

Optimization of forming load and variables in deep drawing process for automotive cup using Genetic Algorithm

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1 Abstract

Sheet metal forming is a significant manufacturing process for producing a large variety of automotive parts and aerospace parts as well as consumer products. Deep drawing is a compression-tension forming process involving wide spectrum of operations and flow conditions. The result of the process depends on the large number of parameters and their interdependence. With the developments in the technology the design of deep drawing is an art than science still today .It depends on the knowledge and experience of the design engineer only. The selection of various parameters is still based on trial and error methods. In this paper the authors presents a new approach to optimize the geometry parameters of circular components, process parameters such as blank holder pressure and coefficient of friction etc. The optimization problem has been formulated with the objective of optimizing the maximum forming load required in deep drawing. Genetic algorithm is used for the optimization purpose to minimize the drawing load and to optimize the process parameters. A finite element analysis simulation software fast form advanced is used for the validations of the results after optimization. The results obtained for the automotive cup shows the potential interest of the proposed approach.

Keywords: Sheet metal forming, Deep drawing, Genetic algorithm, Optimization, Spring seat

2 Introduction

Deep drawing is a compression-tension forming process. In this process the blank is generally pulled over the draw punch into the die; the blank holder prevents the wrinkling taking place in the flange. There is great interest in the process because there is a continuous demand on the industry to produce light weight and high strength components. Design in sheet metal forming, even after many years of practice, still remains more an art than science. This is due to the large number of parameters involved in deep drawing and their interdependence. These are material properties, machine parameters such as tool and die geometry, work piece geometry and working conditions. Research and development in sheet metal forming processes requires lengthy and expensive prototype testing and experimentation in arriving at a competitive product. The overall quality and performance of the object formed depends on the distribution of strains in the sheet material. Material properties, geometry parameters, machine parameters and process parameters affect the accurate response of the sheet material to mechanical forming of the component. The stretching primarily depends on the limit strains. The limit strains are sensitive to strain distribution as shown by Keeler-Goodwin (Date P.P.[1]). The limit strains are described by the concept of forming limit curve. The forming limit represents the onset-localized necking over all possible combinations of strains in the plane of the sheet. Ghosh and Hecker showed that the deformation geometry has a great impact on FLC's. Recently, sensitivity analysis combined with incremental FEM has been widely studied by many researchers to automatically identify optimal conditions. Inverse finite element method using the deformation theory has been developed for sheet metal forming process to optimize initial blank shapes and process parameters with the promise of obtaining reasonable accuracy in a very short time period. Now a day's simulation based design approaches have been used for forming processes, which carries many similar simulations with different process parameters and different tool geometries. It is not sure whether the optimal process parameters and tool geometries have been found, even after having carried out several simulations. A new Approach has been proposed here, Genetic Algorithm is used for finding out the optimum combinations of the process parameters, geometry parameters and machine parameters for deep drawn components of circular geometry instead of trial and error methods. An optimization problem has been formed with the objective function of optimizing the forming load.

2.1 Drawing load for circular components for first draw

The required drawing load for deep drawing and its variations along the punch stroke can be determined in two ways, either from theoretical equations based on plasticity theory, or by using empirical equations. The following equation for calculating the maximum drawing load $F_{d,max}$, which is based on the elementary theory by Siebel, has been used for optimization purpose. This equation considers the ideal deformation load, load component produced by friction between die and

flange and also between flange and blank holder, the load increase due to friction at the die radius, and the load necessary for bending the sheet around the die radius.

$$F_{d,max} = \pi d_m S_0 \left[e^{\mu\pi/2} 1.1 \sigma_{f,m,l} \ln \frac{d_{F,max}}{d_m} + \frac{2\mu F_N}{\pi d_{F,max} S_0} + \sigma_{f,m,l} \frac{S_0}{2R_D} \right] \quad (1)$$

2.2 Blank holder pressure

In the flange there are tangential compressive stresses. They can cause wrinkles due to buckling. Wrinkles can be avoided through the use of a blank holder, which is pressured with a pressure P_{BH} against the flange of the drawn component. If the contact area is A_{BH} , then the load applied by the blank holder is $F_{BH} = A_{BH} P_{BH}$. The pressure necessary to avoid wrinkling depends on the sheet material, the relative sheet thickness, and the drawing ratio. An investigation by Siebel and Beisswanger (Date P.P. [1]) shows that the required blank holder pressure can be estimated from following equation. Where the factor c ranges from 2 to 3.

