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Parametric Optimization of Steel Die and Punch in Bowl Manufacturing

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Abstract: In present study few importantcommon research finding involved in deep drawing processes, which is tearing due to internal stresses, wrinkling and sometimes uneven height at the top rim of a drawn part formed due to the material anisotropy. Depending on the scope of present research,Limiting DrawingRatio (LDR) and Centre Line Average value (CLA) of surface roughness (SR) were estimated by considering the three most influencing and significant input parameters such as clearance in die- punch, thickness of blank and Blank Holding Force (BHF). Response surface methodology (RSM) L 20 design approach was involved to conduct the experimentusing three inputs at three levels. RSM technique is being used also for modeling the surface roughness and LDR which was able to give correlation coefficient R^2 96.3% for surface roughness and R^2 95.34% for LDR. The experimental design approach and investigation of numerical studywere done for the die and punch.Critical output SR and LDR were optimizedup to the adequate level which able tofulfill the industrial need regarding to its desire quality and productivity. CATIA software was used to design the die-punch and blanks. ANOVA test was also conducted to check model adequacyand the significance of fit on the SR and LDR.

Key words: Deep Drawing · CATIA · SR · LDR& RSM

INTRODUCTION

Deep drawing is the important metal forming process, which used to produce the bowl etc. In sheet metal forming process,blank sheet under goes plastic deformation using forming tools. Die and punch are used as forming tools in deep drawing processes. The values of deep drawing process parameters are needed to be selected properly to manufacture the defects free product, but it may not be selected arbitrarily. It is being observed that most of the product failure of sheet metal takes place in the form of wrinkling and uneven thinning due to the internal stresses. Therefore, it is very important to optimize the deep drawing process parameters to avoid the common defects in the parts and to minimize the cost of productivity. Many input variables are generally influenced on failure of deep drawn product as blank, die and punch material properties, punch and die clearance,punch and die radius, blank holding force, die cavity depth [4]. Experimentationsareneeded to be conducted to determine the optimal value of the input parameters fordesire outcome in deep drawn parts. These investigations used30 tonnage power press machine and sheet metals blanks of 0.6mm, 1mm and 1.4mm of thickness to produce cylindrical bowl.Sheet metal forming is mostly used in fabrication of a wide range of products manufacturing due to plastic deformation in many industries [5]. Deep drawing is one of the extensively used sheet metal forming processes in the industries to having the capability to mass production of cup shaped components quickly. In deep drawn forming, a thin blank sheet is forced to plastic deformation using designed punch inserted to die designed cavity. Optimization of the process parameters such as die radius, blank holder force, friction coefficient, etc., can be accomplished based on their degree of importance on the sheet metal forming characteristics[12]. In present investigation, a statistical approach based on Response surface methodology (RSM) technique has been adopted to determine the significance of each of the ifluencing input parameters on the LDR and SRin deep drawn circular cup. RSM is applied in forming studies to design of experiments and determine the influence of process parameters on characteristics of the formed part [1]. In this study

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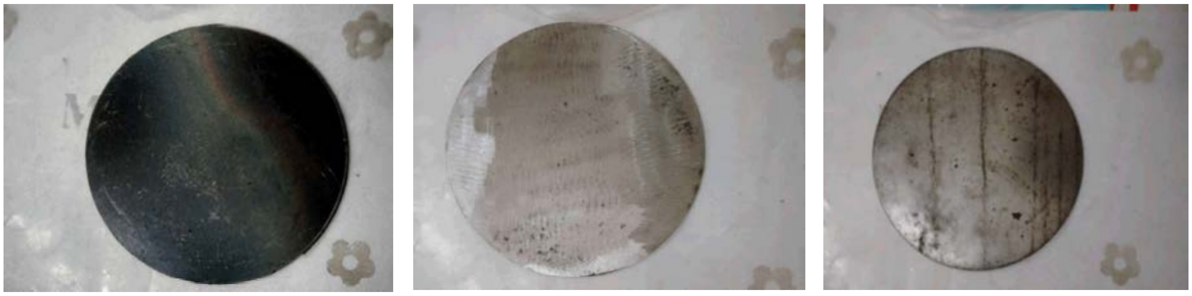
Deep drawing setup (a) Die (b) Punch (c)

