Research Journal of Engineering Sciences ISSN 2278 – 9472
Vol. **6(4),** 1-7, May **(2017)** *Res. J. Engineering Sci.*

Multi-objective optimization of cold rolling system with lubricants using grey relation method

Devesh Shrivastava*, S.K. Ganguly and R. Banchhor
Department of Mechanical Engineering, Bhilai Institute of Technology, Durg, CG, India
devesh.mech@gmail.com

Available online at: www.isca.in, www.isca.me
Received 3rd November 2016, revised 20th April 2017, accepted 15th May 2017

Abstract

Cold Rolling may be defined as the reduction of cross- section area of the metal stock or general shaping of the metal product through the use of rotating rolls below recrystallization temperature. During the cold rolling in a rolling mill synthetic lubricants consisting of mineral oils, biodegradable oil with chemical additives are being used for lubrication to obtain quality rolled surface. The quality of rolled product in cold rolling is largely influenced by surface roughness and chemical wear of rolled surface. Several factors contribute to quality of rolled product among those, composition of lubricant, amount of lubricant and operating speed of roller are more significant. In this study the identified factors were analysed using design of experiment approach. Robust design factor values were estimated by grey relation method. The result indicates that the selected process parameters significantly affect the quality of rolled product. The results are further conformed by conducting confirmation experiments.

Keywords: Cold Rolling, Synthetic Lubricants, Design of Experiment, Grey Relational Analysis.

Introduction

Cold rolling operations related with the smooth processing of rolled products include the use of rolling lubricants. These materials, typically in the form of fatty or mineral oils, applied either neat or in emulsion form, greatly assist the reduction of the strip in that they significantly reduce the rolling force necessary for deformation. Without information of the efficiency of the rolling lubricants used, the adequate operation of commercial rolling services becomes more difficult to achieve. From an economic viewpoint, it is desired to use the economical material that will provide satisfactory lubrication in the roll bite.

Literature review: Although cold rolling lubricants have been widely used since the early 1930's, research into their performance was not commenced to any noteworthy extent until the late 1940's. Base on analyze the association among the main factors related with roll-bending force in reversing multi-pass rolling, such as strip width and rolling force, a present mathematic model of bending force is developed by genetic algorithm. Traditionally cold rolling work uses lubricant to predict adverse dynamic characteristics of rolling mills can prevent severe problems in dimensional quality in addition to expensive mill equipment damage. The successful and efficient running of any system or any process largely depends on the fact that how it has been designed. Before a system or any process is developed it need to go through many experiments and a fruitful experiment helps the system or process to be designed successfully. So Design of Experiment (DOE) has a very important role in development of any system or a process. It is very important to get the most information from each experiment performed. In addition, a well-designed experiment will ensure that the evaluation of the effects that had been identified as important. Experiment has been performing as per DOE to obtain the responses of surface roughness by surface profilometer and chemical wear by SEM analysis. To obtain the most effecting parameter on rolling process optimization technique applied on the responses.

CAO Jian-guo, et al examined the water powered move bowing gadget, which is broadly utilized as a part of present day cool moving plants to direct the strip evenness. The recreation comes about demonstrate that, the quadratic part of strip crown diminishes almost straightly with the expansion of the work move bowing power, when the moving estimation of middle of the road roll is dictated by the moving procedure[1]. Guo then connected two-phase and single-stage transport grid techniques to unravel a direct spring and pillar model of 4high and 6-high factories, whereby contact between the individual rolls and between the strip and the work rolls was demonstrated by a limited number of discrete straight springs[2]. Malvezzi et al in his article proposed method that incorporates a numerical model for oil stream in view of Reynolds condition and a scientific model for plastic misshapening process in light of Orowan approach[3].

