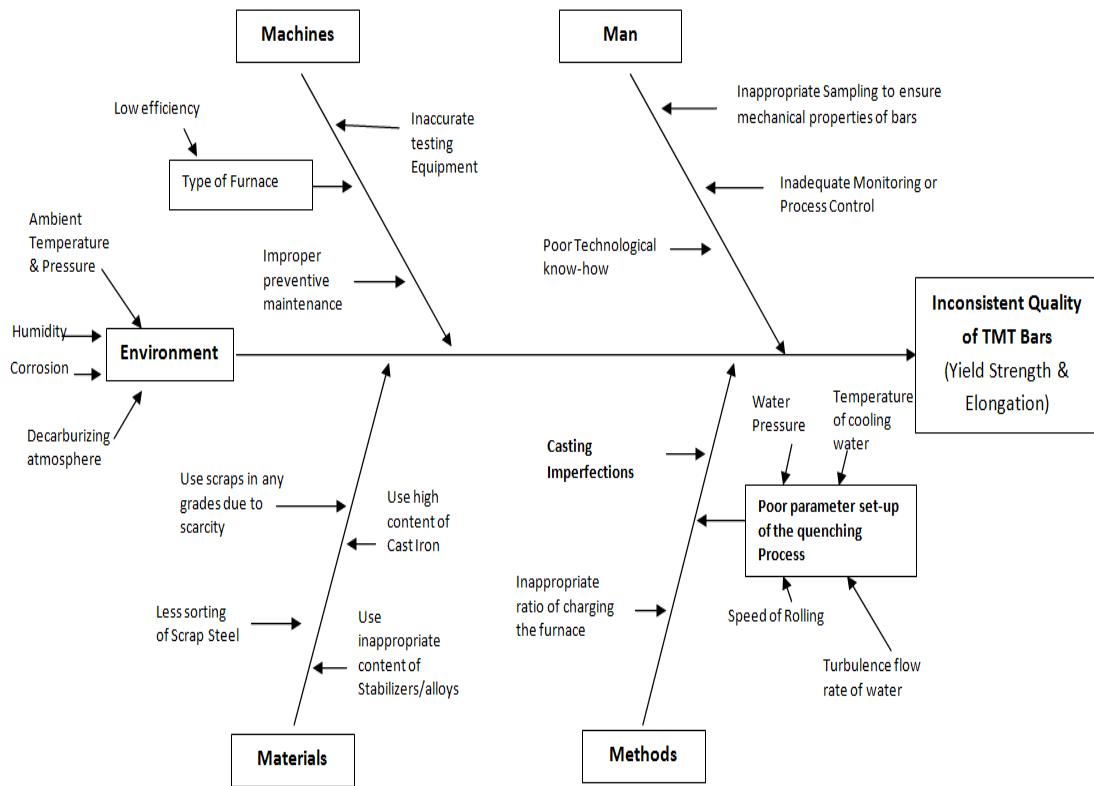


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Cause and Effect diagram



Improving the quenching parameters

Size of rebar: 10 mm

Bar speed: 4.76 m/s

Temperature of the cooling water: 30 – 40 °C

Water Pressure (kg/mm ²)	Water Flow rate (m ³ /h)	Mass per metre run (kg)	Cross sectional area (mm ²)	Yield strength R _e (N/mm ²)	Tensile strength R _m (N/mm ²)	Stress ratio R _m /R _e	Valve positions of the TMT box			
							1 st set	2 nd set	3 rd set	4 th set
10	90 – 110 m ³ /h	0.588	74.9	626.28	686.89	1.10	01 – 05 % opened	10 – 20 % opened	30 – 40 % opened	80 – 90 % opened
9.5		0.591	75.34	560.30	618.28	1.10				
9.5		0.609	77.63	513.03	631.42	1.23				
10		0.591	75.34	566.32	605.38	1.07				
10		0.592	75.47	605.09	746.28	1.23				
10		0.600	76.39	582.05	737.26	1.27				
10		0.608	77.39	551.18	608.19	1.10				
10		0.598	76.18	515.96	630.61	1.22				
9.5		0.590	75.18	533.24	671.49	1.26				
9.5		0.593	75.50	562.50	675.00	1.20				
9.5		0.594	75.63	545.52	564.33	1.03				
9.5		0.599	76.36	502.16	622.68	1.24				
9.5		0.601	76.52	511.05	602.31	1.18				
9.5		0.599	76.27	536.71	610.74	1.14				
9.5		0.613	78.14	508.04	639.75	1.26				
10		0.601	76.59	533.24	570.02	1.07				
10		0.601	76.57	622.66	659.29	1.06				
9.5		0.600	76.47	536.36	590.00	1.10				
10		0.593	75.52	622.75	765.10	1.23				
9.5		0.603	76.76	563.72	657.68	1.17				
9.5		0.594	75.68	502.30	538.18	1.07				
9.5		0.609	77.63	513.03	631.42	1.23				
10		0.591	75.34	566.32	605.38	1.07				
10		0.599	76.32	545.74	591.22	1.08				
10		0.601	76.59	564.96	659.12	1.17				

