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Application of MATLAB to predict the physical quality parameters of Rimming Steel Ingot

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Abstract

Rimming steel is the low Carbon (C) steel mainly used for producing Electrode quality wire rods and Buss-bars for Metro rail etc. Rimming grade steel is only casted through ingot teeming route.Rimming steel consists low Carbon ~0.08-0.09% and Manganese (Mn) 0.40-0.50%. Rim thickness and Rimming duration are the main physical quality parameters of a rimming steel ingot. They mainly depend on the contents of C, Mn in the cast steel. Rimming Steel is a grade which contains high oxygen (ppm) level in bath ~1000-1200 and ~225-275 in ladle after tapping. The recovery of alloys decrease with increase in oxygen level in liquid metal and this higher level of residual oxygen in the bath makes the Mn recovery varies much. The percentage of Mn and oxygen level in ladle have significant effect on rimming duration and rim thickness of the ingot teemed. A study has been carried out, analyzing the practical data, to predict the relation between these physical parameters and quality using MATLAB application.

Keywords: Matlab, Physical Parameters, Rimming Steel Ingot.

Introduction

Rimming steel containing low carbon 0.08-0.09% and Manganese 0.40-0.50 % in steel can be cast through Ingot teeming route only. This steel is mainly used to produce Electrode quality wire rods and Buss-bars of Metro rail because of its pure metal outer rim (Figure-1). This grade contains high oxygen level (~1000 -1200 ppm) in bath and 225-275 ppm in ladle after tapping. Due to high oxygen in ladle the recovery of alloy added gets reduced to some extent. The recovery of Mn in liquid metal gets affected by the residual oxygen in ladle. Also to reduce excess oxygen in ladle some deoxidizer added in ladle. The addition of deoxidizer should be such that it should not decrease the oxygen level below a certain limit since the rimming behavior and rim thickness significantly depends on the oxygen level in ladle. Also the addition of ferromanganese (FeMn) should be such that Mn should come within the aforementioned range, because it is also a factor whose recovery gets affected by the oxygen content in liquid metal. The residual oxygen and the Manganese percentage are the two major factors that affect the Rimming duration and Rim thickness and therefore the quality of rimming grade steel. The Rimming grade steel is such a critical grade having very less yield (~55-60%) and that depend mainly on oxygen and Manganese content, Al addition, rim thickness, rimming duration etc.

The performance of Rimming steel mainly depends up on the Rim thickness formed while the ingot solidification is occurring. The uncertainty of Mn recovery and the thickness of the Rim formed was causing the maximum rejection of steel to lower grades. A study has been carried out in which some practical data at different steel making stages have been collected and correlated with each other to predict the various parameters and their effect on quality of rimming steel with the help of MATLAB software (Figure-2).

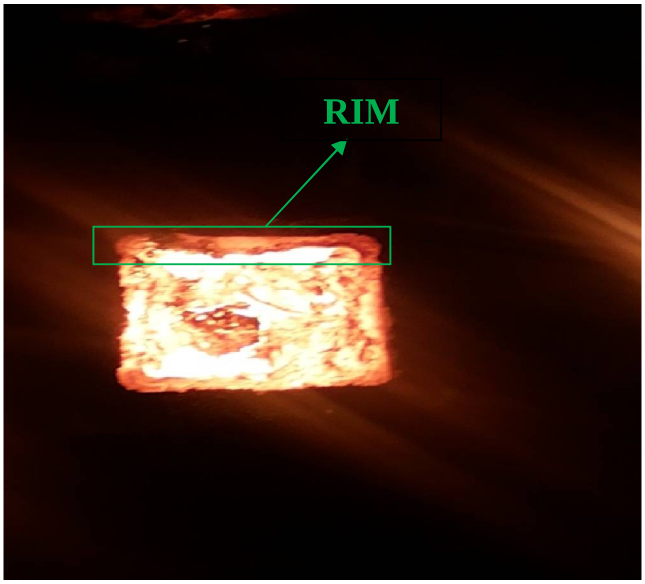
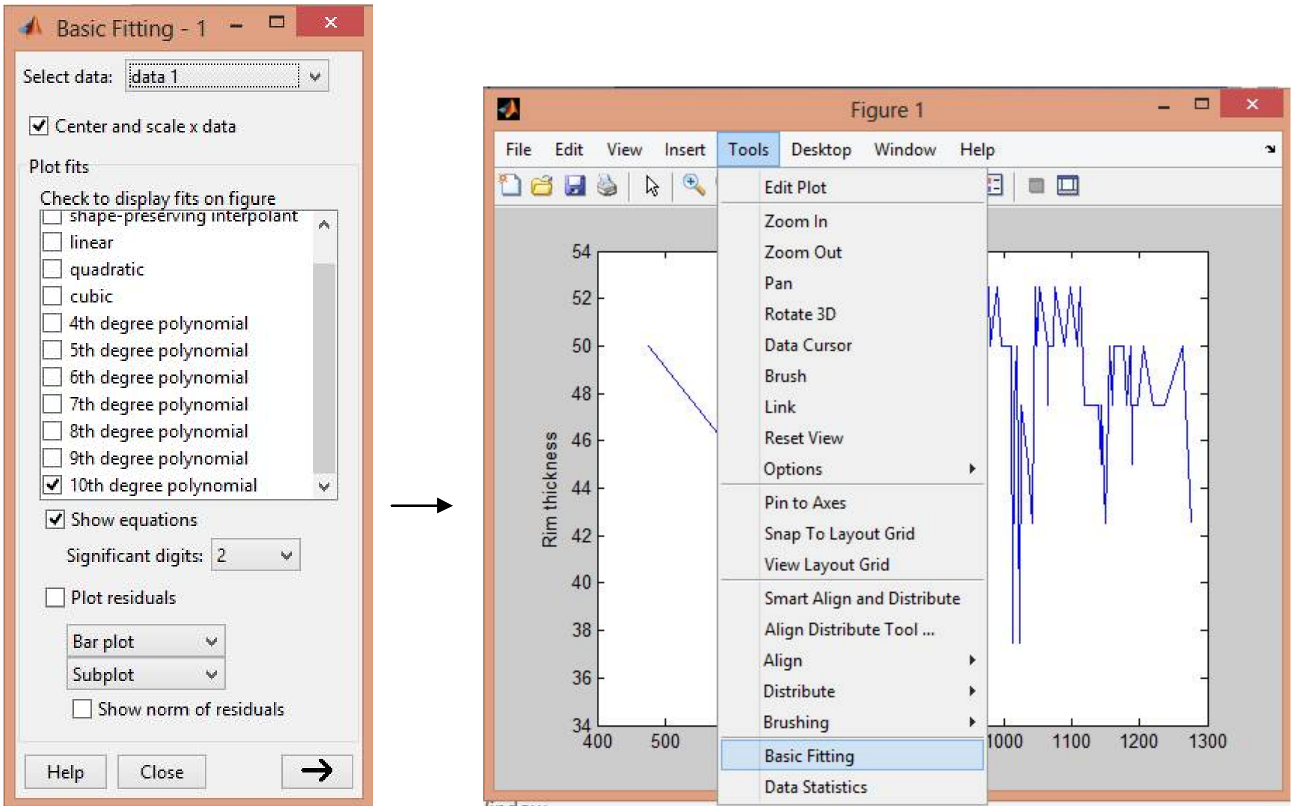


