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Optimization of TMT Process by Taguchi Methodology

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Abstract—*Designing high quality products and processes at low cost is an economic and technological challenge to the engineers. The main task of design Engineer is to build in the various functions as specified by the product planning people at a competitive cost. Therefore, a product designer must identify, what is input, what is output and what are the ideal functions while developing a new product.*
This paper addresses the application of Taguchi methods and concept of Design of experiment (DOE) for optimization of Thermo Mechanical Treatment Process parameters in Indore Steels and Iron Mills Limited Company, Bhagirath Pura, Indore. In steel industries there are number processes and number of factors which are affecting the mechanical properties of the metals. In which TMT process is the familiar one to produce high Yield Strength bars, up to 600 N/mm^2, to meet the demands of the market. Ishikawa diagram used here to identify the control parameters. Results are industrially recommended.

Keywords*: Design of experiments, Ishikawa diagram, control parameters, Thermo Mechanical Treatment.*

1. INTRODUCTION

The Taguchi philosophy based on three simple yet powerful fundamental concepts. [2]

1. Quality should be designed into the product and not inspected into it.
2. Quality is best achieved by minimizing the deviation from target. The product should be so designed that it is immune to uncontrollable environmental factors.
3. The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

Taguchi philosophy is to design quality into the product rather than to improve by inspection, for it after its production. Quality improvement should begin at the very beginning i.e. during the design stage of the product development and should continue through the production process by process design and control. [1]

Dr Taguchi observed that no amount of inspection could put quality back into the product and it only treated the symptom, therefore he argued that quality concepts should be based upon, and developed around, the philosophy of prevention. The Taguchi Method is a multi-stage process, namely, Systems Design, Parameter Design, and Tolerance Design. This is also known as Taguchi's Robust Design.

The design of experiment is one of the best techniques of Taguchi method. The DOE (Design of Experiments) is an experiments plan to be conducted to determine the most important variables which affect the performance and objective functions. The DOE can show how to carry out the fewest number of experiments while maintaining the most important information. The DOE technique helps in study many factors (variables) simultaneously and most economically. The most important process of the DOE is determining the independent variable values at which a limited number of experiments will be conducted. [3]

2. TAGUCHI'S DOE METHODOLOGY FOR PROCESS OPTIMIZATION

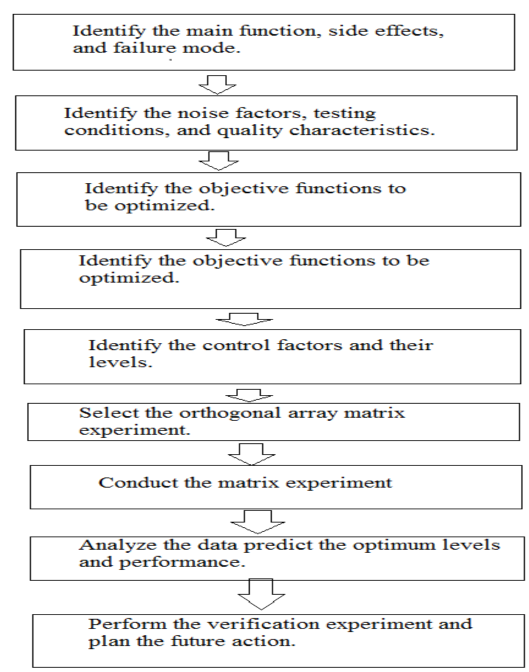


Fig. 2.1: Steps Applied In DOE Optimization Method

3. A CASE STUDY: TMT PROCESS OPTIMIZATION.

TMT-An Overview

For many years a strong and definite trend towards high quality rebar is observed in the market. The main concerns of the consumer are economy and safety. The basic requirements of rebars today are low cost deformed bars with guaranteed yield strength of 500N/ mm^2 with adequate ductility for the Seismic (earthquake prone) zones. As we know nearly 55-60 per cent of India falls under the seismic zone. [10]

Depending upon the requirements of the consumer in the Indian market as well as global market the specifications to be fulfilled by up-to-dated concrete reinforcing steel appear clearly:

- High yield strength,
- Weldability,
- Bendability and rebending ability,
- Ductility.

In earlier days, in India generally high strength bars are produced with the maximum yield strength of 415 N/mm2 by cold twisting process. But throughout the world advanced technology of Thermo-mechanical Treatment (TMT) is gaining popularity and which can produce reinforcement bar of yield strength even up to 600 N/mm^2

TMT rebar with high yield strength

Special Features of TMT Bars

- Excellent weldability and formability
- Better corrosion resistance
- Higher strength combined with extra high ductility
- Resistance of fire hazards
- Higher fatigue strength
- Easy working at site due to ductility and bendability
- Resistance to strain aging. [9]

4. THERMO-MECHANICAL TREATMENT PROCESS

The schematic representation of the Thermo-Mechanical Treatment process is given in 4.1. The rebar leaving a special water cooling section. The cooling efficiency of this installation is such that a surface layer of the bar is quenched into martensite, the core remaining austenitic. The quenching treatment is stopped when a determined thickness of martensite has been formed under the skin. [11]