Dates: 2014-07-19 and 2014-07-20

Appendix 02

Size of rebar: 12 mm Bar speed: 4.76 m/s Temperature of the cooling water: 30 – 40 °C

Water Pressure (kg/mm ²)	Water Flow rate (m ³ /h)	Mass per metre run (kg)	Cross sectional area (mm ²)	Yield strength R _e (N/mm ²)	Tensile strength R _m (N/mm ²)	Stress ratio R _m / R _e	Valve positions of the TMT box			
							1 st set	2 nd set	3 rd set	4 th set
10	125 – 145 m ³ /h	0.883	112.43	516.42	609.11	1.18	05 – 10 % opened	10 – 20 % opened	40 – 50 % opened	80 – 90 % opened
10.5		0.856	109.10	558.41	618.78	1.11				
10.5		0.865	110.16	547.62	612.81	1.12				
10.5		0.869	110.69	556.87	609.91	1.10				
10.5		0.867	110.49	532.54	641.78	1.21				
10.5		0.867	110.40	524.19	615.92	1.18				
11		0.856	109.04	568.79	659.28	1.16				
11		0.871	110.99	525.12	617.02	1.18				
11		0.875	111.45	625.52	714.88	1.14				
11		0.879	111.95	594.92	672.51	1.13				
10		0.857	109.16	541.82	609.54	1.13				
10		0.872	111.15	543.32	646.81	1.19				
10		0.878	111.80	525.13	590.77	1.13				
10.5		0.871	111.00	541.41	616.95	1.14				
10.5		0.874	111.35	531.12	614.98	1.16				
10.5		0.863	109.95	535.96	640.54	1.20				
11		0.877	111.66	572.27	643.81	1.13				
11		0.885	112.73	574.04	616.05	1.07				
11		0.861	109.67	521.77	642.18	1.23				
11		0.863	109.97	582.53	693.49	1.19				

