A STATE OF ART IN A SHEET METAL STAMPING FORMING TECHNOLOGY - AN OVERVIEW

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Abstract - Sheet metals are widely used for industrial and consumer parts because of its capacity for being bent and formed into intricate shapes. Sheet metal parts comprise a large fraction of automotive, agricultural machinery, and aircraft components as well as consumer appliances. Sheet metal forming is the process of obtaining the required shape and size on the raw material by subjecting the material to plastic deformation through the application of tensile force, compressive force, bending or shear force or combinations of these forces. Forming is a widely-used process which finds applications in automotive, aerospace, defense and other industries. Sheet metal forming is one of the non-cutting operations that can be performed on power press. Sheet-metal forming is a more complex operation than cutting or bending, and more things can go wrong. Several defects can occur in a formed product like wrinkling in flange and cup wall, tearing, earing and surface scratches etc. To reduce various defects in deep drawing process it is essential to control or vary some parameters of it. 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.

This paper presenting important researches undertaken in the field and their valuable findings which may be helpful for future work.

Keywords – Sheet metal forming, formability, simulation, finite element analysis, wrinkling.

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1. INTRODUCTION

Stamping is one of the main methods of metal plastic working and belongs to material forming engineering. Sheet metal stamping is a kind of manufacturing technology that deforms sheet metal using a tool known as die. The deformation force is supplied by the power of regular or special stamping equipments such as press or machines to obtain a product components with certain shape, size, and performance. Sheet metal stamping is one of the main manufacturing processes which is widely used to create majority structural components for modern automobiles due to its merits such as the high production rates, low manufacturing costs and maximum material utilization which again in turn reduces cost of material scrap. To produce such improvements using more advanced materials, which are more expensive, is not always the solution as the material cost can be approximately 70% of the final part cost in sheet metal forming applications.

Nowadays, sheet metal forming is experiencing a fully automatic mass production in the field of automotive industry, household commodity, beverage cans, and other industries. With the rapid growth of automobile production, intense competition among many automakers with overcapacity results in the reduction of sales price of different car models. Meanwhile, a growing demand for cars with lighter weight, lower power consumption, higher reliability, and higher quality puts forward higher requirement for stamping technology. The tailor-welded blank, high-strength steel, bake-hardening sheet, and aluminum alloy have been applied in automotive production in succession. CAD/CAE/CAM integration technology is playing an increasingly important role in product design, mold design, and manufacturing process. In addition, internal high pressure-forming parts and air springs are also applied more and more widely, which effectively improves the vehicle's reliability and comfort. There are many different types of stamping processes to meet the requirements on the shape, size, internal and external quality, and number of workpieces. Generally, a multi-channel stamping process is needed for a stamping part. Due to the variety of shape, size, precision, production volume, and raw materials, there are also different processing methods which are used in cold stamping.

To sum up, sheet metal stamping can be divided roughly into separating process and shaping process. Separating process is a stamping process through which the sheet can be separated by a certain contour to obtain stampings (also known as blanking) with certain shape, size, and cut surface quality. It includes blanking, piercing, incision, slice and other processes. Shaping process is a stamping process in which plastic deformation is produced under the condition of no material cracking and then the stamping parts with a certain shape, size, and precision are obtained. It includes bending, deep drawing, flanging, distortion, bulging, necking, etc. Materials used in stamping should not only meet the technical requirements for product design, but also shall meet the functional requirements of the stamping process and subsequent processing requirements. It is assumed that the failure limits are a property of the sheet. This assumption is reasonable if through-thickness stresses are negligible, and if each element follows a simple, linear path represented by a straight line radiating from the origin. In stamping, drawing, or pressing, a sheet is clamped around the edge and formed into a cavity by a punch. The metal is stretched by membrane forces so that it conforms to the shape of the tools. The membrane stresses in the sheet far exceed the contact stresses between the tools and the sheet, and the through-thickness stresses may be neglected except at small tool radii. Stamping processes to be used for a panel depend on its design. However, normally the processes used extensively are blanking, drawing, piercing, forming, notching, trimming, hemming, etc.

