Optimizing the behavior of deep drawing process with stress and strain variation using finite element simulation by changing different die angle

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Abstract— Deep drawing is a sheet metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch. Deep drawing process is a shape transforming method. Defects like cracks and wrinkling of deep drawing occur very often in conventional cylindrical deep drawing process because of the lower forming ability of aluminum alloy sheet at room temperature. Therefore, a different approach is discussed in my research to obtain some new prediction of behavior with variations of deep drawing. This method helps to push the sheet metal in different angular direction. In addition, the effect of co-efficient of friction is predicted while performing deep drawing. In order to avoid the costly, tedious and difficult experiments, modern manufacturing industry is based on the analysis of forming processes in numeral atmosphere before the actual production set-up. In the work, the single stage deep drawing process is used by means of a finite element analysis. Simulation of the deep drawing process for determining stress distribution in the drawn component for different variations is explained in my work. The distribution of stress in the drawn component is obtained. Thus simulation of deep drawing is being carried out on alloy steel at different die angles and to check its performance. Also its behavior is tested at various co-efficient of friction. The result of simulation will be beneficial to the tool designer and the manufacturing industries doing work in this field.

Key words: Finite element method, Simulation, Sheet metal forming, blank holding force.

I. Introduction

As we know there are a lot of uses of the finite element method, still the simulation of forming process provides great challenges to overcome because of the complex physical phenomena. Failure in sheet metal parts during deep drawing phenomena usually occur in the form of bulging, wrinkling, or necking. After viewing so many research papers it can be seen easily that there are many variable that affect the failure in deep drawing problems. These include material parameters, die design and process parameters like friction conditions, work element of die, the material characteristics and material anisotropy, design of die, height of die depth, the drawing ratio as well as the blank- holder force (BHF), and the effective control of these parameters can reduce the failure of the parts and can produce better end products. Generally , the blank holding force has to increase along with the increase along with the increase of the drawing depth, but we should take into our consideration the process fact that if its value is too large then it may lead to cracks and even a break of the material. The main geometric parameter, wrinkling like phenomena is punch diameter and punch radius. Increase of friction can reduce the defect related to wrinkling; on the other hand very high value of coefficient of friction can cause cracks and material breakage. Phenomena of instability which appears at the end of process of plastic deformation and which lead the modification of the shape of the deformed parts after the deformation forces have stopped. Therefore the important behavior of this kind is the process of elastic recovery.

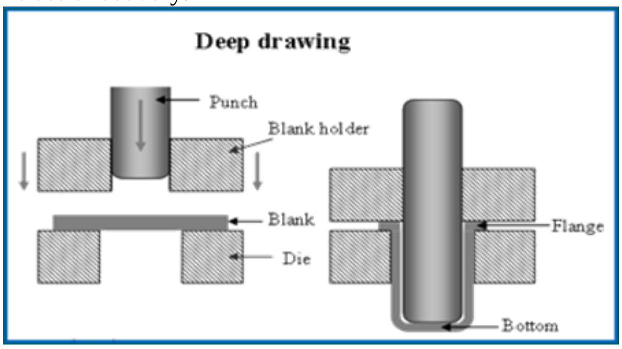


Fig. 1:

The forming processes of sheet metal are technically among the most important metal forming processes. Various end products obtained by sheet metal include a very large variety of different geometrical shapes and sizes, like simple bend to double curvatures even with the deep recesses and very complex shapes as well. Various common examples include aircraft panels, appliance bodies, kitchen utensils and beverages cans. Sheet metal processes are widely used in the manufacturing industries.