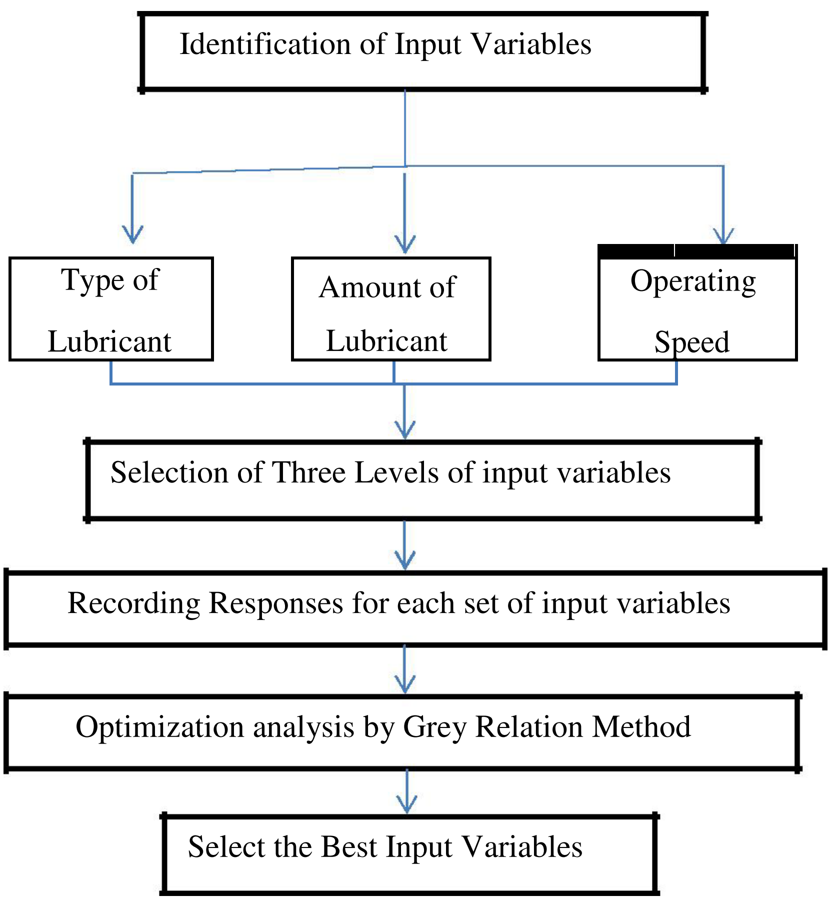
Shen et al have demonstrated the significance of moving oil and coolant utilized as a part of the procedure of Cold rolling. They have led their review on research facility recreation and genuine temper moving procedure[4]. Saboonchi and Aghili have examined about the part of temperature in moving plant and on rolls. The temperature is one of the essential parameter which is being constituted by different analysts for breaking down the execution of the roll. The review led on the headers having arrangement of spouts, which are in charge of the cooling and extension of the work rolls[5]. Wendt et al have examined about the staying issue in the wake of strengthening procedure in icy moved steel. The curl of frosty moved steel when uncoiled in the wake of tempering face staying. The staying is named as welding and the cause might be dispersion or sintering or other bond component. Fundamentally in staying the part of roll and their traits are having no noteworthiness however as the warmth increments because of hard material and rapid moving factories[6].

Sukhdev and Ganguly has implemented grey relational analysis to optimize a set of operational parameters which are called as input variables of any process to achieve best result of any performance parameter, which is also known as response variable, of that process. Taguchi based DOE is important as a formal way of maximizing information gained while minimizing resources required. It has more to offer than one change at a time experimental methods, because it allows a judgment on the significance to the output of input variables acting in combination with the other[7]. Srinivasa and Reddy suggested optimized control factors for the whole quality by using Taguchi - Gray relational analysis. Cutting speed, feed rate, drill diameter, point angle and cutting fluid mixture ratio were considered as control factors, and L18 (3*5) orthogonal array was used for experimental trials. Gray relational analysis was employed to minimize the surface roughness and roundness error achieved via experimental design[8].