Dates: 2014-07-22 and 2014-07-23

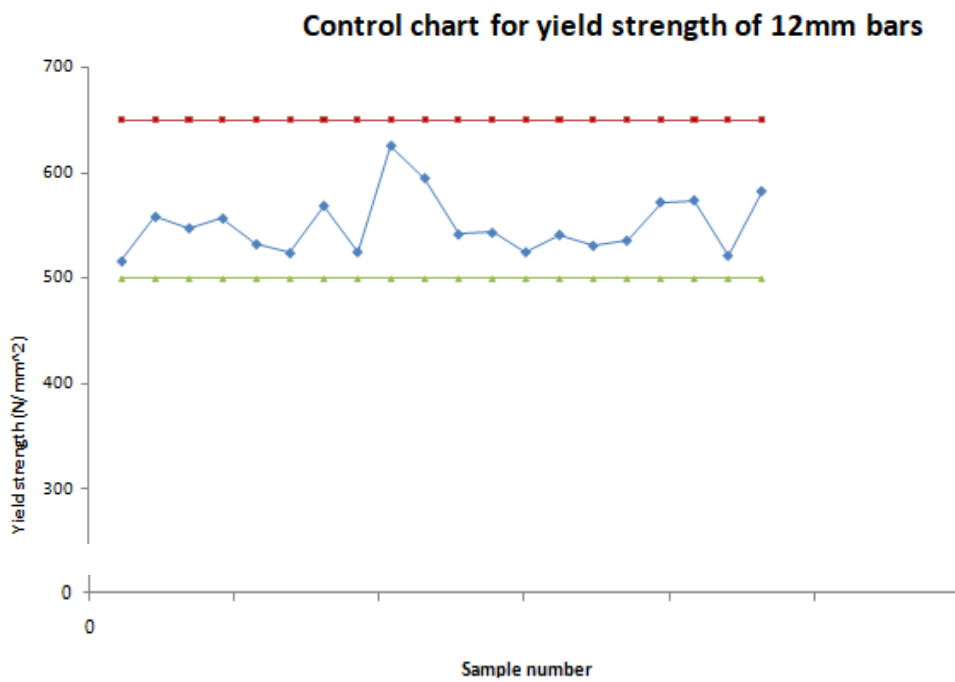
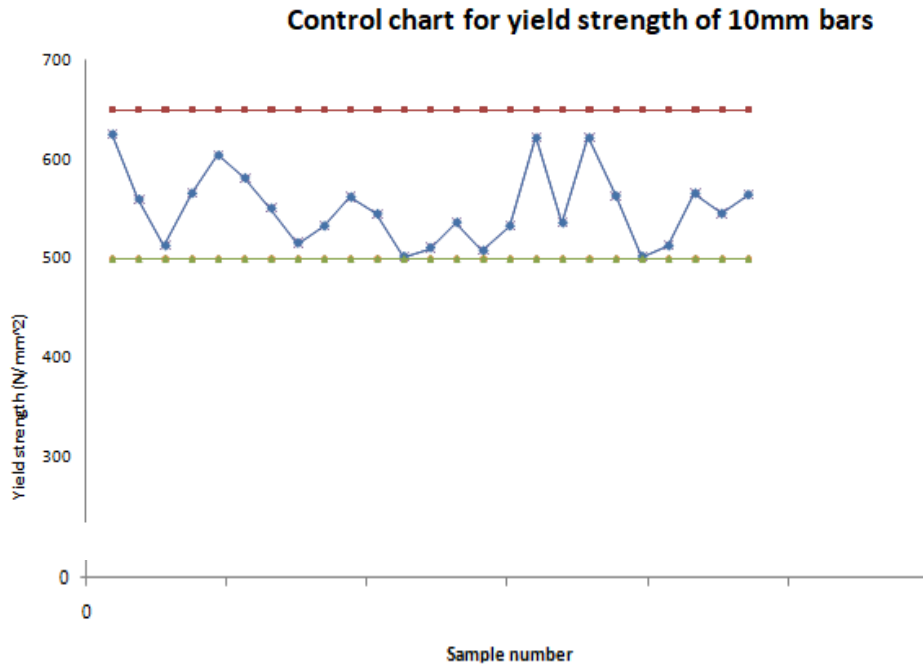
Size of rebar: 16 mm Bar speed: 4.76 m/s Temperature of the cooling water: 30 – 40 °C