$$p_{BH} = 10^{-3} c \left[(\beta - 1)^3 + \frac{0.005 d_0}{S_0} \right] S_u \quad (2)$$

2.3 Cracking load

The largest allowable drawing load is limited by the load that can be transmitted by the sheet in the region of the punch radius or at the transition from cup wall to bottom radius, which is called as cracking load. It must always be larger than the maximum drawing load. The cracking load can be determined approximately by the equation (Kurt Lang [2])

$$F_{cr} = \pi d_m S_0 S_u \quad (3)$$

3 Tool design

3.1 Die clearance

In practice the dimensions of the die clearance are often determined from the empirical equations suggested by Oehler and Kaiser (Kurt Lang [2]). These equations are valid only for deep drawing of circular components without ironing

$$u_D = s_0 + 0.07 \sqrt{10 s_0} \quad \text{For steel} \quad (4)$$

If the die clearance u_D is too large, the component does not form a true cylinder, but the upper edge of the cup remains expanded. If the die clearance is too small, ironing can take place, which increases the drawing load and increases the danger of cracking. Furthermore cold welding between the die and the work piece is possible.

3.2 Die and punch radii

The die radius R_D depends on the size of the work piece and its thickness. In order to lower the drawing load and to increase the limiting drawing ratio, large die radii are desired. Large radii, however, reduce the contact area between the blank holder and the flange and increase the tendency to form wrinkles in the region of the die radius. Conversely, the possibility of wrinkles formation is reduced if the die radius is made small. Oehler and Kaiser have developed the following empirical equation for the die radius which have been used for optimization (Roger Pierce [3])

$$R_D = 0.035[50 + (d_0 - d_1)]\sqrt{s_0} \quad (5)$$

Koelzer has found that the factor 0.035 in Eqn (5) can be increased to 0.08. The die radius should be reduced for each subsequent redraw. It has been found to be good practice to reduce the die radius by a factor of 0.6 to 0.8 from one draw to the next. Sellin has found that the die radius should be related to the sheet thickness by the following expression

$$R_d = (5-10) * S_0 \quad (6)$$

The punch radius R_p should be larger than the die radius by a factor of 3-5. R_p must never be smaller than R_d or the punch might pierce the material. For small components of large sheet thickness it is advisable to use a gentle transition (e.g. parabolic) from the punch radius to the cylindrical portion of the punch in order to avoid wall thickness reductions in the transition zone from the bottom of the cup to the wall.

4 Genetic algorithm

Genetic Algorithm is computerized search and optimization method based on the mechanics of natural genetics and natural selection. Genetic Algorithm mimics the principle of natural genetics and natural selection to constitute search and optimization procedures. Professor John Holland of the University of Michigan, Ann Arbor envisaged the concept of these algorithms in the mid sixties. A Genetic Algorithm simulates Darwinian theory of evolution using highly parallel, mathematical algorithms that, transform a set (population) of mathematical objects (typically strings of 1's and 0's) into a new population, using operators such as; reproduction, mutation and crossover (Goldberg [4]). The initial population is selected at random, which could be the toss of a coin, computer generated or by some other means, and the algorithm will continue until a certain time or a certain condition is met. In order to use GA to solve the problem, variables x_i 's are first coded in some string structures. It is important to mention here that the coding of the variables is not absolutely necessary. There exist some studies where GA is directly used on the variables themselves. Binary-coded strings having 1's and 0's are mostly used. In general, a fitness function $F(x)$ is first derived from the objective function and used in successive genetic operations (Goldberg[4]). Reproduction is usually the first operator applied on a population. Reproduction selects good strings in a population and forms a mating pool. That

is why the reproduction operator is sometimes known as the selection operator. In the crossover phase new strings are created by exchanging information among strings of the mating pool. Many crossover operators exist in the GA literature. In most crossover operators, two strings are picked from the mating pool at random and some portions of the strings are exchanged between the strings. A crossover operator is mainly responsible for the search of new strings, even though a mutation operator is also used for this purpose sparingly (Deb K. [5]). The mutation operator change 1 to 0 and vice versa with a small mutation probability, p_m . These three operators are simple and straightforward and after some number of generations they will give you an optimal solution.

