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Numerical Evaluation and Influence of Product Quality and its defects Measures on the drawing of Stainless Steel Cross Member for Automobiles

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ABSTRACT:

Industrial enterprises increasingly demand optimum quality of products keeping in consideration a strict adherence where forming parameters are concerned. As far as incorporating the vital forming process upon an assortment of materials is concerned, it has grown excruciatingly challenging for industrial enterprises for laying out the adequately precise and suitable parameters. The flaws that are engendered during the process of sheet metal forming are inevitable. Flaws of this nature can be, however, kept within minimal proportions by introducing variations into the process parameters by Trial and Error methodology. This evidently results in a subsequent financial loss, not to mention an irrevocable loss of time and material. Dynaform simulation of defects combined with optimization is carried out with the help of Minitab. This method, as can be conjectured with considerable ease, yields optimum results, for it replaces much to our convenience the need for specialist industrial expertise besides leading to considerable savings in cost, time and material. This study would optimize the SS304sheet metal forming parameters FLD, thickness and thinning with three input parameters, namely, the lower binder force, tool travel velocity and binder close velocity.

KEYWORDS:

Sheet metal forming; Binder close velocity; Taguchi orthogonal array; Defect measurements

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1. Introduction

Sheet metal forming can be deemed an indispensable technique, one of much importance to the automobile industry wherein it serves to furnish most of the parts that make up the body. During this process, a thin blank sheet is subjected to plastic deformation using forming tools to conform to a designed shape. The blank sheet can possibly develop defects if a proper selection of parameters has not been carried out. Therefore, it is of utter importance to optimize the process parameters beforehand so as to keep both defects and the costs of production to the absolute minimal proportions. Optimization of the process parameters (lower binder force, tool travel velocity and binder close velocity, etc.) can be achieved with firm ground upon their extent of significance on the forming characteristics A statistical approach based on the Taguchi Technique was carried out in order to determine the extent of significance of each of the process parameters on the percentage of wrinkle, percentage of wrinkling tendency, percentage of safe region, percentage of crack, percentage of risk of crack, percentage of severe thinning of a drawn cross member. Taguchi method [1-8] has been applied in forming studies to lay out a template for the experiments and to determine the influence of process parameters on characteristics of the formed part [2-16].

Taguchi propounded a wide assortment of approaches towards experimental designs [1-19]. This method utilizes an orthogonal array, which is a form of fractional factorial design containing a representative set of all possible combination of experimental conditions. Using Taguchi method, a balanced comparison of levels of the process parameters and significant reduction in the total number of required simulations can both be achieved. Colgan et al [11] reported preliminary study made on the influence of process parameters in deep-drawing process. Taguchi L9 orthogonal array was used to investigate the effect of three process parameters in nine experiments. The process parameters studied were lower binder force, tool travel velocity and binder close velocity. Three levels (low, med, high) were used for each parameter. The results indicate that the optimized value of all three parameters have the greatest effect on the thickness of the deformed cross member section. The notion of the forming-limit diagram has gained considerable popularity as one of the principal criteria for the purpose of optimizing forming processes and in the design of dies. It also aids greatly in figuring out with precision as to which material has relatively better formability. Optimization by Taguchi analysis was applied to establish relationships between lower binder force, binder close velocity and the punch velocity with the percentage of wrinkle, wrinkling tendency, crack, and risk of crack.

The main effects plot and the interaction plots which fall under ANOVA are used for the optimization The binder force, punch velocity and the binder close velocity are the imperative parameters in the drawing of the cross member. Increasing the binder force on a material creates more restrain on material going into the tool. Sufficient binder force needs to be exerted to control the flow of the metal. If sufficient binder force is not present, the material is altered by wrinkles during compression. These wrinkles may cause the binder to separate from draw region and the material control will be lost. Increase in punch velocity will lead to better draw ability of the punch in the sheet metal to form the final component without fail keeping in mind of the binder force and the binder close velocity. The punch velocity should not be less as it would lead to more machining time, cost of operations, less efficiency and more power consumption of machine. The punch velocity, however, need not be too high, for voluptuous amounts of it is bound to lead to cracks, fracture. Risk of crack region may grow on the component. Binder close velocity too should be sufficient for holding the sheet metal during drawing if the maximum safe region or the exact component shape is to be obtained. As a matter of fact, the binder close velocity is the holding force for holding the punch drawing process employed with the intent to obtain the desired shape of the specimen.

