approach this experiment sequentially. We used two different designs, a total of 58 runs and 3 lab days to complete the experiment.

Design 1:

We had a total of eight factors but had the budget to run only 64 runs. So, keeping in mind the Sparsity of effects principle, the higher order interactions were neglected and a 2^{8-3} resolution IV fractional factorial screening design was selected. The design also has 4 center points to test for the curvature. In total, our design has 36 runs and will be completed in two days.

The generators for the design are:

F = CDE, G = ABDE and H = ABCE

The defining relation is:

I = CDEF = ABDEG = ABCEH = ABCFG = ABDFH = CDGH.

The aliasing effects for this design are given below.

Aliasing of Effects

Effects	Aliases
Distance*Passes	= Nozzle Size*Nozzle Shape = Speed*Area
Distance*Nozzle Size	= Passes*Nozzle Shape
Distance*Nozzle Shape	= Passes*Nozzle Size
Distance*Speed	= Passes*Area
Distance*Area	= Passes*Speed
Nozzle Size*Speed	= Nozzle Shape*Area
Nozzle Size*Area	= Nozzle Shape*Speed

Figure 1: Aliasing of effects.

This design will help us estimate all the main effects and some two factor interactions as the design has aliasing between some two factor interactions.

Results :

Our team used the screening option in jmp to decide on the interactions that we wanted in our model as fitting a full model biased or zeroed some of the parameter estimates due loss of degree of freedom.

The parameter estimates table for the fitted model is given below.

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	16.1975	0.139759	115.90	<.0001*
Grit Size(20,100)	-1.485313	0.049412	-30.06	<.0001*
Pressure(50,100)	1.9365625	0.049412	39.19	<.0001*
Distance(6,18)	0.5784375	0.049412	11.71	<.0001*
Passes(1,9)	0.0721875	0.049412	1.46	0.1604
Nozzle Size(0.125,0.5)	-3.039062	0.049412	-61.50	<.0001*
Nozzle Shape[Shape 1]	0.1755556	0.046586	3.77	0.0013*
Speed(50,150)	0.0221875	0.049412	0.45	0.6585
Area(1,3)	1.9234375	0.049412	38.93	<.0001*
Nozzle Size*Nozzle Size	6.2946875	0.148236	42.46	<.0001*
Nozzle Size*Grit Size	-1.326562	0.049412	-26.85	<.0001*
Nozzle Size*Area	-0.511563	0.049412	-10.35	<.0001*
Nozzle Size*Area*Passes	-0.399063	0.049412	-8.08	<.0001*
Pressure*Nozzle Shape[Shape 1]	-0.119687	0.049412	-2.42	0.0256*
Pressure*Grit Size	-0.115937	0.049412	-2.35	0.0300*
Pressure*Distance	-0.104688	0.049412	-2.12	0.0475*
Pressure*Area	0.1028125	0.049412	2.08	0.0512

Figure 2: Parameter Estimates of Design 1.

From the above table our team concluded that the main factors, Passes and Speed were not significant. Hence, we decided to remove them from the model.

Our model after removing all the non significant factors is given below.

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	16.1975	0.283191	57.20	<.0001*
Grit Size(20,100)	-1.485313	0.100123	-14.83	<.0001*
Pressure(50,100)	1.9365625	0.100123	19.34	<.0001*
Distance(6,18)	0.5784375	0.100123	5.78	<.0001*
Nozzle Size(0.125,0.5)	-3.039062	0.100123	-30.35	<.0001*
Nozzle Shape[Shape 1]	0.1755556	0.094397	1.86	0.0743
Area(1,3)	1.9234375	0.100123	19.21	<.0001*
Nozzle Size*Nozzle Size	6.2946875	0.300369	20.96	<.0001*
Nozzle Size*Grit Size	-1.326562	0.100123	-13.25	<.0001*
Nozzle Size*Area	-0.511563	0.100123	-5.11	<.0001*

Figure 3: Parameter Estimates of reduced model.

Even though the main factor Nozzle Shape is not significant for alpha = 0.05 we decided to keep that in our model as its p-value is close to 0.05.

Our team conducted residuals analysis on the reduced model and concluded that the residuals follow all three model assumptions of normality, constant variance and independency. From the Lack of fit test we found that our model has no lack of fit.