4.1 Algorithm

1. Choose a coding to represent the problem parameters, a selection operator, and a mutation operator. Choose population size n , crossover probability, p_c , and mutation probability, p_m . Initialize a random population of strings of size l . Choose a maximum allowable generation number t_{max} . Set $t=0$.
2. Evaluate each string in the population.
3. If $t > t_{max}$ or other termination criteria is satisfied, **Terminate**.
4. Perform reproduction on the population.
5. Perform crossover on random number of pairs.
6. Perform mutation.
7. Evaluate string in the new population. Set $t = t+1$ and go to step 3.

5 Automotive cup under study

An automotive cup manufactured by Vishwadeep Enterprises, Bhosari, Pune, Maharashtra is selected for the study. The cup is single step drawn, with straight walls. The company still manufactures it with trial and error methods and all the process parameters as well as dimensions of the product are decided within the given tolerances of customers. It is found that many times the cracking takes place during drawing itself and also after use of the component for some period. The cup material is Mild steel having thickness of 1 mm and Ultimate Tensile strength of 282.14 Mpa.

5.1 Proposed Methodology

For optimizing the geometry of the automotive cup the optimization problem has been formed with the aim of optimizing the maximum drawing load required. The equation for the drawing load is selected, which is expressed in terms of all the related geometry parameters, process parameters as well as machine parameters. The constraint equations have been formulated in terms of geometry parameters as blank diameter, drawing ratio, diameters of cup and corner radii of cup, Machine parameters such as radius on die and radius on punch and process

parameters such as blank holder pressure and coefficient of friction. All these variables are optimized with Genetic Algorithm with optimization of forming load with due respect to material properties and working conditions. The formability analysis is carried out of both the original geometry supplied by the industry and optimized geometry with a finite element analysis simulation software FAST FORM ADVANCED. The failure limit diagrams are plotted to study and compare the formability analysis results of both the geometries and results are concluded.

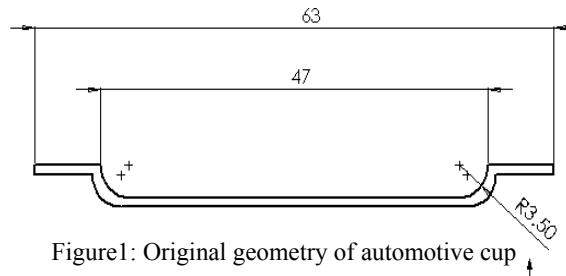


Figure1: Original geometry of automotive cup

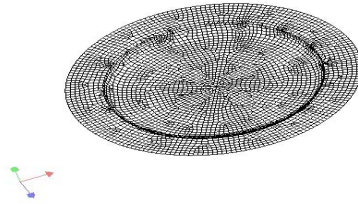


Figure 2: Automotive cup original geometry with meshing

5.2 Problem formulation for automotive cup

Minimize

$$F_{d,\max} = \pi d_m S_0 \left[e^{\mu\pi/2} 1.1\sigma_{f,m,I} \ln \frac{d_{F,\max}}{d_m} + \frac{2\mu F_N}{\pi d_{F,\max} S_0} + \sigma_{f,m,II} \frac{S_0}{2R_D} \right]$$

Subject to

$$1.25 \leq \beta \leq 2.2$$

$$3R_D \leq R_P \leq 6R_D$$

$$F_{d,\max} \leq \pi d_m S_0 S_u$$

$$R_D \geq 0.035[50 + (d_0 - d_1)]\sqrt{s_0}$$

$$p_{BH} = 10^{-3} c \left[(\beta - 1)^3 + \frac{0.005d_0}{S_0} \right] S_u \geq 0.250$$

The ranges of variables and parameters for Genetic Algorithm are selected as below in consultation with company professionals.

Table 1: Ranges of variables selected for optimization

Sr.No.	Variable	Lower Bound	Upper Bound
1	d1	45	48
2	d2	61	64
3	μ	0.10	0.15
4	R_D	04	06
5	R_P	12	20
6	r	1.5	3.5
7	c	2	3

Table 2: Parameters for Genetic Algorithm

Population	500
Generations	500
Reproduction Type	Uniform Crossover
Selection Type	Rank Selection
Elitism	5
Mutation Probability	0.02
Reproduction Probability	0.95
Selection Probability	0.85

5.3 Optimized design for automotive cup

After the optimization of deep drawing for automotive cup with Genetic Algorithm the geometry of the automotive cup has been changed as follow. In the

new design various diameters of the cup are changed. Cup diameter is changed from 47 to 48. Diameter of flange is changed from 63 to 61.5. Corner diameter between wall and base is changed from 3.5 to 2.5. Where as the height of the cup remains unchanged to 3.5.