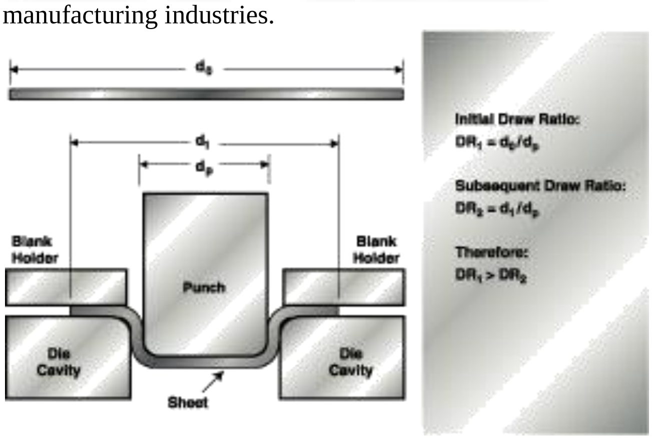


Fig. 2:

A. Advantages of Deep Drawing:

Deep drawing may be a viable solution for any manufacturing process that includes one or more of the following:

Seamless parts: deep drawn metal parts are created from a single sheet of metal.

Rapid cycle times: large quantities of products are easily manufactured through the deep draw process.

Complex geometries: deep drawing delivers exceptional detail and accuracy.

Reduced technical labor**:** precision deep drawing can deliver similar results as technical labor in quicker time frames

B. Finite Element Method:

The finite element method is a numerical technique which is commercially used for the finding of an approximate solution of partial differential equation as well as integral equation. In some solving partial differential equations the first problem is to create an equation that approximate the equation which is to be studied. It means that during calculations the error should not accumulate, thereby causing the output as to be meaningless.

C. How FEA does work?:

There is complex system of points used by FEA, called nodes which make a grid called a mesh. It is programmed to constitute the material and structural properties. These properties define behavior of structure on loading conditions. Nodes are assigned at certain region throughout the material depending on the stress levels of a particular area. The areas having larger stress usually have a higher node density as compared to those which experiences little or no stress. Various points of interests may consist of: fillets, corners, high stress areas, fracture point of earlier testes materials. The meshed part will be seen like a spider web in that from each node, and it extends to each adjacent nodes.

The concept of popular method finite element analysis is to simplify and solve the solution of complicated problem in relatively easy way. The finite element analysis is a powerful and useful tool for the numerical solution of a wide range of engineering problem. Applications ranges from deformations to stress analysis of automotive, aircraft, building, defense, missile, and bridge structures to the field of stability, fracture mechanics, dynamic analysis, heat flux, fluid flow, seepage, and other flow problems. With the advances in computer technology and CAD systems, complex problems can be modeled with some other relative case. Several alternate configurations can be tried out on a computer before the first prototype is built.

The solution region in FE method is considered as built up of many small, interconnected sub regions called finite elements. The need is to predict the behavior of structure the designer takes three types of tool such as analytical, numerical and experimental methods. The method of finite element I very much popular because of its favorably usage of computers. The FE method gives the component behavior at desired accuracy for any complex structure and any irregular geometry.

In finite element analysis (FEA) though exact equations are formed but approximate solutions are obtained, unlike to that of classical methods in which exact equations are formed and exact solutions are obtained. In this FEM solutions obtained are not limited to few standards only; here solutions can be obtained for all problems by finite element analysis. FEM can handle structures with anisotropic material properties also without any difficulty. FEM has also advantage that if structure consists of more than one element, it is easy to use it without any difficulty. Also the problems with material and geometric non-linearity are not to be handled by classical methods. There is no difficulty in FEM.

FEM make piecewise approximating function i.e., it ensures the continuity at node points as well as along the sides of the element. FEM can give the values at any point. However, the outcome occurs at points other than nodes by using interpolation formulae. FEM can consider the slopping boundaries exactly. If curved elements are used, even the curved boundaries can be handled exactly. Also FEM have advantage to get good results by using fewer nodes as compared to FDM.

Field variables: In engineering problems there are some basic unknowns. If they are found the behavior of the entire structure can be predicted. These unknowns are called field variables in FEA. For example: Displacements in structural mechanics, Temperature in Heat flow processes, velocities in fluid mechanics, electric and magnetic potentials in electrical engineering etc.

