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*Research Article*

# Study of Factors affecting to Mechanical Strength of Hot Rolled Reinforcement Bars using Regression Analysis

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***Abstract***

*The mechanical strength of reinforcement bars is contributed by the chemical composition and process variables of hot rolling process. To identify the grade of the material, the mechanical strength of the rolled material is essential. To know this, a statistical model is developed to predict the mechanical strength of reinforcement bars produced by hot rolling. Multiple linear regression technique is used to study the relationship between mechanical properties, process variables and carbon equivalent of hot rolled reinforcement bars. This model gave an insight for predicting the mechanical strength of the material before taking up the tensile test of the material. Also useful for optimizing the process parameters for rolling the required material.*

***Keywords:*** *mechanical strength, process variables, carbon equivalent, multiple linear regression analysis.*

## 1. Introduction

Reinforcement bars produced during hot rolling are primarily used for mechanical strength requirement. In hot rolling process the semi-finished products are heated in a reheating furnace. Once these semi-finished products attain the austenizing temperature, it was taken out from reheating furnace and made to pass through a series of rolls for reducing to desired cross section of reinforcement bars. Then it undergoes thermo mechanical treatment for obtaining mechanical strength. This process is complex as it involves chemical composition of steel and many process variables.

Modeling of steel properties is demanding because many of the required properties are achieved only if the interactions of composition and thermo mechanical treatments can be predicted and controlled reliably (IlmariJuutilainen, *et al*, 2003).In order to achieve this objective, a study was made using multiple regression analysis technique which is effective for interpreting, estimating and for implementation (IlmariJuutilainen, *et al*, 2003). Most often used for prediction and forecasting, regression analysis has become one of the most widely used statistical tools for analyzing data involving multiple variables (Chatterjee&Hadi, 2012, Lucas Hopkins & Keith E. Ferguson, 2014). This method enables the prediction values of one response variables (dependent) through a set of explanatory variables (independent), or assesses the effects of the explanatory variables as predictor of response variables (Stevenson, 2001, Andrea Parisi Kern, *et al*, 2015).

## 2. Materials and Methods.

For this study, the data was collected from hot rolling mill. Each steel grade has specifications for mechanical properties and the strength of the material is controlled by tensile testing. A test bar is usually cut off and its strength is measured by drawing the bar until it breaks (IlmariJuutilainen, *et al*, 2003). Yield strength (YS) and Ultimate tensile strength (UTS) are measured to know mechanical strength and the grade of the steel is declared accordingly.

Mechanical property is dependent on the chemical composition and process variables of hot rolling mill. The elemental concentration of reinforcement bar was obtained through analysis and converted to Carbon Equivalent (CEq).

$$CEq = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15} \quad (1)$$

### *2.1 Independent Variables*

The Independent variables include carbon equivalent and section weight of reinforcement bars, rolling speed of hot rolling mill denoted as Mill level and the process parameters involved in thermo mechanical treatment. The process parameters involved in thermo mechanical treatment are water pressure [bar], water flow [m3/hr.] and inlet pressure [bar].

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All dependent and independent variables are quantitative in nature and are expressed as numerical figures for statistical analysis (Andrea Parisi Kern, *et al*, 2015).

*2.2 Dependent Variables*

The value of Yield strength (YS) and Ultimate tensile strength (UTS) obtained from tensile testing method are the dependent variables. Both these quantities are measured in MegaPascal (MPa) (Tim Marchant, *et al*, 2005).

*2.3Data analysis*

Ryan-joiner statistical tests were used to find out the applicability of multiple linear regression. From the Fig.1 and Fig.2, p value greater than 0.1 indicates that normality hypothesis cannot be rejected. The box plot is also drawn given at Fig. 3 and Fig.4 indicates that there are no outliers in the data considered for the study.