We also did a design evaluation test and found that our model has a D efficiency of 73.05% with an average variance of prediction 0.226.

From all the above results our team concluded that our model is adequate and ready for predictions.

We used the reduced model to find the optimum settings for our Ra to be less than 10μm.

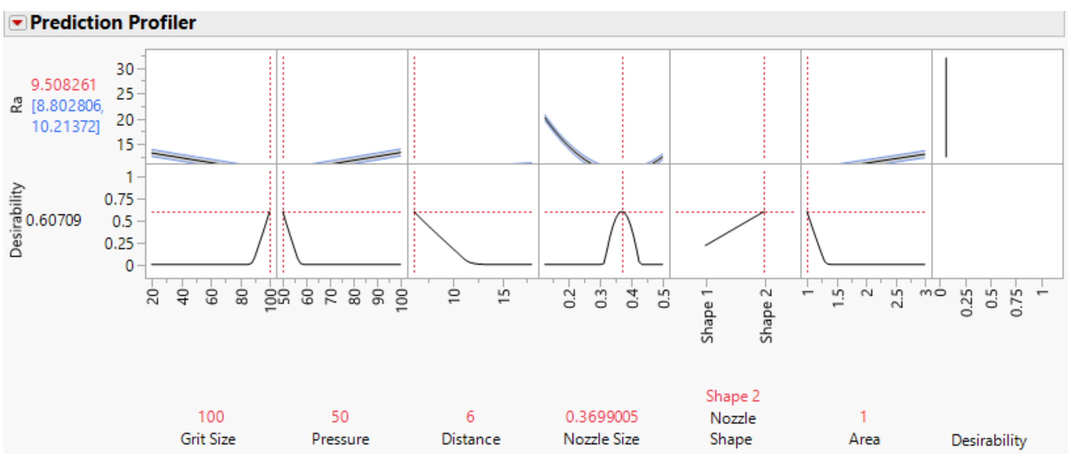


Figure 4: Prediction Profiler for Design 1.

Since Passes and Speed are not significant our team decided to keep them at a low level as 1 pass will save time in comparison to 9 and keeping at low speed will save energy. So the decided settings for Passes = 1 and Speed = 50 mm/sec.

We conclude that keeping Grit Size = 100, Pressure = 50 psi, Distance = 6 inc, Nozzle Size = 0.37 inc, Nozzle Shape = 2 and Area = 1 sq.ft will give a Ra of 9.51 and with 95% confidence we can say that for the above setting the Ra value will be between the interval [8.803, 10.214].

Design 2:

From the first design our team concluded that we had a significant curvature as one of the quadratic effects was active. We couldn't conclude which quadratic effect was active because of confounding so we decided to add some axial points in the design. Also, from the first design we concluded that the main factors, Passes and Speed should be kept at low settings as their effects were not significant. Hence, our team decided to run a Definitive Screening design with six factors and eight extra runs. In total, our model has 22 runs and we will require one day to complete the experiment. We decided to go with Definitive Screening design as in Definitive Screening design quadratic effects and two factor interactions are orthogonal to the main effects and all quadratic effects can be estimated.

Results:

From the parameter estimates table we concluded that the main factor shape was also not significant at alpha = 0.05 and decided to remove it from the model. The parameter estimates for the reduced model are given below.

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	16.162545	0.163288	98.98	<.0001*
Grit Size(20,100)	-1.640556	0.070063	-23.42	<.0001*
Pressure(50,100)	1.9872222	0.070063	28.36	<.0001*
Distance(6,18)	0.5183333	0.070063	7.40	<.0001*
Nozzle Size(0.125,0.5)	-2.909444	0.070063	-41.53	<.0001*
Area(1,3)	1.8816667	0.070063	26.86	<.0001*
Grit Size*Distance	0.5127966	0.080945	6.34	<.0001*
Grit Size*Nozzle Size	-1.520754	0.079612	-19.10	<.0001*
Nozzle Size*Area	-0.508048	0.079107	-6.42	<.0001*
Pressure*Pressure	6.1857778	0.183929	33.63	<.0001*

Figure 5: Parameter Estimates of Design 2.

