Optimization of Strain Distribution in the Roll Forming Process Using the Desirability Function and Finite Element Methods

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ABSTRACT

Defects of the roll forming process are affected by the amount and situation of the strains distribution. The effect of the process parameters on the strain distribution in the round cross section roll forming process has been studied. Finite element and response surface method have been used for process modelling. Then, desirability functions approach and overlaid counter plots were employed for optimization of the process. Three factors including the roll diameter, distance between the stations and linear speed of the sheet were considered as the input parameters. The sum of longitudinal maximum strain and transverse strain distribution uniformity were taken as response functions. Response function model for each function was obtained using the RSM. Finally, optimization of the process was done using the desirability function approach and overlaid contour plots. The results show that both of the response surface models have good model adequacy. Optimization by desirability functions approach was presented as points which according to the type of the process and production requirements can only be used to start and preliminary design. But the overlaid contour plots have flexibility in output for manufacturing processes. Output overlaid contour plots provide optimum area that there is wide range of values for choices in different condition.

1-Introduction

Roll forming is a continuous process for forming the sheet, strip or coiled metal stock into long shapes of essentially uniform cross-sections. The material is fed through multiple pairs of contoured forming rolls, which progressively shape the metal until the desired cross section is produced. However, cold roll forming in its present form is a relatively young forming process and its use did not become widespread until the demand for better and faster methods of producing sheet metal parts was recognized [1]. In this process, severe plastic deformation does not occur at one stage because deformation can cause severe damage to the rolls and even some geometrical defects in the final product [2]. Transverse bending as the main deformation is imposed in sheet metal (strip) that occurs in several stages during the process. According to different situations and roll types, transverse and longitudinal strain is applied in cross section sheet metal [1]. Due to the effect of various factors in this process, the standard relationships have not been stabilized yet and are generally designed to be performed on the basis of experience and personalization [3]. Today, with development of finite element methods, researchers can perform a wide range of investigations at a lower cost. Bhattacharyya et al. [4] investigate the shell longitudinal strain in

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the process when one or more pairs of rolls are used and their results demonstrated that the peak strain is related to the amount of bend angle.The effect of the line speed, the distance between stations, the distance between the pair of rolls, the friction coefficient and the diameter of the rolls on the product characteristics was investigated by Paralikas et al. [5] and it was found that the changes in the distance between the rolls were effective on the maximum longitudinal strain, residual strain and transverse strain. Zeng et al. [6] used the response surface method (RSM) to optimize design flower pattern for channel-shaped. They investigated the interaction effects of increasing angle and diameter of rolls on the spring back and maximum longitudinal strain of the edge using the mathematical model. Salmani Tehrani [7] studied the deformed length in roll forming for the round section. He used assumptions considered by Bhattacharya [8] for roll forming of channel cross-sections. Jinmao Jiang [9] and Moslemi Naeini [10] simulated cage roll forming for indicating non-bending area at different forming stands. Their results showed that by increasing the initial strip width, the difference between longitudinal strain at the edge and center of the sample increased. It was found that more circumferential length reduction is induced to the deformed strip in the fin pass stands. In other works [11, 12], the effective parameters on ovality were investigated in the pre-notched strips in cold roll forming process. The results demonstrated that the forming angle increment has the most influence on the hole ovality. Artificial neural network was used by Moslemi Naeini et al. [3, 13] for prediction of the required torque and estimation of spring back in the cold roll forming process. Slide rail samples produced in the roll forming process were examined by Naksoo Kim et al. [14] and according to the effective parameters in this process, the cost function was obtained using design of experiments (DOE) and response surface method (RSM). By investigating the effect of forming parameters on the defects of the process, it was found that increasing the angle of bending causes the increase of bow defect and the maximum longitudinal strain at the edge of the channel increases with increasing the angle of bending and thickness strips [15]. Mohd Saffe [16] studied the residual stress that occurs in hot steel channel roll forming. The effect of residual stresses in the roll forming process has been examined by Abvabi [17]. The results showed that prediction of defects such as spring back in the process by the tensile test data is not enough if a residual stress profile exists in the material. The robust optimization was used by Paralikas [18] in cold roll forming to demonstrate the effect of process parameters on the energy efficiency. Due to non-uniform transversal distribution of strains in cross section, defects such as twisting and longitudinal bow will occur. The edge buckling is caused by large longitudinal strain and this phenomenon is intensified with increasing difference between the longitudinal strain at the edges and the center of strip [5, 10, 19].

As it has been mentioned in the previous studies, the effect of the roll forming process parameters on the process performance has been investigated. Strains distribution situation has a substantial influence on the defects of the roll forming process. However, optimization of the process parameters for improving the strain distribution has not been reported yet. In this study, roll forming process for round cross section (tube) was simulated. Then, by using the central composite design (CCD), some experiments were designed for three factors including the roll diameter, the distance between the stations, and the linear speed of the sheet. Next, by using the RSM and FEM, strain distribution functions were modeled and the effect of the parameters was investigated. Finally, the effect of the parameters on the strain distribution was optimized using the DFA and overlaid contour plots.

2- Finite Element Modelling

The more recent application of the finite element methods has the advantage of determining the deformed surface and the strain distribution simultaneously, and undoubtedly far more work can be anticipated in this direction [1]. Round cross section roll forming process is simulated by commercially available finite element software ABAQUS/Explicit 6.11. Considering that the sample product has a symmetric plane, to reduce the analysis time, just half of the section was modeled. The model includes a pair of cylindrical rolls zero station, five pairs of rolls and four guide roll in main stations, as shown in Fig. **1**. Considering the coulomb model, friction coefficient is considered as constant μ=0.2 [7]. In this work, the rolls are modeled as rigid body because they have negligible deformation. The strip is considered as deformable and meshed using four node thin shell elements (S4R). The strip material used in this study was steel and its chemical composition is given in Table 1. Mechanical behavior of the material used in the simulation was obtained using ISIRI 10272 standard tensile tests (See Table 2 for mechanical properties of the material). True stress-strain curve is shown in Fig. **2**.