2. LITRATURE SURVEY

Literature review has been categorized based on parameters which decides the successful execution & the quality of the final formed part. These utmost important parameters are:

1. Material formability
2. Simulation & Finite element analysis.
3. Optimization of process parameters
4. Failure modes in forming.

i. Material formability:

Recent materials developments include the introduction or increased application of advanced high-strength steels, magnesium alloys, and various ultrafine-grain materials for superplastic sheet forming. The basic physical properties of material are: E, ν & ρ. Basic mechanical properties are: YS, TS, and % El.

The material properties which are requires in forming are:

1- n - It is a coefficient, which gives a quantitative measurement of the strain hardening characteristic of a material. In materials with high n value, the flow stress increases rapidly with strain. Larger the n value, the more the material can be deformed before necking i.e. higher n value increase resistance to necking. Therefore, due to the uniform deformation, forming limit or formability increases.
High n - good formability in a stretching operation.

2- K- Strength coefficient.

3- r - Plastic strain ratio = $\varepsilon w / \varepsilon t = \ln (wf / wo) / \ln (tf / to)$. It is the ratio of the true width strain to the true thickness strain. r value frequently changes with direction in the sheet. It measures of the ability of a material to resist thinning. Higher 'r' value increases the drawability of a component.

4- R - average normal anisotropy = (r 0 + 2 r 45 + r 90) / 4, subscripts refer to the angle between the tensile specimen axis and the rolling direction. It determines the average depth of the deepest draw possible in a single draw operation

Formability is a term applicable to sheet metal forming. Formability is the ease with which a sheet metal could be formed into the required shape without undergoing localized necking, thinning or fracture. When a sheet metal is subjected to plane strain deformation, the critical strain, namely the strain at which localized necking or plastic instability occurs can be proved to be equal to 2n. Forming limit diagram is a very effective way of optimizing sheet metal forming. A grid of circles is etched on the surface of a sheet metal. Then the sheet metal is subjected to deformation. A plot of the major strain versus minor strain is then made. This plot is called Keeler-Goodwin forming limit diagram. This plot gives the limiting strains corresponding to safe deformations. The FLD is generally a plot of the combinations of major and minor strains which lead to fracture. Combination of strains represented above the limiting curves in the Keeler-Goodwin diagram represent failure, while those below the curves represent safe deformations.

The forming limit diagram for component can be found by experimentally and by simulation software. Experimental and numerical results were found to agree closely. Also, it was found that Fast form advanced software can simulate the forming of component accurately. The results of study are summarized as:

1. The safe point obtained by experimentally is having maximum minor strain and major strain coordinates -2.5 and 8.9 respectively and that of numerically are -2.786 and 8.673.
2. The wrinkling tendency point obtained by experimentally is having minor strain and major strain coordinates -12.5 and 7.5 respectively and that of numerically are -14.774 and 10.802.
3. The wrinkling tendency present on the side wall. 4. Safe zone present on the bottom part of the component[20].

Forming Limit Diagrams represent the formability limits in the coordinate system of major (ε1) and minor (ε2) principal strains as shown in Figure 1. The formability limit is usually characterized by the failure (rupture) and this is called as formability (fracture) limit curve. At certain level of compressive stresses a local instability of sheet can also occur: this phenomenon is regarded as wrinkling. It is also evident that besides rupture and local necking, wrinkling should also be avoided. The forming limit diagram with these limit curves and zones is shown in Fig 1. Below the local necking zone, the green zone indicates the safe region of normal forming conditions in terms of major (ε1) and minor (ε2) principal strain[11].