From the above parameter estimates table, we conclude that the active quadratic effect in the model is Pressure*Pressure. We can also conclude that the Grit Size*Distance, Grit Size*Nozzle Size, Nozzle Size*Area are the active interactions in the model.

Next, we conducted residuals analysis on the reduced model and concluded that the residuals follow all three model assumptions of normality, constant variance and independency. From the Lack of fit test we found that our model has no lack of fit.

We also did a design evaluation test and found that our model has a D efficiency of 65.73% with an average variance of prediction 0.286.

From all the above results our team concluded that our model is adequate and ready for predictions.

We used the reduced model to find the optimum settings for our Ra to be less than 10µm.

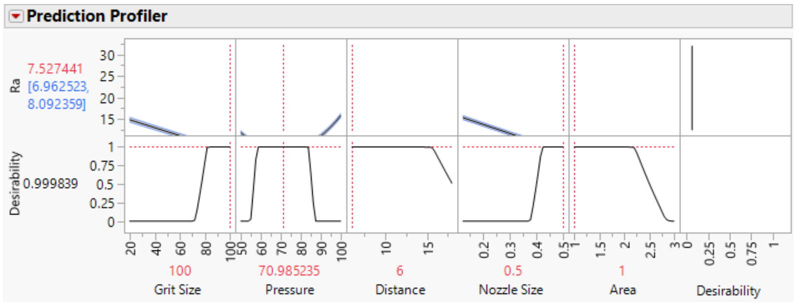


Figure 6: Prediction Profiler for Design 2.

Since Shape is not significant our team decided to go with shape 2.

So we conclude that keeping Grit Size = 100, Pressure = 71 psi, Distance = 6 inc, Nozzle Size = 0.5 inc and Area = 1 sq.ft will give a Ra of 7.53 and with 95% confidence we can say that for the above setting the Ra value will be between the interval [6.963, 8.092].

Conclusions:

1. From design 1, our team concluded that the main factors Passes and Speed were not significant and decided to keep them both at a low level.
2. The settings decided for the factors by our team after analysis of the first design are given below.

   Grit Size = 100, Pressure = 50 psi, Distance = 6 inc, Nozzle Size = 0.37 inc, Nozzle Shape = 2, Area = 1 Sq.ft, Passes = 1 and Speed = 50 mm/sec.

3. From the second design we concluded that the main factor Nozzle Shape is also not significant and decided to go with Shape 2.
4. The settings decided for the factors by our team after analysis of the second design are given below.

   Grit Size = 100, Pressure = 71 psi, Distance = 6 inc, Nozzle Size = 0.5 inc, Nozzle Shape = 2, Area = 1 Sq.ft, Passes = 1 and Speed = 50 mm/sec.

5. From the second model we also concluded that the quadratic effect Pressure*Pressure was active.

   We also saw that the Grit Size*Distance, Grit Size*Nozzle Size, Nozzle Size*Area are the active interactions in the model.

   I.e we get the best results when,

   - Grit Size is at high level and Distance at low level.
   - Grit Size is at high level and Nozzle Size at high level.
   - Nozzle Size is at high level and Area at low level.
6. We also concluded that our model satisfies all the three assumptions of normality, constant variance and independency.