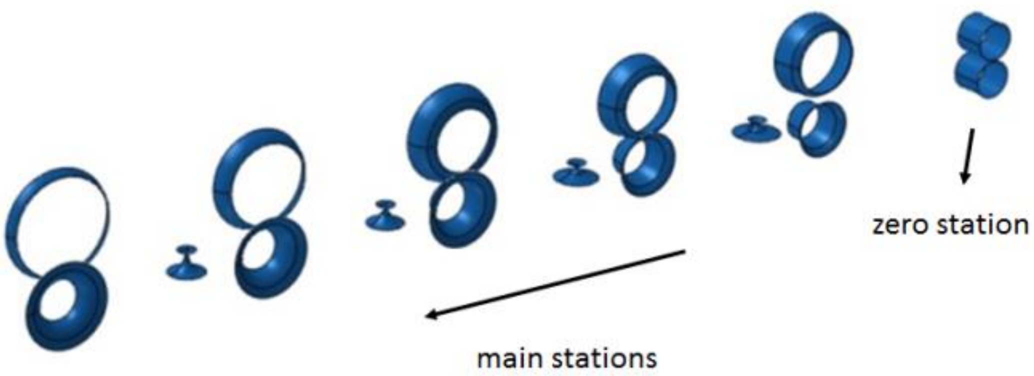

Fig. 1. Finite element modelling of the roll forming process.

Table 1. Chemical composition of sheet metal.

Fe%	Mn%	C%	Si%	Cu%	Al%	Nb%	W%	Cr%	B%	Mo%	Ni%
<98.460	0.660	0.240	0.270	0.053	0.036	0.043	0.024	0.046	0.048	0.005	0.02

Table 2. Average mechanical properties of sheet steel from tensile test.

Young's Modulus(N/mm2)	YS(N/mm2)	UTS(N/mm2)	Elongation (%)
191000	458.33	524.44	14

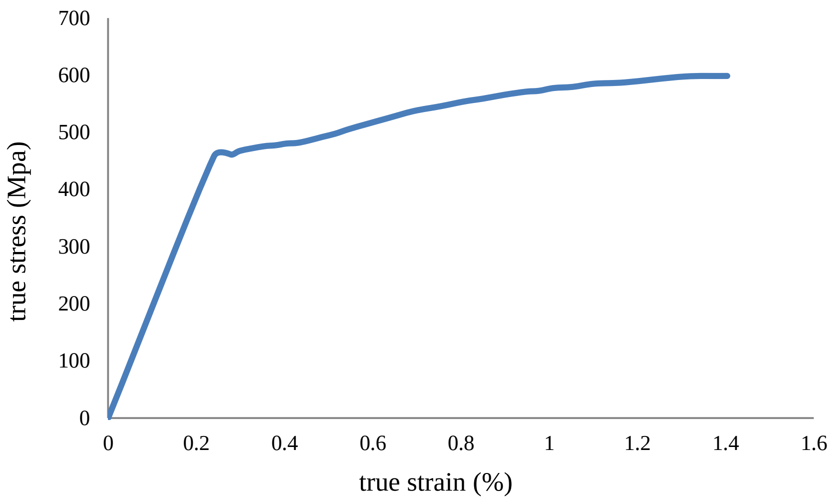

Fig. 2. True stress-strain curve of the material.

In Fig. 3, the strain imposed during the process in the two areas of edges and the floor sheet is visible. As can be ssen, plastic strain values at the edge of the sheet are higher than at the floor sheet.

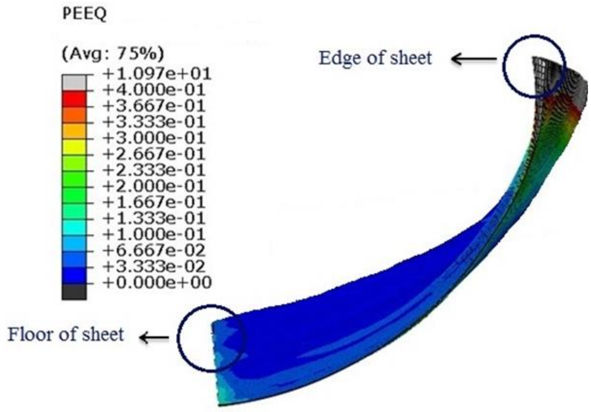

Fig. 3. Plastic strain in edge and floor of the sheet.

3- Response Surface Methodology and Desirability Function

3-1- Response Surface Methodology

Response surface method (RSM) is a procedure for modeling and analyzing problems that respond influence of several factors. This method is used for optimization of response by using the mathematical and statistical techniques. Box and Wilson introduced RSM in 1951 which was then developed by Montgomery and Myers [2]. In many cases, a second-degree polynomial model is used in RSM. This model is only an approximation, but because of its flexibility, it is widely used in the engineering problems [2]. This model is expressed as:

$$y = \beta_0 + \sum_{i=1}^{k}(\beta_i x_i) + \sum_{i=1}^{k}(\beta_{ii} x_i^2) + \sum_i \sum_j \left(\beta_{ij} x_i x_j\right) + \varepsilon \quad (1)$$

Where y is the response, β0 , βi , βii , βij are unknown constant coefficients and xi and xj, denote the independent design variables, k is the number of the independent variables, and ε is the statistical error. The coefficients of the model equation are obtained using the regression methods. The regression model in matrix form is as follows:

$$Y = X\beta + \varepsilon$$

$$\begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ . \\ y_n \end{bmatrix} = \begin{bmatrix} 1 & x_{11} & x_{12} & . & . & . & x_{1k} \\ 1 & x_{21} & x_{22} & . & . & . & x_{2k} \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ 1 & x_{n1} & x_{n2} & . & . & . & x_{nk} \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ . \\ . \\ . \\ \beta_k \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ . \\ . \\ . \\ \varepsilon_n \end{bmatrix} \quad (2)$$