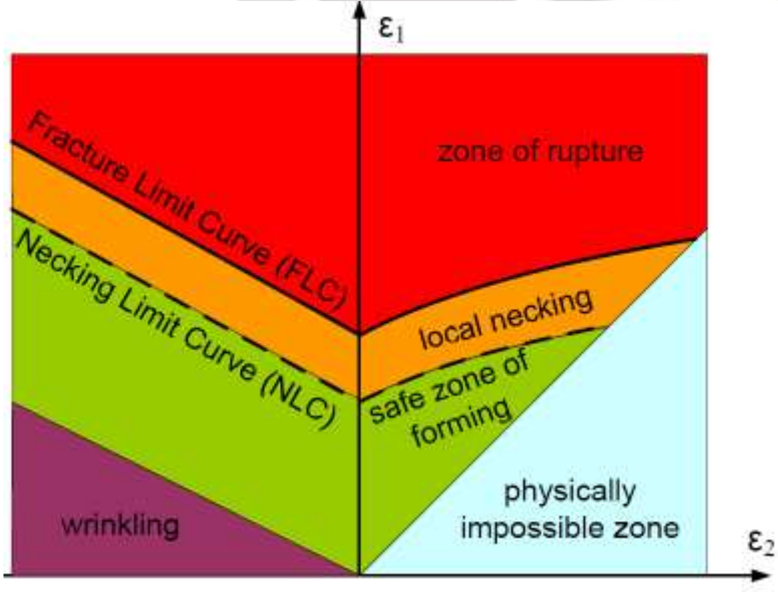


Fig 1: Characteristics limit curves & zones of FLD[11].

As it can be seen from the Fig 1, there are various limit curves and the zones denoted by different colors mean different behavior from the point of view of formability. The FLC represents those limit values of ε1 and ε2 where fracture occurs. While to observe the onset of fracture is quite easy, however to determine the principal strain values at the onset of rupture is rather complicated. The NLC represents the onset of local necking[11]. Though the exact measurement of principal strain components at the limit state of necking is at least as difficult as it is for the onset of fracture, but this limit is more acceptable for real industrial parts, since at this stage still there is no any undesirable local necking. It can also be stated physically wrinkling impossible zone of rupture ε_1 ε_2 that due to the modern optical strain measurement facilities, continuously improved and further developed possibilities are available for both the scientific research and for the everyday industrial practice, too. Among the several parameters affecting the sheet formability, the effect of material grades, the strain hardening exponent and the anisotropy coefficient were studied as material properties. Besides these material properties, the effect of sheet thickness was also investigated. It was stated that the sheet formability is increased with the increasing value of strain hardening exponent and the anisotropy coefficient. It was also proved that the increase of the sheet thickness has a favorable effect on the forming limit diagrams concerning the available strain limits[11].

The forming behavior of cold rolled closed annealed steel sheet in Selected samples with proper annealing and chemical composition for better formability was investigated by Erichsen Cupping test method. The results showed that the formability of cold rolled closed annealed steel having lower percentage of carbon is lesser forming property and ductility. It was found that the stress distribution and the grain density of the sheet material confirm the formability. The best combination of strength and ductile properties has steel with the low carbon and better forming property. Carbon percentage is less in CR4 other than three samples because of less grain in unit area as compared to other three samples. The grain size of CR4 material is smaller than the other steels indicating bigger size of grain with low grain boundary area making the material ductile with less week spots. Large surface area of grain and less boundary area confirm that CR4 is more soft and ductile in nature as compared to other three samples. Fine grain structures give more grain boundaries and hence development of internal stress whereas a CR4 has better stress relief property because of less number of grains. Better formability in CR4 as compared to other three samples and therefore more depth in forming can be achieved[16].

In other experiment, Deep draw quality steel was subjected to forming at room temperature under various input conditions and results observed. **From this, it can be concluded that:**

1. The maximum blank diameter of the sheet formed without cracks within the present experimental range was 110 mm and a limiting draw ratio of 2.2 was achieved.
2. The best forming characteristics were obtained at a punch stroke of 50 mm.
3. Thickness variations of the deep drawn steel sheet were less. The maximum thickness variation observed was only 0.24 mm.
4. Good correlation was obtained between the finite element predicted results and experimental results.
5. The developed Von Mises stresses are minimum on the surface of the cup (20.54 MPa) and maximum nearer to the punch radius and die radius (186.4 MPa)[10].