Fig 1: Deep drawing setup with available die & punch

influencing input parameter on the SRin formed part was identified. RSM orthogonal array (OA) design was used to investigate the effect of three process parameters in twenty experiments. The surface roughness influencing process parameters were studied on punch-die clearance, thickness of sheet metal and BHF [3]. The SR and LDR influencing critical input parameterswere identified to optimize its values.It is concluded that enough clearance is needed for thickening of the deep drawn plastically formed product. When the clearance is equal or less than the metal thickness, burnishing of the metal will get appear near the top of the bowl.The selection of the punch-die clearance depends on the thickness of blank sheet and requirements of the drawn part specifications. Thequality of deep drawn manufactured items is significantly affected by the nature of flow of metal in the die cavity. While forcesare exerted by the blank holders on the sheet a restoring force controls the flow ability of material during metal forming. This restoring action is broadly applied through friction. Blank holding force is usually small at beginning, which is usefulto keep the proper flow of material towards die cavity. But if blank holding force is less,lead to increase the wrinklingand if blank holding force is higher,it leads to increase the tearing, therefore BHF is an important parameter in the deep drawing process. Wrinkles are generally formed in the flange of the drawn part and also the uneven thickness of materials gets distributed. The deep drawing process needs a blank which is part of metal stamping process(9).The blank is one type of piece of sheet metal in rectangular shape which is pre-cut from the stock of material(10). As per the theory concern regarding deep drawing, volume of theblank material before drawing should be equal to the volume of bowl material after deep drawing. However, if the thickness ofmaterial remains unchanged throughout the deep drawing process the area ofwork piece will also remains constant at all. Thus, the blank diameter may be selected from the area of blank material before drawing. The blank size required for this research work is 90 mm.

It is verdict that combined optimization of surface roughness and LDR of the steel bowl under deep drawing processes is needed to be done to fulfill the customer demand and economic production. RSM is the robust modeling technique rather than Genetic Algorithms (GA) and Taguchi. RSM modeling has ability to predict responses using less number of experimental runs. In this deep drawing operation,clearance (mm), blank thickness and blank holding force were selected as critical influencing parameters which affects directly to the LDR and SR. The combined effect of the parameters will be critically analyzed on responses. Experiments were carried out on mild steel (MS)blank usingsuitable die and punchas per design in deep drawing. The experimental setup is being shown as Fig. 1. The experimentation is conducted on the deep drawing set up using RSMdesign of experiments (DOE) and methodology as mentioned in Fig. 1.

Experimental Set-Up: Various experiments were conducted as per DOE to study the effects of machining parameters on deep drawing process. The critical input such as clearance (mm), blank metal thickness and blank holding force were selected as most influencing parameters which affects directly to the LDR and SR. The selected work piece material for this research work was mild steel. Tool die steel is also selected appropriately as per the industrial scope for die material in bowl manufacturing. Blank materialsof different thickness and design specifications of deep drawing setup are given in Fig. 2. The mechanical power press having 30 ton capacity was selected to perform the deep drawing experiments.



a) Blank with 0.6mm thickness b) Blank with 1mm thickness c) Blank with 1.4mm thickness

Fig. 2: Three level thickness of blanks

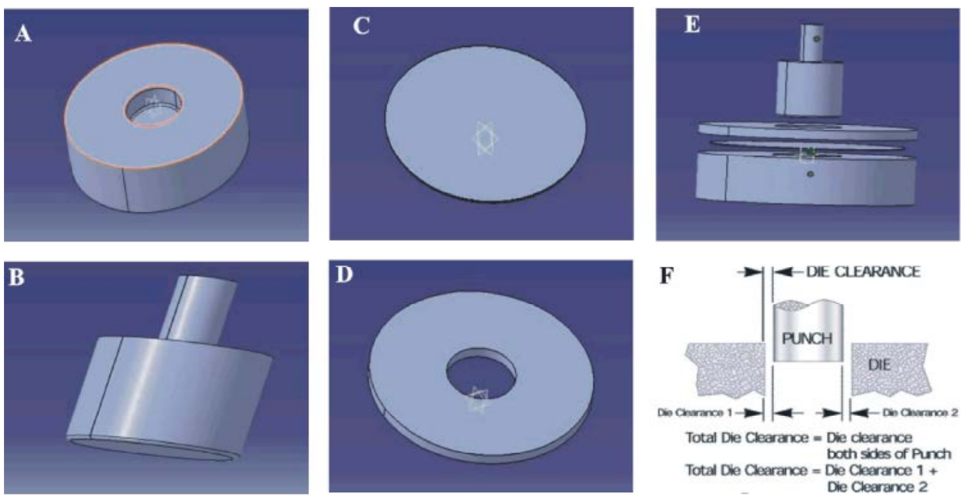


Fig 3: Die & Punch (A & B) Fig 3:Blank & Blank Holder (C & D) Fig 3:Assembly & die clr. (E & F)

Different parts such as diepunch and guide plate were designed appropriatelyto travel the punch inside the die cavity in bowl manufacturing. Die and Punches used for the experimental purpose is shown in Fig 3.