The unknown values of β are obtained by solving the system of equations as follows:

$$\beta = (X^T X)^{-1} XY \quad (3)$$

3-2- The Desirability Function Approach

Optimization methods are important in practice, especially in engineering design, experimental test, and trading decisions [2]. Desirability 2
function is one of the multi-objective optimization methods used in this study. To optimize by using the desirability function, firstly, the individual desirability degree for each response should be calculated. If the aim is to minimize a response, the individual desirability is calculated using Equation (4). Also, Equation (5) is used for maximizing the response.

$$d_i = \begin{cases} 0 & y_i > U_i \\ \left[\frac{(U_i - y_i)}{(U_i - T_i)}\right]^{r_i} & T_i \le y_i \le U_i \\ 1 & y_i < T_i \end{cases} \quad (4)$$

$$d_i = \begin{cases} 0 & y_i < L_i \\ \left[\frac{(y_i - L_i)}{(T_i - L_i)}\right]^{r_i} & L_i \le y_i \le T_i \\ 1 & y_i > T_i \end{cases} \quad (5)$$

In the Equations (4) and (5), di is the individual desirability degree, yi is the predicted value, Ti is the target value, Ui is the maximum acceptable value, Li is the minimum acceptable value, and ri is the weight of desirability function for the its response. Then, composite desirability is obtained using Eq. 6.

$$D = \left(\prod (d_i^{w_i})\right)^{\frac{1}{W}} \quad (6)$$

Where D is the composite desirability degree, wi and W are the importance of its response and overall weight, respectively.

4- Designing and Performing the Experiments

Central composite design (CCD) was used for design of experiments by Minitab software [2]. In the present work, three factors of the cold roll forming process that are effective and controllable in the experiments were considered as input parameters. These factors include the roll diameter (D), the distance between the stations (L), and the line speed of the sheet (V). The maximum and minimum magnitudes of the input parameters are shown in

Table **3**. Based on CCD, five levels of the parameters are specified that are given in Table **4**. Design of the experiments using the CCD is shown in Table **5**.

Table 3. Maximum and minimum magnitude of the input parameters in CCD.

parameter	minimum	Maximum
Roll diameter(mm)	55	90
Distance of station(mm)	530	600
Line speed(m/mm)	30	35

Table 4. Levels of parameters.

Parameter		Level				
		1	2	3	4	5
Roll diameter (mm)	D	43	55	72.5	90	102
Distance of station (mm)	L	506	530	565	600	623
Line speed (m/mm)	V	28.2	30	32.5	35	37

Table 5. Design of experiments.

Exp. No	1	2	3	4	5	6	7	8	9	10
D	55	90	55	90	55	90	55	90	43	102
L	530	530	530	530	600	600	600	600	565	565
V	30	30	35	35	30	30	35	35	32.5	32.5
Exp. No	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
D	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5
L	565	565	506	624	565	565	565	565	565	565
V	28.3	37	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5

Quality of roll forming products is affected by the amount and situation of the strains distribution. So, it is required to study two parameters of the strain. One of them, plastic maximum strain, is imposed on the edge of the sheet that is called maximum longitudinal strain (M.L.S) and causes the edge buckling. Edge buckling which appears as a wave at the strip edge is a defect in the cold roll forming process that is shown in Fig. **4**. It is a big problem for obtaining a product with expected quality; therefore, prevention of edge buckling is very important during the forming process [19]. The reasons of longitudinal compression at the edge in the cold roll forming have been reported in several literatures [24, 25, 26]. In this work, in order to extract maximum longitudinal strain, we defined an element within 73 mm center of the strip and at each station maximum plastic strains are elicited and then the sum of five stations will be calculated eventually and investigated as M.L.S.

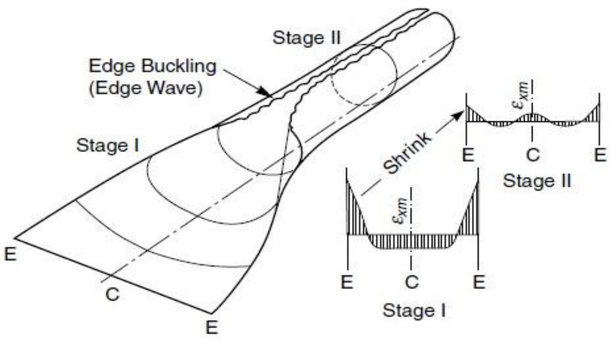

Fig. 4. Schematic illustration of edge buckling takes place during roll forming [19].

Strain distribution uniformity (S.D.U) across the product is another parameter that was studied. Because of longitudinal bow, camber and twist are the most frequent defects in narrow roll formed products. As shown in Fig. 5, longitudinal bows are caused by non-uniformity of transversal elongation and shrinkage of the strip. However, these defects can be reduced by using proper conditions [19]. S.D.U in the cross section for each of the simulated samples is given by:

$$\psi = \frac{\sum_{i=1}^{n}(|\bar{\varepsilon}-\varepsilon_i|)}{n} \quad (7)$$

where $\bar{\varepsilon}$ is avarege of strains, ε_i is the strain at each point, and n is the number of points.

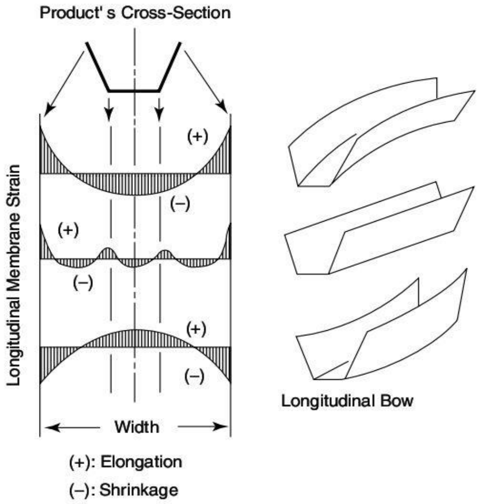

Fig. 5. Relation between transversal distribution of strain and longitudinal bow [19].

Therefore, the effects of three factors as input parameters were studied on the M.L.S and S.D.U across the product as response functions. Each of the experiments according to the design of experiments was simulated in ABAQUS/Explicit 6.11 software. Then, M.L.S and S.D.U outputs were obtained, as shown in Table **6**.