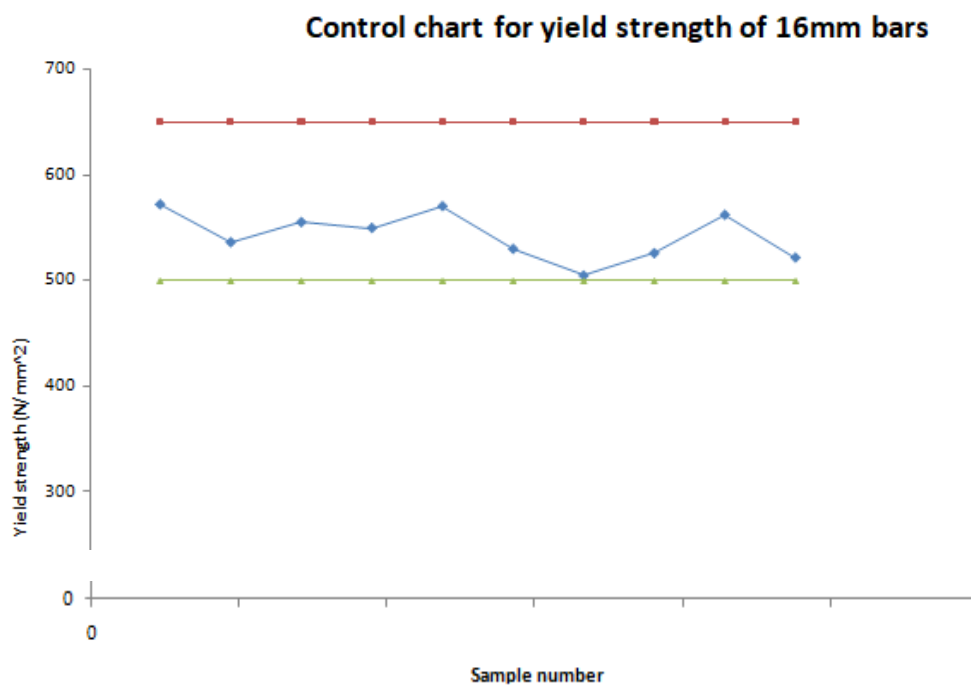
Water Pressure (kg/mm ²)	Water Flow rate (m ³ /h)	Mass per metre run (kg)	Cross sectional area (mm ²)	Yield strength R _e (N/mm ²)	Tensile strength R _m (N/mm ²)	Stress ratio R _m / R _e	Valve positions of the TMT box			
							1 st set	2 nd set	3 rd set	4 th set
11.5	230 - 250 m ³ /h	1.540	196.24	571.66	672.09	1.18	10 – 15 % opened	30 – 40 % opened	70 – 80 % opened	Full opened
11		1.522	193.83	536.10	571.84	1.07				
11		1.543	196.51	555.01	581.43	1.05				
11		1.525	194.27	549.58	593.20	1.08				
11		1.543	196.51	569.98	613.83	1.08				
11		1.578	201.04	529.88	578.05	1.09				
11		1.572	200.24	504.83	599.94	1.19				
11.5		1.522	193.83	525.82	609.64	1.16				
11.5		1.541	196.36	561.83	659.21	1.17				
11.5		1.555	198.10	521.74	640.99	1.23				

Date: 2014-07-18

Process control charts

- Yield strength variation
- Upper bound (650 N/mm²)
- ▲— Lower bound (500 N/mm²)





Conformity test results under improved control factor setting of the cooling system

Sample 01: TMT bars of size 10 mm

Parameter	Steel grade RB 500					SLS 375: 2009 Standard Specification (size 10 mm)
	Specimen number					
	01	02	03	04	05	
Mass per metre (kg/m)	0.614	0.602	0.600	0.611	0.600	0.588-0.644
Yield Strength (R_e) N/mm ²						650 > YS > 500
Individual	593.5	595.2	593.4	595.5	573.8	
Mean value \bar{x}	590.2					
Standard deviation [s]	9.2					
\bar{x} - ks (k=1.53)	576					
Total elongation at maximum force (A_{gt}) %						(> 2.5)
Individual	6.24	7.74	8.34	6.94	7.33	
Mean value \bar{x}	7.31					
Standard deviation [s]	0.79					
\bar{x} - ks (k=1.53)	6.1					
Stress Ratio (R_m/R_e)	1.15	1.15	1.15	1.15	1.18	(> 1.05)

Sample 02: TMT bars of size 12 mm

Parameter	Steel grade RB 500					SLS 375: 2009 Standard Specification (size 12 mm)
	Specimen number					
	01	02	03	04	05	
Mass per metre (kg/m)	0.873	0.857	0.859	0.857	0.863	0.848 - 0.928
Yield Strength (R_e) N/mm ²						650 > YS > 500
Individual	617.6	617.4	619.2	608.2	618.1	
Mean value \bar{x}	616.1					
Standard deviation [s]	4.4					
\bar{x} - ks (k=1.53)	609					
Total elongation at maximum force (A_{gt}) %						(> 2.5)
Individual	7.55	11.55	9.35	8.05	7.55	
Mean value \bar{x}	8.81					
Standard deviation [s]	1.69					
\bar{x} - ks (k=1.53)	6.2					
Stress Ratio (R_m/R_e)	1.16	1.14	1.16	1.15	1.15	(> 1.05)