The parts were designed first in CATIA. The individual parts were then assembled together using the Assemble Design command in the CATIA software itself. The designed parts are shown below as Fig 3:

Surface Roughness: Surface roughness or texture is the measure of finer surface irregularities in the surface texture and is composed of three components: roughness, waviness and form. These are the result of manufacturing process employed to create the surface.Surface roughness average (R_a), also known as arithmetic average (AA) is rated as the arithmetic average deviation of the surface valleys and peaks expressed in micro inches or micro meters. ISO standards use the term CLA(Center Line Average). Both are interpreted identical.Where Ra is the arithmetic average or departure from profile front i.e., center line, the equation for the four as measured values.

$$R_a=CLA=AA=\frac{M1+M2+M3}{3} \quad (1)$$

where, M_i is the measured value.

Limiting Drawing Ratio: Limiting drawing ratio (LDR) is commonly used to measure the ability to deep drawing in sheet metal. The correlation of the LDR of a sheet metal with its material properties and process parameters has been activated by industrial necessity for improving draw ability (7). LDR of draw abilityis computed mathematically using the ratio between the maximum blank diameter that can be drawn successfully to the punch diameter (11). The draw ability of sheet metalcan be determined from different thickness of blanks with constant diameter. The LDR can be expressed as equation 2.

$$LDR = \frac{\text{maximum blank diameter}}{\text{Punch diameter}} \quad (2)$$

RSM Design of Experiments: Design of experiments (DOE) is a statistical technique for quickly optimizing performance of systems with known input variables.

It starts with a screening experimental design test plan involving all of the known factors that are suspected to affect the system's performance (or output). When the number of input variables or test factors is large, the primary experimental objective is to compare this number down into a manageable few. This is usually followed by another designed experiment design or test plan with the objective of optimizing the system's performance. The most common initial and final optimization designs of experiment are called the screening design and the response surface method (RSM). Three factors at three level L 20 RSM design were selected to perform the experiments.

Table 1: Process Parameters and levels of variations.

Process Parameter	Levels and their range -1	0	1
A.)Clearance (mm)	1.8	2.8	3.8
B.)Blank Thickness (mm)	0.6	1	1.4
C.)Blank Holding Force (BHF)tonne	3	7	11
Specification of die & punch setup.			
Size of die	61.8 mm		
Size of Punches	60mm, 59mm, 58mm		
Die material	Tool steel with 207 GPa		
Sheet metal material	Mild Steel cr4		
Thickness of blank	1.4mm, 1 mm, 0.6mm		
Machine tonnage	30	Tonne	

The formula for calculating LDR is shown below:

Area of flat blank = 0.7849 x D^2

Diameter of flat blank, D = v Area / 0.7849

Observation based on DOE:

Table 2: Deep drawing process parameters and their effects on SR and LDR

Clearance (mm)	Blank Thickness (mm)	BHF (Ton)	LDR	SR (microns)
2.8	1.0	7	1.57	1.14
1.8	0.6	11	1.75	0.18
2.8	1.0	7	1.60	0.56
2.8	1.0	11	1.76	0.51
3.8	1.4	3	1.42	0.94
2.8	1.0	7	1.58	0.95
3.8	0.6	11	1.88	0.22
3.8	0.6	3	1.58	0.95
1.8	1.4	11	1.69	0.32
2.8	1.0	7	1.65	0.54
2.8	0.6	7	1.52	0.17
2.8	1.4	7	1.93	0.33
2.8	1.0	7	1.58	0.77
3.8	1.0	7	1.63	0.50
2.8	1.0	7	1.57	0.56
1.8	1.0	7	1.54	0.37
3.8	1.4	11	1.80	2.07
1.8	0.6	3	1.56	0.57
1.8	1.4	3	1.73	0.88
2.8	1.0	3	1.59	0.53

It is evident that surface roughness of deep drawn bowl increases with increase in clearance and blank thickness and decreases with blank holding force as Fig 4, whereas clearance is not significantly affected on LDR. LDR is being observed lower at moderate value of blank thickness and increases with increase inblank holding force. The residual plots for R_a and LDR are given as Fig 5 & Fig. 6. It is very critical case to optimize both the output at critical parametric combinations.

