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Research Article

Optimization of Stamping Process Parameters

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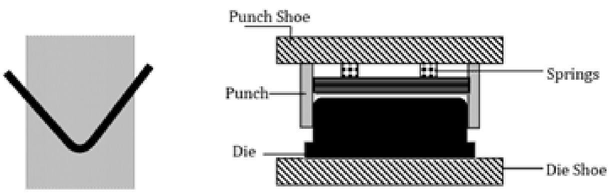
Abstract:

Stamping is one of the significant sheet metal forming process which is used for producing components especially in automobile industry. Sheet metal flow into the die cavity occurs the applied force in stamping process. While the extreme compressive stresses of sheet metal end up with wall thickening, tensile stresses lead of thinning problems in the wall zone of the part. The excessive thinning may cause crack formation or fracture of the metal sheet. This faulty process design eventually produces non-conforming products. In order to have successful design of stamping process, designing of tooling and identification of the optimum level of the process parameters are needed. In this regard, the present paper is an attempt to set the stamping process parameters for minimum thinning of blank and optimal results by a stochastic search method (modified Differential Evolution) based on multiple nonlinear regression analysis. The results have been compared with the results those of the previous study. It is shown that the current results show that the present optimization study is successful as further increase the thickness.

1. Introduction

The stamping process is a process in which variety of sheet metal forming production processes, such as; punching, drawing, bending, flanging, coining and embossing are performed by using machine presses or stamping presses. The process is generally carried out the sheet metals as well as other materials such as polystyrene.



(a) Bending using matched (b) Wipe Forming punch and die set

Figure 1. *a) Bending using matched punch and die set [2] b) Wipe forming [2]*

Stamping can be done in a single mold station or in multiple mold stations with the help of progressive dies. When the workpiece has a bending angle greater than 90 ° or the part contains intermittent properties, progressive dies are generally used [1].
As showing in figure 1. bending using matched punch and die set (in a) and wipe forming (in b) [2]. During the design of prosperous sheet metal forming process, it is need of real experiments to reach a successful prod.uct as well as expensive and time-consuming prototype tests [3].

One of the significant step of stamping is the drawing processing. In the drawing, the plate holder is formed against the mold with the help of the upper die of punch, while the blank holder is applied to the mold by a foregone force in order to check the material flow. In the drawn part, usually the team experiment stage, forming errors which are wrinkling, thinning and fracture of the material are monitored [4,5]. The Finite Element Method

(FEM) is comprehensively put to use for simulation of sheet metal forming to remove unwanted forming defects, and to anticipate blank stresses for prevent failures [6,7]. The parameters which are related to the blank geometry, work material, die and presses are some of the important parameters that influence the process. Also the other significant process prameters are punch radius, die radius, blank holder force, draw tonnage, binder stroke, drawbead hight and contect coefficient of friction.

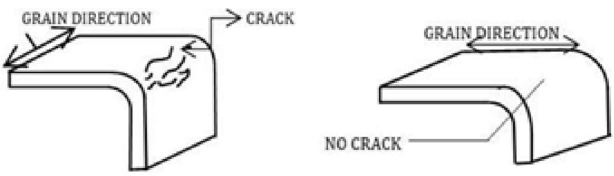


Figure 2. *Example of Forming Error, Cracking [8]*

An example of Forming Error, Cracking is shown in figüre 2 [8]. It is quite hard to determine the process parameter effects on the quality of final product. For the better efficiency of the process, the parameters must set at an optimum level [9]. The traditional method of determination the optimum level of the process parameter is expensive and time consuming. It seriously depends on the trial and error, expertise, and skill of workers. The improper setting of the parameters can cause to manufacturing of faulty products. So the primary purpose of stamping process designers is designing manufacture forming tools and setting process parameter for the production of flawless products within the required surface quality and desired dimensional tolerances. In the present study, it is aimed to create an 'Objective Function' that expresses the relation between predictor parameters and response of stamping process by using the FEM simulation results from the reference article [10]. Optimization works at this stage and enables to find the conditions where the process parameters are optimum level.

1.1. Process parameters

The process parameters which is also called as 'Desing Variables'of the stamping process are given in the Table 1.