Objective: There has been limited study done in the area of surface quality of cold rolled product roller under the effects of different lubricants. This study examines the surface roughness and chemical wear that occur during the cold rolling of low carbon steel. The roller currently used in the industry is the steel alloy. Usually, higher roll hardness gives more thickness reduction to rolled low carbon steel and enhances metal working efficiency during cold rolling. The main objective is to find optimum set of input variables in terms of cooling lubricant, its amount and operating speed for the rolling mills to achieve desired surface roughness and reduce chemical wear.

Methodology

A simplified and precise framework is developed for optimization of cold rolling system. The flow chart of methodology is shown in Figure-1.



Figure–1: Flow Work.

Design of experiment: Classical experimental design methods are too complex and are not easy to use. A large number of experiments have to be carried out when the number of process parameters increase. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. The DOE technique and the number of levels are to be selected according to the number of experiments which can be afforded. By the term levels we mean the number of different values a variable can assume according to its discretization. The number of levels for all variables are compatible as per their requirement i.e. DOE techniques uses the differentiation of the number of levels for each variable as shown in Table-1.

Table-1: Factor and level.

Factor Level	Product Name	Amount of lubricant (ml)	Operating Speed in RPM
1	Rhenus	20	200
	CGN 2		
2	Rhenus	25	300
	NAN 02		
3	Rhenus	30	400
	LMN 2		

Orthogonal arrays are special standard experimental design that requires only a small number of experimental trials to find the main factors effects on output. On the basis of factors and their level L9 orthogonal array has to be design in Minitab software as shown in Table-2, Where 1, 2 & 3 indicating the level of factors. Taguchi experimental design of experiments suggests L9 orthogonal array, where 9 experiments are sufficient to optimize the parameters. Based on main factor, the variables are assigned at columns, as stipulated by orthogonal array.

Table-2: DOE in Minitab.

Product Name	Amount of lubricant (ml)	Operating Speed in RPM
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

Once the orthogonal array is selected, the experiments are selected as per the level combinations. It is important that all experiments are conducted. The performance parameter (output) is noted for each experimental run for analysis and the set of the nine experiments to be performed to obtain their responses as shown in Table 3 respectively. The Specimen dimension before and after has shown in Figure-2. Surface roughness and chemical wear is measured of each specimen is tabulated in Table-3.

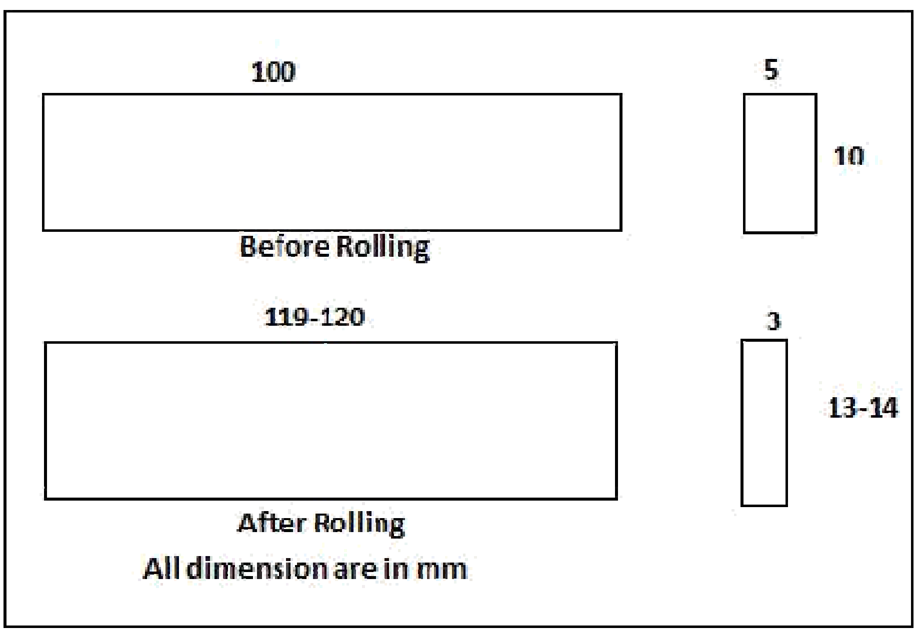


Figure-2: Specimen dimension.