2. Numerical simulation

In this study, Taguchi orthogonal method of experimental design was used to plan the numerical simulations. Taking in consideration the two levels of each factor from screening experiments to determine a model of the system to a linear approximation, the least authoritative parameters are identified and annihilated before the most pivotal process parameters can be scrutinized further. In order to capture non-linear effects more than two levels [2-7] are entailed to foretell and conjecture upon the factor's behaviour since two levels [7, 8] produce only linear effects. Hence, three levels of the process parameters were made use of in this study to capture the non-linear effects in the experimental design. There are several factors, both process and material parameters, which exert varying degrees of predominance over the deep-drawing process.

In this study, deep drawing of automobile cross member was considered a case of interest and also the option that it should show high resistance to corrosion and heat resistance material such as AISI 304 stainless steel can be used. Among all process parameters, lower binder force, tool travel velocity and binder close velocity play a pivotal role in the quality of the formed component. Hence the above parameters are taken into consideration in this study. For the purpose of evaluation, three levels are chosen for each parameter. The levels form their basis on the process window and conform to low, medium and highly feasible values. Table 1 shows the chosen process parameters and their levels used in the FE simulations. The high order interactions among the above three factors are assumed negligible and the information on the main effects can be obtained by running 3^2=9 experiments. However, the appropriate Taguchi orthogonal array for the above three parameters with three levels is L9 as given in Table 2. The first column depicts the number of simulation and the subsequent columns represent the process parameters while the rows represent simulations with the levels of each parameter.

After the experiments are designed with various combinations of process parameter levels, FE simulations were carried out to predict the deformation behaviour of the blank sheet. The results obtained from the FE simulations were treated using statistical approach namely, ANOVA method. The purpose of using ANOVA is to elucidate the parameters that govern the drawing process that markedly influence the various interactive and main effects plot distribution. This will yield information about the impact of each parameter on the results predicted by the FE method. Consequently, the degree of importance of each process parameter in the deformation behaviour of the blank sheet can be determined.

Table 1: Process parameters and their levels

Process parameter	Level		
	1	2	3
Lower binder force	120	200	800
Binder close velocity	200	300	1050
Tool travel velocity	300	500	2000

Table 2: Orthogonal array L9 of Taguchi method

Numerical simulation trails	Process parameter		
	Lower binder force (kN)	Tool travel velocity (m/s)	Binder close velocity (m/s)
1	120	300	200
2	120	500	300
3	120	2000	1050
4	200	300	300
5	200	500	1050
6	200	2000	200
7	800	300	1050
8	800	500	200
9	800	2000	300

3. Dynaform simulations of drawing of stainless steel cross member

The blank sheet formability is contingent on the lower binder force, punch velocity and binder close velocity besides the mechanical properties and thickness of the sheet metal and the part's geometry. Fracture and wrinkle are the two dominant modes of failure in sheet metal parts. Hence, using appropriate value of punch velocity is a truly essential criterion to restrict the wrinkling tendency and to avert an otherwise tearing up of the blank sheet. Antecedent research on these failure modes has brought to foreground the role of binder close velocity force in forming, suggesting in part different blank holder force application schemes to obliterate these failure modes [9-14]. However, a constant binder close velocity values are used in this study for the sake of simplicity. In addition to the binder close velocity, the tool travel velocity and the punch velocity values are used so that the metal flow into the die cavity takes place appropriately in drawing process in paper [15-17]. The flow of material into the die cavity diminishes with tool travel or punch velocity values while a large tool travel velocity results in an enforced redundancy which can cause crack and fracture of the sheet metal into the die cavity. An appropriate tool travel velocity values allows smooth flow of materials on one hand and reduces material wastage on the other. In a similar fashion, proper lubrication condition enhances the flow of material into the die cavity. The quality of the formed part is dictated by the extent of influence of these process parameters used in sheet metal forming process. Another of the quality criteria in sheet metal formed parts is percentage of wrinkle, percentage of wrinkling tendency, percentage of safe region, percentage of risk of crack and percentage of severe thinning distribution.

