Optimization of rolling parameters for improving Quality Factor of Thermo mechanically treated bar using soft Computing Techniques

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Abstract:
The primary responsibility of a design engineer is to include all of the different functionalities that have been defined by the individuals in charge of product planning at a price that is as low as possible. Consequently, in order to create a new product effectively, a product designer has to determine what the inputs are, what the outputs are, and what the ideal functionalities are. For the manufacturing of TMT bars, the important quality parameter is yield strength and ductility. The goal of this study is to choose the optimal variables that will achieve the needed yield strength and ductility. In this research work, the use of the Taguchi Technique in conjunction with the conception of DOE (Design of experiment) for the purpose of optimizing the parameters of the Thermo Mechanical Treatment Process. In the plant, readings have been taken and by Taguchi Method and by using MINITAB and MATLAB Software to find out optimal combination factors. For optimizing the process parameters ANOVA, S/N ratio (Signal to noise ratio), and orthogonal array have been utilized. Optimum values have been obtained with the help of graphs as well as confirmation experiments.

Keywords- Yield Strength;% elongation; TMT; Control Parameters; S/N Ratio; Taguchi Method

Introduction-

In the past, unprocessed iron rods, as well as concrete slabs, have been used to construct homes and buildings. [1] The difficulty with this method was that the rods began to corrode more sooner than intended. TMT (“Thermo Mechanically Treated”) bars are the solutions to all of the concerns listed above.

The idea behind the Taguchi concept is to build quality into a product from the beginning, rather than relying on post-production inspections to make adjustments. The process of improving product quality must start right at the beginning, in other words, at design phase of the product development process, as well as it must continue all the way through the manufacturing process by means of process design as well as control. [2]

As Dr. Taguchi pointed out, no amount of examination could ever restore quality to the product; it had been treating the symptoms. Because of this, he advocated those excellent ideas should be based on the principle of prevention. In the Taguchi Method, Parameter Design and System Design are two separate processes.

In the Taguchi technique, the design of experiments is considered to be one of the most effective strategies. The Design of Tests, often known as DOE, is a plan for experiments that are to be carried out in order to discover which variables are the most relevant and how they impact objective as well as performance functions. The DOE is able to demonstrate how to do the minimum number of tests necessary while still collecting the most essential data. The DOE method is useful for studying several factors (variables) concurrently and in the most cost-effective way possible. The Department of Energy's determination of the independent values where a select series of experiments will be carried out is the most essential step it undertakes.

Literature Review in Brief:

TMT bars are an innovation in the manufacturing of high-strength deformed steel bars for reinforcing materials. Thermomechanical treatment, in which the steel bars are subjected to intense cooling immediately after rolling, is used to achieve increased strength in this procedure. A hardened top layer is formed by a sudden drop in temperature, while the central core remains heated. The heat from the core tempers the cooling in the atmosphere. The bar's strength and ductility are predicted to increase as a result of this treatment. TMT bars combine the best qualities of strength, ductility, bendability, and other desired characteristics. TMT bars are used below half as often as mild steel bars, according to Sandhwarand Roy (2015). Owing to its greater UTS/YS ratio, TMT bars can withstand strong seismic (earth quake prone) loads. When the Fe415 rebar is substituted with the Fe500 rebar, the overall amount of steel used is reduced by 10% to 25%. According to Gaur et al., proper management of the ultimate quenching temperature results in optimal strength and a high UTS/YS ratio (2018). According to Roy and Ranjit (2001), today's fundamental rebar criteria are low-rate deformed bars with a 500N/mm2 yield strength and enough ductility for seismic zones. Approximately 55percent to 60 percent of India is inside the earthquake zone.

When the rebar is rapidly cooled while passing through a quenching box in the TMT process, the temperature differential created causes heat to travel from the core to the surface. Due to the heat remaining in the core at the conclusion of this cycle, the martensite structure of the rebar self-tempers. The austenitic core converts into pearlite as well as ferrite or pearlite ferrite, & bainite when the rebar cools further in the cooling bed, according to Ravi Kumar et al (2015). As per Dean and Edwin (2002), based on cooling conditions, this method boosts yield strength from 150 to 250 Mpa.