Table-3: Response of L9 Orthogonal Array experiment of synthetic lubricant.

Experiment No.	Product Name	Amount of lubricant (ml)	Operating Speed in RPM	Surface Roughness Ra in µm	Chemical Wear in µm
1	Rhenus CGN 2	20	200	0.45	1.5
2	Rhenus CGN 2	25	300	0.47	1.4
3	Rhenus CGN 2	30	400	0.49	1.3
4	Rhenus NAN 2	20	300	0.56	1.2
5	Rhenus NAN 2	25	400	0.58	1.4
6	Rhenus NAN 2	30	200	0.62	1.6
7	Rhenus LMN 2	20	400	0.57	1.7
8	Rhenus LMN 2	25	200	0.49	1.6
9	Rhenus LMN 2	30	300	0.63	1.9

Grey relation analysis: The grey means the primitive data with incomplete and uncertain information in the grey systematic theory; the incomplete relation of information among these data is called the grey relation. First, the grey relation analysis was carried out to normalize the responses. In reality, grey relational analysis compares relations of sequences in their appropriate metric spaces.

If two systems agree at all points, then their grey relational coefficient is 1 everywhere, and therefore, their grey relational grade should be 1 or close to 1. In view of this, the relational grade of two comparing sequence can be quantified by the mean value of their grey relational coefficients;

For lower-the-better criterion, the normalized data can be expressed by equation (1)

$$X_i = \frac{max(y)_i - (y)_i}{\max(y)_i - \min(y)_i} \quad (1)$$
$$where\ i = 1,2 \ldots\ldots n$$

The calculation of the grey relational coefficient and the weight of each quality characteristic is determined by equation (2):

$$G_i = \frac{L_{min} + \varepsilon L_{max}}{L_i(k) + \varepsilon L_{max}} \quad (2)$$

Where, L_{min} is the global minimum, L_{max} is the global maximum and ε is distinguish to 1 in this case 0.5 weight is taken. Grey relation coefficient which is taken in between 0 grade can be calculated by equation (3).

$$Grg_i = \frac{1}{n}\sum_{j=1}^{n} G_i(j) \quad (3)$$

Where n is the number of process responses. The lower value of the grey relational grade represents the reference sequence Grg_i. As mentioned before, the reference sequence Grg_i is the best process response in the experimental layout is taken whose grey relation grade is maximum.

Results and discussion

In this optimization, the synthetic lubricants are optimizing on the basis of Grey relation grade(GRG), which transforms the input values into suitable linguistic values; a rule base, which convert the input value in normalized form, then convert the multi-objective problem in single objective problem as per their weight in terms of GRG.

The challenge of modern machining industries is generally focused on the attainment of high quality, in terms of work piece dimensional accuracy, surface roughness, high production rate, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact.

The inputs for the normalized are the surface roughness and chemical wear data which is obtained from their lubricant property. The normalized value of lubricant response, grey relation coefficient and grey relation grade (GRG) is shown in Table-4.

Table-4: Calculation of GRG response.

Exp. No.	NRa	NCw	LRa	LCw	Gi_{Ra}	Gi_{Cw}	GRG
1	1	0.571429	0	0.428571	1	0.538462	0.769231
2	0.888889	0.714286	0.111111	0.285714	0.818182	0.636364	0.727273
3	0.777778	0.857143	0.222222	0.142857	0.692308	0.777778	0.735043
4	0.388889	1	0.611111	0	0.45	1	0.725000
5	0.277778	0.714286	0.722222	0.285714	0.409091	0.636364	0.522727
6	0.055556	0.428571	0.944444	0.571429	0.346154	0.466667	0.406410
7	0.333333	0.285714	0.666667	0.714286	0.428571	0.411765	0.420168
8	0.777778	0.428571	0.222222	0.571429	0.692308	0.466667	0.579487
9	0	0	1	1	0.333333	0.333333	0.333333

The leading step of Grey Relational analysis in which the output responses are first normalized, ranging from zero to one which is depicting in Figure-3. Based on this above obtained value grey relational coefficient is evaluated in next step in order to find out interaction between actual and desired experiment value whose graph is shown in Figure-4.