Figure-1
Top view of rimming steel ingot



Basic Fitting - 1

Select data: data 1

☑ Center and scale x data

Plot fits

Check to display fits on figure

☐ shape-preserving interpolant
☐ linear
☐ quadratic
☐ cubic
☐ 4th degree polynomial
☐ 5th degree polynomial
☐ 6th degree polynomial
☐ 7th degree polynomial
☐ 8th degree polynomial
☐ 9th degree polynomial
☑ 10th degree polynomial

☑ Show equations

Significant digits: 2

☐ Plot residuals

Bar plot

Subplot

☐ Show norm of residuals

Figure-2
Snapshots from MATLAB

The use of MATLAB is preferred over the use of other applications because by using this application, curve fitting of upto 10th degree polynomial can be done which is not possible in other commonly used applications viz. Microsoft excel etc. This feature enhances the precision of prediction.

Work Done

Data at different steel making stages of rimming steel have been collected and a correlation has been established between them to predict the quality of Rimming steel.

Correlation between various factors like: i. Mn recovery and oxygen level in bath, ii. Rim thickness and Mn%, iii. Rim thickness and Oxygen ppm

Mn recovery (%) vs Oxygen level in bath (ppm): The recovery of manganese was calculated for 1430 heats by taking various parameters into consideration viz. percentage of Mn increase between bath and ladle, heat size, percentage of Mn in FeMn and the amount of FeMn added in ladles. The principle used for alloy recovery calculation theoretically is[1]

$$\text{Recovery} = \frac{(\%\text{ increase of Mn})*(\text{Heat Size})}{(\%\text{Mn in FeMn})*(\text{Amt. of FeMn added})}$$

Graphs have been plotted showing the relationship between the Mn recovery and the bath oxygen level. The first plot (Figure-3) shows linear relation between the two parameters, which is in conformity with the theory that the recovery of manganese should decrease with an increase in the oxygen level in bath[4].

The following plot (Figure-4) shows the 10th degree polynomial curve of best fit whose equation is given below. The 10th degree polynomial curve has been chosen for high degree of precision in prediction.

Regression model: $y = 0.00355*z^{10} - 0.0164*z^{9} - 0.0308*z^{8} + 0.205*z^{7} + 0.00396*z^{6} - 0.771*z^{5} + 0.314*z^{4} + 1.13*z^{3} - 0.054*z^{2} - 1.7*z + 50.9$
Where: $z = (x - 1.05e{+}03)/172$

Rim thickness (mm) vs Mn content (%): Manganese plays a very crucial role in determining the quality of rimming steels. The Mn content effects the rimming duration as well as the rim thickness[3].

Effect of Mn content (ladle) of rimming steel on rim thickness have been analysed using the data of 94 heats. The resultant plot (Figure-5) shows an inversely proportional relation between the Mn content and rim thickness. Since, a good quality rimming steel has more rim thickness than a bad one, therefore, from the analysis it can be said that an increasing Mn content hampers the quality of rimming steel.

