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Experimentation and Mathematical modeling methodology to predict the impact of roller speed on the surface roughness in hot rolling process

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Abstract:

Forming metal is a crucial part of the industrial process. Cross-sectional metal components with various cross-sectional shapes may be formed using metal forming processes. One of the methods for generating the forms discussed previously is plate bending. There are a variety of loading limits that affect the plate rolling mill when metal is bitten by the side rollers of a reversed roller stand. Steel sheet manufacturing and fabrication would be incomplete without the use of hot rolling, which produces a flexible end product. For the experiment, a mathematical model for hot rolling process production rate is used to verify its experimental results. The Buckingham Pi approach and the dimensional analysis method were used to create the mathematical model. Roller speeds of 230, 280, and 330 rpm were used to determine the impact of roller speed on surface roughness. The maximum surface roughness of 60 microns was observed. The percentage error between experimental and mathematical readings varies from -3.79 to 11.75%, -12.46 to 11.75% and -6.79 to 10.68% at a roller speed of 230 rpm, 280 rpm and 330 rpm respectively. The mathematical model built using the Buckingham Pi technique is further validated by the experimental data, which are closely matched to mathematical a modelling value.

Keywords: Surface roughness, Hot rolling process, Mathematical model, Buckingham Pi (p) theorem

Introduction:

The number of rollers in each stand, as well as the product, layout, and temperature, are used to classify rolling mills. The number of rolls determines whether the stand is two, three, four, twelve, or twenty-high. Cluster mills are defined as mills that have six or more rollers. Rolling is used to reduce big cross-sectional material into smaller portions of varied shapes. Compressive force is applied using a sequence of rollers to achieve this deformation. [31]

As a result of its high production capacity and precise control over the final quality and shape of the finished product, hot continuous rolling of rods or bars is a widely used industrial technique. Steel consumption per capita is regarded as a key indication of a country's socioeconomic advancement and level of living. It's the outcome of a massive, technologically advanced industry with strong forward and backward material flow and revenue-generating connections. It accounts for more than 80% of metals produced throughout the production process. In the metalworking business, rolling is one of the oldest operations. Rolling might be regarded one of the most essential forming processes due to the enormous volume and variety of rolled items produced each year. Depending on whether work hardening occurs, cold and hot rolling are two types of rolling processes. [4]

There is no toughening of the metal throughout the hot rolling process. This research focuses solely on the process of hot rolling bar. In Mahalaxmi Rolling Mills roughing first pass deformation, simulation and modelling Steel bars are manufactured and sold at the Mahalaxmi steel rolling factory. The firm is situated in Hingna MIDC, Nagpur created in 1995.

Despite the fact that the mill's installed capacity was constantly described as the new nominal volume indicated by the manufacturing facility, the machineries and equipment were first known to be reconditioned second-hand. There is a total of 50,000 to 60,000 tons of various steel products produced each year by the mills investigated. However, in its more than 15 years of operation, the mill has never hit a quarter of its capacity.

Even if there are other restrictions that may have impacted the mill's overall production, it's difficult to rule out the technical fault for below-capacity mill production. As a result, this study will attempt to analyse the mill's manufacturing processes and identify the elements that influence the number of defects produced by technical issues. One of the primary causes is billet deformation during the 3-high roughing stand's first pass. The main idea of the rolling mill is metal plastic deformation, and as a result of this technological aim, the rolling mill is presently behind a significant amount of its commodities as cobblestones. To reduce amount of loss to the standard, it is possible to optimise the pass in which the row material is bent by adjusting the form. Years have passed with no satisfactory results, and due to a number of technical challenges, the mill has never been successful in reaching even a small percentage of the capacity that was intended for it when it was erected. In demand to offer effective elucidations in the next production schedules, we need to focus on technological issues. These issues should be recognised and prioritised based on their severity. The following is a summary of some of the Mill's most serious technical issues:

Its downtime is significant as a result of the production process being interrupted often for various causes. In a year, this period is predicted to be more than 155 working days (in 2021). As a result, the Mill is now losing a significant amount of its output in the form of scales, cut-offs, and cobbles. It is anticipated that this loss will equal to more than 15 percent of the total billet that will be used (the standard is only 8 percent).

Due to the process halt, the Furnace's fuel consumption is uneconomical and extremely high. The present Furnace capacity is projected to be able to manufacture up to 11 tonnes of products per hour at cost of 70 kilogrammes of fuel per tonne. By any measure, this is intolerable, especially given the present inflated local gasoline price.