DR. Die Radius

The radius of die is the one of the parameters that influences drawing operations using the flat blank holder. When the die radius set too bit, there is

Table 1. *Process Prameters of Stamping Process [10].*

Nomenclature
DR Die radius (mm)
PR Punch radius (mm)
DT Draw tonnage (Ton)
BH Blank holder force (Ton)
BS Binder stroke (mm)
CCF Contact coefficient of friction
DH Drawbead height (mm)

chance of split of material owing to the excessive limiting force which are caused by the sheet's bending and unbending around a small radius. Besides, these bending and unbending generate heat in high quantity throughout the operation. Nevertheless, wrinkling of blank occurs due to a large die radius [10,11].

PR. Punch Radius

Pressure is practiced by using a punch standing on the blank results in deformation in sheet metal forming. For material behaviour, the punch radius is an important influence, the tiny radius punch leads to shearing of the sheet metal between the die and punch, while the excessive radius causes streching of the sheet throughout the radius. The proper punch selection is affected by material properties and thickness of a blank [10,12,13,14].

DT. Draw Tonnage

DT is the required force for the blank's deformation in the desired form. The too many variations in present DR might cause the faults. It can be given examples for faults such as compressive stresses development in the blank and unfinished deformation of the blank [10].

BHF. Blank Holder Force

Inadequate material flow into the die causes stretching and ultimately causes blank's tearing. In contrast, the excessive flow results in blank's wrinkling. Thus, the optimal setting of blank holder force might prevent the occurrence of wrinkling and tearing in the installed part. The fundamental blank holder force characteristically is applied by the press cushion system. Blank holder force checks the material flow in the die and significant impact on quality of the product. Higher BHF reduces wrinkling in deep drawn products. However, it is common practice (maybe, it might be application to calculate the minimum required BHF [10,15,17].

BS. Binder Stroke

In forming operations of the sheet metal, the circumferential compressive force is exerted by a punch on blank force the blank in the die cavity, whereas the blank put up resistance to flow. The blank's quite high resistance to flow might cause crack of the cup. The blank's thinning and stretching are also affected by the distance between post and blank edge. When the post is properly set from the blank edge, and the die's inlet radius is properly placed, the metal enters into the die as gradually and freely flow in the cavity. Binder stroke is accommodately locked by using shoulder bolts or spool keepers [10].

CCF. Contact Coefficient Friction

Contact coefficient friction has crucial influence on the quality of surface of the product. The static friction between the blank and tool affects draw ability of sheet metal. The existence of decent lubricating film between the contact areas is crucial for getting more effective stamping process qua strain distribution in the vacancy is influenced by contact friction. Also the contact friction makes contribution to the blank wear and tool. The more stable strain distribution is possible when the large value of full film lubrication regions applied. The largest contact area ratio is happened when the surface roughness of blank and mold contacts, and it will couses the larger frictional stress values. Friction which have lower value cause a more stable radial strain distribution [10,12,18].

DH. Drawbead Height

The draw bead and blank holder provide the restrictive force which is required for controling the material flow. The minor groove on the binder surface/die surface, which is called the draw bead, matched together by a protrusion on the die or binder surface. After the binder with closure, the sheet metal is drawn above the drawbead [10,19].

2. Methods

2.1. Optimization

Optimization can be defined as making something the best as much as possible by using of any available resources. With optimization by using the mathematical function, results can be maximized or minimized with respect to the desired situation, by changing with specific parameters. To make optimization studies which is related to a subject, firstly we should have certain data set composed of parameters which is called as design variables. After that with respect to regression analysis type the mathematical model which is called as 'Objective Funtion' of the problem must be defined. After that the objective function can be minimized or maximized by optimization [20].

2.2. Regression

The definition of regression analysis can be described as forming approximative modelling technique that examines relationships between independent and dependent variables. This technique is used for estimating, finding and modelling the causative effects to the relationships between the variables. In the analyzing and modelling data, regression analysis is crucial technique. There are also several advantages of this technique. Such as:

- Important relationships between the dependent variables and independent variables can be indicated by regression.
- It enables to see the power of effects of several independent variables on a dependent variable.

Also, comparing the effects of variables, which made measurement on different scales, for instance, the effect of price changes and the number of promotional activities, are calculated by the regression analysis. These advantages offer service market researchers, data scientists or data analysts to evaluating and selecting the best set of variable to be used for setup successfull approximative models between the input and output variables [21].

There exist several kinds of useful regression methods in order to make a guess. In the main, these methods are seperated into three groups such as; number of independent variables, dependent variable types and regression line shape (See Fig. 3).