Sample 03: TMT bars of size 16 mm

Parameter	Steel grade RB 500					SLS 375: 2009 Standard Specification (size 16 mm)
	Specimen number					
	01	02	03	04	05	
Mass per metre (kg/m)	1.56	1.57	1.57	1.57	1.57	1.51 - 1.65
Yield Strength (R_e) N/mm ²						650 > YS > 500
Individual	579.5	595.1	597.0	597.0	595.7	
Mean value \bar{x}	592.8					
Standard deviation [s]	7.5					
$\bar{x} - ks$ (k=1.53)	581					
Total elongation at maximum force (A_{gt}) %						(> 2.5)
Individual	8.66	8.86	9.36	8.36	8.86	
Mean value \bar{x}	8.82					
Standard deviation [s]	0.36					
$\bar{x} - ks$ (k=1.53)	8.3					
Stress Ratio (R_m/R_e)	1.24	1.23	1.23	1.22	1.23	(> 1.05)

Spectrometer analysis data (cast analysis) used in the study

Charge No	C	Mn	Cr	Mo	V	Ni	Cu	CE	S	P	Si	Fe
1	0.177	0.725	0.057	0.021	0.0061	0.059	0.525	0.35	0.014	0.029	0.161	98.089
2	0.196	0.793	0.069	0.021	0.0036	0.051	0.615	0.39	0.021	0.023	0.213	97.904
3	0.169	0.817	0.061	0.026	0.0021	0.057	0.420	0.35	0.019	0.017	0.177	98.092
4	0.192	0.725	0.057	0.021	0.0060	0.059	0.600	0.37	0.014	0.029	0.210	97.999
5	0.190	0.919	0.063	0.023	0.0047	0.047	0.520	0.40	0.016	0.015	0.214	97.909
6	0.193	0.854	0.043	0.021	0.0023	0.056	0.610	0.39	0.029	0.021	0.219	98.065
7	0.186	0.845	0.047	0.018	0.0057	0.026	0.565	0.38	0.021	0.019	0.178	97.998
8	0.189	0.814	0.088	0.026	0.006	0.073	0.595	0.39	0.017	0.025	0.221	97.854
9	0.183	0.821	0.087	0.025	0.0059	0.064	0.475	0.38	0.028	0.029	0.209	97.968
10	0.200	0.844	0.058	0.024	0.0054	0.079	0.545	0.40	0.015	0.028	0.172	97.886
11	0.179	0.826	0.078	0.014	0.0077	0.059	0.455	0.37	0.017	0.021	0.196	98.021
12	0.196	0.910	0.014	0.016	0.0072	0.073	0.470	0.39	0.017	0.026	0.144	98.019
13	0.196	0.847	0.071	0.036	0.0071	0.088	0.390	0.39	0.028	0.028	0.205	98
14	0.198	0.915	0.076	0.025	0.0052	0.087	0.550	0.41	0.027	0.032	0.189	97.79
15	0.202	0.759	0.076	0.025	0.0055	0.090	0.455	0.39	0.029	0.032	0.207	97.994
16	0.185	0.751	0.057	0.029	0.053	0.072	0.355	0.37	0.014	0.028	0.197	98.141
17	0.201	0.798	0.061	0.023	0.0078	0.072	0.490	0.39	0.022	0.026	0.218	97.976
18	0.189	0.822	0.083	0.032	0.0077	0.086	0.595	0.40	0.03	0.023	0.196	97.825
19	0.201	0.872	0.071	0.026	0.0074	0.084	0.380	0.40	0.03	0.025	0.187	98.026