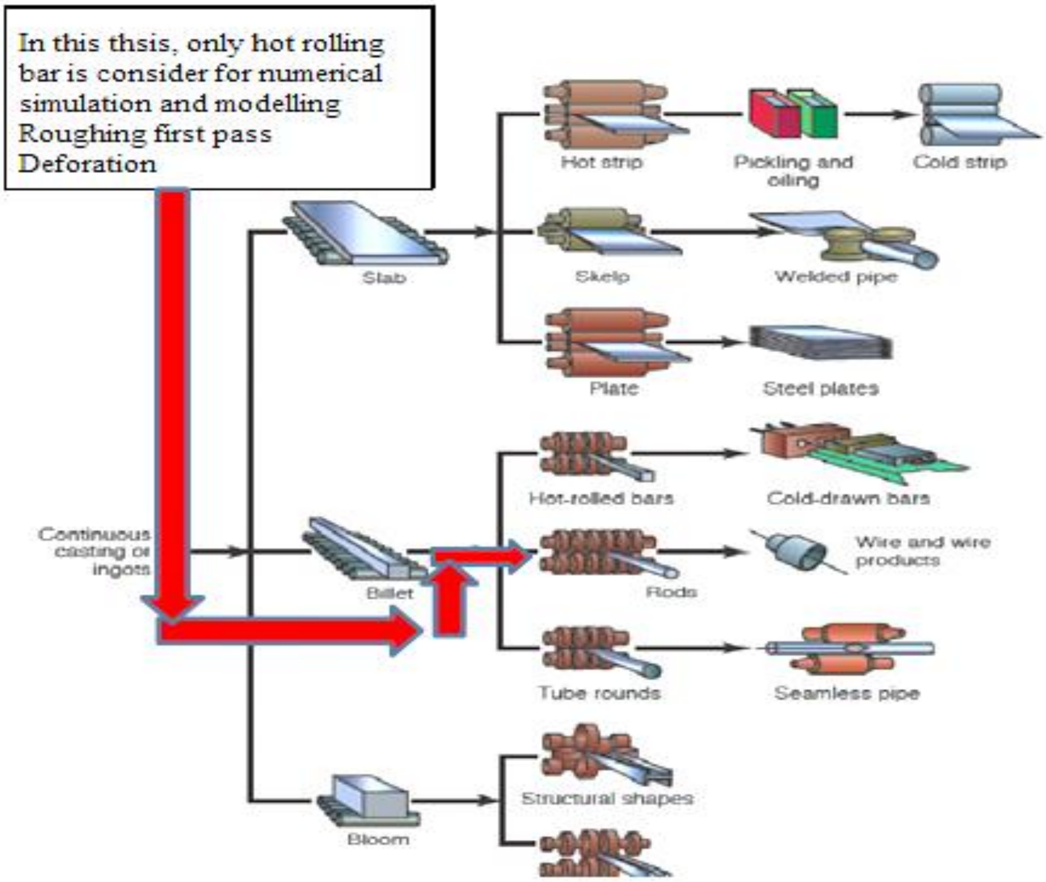

Figure 1 Diagrammatic representation of operation of rolling mill

Several authors have published various research articles on the rolling mill. In the rolling process, there are three zones. Backward or Neutral Zone, trailing zone, and leading or Forward zone are the three zones. Deformation is defined as a change in dimensions or shape caused by applied forces. Deformation is induced by external mechanical forces or by a variety of physical and physiochemical processes. Plastic deformation, Elastic deformation, and Fracture are three types of deformation processes. Metal plastic deformation can occur as a result of slipping. Plastic deformation of metal is the fundamental idea behind the rolling process, which is widely employed in the fabrication of materials. The smallest component of the material is known as a crystal grain, which has homogeneous qualities. However, there is a scarcity of research in this field. The following are some of the research outcomes that are relevant to the thesis's goal:

Chetan S Sethia et al [1] investigated a manufacturing process and the resources available for making TMT Bar, as well as breakdowns such as mechanical, electrical, and other that occur during operation, in their case study work on "Total Productive Maintenance in Rolling Mill." When compared to the World Class Measurement, the Rolling Mill's (A, P, Q) was determined to be relatively low. According to World Class Manufacturing, the OEE should be 85 percent, and the Rolling Mill. Z. Domazet et al [2] revealed that both couplings shattered owing to fatigue as a result of poor design. The fracture began at the corner of the paddle and the coupling body in both cases and spread around the corner. When the fatigue fracture propagation reached 60–65 percent of the paddle, the paddle finally broke. According to actual estimated fatigue life, expanding the external diameter from 340 mm to 360 mm decreases maximum local stress by roughly 15% and improves fatigue life by almost 100% in the second choice. According to a numerical research, rebuilding the coupling by adding a stiffener between the paddle and the coupling body decreases the maximum local stress and increases the coupling's actual service life from finite to unlimited.V. Vinogradov et al [3]studied the effects of local overloads on cold rolling mill work rollers were investigated. The near-contact zone is subjected to significant stresses, especially when contact lengths are short and contact loads are high. The upper limit of the plastic zone is the most essential zone. At the border between the elastic and plastic zones, maximum tensile stresses, as well as tensile stresses on the free surface at the contact zone, occur. DenizAltun [4]has investigated the operational aspects that impact the performance of vertical roller mills. The impacts of operational factors for example operating pressure and classifier rotor speed on product mass flow and size were explored as a result of the research. The findings revealed a link between particular grinding energy consumption and product size and rate. The rotor speed of the classifier is found to be inversely proportional to the product rate and size. KaanEsendag et al.[5] has been designed and implemented an iterative algorithm. For prediction, regression and artificial neural network techniques were utilised and compared. In order to achieve high accuracy, the best-fitting algorithm is chosen in each run. In addition, regression ANN hybrid algorithms have been created for situations where a single method is insufficient to reliably predict all parameters.

Ali Heidari and Mohammad R. Forouzan [6]have completed the task satisfactorily according to the chatter phenomenon. Friction factor, reductions, tensions, and strip speed were among the design considerations considered. Existing rolling stands' operating characteristics were optimised using the suggested optimization methods. These methodologies may also be used to optimise the design of new rolling stands by taking into consideration additional features such as inter-stand distances, roll masses, system stiffness, and damping. Matteo Biondi [7] have discussed the production Optimization and Scheduling in a Steel Plant Hot Rolling Mill, they looked at the production scheduling of a hot rolling mill in a steel plant. A typical problem size ranges from 3000-5000 coil orders, with the appropriate rolling programmes prepared in seconds. This is a fantastic outcome that outperforms both manual capabilities and many existing alternative ways.K. Dick et. al. [8] investigated the outcome of lubricant viscosity and roll roughness on mill loads during cold rolling of steel strips. During cold rolling of low carbon steel strips, the tribological processes of three commercially available oil-in-water emulsions were investigated. Increased speeds resulted in a reduction in load with increased roll roughness, but there was no such effect with smoother rolls. Roll roughness was increased, resulting in virtually hydrodynamic conditions. The dynamic concentration hypothesis was discovered to be a good match for the data. This is especially true when the plate enters and exits the mill stand from pass to pass in a reversing mill. In their paper Modeling and control of plate thickness in hot rolling mill.S. Serajzadeh [9] have developed A model for calculating temperature distribution in hot rolling of steels was using the effects of rolling parameters. Two-dimensional FEM studies were used to calculate the temperature profile and the effects of different factors, as well as the thermal interactions between the roll and the metal strip and the rolling speed. The present study in cold rolling entails a combined investigation of the work roll and slab temperature.

Roland Heeget. al. [11] suggested a non-linear control technique to improve the uniformity of the thickness at the plate's ends in order to restrict the quantity of plate cut off by the crop shear. When the dynamics in are ignored, the controller presented here transforms into a traditional gauge metre controller. In comparison to typical mill automation systems, the author used genuine non-linear mill stretch functions, which are used on-line for pass schedule computation, and a rolling force model instead of the standard deformation resistance and mill stretch coefficient. A forward slip model must be employed to track the plate's location in order for the specified controller to operate in practice. The entry thickness and temperature profiles are also required. Variables impacting productivity, such as draught, spreading, speed, slip factor, roll force, and quality, such as roll gap, deflection, temperature, force, mill spring, internal stresses, and excess convexity, were researched by NimishDhomne et al [12].Jamil J. [13] offered a case study and analysis of the technical and energy management components of proposed steel plant designs in Jordan's production lines. Based on Supervisory Control And Data Acquisition technology (SCADA), a new control system structure was presented. Ahasan R [14] was explored thermal stress as a key metric for assessing the physical effort of steel re-rolling mill workers. In all, 34 adult male respondents (age: 36 4.1 years) agreed to participate in physiological tests that revealed physiological responses as a result of their severe occupational demands and heat exposure. As a result, developing a local standard that can be used to avoid the potential biassing impact of monitoring heart rates for evaluating thermal stress in tropical nations would be acceptable. Due to the varied socio-cultural, environmental, and psychological variables of the sample employed in Bangladesh, more research with control participants is needed. Shuji Yokota [15]have focused on increasing production. The technologies for increasing productivity were presented. Reducing the extract target temperature of the reheating furnace and predicting the extract time with high precision in order to reduce the demanded heating capability and Control of both the reheating furnace and the mill pace.

