PREDICTION OF WORK ROLL INITIAL CROWN ACCORDING TO DESIRED STRIP PROFILE IN HOT ROLLING

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(Received: November 02, 2010 – Accepted in Revised Form: December 15, 2011)

doi: *10.5829/idosi.ije.2011.25.01c.09*

Abstract The final hot strip profile is a superposition of the roll initial crown, the roll bending and flattening crown, the roll wearing crown and the roll thermal crown. In this research, linear regression models are proposed to predict the roll force, the roll wearing crown and the roll thermal crown using experimental data provided by Mobarake Steel Complex (MSC). The Euler-Bernoulli beam theory based on elasticity approach is also used to predict the roll bending and flattening crown. Finally, the work roll initial crown in order to obtain desired strip profile in hot rolling is predicted utilizing a computer programming. The obtained initial crowns are then used for seven stands of an actual roll schedule for hot strip mill of MSC. The measured strip profile shows a good agreement with the desired one for the mentioned mill.

Keywords Hot rolling; Initial crown; Wearing crown; Thermal crown; Bending crown; Empirical data; Regression

چکیده پروفیل نهایی ورق حاصل تاج اولیه غلتک، تاج خمشی و تخت شدگی غلتک، تاج سایشی غلتک و تاج حرارتی غلتک می‌باشد. در تحقیق حاضر با استفاده از داده‌های تجربی اخذ شده از مجتمع فولاد مبارکه مدل‌های رگرسیون خطی برای پیش‌بینی نیروی نورد، تاج سایشی و تاج حرارتی غلتک و با استفاده از تئوری تیر کوتاه بر طبق اصول الاستیسیته تاج خمشی و تخت شدگی سطح تماس غلتک بدست آورده شده است. نهایتاً تاج اولیه غلتک جهت ایجاد پروفیل دلخواه ورق در نورد گرم با استفاده از یک برنامه کامپیوتری پیش بینی شده است. مقادیر پیش بینی شده فوق به عنوان تاج‌های اولیه هفت قفسه خط نورد گرم مجتمع فولاد مبارکه در یک برنامه واقعی نورد انتخاب شدند و پروفیل بدست آمده ورق در تطابق بسیار خوبی با مقدار اندازه گیری شده توسط مجتمع فولاد مبارکه می‌باشد.

1. INTRODUCTION

Hot rolling is one of the most common methods in steel production. In fact, more than 80 percent of steel production is produced by this method. The efficiency and delicacy of rolling production makes this industry to be a precise process against other methods of metal forming. Among different methods of rolling, hot rolling mill encounters many parameters to predict the work roll initial crown in order to obtain desired strip profile. Precise prediction of strip profile is possible based on the initial crown, the thermal crown, the wearing crown and the roll forces on the work roll. This causes quality of product and decreasing of cultch. Investigation of rolling was started from early decades of 20th century. Some of these investigations are mentioned in this article.

Liu [1] used finite element method for modeling the rolling process. Chakraborti et al. [2] studied the surface profiles of hot rolled slabs, quantified in terms of crown, by genetic algorithms. They used two different models and carried out the simulations in a multi-objective mode to generate the relevant Pareto fronts, which, in turn, was tested against the operational data of an integrated steel plant. Tudball et al. [3] used a transient 3D finite element model to capture thermal variations during hot rolling of steel. They demonstrated the versatility of their code by a series of validation exercises. John et al. [4] minimized the flatness defects in HR strips using a novel hybrid model with the combination of a predictive artificial neural network (ANN) and a genetic algorithm (GA). Nandan [5] et al. used a genetic algorithms-based multi optimization for the hot rolling practice in an integrated steel plant. Their aim was to identify the parameter settings and rolling schedules that would result in the optimum values of crown and flatness. Rossomando et al. [6] presented a real application of optimal control of a hot rolling mill. They used the state space model formulation in the minimization of the strip thickness variations and presented the simulation results of the control model. Kazeminezhad et al. [7] developed a slab analysis to predict the rolling pressure distribution and rolling force in the wire flat rolling process. Zhang Guo-min et al. [8] developed a three-dimensional model for strip hot rolling, in which plastic deformation of strip, thermal crown of rolls, roll deflection and flattening were calculated by rigid-plastic finite element method, finite difference method, influential function method and elastic finite element method, respectively. The roll wear was taken into consideration in their work. Younes et al. [9] presented the application of parameters design to improve both the product quality and the equipment performance in a hot sheet and they developed three empirical models to predict and explain the relationship between variations in some process parameters. The three process parameters considered were the reduction ratio (R_d), the slab temperature (T_s), and the exit strip speed (S_p).