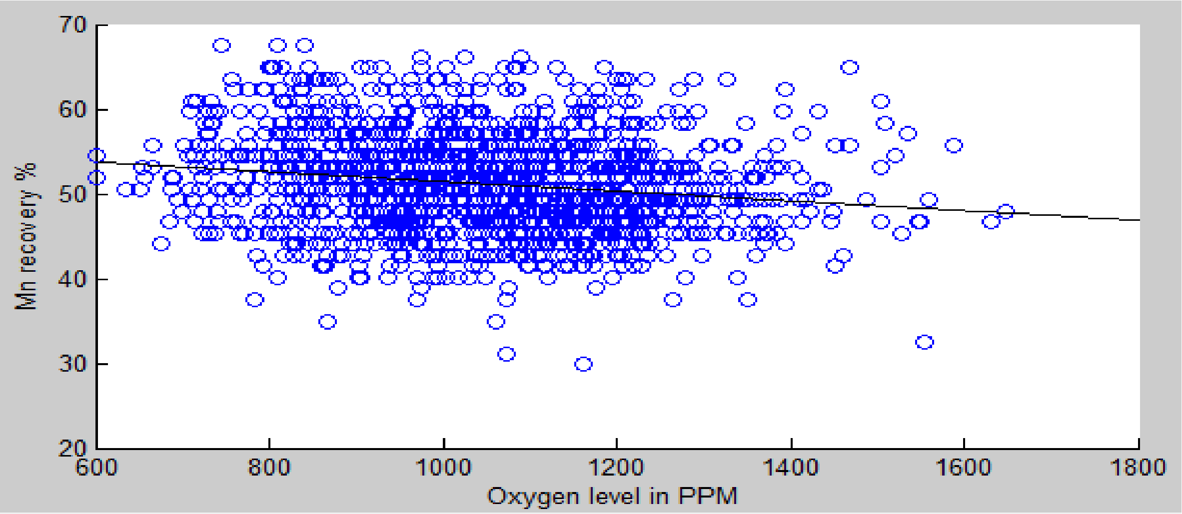


Figure-3
Linear variation of Mn recovery % with bath oxygen level in ppm

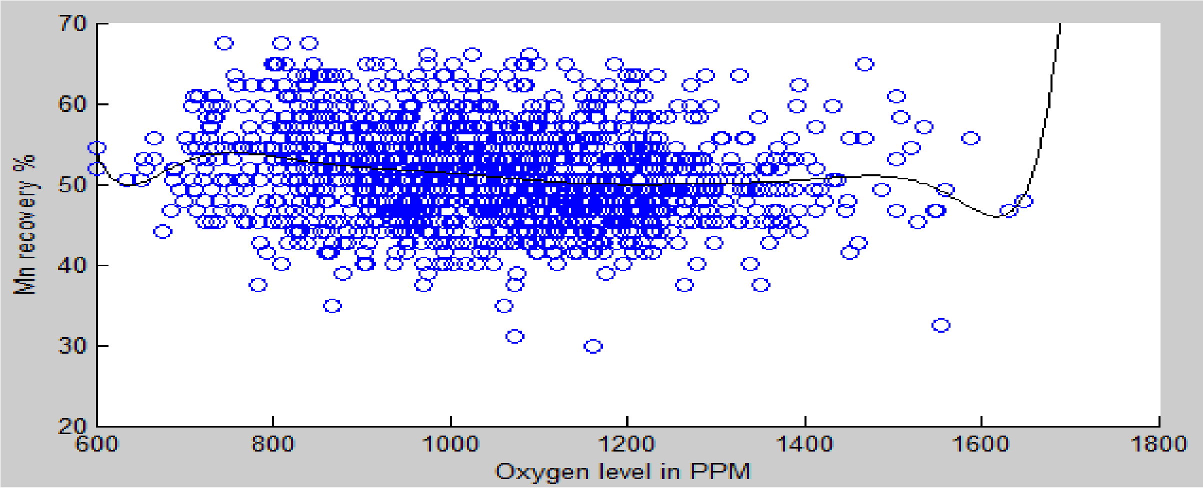


Figure-4
Scatter plot of Mn recovery % vs bath oxygen level in ppm, with 10th degree polynomial curve of best fit

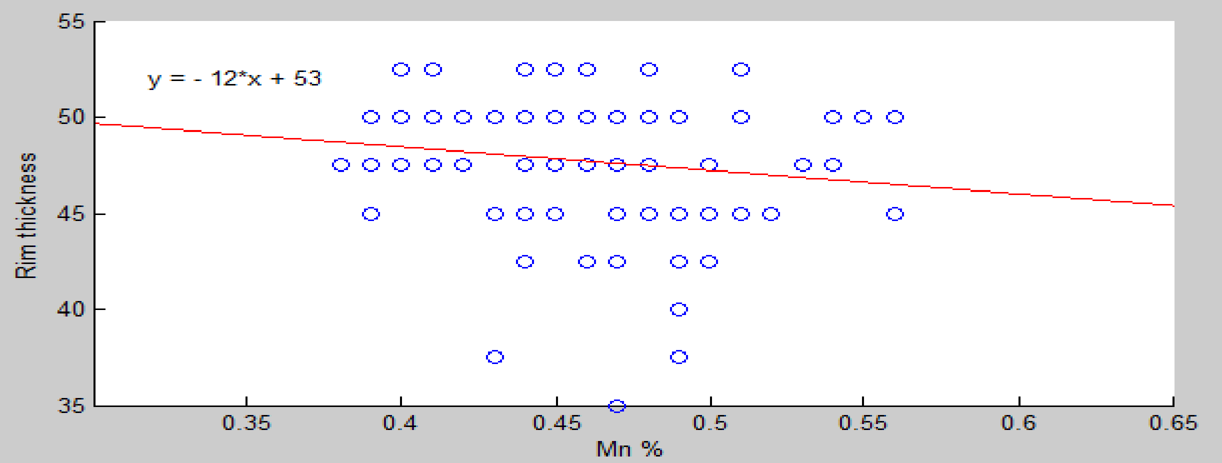


Figure-5
Linear variation of rim thickness with final Mn content

The following plot (Figure-6) shows the 10th degree polynomial curve of best fit whose equation is given below.