The effects of forming conditions and material properties over the formability of high-purity ferritic stainless steel, NSSC 180, were examined and the findings were: (1) NSSC 180 has a high r-value, which is effective in improving cup formability, and thanks to this, its limit-drawing ratio is higher than that of JIS SUS304 material. Stretching is the major mode of plastic deformation in drawing work to leave a flange, and therefore, under the same forming conditions, NSSC 180 is more likely to crack than SUS304. Thus, to improve the formability of NSSC 180 in this type of forming work, it is necessary to set forming conditions to allow easy material influx.
(3) NSSC 180 is superior to SUS304 in its hole-expanding ratio □□in the case of a punched initial hole.□
(4) The above indicates that NSSC 180 applications can be expanded□□by carefully analyzing forming conditions and changing them to□□optimize the mode of plastic deformation (less stretching and more drawing)[4].

Factors Influencing FLD are: Strain path, Material properties (n, r), Size of the grid modulus. FLD shifts upward with the increase in sheet thickness & FLD shifts upward with the increase in n value.

ii. Simulation & Finite element analysis:

Computer aided engineering has a vital and central role in the recent developments in sheet metal forming concerning the whole product development cycle. The application of various methods and techniques of CAE activities resulted in significant developments. The formerly trial-and-error based workshop practice has been continuously transformed into a science based and technology driven engineering solution. An integrated approach for the application of knowledge based systems and finite element simulation is introduced. Applying this knowledge and simulation based concept for the whole product development cycle – from the conceptual design through the process planning and die design as an integrated CAE tool – provides significant advantages both in the design and in the manufacturing phase. Sheet metal forming simulation results today are already reliable and accurate enough that even tryout tools and the time-consuming tryout processes may be eliminated or at least significantly reduced. Thus, the integrated solution described results in significantly shorter lead times, better product quality and therefore more cost-effective design and production[11]. Substantial progress in the design and control of sheet-forming processes has been realized since the 1980s. As for bulk forming, much of this progress has been paced by the development and application of powerful computer codes for process simulation. Process simulation tools for sheet forming have been largely FEM based, as has been the case for the simulation of bulk-forming processes. However, there are several special challenges associated with the application of FEM for sheet forming. These include the selection of element type, the treatment of contact conditions, and the description of the constitutive behavior of the workpiece material. the most accurate simulation results are obtained when texture evolution is simulated simultaneously with deformation and then used to formulate the yield function and flow rule that are important parts of the FEM formulation. The complete simulation of sheet-forming operations in which texture is tracked and updated continuously with strain, however, can be very complex and computationally intensive[15].

The numerical simulation of the hydroforming of sheet metal pairs has helped to gain knowledge about the hydroforming process. Simulations of simplified models as well as the simulation of large, three-dimensional models showed the need for finding a suitable process control to prevent process specific defects. With the results of the simulation, it was possible to suppress wrinkling due to non-flat blankholder surfaces as well as to describe the experimental results in a good manner. Derived from the conducted simulations and theoretical modelling, an optimized process control of the blankholder load has been developed and has successfully been verified in experiments. The numerical simulation is an important module to economically produce failure-free parts by saving time and costs for building the tooling and for reducing tooling try-out[13]. The use of sheet-metal-forming simulation leads to a significant reduction in both cost and time compared with the use of try-out tools. The requirement is that the respective parameter for study demonstrates good correspondence between simulation and actual production processes. Sheet metal- forming simulation is also superior to try-out tools about predicting and verifying the forming process. The investment requirements are relatively small when starting to implement sheet-metal-forming simulation. It is necessary to invest in a workstation and software. In addition, it is necessary to have competent personal for handling the sheet-metal-forming simulation. Compared with the investment for one try-out tool, there is a lot to gain in reducing cost and time if sheet-metal forming simulation is used when it is suitable. As stated above, today the accuracy of the results in sheet-metal-forming simulation is high enough to replace the use of try-out tools to a great extent[1]. The formability analysis is performed for various cases of different values of parameters blank holding force and friction coefficient and various virtual tryout set is developed and thickness variation are analyzed. The die, punch, binder and blank are the main components developed as virtual tryout set. Metal forming, product design & die design industry can be largely benefited to carry the virtual forming simulation and thus reduce the manual tryouts which involves time and money. Simulation technique can be used effectively to optimize the die design and process parameters. Using Hyper Form and available CAE technology, any modification required to modify the die or the component can be carried out in the software and multiple iterations can be performed and accordingly the design can be finalized[17]. Based on the results of numerical simulations, with the decrease of the hardness of deformable material punch, its deformation increases, with a simultaneous decrease of the maximum depth of forming draw piece. Appropriate selection the hardness of the elastic punch can eliminate the disadvantage of the corrugation sheet metal. Numerical simulations have shown that only the drawing punch elastomer with a hardness of 90 allows for draw piece without defects as wrinkle. Comparing the results of measuring the deformation by MES and Argus, in flat areas on draw piece equivalent strain values are close substitute. Larger divergences are present at the measuring points located in areas of high curvature. The results of FEM calculations depend on the correctness of the defined mathematical models that describe the simulated process[14].The brief survey has shown that by means of numerical simulation the innovative sheet metal processing was greatly improved. The application would not have been possible in the case of the hydroforming process sequence without the insight gained from the simulation. Information on the feasible materials and the needed redesign of the tools could be gathered. For the THTB the improved insight into the process internals is even more evident since the stress distribution could not be measured during a real process but can be visualized using validated numerical models. Understanding the process the heat treatment could be improved. Forming results not possible without THTB were reached in simulation and reality. The ongoing research towards better numerical modeling of forming processes will help to further improve the capabilities of metal forming[6].