In this research, first new empirical models based on measured data by Mobarake Steel Complex (MSC) and linear regression method are obtained to predict the roll force, the roll wearing crown and the roll thermal crown. In addition, Euler-Bernoulli theory based on elasticity approach is presented to predict the roll bending and flattening crown in hot rolling milling. Then, a computer program was written in Delphi to predict the roll initial crown according to desired strip profile.

2. CROWN

The aim of an ideal rolling is to produce a strip with homogeneous width and thickness. However, the product usually is not flat and has some wave on it. One of the parameters that deals with flatness of strip is crown. Crown in each point is defined as the variation of central thickness to the thickness of that point. The parameters for defining the crown are shown in Figure 1. So, central crown is defined as shown in Eq. 1 [10]:

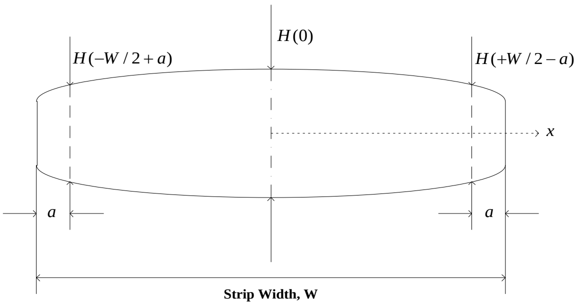

Figure 1. Parameters for defining the crown

$$\text{Central Crown}= H_m - (\frac{H_1+H_2}{2}) \quad (1)$$

In this equation, H_m is the thickness in the central width of strip (mm) and H_1 and H_2 are the thickness at the edge of strip (mm) with the distance a. The distance a is about 19-40 mm and depends on the strip width (W), strip thickness (t), and the adopted standard [21]. There are some parameters that affect the profile of strip. These parameters are the work roll initial crown, the work roll thermal crown, the work roll wearing crown and the work roll elastic deformation due to the bending and flattening. The effect of all these parameters in order to obtain desired strip profile must be considered. So, the total profile of strip is calculated using Eq.2:

$$y_x = y_{cvc-prof} + y_{therm-\exp} + y_{we} + y_{def} \quad (2)$$

In this equation $y_{cvc-prof}$ is the work roll initial crown, $y_{therm-\exp}$ is the work roll thermal crown, y_{we} is the work roll wearing crown, y_{def} is the work roll elastic deformation due to bending and flattening.

The strip profile is defined as:

$$C = y_{(w/2-40)} - y_0 \tag{3}$$

The effects of all above parameters are investigated in this article.

In this equation, C is the strip profile and subscripts ($w/2\text{-}20$) is the value of y at 40mm from the edge and the subscript (0) is the value of y at strip center.

3. EXPERIMENTAL WORK

The experimental work was carried out in the hot strip mill of MSC illustrated in Figure 2. In the selected hot strip mill, slabs from the slab caster are rolled into strips, with a corresponding reduction in thickness from an input value of 203 mm to about 1.6–16 mm, while the width ranges from 800 to 1600 mm. During this process, the slabs are heated and soaked in a walking beam type reheating furnace up to a temperature of 1250°C. The heated slab is then reduced to a desired thickness at the finishing mill with seven stands. From the finishing stand, the strip goes to the run out table (ROT), where it is water cooled and finally coiled in down coiler. The finishing mill is equipped with continuous variable crown (CVC) technology and work roll bending for shape control. The roll force, the roll wearing crown and the roll thermal crown were measured in this plant.