Research Methodology-

The yield strength of the rebar is tested using a universal testing machine for studying the impact of various conditions on the bar’s yield strength. Work Piece material has been IS2830C20 M Mn (C) RC grade of 32 mm dia with C Equivalent to 0.34 Selected. Control factors are selected from the given bar. Taguchi methodology is used for process optimization.

Taguchi Methodology for Process Optimization

Steps Involved in Taguchi Method [3]

1. Determine the primary function and any adverse impacts it may have.
2. Determine the causes contributing to the noise, the testing settings, and the quality attributes.
3. Determine the target goal function that has to be optimized.
4. Determine whatever control variables there are and how much they affect things.
5. Choose an appropriate Orthogonal Array to use, and then proceed to create the Matrix.
6. Perform the experiment using the Matrix.

7. Analyze the data and make guesses about the optimal control factor values and the effect they will have.
8. Carry out the experiment designed to confirm.

Objective function can be

1. Find out optimal factors for higher yield strength to improve quality of TMT Bar.
2. Find out optimal factors for higher % elongation of TMT Bar.

Table 1 represents noise factors along with control factors.

Table 1: Control Factor "Affecting Tensile Strength of TMT Bars

SL. NO.	CONTROL FACTORS	NOISE FACTORS
1.	Tb (Bar Temperature), in^{0}C	Fuel
2.	RS (Rolling Speed), in mps	Energy fluctuations
3.	WP (Water Pressure), in bar	Type of Pump
4.	WQ (Water Flow Rate), in m^3/hr.	Pipe condition"

For these experiments, tests on UTM are conducted till the give measurements. In experiment, table 2 gives the four control factors along with three levels analyzed. L9 Orthogonal array can be recognized.

Table 2: "Control Factors and Their Levels

S.No.	CONTROL FACTORS	LEVELS"		
		1	2	3
1.	Tb (Bar Temperature)," in^{0}C	1080	1100	1120
2.	RS (Rolling Speed), in mps	6	6.5	7
3.	WP (Water Pressure), in bar	17	18	19
4.	WV (Water Flow Rate), in m^3/hr.	930	960	980

For higherquality attributes,Optimum yield strength is achieved by selecting S/N ratio on bar'stensile strength error, which has minimum error. For S/N ratio, value ofηis calculated as:

η= -10log10(1/r ∑ (1/yi^2))…………… (1)

i = 1

Where r is the sample size and yi is the measured yield strength error value.

The S/N ratio of higher the better type is selected and S/N ratio for yield strength variation are computed and represented in Table 3.

Experimental Details

The S/N ratio was calculated using a better-type control function since the goal function (optimum yield strength) is greater. Table 3 represents the computed and tabulated S/N ratios for yield strength in all of the experiments.

Table 3: Yield Strength Variation Measured for 32mm TMT Bar with S/N Ratio

Trial No.	CONTROL FACTORS				YIELD STRENGTH, MPa READINGS TAKEN						S/N Ratio
	Tb	RS	WP	WV	1	2	3	4	5	Mean	
1	1	1	1	1	559	562	564	566	568	563.8	55.02
2	1	2	2	2	560	561	563	567	571	564.4	55.03
3	1	3	3	3	558	563	564	566	572	564.6	55.034
4	2	1	2	3	562	564	567	569	571	566.6	55.06
5	2	2	3	1	565	566	568	570	572	568.2	55.08
6	2	3	1	2	568	570	572	574	578	572.4	55.15
7	3	1	3	2	567	568	569	571	577	570.4	55.12
8	3	2	1	3	568	570	576	580	582	575.2	55.19
9	3	3	2	1	570	572	574	576	580	574.4	55.18

Table 4 represents the computed and tabulated S/N Ratio for % elongation in all the experiments.