In a continuum, these unknowns are finite. The FE procedure reduces such unknowns to a finite number by dividing the solution region into small parts called elements.

In FE procedure the unknown field variables are expressed in terms of assumed approximating functions within each element. The approximating functions are defined in terms of field variables of specified points called nodes or nodal points. This function which relates to the field variable at any point within the element to the field variables of nodal points is called shape function.

II. LITERATURE REVIEW

The applications of the finite element method to the numerical simulation of the deep-drawing process has evolved in efficient and significant way in the course of the last few years. Many of the problems associated with numerical simulation of this process have been solved or at least are better understood. Reviewing the research papers of various authors available on simulation of drawing of cylindrical product. Relatively a few research works has been done for finite element simulation conical product. The conical shaped product made on hydraulic power press was extensively used in the engineering and day life.

Various related literature such as transactions, proceeding of various national and international conferences and other journals which were available are reviewed.

A. Existing Related Researches:

Marek Hauptmann, [February 2016] the aim of his paper was to describe the capabilities of variable blank holder force trajectories for improve the distribution of wrinkles and the quality of 3 D structures. The results showed that the blank holder force should be adapted to the punch position keeping the highest possible force level. The force can increased during the drawing process and needs to be strongly reduced short before the blank is drawn out of the blank holder completely. The induced force trajectories lead to an optimized visual quality increasing the initial height where wrinkles occur encouraging fiber to fiber movement at the beginning of the process. The results further more contribute to a better understanding of the rupture behavior.

Sachin S Chaudhary, [December 2015] In this paper the effects of reverse deep drawing process parameters was determined by FEA study with the use of Design Experiment method and analysis of variance (ANOVA) using Minitab software for CRDQ steel in order to reduce the amount of spring back. Finaly confirmation test showed optimized spring back effect. Improved spring back quality characteristics of weld joint obtained.

Raghuram Karthik Desu, [October 2015] in this paper the experimental results were compared with finite element simulations. Holding force in simulation was calculated by inverse analysis of comparing the load displacement curves. In hydro mechanical deep drawing, the process was assisted by a counter pressure of hydraulic nature.

Martinez-Martinez, [August 2015] Transformation induced plasticity (TRIP) steels, which were made initially for automotive applications, have attracted a growing interest due to the fact that they exhibit a combination of high strength and ductility through their multi-phase microstructure that includes ferrite, bainite and retained austenite. This one transforms to martensite under the external tensile stress. Electron Back Scatter Diffraction (EBSD) technique could be used successfully for determining the texture and fiber components in the body centered cubic (BCC) and face centered cubic (FCC) Phases and try to establish the role of deformation in the microstructure transformation. The main aim of the presented work was to evaluate the changes in the microstructure and texture of TRIP sheet steel by EBSD technique due to the multiaxial stresses taking place during stamping operations.

M. Huseyin Cetin, [July 2015] Temperature is the effective parameter which is used in the warm deep drawing (WDD) process to make it better for the formability of light-weight engineering tools, and this feature requires very accurate means of calibrations and observation of temperature for process stability. In this study, an evaluation of the WDD process was conducted according to the forming temperature curves characterized from work-piece temperatures otherwise of tool temperatures, as usual. The characteristic behavior of these curves was experimented under non-isothermal WDD of AA 5754-O. In the experimentation stage, the process parameters, namely FTC, blank holder force and punch velocity, which assure successful deep drawn ability, were determined according to the failure-free cups by analyzing the wrinkling and tearing conditions and minimum cup height parameter as output. As the next step optimum conditions were investigated by evaluating the volume of cup and its spring back parameters. As a general conclusion, approximately 330^{o} C in the Flange-die radius region and 100^{o} C in the cup wall-punch bottom region are the optimum temperatures for the warm deep drawing process.