5- Results and Discussion

This study seeks to examine and optimize the factors effect on the quality of the product. To achieve this aim, design of experiments using CCD with three factors including the diameter of the rolls, the distance between the stations and the linear velocity of the sheet was performed in 20 modes. Then, process simulation according to each of the experiments condition was done. Sum of M.L.S and transversal S.D.U for each of the experiments was calculated and the results were extracted.

5-1- Maximum Longitudinal Strain (M.L.S)

5-1-1- Response Function Model

By using response surface method (RSM), responses function for sum of M.L.S was obtained as follows:

$$\mathrm{M.L.}S = -0.0264861 + 0.0016873\mathrm{D} + 0.0141349\mathrm{V} - 6.683 * 10^{-4}\mathrm{L} - 4.0227210^{-6}\mathrm{D}^2 - 2.174 * 10^{-4}\mathrm{V}^2 + 5.59724 * 10^{-7}\mathrm{L}^2 - 5.03429 * 10^{-6}\mathrm{DV} - 1.89551 * 10^{-6}\mathrm{DL} + 1.2657 * 10^{-6}\mathrm{VL} \quad (7)$$

Where D is the diameter roll, V is the Line speed of the sheet and L is the distance between stations. Also, the model adequacy was achieved as R2=96% for sum of M.L.S, which are acceptable values for this response. Analysis of variance (ANOVA) was used by the statistic P-Value for determining the influence of factors on the responses. The P-Value represents the type first error that is occurring. If the P-Value is less than 0.05, it indicates that the parameter has a significant effect on the response. Table 7 illustrates the P-Value for sum of M.L.S. According to the results of ANOVA, for M.L.S, terms in linear and Line speed in square state are effectively in the regression model.

Table 6. The obtained values of M.L.S and S.D.U.

Exp. No	1	2	3	4	5	6	7	8	9	10
Sum of M.L.S($\times 10^{-3}$)	41.532	40.244	43.375	42.863	33.557	29.282	37.500	30.687	41.247	30.354
S.U.D($\times 10^{-3}$)	6.3128	6.5742	6.5874	6.8198	6.7546	6.3976	6.7275	6.4167	6.4864	6.1915
Exp. No	11	12	13	14	15	16	17	18	19	20
Sum of M.L.S($\times 10^{-3}$)	34.760	36.124	52.407	30.388	39.285	39.285	39.285	39.285	39.285	39.285
S.U.D($\times 10^{-3}$)	6.5116	6.2566	5.8713	6.6070	6.2452	6.2452	6.2452	6.2452	6.2452	6.2452

Table 7. ANOVA for M.L.S.

Source	Degree of Freedom	F	P
Regression	9	27.36	0.000
Linear	3	54.50	0.000
Roll Diameter	1	46.08	0.000
Distance of Station	1	110.49	0.000
Line Speed	1	6.93	0.030
Square	3	7.15	0.012
Roll Diameter*Roll Diameter	1	11.77	0.315
Distance of Station*Distance of Station	1	1.15	0.109
Line Speed*Line Speed	1	14.31	0.005
Interaction	3	2.43	0.141
Roll Diameter*Distance of Station	1	6.97	0.030
Roll Diameter*Line Speed	1	0.25	0.630
Distance of Station*Line Speed	1	0.06	0.808
Residual Error	10	*	*
Total	19		

5-1-2- Response Surfaces for M.L.S

Error! Reference source not found., Fig. **7** and Fig. **8** show the surfaces obtained for sum of M.L.S. The result of response surface diagrams explicitly indicated that the roll diameter and distance between stations have a significant effect on the M.L.S. But the effect of linear speed is less than the other two factors. It is worth considering that by increasing the linear speed of the sheet the sum of M.L.S increases.

For roll diameter and the distance of stations parameters (constant linear speed of sheet), Fig. 6 shows that sum of M.L.S decreases with increasing the distance of stations as it was reported previously [15] and the effect of roll diameter has a peak value (about 70mm of roll diameter size). Also, the effect of roll diameter is more with increasing the distance of stations. On the whole, the effect of distance between stations is greater than the diameter of the roll in sum of M.L.S.

Fig. 7 shows that with increasing the distance of the station sum of M.L.S is reduced and at all levels of distance of stations the effect of the linear speed is almost uniform. Ineffective linear speed parameter on the longitudinal strain has been reported before [15].

By reducing the roll diameter, the sum of M.L.S increases and in a median value of linear speed (33.5) it reaches its maximum as shown in Fig. 8.

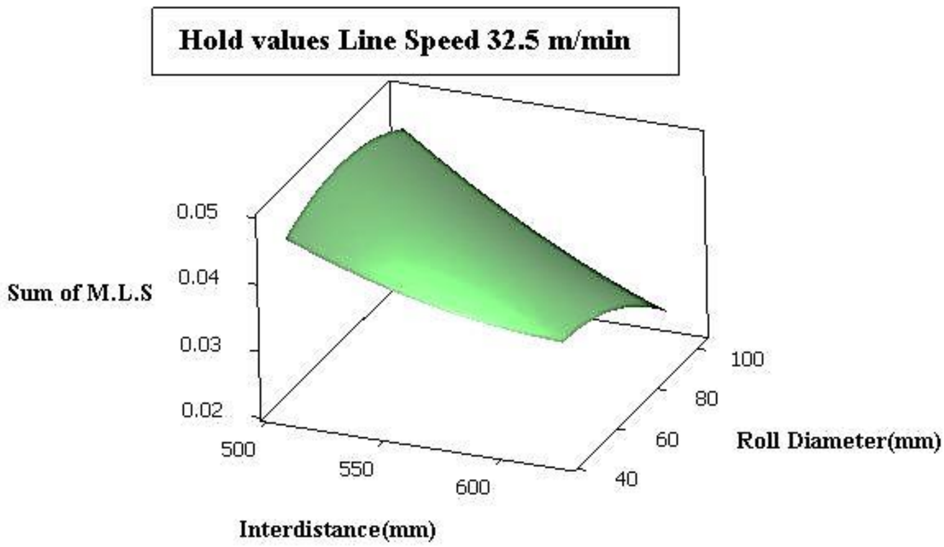

Fig. 6. Surface plot sum of M.L.S on the Interdistances and Roll diameter.

