

Design and Analysis Report

Tables 1a and 1b summarize the factors and responses studied.

Factors	Role	Changes	Values
Load	Continuous	Easy to change	200, 800
Temperature	Continuous	Easy to change	-40, 150
Bolt Diameter	Discrete Numeric	Easy to change	7, 8, 10
Grade of Stainless Steel	Categorical	Easy to change	18-8, 304, 316

Table 1a: Factors

Response(s)	Goal	Limits	Importance	Detection Limits
MoP 1	Maximize	$3700 \leq \text{MoP 1}$	NA	NA
MoP 2	Match Target	$700 \leq \text{MoP 2} \leq 900$	NA	NA
MoP 3	Minimize	$\text{MoP 3} \leq 0.28$	NA	NA

Table 1b: Responses

The initial model used in designing the experiment included the following model terms.

Load, Temperature, Bolt Diameter, Bolt Diameter*Bolt Diameter, Grade of Stainless Steel, Load*Load, Load*Temperature, Temperature*Temperature, Load*Bolt Diameter, Temperature*Bolt Diameter, Load*Grade of Stainless Steel, Temperature*Grade of Stainless Steel, Bolt Diameter*Grade of Stainless Steel

The experimental results are presented in Table 2.

MoP 1	MoP 2	MoP 3	Load	Temperature	Bolt Diameter	Grade of Stainless Steel
3510.43	521.225	0.20907	200	150	8	316
3823.99	612.716	0.17284	200	55	10	18-8
3674.84	627.291	0.23711	248	18.9	7	316
3430.82	411.018	0.68239	800	-40	7	304
3859.1	758.912	0.32836	500	55	8	316
3768.58	713.432	0.31497	800	150	7	316
3602.54	622.523	0.6816	800	-40	10	18-8
3751.91	666.062	0.42651	500	-40	7	18-8
3641.1	541.8	0.16907	200	150	10	304
3789.15	731.455	0.36753	500	55	8	304
3738.59	831.116	0.27029	800	150	8	18-8
3684.92	677.327	0.36808	800	55	7	18-8
3609.73	573.272	0.72558	800	-40	8	316
3789.88	618.964	0.20473	200	-40	10	316
3592.88	505.158	0.2295	200	-40	7	304
3822.43	709.409	0.31649	500	150	10	316
3387.51	459.047	0.19363	200	150	7	18-8
3760.82	658.618	0.28436	500	150	7	304
3807.91	596.034	0.48489	500	-40	10	304
3812.69	755.76	0.36673	500	55	8	304
3747.93	659.036	0.24124	200	-40	8	18-8
3786.43	695.404	0.58135	800	55	10	316
3786.47	775.371	0.44364	800	150	10	304
3790.99	759.345	0.26398	500	150	10	18-8

Table 2: Design

Final parameter estimates for the remaining terms after model selection are presented in Table 3.

Term	Response MoP 1		
	Estimate	Lower 95%	Upper 95%
Intercept	3860.12	3829.56	3890.67
Load(200,800)	14.748	0.45447	29.0414
Bolt Diameter(7,10)	59.2244	45.3534	73.0954
Bolt Diameter*Bolt Diameter	-18.772	-48.522	10.9794
Grade of Stainless Steel[18-8]	3.42018	-12.823	19.6634
Grade of Stainless Steel[304]	-18.775	-35.477	-2.0727
Load*Load	-135.52	-161.52	-109.52
Load*Temperature	103.791	87.7943	119.787
Temperature*Temperature	-68.421	-95.135	-41.708
Load*Bolt Diameter	-32.599	-48.679	-16.518
Load*Grade of Stainless Steel[18-8]	-7.265	-26.641	12.1105

Response MoP 1			
Term	Estimate	Lower 95%	Upper 95%
Load*Grade of Stainless Steel[304]	-18.921	-40.396	2.55408
Temperature*Grade of Stainless Steel[18-8]	-35.547	-54.464	-16.63
Temperature*Grade of Stainless Steel[304]	38.6799	19.4363	57.9236
RSquare	0.9833		
Root Mean Square Error	24.918		

