Cold Rolling Mill Optimization Using Fuzzy Logic

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Abstract: This work studied influence of the input process parameters used in cold rolling process. In this study DOE (Design of experiment) methodology is used for some quality outputs. Taguchi method is used for experiment design, L16 orthogonal array is solve in ANSYS Explicit dynamics software. As a input parameters factors used are thickness, velocity, friction and the FOUR levels of the input parameters are and finally in output as a result stress and strain produced in the final product are optimize using following model. ANOVA Analysis is also performed in this study using Minitab software. And finally FUZZY logic is applied in this study for the validation of results predicted from taguchi method. Result shows that thickness is most critical parameters which effects the stress developed during rolling process and velocity is most critical factors which effect the strain produced during rolling process. Finally in this research model equation are generate for stress and strain using linear regression modeling technique in Minitab software.

Keywords: Cold rolling mill , DOE , ANOVA, Orthogonal array , FUZZY logic.

INTRODUCTION

In the cold roll mill forming process thick metal strips is deformed into a desired cross section passing through the successive pair of the roll in different consequent stands. The rolls from which the metal sheet is forwarding are known as work roll and back up roll, numbers of these successive pair of rolls depends upon the mill configuration. The process of cold rolling mill is sheet metal forming process for mass production of all types of open and closed section. The process of cold rolling mill is very precise and complex forming process, having large amount of nonlinearity coupled effects with multiple parameters. For Example size, stress developed, strain developed, friction, amount of HAGC pressure etc.

APPLICATIONS OF COLD ROLL MILL PRODUCT

As cold rolling mill product considered as a economic profile product and hence widely used in transportation, engineering machine and civil construction because of its uniform cross section. Cold rolled products are having better surface finish,and also the improved quality of steel such high tensile strength and reduced thickness to its precise gauge. As a result cold rolled product generally demands high price. The product of cold rolling mill such as cold rolled sheet and coil are used for precision tubes, containers, bicycles, furniture and use by the automobile industry to produced car body panels. Cold rolled product are also used for further processing to galvanizing, colour coating and tinning.

1. M. **SALAMI TEHRNI et al**. studied that in this research researcher are trying to minimizing the edge buckling effect which is major defect facing in resultant product and also the allowable deformation that can be achieved in single stage is one of the important factor for the design of cold rolling forming process. For the prediction of the local edge buckling effect in the symmetric channel section, the researchers are used finite element simulation. And comparison made between the computed and measured longitudinal strain. And finally results indicates that during the rolling mill setup, the fold angle at first station should be kept below a particular limit. And above this limit local edge buckling may induces by reverse bending applied by the rolls at second station. And finally the influence of changing the fold angle at subsequent roll station is edge buckling found to be negligible.

2. **ZENG GUO et al**. studied that in this research paper a new booted finite element analysis model is using updated lagrangian method for multistate roll forming process is developed and validated. The whole work is compared with most of the literature related with cold rolling forming process. The process of channel section with outer edge

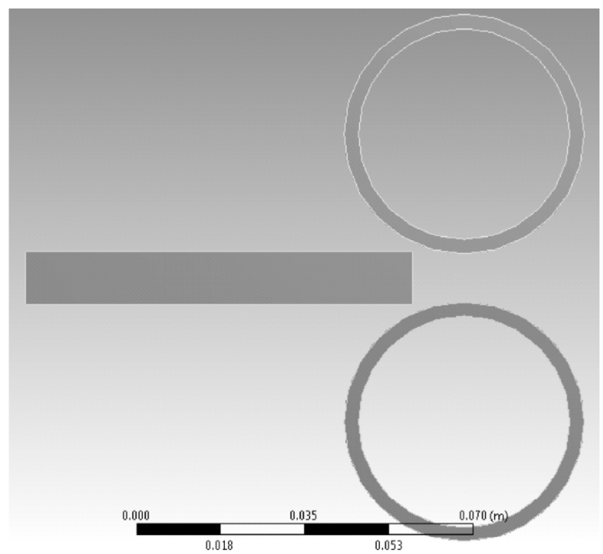
formed with twelve passes is simulated and it is found that the multistand roll forming process is efficiently analysed by the new booting model.by this research i do familiar with FEM and lagrangian method.