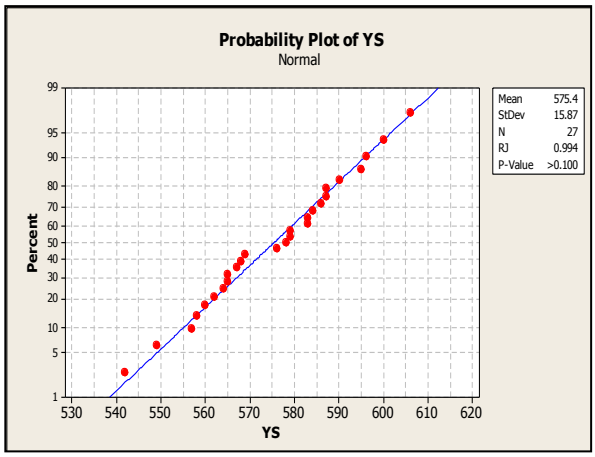


**Fig.1** Normal probability plot of dependent value of Yield Strength (YS)

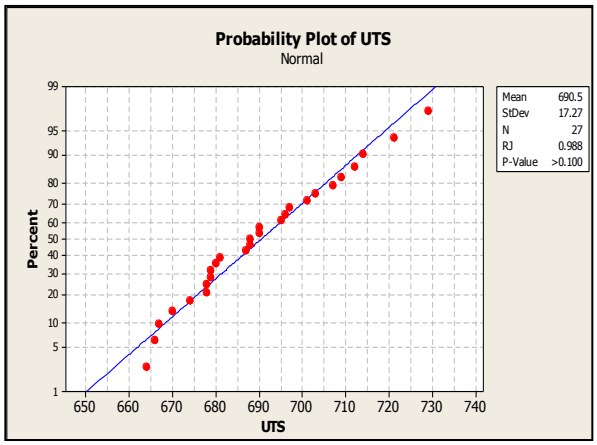


**Fig.2**Normal probability plot of dependentvalue of Ultimate Tensile Strength (UTS)

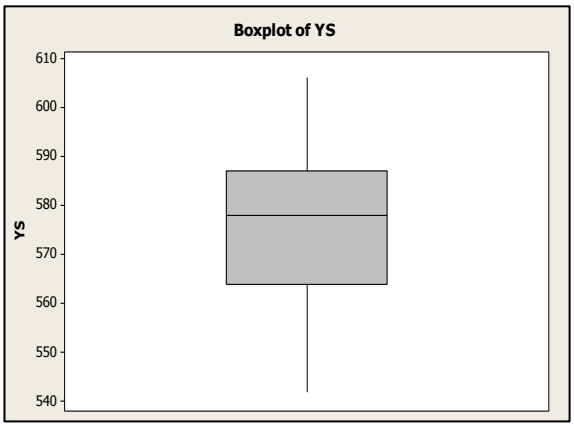


**Fig.3** Box plot of Yield Strength (YS)

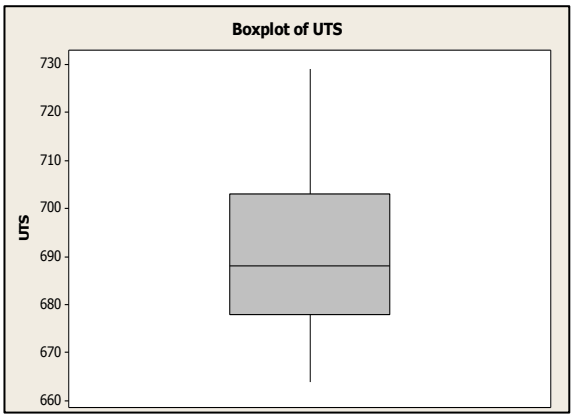


**Fig.4** Box plot of Ultimate tensile strength (UTS).

## 3. Results

*3.1 Model development*

The statistical technique of multiple linear regression (MLR) analysis is used and the equation for the model is:

$$Y= a + b_1X_1 + b_2X_2 + .... bnXn + c \quad (2)$$

where Y is the dependent variable, $X_1$ and $X_2$ are first and second independent variable respectively, $b_1$ and $b_2$ are coefficients of first and second independent variable respectively, a is constant, and c is the error (F. Mekanik, *et al*., 2013).

The hypothesis testing, $R^2$, the adjusted $R^2$, the F test and analysis of the residuals are evaluated for the goodness-of-fit and the statistical significance of the estimated parameters of the constructed regression models.

Multi-collinearities occurs when the predictors are highly correlated which will result in dramatic change in parameter estimates in response to small changes in the data or the model (F. Mekanik, *et al*., 2013). A variance inflation factor (VIF) is calculated for multi-collinearities among the descriptors to test the independent variables (Lucas Hopkins & Keith E. Ferguson, 2014), which is defined as

$$VIF = \frac{1}{1-R_j^2} \quad (3)$$

Where, $R^2_j$is the squared correlation coefficient between the jth coefficient regressed against all the other descriptors in the model. If VIF equals to one, no inter-correlation exists for each descriptor; if VIF maintains within the range 1.0–5.0, the corresponding models acceptable; if VIF is larger than 10.0, the corresponding model is unstable and rejected (G. R Famini, *et al*, 1992, XiaojunWang, *et al*., 2014).

To evaluate the independence of the errors of the models, Durbin-Watson test (DW) is applied to know the serial correlation between errors. The test statistics have a range of 0–4, according to (Field (2009))values less than 1 or greater than 3 are definitely matter of concern(F. Mekanik, *et al*., 2013).

*3.2 Regression analysis.*

Various combinations of independent variables were tested using regression analysis in order to find the best fit (Andrea Parisi Kern, *et al*, 2015). The default value of 0.05 was selected as a level of significance α.

