A Design Calculating System for Deep Drawing Die by Using Simulation Model

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Abstract

In this research, the deep drawing dies are designed by using a "computer - aided designed calculating system" to save time and facilitate the design process. Also finite elements method (FEM) is used to simulate the drawing process to select the best die design. A programming language (VISUAL BASIC 6.0) was used to build the computer – aided design system, which was linked to drafting package (AutoCAD) to plot the deep drawing dies. A commercially available finite elements program code (ANSYS) was used to perform the numerical simulation. Finite elements results is compared with experimental results. Though the compression between the experimental and FEM, it has concluded that finite elements method is more accurate than the experimental method in predicting the best die design, and a good match between the two methods was found.

Keywords : Deep drawing , dies design , finite element.

نظام الحسابات التصميمية لقوالب السحب العميق باستخدام المحاكاة

المستخلص

في هذا البحث تم تصميم قوالب السحب العميق باستخدام " نظام الحسابات التصميمية بمساعدة الحاسوب" ، لتوفير الوقت ولتسهيل عملية التصميم. كذلك تم استخدام طريقة العناصر المحددة (FEM) لمحاكاة عملية السحب العميق ولاختيار تصميم القالب الأفضل. استخدمت لغة البرمجة (VISUAL BASIC 6.0) لبناء نظام تصميم قوالب السحب العميق بمساعدة الحاسوب التي تم ربطها مع برنامج الرسم (AutoCAD) لرسم قوالب السحب الناتجة من النظام. وتمت الاستفادة أيضا من إمكانيات برنامج العناصر المحددة الشائع (ANSYS) لانجاز المحاكاة الرقمية لعملية السحب العميق. وقد تم مقارنة النتائج المستخرجة من المحاكاة باستخدام العناصر المحددة مع النتائج العملية في ضوء البحوث المنشورة. لقد وجد من خلال المقارنة بين الطريقة العملية وطريقة العناصر المحددة, إن طريقة العناصر المحددة أكثر دقة من الطريقة العملية في اختيار تصميم القالب الأفضل، وانه يوجد تطابق جيد بين النتائج المستخرجة نتيجة لاستخدام الطريقتين.

1- Introduction

This work demonstrates the design and development of an algorithm that represent stages of computer-aided design calculation and finite elements simulation of deep drawing process that facilitate in making the design of drawing process and predicting drawing variables easier, faster , cheaper and more reliable[1]. The computer – aided system requires developing and using a database to present inputs (blank material properties) to this algorithm. VISUAL BASIC programming used to build the computer-aided calculation system , AutoCAD program linked automatically to the computer aided system to plot the deep drawing dies. ANSYS programming is used to simulate the drawing process as a finite elements software.

2- Computer-aided design of deep drawing

The architecture of Computer – Aided Deep Drawing Design and Simulation system as shown in Figure (1)

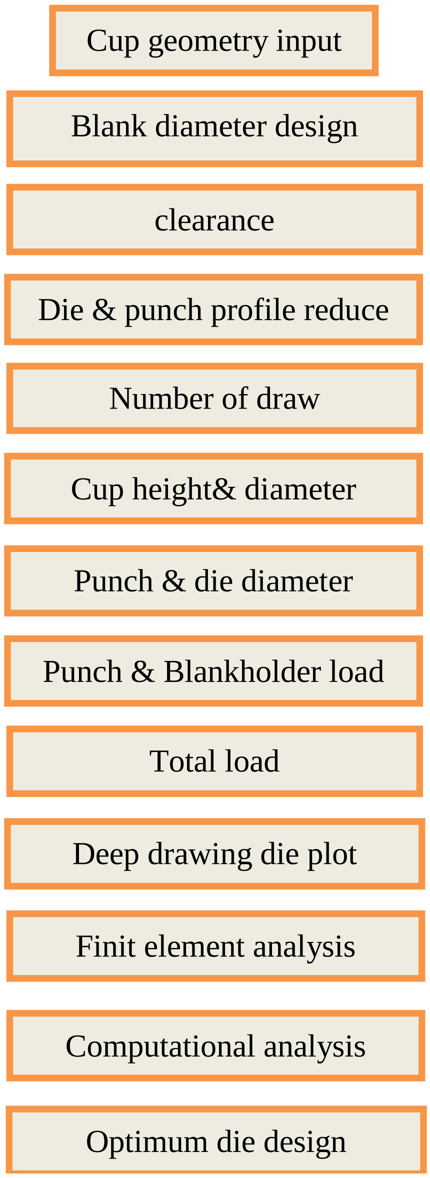

Figure (1). The system architecture.

