Control of critical parameters for square cup deep drawing of AISI 304 DDQ using genetic algorithm

Control de parámetros críticos en la embutición de una copa rectangular de AISI 304 DDQ empleando algoritmo genético

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Abstracts

The main purpose of this work is to develop an intellectualized control technique on the deep drawing of square cup made of AISI 304 DDQ stainless steel using genetic algorithm. These control methods are employed in order to investigate the most significant parameters in sheet metal forming process such as drawing force, with a view of optimizing these parameters. The genetic algorithm is used for the optimization purpose to minimize the force of the deep drawing process and to investigate the roles of other parameters as blank holder force. Experimental results show that these combinations of control system can cover a wide range of both materials and influential forming parameters automatically. The results further confirm that the developed system is effective and valid alternative for quick responsible control system with high flexibility.

Key words: intelligent control, deep drawing, genetic algorithm, sheet metal forming.

Resumen

El objetivo principal del trabajo es desarrollar un método de control inteligente para la embutición de una pieza rectangular fabricada en AISI DDQ empleando algoritmo genético. Este método de control se utiliza para investigar parámetros críticos en el proceso de conformado de chapa metálica, tales como la fuerza en el prensachapas y la fuerza máxima de embutición, con el fin de minimizar este parámetro. Los resultados experimentales obtenidos demuestran que el método de control puede cubrir un amplio espectro de combinaciones, tanto para los materiales, como para los parámetros críticos y es una técnica alternativa y flexible, válida para desarrollar sistemas de control en los procesos de embutición con gran flexibilidad.

Palabras claves: control inteligente, embutición profunda, algoritmo genético, conformado de chapa metálica.

Introduction

Sheet metal deep drawing process is a means in manufacturing of complicated parts from sheet metal used in many industries such as domestic, automobile, aerospace and so on. In this process, a flat metal blank is placed between the blank holder and the die. The blank is deformed by the action of a punch forcing the material into the die cavity. The trial-and-error method is a traditional means to investigate and optimize engineering design processes conditions in virtually every manufacturing process. Compared to other numerical approximation techniques, the finite element method (FEM) is presently the most frequently employed mathematical tool in the computer-aided analysis of sheet metal forming processes. Consequently, systematical design and process simulations have presented as a vital part in modern competitive systems. The computer-aided engineering (CAE) using a FEM, predict a forming process by detecting defects as wrinkling and fracture in design stage, in this way reducing prototyping costs to a considerable level. In this regard, a numbers of researchers have reported the utilization of sheet-metal forming simulations in the last decade with several purposes.

De Souza and Rolfe [1] in a recent study reported the consistency and accuracy of FEM predictions to assess the sensitivity of a stamping process. Zhenyu-Hu [2] demonstrated that the friction functions from deep drawing of circular parts is also valid for the deep drawing of rectangular work pieces. He has used size dependent FEM-simulation for this process. Firat [3] used a finite element modeling technique based on necking models to calculate Forming Limit Curve (FLC) and stretch formability of steel in square cup drawing process. The computer aided analysis based on the finite element method may help the stamping methods engineer to reduce the costly trial-and-error iterations through the qualification of the sheet metal forming process in accordance with the objective stamping criteria [4]. The computational requirements and the desired accuracy of the results must balance against the cost of modeling and process simulation.

The problem of optimal blank shape design, blank holder force, die and punch radii, friction coefficient and drawing ratios for the drawing forming process has attracted the attention of several researchers. In order to achieve this optimization objective, a large number of solution runs need to be performed to facilitate search for the optimum or near optimum solution. A different contributions in terms of integration between FEM and computer aided optimization techniques for stamping process design have been presented recently, namely in order to: a) tooling configurations [5, 6], b) blank configurations [7-9], c) material properties [1, 10] and d) forming condition [11-13]. A response surface methodology (RSM) based on design of experiments was used in [14] to minimize the forming force and maximum the forming height during the deep drawing process. As can be seen from these results to optimization a deep drawing process, many important factors must be taken into account.