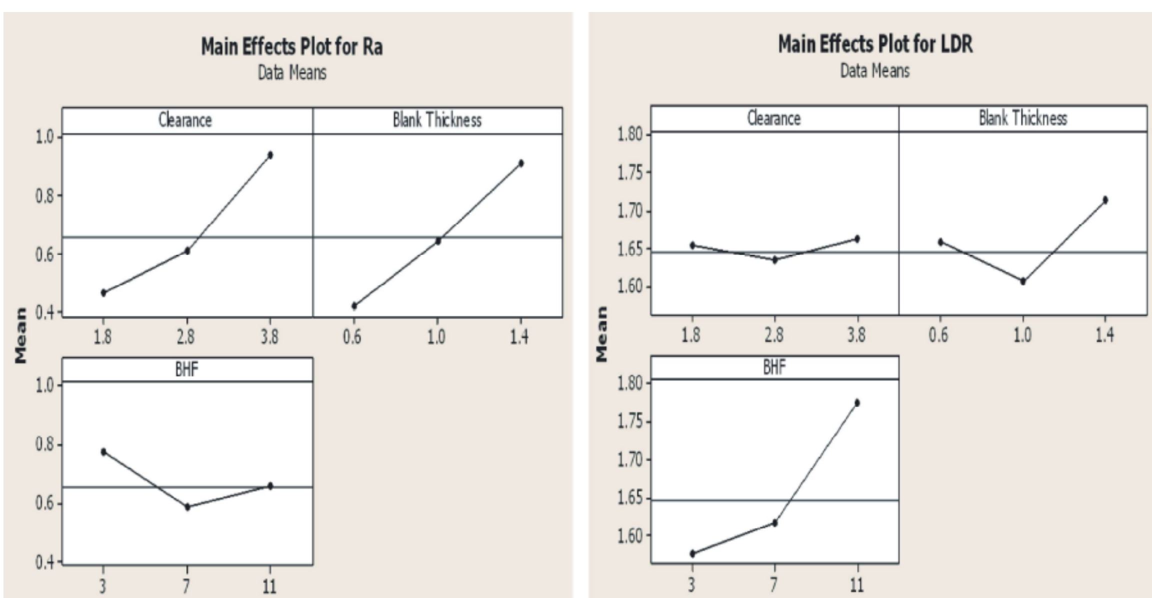


Fig 4: Main effect of inputs on surface roughness & LDR

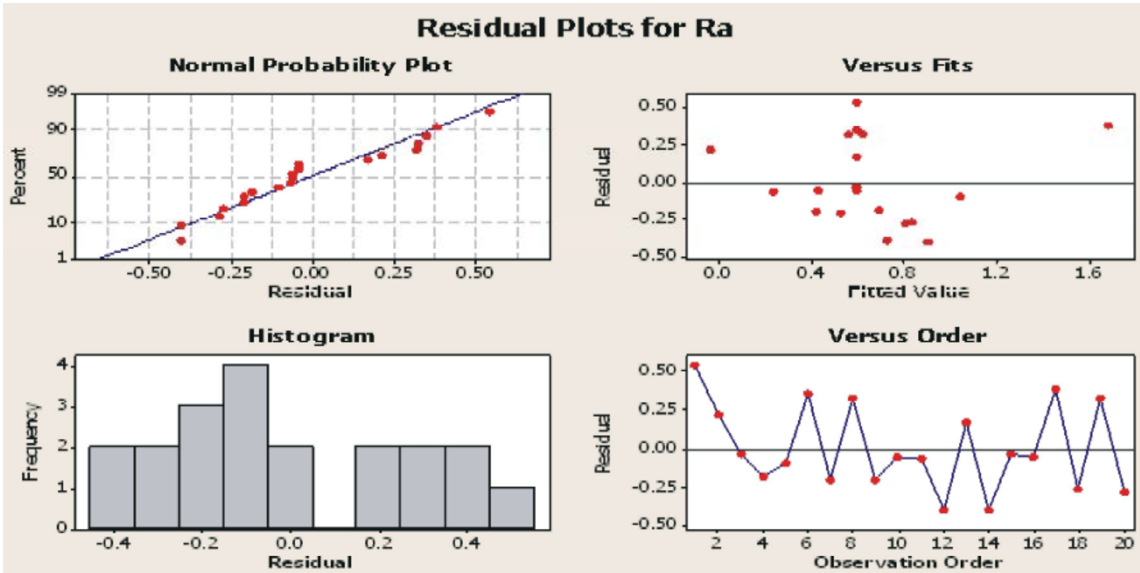


Fig 5: Residual plot for R_a

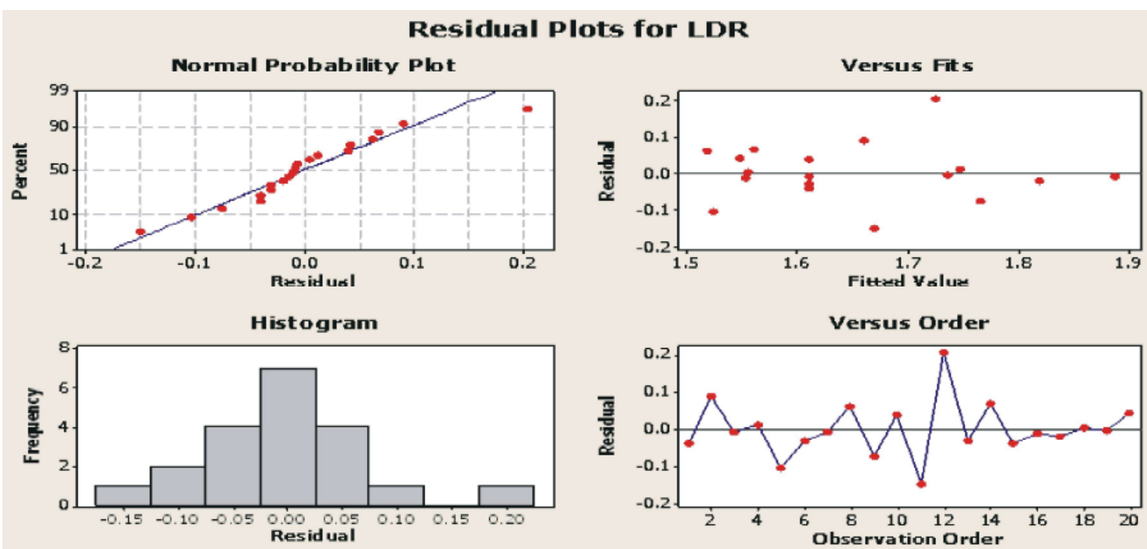


Fig 6: Residual plot for LDR

The ANOVA for the curtailed quadratic model depicts the value of coefficient of determination of R_a and LDR are R^2 as *96.3*%% and 95.34%, which signifies that how much variation in the response is explained by the model. The higher of R^2, indicates the better fitting of the model with the data. However, R^2adj is 92.62% and 94.14%, which accounts for the number of predictors in the model describes the significant coefficient relationship. Model adequacy test is needed for estimation of goodness of fitto avoid misleading the conclusions. The model adequacy test includes the test for significance of the regression model, model coefficientsand lack of fitwhich also carried out using ANOVA. The total error on regression is estimated by summation of errors in linear, square and interactions terms. The residual is the error which estimated by summation of pure and lack-of-fit errors. The fit summary recommended that the quadratic model is statistically significant for analysis of SR and LDR. In the Table 3 & 4, p-value for the lack-of-fit is 0.06175 & 0.002, which is insignificant, so the model is certainly adequate. Moreover, the mean square error of pure error is less than that of lack-of-fit.