Failure in drawn part normally occurs by thinning, risk of crack and fractures. Therefore, it is a formidable priority to determine the variation of all parameters distribution during deformation was reported in paper [18-32]. The primary intent behind this is to shrink the levels of thickness variation in the drawn part, i.e. to maximize the minimum thickness and minimize the maximum thickness. Thus, in the present investigation, an attempt has been made to study the effect of these three important process parameters, namely the lower binder force, tool travel velocity and binder close velocity on the parameters variation of the part. The tools used in the simulations and trail outcomes are shown in Fig. 1. The dimension of defects was done by using the FLD diagram which shows about the percentage of crack, percentage of risk of crack, percentage of severe thinning, percentage of safe region. These parameters measurement are very important as it helps in telling about the quality of the product. For calculating these values it has been implemented from FLD by dividing into many sections of the FLD diagram. Wherever the distribution of the stresses is more in the diagram it means it covers the larger portion in the material. So that is the maximum values which are implemented as the parameters of the FLD for optimization and numerical evaluation further for getting percentage of wrinkling tendency, percentage of wrinkle, percentage of safe region, percentage of risk of crack, percentage of severe thinning.

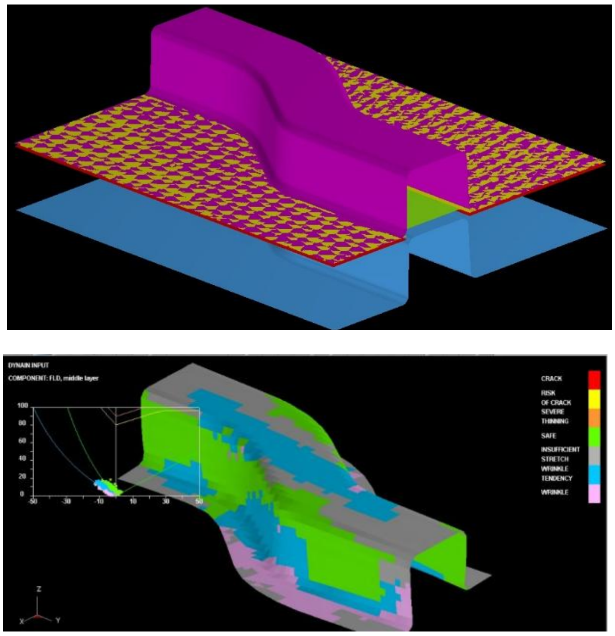

Fig. 1: Tools used in the simulations and trail outcomes

4. Results and discussion

Computation of result averages and averages for factor level effects, which merely involve simple arithmetic operations, yield answers to major questions that were unconfirmed in the preliminary stages of the investigation. However, questions concerning the ascendancy of factors on the variation of thickness in terms of discrete proportion can be obtained by performing ANOVA. In this study, ANOVA [24], quantifies the pertinence of each process parameter in deep drawing process. A better way to draw comparisons between the sheet metal behaviour and deep drawing is to use the mean squared deviation, which amalgamate the effects of both average and standard deviation of the results. In order to increase the robustness of design against noises and to accommodate wide ranging data, Taguchi [1] recommended a logarithmic transformation of MSD (called the signal-to-noise ratio) for perusal of the results obtained. Table 3 gives the percentage of simulation defects outcomes.