The main purpose of this research is to develop an intellectualized control technique on the deep drawing of square cup made of AISI 304 DDQ stainless steel using genetic algorithm. These control methods are employed in order to investigate the most significant parameters in sheet metal forming process such as drawing force, with a view of optimizing these parameters. The genetic algorithm is presented for the optimization purpose to minimize the force of the deep drawing process and to investigate the roles of other parameters. Experimental results show that these combinations of control system can cover a wide range of both materials and influential forming parameters automatically. The results further confirm that the developed system is effective and valid alternative for quick responsible control system with high flexibility.

Materials and Methods

According to the DIN standard, DIN 8584, deep drawing is defined as a tensile-compressive sheet forming process in which a plane blank is formed into a hollow part open on one side (direct drawing) or an open hollow part is formed into another hollow part with a smaller cross-section (re-drawing). Deep drawing processes typically involve many complicated physics and mechanical conditions. The main difficulty to improving the quality of this system is the variability of the inputs (independent variables) and the constant change in process conditions.

A workpiece is taken in to consideration from home industry. This workpiece is one of the component parts from a cooking home and was chosen because there were many problems with it, especially with critical corner areas and wrinkling formation. The workpiece has a different depth of draw on both sides, on the higher side 125 mm and on the lower side 102 mm. The dimensions of the initial blank are A = 800xB = 625x s = 0.6 (mm). To improve the material flow control, drawbeads are used. No wrinkles, scratches or cracks are allowed. The main parts of the tool computer model contain die, blank, blank holder and punch. It is reasonable for tools to be rigid, and only blank has to be deformable.

In order to define the formability of the material, the Forming Limits are widely applied. A forming limit can be determined experimentally, analytically or numerically. Analytically, theories based on diffuse necking proposed by Swift, localized necking introduced by Hill and thickness imperfection developed by Marciniak and Kuczynski are used [15]. These theories may be applied in forming of complicated geometries where strains and stresses required are calculated using FEM.

A successful performance of the experiment demands the identification and limitation of certain influential process parameters to a concrete number. It refers to defining of only a certain input variables, as the independent variables x_i, as an input into the process, and function defining of output process y_i that are variable dependent dimensions. Such approach enables qualitative managing of the process and development towards modelling achievement. The input-output process parameters included in the experiment, according to [16] are shown in figure 1.
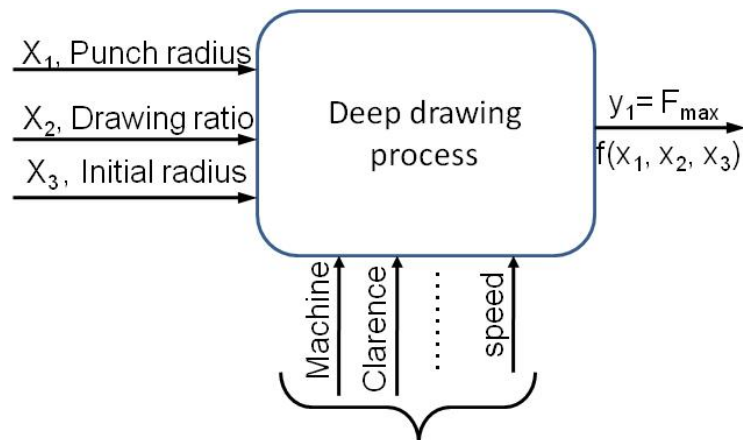

Fig. 1. Election of the input-output process parameters

Drawing load for rectangular pan

The required drawing load for workpiece in figure 1 can be determined in two ways, from theoretical equations based on plasticity theory, or by using empirical equations. In scientific literature is possible to find many different equations for calculating the maximum drawing load (F_{dmax}) and Blank Holder Force (BHF) in cylindrical shapes drawing. There no exists a unique equation to calculate required drawing load for deep drawing, in wide ranging shapes, the generalized expression take the form (equation 1):

$$Fdmax = f(h, BHF, \mu, n, K, r) \tag{1}$$

where h represents the drawing height, BHF is the blank holder force, μ the friction coefficient, n the strain hardening exponent, K the material strength coefficient, and r the normal anisotropy coefficient. The following equation (2) to assess the maximum drawing load F_{dmax}, has been used for optimization purpose:

$$F_{dmax} = \pi d_1 s \left[e^{\frac{\mu\pi}{2}} (1.1) K_{fm1} \ln\left(\frac{D_r}{d_1}\right) + \frac{2\mu F_n}{\pi D_r s} + K_{fm2}\left(\frac{s}{2r_p}\right) \right] \tag{2}$$

The equation 2 considers the ideal deformation load, load component produced by friction between die and flange and 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. Here, d_1 represent the final dimension of workpiece, D_r the initial dimension in the blank (both d_1 and D_r used for rectangular cup are determined from equivalent diameter), s the initial width of sheet and r_p the die punch.

