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CONTROL OF CYLINDRICAL DEEP DRAWING USING GENETIC ALGORITHM

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ABSTRACT: The main purpose of this work is to develop an intellectualized control technique on the deep drawing of cylindrical cup made of 3003 ASTM aluminum 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. The 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.
KEYWORDS: optimization, deep drawing, genetic algorithm

INTRODUCTION

The optimization of the deep drawing process is necessary to improve important industrial performance measures such as productivity and cost of goods manufactured. Deep drawing is among the most dominant technologies in modern industry. Such declaration is best confirmed by Aleksandrović [1] in relation to produced quantities, consumption and intensity of development of these processes during the last few decades. In deep drawing processes many variables affect the failure of stamping parts. Failure usually takes place in the form of wrinkling, earing and fracture. These take account of material properties, die design, and process parameters such as blank- holder force (BHF), friction conditions, the drawing ratio as well as maximal punch load (FDmax); the careful control of these parameters can delay the failure of the part.

The coupling of simulation software's with mathematical algorithms for optimizing the deep drawing process parameters is widely increasing in various fields of forming. It was demonstrated [2] that this kind of coupling reduces and improves the products' cost. Compared to other numerical approximation techniques the finite element analysis (FEA) is presently the most frequently employed mathematical tool in the computer-aided analysis of sheet metal forming processes.

Actually, if a complex sheet stamping process is investigated, there is the possibility to analyze it under particular hypotheses, which allow the application of mono-objectives optimization approaches by means of genetic algorithm. Techniques which are getting more attention in these days are neural network model and genetic algorithm. Genetic algorithm employs a random, directed, search for locating the globally optimal solution. Like other methods, can be applied to problems for which it is not possible to have an analytical relationship for the objective function or to improve the solution to a local optimum, but also to explore a larger extension of the design space.

D. Singh [3] explored the roles of die radius, punch radius, friction coefficients and drawing ratios for cylindrical products deep drawing parameter. This work developed an evolutionary neural network, specifically, error back propagation in collaboration with genetic algorithm. The output of the network is used to establish the best parameters to the uniform thickness in the product via the genetic algorithm.

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When multi-objective optimization problems are developed within a sheet metal stamping design, some critical topics to be taken into account, especially conflicting objectives as referred in [4].

The maximal punch load (FDmax) is an important parameter in the deep drawing process. It is used to selection of the machine pressing, tools and restrains in the formation of wrinkles that can appear in the flange of the drawn part.

There no exists a unique equation to calculate required drawing load for deep drawing, see for example [5-6], in general point of view, the drawing load for circular components for first draw can be obtained in two ways, either from theoretical equations based on plasticity theory, or by using empirical equations, the generalized expression to take the form:

$$FD_{max} = (\sigma_1, h, BHF, \mu, t, n, K_{fm}, r) \quad (1)$$

where σ_1 is the principal stress component; h represents the drawing height; t is the initial thickness of sheet; BHF is the blank holder force; μ the friction coefficient; n the strain hardening exponent; K_{fm} the strength coefficient (or strain-hardening coefficient), and r the normal anisotropy coefficient.

Appropriate values of σ_1 and t will be obtained by maximizing FDmax with respect to $\bar{\sigma}$ (effective stress), by writing:

$$\frac{dF}{d\bar{\sigma}} = 0 \quad (2)$$

According to Abdalla S. Wifi and coworkers [7] in the optimization of the deep drawing process, five main lines of research are identified. This research work is according to the lines based on optimization of the maximal punch load to avoid wrinkling and fracture and the design parameters of the deep drawing mechanism including the die, the punch and the blank holder force. Tsu Hsiao-Chu [8] and coworkers reported the prediction of the deep drawing force and forming height in view of optimizing the values of the working variables involved in the process parameters.

In this paper an intellectualized control technique on the deep drawing of cylindrical cup made of 3003 ASTM aluminum 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.

Genetic Algorithm is computerized search and optimization method based on the mechanics of natural genetics and natural selection. Genetic Algorithm imitates the principle of natural genetics and natural selection to constitute search and optimization procedures. A Genetic Algorithm simulates Darwinian Theory of evolution using highly parallel, mathematical algorithms that, transform a set (population) of mathematical objects into a new population, using operators such as, reproduction, mutation and crossover. Reproduction is usually the first operator applied on a population. The standard genetic algorithm an initial population of individuals is generated at random or heuristically. Every evolutionary step, known as a generation, the individuals in the current population are decoded and evaluated according to some predefined quality criterion, referred to as the fitness, or fitness function. To form a new population (the next generation), individuals are selected according to their fitness as following:

1. Choose parameters for genetic algorithm. Initialize a random population of strings of size 1. Choose a maximum allowable generation number $gn=gn_{max}$ .Set gn=0.
2. Evaluate each string in the population.
3. If gn> gn max or other termination criteria is satisfied, terminate.
4. Perform reproduction on the population, crossover on random number of pairs and perform mutation.
5. Evaluate string in the new population. Set gn= gn+1 and go to step 3.