Minsoo Kim, [August 2014] in his work, an additional 1st stamping tool with a 2-step stamping model was used to minimize stamping flaws in the curved parts of dimple, which is used in nuclear fuel spacer grids. Firstly, the strains are analyzed and compared with solution of strains for pure bending. A reference model (2D FE) is designed and corresponding strains were obtained. The solution obtained by FEA for 1st stamping was used in 2nd stamping. Strains are expressed as a function of process variable on the basis of these obtained solutions after applying RSM (Response Surface Method). This helped in evaluation of optimum variable values of a process. Finally, he confirmed the optimized formability of the proposed 2-step stamping model, by transferring the obtained optimized value to 3D FE model.

Jay N. Mistri, [June 2014] A blank holding force, punch force, material property of sheet metal, thickness of sheet, velocity of punch, these are all affecting parameters in deep drawing process to regulate wrinkling effect, tearing effect and fracture defect. Nowadays composite material is extensively used in manufacturing industries due to its better strength. Therefore with the help of experimental and simulation tools investigation of stress and strain distributions in the deep drawn cup were also done the finite element results can be predicted the sample of tearing and wrinkling error for bimetal cup as occurred in experimental tests.

Sachin Ramdas Jadhav, [June2014] as we know that sheet metal forming problems is typical in nature since they involve geometry, boundary and material non-linearity. Drawings part involves many parameters like punch and die radius, clearance, lubrication, blank holding force and its trajectories etc. thus designing of tools for part drawing involves a lot of trial and error method. This paper was relevant in the context of developing a cost effective die with a lower lead time through the phase of design, development, trials and testing, pilot lot production & regular supply. The deep drawing process being critical for calculate offers higher scope for study and research while addressing the most effective design for the drawn die. Sheet metal die was an inseparable constituent of the development process of any given automotive or consumer appliance. In most of the cases, this accounts for a high proportion in the tooling needed of the large size and structural member in any automotive lie the chassis and the BIW.

R. Venkat Reddy, [March 2013] in this paper it was shown that how wrinkling and fracture defects can be prevented using blank holding force (BHF) which has to be optimized as lower BHF promotes wrinkle formation and higher BHF promotes fracturing. Hence the limits of wrinkling and fracture had to be established. Dependency of these limits is on tooling and process parameters. In his work the effect of tooling parameters like die corner radius and punch corner radius on wrinkling and fracture limits were investigated using a finite element explicit solver LS-DYNA. And for the analysis he used constant blank holding force.

Bharat Kumar A. Modi, [August 2012] in his work, he has designed an experimental set up. And deep drawing has been performed using aluminum sheets of ally AA5182 with the help of developed experimental set-up. Through finite element method an optimum blank shape has been found. A methodology is used in order to find blank force path for successful hydro forming of the cups. Better formability is achieved in terms of minimum corner radius. Dependency of process parameters peak pressure, blank holding force and pressure path is checked with numerical simulations and experimental work.. Taguchi method is used for the experiments. For the prediction of minimum thickness in the cup and corner radius regression models have been developed. Also it has shown that high peak pressure can be withstood by lubricated conditions with Teflon. To predict forming limits by modifying Stoughton's stress based criterion using Barlat's 3-parameter yield function some analytical procedure is developed.

III. METHODOLOGY

In this section framework is to optimize the die angle for deep drawing process. Various parameters which are used for the process are explained in detail

A. Activities:

List of activities that has been performed in order to achieve our goal is enlisted below:

1) Problem identification
2) Literature survey
3) Study of parameters
4) Study of existing types of deep drawing
5) Selection of material for sheet metal
6) Selection of simulation process
7) Application of FEA on deep drawing process.
8) Finally conclusion will be discussed.

IV. IMPLEMENTATION

A. Material used:

Sheet material used is AISI 1020. It is most commonly used low carbon steel. It is a material having low hardenability and low tensile carbon steel having Brinell hardness of 119-235. It has high machinability, high strength and high ductility. It is usually used in cold drawn condition. AISI 1020 steel can be used very extensively in industrial sectors. It has tensile strength of 395 MPa.