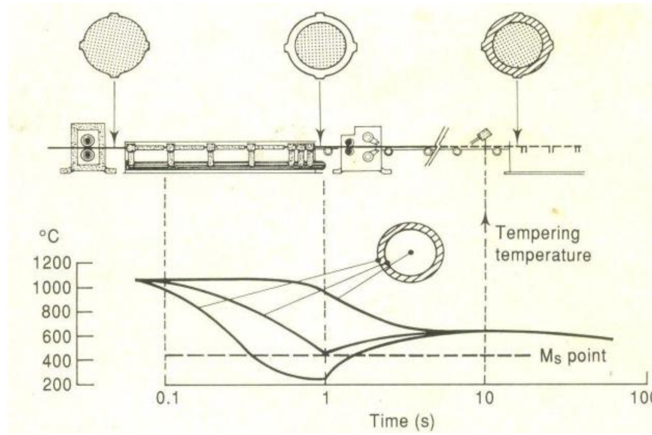


Fig. 4.1: Schematic representation of the TMT process

When the rebar leaves the drastic cooling section, the temperature gradient established in its cross section, causes heat flow from the center to the surface. This increase of the surface layer temperature results in the self layer temperature results in the self-tempering of the martensite. The fact is that the martensitic layer is tempered by the heat left in the core at the end of the quenching stage.

Finally, during the slow cooling of the rebar on the cooling bed, the austenitic core transforms into ferrite and pearlite or into bainite, ferrite and pearlite.

The temperature-time history of the rebar is also given in the above The three stages of TMT process clearly appear.

- Quenching of the surface layer;
- Self-tempering of the martensite;
- Transformation of the core.

Properly applied, the process leads to an increase in the yield strength of 150 to 250Mpa, depending on the cooling conditions. [6]

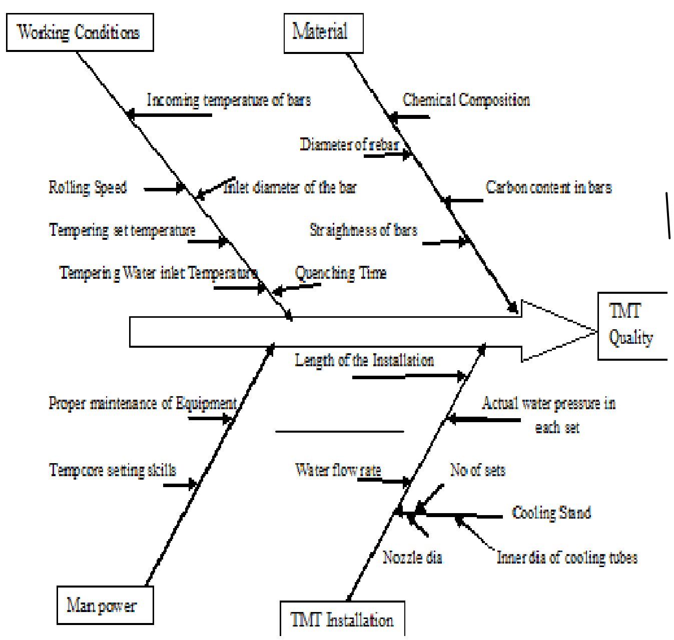
5. NEED FOR OPTIMIZATION OF TMT PROCESS

Many models have been developed to search optimal or near optimal solutions. The best possible performance is called optimum operations. The progressive firm runs their facility optimally to get competitive advantages and when most of them achieved this, and then further cost reduction is necessary, to get competitive edge again. In such case, examination of parameters is essential. Sometimes demand of product should be exchanged for cost reduction. The manufacturing design optimization problems need reduction of design process, design time and high design quality. [4]

In our case, in India generally high strength bars are produced with the maximum yield strength of 415 N/mm^2 by the conventional methods like cold twisting or micro alloying. But throughout the world the advanced technology of TMT is gaining popularity. And it can produce reinforcement bar of yield strength up to 600 N/mm^2. The basic requirements of rebars today, in India are low cost deformed bars with guaranteed yield strength of 500 N/ mm^2 with adequate ductility for the Seismic (earthquake prone) zones.

The customer is now not satisfied with high quality only or low cost, but they need variety and variability as per situations. To respond their demands and difficulty to change in production system, the industry has been required to realize and to be more responsive and flexible. The optimization techniques can be used for design of system, operation analysis and planning, engineering analysis and data reduction, and for control in dynamic situation. [1]

2.10.1 Fish Bone Diagram for TMT Process:



1. To Plan The Experiment

A series of experiments were performed on a Universal Testing Machine from the readings we can measure yield strength of the rebar to examine the effects of the different factors on the yield strength of the bar. The work piece material was TMT450 grade bars with 0.16% carbon and o.7% Mn. For these experiments we conduct tests on UTM for every 1 meter of the rebar till the four measurements. Many experiments are to be performed when the numbers of controls factors are more, but it is time consuming. Table 1 gives five control factors and two levels analyzed in the experiment. L8 orthogonal array can be established.