METHODOLOGY. Configuration and Dimensions of Tools and Workpiece Modeled in FEA

To demonstrate the main objective of this work, for a practical problem with industry interest, a workpiece from National Home Industry is taken in to consideration in this paper. 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 flange areas and wrinkling formation. The workpiece has a high of h=190 mm and final inner diameter of d1=214 mm; the initial thickness is t=3.0 mm. To improve the material flow control a constant blank holder force is used. No wrinkles, scratches or cracks are allowed. The setup and geometry of tools used are given in Figure 1. The chemical composition of the studied material is given in Tab. (1).

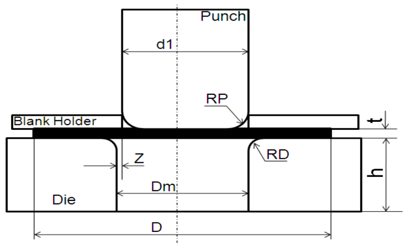

Figure 1. The Configuration and Dimensions of Tools and Workpiece Modeled in FEA

The deep drawing of the sheet metal parts are governed by the limitations of wrinkling (buckling) and fracture. These limiting factors are measured by the drawability of the workpiece and is determined by the factor called limiting drawing ratio (LDR) defined by the ratio of the original material radius (D) to the final perfect product radius.

$$LDR = \frac{D}{d_1} \quad (3)$$

Table 1. Chemical composition (Mass Percent) of the Studied Material

	Al	Si	Fe	Cu	Mn	Zn
3003	96.75	0.62	0.71	0.05	1.2	0.11

The initial diameter of the blank is calculated as:

$$D = \sqrt{(d_1^2 + 4hd_1)} \quad (4)$$

The main strains (effective strain) in the radial, circular and thickness directions, satisfying the condition of volume constancy:

$$\varphi_1 + \varphi_2 + \varphi_3 = 0 \quad (5)$$

At symmetric condition the forming of sheet metal occurs in plane stress state. Stress and strain can be defined by the joint solution of the equations of plasticity theory and the equation describing deformation hardening. It is convenient to present the dependence between the strength coefficient (or strain-hardening coefficient) and the effective strain the form of following function:

$$\sigma = K_{fm}\varphi^n \quad (6)$$

The strain-hardening exponent, strain-hardening coefficient and plastic strain ratio were obtained using a tensile test to construct the stress curve versus true strain. Based on this curve, the flow curve is obtained that will supply the values of the strain-hardening exponent and strain-hardening coefficient. The plastic strain ratio (r) is obtained with the same test.

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. Schaeffer [9] has recommended the following equation:

$$PBH = 10^{-3} c\left[\left(LDR - 1\right)^3 + \frac{0{,}005 d_1}{s}\right]\sigma_m \qquad (7)$$

The factor c ranges from 2 to 3; σ_m is the ultimate tensile strength of the sheet.

Blank Holding Force can be calculated using Siebel equation too:

$$PBH = 0{,}025\left[\left(\frac{1}{LDR} - 1\right)^2 + 0{,}5\frac{d_1}{100t}\right]\sigma_m \qquad (7.1)$$

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

$$F_{cr} = \pi d_1 s \sigma_m \qquad (8)$$

In practice the dimensions of the die clearance (U_D), die radius (RD) and punch radius (RP) are often determined from the empirical equations suggested in technical literature:

$$U_D = t + 0{,}02\sqrt{(10t)} \text{ for aluminum} \qquad (9)$$

$$R_D = 0{,}035\left[50 + (D - d_1)\right]\sqrt{t} \qquad (10)$$

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. The punch radius RP should be larger than the die radius by a factor of 3-5.

Selection of the Objective Function

The selection of the right objective is the most critical aspect of optimization in drawing processes. With this information, the solution of the identification problem consists in the minimization of a function that measures the difference between theoretical predictions and experimental data for a given set of parameters. According to the input and output parameters in relation to optimization in deep drawing process the relation involving is presented in Figure 2.

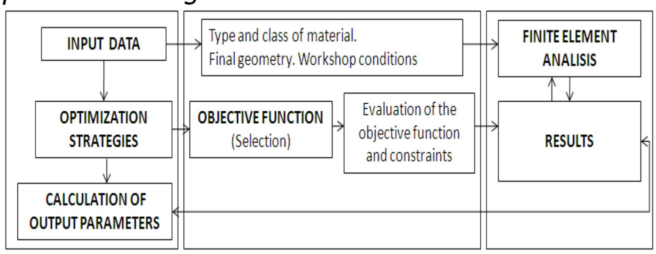

Figure 2. Input and output parameters in relation with FEA and optimization in deep drawing process

In relation to Figure 2, optimization of process parameters such as blank holder force, punch load, friction coefficient, etc., can be accomplished based a on their degree of importance on the sheet metal forming characteristics. An optimal punch load eliminates wrinkling as well as tearing, the two major phenomena that cause failure in formed parts.