Regression model: $y = 0.0489*z^{10} - 0.509*z^{9} + 0.739*z^{8} + 2.95*z^{7} - 5.92*z^{6} - 5.37*z^{5} + 12.7*z^{4} + 4.01*z^{3} - 8.74*z^{2} - 2.52*z + 48.6$
Where: $z = (x - 0.456)/0.0451$

Rim thickness (mm) vs Oxygen level (ppm): Rimming action depends on the oxygen level of liquid steel. Therefore, the oxygen content plays a very important role in determining the rim thickness of rimming steel[4].

The plot fitted with the straight line (Figure-7) shows the linear trend between rim thickness and oxygen content. However, for modeling the data, a polynomial 10th degree curve (Figure-8) is preferred for precision

Regression model: $y = - 0.26*z^{10} - 1*z^{9} + 1.2*z^{8} + 6.7*z^{7} - 1.3*z^{6} - 13*z^{5} - 0.074*z^{4} + 6.1*z^{3} + 0.29*z^{2} + 1.4*z + 48$
Where: $z = (x - 1e+03)/1.5e+02$

Result and Discussion

After arriving at the regression models, the models were tested using a different set of data, shown in the annexures, which comprises of 187 heats. To test the models, actual data have been compared with the corresponding predicted data and the differences between the actual and the predicted values have been analyzed.

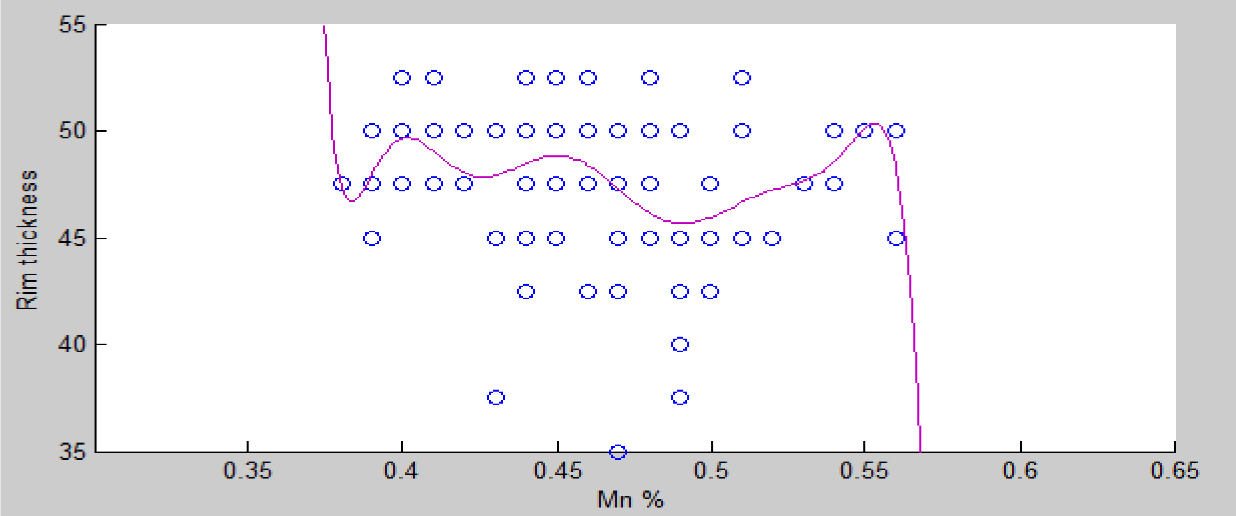


Figure-6
Scatter plot of Rim thickness vs final Mn content, with 10thdegree polynomial curve of best fit