Trial No.	CONTROL FACTORS				% ELONGATION READINGS TAKEN						S/N Ratio
	Tb	RS	WP	WV	1	2	3	4	5	Mean	
1	1	1	1	1	17.2	17.4	17.8	18.0	17.7	17.62	24.91
2	1	2	2	2	17.6	17.8	17.6	18.0	18.2	17.84	25.02
3	1	3	3	3	17.0	17.9	18.1	18.4	18.8	18.04	25.10
4	2	1	2	3	18.0	18.2	18.5	18.6	18..7	18.40	25.29
5	2	2	3	1	17.5	17.8	18.0	18.4	18.9	18.12	25.15
6	2	3	1	2	18.2	18.6	18.7	18.8	17.6	18.38	25.27
7	3	1	3	2	17.0	17.5	19.0	19.5	17.0	18.00	25.06
8	3	2	1	3	17.0	17.8	18.7	19.0	19.2	18.34	25.24
9	3	3	2	1	17.4	17.6	18.5	18.7	19.0	18.24	25.20

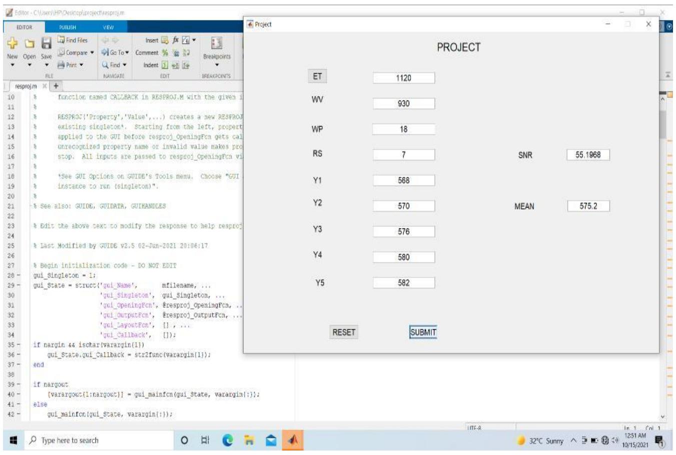

Fig.-1 Signal Noise Ratio have been determined by MATLAB Software

Results and Discussions

For every individual control factor, S/N ratio are computed as given below:

Sbt1 = (**η1+ η2+ η3**), Sbt2 = (**η4+ η5+ η6**) & Sbt3= (**η7+ η8+ η9**)

Srs1 = (**η1+ η4+ η7**), Srs2 = (**η2+ η5+ η8**) & Srs3 = (**η3+ η6+ η9**)

Swp1 = (**η1+ η6+ η8**), Swp2 = (**η2+ η4+ η9**) & Swp3 = (**η3+ η5+ η7**)

Swv1 = (**η1+ η5+ η9**), Swv2 = (**η2+ η6+ η7**) & Swv3 = (**η3+ η4+ η8**)

In order to select the **η1, η2, η3** etc. values as well as to compute Sbt1, Sbt2 & Sbt3 see Table 3.

ηk is the S/N ratio corresponding to Experiment k.

Average S/N ratio corresponding to bar temperature at level 1 =Sbt1/3

Average S/N ratio corresponding to bar temperature at level 2 = Sbt2/3

Average S/N ratio corresponding to bar temperature at level 3 = Sbt3/3

j is defined as a comparable level for every factor. Likewise, Srsj, Swpj as well as Swvj are computed for rolling speed, water pressure as well as flow rate. Table 4 shows an average S/N ratios.

Table 5: Average S/N Ratios of each factor for Yield Strength

Level	Bar temperature Tb		Rolling Speed (RS)		Water Pressure (WP)		WATER Flow Rate (WV)	
	Sum (Sbtj)	Avg S/N ratio	Sum (Srsj)	Avg S/N ratio	Sum (Swpj)	Avg S/N ratio	Sum (Swvj)	Avg S/N ratio
1	165.09	55.03	165.2	55.07	165.36	55.12	165.29	55.098
2	165.29	55.10	165.3	55.10	165.28	55.093	165.3	55.10
3	165.49	55.16	165.36	55.12	165.234	55.082	165.284	55.096

As shown by these linear graphs, the best values and levels of yield strength for each component are as stated in the table.