Owing to the research constraints and the identified research gaps, the goal of this study is to use the Buckingham Pi (p) approach to construct a mathematical model for surface roughness. Also, tests were carried out. The hot rolling process's production rate may be predicted using the mathematical model that was created.

2. Material and Methods:

2.1 Identification of various quantities affecting the experimental modelling of production rate and surface roughness.

Variable refers to any physical quantity that changes over time. The term "independent variable" refers to a variable that may be changed independently of other factors, whereas "dependent variable" refers to a parameter that changes as a result of changes in another variable or variables. The Material flow rate has been given a lot of thought since the rolling mill product's production rate and surface roughness are the most important factors. Material properties have a significant impact on both conveying conditions and material flow rate.

The importance of conveying distance and conveying line pressure drop are both critical considerations. Universal connections are virtually impossible to illustrate in tabular or graphical form since there are five independent variables in this small group. There are no mathematical models that can appropriately encompass even this modest set of variables or the ranges that must be addressed. To emphasise the capacity of the hot rolling system and to illustrate the influence of the key components, many sets of curves are given and the relationships are developed individually.

Table 1 MLT form of Variables

Parameter	*Details*	*Unit*	*Dimensions*
Independent	Speed of roller (N)	rpm	$[M^0L^0T^{-1}]$
	Roller diameter (D)	mm	$[M^0L^1T^0]$
	Distance between roller (d)	mm	$[M^0L^1T^0]$
	Thickness of fillet (t)	mm	$[M^0L^1T^0]$
	Pressure applied on roller (P)	Pa	$[M^1L^{-1}T^{-2}]$
	Young modulus of raw material (E)	GPa	$[M^1L^{-1}T^{-2}]$
Dependent	Surface roughness	μ	$[M^0L^1T^0]$

2.2 Dimensional analysis of surface roughness

The functional relationship between these independent and dependent variables is obtained by using Buckingham π –theorem, the details steps involved are as given below.

The production rate depends on the as diameter of roller (D), Speed of the roller (N), distance between the roller (d), pressure applied on roller (P), young's modulus of raw material (E). Mathematically,

$μ = f(D,N,E,d,P)$ …..…………………(i)

$f = (μ,D,N,E,d,P)$ …..…………………(ii)

$f (л_1, л_2, л_3, л_4,) = 0$……………………………………………………….. (iii)

Each л – term is written as according to the equation

$л_1 = D^{a1} * N^{b1} * E^{c1} * d$

$л_2 = D^{a2} * N^{b2} * E^{c2} * P$

$л_3 = D^{a2} * N^{b2} * E^{c2} * PR$

$л_4 = D^{a2} * N^{b2} * E^{c2} * μ$...........……………………………………………………….. (iv)

л – terms are determined by the principle of dimensional homogeneity.

For the л – term, we have

$л_1 = D^{a1} * N^{b1} * E^{c1} * d$

$л_1 = D^{-1} * N^0 * E^0 * d$

$$\pi_1 = \frac{d}{D}$$

Similarly,

$$\pi_2 = \frac{P}{E}$$

$$\pi_3 = \frac{N * PR}{D * E}$$

$$\pi_4 = \frac{μ}{D}$$

Table 2 shows the lists of various Pi Terms

Table 2 List of Pi Terms

Sr. No.	Pi Term
1	$\pi_1 = \frac{d}{D}$Roller geometry
2	$\pi_2 = \frac{P}{E}$ Material Stress
4	$\pi_3 = \frac{N*PR}{D*E}$Production rate
5	$\pi_4 = \frac{\mu}{D}$ Surface roughness of product

2.3. Experimentalupon the machine

There is a detailed plan in place for how the testing will be carried out. A thorough description of implementation is required in order to carry out the experimental design and practical trial run. We've collected information on machine specifications, material options, and material qualities from the several sectors we profiled earlier [21]. The following is a quick rundown of what happened throughout the experiment. These experiments are used to collect data on dependent factors like surface roughness (i.e. 81 sets of trials). The full factorial mixed-level experimental technique [22] is used to compute data for every possible combination of independent parameters.