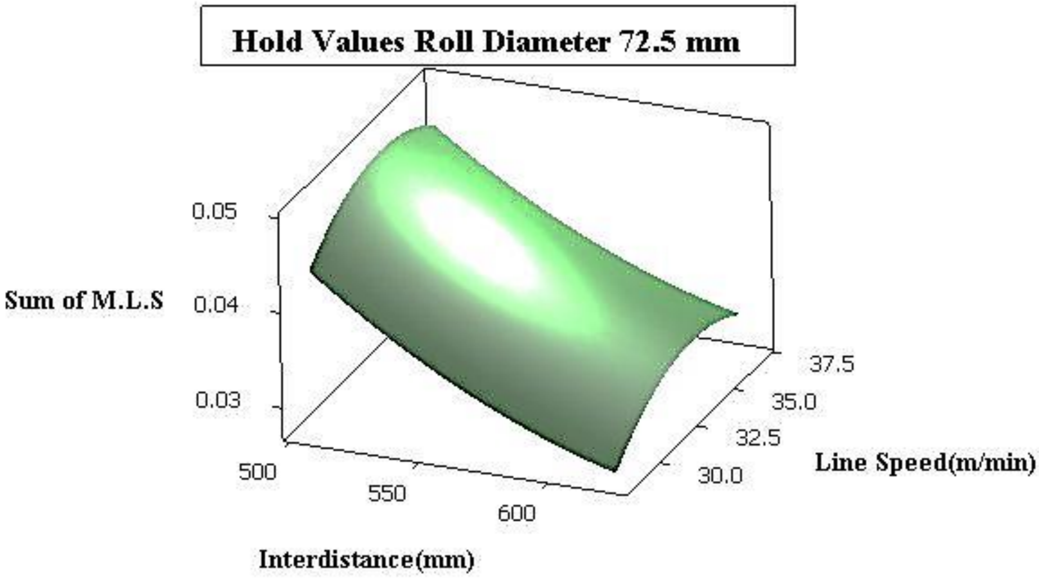

Fig. 7. Surface plot sum of M.L.S on the Interdistance and Line speed.

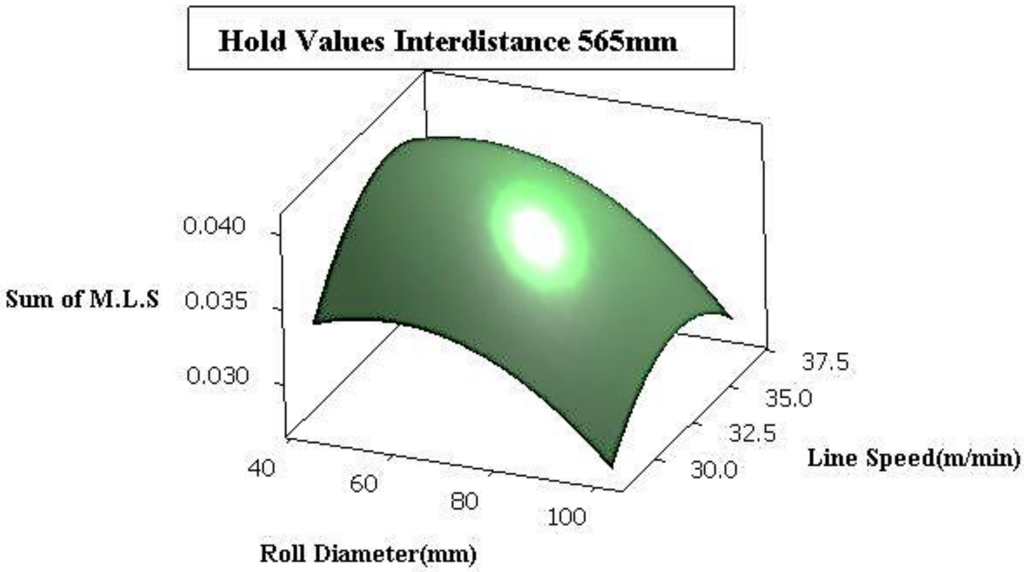

Fig. 8. Surface plot sum of M.L.S on the Roll diameter and Line speed.

5-2- Strain Distribution Uniformity (S.D.U)

5-2-1- Response Function Model

Same as before using RSM, response function for S.D.U was obtained as follows:

$$\mathrm{S.D.U} = 0.0434 + 0.000109\mathrm{D} - 0.00104\mathrm{V} - 8.6 * 10^{-5}\mathrm{L} + 1.2 * 10^{-7}\mathrm{D}^2 + 2.2 * 10^{-5}\mathrm{V}^2 + 1.08 * 10^{-7}\mathrm{L}^2 - 2.1 * 10^{-7}\mathrm{DV} - 2.1 * 10^{-7}\mathrm{DL} - 6.2 * 10^{-7}\mathrm{VL} \quad (8)$$

Where D is the diameter roll, V is Line speed of the sheet and L is the distance between stations. In this case, the model adequacy was achieved as R2 =97.11% for S.D.U which are acceptable values for this response.

Table **8** illustrates the P-Value for S.D.U. According to the results of ANOVA for S.D.U, all of the terms are effective in the regression model.

Table 8. ANOVA for S.D.U.

Source	Degree of Freedom	F	P
Regression	9	26.11	0.000
Linear	3	10.46	0.006
Roll Diameter	1	13.17	0.008
Distance of Station	1	0.09	0.772
Line Speed	1	7.41	0.030
Square	3	39.74	0.000
Roll Diameter*Roll Diameter	1	8.86	0.023
Distance of Station*Distance of Station	1	49.13	0.000
Line Speed*Line Speed	1	52.50	0.000
Interaction	3	16.00	0.002
Roll Diameter*Distance of Station	1	36.78	0.001
Roll Diameter*Line Speed	1	0.18	0.685
Distance of Station*Line Speed	1	6.12	0.043
Residual Error	10	*	*
Total	19		

5-2-2- Response Surfaces for S.D.U

Fig. 9, Fig. **10** and Fig. **11** show the respond surfaces for S.D.U. According to the results it can be generally said that roll diameter has the greatest influence on the response, which seems reasonable due to the types of process and deform areas between dies. After that, the linear speed of sheet is the most effective but the distance between stations is ineffective.

