Review of Optimization Aspects for Metal Forming Process

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***Abstract*—Metal forming processes are used to produce structural parts and components that have widespread applications in many industries including automobile, aerospace, appliances. A large number of process parameters need to be optimized in order to meet customer expectations about performance as well as ergonomic and aesthetic aspects of the final product. This paper provides comprehensive literature review about optimization aspects of deep drawing, a kind of metal forming process and shows shear necessity of investigation of the process parameters and process optimization.**

Keywords- Metal forming process; Deep drawing; finite element simulations;design of experiments

I. INTRODUCTION

Metal forming processes include a wide range of operations which deform sheet metal to form the component with the desired geometry. Deep drawing is a metal forming process used to produce a cup like cylindrical component by radially drawing metal blank into the die cavity with the help of a punch. The cup shaped part thus produced has the depth greater than half of its diameter. The change in cross-section is achieved by plastic deformation of the initial blank. Optimization of the process plays an essential role in improving industrial performance measures such as productivity and cost by improving formability, reducing tool wear and reducing scrap percentage. In order to achieve this improvement, a number of process parameters such as blank shape, sheet dimensions, blank holding force, lubrication and punch/die design need to be controlled and optimized. [5]

Due to complexity of the deep drawing process and large number of factors involved in it, it is difficult yet essential to analyze the effect of various parameters and select their optimal values. Traditionally analytical or experimental approaches were used by the industry in order to analyze and optimize the process. However finite element analysis is nowadays accepted and preferred by the industry as it is more economic, time saving and equally effective in predicting the process output. Numerical simulation technology combined with optimization techniques have been applied in sheet metal forming processes in order to improve design quality and shorten design cycle.[29]

II. LITERATURE REVIEW

A. *Review of Parameters Investigated*

Conry et al. (1980) [1] studied and optimized the die profile to avoid fracture. The problem was formulated as a mathematical nonlinear programming model and was solved using regression curve fitting and constrained optimization techniques.

Plevy (1980) [2] studied the effect of lubricating system to minimize the drawing energy consumed in the deep drawing process. He suggested the use of a solid polymer film instead of oil lubrication. The film was shown to be more effective in reducing the drawing energy requirements for low tooling clearances and preserving the surface integrity of the coated metal sheet.

Doege and Sommer(1983) [3] optimized blank holder force for the deep drawing of rectangular parts using FE simulations. In addition, they studied the effect of material selection and lubrication on avoiding fracture and wrinkling.

Bauer and Mueller (1990) [4] were the first to develop a computer-optimized system to control the blank holder force to avoid wrinkling by representing it as a function of the drawing path.

Bauer and Krebs (1994) [6] studied various combinations of lubricant and sheet surface microstructure experimentally and analyzed statistically in order to determine the optimum combination of the two parameters.

Iseki and Murota (1986) and Iseki and Sowerby (1995) [7] investigated the blank shape design for deep drawing of non-axisymmetric cups using finite element simulations with an objective of eliminating the earing effect. They optimized the blank shape for square cup and partially drawn cylindrical cup with a square flange. They developed an inverse finite-element technique to calculate the optimum blank shapes.

Moshksar and Zamanian (1996) [8] conducted a series of cup-drawing tests on commercial aluminum blanks by recording the critical die and punch shoulder radii, the limiting blank diameters and the limiting drawing ratios. They concluded that the process is highly sensitive to the die and punch-nose radii.

Eriksen (1997) [9] studied the relationship between die edge geometry and maximum wear and wear distribution over the die edge. He developed a numerical model and validated it against experimental results. Using this model he examined different die edge geometries, including a standard circular edge, an elliptical edge, a tractrix edge and an edge designed for making wear distribution mode uniform. They concluded that the drawing process is strongly influenced by die and punch nose radius.

Gea and Ramamurthy (1998) [10] developed a numerical model for square shells to maximize the drawability without the occurrence of fracture failure or draw-in failure. They conducted FE simulations using this model in order to determined the optimal blank shape and concluded that circular blank shape is the optimal shape for deep drawing of a square cup.

Jensen et al. (1998) [11] worked on reducing tool wear using the finite-element method and a general optimization technique to redesign the draw-die profile in deep-drawing to reduce tool wear and increase tool life for uninterrupted production.

