Jour of Adv Research in Dynamical & Control Systems, Vol. 10, 13 Special Issue, 2018

Enhancement the Mechanical Properties of the Deep Drawing Products through Intelligence Design and Finite Element Analysis

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Abstract- Nowadays; any manufacturing process for mass production like forming process requires high precision tools (punch and die) for re-shaping the metal to a new product. During forming process; there are a lot of defects will appears in the products due to sever friction forces between the contact surfaces. The dislocation of particles due these forces will generates huge amount of stresses and strain hardening which consider the main causes of these defects. The present work is focus on analysis the process of forming a thin sheet of metal theoretically and practically. The main approach of this work is to analysis and estimates the main effecting parameters on this manufacturing process theoretically and experimentally. ANSYS (R18) software has been adopted for analysis this process to find and estimate the main parameters that effects on the product quality. Specially the values of stresses and strain hardening which has the main cause of defects like wrinkling and cracks. Theoretical analysis focuses on the onset of metal distortion depending on the values of stress concentrations, while the empirical part focused on the microstructure behaviour of metal before and after the forming process. For this purposes; thin square aluminium blank is adopted by means of drawing die as a square cup. In simulation process; the blank distortion in many directions has measured in terms of von-mises stresses distribution, strain hardening and total deformation measurements. This research will enhance the knowledge about these types of manufacturing technology and help the researchers that working in this fields.
Keywords: ANSYS, Simulation, Metal Blank Forming, Damage, Drawing.

1- Introduction

The process of forcing and forming a sheet metal to drawn radially in to a forming die by using an external mechanical force without loss in metal is called a forming process. Drawing process is a type of forming process in which the sheet metal (blank) is drawn and formed by the die due the action of the punch. The important thing in any successful drawing is preventing the wrinkles in the products by using a suitable blank holder. The material formability of any material are depends on the limiting draw ratio. The value of limiting draw ratio (LDR) can be estimated by the following formula:-

$$LDR=\frac{\text{Maximum Blank Diameter}}{\text{Punch Diameter}} \qquad (1)$$

The (LDR) are affected by many variables like properties of Material, geometry of die and punch, thickness of the metal blank , lubricant type and blank holder force [1]. Drawability of square metal and other parameters associated with this process can be estimating and evaluating by using (LDR) limiting drawing ratio. Many parameters can predict by using (LDR) [2].

Forming process needs a good understanding for many variables which control the process like the interactions and contact behaviour of the active parts like punch, die, and punch holder. Numerical analysis by using advanced software like (ANSYS) are widely contribute in solving many forming problems or at least increase the understanding and evaluation by decrease the errors before practical part. Furthermore; it can make a major optimization to the error by following some extra steps [3]. Sheet metal forming is widely used in mass production for different products, and for any manufacturing process; it's very important to minimize the response time, cost and maximize the quality and efficiency. Nowadays finite element technique can compute and analysis the various

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Article History: Received: Sept 5, 2018, Revised: Oct 6, 2018, Accepted: Nov 20, 2018

loading behaviour and predict how the real part will react by determining the exact value on each element [4]. Forming process of any metal will leads to increase hardness and decrease the ductility due to strain hardening, so the stress of material will increase while the strain will decrease [5]. In drawing process; blank holder force is very important, because it will prevent the wrinkle and some other defects [6].Using different blank forces is better than depend on constant one to optimize the whole drawing process and enhance the overall results. The deep drawing of rectangular blank is associated with a various defects like, tearing, earing, wrinkling, and other parameters. Using variable blank holder is necessary specially for drawing the complex parts [7].
The main simulation idea and theory in finite element is that the elements are connected by nodes, and the structures assembly of these nodes are called mesh of these elements. Solving of any loading structure includes many steps starting from define all the parts, materials, boundary conditions, loads, interactions and finally define the output setup before submitting for analysis to find the results [8]. Many of drawing process parameters can be obtained by using finite element analysis. Finite element Simulation process is more economic and less time costing comparison with experimental method and can predict the error before any further action. It's very useful technique for analysis and determines the parameters that cause the main defects and faller during the actual work [9-10].It's very important for detection and prediction the onset of necking during the forming process. Finite element analysis can help in determining the strain field in each element and this can diagnose the weak points and prevent the onset necking and failure early [11-12].
The length and total area of die bearing has the main cause of generation stresses like shearing and compression stresses, and these stresses can increase or decrease depending on this value. Hardness of specific tools should be in maximum values to avoid this problem [13].

2- Mold Design And Modeling Process

2.1- Part Design and Material Properties

The first step in this research is establishing and layout the product design with all required dimension [14]. Figure 1(a) and 1 (b) explain this product.

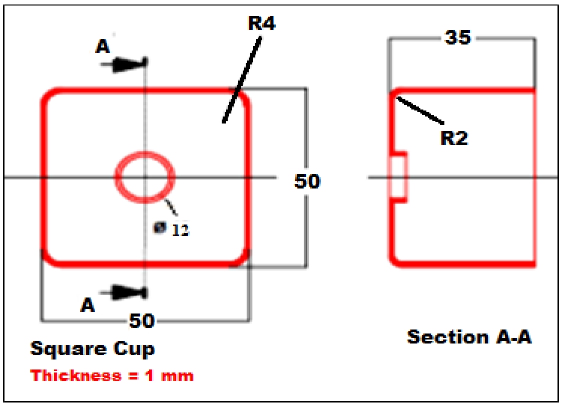


Figure 1(a). Two dimensional Product.