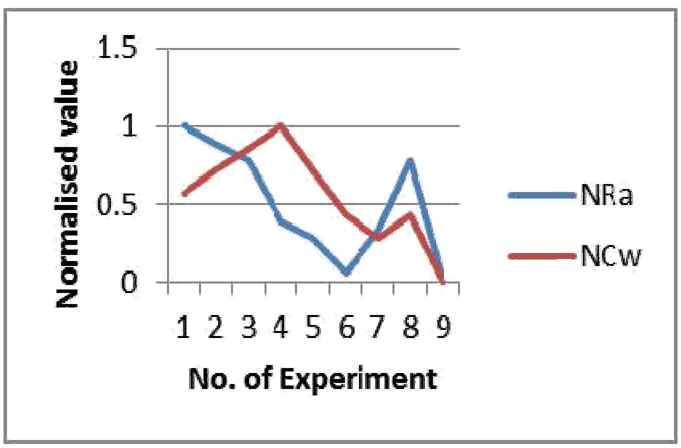


Figure-3: Normalized graph of Synthetic Lubricant Responses.

GRG and the Reference Sequence represent the best process sequence. Therefore the parameter combination having higher GRG value is closer to optimal. The process parameters are selected as optimized factors which are recommended for further process. The Figure-6 shows the higher values of each parameter are major factor. Out of these three parameter categories "A" denoted lubricants, "B" denotes amount of lubricant, "C" denotes Speed of rollers.

In these factors category "A" showing higher value so the lubrication is the major factor in between all parameters.

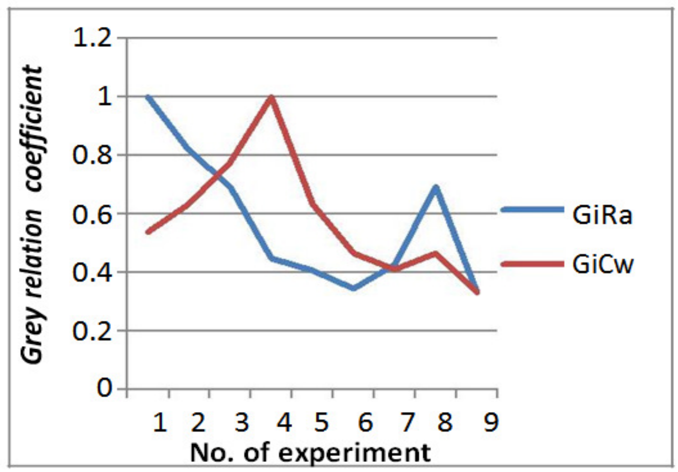


Figure-4: Grey Relation Coefficient graph of Synthetic Lubricant Responses.

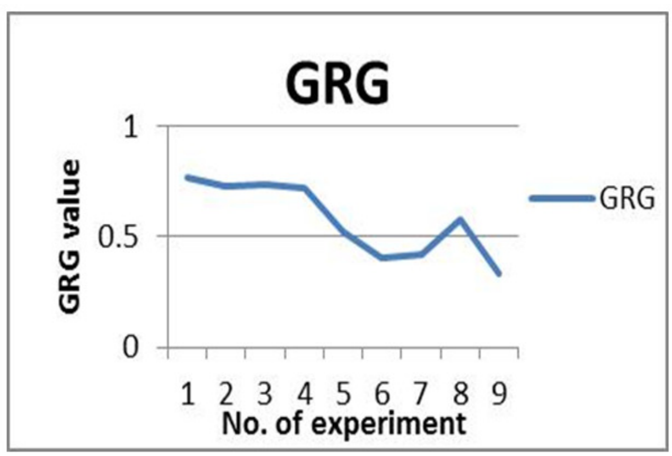


Figure-5: GRG graph of Synthetic Lubricant Responses.