B. Significance of AISI-1020:

- AISI stands for American Iron and Steel Institute.
- The digit at first place indicates that this is Plain carbon steel.
- The second digit indicates there is no any alloying element.
- The two digits at last indicate that the steel contains approximately 0.20 % carbon by weight.

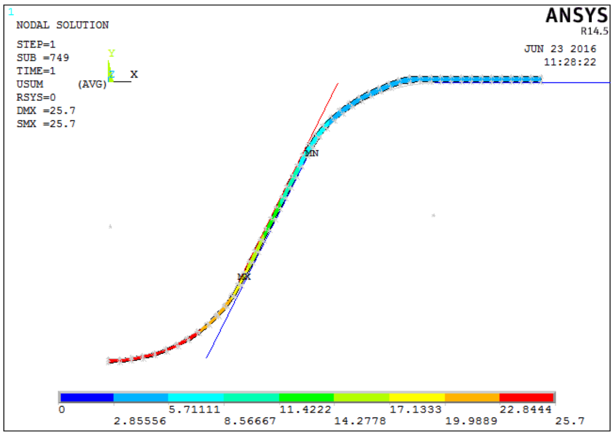
C. Material properties:

In this work various parameters that are used for the getting optimized result are as follows:

Mechanical properties	Metric system
Hardness, Brinell	111
Hardness, Rockwell	64
Tensile strength, Ultimate	394.85 MPa
Tensile Strength, Yield	294.74 MPa
Elongation at break	36.5 %
Modulus of elasticity	200 GPa
Bulk Modulus	140 GPa
Poisson ratio	0.29
Shear Modulus	80 GPa

Table 2:

V. RESULT



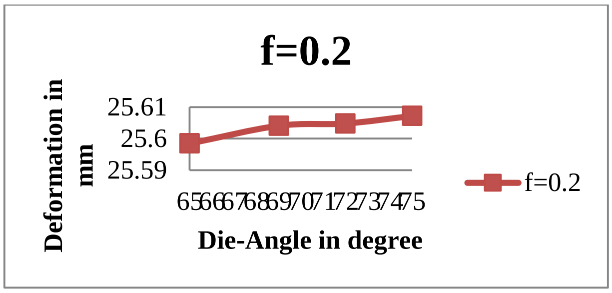
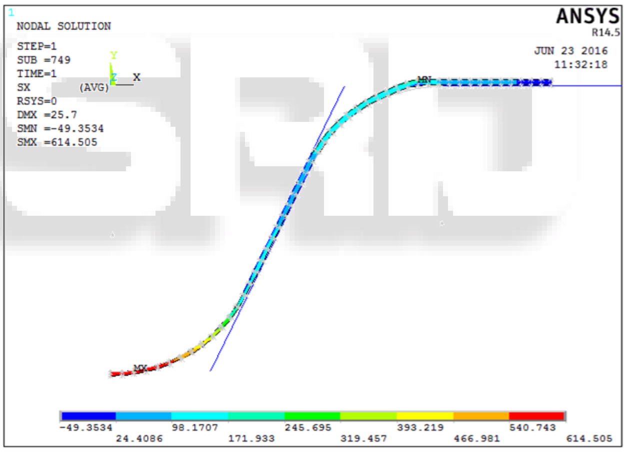