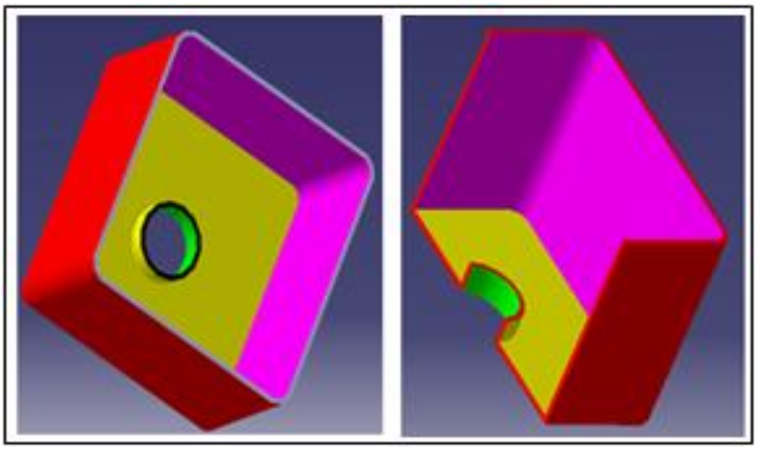


Figure 1(b). Three dimensional Product.

The blank material which implemented for this forming process is aluminium (Aluminium alloy 6060) sheet metal with dimension (135 *135 *1) mm. This material has the following mechanical properties as in Table (1).

Table (1): Mechanical Properties of (Al 6060)

No.	Properties	Values
1	Ultimate tensile strength	140 to 230 MPa
2	Yield strength	70 to 180 MPa
3	Modulus of elasticity	70 GPa
4	Poisson’s ratio	0.33
5	Expansion Coff.	8.42 E-005
6	Thermal Expansion	23.4 µm/m-K
7	Density	2.70 g/cm^3

2.2- Tools Design

Tools design process is the main important step, in which the successful of all following steps will depend on it. Tools design includes design and drawing each part individually [15] with all dimensions and tolerances based on international standard of molds design, and then assembling these parts accordingly. Figure (2) and Figure (3) illustrate the mould assembly including all the tool parts during both the forming action and during removing and ejecting the product at the end step respectively [16].

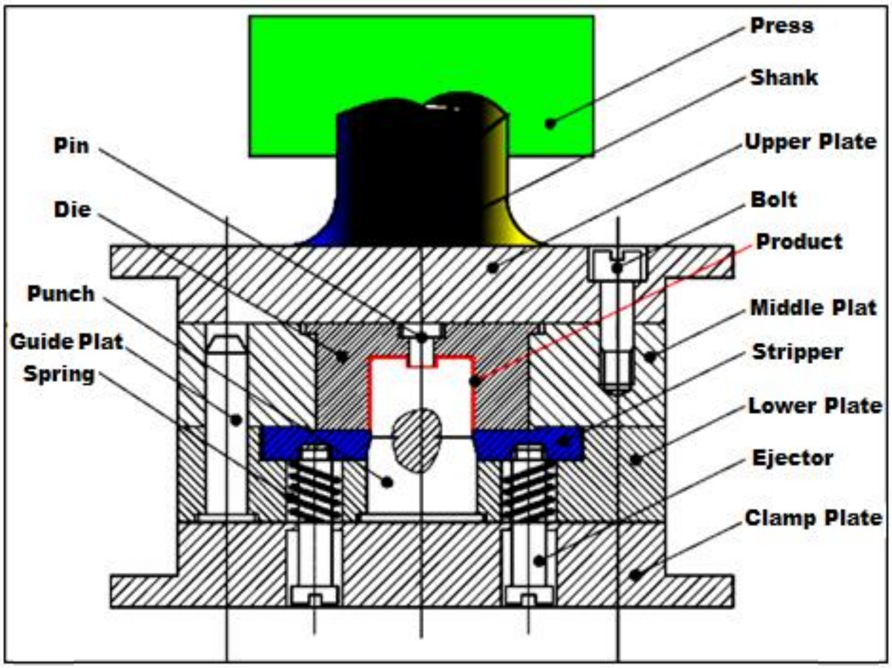


Figure 2. Mould assembly explain all the tool parts during the forming and drawing the product.

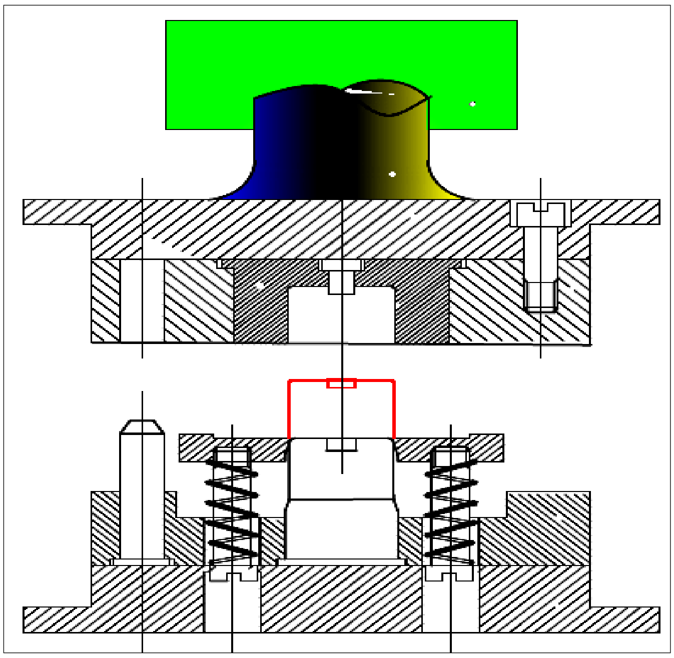


Figure 3. Mould assembly movement during product ejection.