The initial equivalent diameter concept (D_r) [17] can be used here to overcome the limitations for the calculation of process parameters of non-circular shapes drawing.

$$D_r = \left(0.77\frac{D}{d} + 0.23\right) d \tag{3}$$

$$D = 2\sqrt{\frac{A*B}{\pi}} \ and \ d = 2\sqrt{\frac{a*b}{\pi}} \tag{3.1}$$

Blank holder force

The required blank holder pressure can be estimated from different empirical equation. Blank holder is forced with a pressure (PBH) to elude wrinkles. The pressure necessary to avoid wrinkling depends on the sheet material and the drawing ratio. If the contact area is ABH, then the load applied by the blank holder is, BHF = ABH PBH.

$$PBH = 10^{-3}c\left[(m-1)^3 + \frac{0.005D_r}{s}\right]\sigma_m \tag{4}$$

The factor c ranges from 2 to 3; m is the limited drawing ratio and σ_m is the ultimate tensile strength of the sheet.

Cracking load

The cracking load (F_{cr}) must always be larger than the maximum drawing load. It can be determined approximately by the equation.

$$F_{cr} = \pi D_r s \sigma_m \tag{5}$$

Optimization search method

In order to achieve the optimization objective, genetic algorithms (GA) are used. Evolutionary algorithms are probabilistic optimization algorithms based on models of natural evolution. These algorithms present advantages, such as: robustness, works with most functions: discontinuous, multimodal, etc. and effectiveness [10]. These tools also appear to be robust since they remain effective for many types of applications; GA effectiveness is little problem dependent [18]. The GA search process is generally governed by the size of population, the number of generations, the probabilities of crossover and mutation, and probably the generation gap or proportion to be replaced with new solutions in the next generation. These parameters could be adjusted to improve the quality of GA search. The standard genetic algorithm proceeds, as see in figure 2.
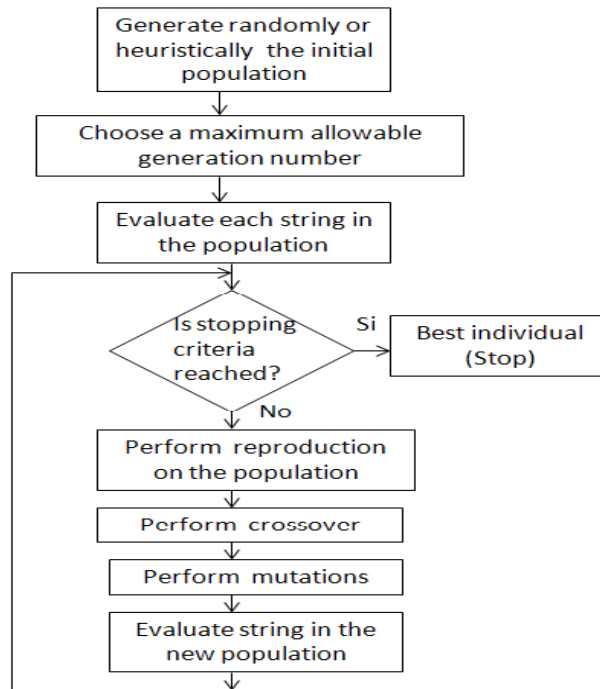
Fig. 2. Basic structure of genetic algorithm

Results and discussion

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.

Minimize:

$$F_{max} = \pi d_1 s \left[e^{\frac{\mu\pi}{2}} (1.1) K_{fm1} \ln\left(\frac{D_r}{d_1}\right) + \frac{2\mu F_n}{\pi D_r s} + K_{fm2}\left(\frac{s}{2r_p}\right) \right]$$

Subject to:

$1.31 \leq \beta \leq 1.58$
$F_{cr} \leq \pi D_r s \sigma_m$
$3r_D \leq 6r_P$

The ranges of variables and parameters for Genetic Algorithm, table 1 and table 2, are selected as below in consultation with company professionals.