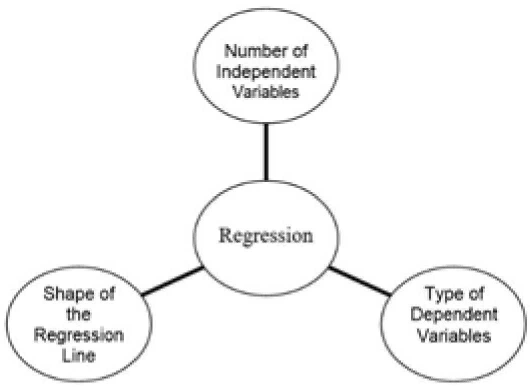


Figure 3. *Various kinds of regression techniques [21].*

The regression analysis may be linear/non-linear or may multiple/simple. These are the examples of regression techniques;

- Linear Regression
- Logistic Regression
- Polynomial Regression
- Stepwise Regression
- Lasso Regression
- ElasticNet Regression
- Ridge Regression

In the peresent study, multiple non-linear regression analysis was used and the mathematical model of the problem was formed as second order multiple polynomial function [21].

2.3. Wolfram Mathematica

In present study, the regression and optimization studies were performed by using
'Wolfram Mathematica' Software.

Mathematical operations with mathematics, equations, integrals, matrices, arrays, functions, vectors can be made with a few simple Wolfram Language commands. Wolfram Mathematica, with its features in mathematics, provides solutions in a very short time. Wolfram Mathematica includes the Wolfram Notebook file type, which has an .nb extension for you to do any kind of process or project, including mathematical operations. In this file type, you can write your commands int input cells and display the output of your codes in Out cells. The commands that used in the present study by using Mathematica, is introduced below [22].

2.3.1. FindFit

The general expression of FindFit command can be described as:
FindFit [data, expr, pars, vars]
This command finds out numerical values of design parameters which is represented as 'pars' that make 'expr' give best fit to 'data' as a function of 'vars'. The possible method choice include for the FindFit command, "ConjugateGradient", "Gradient", "LevenbergMarquardt", "Newton", "NMinimize", and "QuasiNewton", with the default being Automatic that was used in the present study [22].

2.3.2. NMinimize

The general expression of NMinimize command can be described as:
NMinimize [f, x∈ reg]
This command minimizes f function numerically with respect to x and constrains x to be in the region reg. The Method option in Mathematica for the NMinimize command include "NelderMead", "DifferentialEvolution", "SimulatedAnnealing", and "RandomSearch". The method was chosen as default being Automatic in the present study [22].

3. Problem Definition

The problem that concerned in this study is the thinning problem that occurs in stamping process. Thinning problem is caused when thickness variation in metal forming operation beyond the limit and it is the important fault of concern at the die tryout stage, while ideally the thickness of the stamped component is desired to remain unchanged. Thinning of the sheet at several critical sections or points might cause thinness of the wall and might cause cracking.

In the reference article, the data set consisting of 27 experiments were obtained from the experiments with FEM simulations by using Taguchi Orthogonal Array Method. In the present study, the data set that taken from the reference article was used. Simulation results for 27 experiments of Stamping process are given in Table 2.

Table 2. *Simulation Results for L27 Orthogonal Array Experiments [10].*

Run				Parameters				Thinning
	DR	PR	DT	BH	BS	CCF	DH	(%)
1	19.2	20	350	35	100	0.125	6	27.42
2	19.2	20	350	35	110	0.250	8	22.89
3	19.2	20	350	35	120	0.375	4	--
4	20.2	20	300	40	100	0.125	6	20.18
5	20.2	20	300	40	110	0.250	8	17.65
6	20.2	20	300	40	120	0.375	4	22.13
7	18.2	20	325	45	100	0.125	6	20.27
8	18.2	20	325	45	110	0.250	8	20.74
9	18.2	20	325	45	120	0.375	4	25.22
10	19.2	22	325	40	100	0.375	8	18.06
11	19.2	22	325	40	110	0.125	4	18.54
12	19.2	22	325	40	120	0.250	6	--
13	20.2	22	350	45	100	0.375	8	24.69
14	20.2	22	350	45	110	0.125	4	18.16
15	20.2	22	350	45	120	0.250	6	19.86
16	18.2	22	300	35	100	0.375	8	20.63
17	18.2	22	300	35	110	0.125	4	22.10
18	18.2	22	300	35	120	0.250	6	17.00
19	19.2	18	300	45	100	0.250	4	15.35
20	19.2	18	300	45	110	0.375	6	22.27
21	19.2	18	300	45	120	0.125	8	19.74
22	20.2	18	325	35	100	0.250	4	25.18
23	20.2	18	325	35	110	0.375	6	28.87
24	20.2	18	325	35	120	0.125	8	30.35
25	18.2	18	350	40	100	0.250	4	26.14
26	18.2	18	350	40	110	0.375	6	27.94
27	18.2	18	350	40	120	0.125	8	25.31