2-1 Cup geometry input

Include input of cup internal diameter (d), cup height (h), and thickness (t). This is the first stage in deep drawing dies design, which depends on cup geometry.

2-2 Product (cup) database

Consist of empirical equations which used to build the system, and database file containing necessary information about sheet metal to be drawn, such as metal name , and type using two international classifications (US), and (DIN) , also yield stress, ultimate stress, drawing ratio (LDR) , and lubrication.

2-3 Blank and Die design calculation[2]

Blank and die design include the following:

2-3-1 Blank design

Blank diameter can be calculated using equation (1):

$$D = (d^2 - 4\, d\, h)^{0.5} \quad (1)$$

where h= cup height (mm),

d = cup diameter (mm),

D= blank diameter (mm).

2-3-2 Die design

Die design includes many stages

- Clearance determination:

Clearance is the gap between punch and die, in this work clearance is equal to 0.55 mm.

- Determining punch profile radius (r_p)

Punch profile radius ranges from 4 to 10 times of metal thickness, in this work (r_p) is set as (10 mm). The value of (r_p) can be changed to match the profile radius of the cup to be drawn, or by the designer.

- Determining die Profile radius (r_D) :

Die profile radius range from 4 to 10 times of metal thickness, in this design (r_D) is set as (10 mm) .The value of (r_D) can be changed by the designer.

- Determining number of draws:

Number of die(s) necessary to produce the desired product (cup) depends on "cup height over cup diameter" (h/d) ratio as shown in (Table 1).

Table(1). The relationship between the (h/d) ratio and number of draws.

If h/d < 0.75	then no. of draws = 1
If 0.75 < h/d < 1.5	then no. of draws = 2
If 1.5 < h/d < 3.0	then no. of draws = 3
If 3.0 < h/d < 4.5	then no. of draws = 4

- Determining cup(s) height:

Cup (s) height for each draw can be estimated using equation (1):

- Determining cup(s) diameter:

Cup(s) diameter for each draw can be estimated using equation (2):

$$P = 100\left(1 - \frac{d}{D}\right) \qquad (2)$$

where P = percentage reduction

d = inner diameter of drawn cup (mm)

D = blank diameter (mm)

- Determining punch(s) diameter:

Punch diameter for the first draw is equal to the diameter of the cup to be drawn (d), and for other draws equal to the cup diameter at that draw.

- Determining die(s) diameter:

Die diameter for each draw can be determined using the following formula:

Die diameter = punch diameter + (2 * clearance) (3)

- Determining punch load(s):

Maximum punch load for each draw can be estimated using equation (4):

$$F_{max} = \pi \, d \, t \, \sigma_{ult} \, ((D/d) - 0.7) \quad (4)$$

where F_{max} = maximum drawing force (N),

t = original blank thickness (mm),

σ_{ult} = tensile strength (Mpa),

D = blank diameter (mm),

d =punch diameter (mm)

The constant (0.7) is a correction factor to account for friction.

- Determining blankholder load(s):

Blankholder load for each draw can be determined using the following formula:

Blank holder load = 1/3 * maximum punch load (5)

- Determining total load(s):

Total load for each draw can be determined using the following formula:

Total load = maximum punch load + blank holder load (6)

2-3-3 Plot the die(s)

Result of the design will be plotted using (AutoCAD) programming.

3- Simulation of deep drawing

In this work finite element method was used to simulate deep drawing process which is performed experimentally by (Al – Bassam) [2], and a comparison between results of the two methods (FEM& experimental) achieved.

3-1 Finite element method

The use of finite element analysis is beneficial in the design of tooling in sheet metal forming operations because it is more cost effective than trial and error. The prime objective of an analysis is to assist in the design of the product by: (1) predicting the material deformation and (2) predicting the forces and stresses necessary to execute the forming operation. FE of the sheet metal forming problem usually adopts one of three analysis methods based on the membrane, shell and continuum element [3,4].