Fig. 3: Relationship between deformation and Die-Angle



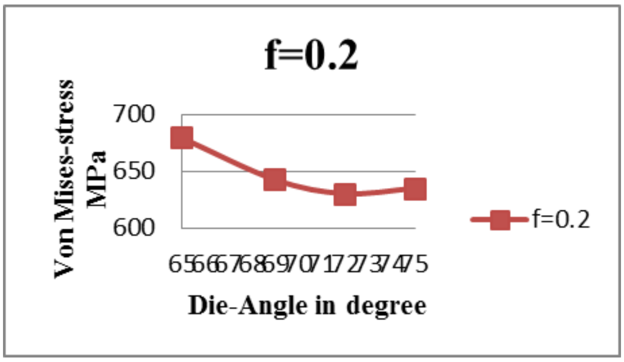
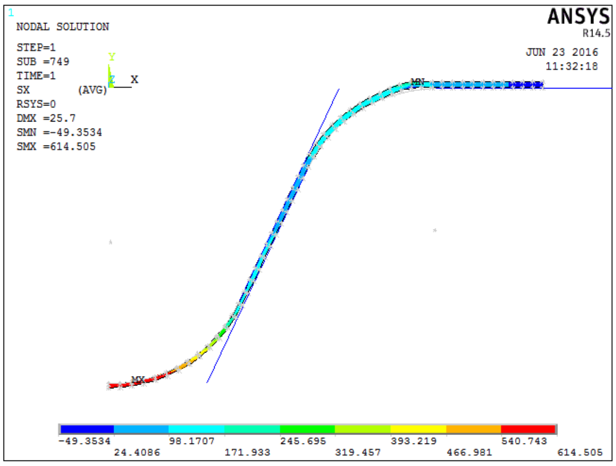


Fig. 4: Relationship between Vonmises strain and Die-Angle



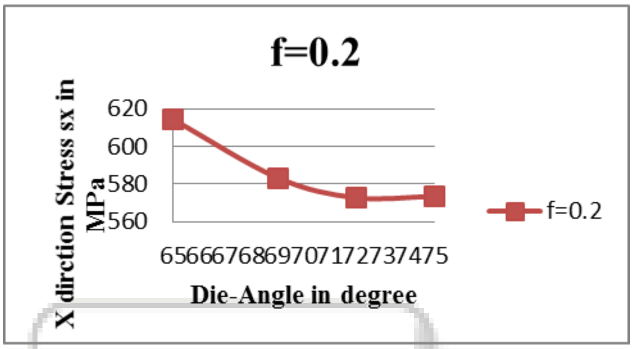


Fig. 5: Relationship between Stress in X direction and Die Angle

Die angle	Friction	Deformation mm
65	0.1	25.5985
69	0.1	25.5988
72	0.1	25.6037
75	0.1	25.6084

Table 3: Relationship between die angle and deformation

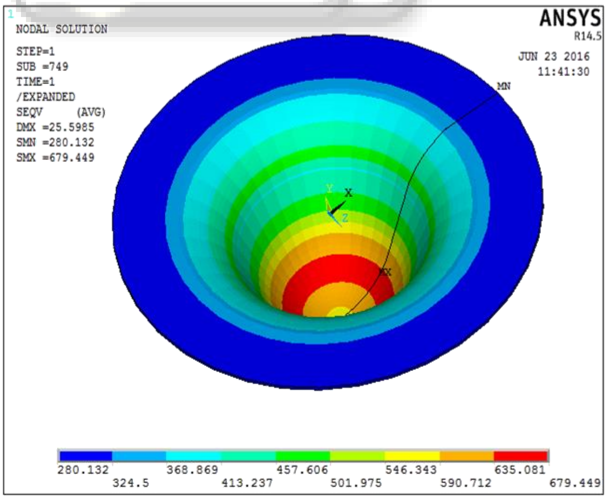


Fig. 6:

Die angle	Friction	Total mech-strain	Vonmises stress MPa
65	0.2	0.508555	679.449
69	0.2	0.469534	642.604
72	0.2	0.457046	630.233
75	0.2	0.461951	634.925

Table 4: Relationship between die angle, total mechanical strain and stress

Die angle	Friction	X stress	Y stress
65	0.2	614.505	565.633
69	0.2	583.468	575.902
72	0.2	572.796	596.548
75	0.2	573.554	624.723

Table 5: Relationship between die angle and stresses in X and Y directions

VI. CONCLUSION AND FUTURE SCOPE

Finally a useful conclusion is obtained regarding the behavior of stress and strain variation in deep drawing process. The best angle used for deep drawing process is 72^0.

Material parameters obtained at 72^0 die angle are optimum and are quite better than that used by Jamal Hematian in his research work "finite element modeling of wrinkling during deep drawing".