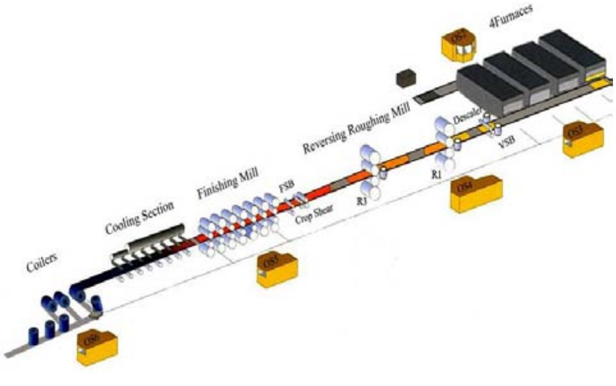

Figure 2. Hot rolling mill of Mobarake Steel Complex (MSC)

The roll force is measured by load cells of each stand and is recorded by ibaAna5.7.1 software. Figure 3 shows the measured roll force in a sample rolled schedule for stand No. 3. As this figure shows, the roll force is not constant during a rolled schedule and may be a function of strip width (W), strip initial thickness (H), reduction (r), roll velocity (Vr), strip initial temperature (T) and strip exit length (Le). Table 1 contains some portion of the measured roll force as a function of mentioned parameters during a rolled schedule for stand No. 3.

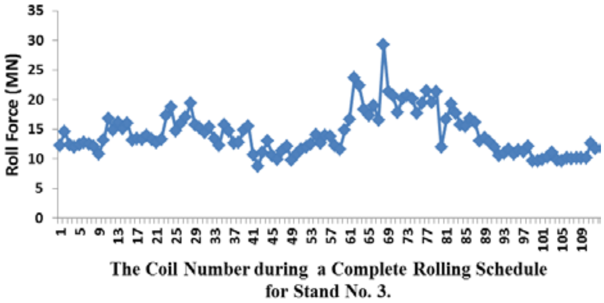

Figure 3. Measured roll force for one of the rolling schedules of stand No 3.

In order to measure the wearduring a roll program, the roll profile before and after a rolling schedule are measured by Herkules WS450 machine shown in Figure 4.

Figure 4. Herkules WS450 machine for measuring the rolls wearing crown

First, cooled rolls are put in this machine and measuring sensors measure the roll diameter. Then, the control system programs the machining steps. After machining, the grinded roll profile is measured and is recorded in the system. The roll profile before and after a rolling program measured by this machine is shown in Figures 5 and 6, respectively. The roll wearing crown can be measured by comparing the diameter profile of roll which is shown in these figures.

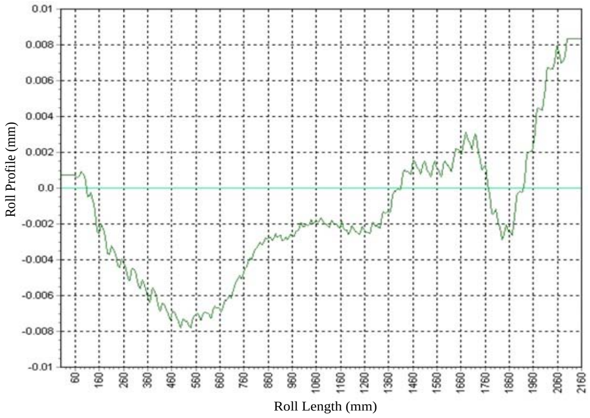

Figure 5. Measured roll profile before one of the rolling schedules for stand No. 6.