Response MoP 2			
Term	Estimate	Lower 95%	Upper 95%
Intercept	781.444	759.968	802.92
Load(200,800)	48.7472	38.7243	58.77
Temperature(-40,150)	33.8094	24.0697	43.5492
Bolt Diameter(7,10)	27.088	17.3108	36.8651
Bolt Diameter*Bolt Diameter	-63.712	-84.692	-42.733
Grade of Stainless Steel[18-8]	30.927	19.5083	42.3458
Grade of Stainless Steel[304]	-30.061	-41.821	-18.301
Load*Load	-88.378	-106.83	-69.925
Load*Temperature	82.292	71.0384	93.5457
Temperature*Temperature	-43.963	-62.825	-25.101
Load*Bolt Diameter	4.99268	-6.2841	16.2695
Load*Grade of Stainless Steel[18-8]	18.502	4.91678	32.0873
Load*Grade of Stainless Steel[304]	-13.889	-28.946	1.16699
Temperature*Grade of Stainless Steel[18-8]	-16.274	-29.697	-2.8505
Temperature*Grade of Stainless Steel[304]	32.3929	18.6084	46.1774
Bolt Diameter*Grade of Stainless Steel[18-8]	4.88212	-8.3329	18.0971
Bolt Diameter*Grade of Stainless Steel[304]	6.09457	-7.5097	19.6988
RSquare	0.9926		
Root Mean Square Error	16.46		

Response MoP 3			
Term	Estimate	Lower 95%	Upper 95%
Intercept	0.34804	0.33258	0.3635
Load(200,800)	0.1588	0.15104	0.16656
Temperature(-40,150)	-0.0948	-0.1022	-0.0875
Bolt Diameter(7,10)	0.01968	0.0123	0.02705
Bolt Diameter*Bolt Diameter	-0.0105	-0.0265	0.00554
Grade of Stainless Steel[18-8]	-0.0322	-0.041	-0.0235
Grade of Stainless Steel[304]	0.01901	0.01027	0.02776
Load*Temperature	-0.0796	-0.0883	-0.0709
Temperature*Temperature	0.02835	0.01413	0.04256
Load*Bolt Diameter	0.03468	0.02598	0.04337

Response MoP 3			
Term	Estimate	Lower 95%	Upper 95%
Load*Grade of Stainless Steel[18-8]	-0.0362	-0.0468	-0.0257
Load*Grade of Stainless Steel[304]	0.02306	0.0114	0.03473
RSquare	0.9964		
Root Mean Square Error	0.0138		

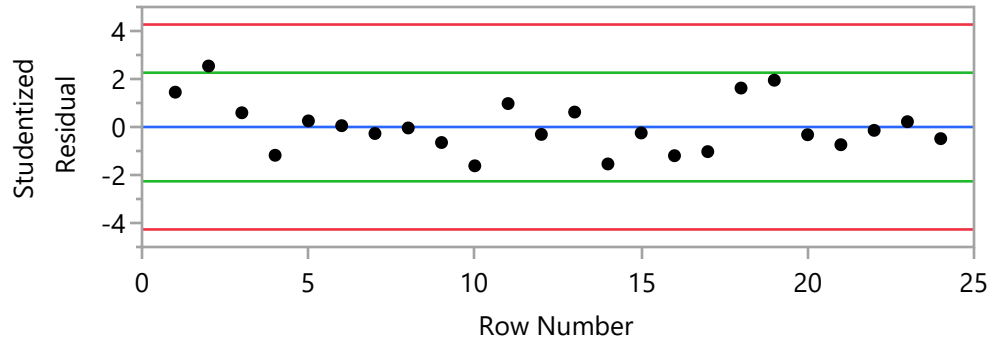
Table 3: Parameter Estimates

The following terms were excluded from the final model.

Response MoP 1: Temperature(-40,150), Temperature*Bolt Diameter, Bolt Diameter*Grade of Stainless Steel[18-8], Bolt Diameter*Grade of Stainless Steel[304];
 Response MoP 2: Temperature*Bolt Diameter;
 Response MoP 3: Load*Load, Temperature*Bolt Diameter, Temperature*Grade of Stainless Steel[18-8], Temperature*Grade of Stainless Steel[304], Bolt Diameter*Grade of Stainless Steel[18-8], Bolt Diameter*Grade of Stainless Steel[304];

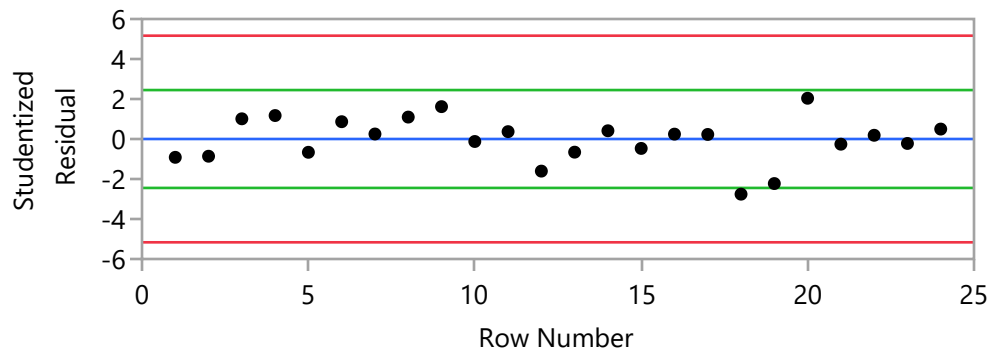
The residual plot from the final model, along with an estimate of residual standard error, is shown in Figure 1.