3.1. Mathematical Modelling

The modelling of the problem was made by using multiple non-linear regression analysis method on Wolfram Mathematica.

Firstly, the Design Variables were introduced to the program as ‘x1, x2, x3, x4, x5, x6, x7’ correspond to the ‘DR, PR, DT, BH, BS, CCF, DH’ respectively. The output variable which is Thinning was introduced as ‘ t’ and for the missing two output variables values were added as the mean value of the output values which is ‘21.68’. As 1st trial linear regression model had tried and the genaral expression of the function is;

$$y = a_0 + \sum^{n} a_i x_i \qquad (1)$$

The objective function with respect to linear regression model was defined as by using ‘FindFit’ command on Mathematica;

$$t = 26.3348 - 1.1525\, x1 + 0.0955556\, x2 - 0.319556\, x3 + 0.0799556\, x4 + 0.0162778\, x5 + 0.183889\, x6 + 3.71556\, x7 \qquad (2)$$

But the R^2 value in according to this model was determined as 0.563326 which showed that the model is not appropriate for the problem, thus as trial 2^{nd} order polinomial regression model had tried. The genaral expression of the function is;

$$y = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n} a_{ii} x_i^2 + \sum_{i=1}^{n}\sum_{j<i}^{n} a_{ji} x_j x_i \qquad (3)$$

The result show that the mathematical model is good. The mathematical model ‘Objective Function’ with respect to 2^{nd} order polynomial multiple regression model was defined as by using ‘FindFit’ command on Mathematica;

$$t = 66.0439 + 2.42924\, x1 + 0.060683\, x1^2 + 0.457953\, x2 - 0.195938\, x1\, x2 + 0.159102\, x2^2 - 4.19963\, x3 + 0.0158941\, x1\, x3 - 0.247609\, x2\, x3 + 0.0276474\, x3^2 - 0.00185789\, x4 - 0.0107405\, x1\, x4 + 0.00896666\, x2\, x4 + 0.0106789\, x3\, x4 - 0.000306033\, x4^2 + 0.125582\, x5 + 0.000599765\, x1\, x5 + 0.0483611\, x2\, x5 + 0.0191\, x3\, x5 - 0.00202111\, x4\, x5 - 0.00302376\, x5^2 + 3.02032\, x6 + 0.197952\, x1\, x6 - 0.032798\, x2\, x6 - 0.00301794\, x3\, x6 + 0.0135547\, x4\, x6 - 0.0545488\, x5\, x6 - 0.288759\, x6^2 - 78.96\, x7 - 2.51938\, x1\, x7 - 1.09745\, x2\, x7 + 2.52829\, x3\, x7 + 0.141346\, x4\, x7 - 0.545977\, x5\, x7 - 3.65277\, x6\, x7 + 163.959\, x7^2 \qquad (4)$$

According to this mathematical model, the R^2 value was determined as 0.944946.

Some graphs were created between the fitness function and DR in order to understand how the obtained model produces values by changing the system parameters (See Figs. 4-7).