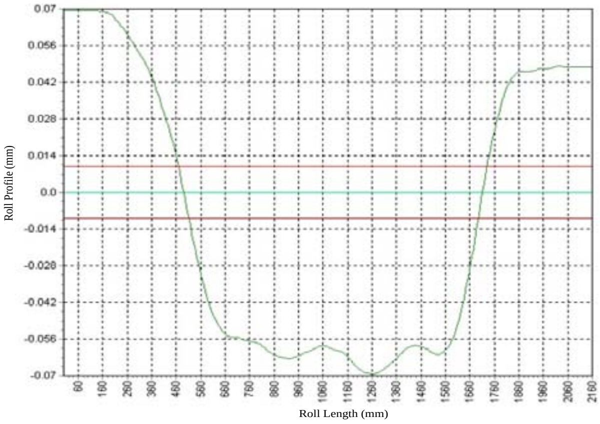

Figure 6. Measured roll profile after one of the rolling schedules for stand No. 6.

The thermal crown model provided by hot rolling stands manufacturer which is used in Level 2 control of the roll line is used for obtaining the thermal crown data. Figures 7 and 8 show the measured wearing crown and the obtained thermal crown in a sample rolled schedule for stand No. 3. Downfall of these diagrams is due to changing the work roll during the program. The wearing crown and the roll thermal crown also vary during a rolled schedule and may be a function of strip width, strip initial thickness, reduction, roll velocity, strip initial temperature, strip exit length and some other parameters. These empirical data were used to obtain a linear regression model for calculating the roll force, the roll wearing crown and the roll thermal crown in the mentioned mill.

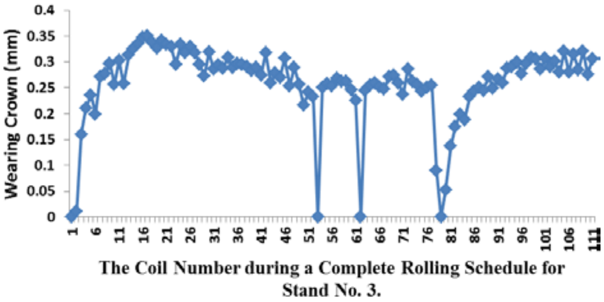

Figure 7. Measured wearing crown for one of the rolling schedules of stand No. 3.

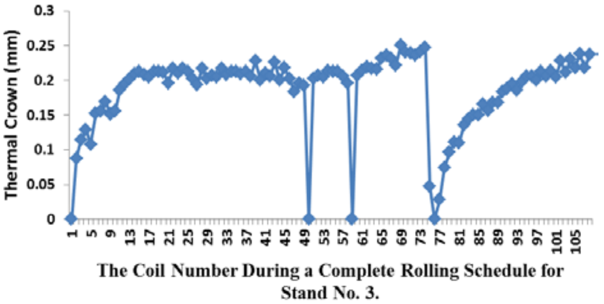

Figure 8. Measured thermal crown for one of the rolling schedules of stand No. 3.

5. LINEAR REGRESSION

Linear regression refers to any approach to model the relationship between one or more variables denoted y and one or more variables denoted x, such that the model depends linearly on the unknown parameters to be estimated from the data.

Such a model is called a “linear model”. Linear regression focuses on the conditional probability distribution of y given x, rather than on the joint probability distribution of y and x, which is the domain of multivariate analysis. Linear regression was the first type of regression analysis to be studied rigorously, and to be used extensively in practical applications. This is because models which depend linearly on their unknown parameters are easier to fit than models non-linearly related to their parameters. The statistical properties of the resulting estimators are determined easier. Regression models are usually expressed as an algebraic function. If the equation is expressed as a linear structure due to the described variables, x_i , a good model can be written as below:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k + \varepsilon \tag{4}$$

In this equation, β_i are unknown constants that are called regression coefficients and ε expresses the models errors. For investigation of model quality, nomination coefficient is used. This coefficient is shown by R^2 and is a simple method for measuring the regression fitting line. Considering Equation (4), if total variation in data (SSTotal) is divided to explained variation by dependent variables (SSReg) and the variations that are not explained by them (SSError), then:

$$SS_{Total} = SS_{\mathrm{Re}\,g} + SS_{Error} \tag{5}$$

So,

$$R^2 = \frac{SS_{\mathrm{Re}\,g}}{SS_{Total}} = 1 - \frac{SS_{Error}}{SS_{Total}} \tag{6}$$

It is obvious that $0 \le R^2 \le 1$. When the model fittsthe data precisely, $R^2 = 1$. The nomination coefficient is not an appropriate method for quality investigation of a model. It rises due to adding xi to the model. Therefore, edited nomination coefficient is used instead.