3. Results and discussion

It is shown in Figure 2 that the surface roughness of hot-rolled steel is affected by roller speed (230 rpm). For example, in Figure 2, the surface roughness values are shown as a function of the percent inaccuracy between the mathematical model and the experimental readings as well as the mathematical model readings.

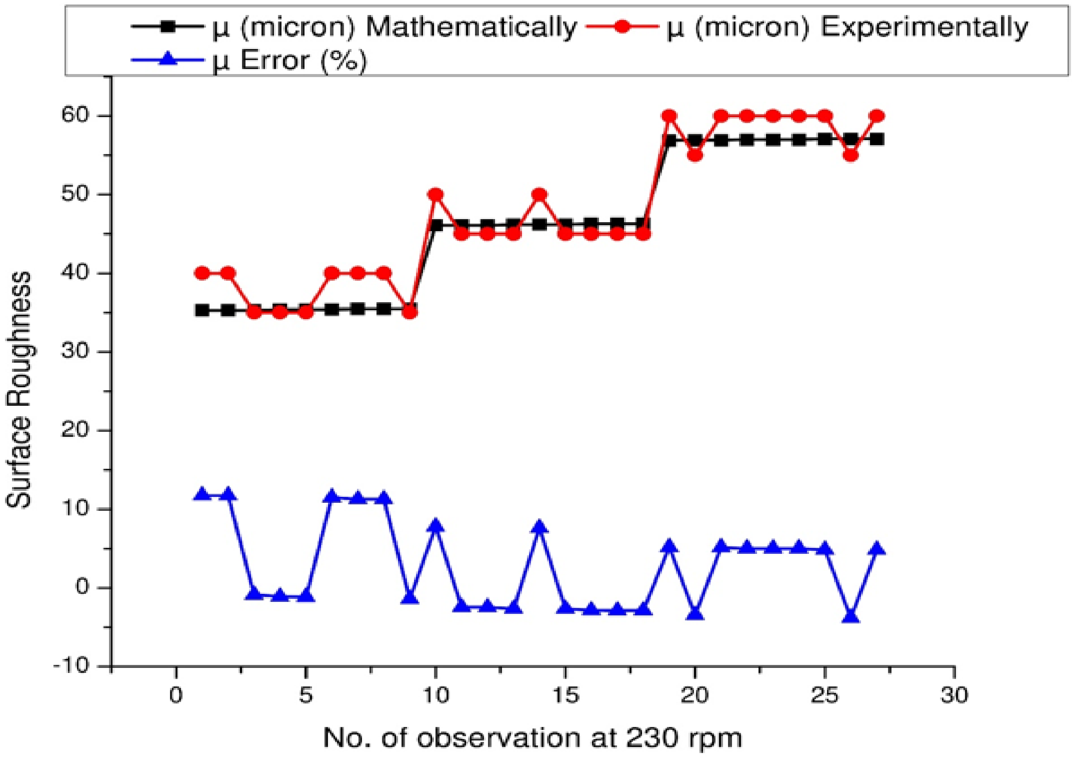

Figure 2. Surface roughness at roller speed of 230 rpm.

The maximum surface roughness observed from Figure 2 is 57.08 microns and 60microns for mathematical and experimental readings. Whilesmallest surface roughness observed from Figure 2 is 35.29 microns and 40 microns for mathematical and experimental readings. The error % varies from -3.79 to 11.75%.

It is shown in Figure 3 that the surface roughness of hot-rolled steel is affected by roller speed (280 rpm). For example, in Figure 3, the surface roughness values are shown as a function of the percent inaccuracy between the mathematical model and the experimental readings as well as the mathematical model readings.