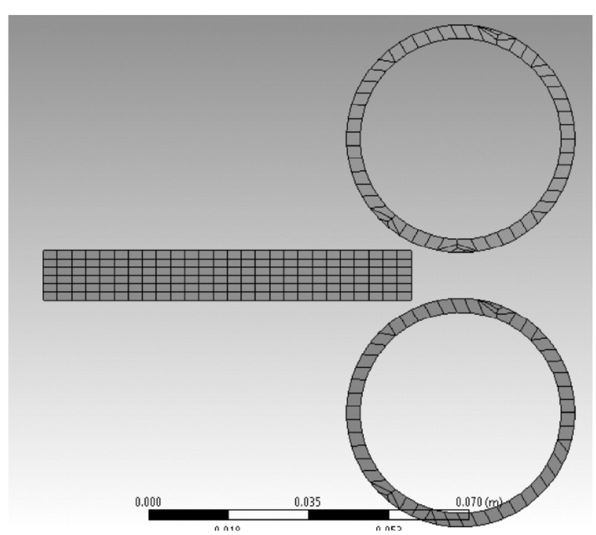
3. GUO LIANG-GANG et al. studied that in this research, effect of roll size on the result is discussed, as in the cold rolling process changing the size of driver roll or idle will leads to change in the feed and contact between the ring blank and forming roll, and because of this there is a change in the shape and dimension of deformation zone located in the gab of forming roll is found. And it has very prominent effect on metal flow and quality of final product, so the effect of sizing of forming roll is investigated by three dimensional dynamic explicit FEM under ABAQUS environment. The final results through the laws of size of forming rolls on the average spread, fishtail coefficient, force, power parameters etc. not only provide the information about design of forming roll, but also the optimization of cold rolling process and also reveal the plastic deformation mechanism of cold roll forming process.

4. M. M. KASAEI et al. studied that in this research simulation is being performed in the cage rolling process, cage rolling forming process is advance process for producing ERW pipes, it is designed to improve the strip deformation and to increase the flexibility in the production line compared with the conventional roll forming of ERW pipes. The most important factor in this research is initial strip width, accurate predicted initial strip will produced sound pipes. In this paper case rolling forming is simulated with explicit elastic –plastic finite method. And they conclude that on increasing the initial width of strip more circumferential length reduced and this effect in difference in the longitudinal strain at the edge and center of the deformed sheet and hence reducing the edge buckling effect. The experimental data is compared with the production line and its shows the good agreement and confirmed finite element simulations.

5. FRANK HEISLITZ et al. studied that in this research paper the, finite element analysis is used to measure strain distribution and sheet geometry during and after the process. Roll forming is the process of manufacturing long sheet metal product with constant cross section. The roll passing schedule, percentage of reduction in each pass, tension at entry and exit level and so many parameters are manually decided by the operator during the process, and this process parameters have lot of effect on the result, or there are so many input parameters which directly effects the output result, in this research by using of finite element analysis strain distribution and deformation or sheet geometry during and after process is predicted. Strain distribution and deformed geometry predicted by simulation are compared with results from previously conduct experiment. By this research it is clear to me, how and when it is best to apply 3D FEM code to design of a cold rolling mill.

DESIGN OF PROBLEM





AIM OF STUDY

The aim of present study is to numerically solve the cold roll mill process to find out the effect on product quality. Design of experiment technique is used in this study to design simulation experiments. For future relevance of this study advanced methodology Fuzzy Logic is also applied in present work. Author wants to develop regression model equations for current study so small scale industries can use these equations in their industries.