2.3- Modeling Process

In order to proceed the analysis and simulation [17]; it's very important to model all the parts and the assembly. according to their original dimensions. CATIA software has been adopted for implementation the modelling process. Figure (4) show the modelling for a (3D) front sectional mould assembly [18].

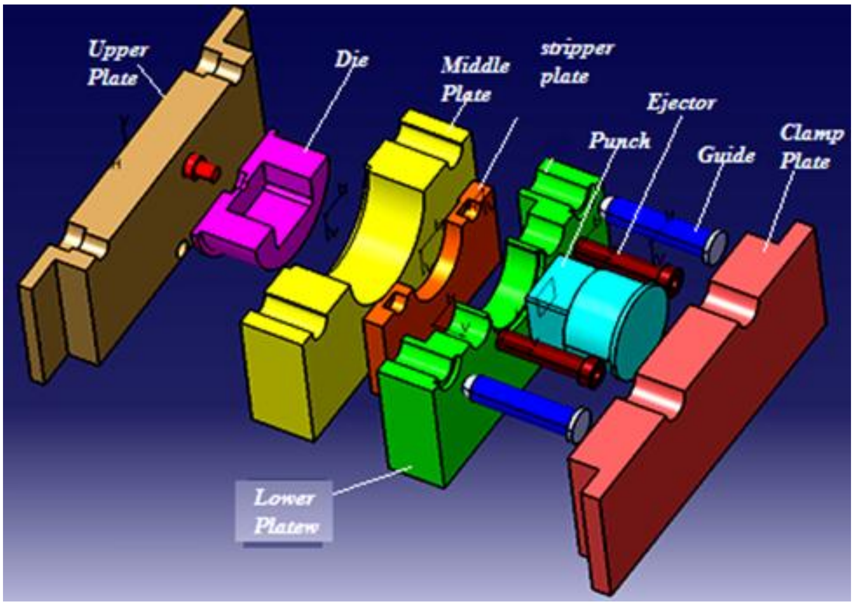


Figure 4. (3D) Front Sectional Model for Mould Assembly.

Modelling process is so important specially in solving contact and interference between the parts during assembly process. Sometimes and whenever the dimension and poison of some parts is not correct, the assembly model can show and avoid this error. In this work, and for perfect simulation process; only the active parts during analysis need to be modelled , especially the sheet metal (Blank), die , punch and the fixed support as shown in Figure (5). CATIA assembly model will be converted to (igs) extension to be accepted during exporting to ANSYS software for analysis purposes [19]**.**

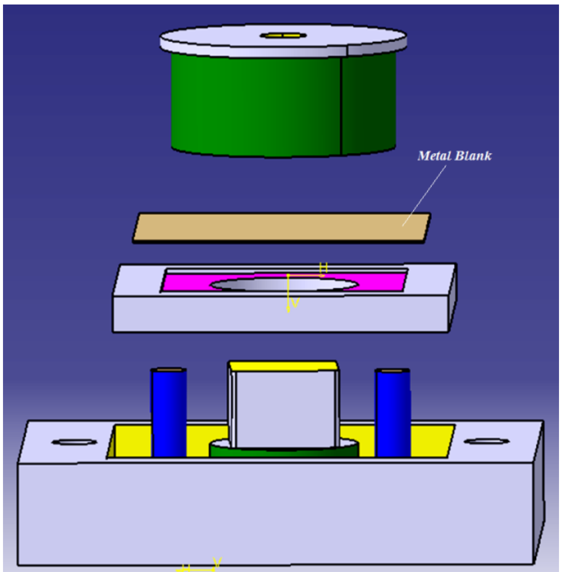


Figure (5). Modelling of the main active parts.

3- Finite Element Simulation

ANSYS (R18) software has been adopted for analysis and simulation this forming process. Explicit dynamic method are used for evaluation the values of stress and strain and other variables. Figure (6) explain the simulation flow chart.

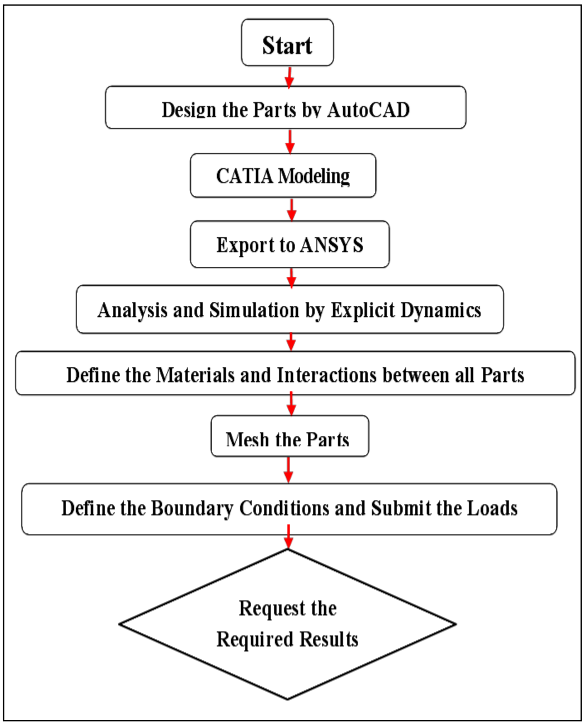


Figure (6). Simulation Flow Chart.

In initial condition, the boundary conditions includes bonded the punch and support plate by fixed support followed by applying pressure on the blank. Interaction between die and blank is considered as friction contact. The blank holder force is limited to (5000) N with (0.12) friction coefficient; whilst the die will move downward with limit velocity. The boundary condition are illustrate in Figure(7).