Table 3: Percentage of simulation defects outcomes

Numerical simulation trails	Process parameter			Percentage of simulation defects outcomes				
	Lower binder force	Tool travel velocity	Binder close velocity	Wrinkle	Wrinkling tendency	Safe region	Risk of crack	Severe thinning
1	120	2000	1050	10	20	21	4	2
2	200	300	300	5	20	20	5	5
3	200	500	1050	5	15	25	6	4
4	200	2000	200	4	15	24	3	4
5	800	300	1050	2	10	85	2	3
6	800	500	200	1	11	90	3	1
7	800	2000	300	2	5	96	1	1
8	120	2000	1050	10	20	21	4	2
9	200	300	300	5	20	20	5	5

Fig. 2 describes the main effects plot for percentage of wrinkle. On comparison of the values of the lower binder force, tool travel velocity and sufficient value of binder close velocity more will be the forming characteristics of the final product i.e., at 800kN of the binder force, 2000m/s of tool travel velocity and 300m/s of binder close velocity, the wrinkle percentage in all the three graphs are very less as compared to other input parameter values and hence the best choice for getting the best component. Fig. 3 depicts the main effects plot percentage of wrinkling tendency. On comparison of the wrinkling tendency percentage we conclude that at 800kN of the lower binder force, 2000mm/s of the tool travel velocity and the 300m/s of the binder close velocity there is minimum wrinkle tendency formation and thus not allowing the wrinkles to form at the surface. Thus this is the best choice as compared to others.

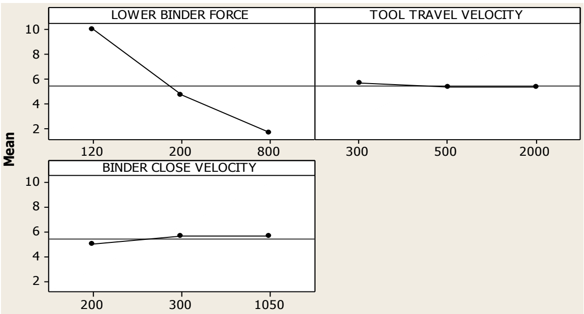

Fig. 2: Main effects plot for percentage of wrinkling

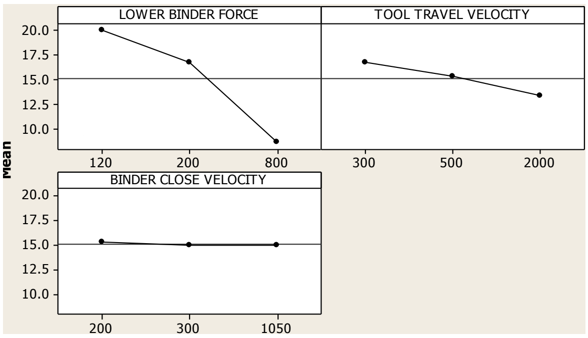

Fig. 3: Main effects plot for percentage of wrinkling tendency

Fig. 4 describes the main effects plot percentage of safe region, and clearly depicts that at 800kN. The percentage of safe region is high, for 2000m/s of the tool travel velocity the safe region is high and at 300m/s of the binder close velocity the safe region is high More the value better the formability hence better the safe region. Fig. 5 explains about the percentage of risk of crack for all the three input parameters. As the risk of crack stage is very low then better will be the formability characteristics of the material. In this graphical representation the risk of crack occurs least for 800kN of the binder force, 2000m/s of tool travel velocity and 300m/s of the binder close velocity. So this is the best option. Fig. 6 explains about the percentage of the severe thinning effect on the material specimen. On the value of 800kN, 2000m/s of tool travel velocity and 300m/s of binder close velocity, the severe thinning is minimum. Hence the metal flow rate at this stage is good and no severe axial or other stresses involved in it. So this is the best option.