Table 3: Estimated Regression Coefficients for Ra (micron)

Term	Coef	SE Coef	T	P
Constant	0.59800	0.1317	4.540	0.001
Clearance (mm)	0.23600	0.1212	1.948	0.080
Blank Thickness (mm)	0.24500	0.1212	2.022	0.071
BHF (Ton)	-0.05700	0.1212	-0.470	0.648
Clearance (mm)*Clearance (mm)	0.07000	0.2311	0.303	0.768
Blank Thickness (mm)* Blank Thickness (mm)	-0.11500	0.2311	-0.498	0.629
BHF (Ton)*BHF (Ton)	0.15500	0.2311	0.671	0.518
Clearance (mm)*Blank Thickness (mm)	0.17375	0.1355	1.283	0.229
Clearance (mm)*BHF (Ton)	0.16875	0.1355	1.246	0.241
Blank Thickness (mm)*BHF (Ton)	0.21125	0.1355	1.559	0.150

S = 0.383169 PRESS = 15.6560

R-Sq = *96.3*% R-Sq(adj) = 92.62%

Analysis of Variance for Ra (micron)

Source	DF	Seq SS	Adj SS	Adj MS
Regression	9	2.13664	2.13664	0.23740
Linear	3	1.18970	1.18970	0.39657
Clearance (mm)	1	0.55696	0.55696	0.55696
Blank Thickness (mm)	1	0.60025	0.60025	0.60025
BHF (Ton)	1	0.03249	0.03249	0.03249
Square	3	0.12060	0.12060	0.04020
Clearance (mm)*Clearance (mm)	1	0.04418	0.01347	0.01347
Blank Thickness (mm)*Blank Thickness (mm)	1	0.01035	0.03637	0.03637
BHF (Ton)*BHF (Ton)	1	0.06607	0.06607	0.06607
Interaction	3	0.82634	0.82634	0.27545
Clearance (mm)*Blank Thickness (mm)	1	0.24151	0.24151	0.24151
Clearance (mm)*BHF (Ton)	1	0.22781	0.22781	0.22781
Blank Thickness (mm)*BHF (Ton)	1	0.35701	0.35701	0.35701
Residual Error	10	1.46818	1.46818	0.14682
Lack-of-Fit	5	1.15945	1.15945	0.23189
Pure Error	5	0.30873	0.30873	0.06175
Total	19	3.60482		