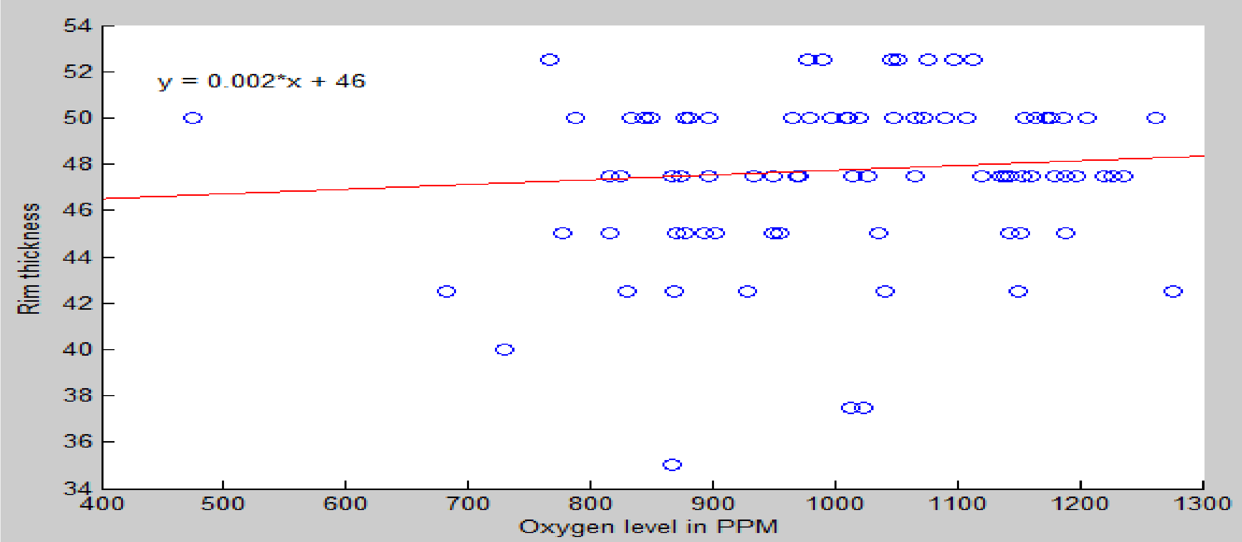


Figure-7
Linear variation of rim thickness with bath oxygen level in ppm

As shown in Table – 1, in case of the first model i.e. Mn recovery vs ppm, the total number of heats which shows variation between ± 10 % are 169 i.e. 90 % of 187 heats show variation between ± 10 % (Figure-10). Variations in recovery for rest of the heats is beyond ± 10 %. In Figure-9 it can be observed that the actual values are concentrated across the predicted values of Mn recovery %. This indicates that the model satisfactorily fits the actual values.

Variations in recovery can be attributed to various factors viz. change in amount of FeMn addition, change in the supplier of FeMn which affects the percentage of manganese in FeMn, fluctuating heat size, Tapping temperature etc.

In case of Rim thickness vs ppm, the following plot (Figure-11) shows the comparison between actual and predicted values.

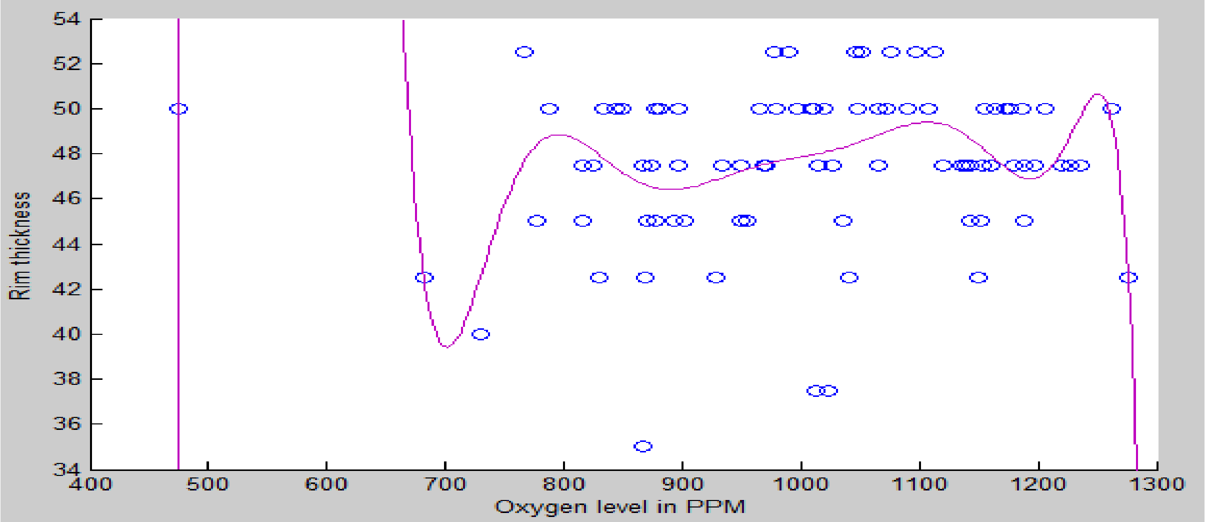


Figure-8
Scatter plot of Rim thickness vs bath oxygen level in ppm, with 10^{th} degree polynomial curve of best fit