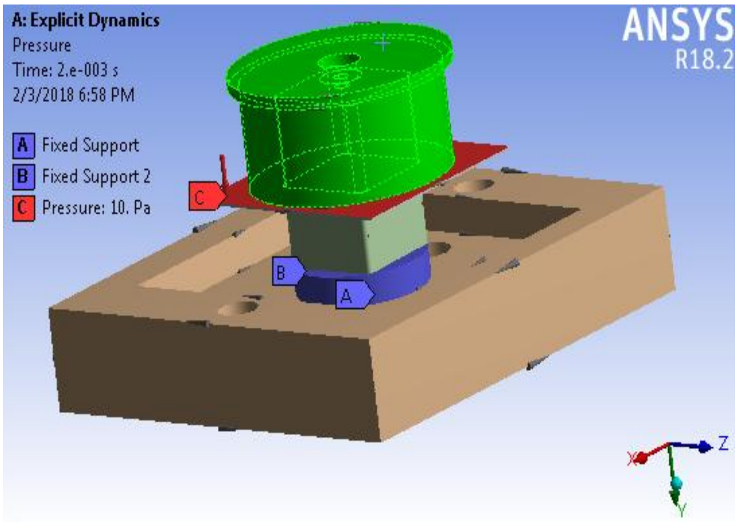


Figure (7). The boundary condition.

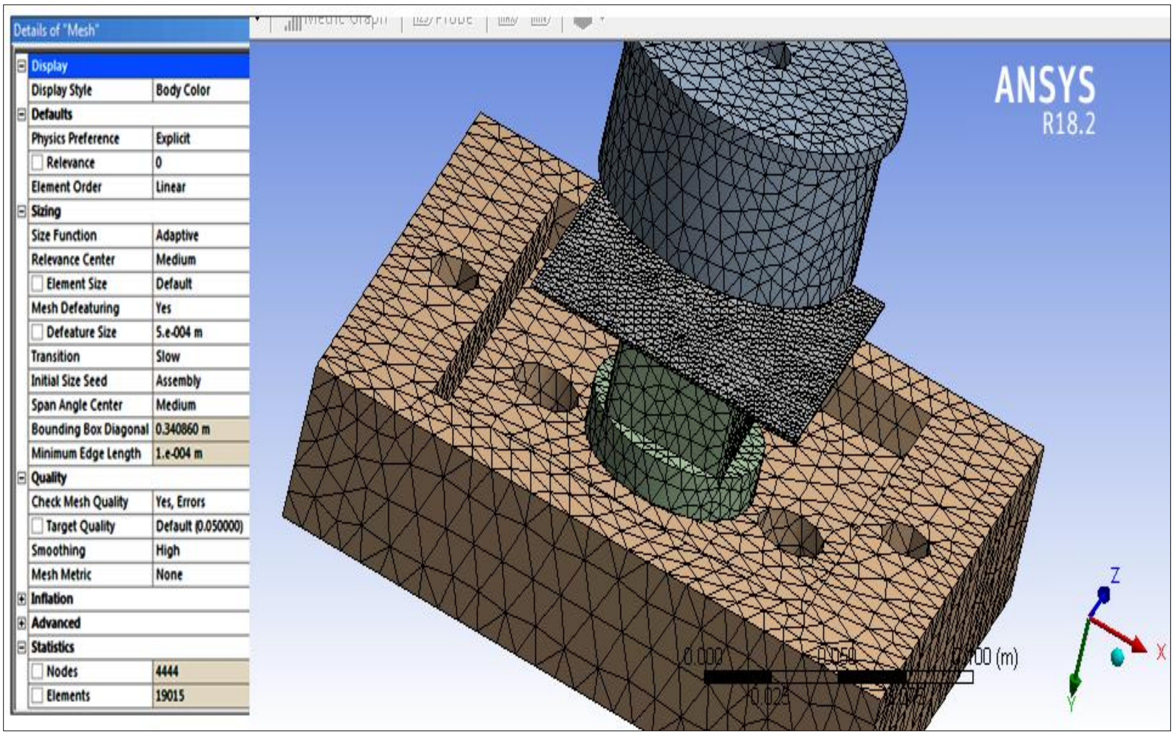


Figure (8). Assembly meshes with statistical.

Some aspects must be taking into consideration in choosing this finite element simulation like product geometry, material behavior during forming, analysis time, friction during contact and plastic incompressibility. The element size used in this analysis is “Hex Dominant’’ with element Size (4) mm. Figure (8) explain the mesh structure with some statistical.

In the starting of simulation process, punch will travel downward to be in touch with the work piece (blank). The interference between the contact surfaces will cause particles dislocation and deformation will start in this direction. Onset of total deformations is shown in Figure (9).