Response MoP 1



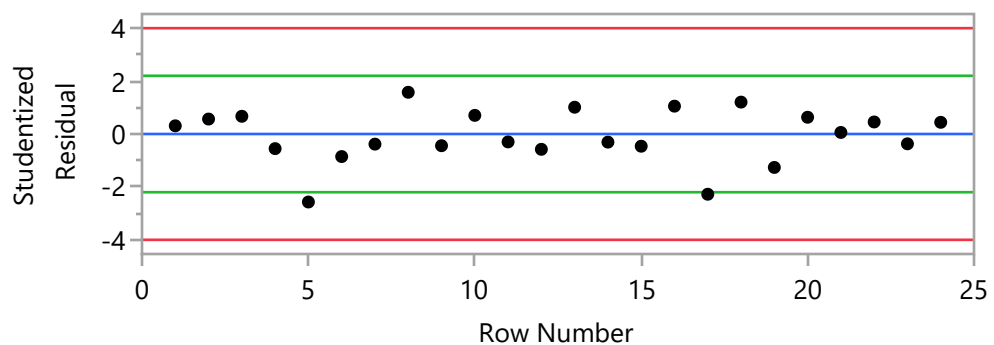
Residuals should appear random (no pattern, trend). Individual residuals should not exceed 95% limits. Green limits assess each residual individually. Red limits account for the number of residuals in the comparison.

Response MoP 2



Residuals should appear random (no pattern, trend). Individual residuals should not exceed 95% limits. Green limits assess each residual individually. Red limits account for the number of residuals in the comparison.

Response MoP 3



Residuals should appear random (no pattern, trend). Individual residuals should not exceed 95% limits. Green limits assess each residual individually. Red limits account for the number of residuals in the comparison.

Figure 1: Studentized Residual Plot and Root Mean Square Error for each response

**Root Mean
Square Error**
24.918081

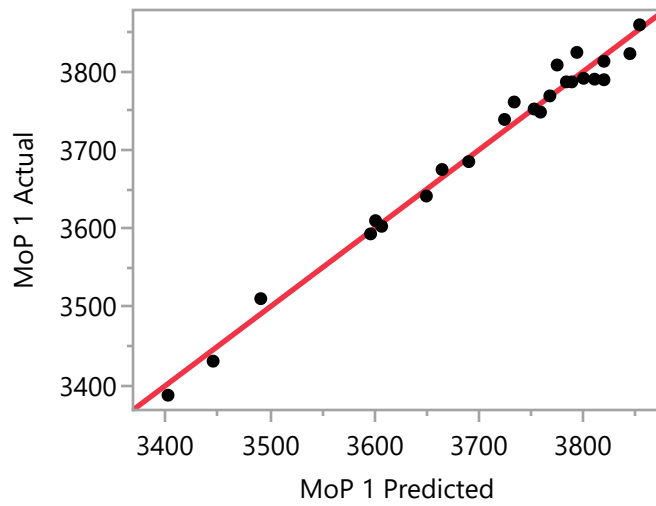
**Root Mean
Square Error**
16.459693

**Root Mean
Square Error**
0.013844

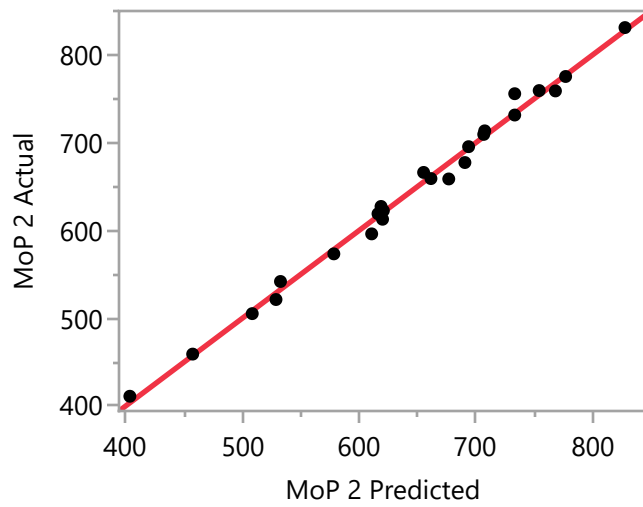
Figure 1: Studentized Residual Plot and Root Mean Square Error for each response.