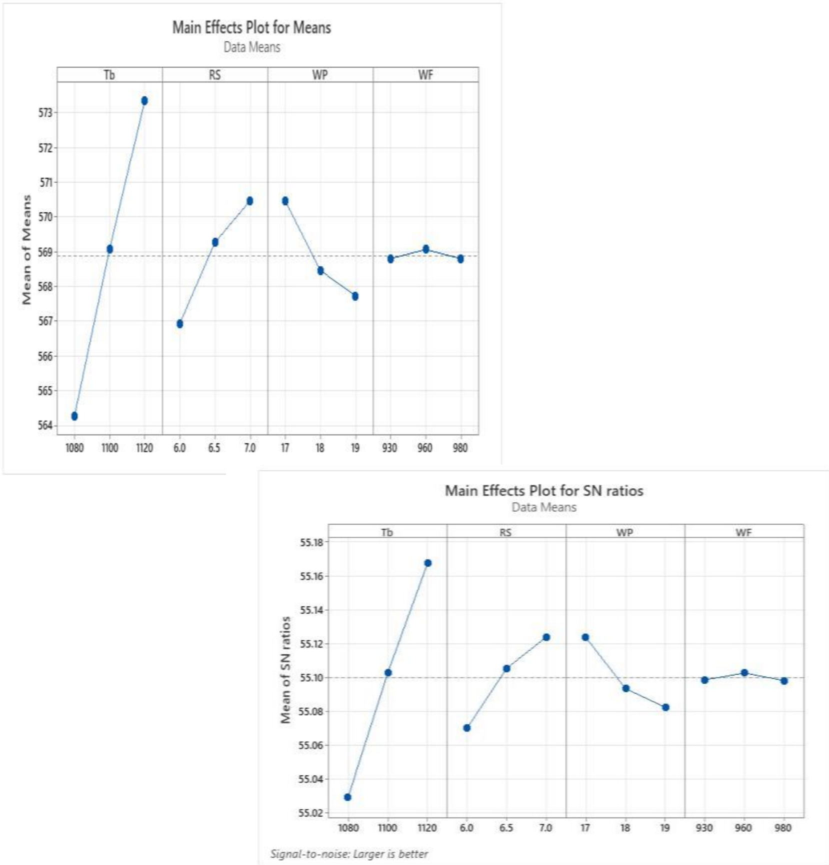

Fig. - 2 Graphs created by MINITAB Software that show the optimal values and levels for each component best values and levels of factors and their respective levels Yield Strength Parameter with the Optimal Value

Bar Temperature (^{0}C)	1120
Rolling Speed (mps)	7
Water Pressure (Bar)	17
Water Flow Rate (m^3/h)	960

Table6 shows an average S/N Ratio of each factor for % elongation.

Level	**Bar Temperature Tb**	**Rolling Speed (RS)**	**Water Pressure (WP)**	**Water Flow Rate (WV)**
	Avg S/N Ratio			
1	25.02	25.09	25.15	25.09
2	25.24	25.14	25.17	25.12
3	25.15	25.2	25.11	25.21

As shown by these linear graphs, the best values and levels of % elongation for each component are as stated in the table.

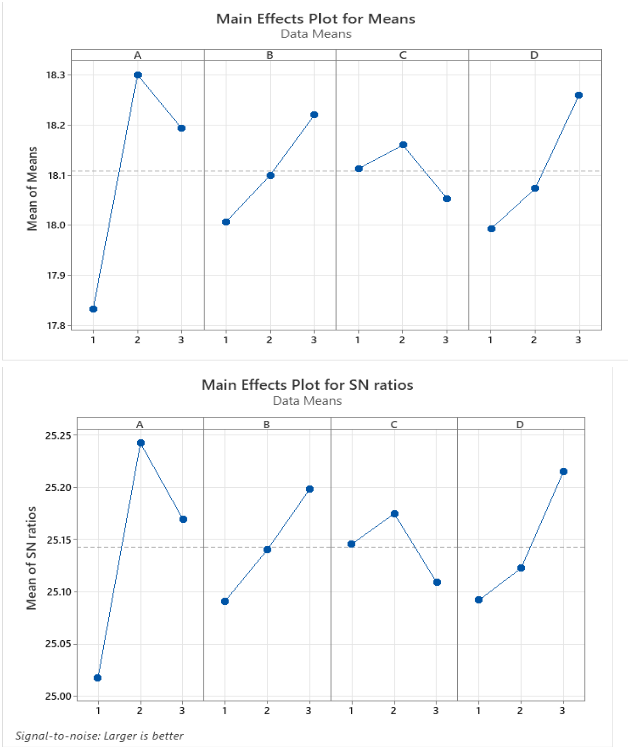

Fig.- 3 Graphs created by MINITAB Software that show the optimal values and levels

optimum amounts and values for the many elements involved Parameter Optimum Value for percentage elongation