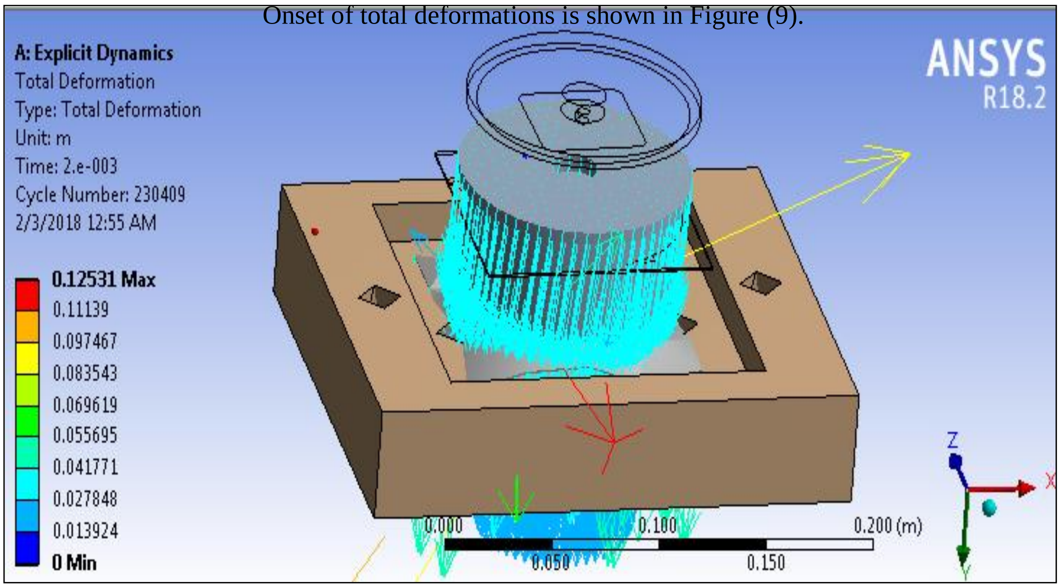


Figure (9). Direction of total deformation.

4- Metallographic Samples Preparation And Microstructure Test

The experimental part of this work includes preparing many samples from different position before and after forming process for microstructure test. Samples preparation for test is very sensitive method which involves cleaning and smoothing these samples without any scratch by using different smoothing papers and chemical solvents, as shown in Figure (10).

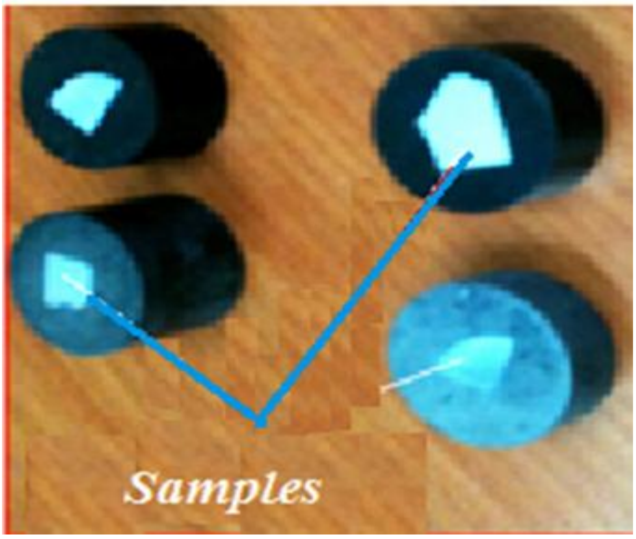


Figure (10). Samples ready for (SEM) test.

Microstructure test for the samples was implemented by Scanning electron microscopy (SEM) according to the standard procedure. (SEM) device is shown in Figure (11).

Figure (11). (SEM) device

5- Results And Discussion

Finite element results showed the total forming of the sheet metal in (Y) direction as in Figure(12).

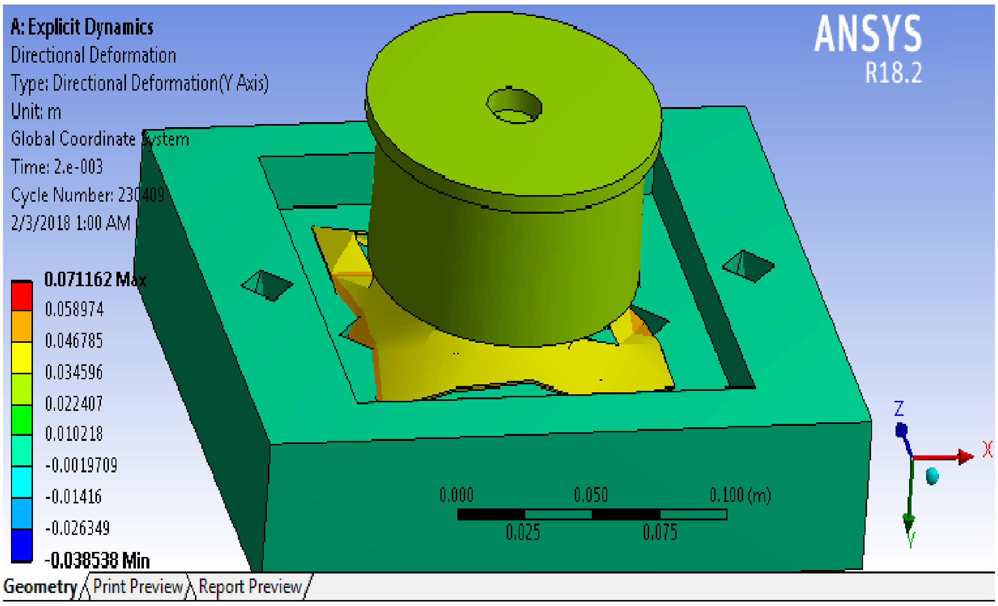


Figure (12). Contour of Total deformation in (Y) direction.

The die displacement toward the sheet metal was (37) mm and the Contour show that the maximum deformation values were registered to the drawing plate as shown in Figure (12) and Figure (13). Von-Mises stresses generation will be in maximum values especially in the beginning of drawing the metal blank due to high friction forces and sever contact between the surfaces, and this will lead to increase the particles energy of dislocations. The Contour in Figure (14) shows the von-mises concentration in the middle(contact surfaces).