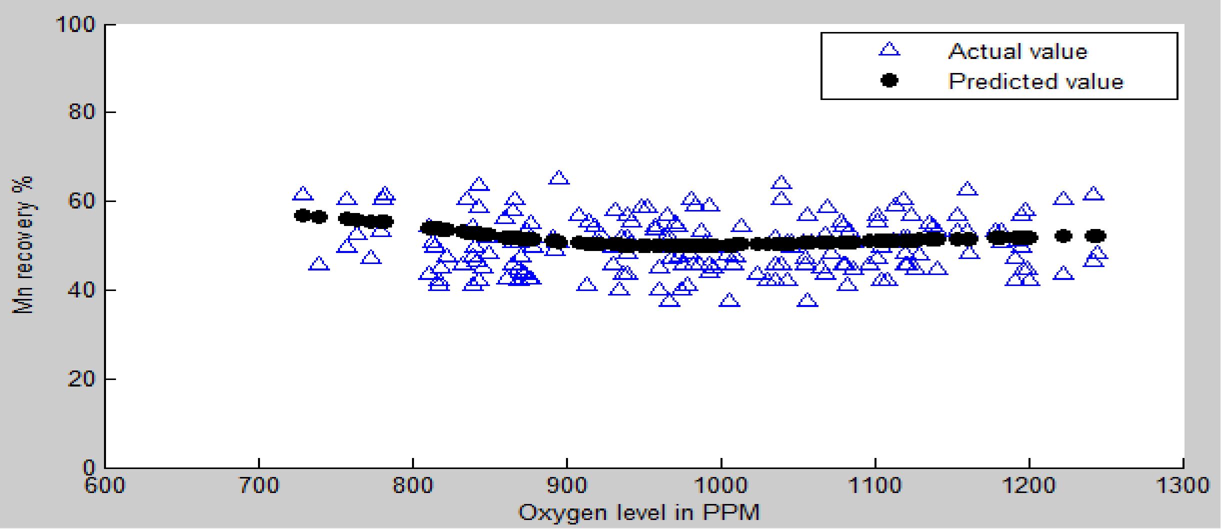


Figure-9
Comparison between actual and predicted values of Mn recovery %

Table-1
Frequency of heats for each range of error in Mn recovery

Error % in Mn recovery	No. of heats	%
+/- 10	169	90.37
+/- 10+	18	9.63

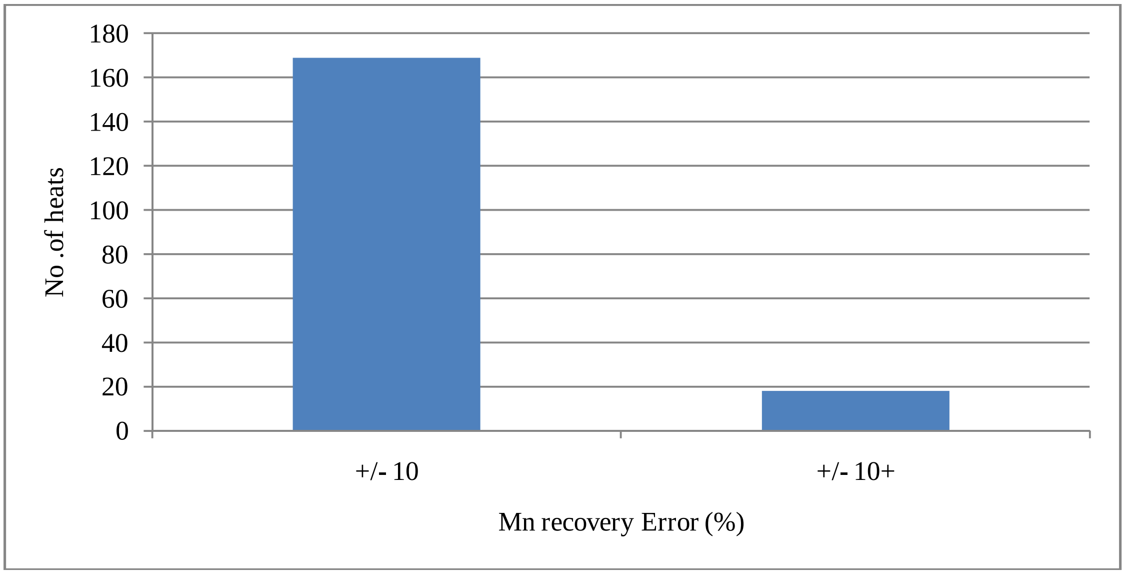


Figure-10
Bar chart showing No. of heats for each range of error in Mn recovery

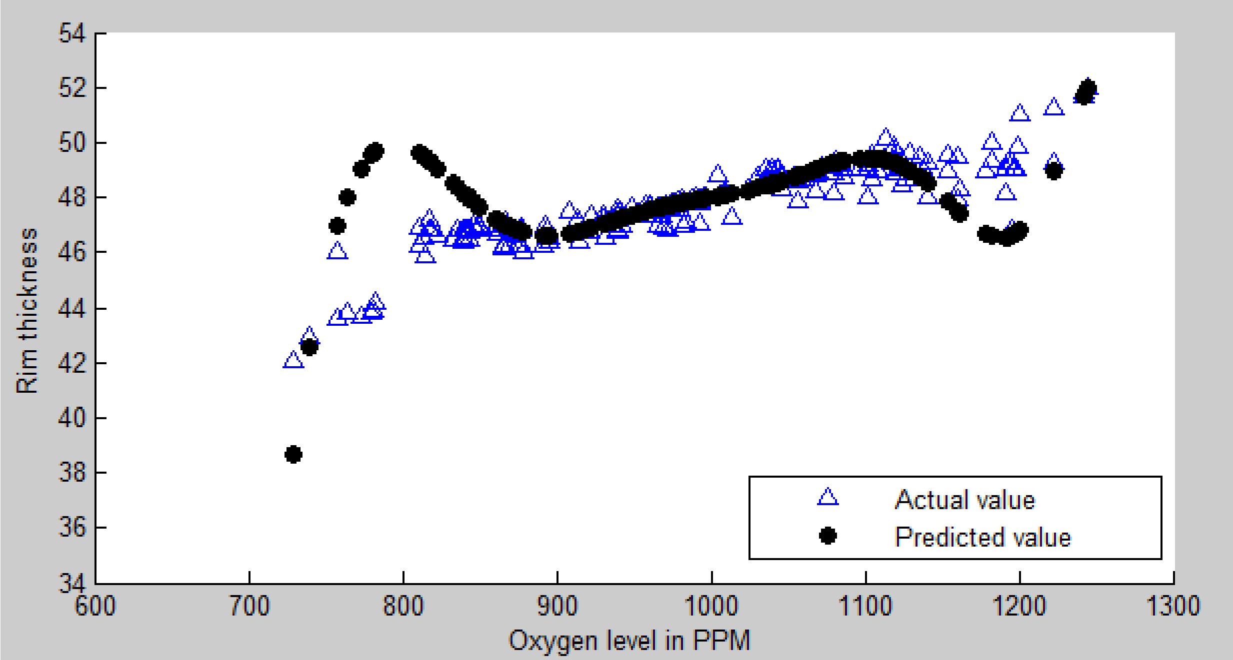


Figure-11
Comparison between actual and predicted values of rim thickness (mm)