Table 4: Estimated Regression Coefficients for LDR

Term	Coef	SE Coef	T	P
Constant	1.60991	0.03550	45.347	0.000
Clearance (mm)	0.00400	0.03266	0.122	0.905
Blank Thickness (mm)	0.02800	0.03266	0.857	0.411
BHF (Ton)	0.10000	0.03266	3.062	0.012
Clearance (mm)*Clearance (mm)	-0.05227	0.06227	-0.839	0.421
Blank Thickness (mm)* Blank Thickness (mm)	0.08773	0.06227	1.409	0.189
BHF (Ton)*BHF (Ton)	0.03773	0.06227	0.606	0.558
Clearance (mm)*Blank Thickness (mm)	-0.04375	0.03651	-1.198	0.258
Clearance (mm)*BHF (Ton)	0.06625	0.03651	1.814	0.100
Blank Thickness (mm)*BHF (Ton)	-0.01875	0.03651	-0.514	0.619

S = 0.103270 PRESS = 0.960482

R-Sq = 95.34% R-Sq(adj) = 94.14%

Table Continued

Analysis of Variance for LDR				
Source	DF	Seq SS	Adj SS	Adj MS
Regression	9	0.201008	0.201008	0.022334
Linear	3	0.108000	0.108000	0.036000
Clearance (mm)	1	0.000160	0.000160	0.000160
Blank Thickness (mm)	1	0.007840	0.007840	0.007840
BHF (Ton)	1	0.100000	0.100000	0.100000
Square	3	0.039770	0.039770	0.013257
Clearance (mm)*Clearance (mm)	1	0.002645	0.007514	0.007514
Blank Thickness (mm)*Blank Thickness (mm)	1	0.033211	0.021164	0.021164
BHF (Ton)*BHF (Ton)	1	0.003914	0.003914	0.003914
Interaction	3	0.053237	0.053237	0.017746
Clearance (mm)*Blank Thickness (mm)	1	0.015312	0.015312	0.015312
Clearance (mm)*BHF (Ton)	1	0.035112	0.035112	0.035112
Blank Thickness (mm)*BHF (Ton)	1	0.002812	0.002812	0.002812
Residual Error	10	0.106647	0.106647	0.010665
Lack-of-Fit	5	0.101964	0.101964	0.020393
Pure Error	5	0.004683	0.004683	0.000937
Total	19	0.307655		
Source	F	P		
Regression	2.09	0.133		
Linear	3.38	0.063		
Clearance (mm)	0.02	0.905		
Blank Thickness (mm)	0.74	0.411		
BHF (Ton)	9.38	0.012		
Square	1.24	0.345		
Clearance (mm)*Clearance (mm)	0.70	0.421		
Blank Thickness (mm)*Blank Thickness (mm)	1.98	0.189		
BHF (Ton)*BHF (Ton)	0.37	0.558		
Interaction	1.66	0.237		
Clearance (mm)*Blank Thickness (mm)	1.44	0.258		
Clearance (mm)*BHF (Ton)	3.29	0.100		
Blank Thickness (mm)*BHF (Ton)	0.26	0.619		
Residual Error				
Lack-of-Fit	21.77	0.002		
Pure Error				
Total				

RESULT AND DISCUSSION

It is very clear that one response is optimum at certain input parametric combinations. Similarly others responses are also optimum at others input parametric combinations. It is very difficult to obtain such influencing parametric combinations which applicable to achieve the optimal responses as surface roughness and LDR. Lot of modeling and optimization techniques are frequently used in the deep drawing processes for different materials. Response surface methodology (RSM) was used as important modeling and optimization tool in present research which applicable for the multi objective response optimization. Multi objective response optimization (MORO) technique is being incorporated as Fig. 7. In the present investigation, intelligence approach (MORO) has been used to combine optimization of SR and LDR at a time using optimal values of influencing parametric combinationsas given in Fig.7.

The effect of the critical machining parameters (clearance between die-punch, blank material thickness and blank holding force) on the response variables SR and LDR have been evaluated using MORO techniques as shown in Fig 7. LDR tends to increase significantly with the increase in clearance for any value of blank thickness as Fig 8. However, the SR tends to decrease with increase in blank holding force, especially at higher clearance. The effect of the machining parameters (clearance between die and punch, blank thickness and blank holding force) on the response variables SR have been evaluated by relation to the process parameters of clearance between die and punch, blank thickness are