DESIGN OF EXPERIMENT AND RESEARCH METHODOLOGY

The advance Design of experiment features helps us to improve our processes. As we can screen all the factor to determine which are more feasible or important for explaining process variation. The effect of process parameters were examined by various researchers, and they find a conclusion that it is very much difficult of design an experiment for any research and therefore they find an scientific approach to solve that problem, is known as "DESIGN OF EXPERIMENT". With the help of DOE, the researcher can determines the control factors which are responsible for output of result, and variation in experiment. DOE in results give us optimum solution for particular solution. After the results from DOE, Taughi method is applied for ANOVA analysis for the taughi method different levels and factors are primary necessities which are shown in table, after understanding the factors and levels for current study, it is very much important to make accurate orthogonal array and for this task we used MINITAB software, the orthogonal array is shown in the table 1.

RESULT AND DISCUSSION

Cold rolling mill process is simulated in this study, ANSYS Explicit Dynamic FEM package is used for simulation purpose. All the experiment are designed according to DOE technique (Taguchi method) which were presented in tables , the main outcomes through the following models are focused in this study are :

ANOAVA ANALYSIS

SIGNAL TO NOISE RATIO

MODEL EQUATION GENERATION

Table 1
16 experiment for input parameters

	Input parameters			*Output parameters*	
	Velocity	*Thickness*	*Friction*	*Stress*	*Strain*
1	1.5	10.5	0.00	288.54	.48601
2	1.5	11.0	.05	362.44	.44590
3	1.5	11.5	.10	377.74	.56972
4	1.5	12.0	.15	385.40	.31157
5	2.0	10.5	.05	336.82	.13142
6	2.0	11.0	.00	362.21	.56520
7	2.0	11.5	.15	386.78	.29544
8	2.0	12.0	.10	365.44	.38514
9	2.5	10.5	.10	352.45	.17038
10	2.5	11.0	.15	365.09	.44426
11	2.5	11.5	.00	381.83	.36807
12	2.5	12.0	.05	382.31	.55011
13	3.0	10.5	.15	351.46	.20915
14	3.0	11.0	.10	353.06	.53641
15	3.0	11.5	.05	377.81	.32146
16	3.0	12.0	.00	393.45	.29113

STRESS AND STRAIN CONTOURS

In this study results are von-misses stresses (MPa) developed during cutting process is selected, and all the results according to L16 experiment is present in table as output parameters. Minitab software is used for ANOVA analysis in this study.

Taguchi Analysis: Stress versus Velocity, thickness, Friction:

Signal to Noise Ratio Analysis

A measure of robustness in taguchi design used to identified the control factors that reduces the variability in product are processed by minimizing the effect of controllable factors (noise factors). Control factors are termed as the factors which are controllable , and Noise factors cannot be controlled during the production but they can be controlled during experiment. The taguchi design manipulate the Noise factors to force variability to occurs from results , and from that identify the optimize control factors that make the product robust. Highest the value of Signal to noise ratio indicates control factor setting that minimize the effect of noise factor. In this study "smaller is better" option is used as quality indication for S/N ratios. The response table for S/N ratio and mean are presented in table2 and table 3.

Table 2
Response Table for Signal to Noise Ratios
Smaller is better

Levels	*Velocity*	*Thickness*	*Friction*
1	-50.91	-50.40	-50.98
2	-51.18	-50.14	-51.23
3	-51.37	-50.62	-51.17
4	-51.33	-51.63	-51.41
Delta	.46	1.23	.43
Rank	**2**	**1**	**3**

Response Table for Means

Table 3
Response Table for Means

Levels	*Velocity*	*Thickness*	*Friction*
1	353.5	332.3	356.5
2	362.8	360.7	364.8
3	370.4	381.0	362.2
4	368.9	381.6	372.2
Delta	16.9	49.3	15.7
Rank	2	1	3

Both tables show factors importance ranking and it is clear that thickness is most important factor, which can reduce von-misses stress magnitude during cold roll forming process.Best and worst cases from experiment factors and their levels are also presented in this study and were calculated from figure 2 and figure 3.