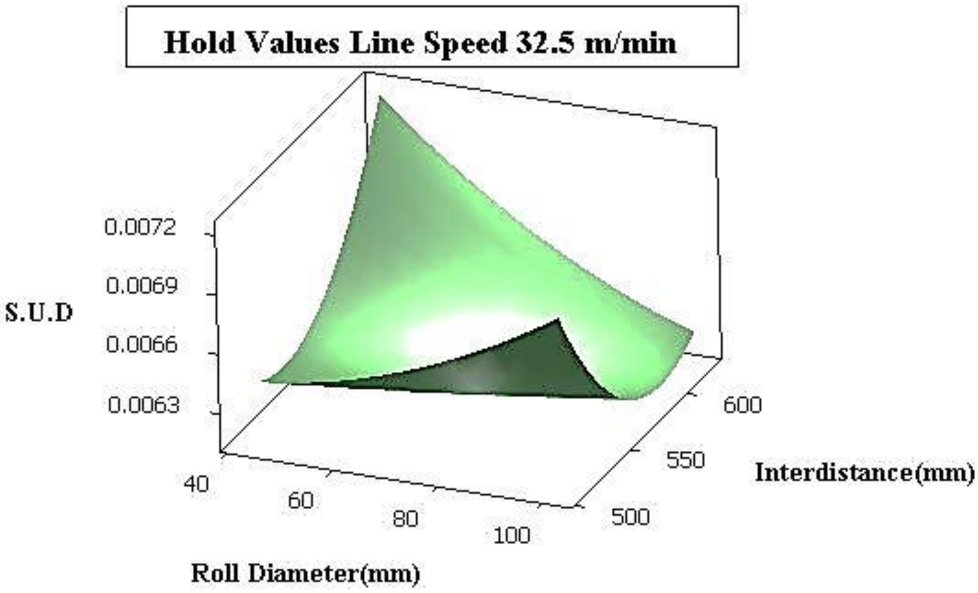

Fig. 9. Surface plot of S.D.U vs the Interdistance and Roll diameter.

The obtained diagram also shows the interaction between the two parameters in Fig 9, so that in smaller amounts for roll diameter, S.D.U amount should increase with increasing the distance between stations while in the large roll diameter this trend is reversed. Therefore, the maximum of S.D.U will be created in the minimum roll diameter and the maximum of distant of stations or in the maximum roll diameter and the minimum distance of the stations.

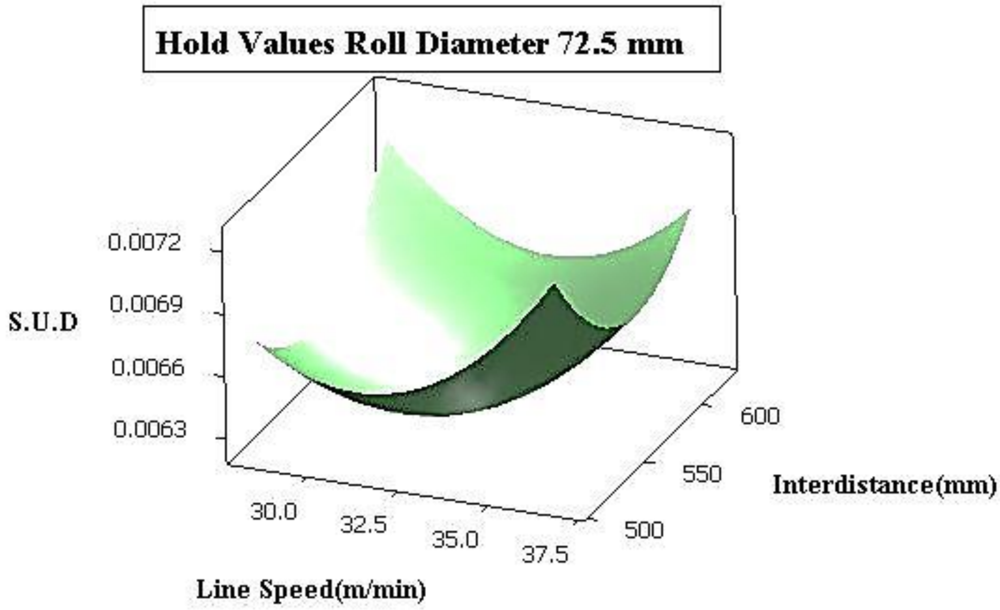

Fig. 10. Surface plot of S.D.U vs. the Interdistance and Line speed.