Table 1: Control factors and levels for the Thermo Mechanical Treatment process

Symbol	Control factor	Level 1	Level 2
A	Incoming temperature, (°c)	1030	1050
B	Water flow rate, (m3/h)	200	250
C	Rolling speed, (m/s)	15	20
D	Quenching time, (s)	0.4	0.5
E	Bar diameter, (6-40mm)	8	10

$$\eta = -10\log_{10}\left(1/r \sum_{i=1} (1/y_i^2)\right) \ldots\ldots \quad (1)$$

The S/N ratio for the higher-the-better quality characteristic on the yield strength error of the bar must be taken, because to obtain the mechanical properties optimally, minimum error of the bar is desired. Therefore, the higher-the-better type S/N ratio should be selected. The η value of the S/N ratio is calculated according to

Where r is the number of measurements made on the bar (in this study, r = 4) and Yi is the measured yield strength error value

Table 2: Yield Strength Variation Measured For TMT Bar at Different Lengths Of The Rebar

Trail No.	Factor & Column No.					Yield strength measured, (MPa), (noise)				S/N Ratio
	A	B	C	D	E	1m	2m	3m	4m	
1	1	1	1	1	1	375	380	383	382	51.59
2	1	1	1	2	2	400	410	395	405	52.09
3	1	2	2	1	1	455	450	452	448	53.08
4	1	2	2	2	2	440	439	436	438	52.83
5	2	1	2	1	2	420	422	423	418	52.49
6	2	1	2	2	1	436	433	438	435	52.78
7	2	2	1	1	2	391	394	399	396	51.93
8	2	2	1	2	1	415	419	410	413	52.34

Table 3: ANOVA for Yield Strength Variation (S/N analysis):

Factors	DOF	Sum of square	Mean square	F value	Contribution
(p)	(DFp)	(SSp)	(Vp)	(Fp)	(Qp)
A	1	0.174	0.174	3.55	9.7%
B	1	0.448	0.448	9.14	25.3%
C	1	0.866	0.866	17.67	48.8%
D	1	0.1152	0.1152	2.35	6.5%
E	1	0.0745	0.0745	1.52	4.1%
Error	2	0.099	0.049		5.6%
Total	7	1.774			100 %

6. RESULT AND DISCUSSION:

Here we have the optimal setting of the control parameters of TMT process. The quenching time and water flow rate contributes 75% on the final results. So proper design of cooling installation is needed for the desired yield strength.

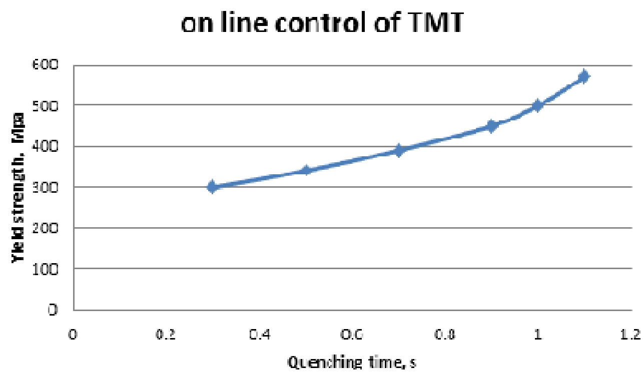


Fig. 7.1: Influence of Quenching time

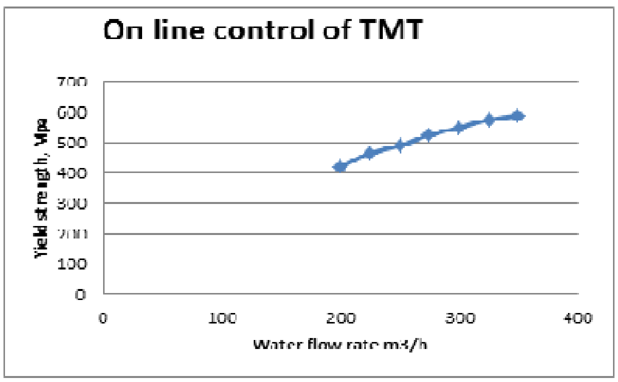


Fig. 7.2: Influence of water flow rate

To achieve the desired mechanical properties, it is obvious control variables are the quenching time, and cooling water flow rate. They are easy to adjust during rolling and they have strong effect on the yield strength of the rebars. The influence of quenching time and water flow rate on yield strength of the bars is shown in the figures above.

The longer the quenching time, the higher the yield strength. Excessive quenching time however, be avoided because this would not ensure a sufficient ductility.

7. CONCLUSION

1. In our study Optimization of Thermo Mechanical Treatment process we observed that the control factors quenching time, water flow rate and bar diameter are contributing more than 75 %.
2. Final yield strength of the rebar greatly affected by these control factors
3. For optimizing the TMT process we need to concentrate more on quenching time and the water flow rate very carefully.

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