Main effect plot for Means

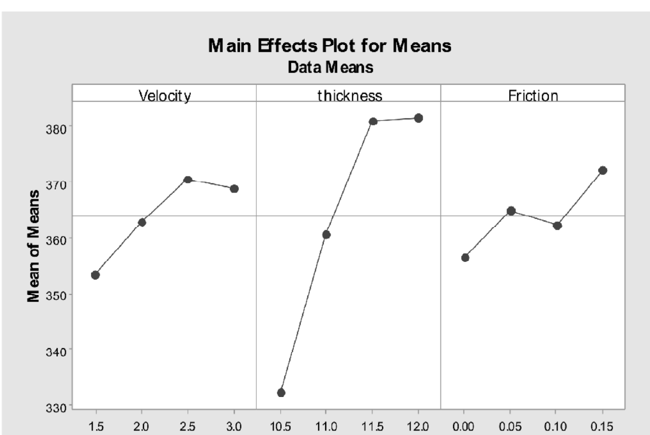


Figure 1 : Main effect plot for Means.
Best case : A3 B4 C4
Worse case : A1 B1 C1

Main effect plot for SN ratios

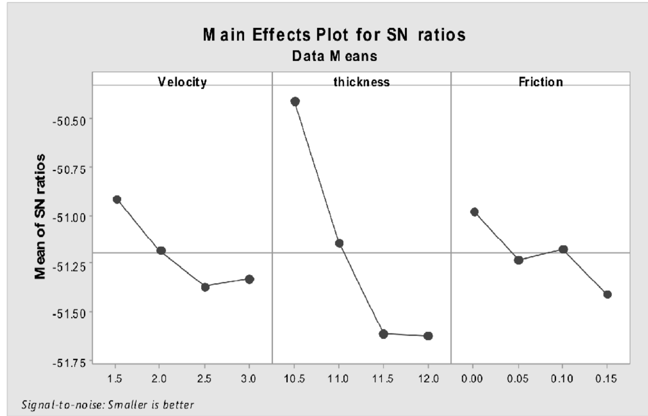


Figure 2 : Main effect plot from SN ratios.
Best case : A1 B1 C1
Worse case : A3 B4 C4

Taguchi Analysis: Strain versus Velocity, thickness, Friction

Table 4
Response Table for Signal to Noise Ratios
Smaller is better

Level	*Velocity*	*Thickness*	*Friction*
1	7.075	13.214	7.656
2	10.365	6.107	9.923
3	9.073	8.504	8.484
4	9.894	8.581	10.339
Delta	3.291	7.107	2.684
Rank	2	1	3

Response Table for Means

Table 5
Response table for means

Levels	*Velocity*	*Thickness*	*Friction*
1	.4533	.2492	.4276
2	.3443	.4972	.3622
3	.3832	.3887	.4154
4	.3395	.3845	.3151
Delta	.1138	.2487	.1125
Rank	2	1	3

In both of this table it is clear that again thickness is the parameter which effects the result of cold roll forming process.

Mean Effect plot for SN ratio

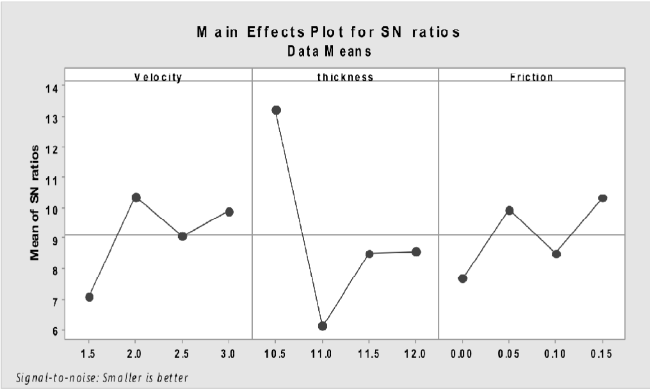


Figure 3: Main effect plot for SN ratios
Best case : A2 B1 C4
Worse case : A1 B2 C1