The statistical tool MINITAB 16 was used for data analysis. The regression model obtained from the data resulted in $R^2$value of 84 % and adjusted $R^2$ value of 79.7 % for Yield Strength (YS) Eq.4.For Ultimate Tensile Strength (UTS) the $R^2$ value obtained is 86.8 % and adjusted $R^2$ value of 84% Eq.5.

The predictive power of the equation obtained from $R^2$ (predictive) is 81.03% for Yield Strength and 78.97 % for Ultimate Tensile strength which means that it predicts 81.03 % and 78.97 % of factors are involved in Yield Strength and Ultimate Tensile Strength respectively.

YS = 1760 - 108 Section Wt. - 2.81 Mill level+ 20.3 Water pressure- 0.260 Water flow- 22.0 Inlet Pressure + 203 CEq (4)

UTS = 1791 - 134 Section Wt. + 34.9 Water pressure- 0.378 Water flow - 25.5 Inlet Pressure + 338 CEq (5)

Analysis of Variance (ANOVA) is computed to test the significance of the regression. Also checked the residuals plots for normal probability (Andrea Parisi Kern, *et al*, 2015).

The coefficients of the regression model were estimated at a significance level of 0.05. The parameters were excluded for the probability value (p-value) >0.05.

The ANOVA tables of all the parameters are shown in Table 1 for YS and table 2 for UTS.

**Table 1**ANOVA table of YS

| Predictor | Coefficient | p value | VIF |
|---|---|---|---|
| Constant | 1759.7 | 0.0001 | |
| Section weight | -108.46 | 0.0001 | 1.534 |
| Mill level | -2.8072 | 0.0001 | 1.263 |
| Water Pressure | 20.318 | 0.0001 | 2.806 |
| Water Flow | -0.26029 | 0.0001 | 2.872 |
| Inlet Pressure | -22.018 | 0.0001 | 1.621 |
| CEq | 202.64 | 0.009 | 1.466 |
| R-Sq = 84.0 % | R-sq (adj.) =79.7 % | R-Sq (pred.)= 81.03% | Fvalue = 29.27 |
| Durbin Watson Statistics=1.96 | | | |

**Table 2**ANOVA table of UTS

| Predictor | Coefficient | p value | VIF |
|---|---|---|---|
| Constant | 1790.9 | 0.0001 | |
| Section wt | -134.19 | 0.0001 | 1.38 |
| Water Pressure | 34.88 | 0.0001 | 2.895 |
| Water Flow | -0.3783 | 0.0001 | 2.885 |
| Inlet Pressure | -25.52 | 0.0001 | 1.573 |
| CEq | 338.4 | 0.0001 | 1.258 |
| R-Sq = 86.8 % | R-sq (adj.) =84.0 % | R- Sq (pred.) = 78.97% | F value = 30.34 |
| Durbin Watson Statistics = 2.739 | | | |

The normal probability plot of the residuals of YS and UTS are shown in fig. 5 and fig.7.The residual vs. fitted value for YS and UTS are shown in fig.6 and fig.8 respectively. The critical value for VIF was 2.872 for YS and 2.895 for UTS