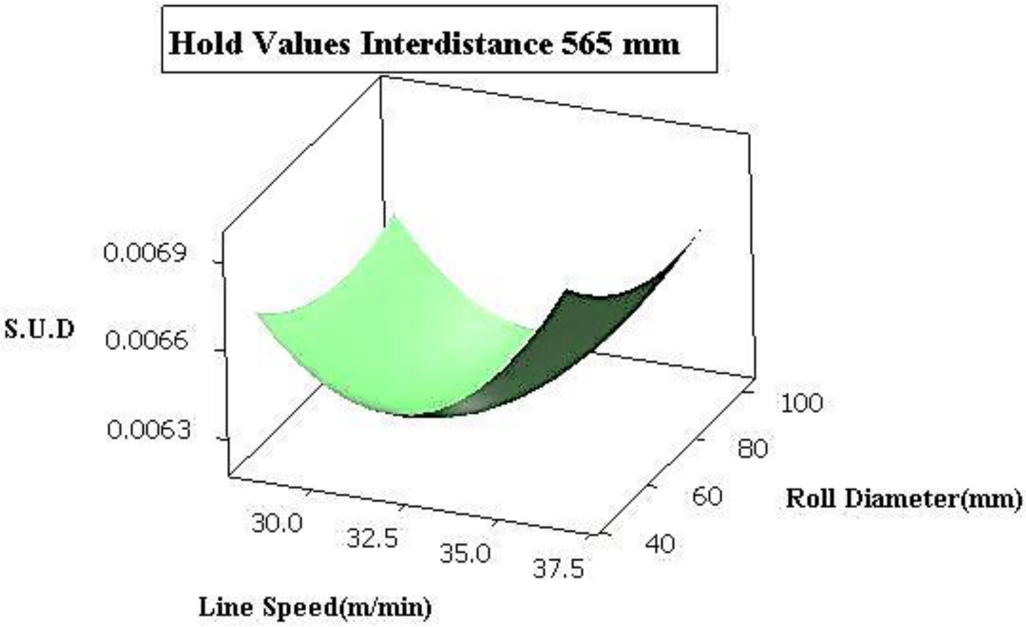

Fig. 11. Surface plot of S.D.U vs. the Line speed and Roll diameter.

Fig. 10 shows that S.D.U that is influenced by two parameters has a quite similar trend, so that for both parameters the lowest S.D.U is achieved in the middle distance of the station and linear speed.
The graph of Fig. 11 shows that the parameters do not have much interaction as mentioned earlier in the ANOVA table. So that the S.D.U changes for linear speed has the same procedure at all levels of roll diameter.

5-3- Optimization

In this section, optimum values of parameters were investigated in various conditions of the process. First, using the desirability function a point was found as the optimal point and then optimal areas were determined using contour curves around the optimal point for each parameter.

5-3-1- Optimization by Desirability Function

Desirability function as optimization method is based on turning the multi-objective problem to a single objective firstly and then proceeds to the optimization problem. Initially, individual desirability was found for every response and then they were combined to optimize the whole problem. In this study, we have two responses to various situations. One of them is sum of M.L.S that should be the minimum. The lower this value, less defect occurs and the higher the product quality. The best mode is when the value is zero, but in terms of theory and experiment it is not allowed. Another transverse is S.D.U that there must be minimum values for this response. In this case, too, more uniform transverse strain distribution causes less camber and twist defects and higher product quality. The ideal amount for this response is zero, but the type of roll design which consists of two arches proves that this is not experimentally possible.

To obtain the optimal point considering limitation of production and testing results, the amount of 30 is selected for sum of M.L.S and for S.D.U the smallest amounts were extracted from experiments, and 0.006 was chosen. Also, by assigning priority to responses, it was considered that sum of M.L.S is five times more important than S.D.U. The results extracted from Minitab software areshown in Fig. 12.

Desirability is calculated based on the input equal to 0.937. As explained earlier, the closer this value to 1 the better. Optimal amounts of factors are shown in Table 9.

Given the results, it should be investigated to what extent these results are efficient in terms of production. According to the process, the roll is constructed with a certain diameter and during the process it is changed due to the abrasion of the roll section. So, its diameter will be smaller when repair is turning again. In addition, the limits of disk length and the rate of product at the time are the points that should be considered. Therefore, the optimal point cannot fully answer for the production process and only those points can be used to design and start the process. Therefore, having the optimal area for factors seems to be vital.

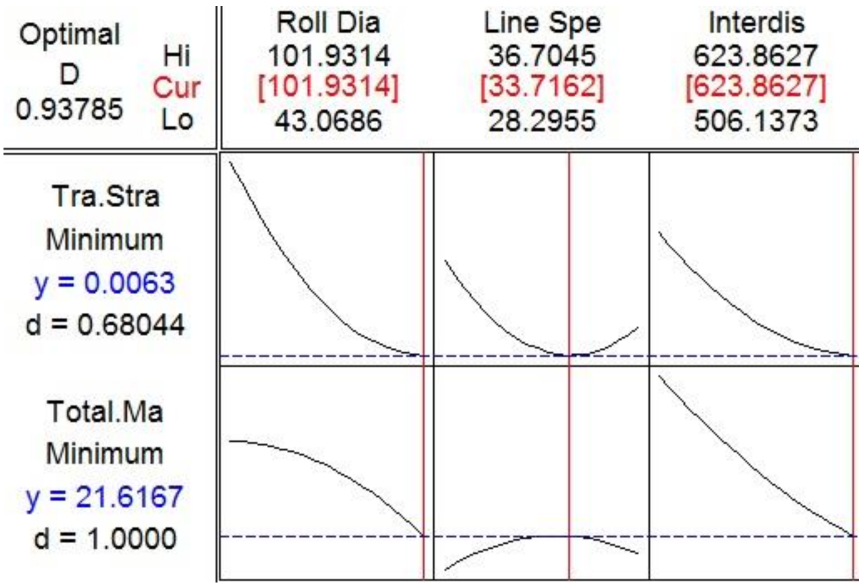

Fig. 12. Optimal values for responses by desirability function.

Table 9. Optimal values obtained using desirability function.

Parameter	Roll diameter (mm)	Interdistance (mm)	Line speed (m/min)
Optimum value	101.93	623.86	33.71

5-3-2- Optimization by Overlaid Contour Plots

As explained in the previous section, overlaid contour plots determine the optimal area and unlike optimization by desirability function, optimal area is specified in the diagrams. Overlaid contour plot indicate the optimal area of each of the two factors assuming that the other factor is constant. This area contains all of the optimized answers for pair factors. In the overlaid contour plot method, the upper and lower values for each response are considered to be two factors was selected and other factors are constant. With drawing curve was indicated each response is the minimum and maximum in which points of factors. The region in which all of the response lines are overlapping is the optimum area and this region is identified by the white color in plot. Fig. 13 illustrates the overlaid contour plots for the constant line speed in three modes of minimum, moderate and maximum values by changing the roll diameter and the distance between the stations. For the sum of M.L.S and S.D.U the acceptable area is determined which may change depending on conditions.