Table-5: Ranking of Experiments.

Experiment No.	Product Name	Amount of lubricant (ml)	Operating Speed in RPM	GRG
1	Rhenus CGN 2	20	200	0.769231
3	Rhenus CGN 2	30	400	0.735043
2	Rhenus CGN 2	25	300	0.727273
4	Rhenus NAN 2	20	300	0.725000
8	Rhenus LMN 2	25	200	0.579487
5	Rhenus NAN 2	25	400	0.522727
7	Rhenus LMN 2	20	400	0.420168
6	Rhenus NAN 2	30	200	0.406410
9	Rhenus LMN 2	30	300	0.333333

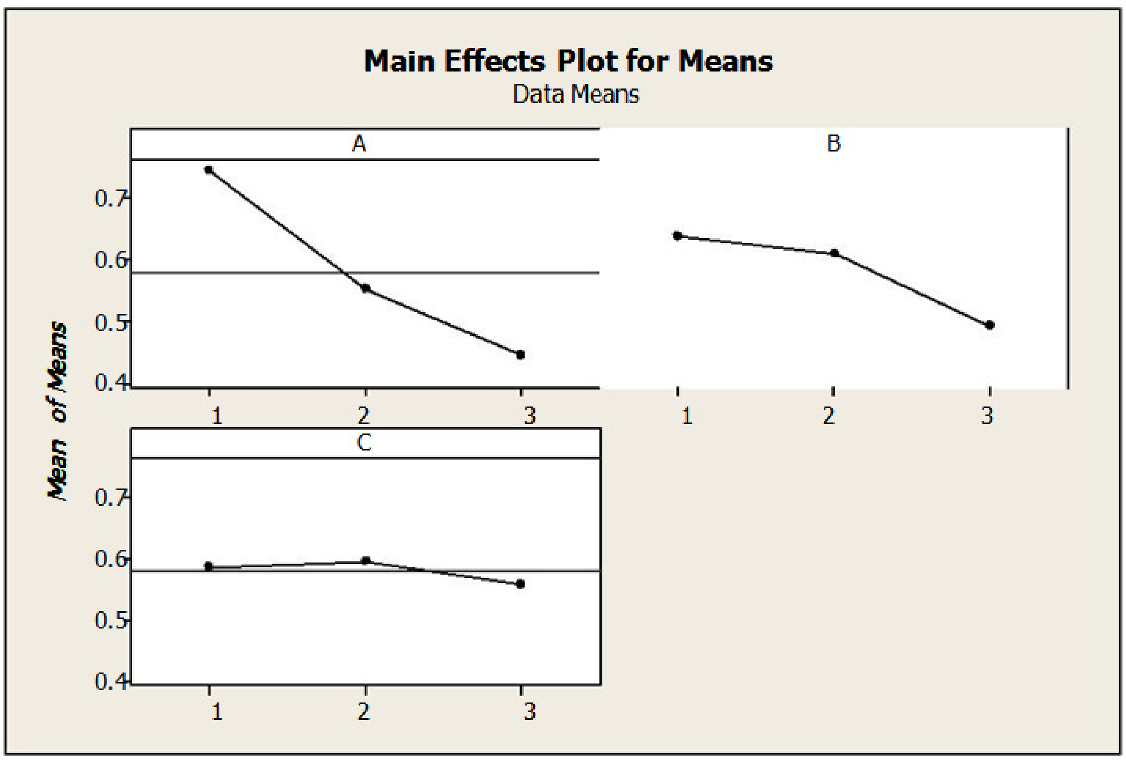


Figure-6: Effect Plot of Parameters.