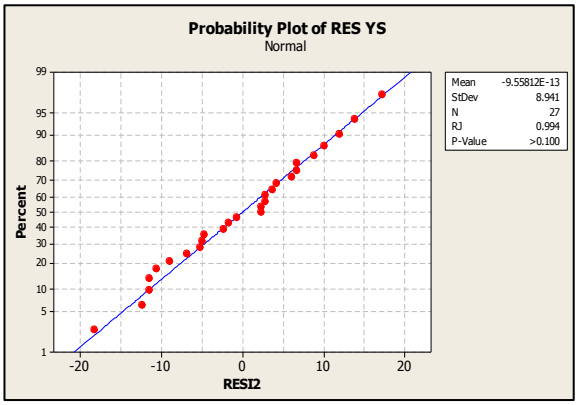


**Fig.5** Normal probability plot for YS

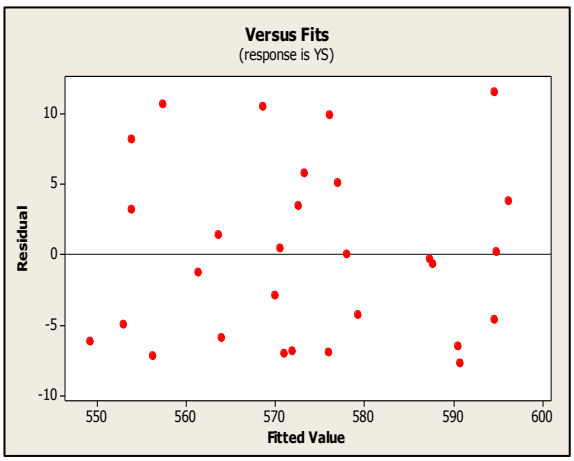


**Fig.6** Residual versus Fitted values for YS.

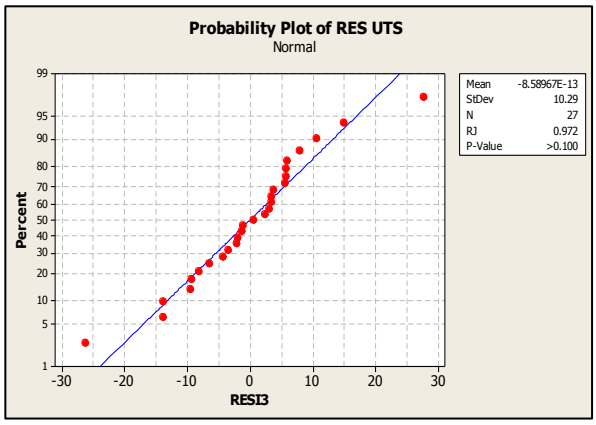


**Fig.7**Normal probability plot for UTS

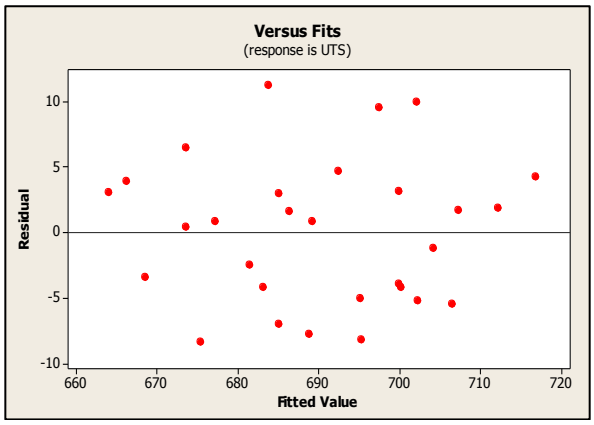


**Fig.8** Residual versus fitted values for UTS

The Yield strength (YS) and Ultimate tensile strength (UTS) obtained during tensile testing was compared with values calculated by the regression model presented in this study.

Mechanical strength obtained from tensile testing and predicted by model is given below table 3.

**Table 3**Actual vs Predicted value

| Actual YS(MPa) | Predicted YS(MPa) | Actual UTS(MPa) | Predicted UTS(MPa) |
|---|---|---|---|
| 563 | 565.25 | 688 | 693.79 |
| 576 | 574.97 | 711 | 703.23 |
| 566 | 564.15 | 677 | 683.89 |
| 561 | 553.41 | 681 | 672.36 |
| 548 | 556.51 | 668 | 675.31 |
| 556 | 553.06 | 673 | 673.07 |
| 561 | 561.72 | 688 | 687.07 |
| 544 | 549.26 | 666 | 663.5 |
| 549 | 551.91 | 665 | 668.11 |
| 587 | 588.03 | 706 | 699.9 |
| 587 | 589.35 | 703 | 706.64 |
| 575 | 572.96 | 688 | 687.81 |
| 578 | 573.84 | 690 | 688.76 |
| 605 | 595.64 | 708 | 707.88 |
| 578 | 570.37 | 691 | 692.19 |
| 595 | 595.29 | 696 | 701.28 |
| 600 | 593.83 | 713 | 712.2 |
| 568 | 575.87 | 682 | 689.78 |
| 586 | 577.03 | 678 | 681.9 |
| 566 | 573.99 | 678 | 679.26 |
| 567 | 558.8 | 671 | 664.04 |
| 568 | 570.71 | 694 | 684.58 |
| 585 | 591.27 | 702 | 706.64 |
| 591 | 593.51 | 720 | 717.66 |
| 584 | 589.51 | 696 | 701.27 |
| 559 | 565.75 | 678 | 682.19 |
| 570 | 570.84 | 696 | 693.36 |

The difference between mechanical strength calculated by the regression model with respect to actual value is in the range of +/- 2% and is significant.

## Conclusion& Future scope of the study

Prediction of mechanical property is a complex process. An attempt was made to predict the mechanical properties using multiple linear regression model. This paper numerically investigates the yield strength and Ultimate tensile strength of reinforcement bar. The authors try to show an empirical way to find out the factors involved in the mechanical strength of hot rolled reinforcement bar. While developing the model, Carbon equivalent (CEq) had been taken instead of elemental composition of the rolled material. The predictors whose p value is not significant are excluded from the model. There is further scope of research by taking the elemental composition of the rolled material with a new set of data where p value of any other predictor might be significant.

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