Park et al. (1999) [12] proposed a new method for blank design by combining the ideal forming theory proposed by Changand Richmond, 1992 with a deformation path iteration method based on FEA which consisted of two stages, the initial blank design stage which generates an approximate initial blank using ideal forming theory and the optimization stage which uses deformation path iteration method to provide an optimum blank design.

Doege and Elend (2001) [13] developed a new blank holding mechanism in which the blank holder was an elastically deformable thin steel plate. It allowed the blank holder to deform and adjust itself to the changes in sheet thickness during the drawing process to exert a more homogeneous blank holder pressure. The design parameters of this blank holder were optimized using FE simulations.

Cao et al. (2001) [14] developed an optimization approach for die design based on suitable design rules and inverse finite elements for the first draw and subsequent drawing steps. This approach could reduce the number of drawing steps from 10 to 6 compared to the practice followed in industry then.

Gašper Gantar et al. (2002) [15] have shared the results of the numerical simulations on various sample parts including determination of optimal product shape and optimal initial blank geometry, prediction of fracture, prediction of final sheet thickness, prediction of wrinkling, prediction of loads acting on the active tool surfaces, prediction of springback and residual stresses in the product. The results of simulations are compared to the samples from the production processes in order to evaluate reliability of the results, costs, benefits, and time required.

Kishor et al. (2002) [16] have studied earing problem in deep drawing of cylindrical cups using a flat bottom punch from extra-deep drawing steel sheets using a finite element method based software LSDYNA and have demonstrated that ear height is significantly reduced by using a noncircular blank.

Pegada et al. (2002) [17] studied the effect of friction, blank holder force and many other parameters to optimize the blank shape to minimize earing. They used the yield function proposed by Barlat (1991)and developed an iterative algorithm based on numerical simulation to estimate earing after each iteration.

H. Naceur et al. (2004) [18] have developed an optimization procedure that combines inverse approach, a BFGS algorithm and analytical sensitivity analysis to optimize material parameters and restraining forces. This procedure helps to estimate large elasto-plastic strains developed in thin sheet metallic parts produced by deep drawing.

Chengzhi et al. (2005) [19] presented an optimization algorithm integrating the finite element method (FEM) and adaptive RSM to determinate the optimal BHFs in deep drawing of aluminum rectangular box. The algorithm was verified experimentally.

Kim and Hong (2007) [20] studied the minimization of the number of drawing steps for molybdenum which requires multiple drawing steps due to its low drawability. They conducted a parametric study using finite element analysis to evaluate the effect of die design variables on number of drawing steps required.

Chen et al. (2007) [21] introduced a new scheme in which the simulation of the blank holding process is based on the blank holder gap (BHG) and showed how the BHF is correlated with the BHG.

F. Ayari et al. (2009) [22] conducted a parametric study of deep drawing using FEM model built using ABAQUS/ Explicit standard code wherein they considered influential parameters such as geometric, material parameters and coefficient of friction and validated them against experimental results.

GAO En-zhi, LI Hong-wei et al. (2008) [23] investigated the effect of material properties on deep drawing of a thin-walled hemispherical surface individually and in combination. The investigation was carried out for two materials, 08AL and CP titanium using 3D-FE model in ABAQUS.

Kopanathi Gowtham et al. (2012) [24] studied the effect of variation in die radius on effective stress, effective strain, max. principal stress, max. principal strain, damage value and load required. They concluded that die radius is an important design parameter and they also optimized it using FE simulations.

Pandhare et al. (2012) [25] used FE simulations to optimize blank holder force in deep drawing process using friction property of CRDQ steel. They studied FLD for different values of μ and found that BHF first increases upto a certain limits and then decreases. For low BHF values, wrinkling defect is observed whereas high values of BHF result into failure, the optimum value is the one which reduces the probability of both the defects.

From above discussion and findings, it is clear that many researchers have contributed to the optimization procedure by investigating various aspects of the process. They have mainly worked towards improvement in formability and elimination of defects such as wrinkling, fracture, thickness variation and other surface defects by careful selection of sheet material and process parameters such as friction, blank holder force, die draw radius, punch radius, blank shape and number of redrawing steps.

B. Review of Optimization Techniques

Three basic approaches adopted for optimization of deep drawing process are analytical, experimental or finite element simulations. In analytical approach, due to the complexity of the process, closed form equations are either difficult to deal with using standard mathematical programming techniques, or are unsuitable in real applications. In experimental approach, following the initial design of the tools and choice of process parameters, an extensive and time consuming trial and error process is required to determine the optimum design and process parameters. Finite Element Simulations can replace experimental trial and error process by a virtual trial and error process.