A plot of the actual responses against the predicted responses for the final model is shown in Figure 2.

Response MoP 1



Response MoP 2



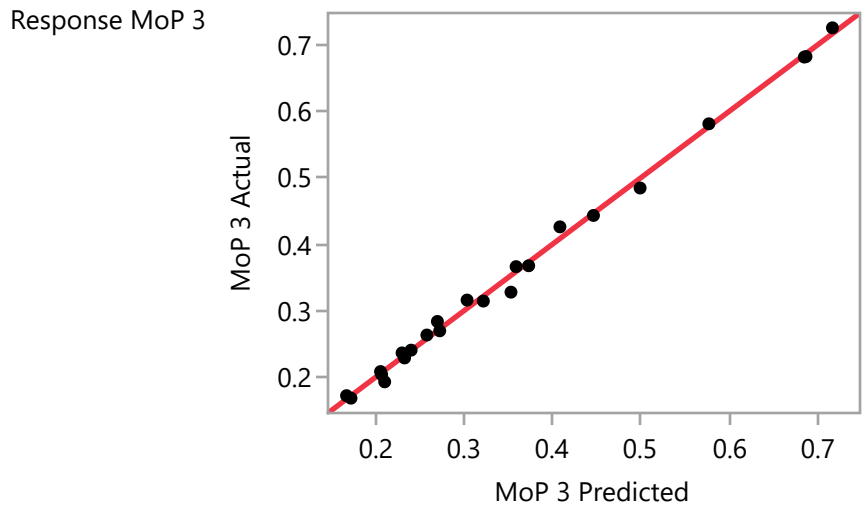


Figure 2: Actual by Predicted plot for each response.

A profiler showing the relationship between each factor and the response is shown in Figure 3.

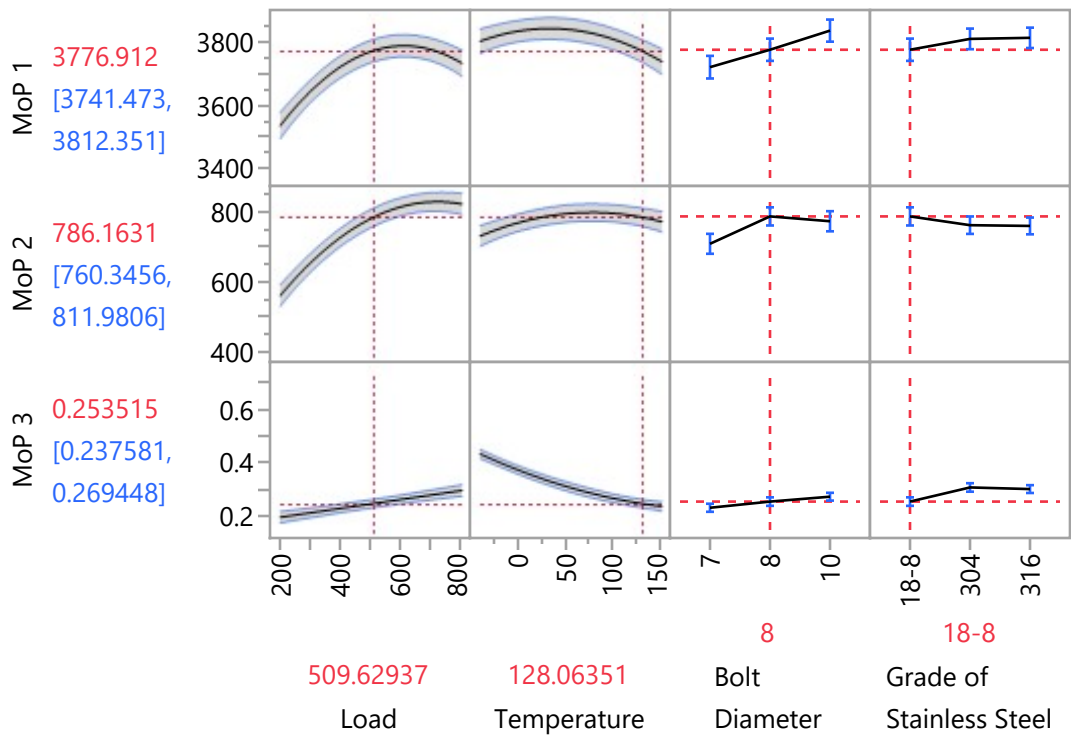


Figure 3: Profiler