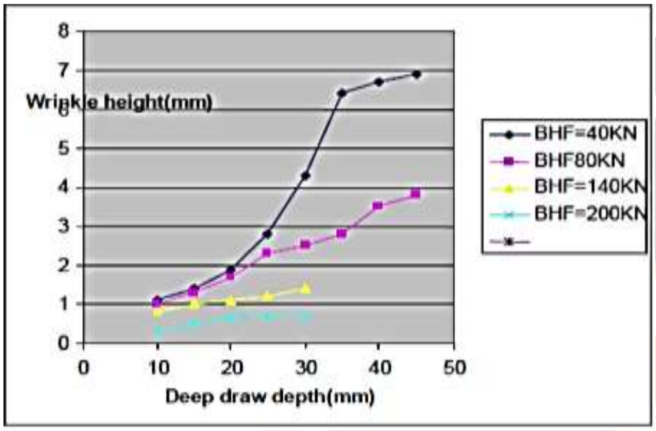
iii. Optimization of process parameters:

Process parameters optimization is a methodology adopted to get the best formed part by incorporating forming benchmarked parameters like FLD, percentage thinning and plastic strains as responses by building up expressions among various variables and thus optimizing the forming process parameters like blank holding pressure, sliding friction, and Draw bead restraining force effectively to meet the formability requirements. This would reduce the time and effort of a forming engineer to reiterate among these parameters to get the desired result effortlessly.

To study the influence of several process parameters which have great influence on the forming quality on the quality of automotive panels, an adopted automotive lower floor board as the research object, selected the BHF, die corner radius, die clearance, and friction coefficient with maximum thinning rate and maximum thickening rate as evaluation indexes, used orthogonal experiment method for simulation analysis on the effects of these four parameters, and carried on optimization. It can be obtained from the experiment that the impact of the four process parameters on the maximum thinning rate from strong to weak is die clearance, friction coefficient, the BHF, and die clearance, while on the maximum thickening, the greatest impact is BHF, followed by the friction coefficient and die clearance and die clearance has little effect. The maximum thinning rate and maximum thickening rate could be effectively controlled through orthogonal experiment optimization, and the high-quality forming parts can be obtained without obvious defects[5]. The optimum process parameters combination obtained by 6σ robust optimization is as follows: BHF is 84.21 ton, friction coefficient is 0.148, die gap is 0.69 mm. The maximum thinning rate of the parts obtained by the parameters is 27.22%, the maximum wrinkling height is 47.52% and the maximum rebound is 1.953mm. The maximum thinning rate obtained by 6σ robust optimization is slightly larger than the rate obtained by determined optimization and the value of the maximum wrinkling height is smaller than the one obtained by determined optimization, which indicates that 6σ robust optimization results can obtain higher accuracy, so that debugging time of fitter is reduced. The value of the maximum rebound obtained by 6σ robust optimization is smaller than the one obtained by determined optimization, which indicates that 6σ robust optimization results makes the dimensional precision higher, so that the amount of later shaping is reduced. So 6σ robust optimization is more suitable for the process parameters optimization of automobile panel drawing forming[21]. The failure limit diagram for original geometry shows some failure points along with safe points whereas the optimized geometry doesn’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 BHF 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[8]. A new method to evaluate degree of wrinkle based on curvature distribution of sheet surface is proposed for the optimization. Results of the numerical optimization and the experimental verification show that an appropriate draw-bead design is successfully determined, wrinkle and torsional springback of the stepped-shape beam are remarkably reduced. In the presented optimum design, draw-bead height changes partially and draw-bead setting becomes unsymmetrical. It is not easy to determine such complicated draw-bead design empirically. Numerical optimization using FE simulation would be indispensable[18].