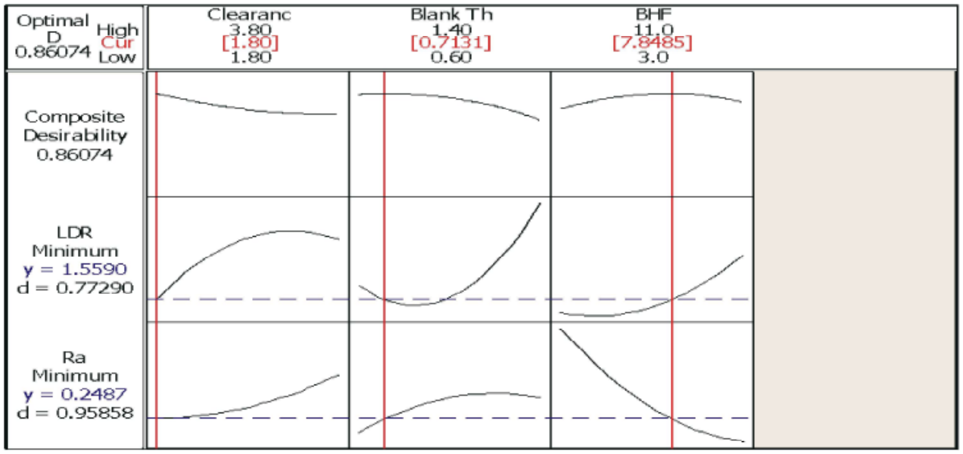


Fig. 7: Optimization of R_a& LDR

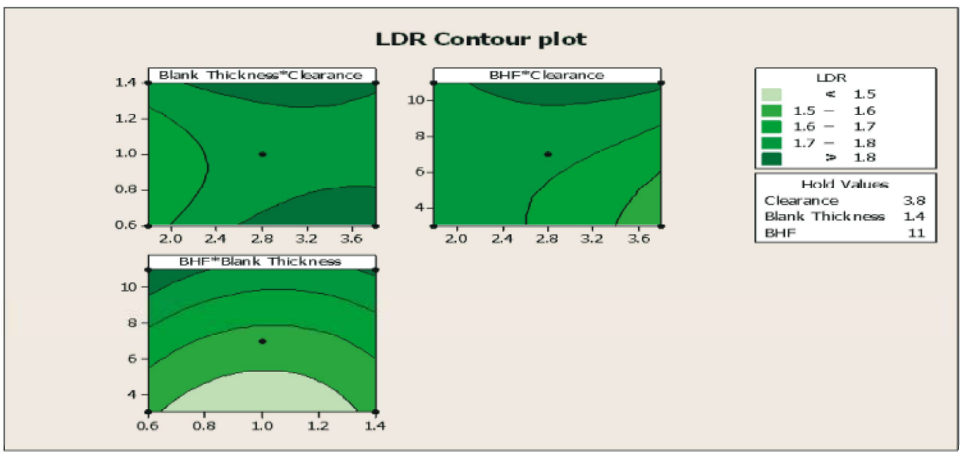


Fig. 8: Impact of inputs on LDR

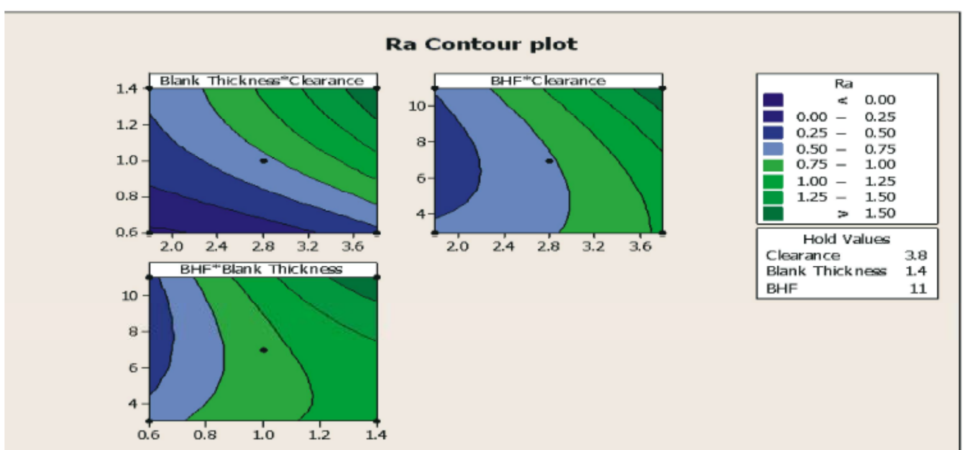


Fig. 9: Impact of inputs on SR

constant at blank holding force.SR tends to increase significantly with the increase in clearance as Fig 9. However, the LDRleads to increase with increase in BHF. The combined impacts of critical inputs on the SR and LDR are presented as Fig 10 and Fig 11 respectively which signify the model adequacy at critical conditions. Overlaid plots have been also drawn for the SR and LDR to estimate the nature of influencing parameters as Fig 12.