The P values which are less are considered significant and the models are adequate to represent the relationship between response and the parameters. The analysis of variance can be used as an exploratory tool to explain observations of experiment in multiple parameters. In this machining work ANOVA result has shown in Table 6, lower P (probability) value indicating more effective parameter is lubricant in all groups. It is observed from the adequacy test by ANOVA lubricant is significant. To analyse the data, checking of goodness of fit of the model is very much required. The model adequacy checking includes the test for significance of the regression model, test for significance on model coefficients, and test for lack of fit. For this purpose, analysis of variance (ANOVA) is performed.

Table-6: Analysis of Variance for Means.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	0.138216	0.138216	0.069108	3.02	0.249
B	2	0.036254	0.036254	0.018127	0.79	0.558
C	2	0.002053	0.002053	0.001027	0.04	0.957
Residual Error	2	0.045842	0.045842	0.022921		
Total	8	0.222366				

Conclusion

Cold rolling simulation experiments were conducted using the steel alloy rollers in order to study the surface roughness and chemical wear occurring during standard operations and to study the lubricant that influence them. Different lubricant materials do affect the morphology of the mating steel surface with apparent surface defects. The Grey relational analysis based on an orthogonal array of the DOE methods was a way of optimizing the process parameters in lubricants. The analytical results summarized as follows: i. From the response table of the average grey relational grade, it is found that the largest value of the GRG is for experiment No.1, ii. The recommended lubricating oil is Rhenus CGN 2 with supply rate of 20ml per piece at 200 rpm of roller speed. iii. The ANOVA indicates that lubricant is major factor in three parameters.

The results are further conformed by conducting confirmation experiments.

References

1. Cao Jian-guo, Xu Xiao-Zhao, Song Mu-Qing , Zhang Jie, Gong Gui-Liang and Zeng Wei (2011). Preset model of bending force or 6-high reversing cold rolling mill based on genetic algorithm. *J. Cent. South Univ. Technol.*, 18(5), 1487-1492. doi: 10.1007/s11771−011−0864−6.

2. Guo R.M. (1998). Development of a single-stage transport matrix method using the beam on elastic foundation theory. 19th south eastern conference on theoretical and applied mechanics, may 2-5,ft. Lauderdale, USA.

3. Malvezzi M. and Valigi M.C. (2006). Influence of plastic deformation models in full film lubrication of strip rolling. aitc-ait 2006, international conference on tribology , 20-22 september, parma, italy.

4. Shen Sen-Tsan, Wu Yi-Ming, Huang Chih-Ching and Huang Min-Zhang (2008). Influence of rolling chemicals on temper rolling process and anti rust performance of cold rolled steels. *china technical report*, 21, 45-51.

5. Saboonchi Ahmad and Aghili Sayyed Majid (2006). The effect of header geometry on temperature distribution in cold rolling. *international journal of ISSN*, 2(2), 24-29.

6. Wendt Peter, Frech Winfried and Leifgen Uta (2007). Cold rolling defects, “stickers” and countermeasures. heat processing, International magazine for industrial furnaces, heat treatment plant and equipments, ISSN 1611-616x, 2, 127-129.

7. Sukhdeve Vikas and Ganguly S.K. (2015). Utility of Taguchi based grey relational analysis to optimize any process or system. *International journal of advanced engineering research and studies*, 4(2), 242-250, issn2249–8974.

8. Sreenivasulu Reddy and Rao C.S. (2012). Application of gray relational analysis for surface roughness and roundness error in drilling of Al 6061 alloy. *international journal of lean thinking*, 3(2), 67-78.

9. Guo R.M. and Malik A. (2005). Development of a new crown/shape control model for cluster mills. *iron and steel technology*, 2(8), 31-40.

10. Malik A.S. and Grandhi R.V. (2005). Reliability analysis of rolled strip exit profile considering random nature of critical rolling variables. the iron & steel technology conference and the 3rd international congress on the science & technology of steelmaking.