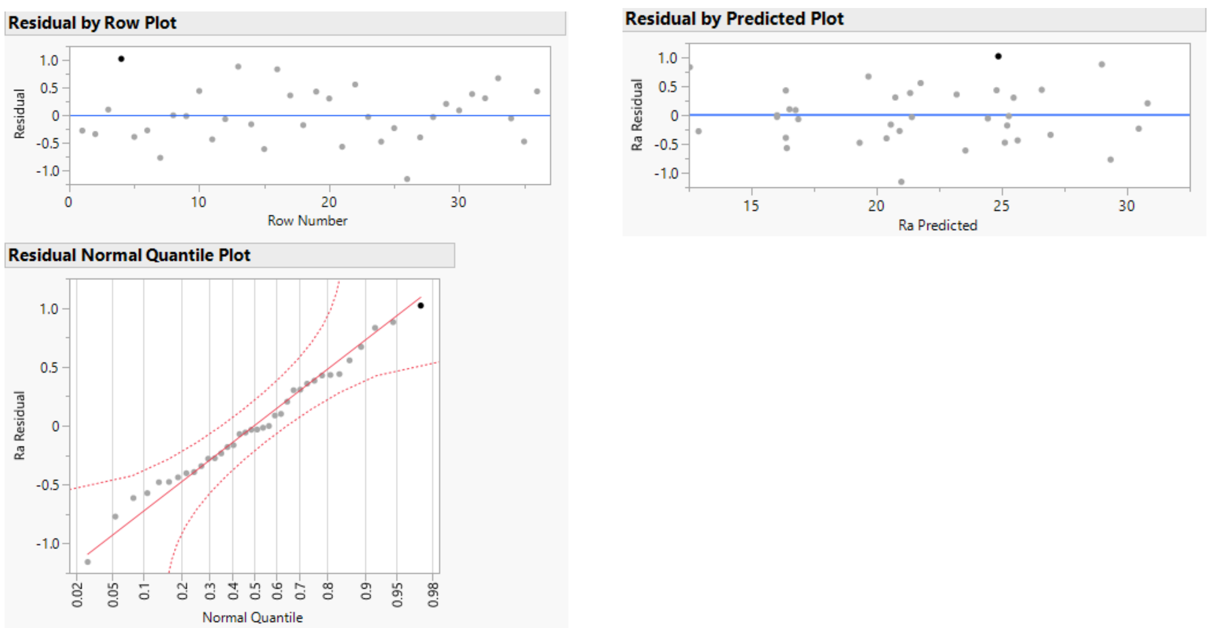
Appendix:

- Lack of fit test for Design 1

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	24	8.0038389	0.333493	1.9812
Pure Error	2	0.3366500	0.168325	**Prob > F**
Total Error	26	8.3404889		0.3901
				Max RSq
				0.9996

- Residual analysis plots for design 1



- Design diagnostics of model 1

Design Diagnostics

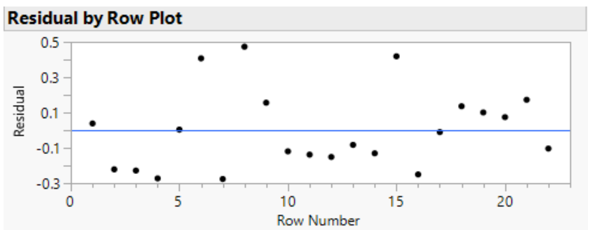
D Efficiency	73.05564
G Efficiency	68.96552
A Efficiency	35.71429
Average Variance of Prediction	0.226389
Design Creation Time (seconds)	0

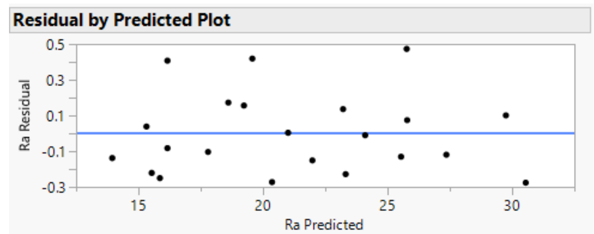
- Lack of fit test for Design 2

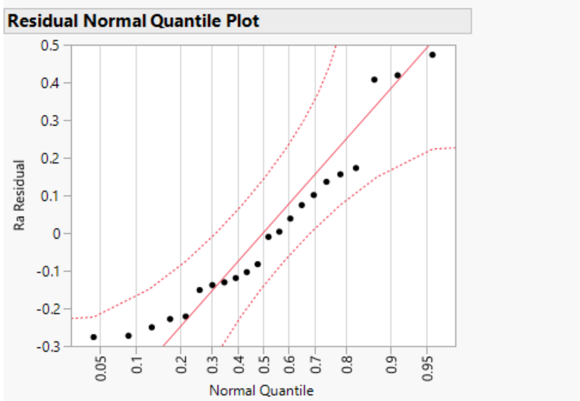
Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	11	0.9402592	0.085478	0.7120
Pure Error	1	0.1200500	0.120050	**Prob > F**
Total Error	12	1.0603092		0.7390
				Max RSq
				0.9998

- Residual analysis plots for design 2







- Design diagnostics of model 2

Design Diagnostics

D Efficiency	65.72575
G Efficiency	49.0274
A Efficiency	38.54989
Average Variance of Prediction	0.286163
Design Creation Time (seconds)	0

- Interaction Plots for design 2