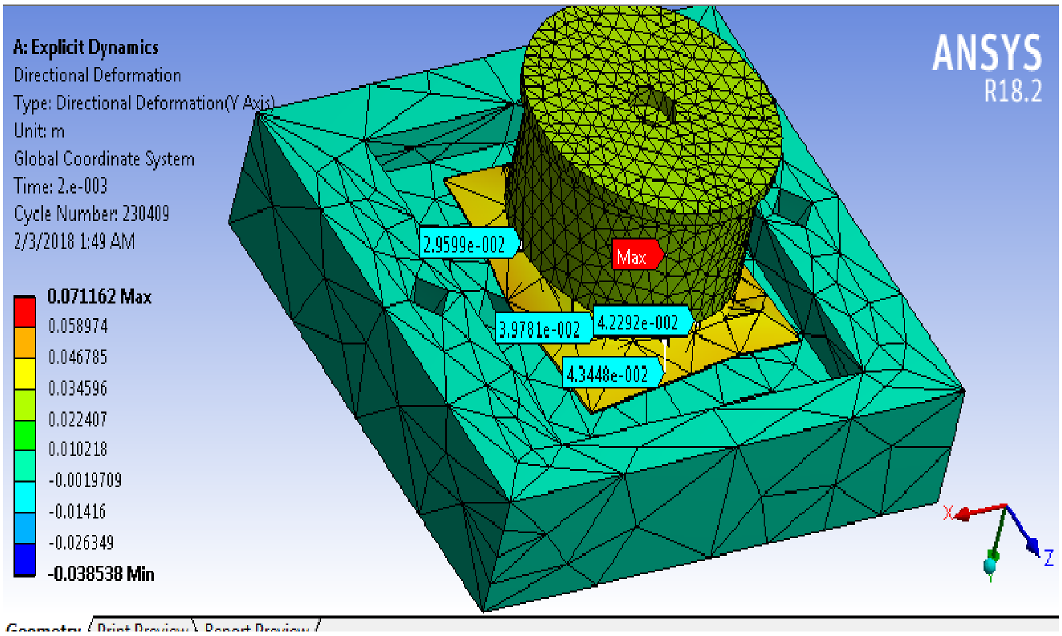


Figure (13). Total deformation in (Y) direction with element labels.

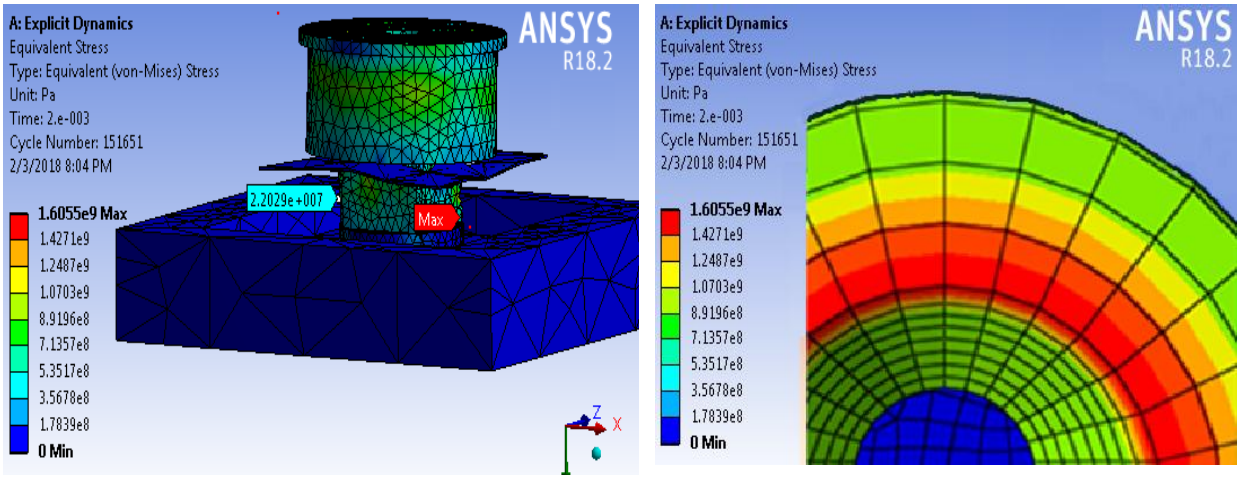


Figure (14) . Von-mises concentration during drawing process.

The particles displacement during the drawing process will be increase rapidly due to gained energy. Plastic strain will generation cannot avoided and if exceed the limit will cause cracks and damage in the product, as shown in Figure (15) and (16).