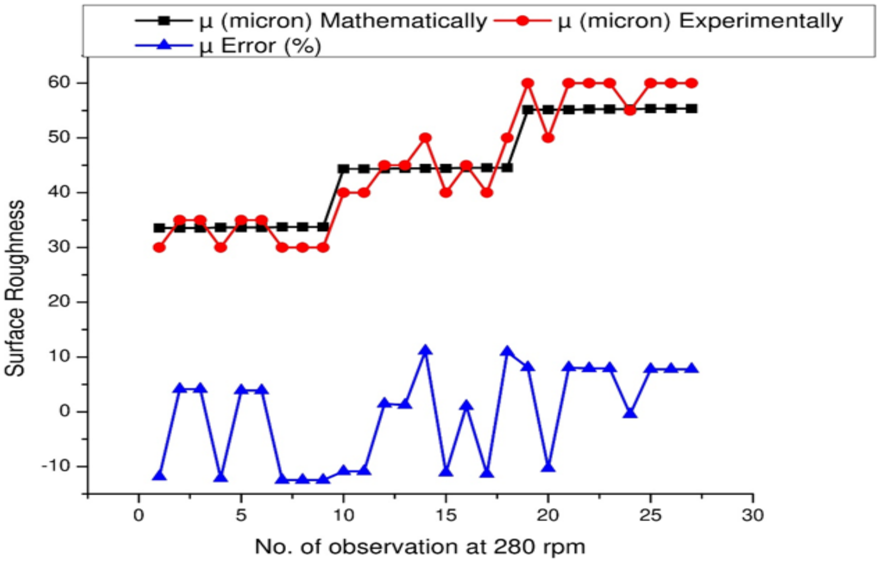

Figure 3. Surface roughness at roller speed of 280 rpm.

The maximum surface roughness observed from Figure 3 is 55.33 microns and 60 microns for mathematical and experimental readings. Whilesmallest surface roughness observed from Figure 3 is 33.54 microns and 30 microns for mathematical and experimental readings. The error % varies from -12.46 to 11.75%.

It is shown in Figure 4 that the surface roughness of hot-rolled steel is affected by roller speed (330 rpm). For example, in Figure 4, the surface roughness values are shown as a function of the percent inaccuracy between the mathematical model and the experimental readings as well as the mathematical model readings.

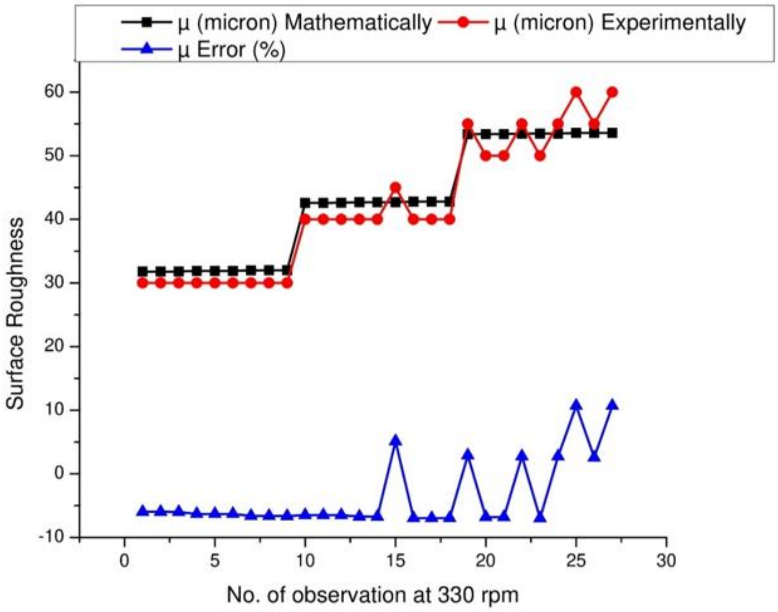

Figure 4. Surface roughness at roller speed of 330 rpm.

The maximum surface roughness observed from Figure 3 is 55.58 microns and 60 microns for mathematical and experimental readings. Whilesmallest surface roughness observed from Figure 3 is 31.79 microns and 30 microns for mathematical and experimental readings. The error % varies from -6.79 to 10.68%.

4. Conclusions

When considering the different hot rolling process parameters, a mathematical model for production rate was developed using the dimensional analysis Buckingham Pi approach.

- In hot rolling process, different parameters are included for the performance of mill like, diameter of roller, distance between rollers, young's modulus of raw material, pressure applied on raw material speed of rollers and production rate.
- Out of these parameters, the identified independent parameter from process are diameter of roller, distance between rollers, young's modulus of raw material, pressure applied on raw material and speed of rollers and dependent parameter is production rate.
- According to the literature study, the classical plan technique is the best for determining the link between these characteristics.
- For the mathematical modelling, 4 independent parameter each having 3 factors are considered, which gives total 81 parameters for study.
- From the overall study, it has been observed that, the most effective parameter on performance of rolling mill are diameter of roller and speed.

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