The following table (Table.2) shows that the number of heats with variation in the range +/- 2 is maximum i.e. 160 which constitutes 85% of the total heats. Variation for 21 % of the heats is between +/- 2-4. Therefore, total number of heats with variation between +/- 4 is 181 or 97 % of the total heats (Figure-12).

From Table-2 it can be seen that the difference between the actual and the predicted values for 85 % of the heats is within the range ± 2mm, this indicates that the regression model satisfactorily explains the variation in the data.

In case of Rim thickness vs Mn %, the total number of heats for different ranges of errors is as follows (Figure-13).

The error observed in practical Rim formed with the calculated data with respect to final Mn % is as shown below in Table-3.

Table-2
Frequency of heats for each range of error in Rim Thickness (mm)

Error in Rim thickness (mm)	**No. of heats**	**%**
+/- 2	160	85.5615
+/- 2-4	21	11.22995
+/- 4-6	6	3.208556

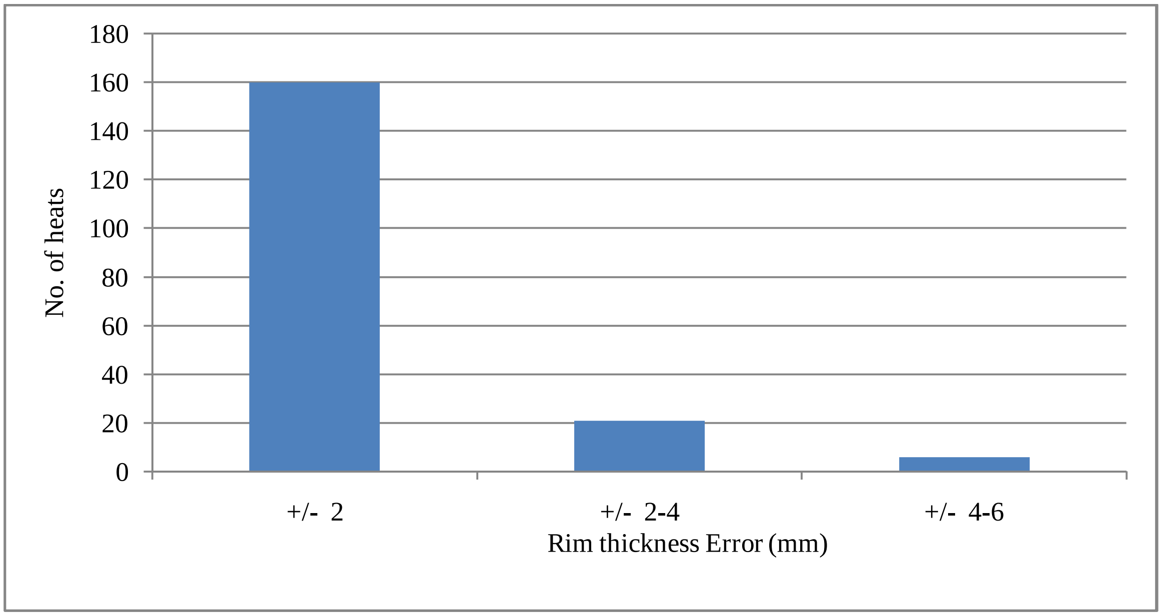


Figure-12
Bar chart showing No. of heats for each range of error in Rim Thickness