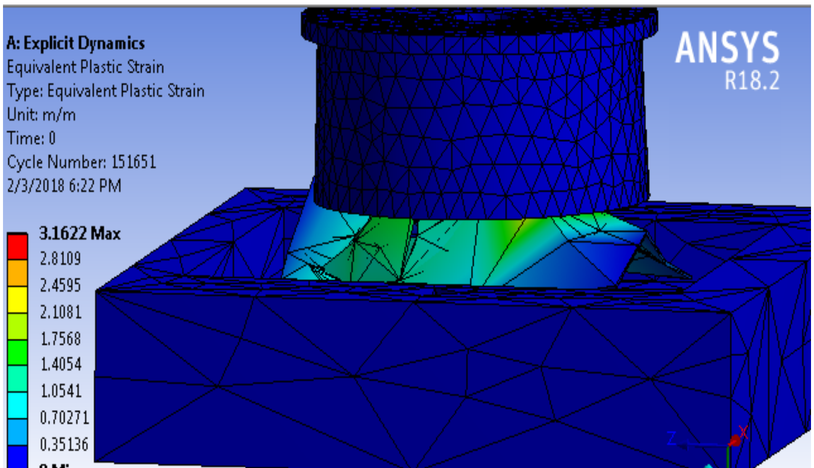


Figure (15). Equivalent Plastic strain

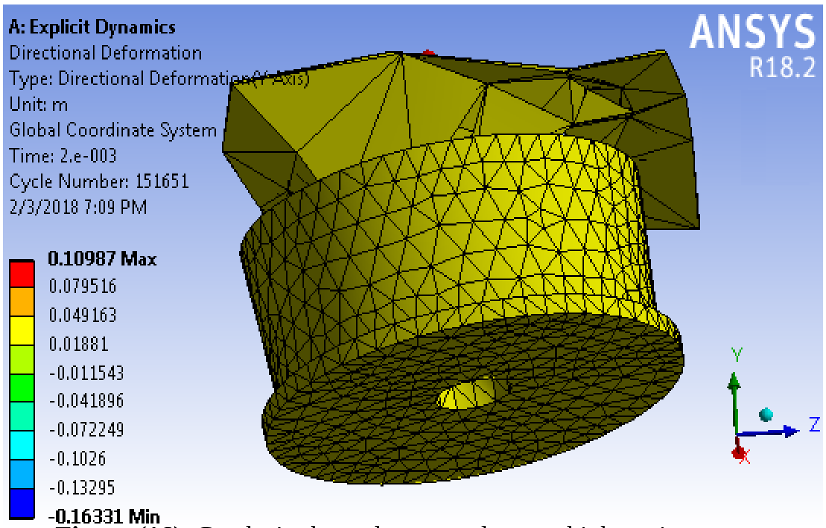


Figure (16). Cracks in the end process due to high strain rate.

To avoid the tearing and wrinkling; the blank holder force should be estimated correctly, because it has a vital role beside the required depth as show in Figure (17).

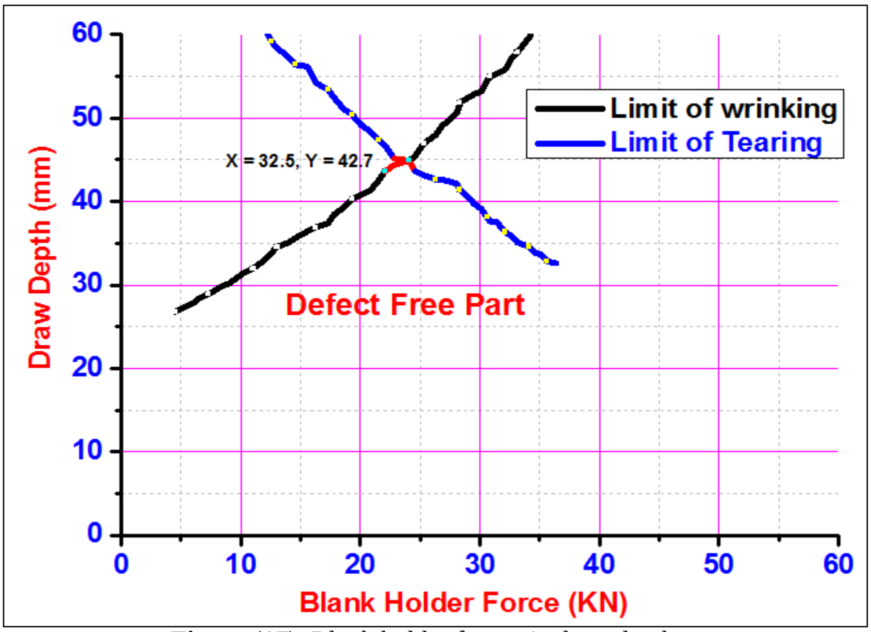


Figure (17). Blank holder force via draw depth.

The values of pressure which required for overcoming the friction forces in the beginning of the forming process is very high due to the resistant of particles for dislocation. After exceeding the yield point; the pressure will be slightly uniform as shown in figure (18).