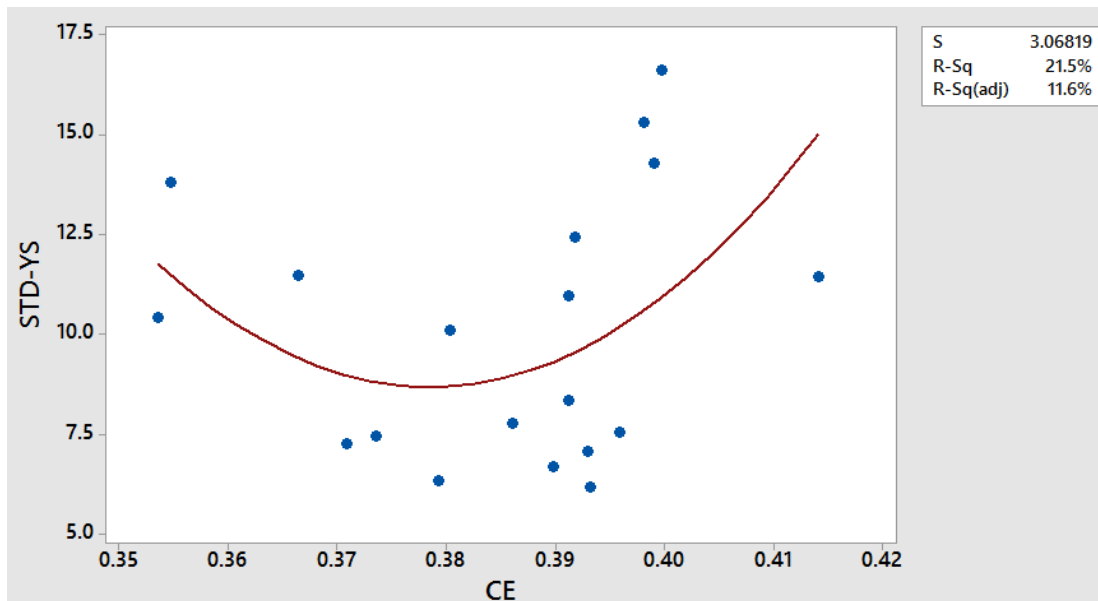
$$CE = \%C + \% Mn/6 + (\% Cr + \% Mo + \% V)/5 + (\% Ni + \% Cu)/15$$

Test data of the tensile properties (10 mm TMT bars)

Charge Number	Tensile Properties															
	Yield Strength (N/mm ²)									Total Elongation at max force (%)						
	Individuals					Mean (X)	ST-DEV (S)	(X-ks) k=1.53	Individuals					Mean (X)	ST-DEV (S)	(X-ks) k=1.53
	1	2	3	4	5				1	2	3	4	5			
1	559.96	576.29	569.82	582.22	586.24	574.91	10.41	559.30	7.31	6.31	5.32	4.31	5.33	5.72	1.14	4.01
2	555.67	568.46	566.10	557.91	576.29	564.89	8.34	552.38	4.37	6.33	3.34	4.33	5.33	4.74	1.13	3.04
3	558.81	559.02	565.62	591.99	573.93	569.87	13.82	549.15	7.34	6.33	5.34	5.33	4.35	5.74	1.14	4.03
4	584.03	574.60	570.79	570.60	563.72	572.75	7.43	561.61	5.32	6.34	4.34	5.34	4.31	5.13	0.84	3.87
5	581.58	547.31	578.11	579.16	577.30	572.69	14.28	551.27	4.33	4.32	3.33	5.32	4.31	4.32	0.70	3.27
6	569.71	575.21	580.53	571.04	561.45	571.59	7.07	560.99	4.33	5.31	4.34	8.30	5.34	5.52	1.63	3.08
7	568.20	544.87	569.39	563.95	566.24	562.53	10.09	547.40	7.32	5.33	6.33	8.32	7.32	6.92	1.14	5.22
8	532.69	539.85	527.35	524.29	535.01	531.84	6.17	522.59	5.31	8.31	5.31	9.31	6.32	6.91	1.82	4.19
9	526.39	518.96	522.54	509.40	517.93	519.04	6.33	509.54	6.31	8.32	6.30	4.31	8.33	6.71	1.68	4.19
10	536.73	566.19	529.24	540.44	563.51	547.22	16.62	522.30	6.31	6.32	6.31	6.31	5.33	6.12	0.44	5.46
11	547.14	540.08	551.24	540.60	557.21	547.25	7.26	536.37	7.31	6.31	5.32	5.31	4.31	5.71	1.14	4.00
12	585.31	582.50	581.11	561.13	565.67	575.14	10.95	558.73	6.32	5.33	7.33	8.31	6.31	6.72	1.14	5.02
13	569.51	579.01	565.40	564.87	544.98	564.75	12.42	546.12	6.32	4.31	4.31	6.32	8.31	5.91	1.67	3.40
14	567.12	544.80	548.95	559.52	571.47	558.37	11.43	541.23	5.32	6.33	4.32	4.32	6.31	5.32	1.00	3.82
15	551.62	533.99	541.04	535.27	532.73	538.93	7.77	527.27	6.32	5.30	8.30	8.31	9.29	7.50	1.64	5.05
16	527.41	553.45	537.74	553.35	550.00	544.39	11.47	527.18	7.28	6.29	5.28	4.31	5.30	5.69	1.13	4.00
17	537.41	524.58	522.53	520.24	527.23	526.40	6.67	516.39	6.28	6.28	5.28	6.27	5.28	5.88	0.55	5.06
18	573.34	570.80	576.72	584.36	563.90	573.82	7.54	562.52	6.32	5.32	8.32	8.31	9.31	7.52	1.64	5.06
19	527.41	553.45	537.74	540.65	567.07	545.26	15.32	522.28	7.3	6.31	5.3	5.31	4.31	5.71	1.14	4.00
500 < Yield Strength < 650									2.5 <							