iv. Failure modes in forming:

One of the most common outcomes in deep drawing forming process is the defects that occur in the cup shell. These defects are caused by many parameters like blank holder force (BHF), Die Radius, Punch Radius, Blank diameter, friction between punch and blank and Die, normal anisotropy of material, blank thickness and many more. The effect of various process parameters will be determined by using statistical as well as experimental methods. The blank holding force has the major influence in the deep drawing process. The die radius also has an influence in the process which is followed by punch nose radius. The failure in the component i.e. tearing in the cup was observed due to less punch nose radius. Wrinkling in the formed part was also seen during the experiments which occurred due to less blank holding force[9]. During deformation of material in deep drawing, it is quite difficult to control defects like wrinkling and tearing, as for higher values of blank holding forces wrinkling tendency over flange area decreases but at the same time problem of tearing is sever. For lower values of blank holding forces cracking problem removed but wrinkling tendency over the flange area increases. In case of deep drawing process of gear cover for BHF values higher than 175 KN the problem of cracks during deformation is sever, whereas problem of wrinkling reduced. For BHF values lower than 175 KN the problem of wrinkling over the flange is sever but problem of cracking removed. As flow of material during deformation is affected by the lubrication condition, over lubrication may leads to excessive flow of material which leads to cracks. whereas insufficient lubrication leads to improper flow of material during drawing process leads to problem like cracks and tear[2]. The height of the wrinkles is reduced by increasing the BHF, decreasing friction, increasing the tools edge radius and reducing deep-drawing depth all together in one operation. Concerning friction, the reduction of coefficient of friction must be made up to a certain limit that won't lead to material breakage. Reducing the coefficient of friction down to the minimal value has a contradictory influence for the desired propose. The defect of wrinkling occurs easily in this process of EDD steel alloy sheets. It is to avoid wrinkling of blank by selecting the correct BHF's, decreasing friction, increasing the tool edge radius and reducing the deep drawing depth all together in one operation[12]. The failure modes of nickel coating during deep drawing have been successfully predicted by using finite element simulations. A set of experiments were performed to test and verify the accuracy of finite element modeling. According to simulations, failure modes are affected by the blank holder force. For the relative low BHF, wrinkling takes place in the flange of nickel coating sheet, and for the relative high BHF, fracture occurs along a circumference zone in contact with the punch radius. The accuracy of finite element modeling has been confirmed by experiments. The results show that finite element simulations based on continuous damage mechanics are a promising method in predicting failure modes during deep drawing of coated metal sheets[7]. For improving surface deflection, the direction of tension application and the timing have a great influence. When applying tension from the start of forming, the tension should be applied in such a direction that the metal flow into the corner portion of automotive outer panel is restricted. The application of tension can improve the surface deflection in whichever direction the tension is applied. The method of evaluating panel surface deflection is strikingly effective in the quantitative evaluation of a multitude of surface deflection phenomenon occurring in parts and components of various shapes. Surface deflections caused by elastic recovery which occur in the large size forming consist of those caused by non-uniform elastic recovery strain. They are classified into various types of deflection from the magnitude of curvature radius of the panel sectional profile. Press forming technology can also be founded on the concept of these mechanisms of surface deflection. Thus, tension balance control, an increased stamping load, etc. can be used as means of reducing surface deflection[3]. It has been a research on the Effect of Various Parameters on the Wrinkling during Deep Drawing process. The appearance of dimensional deviations of shape and position, of the defects in the metal sheets that have been subjected to a cold plastic deformation process (deep drawing), represents a critical problem for the specific industry, especially for the mass production, like the machine manufacturing industry. The aim of this publication is to present the principal aspects that effect of various factors like BHF, punch radius, die edge radius, and coefficient of friction on the wrinkling of cylindrical parts in deep drawing process. The initiation and growth of wrinkles are influenced by many factors such as stress ratios, the mechanical properties of the sheet material, the geometry of the work piece, and contact condition. It is difficult to analyze wrinkling initiation and growth while considering all the factors because the effects of the factors are very complex and studies of wrinkling behavior may show a wide scattering of data even for small deviations in factors. In the present study, the mechanism of wrinkling initiation and growth in the cylindrical cup deep drawing process is investigated in detail. It can be concluding that, the height of the wrinkles is reduced by increasing the blank holding force, decreasing friction, increasing the tools edge radius and reducing deep-drawing depth all together in one operation. Concerning friction, the reduction of coefficient of friction must be made up to a certain limit that won't lead to material breakage. Reducing the coefficient of friction down to the minimal value has a contradictory influence for the desired propose[19]. The fig 2 shows the graph plot of BHF & depth of deep draw effect on a wrinkling height. Also, Fig 3 shows the influence of the die and punch edge radius on the wrinkling.