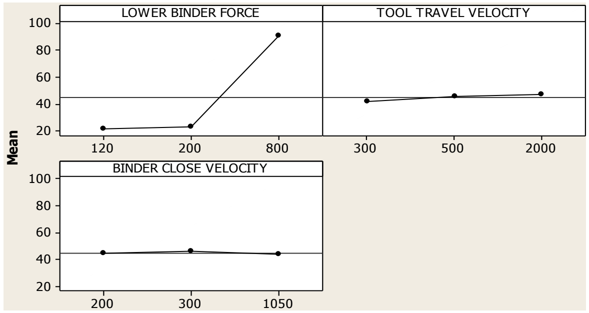

Fig. 4: Main effects plot for percentage of safe region

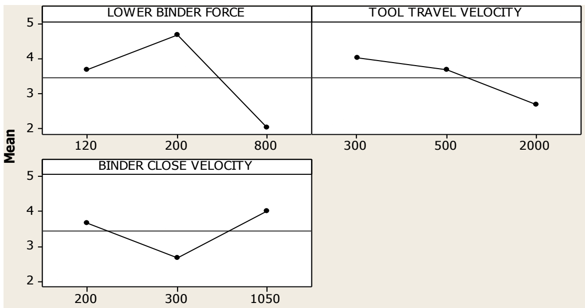

Fig. 5: Main effects plot for percentage of risk of crack

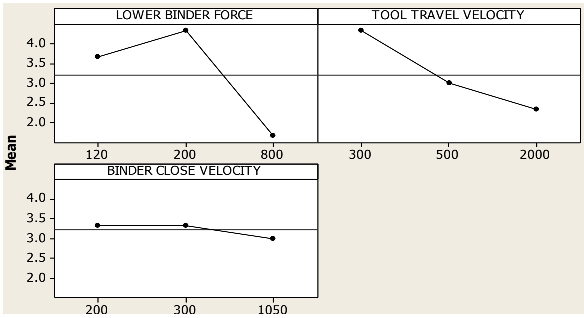

Fig. 6: Main effects plot for percentage of severe thinning

Fig. 7 shows a graphical representation of the interrelationship of all the three input parameters in a single representation with respect to the output parameters. In all three parameters representation, the percentage of wrinkle formation is minimum for the three input parameters i.e., for 800kN of the binder force, 2000m/s of the tool travel velocity and 300m/s of the binder close velocity. So with respect to all the three input parameters this input parameter value is the best choice. Fig. 8 Presents about the percentage of the wrinkling tendency of the component. In this case also the wrinkling tendency is minimum for the tool travel velocity as 2000m/s, 800kN of the binder force and 300m/s of the binder close velocity. So with respect to all the three input parameters this input parameter value is the best choice.