Linear regression has some assumptions. These assumptions must be satisfied in order to obtain an acceptable model. There are some tests which investigate these assumptions. These tests are Durbine-Watson d test, t-student test, Fisher test and Multicolinearity test. For investigation of the model quality, R-Square coefficient is used. This coefficient is a simple method for measuring the regression fitting line. When the model fits to data precisely, then the value of R^2 is equal to 1. Using this coefficient as a criterion is not an appropriate method to investigate the model quality. That is because of the fact that it rises by adding x_i to the model. Therefore, the adjusted R-Square coefficient is used instead [15].

6. MODELING THE WORK ROLL CROWN EFFECTIVE PARAMETERS

6.1 Roll Force Linear Regression Model Roll force is one of the main rolling parameters which affect the strip profile. Due to the nature of rolling, the roll force may be a function of different parameters. This was investigated for different MSC rolled schedules and it showed that the strip width, initial thickness, and initial temperature, the reduction, the roll diameter, the roll velocity and strip exit length are the main parameters which affect the roll force in the mill. Different parameters for some portion of a sample rolled schedule (stand No. 3) are shown in Table 1. These empirical data were investigated for this stand using SPSS software and linear regression method. Finally, the results showed that the roll force is just a function of strip width, the reduction and the strip temperature for stand No. 3. The following formula is then proposed for stand No. 3:

$$F = A + B \times W + C \times r + D \times T \tag{7}$$

where F is roll force in (MN), W is strip width in (mm), r is reduction in (%) and T is temperature in (°C). A, B, C and D are unknown coefficients and must be predicted by linear regression. Table 2 shows the model summary. As this table shows, the model quality is 99.3%. It means that the independent variables can explain 99.3% of the dependent variable variations. Durbine-Watson test value is obtained 1.737. That is, in the range of 1.5 and 2.5 and shows non-auto-correlation between the errors. Fisher test is also performed for this model and the results are shown in Table 3. Considering the value of this test and the probability value shown in the fifth and in the sixth columns of this table, the model significance is satisfied up to 100%. Table 4 shows the model coefficients and t-student test provided for each of variables. As this table shows, the exact value of A is equal to 9.650446004387064, B is equal to 0.014217686021280157, C is equal to -0.030358343243534713 and D is equal to 0.4827355398395615. The obtained model is so sensitive to its coefficients. Therefore, exact values of A, B, C and D must be obtained and used in the model. It is obvious that values of B and D are positive and the value of C is negative. This shows that the roll force has a direct relation with strip width and reduction and a reverse relation with temperature. These relations are adopted with the nature of hot rolling process based on hot rolling experts' experience as well. Considering the fifth and the sixth columns of Table 4, the t-student test and the probability values are shown. Therefore, it can be concluded that the model coefficients significance is satisfied up to 100%. Table 5 shows the eigenvalue and condition index of the model. As this table shows, condition index is below 30 and it shows non-autocorrelation in this model. Normal P-P plot of regression is shown in Figure 9. As this figure depicts, the actual data and predicted data are close to each other.

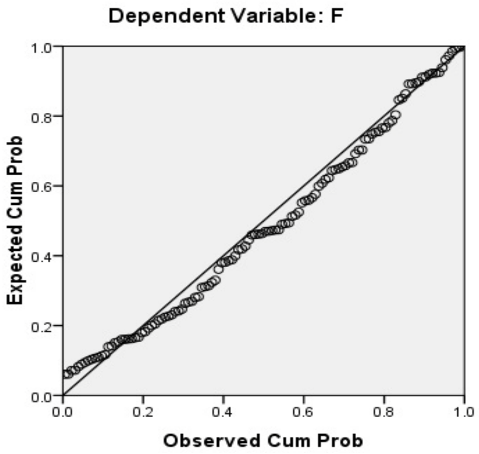

Figure 9. Normal P-P plot of regression standardized residual for roll force model