Blank holding force and stress variation obtained are quite better as obtained by Ali Abbar khleif in his work "effect of blank holder force on strains and thickness distribution in deep drawing process".

As many new materials are coming up into picture with lot of new properties. In future lot of composite materials will be used in order to improve the deep drawing operations. Lot of industrial parts will be made using this deep drawing material. Defects are minimized. Many other fields will be using deep drawing process in order to manufacture their parts.

REFERENCES

[1] M. Hauptmann, J. Weyhe, and J.-P. Majschak, "Optimisation of deep drawn paperboard structures by adaptation of the blank holder force trajectory," J. Mater. Process. Technol., vol. 232, no. ISSN 09240136 June, pp. 142–152, 2016.

[2] S. S. Chaudhari and N. K. Patil, "SPRING BACK PREDICTION OF SHEET," vol. 6, no. 12, pp. 9–17, 2015.

[3] R. K. Desu, "Comparative study of warm and hydro mechanical deep drawing for low- carbon steel," no. October, 2015.

[4] M. H. Cetin, A. Ugur, O. Yigit, H. Gokkaya, and E. Arcaklioglu, "Development of Forming Temperature Curves for Warm Deep Drawing Process Under Non-isothermal Conditions," Arab. J. Sci. Eng., vol. 40, no. 9, pp. 2763–2784, 2015.

[5] N v s Shankar v hari Shankar, v ravi kumar, "fatigue analysis of polymer composite," ijmerr, vol. 4, no. 2, 2015.

[6] U. Pranavi, P. V. Reddy, and P. J. Ramulu, "Formability Studies on Aluminum Alloy Sheets through Deep Drawing Process," no. Aimtdr, pp. 1–6, 2014.

[7] V. Naranje and S. Kumar, "Expert Systems with Applications A knowledge based system for automated design of deep drawing die for axisymmetric parts," Expert Syst. Appl., vol. 41, no. 4, pp. 1419–1431, 2014.

[8] J. Fang, J. Mo, J. Li, X. Cui, and S. Fan, "Electromagnetic pulse assisted progressive deep drawing," Procedia Eng., vol. 81, no. October, pp. 801–807, 2014.

[9] P. A. C. S. Reddy, S. Rajesham, and P. R. Reddy, “Experimental Study on Strain Variation and Thickness Distribution in Deep Drawing of Axisymmetric Components,” vol. 2, no. 12, pp. 2214–2219, 2013.
[10] M. Bennasar, R. Setchi, A. Bayer, and Y. Hicks, “Feature Selection Based on Information Theory in the Clock Drawing Test,” vol. 22, pp. 902–911, 2013.
[11] R. V. Reddy and T. A. J. Reddy, “Effect of various parameters on Wrinkling with imperfections in Deep Drawing of Cylindrical Cup,” vol. 3, no. 5, pp. 679–684, 2013.
[12] Bharatkumar A. Modi, “investigations on formability of aa5182 aluminum alloy in hydro forming of square cups,” 2013. ISSN 1433-3015
[13] M. Karali, “Examination of the Strength and Ductility of AA-1050 Material Shaped with the Multi-Stage Deep Drawing Method,” Arch. Metall. Mater., vol. 56, no. 2, pp. 223–230, 2011.
[14] Jamal Hematian “Finite Element Modeling of Wrinkling during Deep Drawing of Pressure Vessel End Closures (PVECs)”. Queen's University Kingston, Ontario, Canada 0-612-55911-4
[15] Sniekers, Roland Johannes Joseph Marie, “Friction in deep drawing” [April 1996] ISBN 90-386-0417-3
[16] Morovvati, M.R.; Mollaei-Dariani, B.; Asadian-Ardakani, M.H. (2010), "A theoretical, numerical, and experimental investigation of plastic wrinkling of circular two-layer sheet metal in the deep drawing", Journal of Materials Processing Technology, **210** (13): 1738–1747.