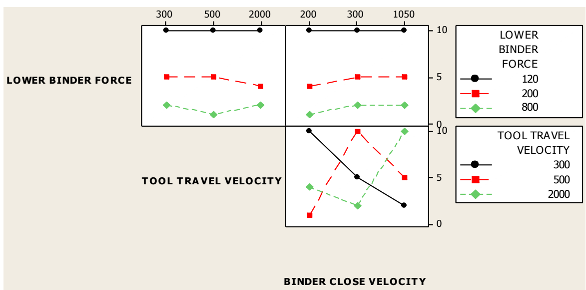

Fig. 7: Interaction plot for percentage of wrinkle

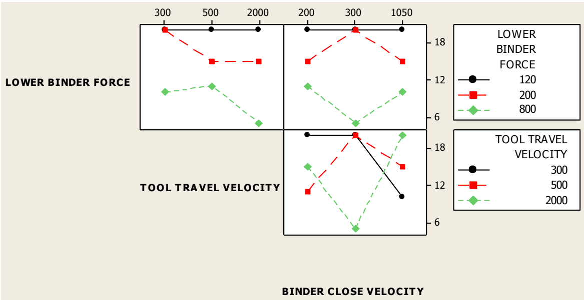

Fig. 8: Interaction plot for percentage of wrinkling effect

Fig. 9 describes that the maximum formability will be attained by the input parameters of tool travel velocity of 2000m/s, 800kN of the binder force and the binder close velocity of 300m/s. So with respect to all the three input parameters this input parameter value is the best choice. More the rise more will be the formability characteristics. Fig. 10 depicts the distribution of risk of crack stage. The risk of crack is coming maximum for the 200 kN of the binder force and at 1050m/s of the percentage is getting higher and for 300m/s of the binder close velocity the value is maximum. The safe value is the 800kN of the binder force, 300m/s of binder close velocity and tool travel velocity of 2000m/s.

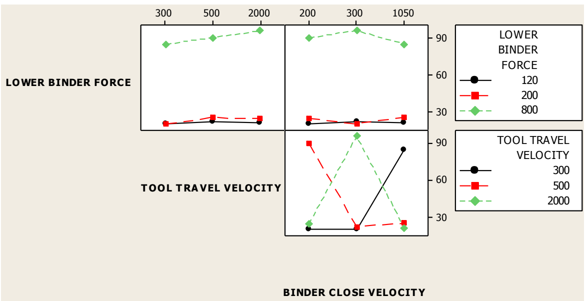

Fig. 9: Interaction plot for percentage of safe region

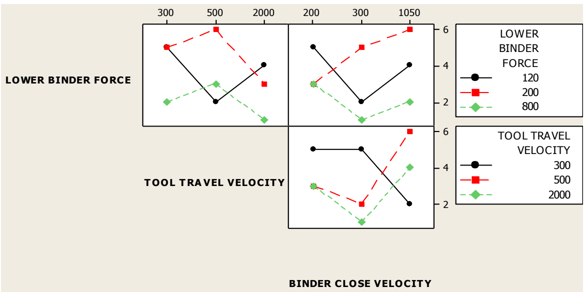

Fig. 10: Interaction plot for percentage of risk of crack

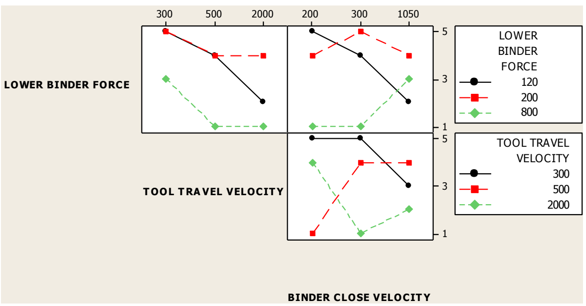

Fig. 11: Interaction plot for percentage of severe thinning

Fig. 11 describes the severe thinning distribution of all the three input parameters. On comparison of the three parameters the severe thinning is maximum for 200kN of the binder force as compared to the minimum value at 800kN of the binder force all the other stages also the comparison made predicts that at 2000m/s of tool travel velocity and 300m/s of binder close velocity, the severe thinning is minimum.

5. Conclusion

The objective of this study would have us influencing and optimization the forming parameters FLD such as wrinkles, wrinkle tendency, safe region, risk of crack and severe thinning concerning all the while with three input parameters, namely, the lower binder force, tool travel velocity and binder close velocity set for SS304 sheet metal with the aid of Minitab. On comparison of the values of the lower binder force, tool travel velocity and sufficient value of binder close velocity more will be the forming characteristics of the final product i.e., at 800kN of the binder force, 2000m/s of tool travel velocity and 300m/s of binder close velocity, the considered forming parameters are very less as compared to other input parameter values. The risk of crack is coming maximum for the 200 kN of the binder force and at 1050m/s the percentage is getting higher and for 300m/s of the binder close velocity the value is maximum. The severe thinning is maximum for 200kN of the binder force as compared to the minimum value at 800kN of the binder force. This study would be better for predicting the influence of each individual or mixed process parameters and response to improve the robustness in sheet metal forming.

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