Table 1. Parameters for Genetic Algorithm

Population	300
Generations	200
Selection Type	Tournament
Elitism	2
Reproduction Probability	0,85
Selection Probability	0,8

Table 2. Ranges of variables selected for optimization

Serie No.	Variable	Lower Bound	Upper Bound
1. Initial equivalent diameter concept	D_r	795	800
2. Final equivalent diameter concept	d_1	500	505
3. Die radii	r_D	3	6
4. Punch radii	r_p	9	30
5. Factor	c	2	3
6. Coefficient of friction	μ	0,10	0,15

Optimized design for workpiece

The workpiece drawing successfully and computer model are illustrated in figure 3. The optimized geometry of the workpiece requires a maximum drawing load of 338.88 KN. Presently geometry requires a drawing load of 2 000 KN. There is 16,94 % 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 7000 N/mm^2 to 73,56 N/mm^2.
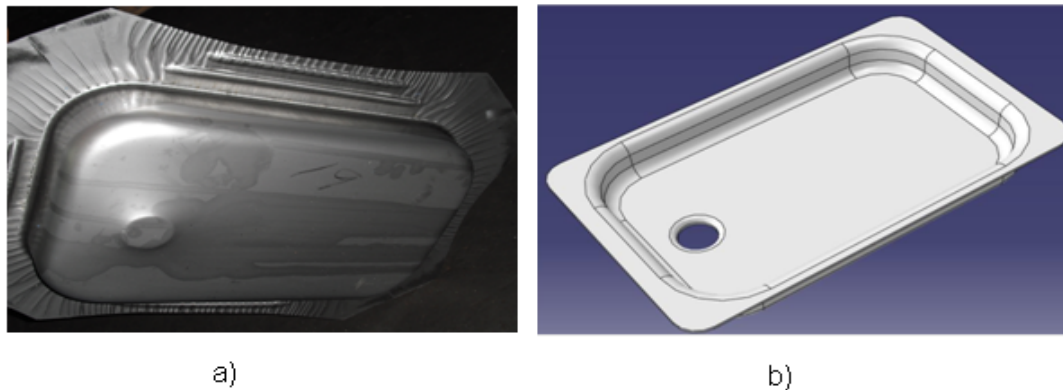
Fig. 3 a) Workpiece drawing successfully and b) Workpiece illustration computer model

The control method development in this work used genetic algorithm and finite element methods in order to develop an intellectualized control technique on the deep drawing of rectangular pan made of AISI 304 DDQ stainless steel. The ranges of variables and parameters for genetic algorithm are selected in consultation with company professionals. The optimized geometry of the workpiece requires a maximum drawing load of 338.88 KN. Presently geometry requires a drawing load of 2 000 KN. There is 16.94 % 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 7000 N/mm^2 to 73.56 N/mm^2.

The preceding results highlight that the one important key parameter for controlling the production process should be the friction coefficient. This phenomenon is familiar to production engineers taking an interest in stamping processes and is proved to be difficult to manage throughout industrial processes. Friction mainly is sensitive to the temperature, lubrication, material roughness and tool wear. Material properties are also influent parameters (K and n) and their variability's provoke significant variability

Conclusions

In this paper, effect of the most significant parameters in sheet metal forming process of a square cup, such as punch and dies radius, and their interaction on drawing force, is well analyzed with a view of optimizing this parameter. The present results show that the intelligent control in deep drawing of sheet metal can be successfully used in the field of parameters optimization.

The present model can be useful in conducting parametric studies on the different parameters affecting the process including die design, process and material parameters.

Maximum drawing load and blank holder pressure are optimized which enables selection of proper capacity press. The other process parameters are also optimized using genetic algorithm. 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 optimized geometry of the workpiece requires a maximum drawing load of 338.88 KN. Presently geometry requires a drawing load of 2000 KN, there is 16.9% reduction in the forming load. Blank holder pressure has been optimized from 7000 N/mm^2 to 73.56 N/mm^2.

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