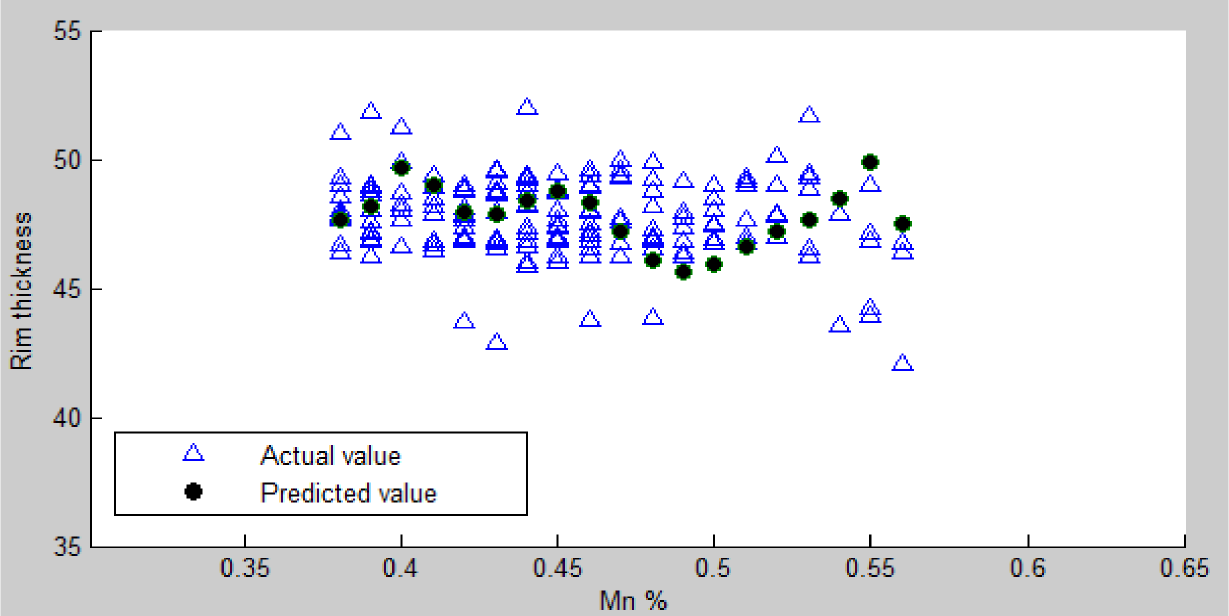


Figure-13
Comparison between actual and predicted values of rim thickness (mm)

Table-3
Frequency of heats for each range of error in Rim thickness (mm)

Error in Rim thickness (mm)	No. of heats	%
+/- 2	139	74.33
+/- 2-4	40	21.39
+/- 4-6	8	4.27

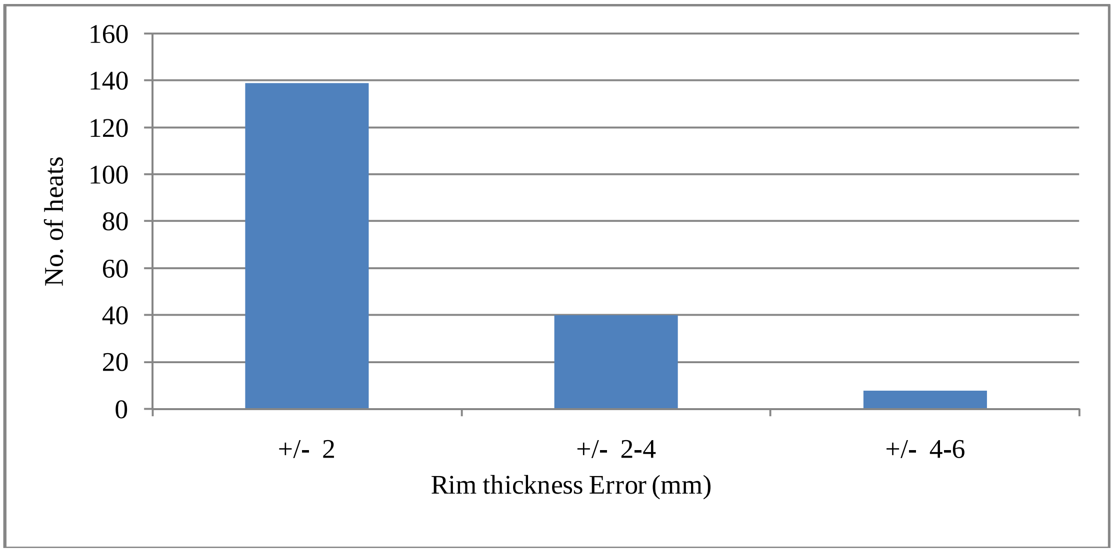


Figure-14
Bar chart showing No. of heats for each range of error in Rim thickness (mm) (mm)

Total number of heats with variation between +/- 2 is 139, i.e, 74.33% of the total heats (Figure-14).

Discussion: The Mn range required in Rimming steel is 0.42 to 0.52 %, i.e., a variation in recovery in the range of 17% is allowed for the quantity of Fe-Mn added per heat. The aim will be to control this in the range of 10% which will be ideal to end up with the middle point of the target range, i.e., approximately 0.48% Mn in finished steel. In the actual data the variation in recovery is about 17 %, therefore, variation of ± 10 % in the predicted values is permissible.

Manganese content between 0.42 – 0.50 % leads to rim thickness of 48 – 49 mm. Therefore, variation of ± 2 mm is tolerable, since, with such variation, the rim thickness will vary between 46 – 51 mm which is within the optimum range of rim thickness i.e. 45 – 52mm. However, variation between ± 2-4 mm is doubtful case because in such cases the rim thickness touches the boundary of the optimum rim thickness limit. Beyond this the rim thickness goes to a range where the Rolling defects will seep in.

From rim thickness vs Oxygen ppm curve, to some extent it is possible to predict the rim thickness beforehand and therefore subsequent actions can be taken accordingly which increases the probability of making a successful rimming heat.

From Rim thickness vs Mn % curve, it is possible to have an idea of the final Mn % in the steel for achieving a particular rim thickness and therefore addition of FeMn can be done accordingly.

Another important piece of information that can be deduced from the curve is that if we know the final Mn % of steel then it is possible to have an idea of approximate rim thickness and therefore capping action can be done accordingly to control the thickness of rim.

Conclusion

The regression models have been put to practical use to optimise the existing practice such as ferroalloy addition, capping action etc. The prior idea of the rim thickness based upon the final manganese content and the oxygen level in bath has led to the improved control over the quality of rimming steels. With the help of this study there has been an increase in the number of successful rimming heats from 84-85% to 97%. This has also helped in planning the heats and delivery to the mill also. A lot of energy and resource saving has occurred.

References

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