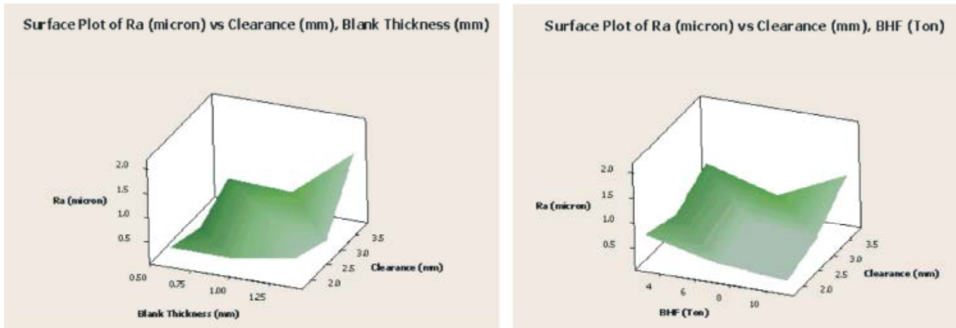


Fig. 10: Impact of two inputs on SR

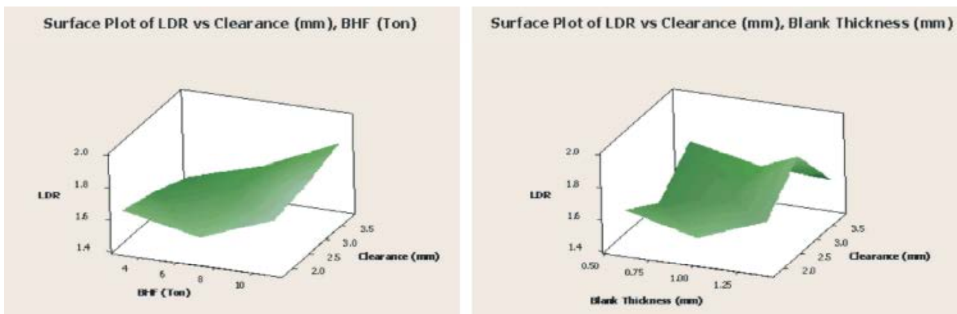


Fig. 11: Impact of two inputs on LDR

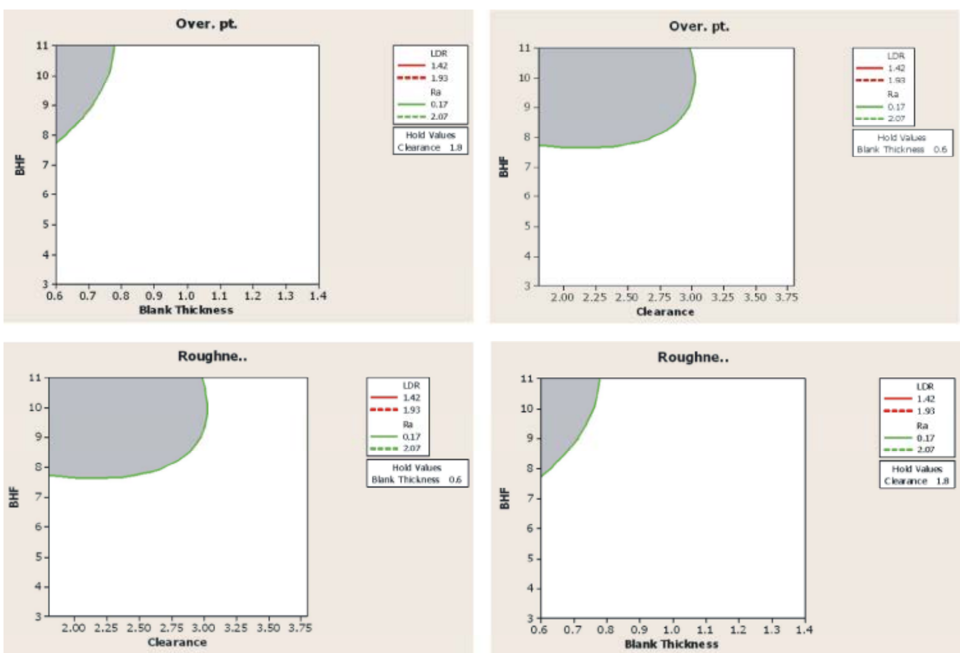


Fig. 12: Overlaid PlotSR& LDR

CONCLUSION

In the present study, the process parameters are significantly influencing on SR and LDR. A second order response model of these parameters are developed and found that clearance between die and punch, blank thickness and interaction between blank holding forces to the blank thickness with other parameters significantly affect the SR and LDR. Deep drawing experiments were conducted on radial machine having different blank thicknessof mild steel work piece. RSM L20 techniques were also implemented to predict the surface roughness and LDR. Correlation coefficient (R^2) values were observed 96.3% and95.34% for SR and LDR respectively. Responses (LDR and SR) were also optimized as 1.5590 and0.2487 micron respectively using critical values of variables (clearance between die-punch, blank thickness and blank holding force) as 1.80 mm, 0.7131 mm and7.8485N respectively using RSM technique. The research findings of the present study are based on RSM models which can be used effectively in bowl manufacturing in order to obtain best possible deep drawing process efficiency. Present research can also help researches and industries for developing a robust model, adequate knowledge base and early prediction of SR and LDR without experimentationindeep drawing process for mild steel.

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