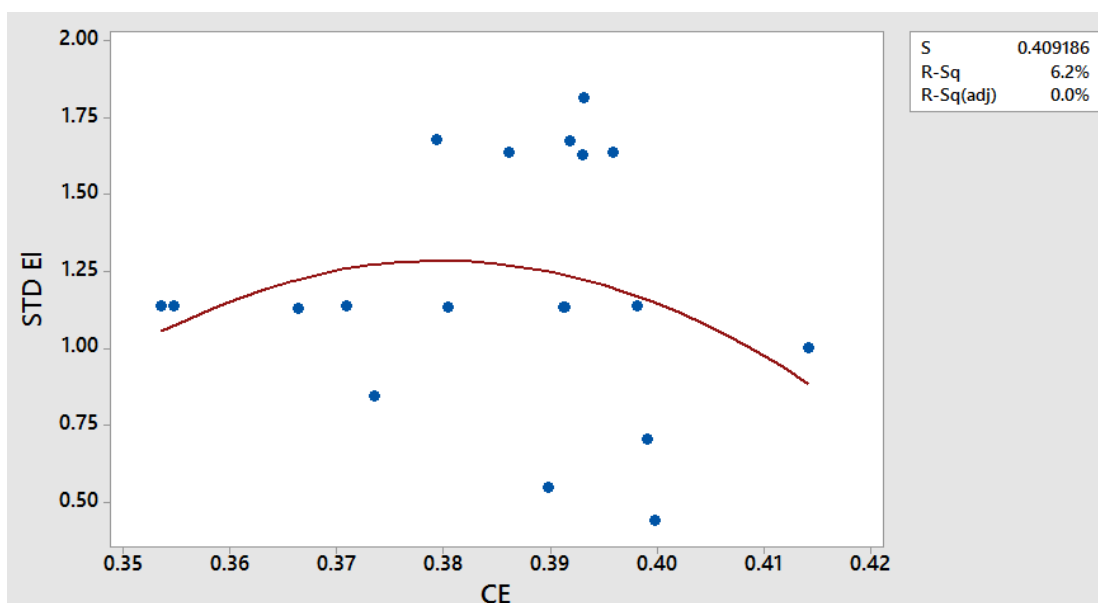
Plots created in second order polynomials (quadratic form)

01. Fitted line plot of CE vs. STD-YS in quadratic form



For the interpretation of data in plot-01, the S is 3.06819 units of STD-YS. Moreover, 21.5% of the variation in STD-YS is explained by CE.

02. Fitted line plot of CE vs. STD-EI in quadratic form



For the interpretation of data in plot-02, the S is 0.409186 units of STD-EI. Additionally, 6.2 % of the variation in STD-EI is explained by CE.