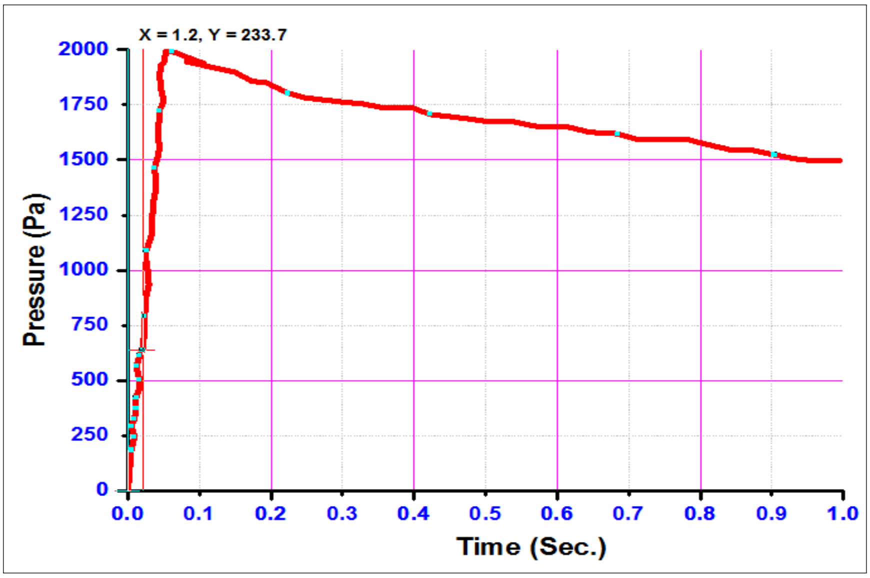
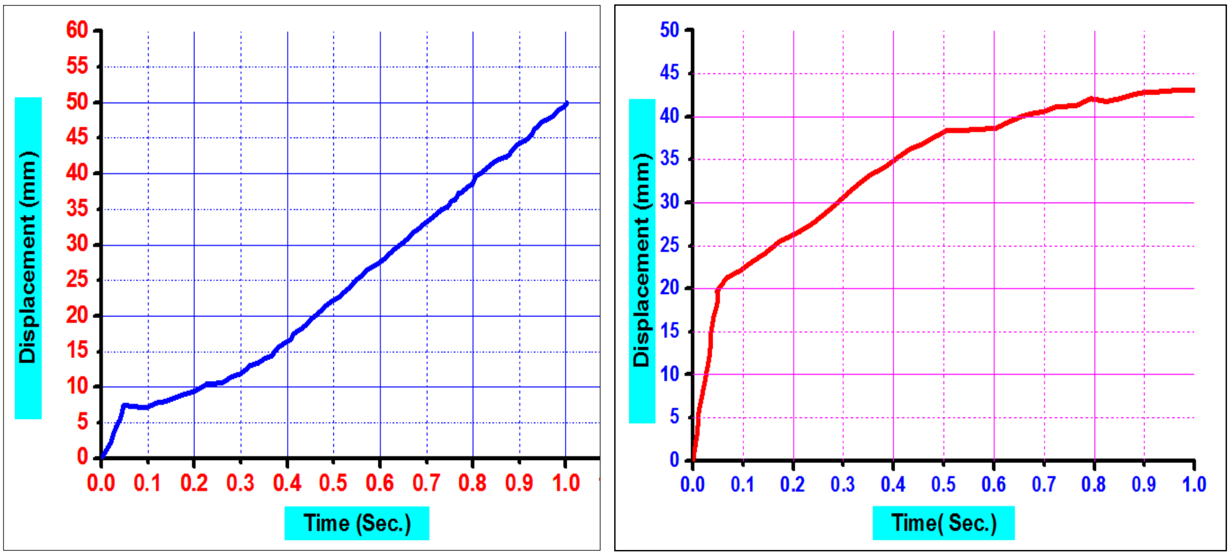


Figure (18). Pressure- Time values during the drawing process.

Comparison between the simulation and experimental results during drawing the sheet metal show that the movement in simulation is more faster due to the element type and mesh nature as shown in Figure 19(a) and (b).



(a) (b)

Figure (19). Die displacement. (a). During simulation (b). During experiment.

Practically the microstructure test for the samples before and after forming process was done. The (S.E.M) micrograph reveals that a good improvement in mechanical properties due to strain hardening and new sub grains formation. Figure 20 (a) and (b). Show the microstructure micrograph before and after drawing process respectively.

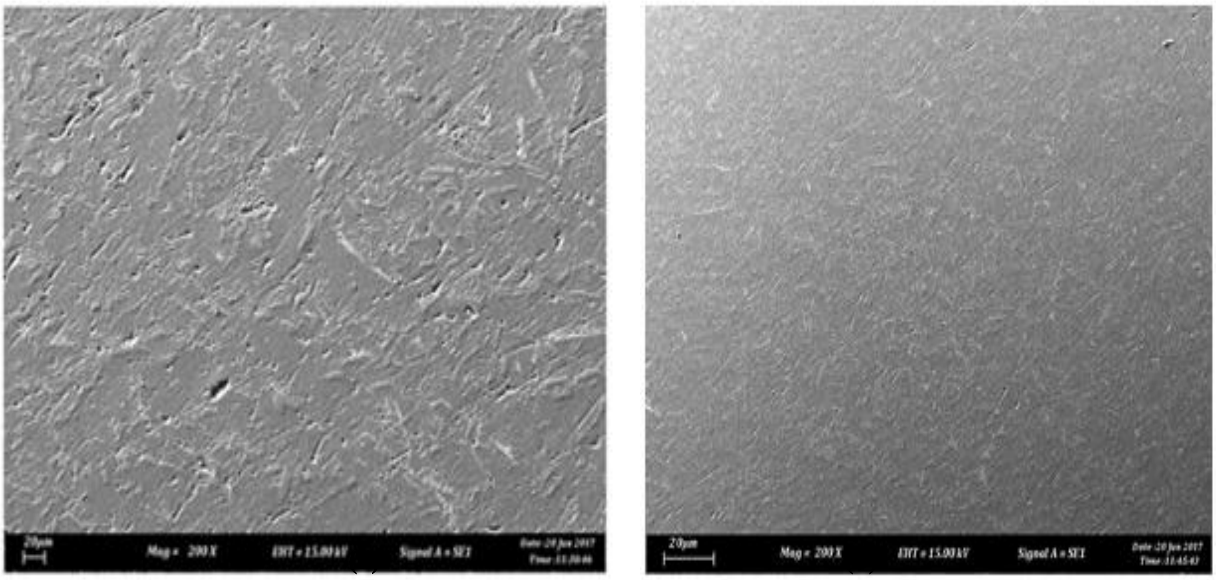


Figure (20). SEM micrographs (a) Raw material; (b) after forming.

6- Conclusions

The results of this research has revealed of the following conclusions:-

1- After many simulation runs, the optimal blank metal can be decided, and the deformed shape also can be predicted.

2- Determining the expected tearing and wrinkling zones before the experimental part and improve the product quality.
3- Minimize the trimming metal loos after forming and reduction in drawing force is possible.
4- It's important to say that the effect of blank holder force is remarkable due to the direct effect on the product quality.
5- Part deformation is various rapidly according to the relative movement of the punch with blank holder. Stress generation and strain rate will be in maximum values is the starting of deformation steps.
6- The failure zone is that region associated with high stresses values.

7- Increase the fillets radius in both of punch and die will help to decrease the crack and wrinkling in the product.

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