Main Effect plot for Means

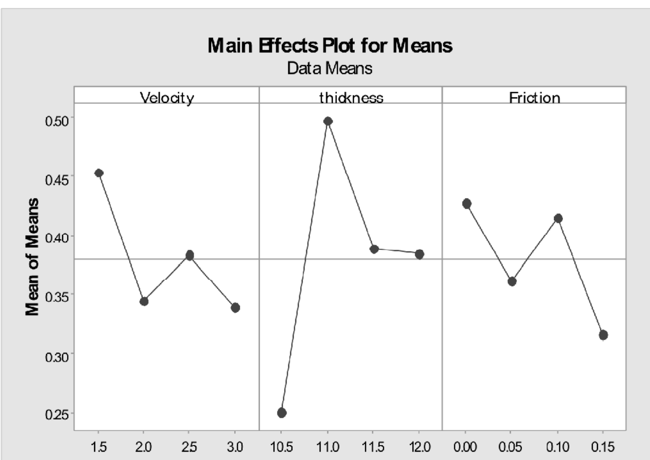


Figure 4: Main effect of plot for means.
Best case : A1 B2 C1
Worse case : A4 B1 C4

Regression Analysis: Stress versus Velocity, thickness, Friction

Analysis of Variance

The analysis of variance is calculated for this study and results are shown in table respectively. In ANOVA analysis F-Test is conduct to compare a model variance with a residual variance. F value was calculated from a model mean square divided by residual mean square value. If f value was approaching to one means both variances were same, according F value highest was best to find critical input parameter.

Table 6
Analysis of variance for stress response

Source	*DF*	*Adj ss*	*Adj Ms*	*F value*	*P – value*
Regression	3	6640.9	2213.6	8.60	.003
Velocity	1	580.0	580.0	2.25	.159
Thickness	1	5667.5	5667.5	22.02	.001
Friction	1	393.4	393.4	1.53	.240
Error	12	3088.0	257.3		
Total	15	9729.0			

Table list out one important result that F value for regression models are very high, than one and P value is very less (approx 0.001) suggested that all cases were significant.From literature review various researchers found that if p value was very small (less than 0.05) then the terms in the regression model have a significant effect to the responses.

ANOVA analysis is also tell that thickness has very low p value than other factor like velocity and friction, although all three factors have acceptable p value so it can concluded that von-misses stress can be reduced by all factors.

Model Summary

Table 7
Model summary

S	*R-sq*	*R-sq(adj)*
16.0417	68.26%	60.32%

Regression Equation

Stress = -45.7 + 10.77 Velocity + 33.67 thickness + 88.7 Friction

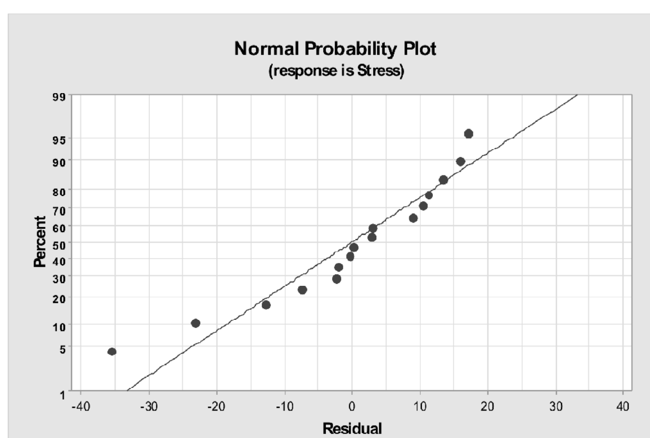


Figure 5: Normal probability plot, response is stress

Regression Analysis: Strain versus Velocity, thickness, Friction

Table 8
Analysis of Variance for strain response

Source	*DF*	*Adj SS*	*Adj MS*	*F- value*	*P –value*
Regression	3	.05203	.01734	.83	.501
Velocity	1	.01829	.01829	.88	.367
Thickness	1	.01758	.01758	.85	.376
Friction	1	.01617	.01617	.78	.395
Error	12	.24962	.02080		
Total	15	.30165			

From the table it is clear that velocity having minimum p value and maximum F value as compare to other parameters so , here velocity is responsible factor for minimizing the strain , but other factor like thickness , friction are also having acceptable P value that is why it can be concluded that strain can be reduced by all this factors.