The overlaid contour plots outlining for the constant distance of stations in three modes of minimum, moderate and maximum by changing the roll diameter and line speed are shown in Fig. 14. By modifying the maximum and minimum values in responses the width and extent of optimal area can be larger or smaller.

Also, Fig. 15 demonstrates the overlaid contour plot performance for the case where the roll diameter in one of three modes of minimum, middle and maximum is kept constant and the distance between stations and the speed line changes.

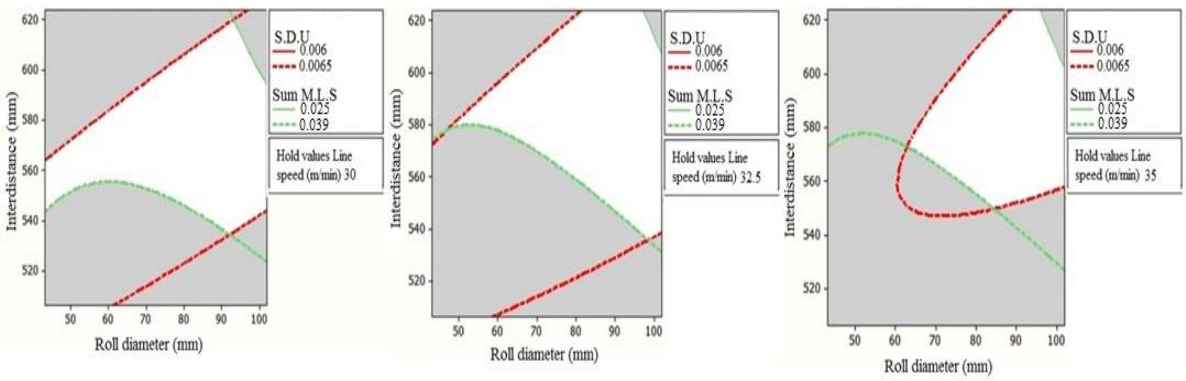

Fig. 13. Overlaid contour plot of S.D.U and sum of M.L.S for roll diameter and interdistance in three modes of line speed.

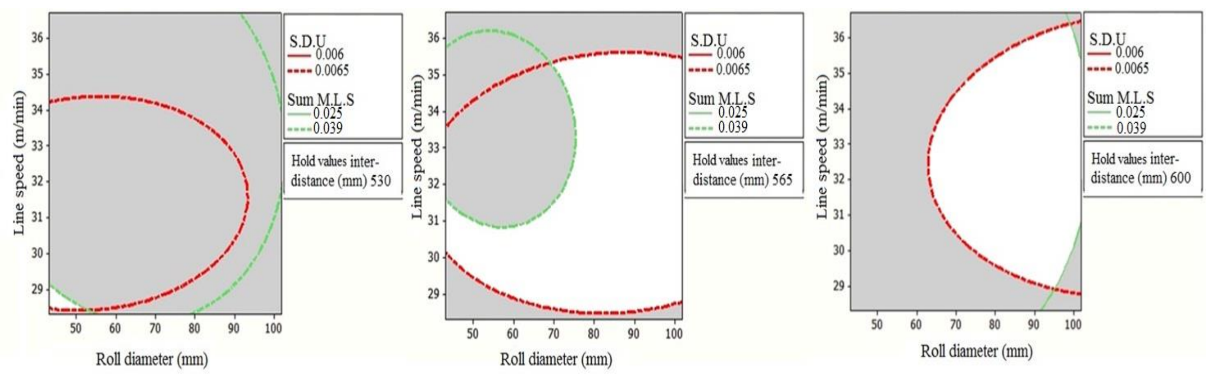

Fig. 14. Overlaid contour plot of S.D.U and sum of M.L.S for roll diameter, line speed in three modes of the distance of stations.

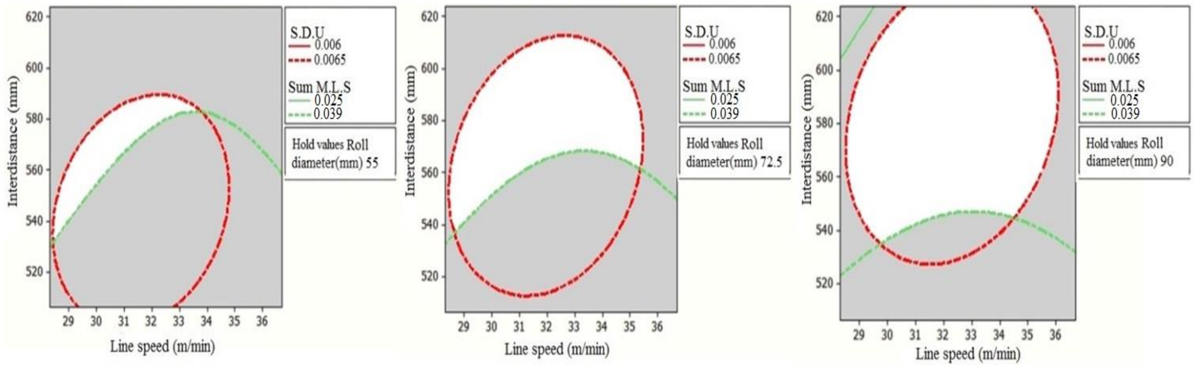

Fig. 15. Overlaid contour plot of S.D.U and sum of M.L.S for distance of stations, line speed in three modes of the roll diameter.

6- Conclusion

In the present study, the affective factors on the quality of the product in cold roll forming process for round cross section were investigated by simulating the finite element method. For this purpose, three factors the roll diameter, the distance between the stations and the line speed of sheet as input parameters and sum of longitudinal maximum strain and transverse strain distribution uniformity were studied as responses functions. By performing the designed experiments by CCD method the results were elicited and response surface for each function was obtained. Finally, using overlaid contour plots and desirability function the optimization of response was done. The results obtained by using the desirability function were presented as points, which according to the type of process and production requirements can only be used for preliminary design. But the overlaid contour plots flexibility in output for manufacturing processes. Output overlaid contour plots provide optimum area so that in different conditions there is a wide range of values to choose from.

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