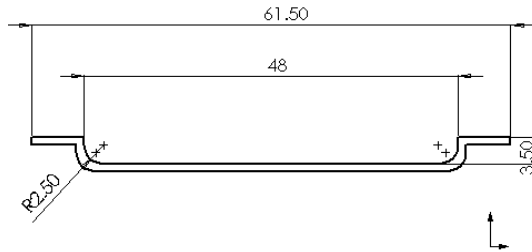


Figure 3: Automotive cup optimized geometry

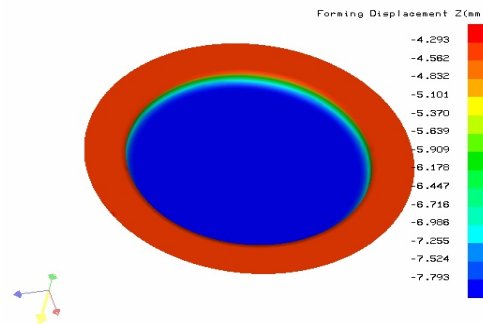


Figure 4: Forming Displacement Optimized Geometry

6 Results and validations

The optimized geometry of the cup requires a maximum drawing load of 8896.3460362639 N where as the original geometry requires a drawing load of 12666.60911 N. There is 29.76 % reduction in the forming load. The appropriate capacity press can be selected by knowing the drawing load. Working with the presses of higher capacities may lead to many types of defects such as cracks and tearing. Blank holder pressure has been optimized from 0.268 N/mm² to 0.304 N/mm² for optimized geometry. The coefficient of friction is optimized from 0.13 to 0.10 for new geometry. Generally the deep drawing objects are analyzed for their strength and failures with circle grid analysis, which is practically carried out on a sample piece, which is known as formability analysis. Then the failure

limit diagram is plotted to study the different strains. After that the production is started if there are no failure points in failure limit diagrams. Now a day's number of finite element analysis simulation software's are available to carry out the circle grid analysis and to plot the failure limit diagram. To prove that the geometry optimized with Genetic Algorithm is really optimum than the original one both the geometries are analyzed for formability analysis with finite element analysis simulation software FASTFORM ADVANCED from Forming Technologies Incorporation, Canada and failure limit diagrams are plotted as follows. The failure limit diagram for original geometry shows some failure points (Red) where as the optimized geometry don't show any failure point.

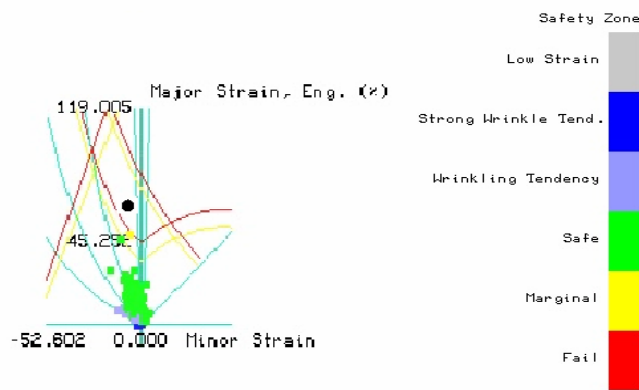


Figure 5: Failure limit diagram – original geometry

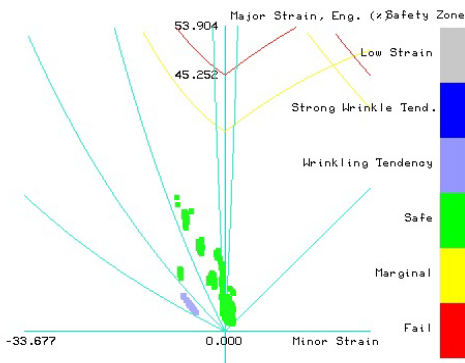


Figure 6: Failure limit diagram – optimized geometry

7 Conclusions

The failure limit diagram for original geometry shows some failure points [Black Circular] along with safe points [Gray-Square] where as the optimized geometry don't show any failure point. The major strain for the original geometry is 119.005 where as it is optimized to 53.904 for optimized geometry. The minor strain for new geometry is optimized as -33.677 from that of original -52.602 . Maximum drawing load and blank holder pressure are optimized which enables selection of proper capacity press. The other process parameters and geometry parameters are also optimized. With all these new parameters the failure limit diagrams for new geometry don't show any failure point so it is safe design and hence optimum design than the original one.

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