TABLE 1. Different parameters for a part of a sample rolled schedule (stand No. 3)

Program	W (mm)	H (mm)	T (°C)	r (%)	Vr (m/s)	Le (m)	F (MN)
16001	1041.8	14.59	944.471	33.072	2.499	139.1364	12.277
16002	1046.6	14.589	987.246	33.07	3.226	278.2823	14.616
16003	1045.6	14.594	1007.479	33.077	3.779	417.3806	12.401
16004	1043.5	14.592	935.269	33.074	2.156	556.4979	11.993
16005	1042.9	14.59	934.589	33.071	2.386	695.6343	12.299
16006	1025	14.59	924.213	33.072	2.375	834.7707	12.732
16007	1049.9	14.592	1021.432	33.074	2.116	973.888	12.466
16008	1044.4	14.591	937.561	33.073	2.305	1113.015	12.152
16009	1025	14.587	981.419	33.066	4.553	1252.18	10.776
16010	1045.5	14.59	938.047	33.071	2.482	1391.316	13.104
16011	1191.8	13.526	928.494	36.616	2.896	1541.398	16.737
16012	1190.9	13.527	937.681	36.616	2.761	1691.468	14.836
16013	1201.8	13.856	943.912	35.883	3.26	1837.975	16.08
16014	1200.2	13.858	944.098	35.886	3.546	1984.461	15.101
16015	1231.1	15.596	936.458	31.045	2.802	2114.622	16.036
16016	1232.6	15.596	956.44	31.045	2.659	2244.784	13.19
16017	1232.6	15.593	956.475	31.04	2.826	2374.97	13.425
16018	1232.8	15.596	960.795	31.045	2.8	2505.132	13.297
16019	1231	15.597	949.166	31.046	2.826	2635.285	13.948
16020	1232.8	15.595	948.33	31.044	2.741	2765.455	13.269
16021	1232.2	15.596	958.459	31.045	2.505	2895.617	12.757
16022	1232.6	15.595	966.24	31.043	2.698	3025.787	13.236
16023	1289.7	15.998	927.753	30.254	2.701	3152.677	17.283
16024	1541.5	15.999	951.609	30.236	3.27	3279.56	18.67
16025	1542.2	16.001	980.504	30.239	2.884	3406.427	14.627

TABLE 2. Roll force model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	**99.3%**	98.6%	98.5%	0.37386	**1.737**

TABLE 3. Roll force model anova and fisher test

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	589.08	3	196.36	**1405**	**.000**
Residual	8.526	61	0.14		
Total	597.607	64			

TABLE 4. Roll force model coefficients and t-student test

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std. Error	Beta		
(Constant)	**9.56**	3.001		**3.216**	.002
W	**.014**	.000	1.256	**63.231**	.000
T	**-0.03**	.003	-0.156	**-9.642**	.000
r	**0.483**	0.01	0.964	**48.806**	.000

TABLE 5. Roll force collinearity diagnostics test

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions			
				(Constant)	W	T	r
1	1	**3.924**	1.000	.00	.00	.00	.00
	2	**.068**	7.605	.00	.23	.00	.14
	3	**.008**	22.374	.01	.76	.01	.82

6.2 Work Roll Wearing Crown Linear Regression Model Work roll wearing crown causes the changes in its crown so that it affects the strip profile. Investigation of different MSC rolled schedules showed that the wearing crown may be a function of strip width, strip initial thickness, strip initial temperature, reduction, roll diameter, roll velocity and strip exit length. This was done for stand No. 3 using SPSS software and empirical data by MSC. The results show that the wearing crown is extremely dependent on final strip thickness which is the exit strip thickness from stand No. 7. Therefore, three different models were obtained to predict the work roll wearing crown based on the final strip thickness. The results show that the wearing crown is a function of temperature, strip width, exit strip length and roll force for final strip thickness, which is below four millimeter. This is a function of temperature, strip exit length, reduction and roll force for final strip thickness in the range of four millimeter and six millimeter. Obtaining final strip thickness more than six millimeters, the wearing crown is almost constant. Therefore, the formula for predicting the wearing crown in stand No. 3 is obtained as below:

$$WC = \begin{cases} A_1 + A_2T + \dfrac{A_3}{W} + A_4L_e + A_5LnL_e + \dfrac{A_6}{L_e} + A_7L_e^3 + \dfrac{A_8}{P} & h_f \prec 4 \\ A_9 + A_{10}T + A_{11}L_e + A_{12}LnL_e + A_{13}r^3 + A_{14}P^3 & 4 \le h_f \le 6 \\ 0.23 & h_f \succ 6 \end{cases} \qquad (8)$$

where WC is wearing crown in (mm), P is roll force in (MN), T is temperature in (^{o}C) (), L_e is strip exit length in (mm), W is strip thickness in (mm), r is reduction in (%) and h_f is strip exit thickness from stand No. 7 in (mm). The model coefficients were obtained utilizing regression method, and are shown in Table 6. All the regression tests explained in part 6.1 were also performed for the wearing crown model and the model could satisfy all of them.

TABLE 6. Coefficients of wearing crown model

Coefficient	Value	Coefficient	Value
$\mathbf{A_1}$	4.446398643639322	$\mathbf{A_8}$	1.7813654875651208
$\mathbf{A_2}$	$-7.406187922551309\times10^{-4}$	$\mathbf{A_9}$	-0.12254452561551915
$\mathbf{A_3}$	-217.9487385310034	$\mathbf{A_{10}}$	$-6.095028372882652\times10^{-4}$
$\mathbf{A_4}$	$7.378810709361287\times10^{-8}$	$\mathbf{A_{11}}$	$-3.7482552082865447\times10^{-8}$
$\mathbf{A_5}$	-0.2432463157114965	$\mathbf{A_{12}}$	0.09686673746775742
$\mathbf{A_6}$	-104035.62134222736	$\mathbf{A_{13}}$	$-8.535071529717156\times10^{-6}$
$\mathbf{A_7}$	$-1.9516456622854154\times10^{-22}$	$\mathbf{A_{14}}$	$-1.3473217778631586\times10^{-5}$

TABLE 7. Coefficients of thermal crown model

Coefficient	Value	Coefficient	Value
$\mathbf{A_1}$	2.087995981026224	$\mathbf{A_8}$	$-2.027408962491758\times10^{-8}$
$\mathbf{A_2}$	$-4.3215934755072826\times10^{-4}$	$\mathbf{A_9}$	0.05454461791246326
$\mathbf{A_3}$	-0.010963153164038472	$\mathbf{A_{10}}$	$2.237107286345748\times10^{-22}$
$\mathbf{A_4}$	-5.899123888367267	$\mathbf{A_{11}}$	$6.3766386654949\times10^{-6}$
$\mathbf{A_5}$	$-4.5219554744054533\times10^{-4}$	$\mathbf{A_{12}}$	-0.5895695243278343
$\mathbf{A_6}$	-550.337563085544	$\mathbf{A_{13}}$	0.0043830898513108835
A_7	$-4.601218736687413\times10^{-11}$		

6.3. Work Roll Thermal Crown Linear Regression Model

Work roll thermal crown causes the changes in its crown so that it affects the strip profile. Investigation of different MSC rolled schedules showed that this parameter also may be a function of the strip width, initial thickness, and initial temperature, the reduction, the roll diameter, the roll velocity and the strip exit length. This was investigated for stand No. 3 using SPSS software and provided data by MSC. The results show that the thermal crown is extremely dependent on final strip thickness, which is the exit strip thickness from stand No. 7. Therefore, two different models were obtained to predict the work roll thermal crown based on the final strip thickness. The results show that the thermal crown is a function of temperature, roll force, strip exit thickness, width, length and the final thickness which is below six millimeters. Obtaining final strip thickness more than six millimeters, the thermal crown is almost constant. Therefore, formula for predicting the thermal crown in stand No. 3 is obtained as below:

$$TC=\begin{cases} A_1+A_2T+A_3P+\dfrac{A_4}{h}+A_5h^3+\dfrac{A_6}{W}+A_7W^3+A_8L_e+ & \\ A_9LnL_e+A_{10}L_e^3+A_{11}F^3+A_{12}Lnh_f+A_{13}h_f^3 & h_f\le 6 \\ 0.46 & h_f\succ 6 \end{cases} \tag{9}$$

where TC is wearing crown in (mm), P is roll force in (MN), T is temperature in (^{o}C), L_e is strip exit length in (mm), W is strip width in (mm), h is strip exit thickness in (mm) and h_f is strip exit thickness from stand No. 7 in (mm).

The model coefficients were obtained utilizing regression method and are shown in Table 7. All regression tests explained in part 6.1 were also performed for the thermal crown model and the model could satisfy all of them.

6.4. Work Roll Bending and Flattening Crown Analytical Model

The deformation of work roll due to bending and flattening is calculated utilizing these equations:

$$EI\frac{d^2y_b}{dx^2}=M \tag{10}$$

$$\frac{GA}{K}\frac{dy_s}{dx}=S \tag{11}$$

In this equation E is Young module (215GPa), G is shear module (82.7GPa), K is 4/3, and I is moment of inertia ($I=\pi d^4/64$). Meanwhile, d is the work roll diameter. Moreover, M and S are the bending moment and the shear force in the beam cross section, respectively.

By solving these two equations, total deformation is calculated as:

$$y_{def}=y_b+y_s \tag{12}$$

7. PREDICTION OF WORK ROLL INITIAL CROWN

Prediction of work roll initial crown according to desired strip profile is calculated utilizing a computer programing written in this research. This program is able to predict the work roll initial crown according to desired strip profile for some portion of rolled schedule with a specific error obtaining by the management information system (MIS) of MSC. This was performed for one case with known desired crown, and the error and the work rolls initial crown was calculated. Table 8 shows the initial crown predicted for the mentioned case. These crowns were implemented for a particular schedule and the measured strip profile shown in Figure 10. The comparison between the measured strip crown and the obtained one is shown in Table 9, which shows a fairly good agreement between them.

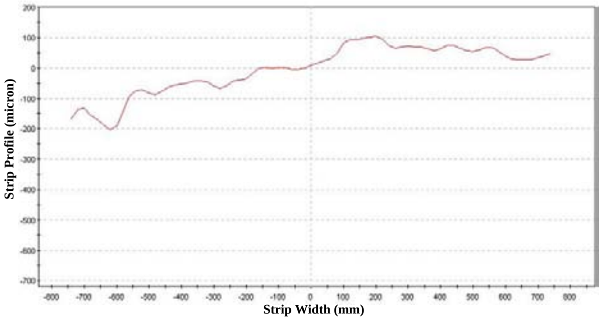

Figure 10. Variation of measured strip profile during the width

TABLE 8. Work roll initial crown in different stands

Stand	F_1	F_2	F_3	F_4	F_5	F_6	F_7
initial crown (mm)	70	90	-110	-83	-65	-107	-6

TABLE 9. Comparison of the measure crown and the obtained crown

measured strip crown	obtained strip crown	Percent of error
50	46	8%

8. CONCLUSION

The roll force, work roll wearing crown, work roll thermal crown and work roll bending and flattening crown are the main factors of rolling process. All of them cause changes in the roll crown, and finally, they affect the strip profile. Many analytical methods have been presented for predicting them which did not match very well with the actual data in the MSC. Therefore, new methods based on the regression analysis were employed for calculating the roll force and the roll wearing in the mentioned mill. The results showed that empirical models could predict physical quantities better than mathematical models, particularly for the mentioned mill.

Finally, the work roll initial crown according to desired strip profile was obtained. The results were applied for a particular rolling schedule and the obtained strip profile showed a good agreement with the measured strip profile for that mill.

9. ACKNOWLEDGMENT

The authors appreciate the Hot Rolling Mill Section of Mobarake Steel Complex for their nice cooperation.

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