Model summary

Table 9
Model summary

S	*R-sq*	*R-sq(adj)*
.144228	17.5%	.00%

Regression Equation

Strain = -0.108 - 0.0605 Velocity + 0.0593 thickness - 0.569 Friction

Normplot of Residuals for Strain

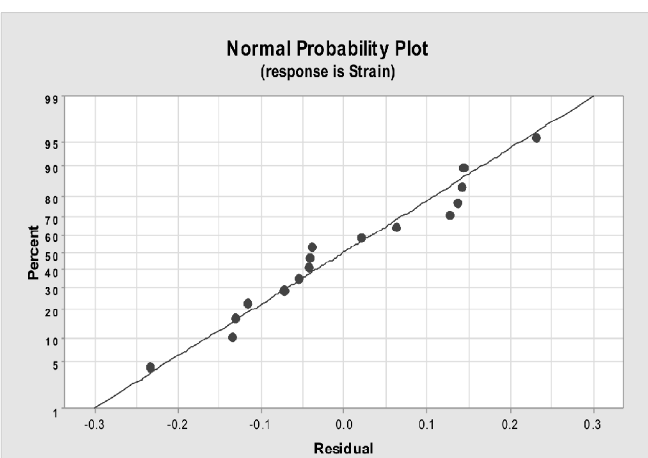


Figure 6: Normal probability plot, response is strain

Results from FUZZY logic and their comparison with result from FEM

	Input parameters			*Output parameters*		
	Velocity	*Thick-ness*	*Fric-tion*	*Stres from taguchi*	*Stress from fuzzy*	*% difference in results*
1	1.5	10.5	0.00	288.54	343	15.8%
2	1.5	11.0	.05	362.44	376	3.0%
3	1.5	11.5	.10	377.74	376	-0.4%
4	1.5	12.0	.15	385.40	343	-12.0%
5	2.0	10.5	.05	336.82	343	2.0%
6	2.0	11.0	.00	362.21	343	-5.56%
7	2.0	11.5	.15	386.78	392	1.5%
8	2.0	12.0	.10	365.44	343	6.0%
9	2.5	10.5	.10	352.45	356	0.99%
10	2.5	11.0	.15	365.09	356	-2.5%
11	2.5	11.5	.00	381.83	343	-11.3%
12	2.5	12.0	.05	382.31	376	-1.6%
13	3.0	10.5	.15	351.46	356	1.4%
14	3.0	11.0	.10	353.06	356	0.82%
15	3.0	11.5	.05	377.81	376	-0.48%
16	3.0	12.0	.00	393.45	343	-14%

Fuzzy Logic Rules: If (velocity is very low) and (thickness is very low) and (friction is very low) then (stress is very low) (1).

2 If (velocity is very low) and (thickness is very low) and (friction is low) then (stress is high)

3. If (velocity is very low) and (thickness is low) and (friction is low) then (stress is very high)

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4. If (velocity is high) and (thickness is high) and (friction is very low) then (stress is Extreme) (1)

CONCLUSION

The aim of study is to try to manage among response and FEM simulation results for cold roll forming process. This study utilize L16 orthogonal array for FEM based data analysis. In this study Analysis of variance (ANOVA), linear regression analysis and FUZZY logic is main key technique are used to show response and factor relation strongly with each other. Main results are summarized as follows:

1. Best parameters combination of FEM results are following

CASE 1 : best set (S/N Ratio) for stress : A1 B1 C1

CASE 1 : best set (mean ratio) for stress : A3 B4 C4

CASE 2 : best set (S/N Ratio) for strain : A2 B1 C4

CASE 2 : best set (mean ratio) for strain : A1 B2 C1

And the result comes from fuzzy logic for validation of results from taguchi method, then it is predicted that the percentage of difference between result is below 15%.

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