Browne and Hillery (2003) [26] also used DOE to study the effect of the deep drawing parameters such as die geometry, blank-holding pressure, top-ram pressure, lubrication, and drawing speed on the punch load and variation in the thickness of the walls.

Ohata et al. (1996) [27] optimized deep drawing process using FE simulations using nonlinear FE analysis code combined with nonlinear optimization code. They developed a nonlinear algorithm called sweeping simplex method for finding out the global optimum and applied it for two design parameters. Ohata et al (1998) then worked on three design variables and verified the results by comparing with experimental results.[28]

On the similar lines many researchers have developed optimization strategies using Finite element (FE) simulation and analysis. Some of the recent researches are quoted here to demonstrate the effectiveness and acceptance of FEA in the field of research.

Y. Q. Li et al. (2006) [29] have developed a CAE-based six sigma robust design procedure to eliminate uncertainties in designing the deep drawing process. This approach integrates Design for Six Sigma (DFSS), reliability optimization and robust design by applying Design of Experiment, Analysis of Variance, and Dual Response Surface Model and the procedure is applied on deep drawing of square and cylindrical cups to optimize thickness variation under the constraints of wrinkle and rupture criteria.

R. Padmanabhan et al. (2007) [30] studied the significance of die radius, blank holder force and friction coefficient on the deep-drawing characteristics of a stainless steel axi-symmetric cup using finite element method combined with Taguchi technique. They carried out a reduced set of finite element simulations based on the fractional factorial design of L9 orthogonal array and analyzed the relative importance of the selected parameters on thickness distribution using ANOVA. From the analysis they concluded that die radius has the greatest influence on the deep drawing of stainless steel blank sheet followed by the blank holder force and the friction coefficient.

Magar et al. (2010) [31] employed analytical, numerical and experimental techniques to determine sheet blank size and estimate formability and thickness distribution. They have suggested a analytical relationship to obtain a initial blank size for cup shaped deep drawn components and have shown 90-95% consistency between the results obtained by the three methods.

P V R Ravindra Reddy et al. (2012) [32] have studied the effect of blank holding force and die draw radius on the limit strains in deep drawing process using an explicit finite element code LSDYNA. They have validated the results of the simulations with the strain values obtained by analytical formulae for power law plasticity models. The observations from the investigation were increase in limit strains with increase in die corner radius. They also concluded that even though safer deformation zone increases with blank holder force (BHF), limit strains are independent of BHF at lower ratio of principal strains.

R. Venkat Reddy et al. (2013) [33] have conducted a parametric study of BHF, sheet thickness, die profile radius, punch profile radius, initial yield stress, sheet anisotropy and imperfections. They found that maximum cup height at the onset of wrinkling increases with Blank Holding Force (BHF), sheet thickness and an increase in the die profile radius as well as punch profile radius. They also concluded that die profile radius is more significant and resistance to wrinkling also depends on anisotropy.

Dhaiban et al. (2014) [34] have used commercial FE-package ANSYS/APDL to investigate the effects of die and punch geometry on limiting drawing ratio (LDR), drawing load and thickness strain of the cup for their new technique of deep drawing for elliptic cups through a conical die without blank holder or draw beads.

Hence it is evident that researchers are successfully using FE approach in order to optimize deep drawing process and FE simulations using various FE softwares such as ANSYS, ABAQUS, Hyperform, LSDYNA are gaining more and more importance in metal forming industry. It is also evident that numerical simulations can be combined with optimization techniques such as design of experiments, analysis of variance, Taguchi's robust design in order to improve design quality and reduce design cycle time.

III. CONCLUSION

Complexity of the process and a large number of factors involved makes analysis and optimization of the deep drawing process challenging and hence many different tools and techniques are developed and will be developed in future. It is evident that optimization of deep drawing process using finite element analysis coupled with various Taguchi techniques is more economic and effective in improving product quality and reducing manufacturing cost by saving costly trial and errors during design phase. There lies a future scope of conducting a more comprehensive parametric study of the deep drawing process parameters using finite element simulations and their interactions for optimizing the process using full factorial design of experiments.

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