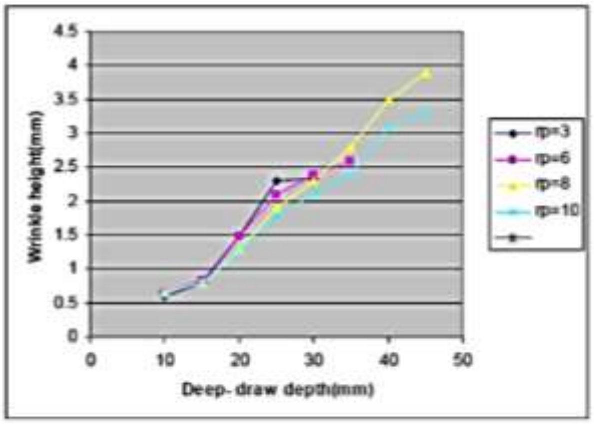


Fig 2: The effect of the blank holding force and the deep drawing depth on the wrinkling[19]

Fig 3: The Influence of the die and punch edge radius on the wrinkling[19]

Conclusion:

Sheet metal forming technology important parameters are well explained. The material properties have major influence on the term – Formability. It can be well understood using FLD by experimentally as well as numerical methods. Simulation has major role in successful forming of any material. Among various defects occurred in a process, wrinkling is one of defects which is produced by a compressive stress field. The prediction of wrinkling is important for the design of stamping and deep-drawing processes. Wrinkling is unacceptable in the outer skin panels where the final part appearance is crucial. Wrinkling on the mating surfaces can adversely affect the part assembly and part functions, such as sealing and welding. In addition, severe wrinkles may damage or even destroy dies. Therefore, the prediction and prevention of wrinkling are extremely important in sheet metal forming. As a concluding remark, it can say that, though we have sufficient theoretical data depicts causes of a wrinkling defect, the scope for future study for its practical elimination is definitely high due to parameter variations.

Nomenclature and Abbreviations:

BHF - Blank Holder Force
CAD - Computer Aided Drafting
CAE - Computer Aided Engineering
CAM - Computer Aided Manufacturing
CR4 - Bright Mild Steel Sheet
E - Elastic Modulus
% El - Percent Elongation
EDD - Extra Deep Drawing
FLC - Forming Limit Curve
FLD - Forming Limit Diagram
K - Strength coefficient.
MPa - Mega Pascal = $10*10^3$ N/mm^2
NLC - Necking Limit Curve
NSSC 180- High-Rust-Resistant Ferritic Stainless Steel
THTB - Tailored Heat Treated Blanks
TS - Tensile Strength
YS - Yield Strength
ε t - Major Principle Stain
ε w - Minor Principle strain
ν - Poisson’s Ratio
ρ - Density

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