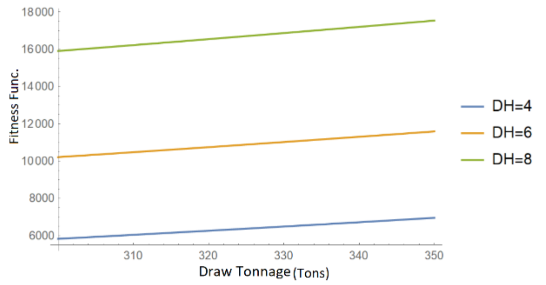


Figure 4. *Variation of sistem output vs DR for different DH values.*

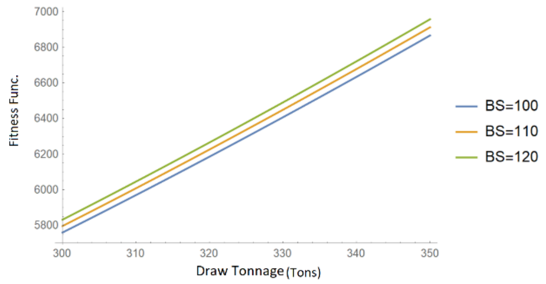


Figure 5. *Variation of sistem output vs DR for different BS values.*

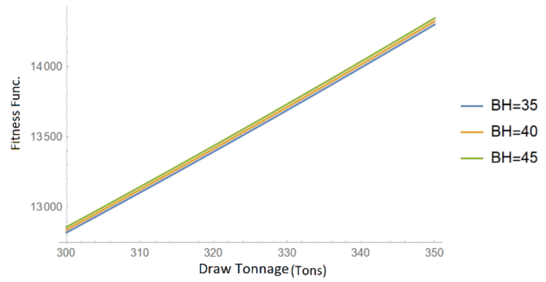


Figure 6. *Variation of sistem output vs DR for different BH values.*

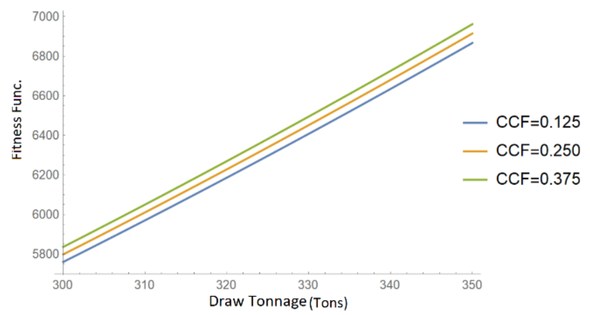


Figure 7. *Variation of sistem output vs DR for different CCF values.*

When the figures are examined, it is possible to see that the output increases linearly with the increase of DR for all cases. In addition, it is obvious that the effect due to the change of DH is much more than the other three parameters. Secondly, we can say that the least effective parameter is the BH, besides, the effect value of CCF and BS difference is close to each other.

4. Results and Discussion

The goal of the study is setting the stamping process parameters for minimum thickness and the optimization study results for thinning problem of the reference article, were given as;

These results shows that the optimized design parameters setting as shown in table 3.

Table 3. *Optimized Stamping Process Parameters of Ref.[10] and Present Study*

	Ref. [10]	**Present Study**
Parameter	**Value**	**Value**
PR	22 mm	22 mm
DR	19.19 mm	20.2 mm
BHF	44.39 Ton	45 Ton
DT	300 Ton	300 Ton
CCF	0.208	0.2122
BS	-	100 mm
DH	-	4 mm

In reference study, the minimum thinning percentage was defined as 11.613 % which is corresponding to minimum thickness of component is 0.707 mm.

In the present study, optimized parameters of stamping process were defined according to the modified Differential Evolution method.

The minimized output (thinning percentage) was defined as 8.53 % with respect to the optimized parameters for minimum thickness. These results corresponding to the amount of thickness is 0.519 mm. If the optimized process parameters of the present and the reference study compared the results shows that even small amount of increasing of the die radius, blank holder force and contact coefficient of friction values provides quite decreasing in thickness of the product. When these two thinning results compare, it shows that the present optimization study is successful as further increase the thickness.

5. Conclusion

Linear and second order multiple polinomial regression models were tried to obtain the mathematical model of the relation between process parameters and the result. In present study, there are 7 design parameters which thinning percentage.

Firstly, linear regression model was tried and it was decided to be insufficient because the result of R^2 value is smaller than 0.85, and decided to set a mathematical model as second order polynomial. The R^2 value for second order polynomial model was determined as 0.944946 which represents that there exist 94.5 % relation between the mathematical model (Objective Function) and the experimental data. It is found that the the main effect due to the change of DH is much more than BH, CCF and BS. Secondly, least effective parameter is the BH, besides, the effect value of CCF and BS difference is close to each other.
In optimization stage of the present study, defining the minimum thinning percentage was aimed. As result, the thinning value was minimized and defined as 8,53 which was found in article as 11,61. When these results were compared, the current results show that the optimization study in the present study is succesfull. It is also noted that the obtained optimum results can be experimentally tested in a future study.

Author Statements:

- The authors declare that they have equal right on this paper.
- The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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