Wagner, G. [10], proposed the greatest difficulty in an optimization task is usually to select an appropriate criterion that meets all the requirements to dynamic or static optimization. In this paper the objective function is the drawing load provided during stamping, which is directly linked to the energy consumed by the forming press. The objective function can be formulated as an optimization problem in the following manner, minimize the maximum punch force in the cup deep drawing process. Regarding to figure 1 and 2, the maximum punch force, (FDmax), is determined as the maximum value obtained from the following equation:

$$F_{\max} = \pi d_1 t\left[e^{\frac{\mu\pi}{2}} 1{,}1 K_{fm1} \ln\frac{D}{d_1} + \frac{2\mu F_n}{\pi D t} + K_{fm2}\frac{t}{2R_p}\right] \qquad (11)$$

This equation 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.

PROBLEM FORMULATION

The theory of genetic algorithm shows that the crossover operators as well as the selective operators have no obvious effect on evolution. At the same time, the mutation operators have great potentials for increasing the searching space. In the sheet metal forming, a genetic algorithm simulation program is usually written in C or C++ language. Due to the complicated algorithm, programming is a very heavy and complicated task, which often requires finding mistakes and restoring repeatedly. The programming precision simulation influences directly the precision of the genetic algorithm too. In this paper, the simulation programming was built using the MATLAB genetic algorithm tool box.

Using stochastic methods, such as genetic algorithm, global minimum is obtained after hundreds of evaluations of the functions. The standard genetic algorithm takings, an initial population of individuals are generated at random or heuristically. Every evolutionary step, known as a generation, the individuals in the current population are decoded and evaluated according to boundaries, referred to as the fitness, or fitness function. In this case, the main selection criterion is the number of simulations needed to reach the minimum. The main objective is to reduce wrinkles development by optimizing the total force as a function of technological parameter. This optimal control problem can be stated as follows:

Minimize: FD_{max}

Subject to: $1{,}84 \le LDR \le 2{,}07$

$$PBH = 0{,}025\left[\left(\frac{1}{LDR} - 1\right)^2 + 0{,}5\frac{d_1}{100t}\right]\sigma_m \ge 0{,}3$$

$$F_{cr} \le \pi D_r s \sigma_m$$

The ranges of variables and parameters for Genetic Algorithm are selected as below in Tab. (2) and Tab. (3). Intelligent sheet metal forming, which includes four basic elements, real-time monitoring, identification, prediction and control, is a cross between control science and sheet metal forming theory.

Table 2: Ranges of variables selected for optimization

Variable	Lower Bound	Upper Bound
μ	0.015	0.03
R_p (mm)	16,5	27,5
R_D (mm)	3.5	5.5
P_{BH} (MPa)	30	50
K_{fm} (MPa)	120	148
c	2	2

Table 3: Parameters for Genetic Algorithm

Population type	Double vector
Population size	500
Selection	Roulette
Mutation	Use constraint dependent default
Crossover	Scatteret
Reproduction, crossover fraction	0.8
Elitism	5

RESULTS AND DISCUSSION

The strain-hardening exponent, strain-hardening coefficient and plastic strain ratio were obtained using a tensile test to construct the stress curve versus true strain. The plastic strain ratio (r) is obtained with the same test.

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 made of cylindrical cup made from 3003 ASTM aluminum. The ranges of variables and parameters for Genetic Algorithm are selected in consultation with company professionals. A maximum drawing load of 500 KN requires the geometry of the workpiece in the workshop. The optimization process was effected and the proposed values for a drawing load is 163.19 KN, μ=0.015, Kfm = 120.004 MPa, DR = 371.002 mm, BHF = 33 MPa y Rp = 27.5 mm. 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.

To verify the proposed solution a new simulation was carried. At this time RP = 23-24 (mm) and Kfm = 142-148 (MPa). The optimization process was effected and the proposed values for a drawing load is at this moment 195.43 KN, μ = 0.015, Kfm = 142.003 MPa, DR = 371.002 mm, BHF = 33 MPa y Rp = 24 mm.

Optimization techniques provide a systematic method for determining the process parameters to achieve a specific objective. The present results show that the intelligent control in deep drawing of sheet metal can be successfully used in the field of optimization of 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 and finite element methods.

Punch load have a significant contribution on the product quality. Appropriate punch load and blank holder force evolved through a process results in controlling the thickness variations in a deep drawn part and thus the quality of the part. Therefore, the punch load criteria are chosen to objective function of 3003 ASTM aluminum in this study.

CONCLUSIONS

A method for the control of parameters in sheet metal using genetic algorithm and finite element methods has been presented and applied in the case of cylindrical deep drawing. This method is based on the punch load as objective function criteria. The most important three process parameters were taken into consideration are the blank holder force, the die profile radius and the punch profile radius. The objective function to be minimized was a selection of the appropriate capacity of the press machine. Working with the presses of higher capacities may lead to many types of defects such as cracks and tearing. The main results are as follows:

1. The prediction scheme of the control of parameters in sheet metal was established based on genetic algorithm
2. The genetic algorithm prediction model was established, and the genetic algorithm structure and genetic algorithm parameters were designed.
3. A maximum drawing load of 500 KN requires the geometry of the workpiece in the workshop. The optimization process was effected and the proposed values for a drawing load is 163.19 KN.
4. There is 32.6 % reduction in the forming load.
5. Maximum drawing load is optimized which enables selection of proper capacity press. The other process parameters and geometry parameters are also take in to account.

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