Bar Temperature (^{0}C)	1100
Rolling Speed (mps)	7
Water Pressure (Bar)	18
Water Flow Rate (m^3/h)	980

Conduct the Verification Experiments

Following table conduct the confirmation experiments conducted by setting control aspects Bar Temperature(^{0}C) 1120, Rolling Speed (mps) 7, Water Pressure (Bar) 17, Water Flow Rate (m^3/h) 960 for yield strength and Bar Temprature (^{0}C) 1100, Rolling Speed(mps) 7, Water Pressure (Bar) 18 and Water Flow Rate(m^3/h) 980 for % elongation. The yield strength (MPa) and % elongation values of all five sets of tests were compared and recorded. This shows that the findings are consistent across all of the experiments.

Table 7

Experiment No.	Yield Strength
1	577 MPa
2	579 MPa
3	580 MPa
4	582 MPa
5	583 MPa
Mean	**580.2 MPa**

Table 8

Experiment No.	% elongation
1	18.7
2	18.9
3	19.2
4	19.1
5	19.4
Mean	**19.06**

Anova and its Significance

In the orthogonal experiment, (ANOVA is performed in order to determine the magnitude of response in percent for each of the parameters. It is vital to make use of this method in order to identify as well as quantify the factors that contributed to the diverse results obtained from the many iterations of the experiment.

Table 9: ANOVA results for Yield strength S/N ratio

Parameter	DOF	Adj SS	Adj MS	SS%
BT	2	0.028743	0.014370	79.86
RS	2	0.004463	0.002232	12.40
WP	2	0.002748	0.001374	07.63
WV	2	0.000036	0.000018	00.10
Error	0	-		
Total	8	0.035990	-	100

This can be noted from the table that for yield strength the contribution of bar temperature (79.86%) and rolling speed (12.40%), water pressure (7.63%) and Flow Rate (0.1%).

Table 10: ANOVA results for % elongation S/N ratio

Parameter	DOF	Adj SS	Adj MS	SS%
BT	**2**	**0.0789**	**0.03949**	**62.12**
RS	**2**	**0.0172**	**0.00860**	**13.54**
WP	**2**	**0.0065**	**0.003287**	**05.12**
WV	**2**	**0.0245**	**0.01288**	**18.89**
Error	**0**			
Total	**8**	**0.12734**		

This can be noted from the table that for % elongation the contribution of bar temperature (62.12%) and rolling speed (13.54%), water pressure (05.12%) and Flow Rate (18.89%).

Conclusion

The use of the Taguchi approach to the optimization of 32mm TMT bar's yield strength and % elongation of IS2830 C20 M Mn (C) RC is demonstrated in this study.

The corresponding C value is 0.34. It has been determined that the bar temperature (Tb), one of the four elements considered, has a large effect on development of yield strength and % elongation that is a quality attribute, as well as that it contributes about 79.86% & 62.12% to the rise in yield strength and % elongation.

Bar Temperature (^{0}C) 1120 Water Pressure (Bar) 17, Rolling Speed (mps) 7, Water Flow Rate (m^3/h) 960 is found to be the optimal level of process parameters for yield strength.

This indicates that the temperature of the bar has a significant impact on bar's final % elongation.

Bar Temperature (^{0}C) 1100 Water Pressure (Bar) 18, Rolling Speed (mps) 7, Water Flow Rate (m^3/h) 980 is found to be the optimal level of process parameters for % elongation

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Nomenclature

Tb: Bar Temperature in^{0}C
RS: Rolling Speed in mps
WP: Water Pressure in bar
WV: Water Flow Rate in m^3/hr
η: Signal noise ratio
DOF: Degree of Freedom
Adj SS: Adjusted Sum of Square
Adj MS: Adjusted Mean Square

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