3-2 Blank properties

An axisymmetric cup was formed using a blank of mild steel type (SAE 1006). Chemical composition of the blank material is C% = (0.08), Mn% = (0.25 – 0.45). Thickness and diameter of the blank used in the FEM analysis are taken as (0.42) mm and (454.31) mm respectively.

3-3 Drawing tools properties

Drawing tools consist of the effective parts (punch, die, and blankholder), other accessories (upper plate, lower plate, guides, and etc.) were neglected to simplify the simulation and to save analysis time. Due to the symmetry of the problem, only one – half of the blank and the tools is modeled. Tool geometry) is as follows:

Punch diameter (D_p) and height (h_p) are taken as 120 mm and 60 mm respectively. Die outer diameter, inner diameter (D_d), and height are taken as 200 mm, 121.1 mm, and 50 mm respectively. Blankholder diameter and height are taken as 123 mm, and 8mm respectively. Punch velocity was constant and equal to 10 mm/min.

To produce the drawn part, one draw is needed, since the ratio of cup height to its diameter is less than (0.75) as mentioned in Table (1).

To study the effect of clearance between punch and die, four dies with different inner diameters of (120.9, 121, 121.1, and 121.14) mm with one punch of 120 mm diameter were used .Thus, clearance between punch and dies were (0.45, 0.50, 0.55,and 0.57) mm respectively. Punch and dies profile radius are taken as 15 mm, and 6 mm respectively.

3-4 Finite element analysis

3-4-1 Preprocessing

This stage includes the creation of a geometric model for the part to be formed, the selection of the appropriate boundary conditions for the forming process, and the selection of material and process variables, and it include the following steps[4]:

i. Define elements types and material properties for blank and tools

❖ Define blank element type:

The element used to simulate the blank is (**VISCO106 2-D Large Strain Solid)** .VISCO 106 is used for 2-D modeling of solid structures, and it is defined by four nodes having up to three degrees of freedom at each node: translations in the nodal X, Y, and Z directions. The geometry, node locations, and the coordinate system for this element are shown in Figure (2).

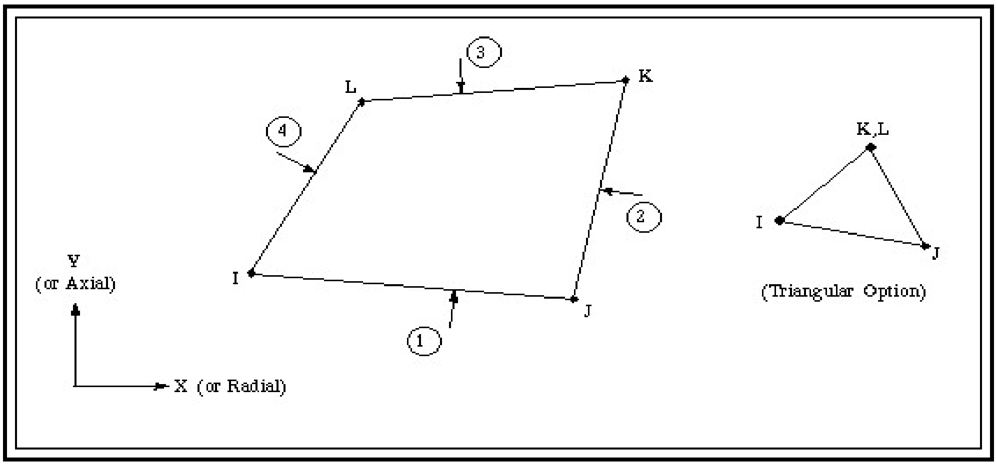

Figure (2). Visco106 2-D large strain solid element [4,5].

❖ Define blank material properties:

Material properties include Young Modulus (200GPa), Density(7800 Kg/m^3), Poisson Ratio (0.3), Coefficient of Friction (0.1), Yield Stress (220 MPa), Tangent Modulus (0.5)

❖ Define tools element type:

In this work, the element used to represent tool set of deep drawing (punch, die, and blankholder) is (**PLANE42 2-D Structural Solid**).PLANE 42 is used for 2-D modeling of solid structures. The element is defined by four nodes having two degrees of freedom at each node: translations in the nodal X, and Y directions. The geometry, node locations, and the coordinate system for this element are shown in Figure (3).

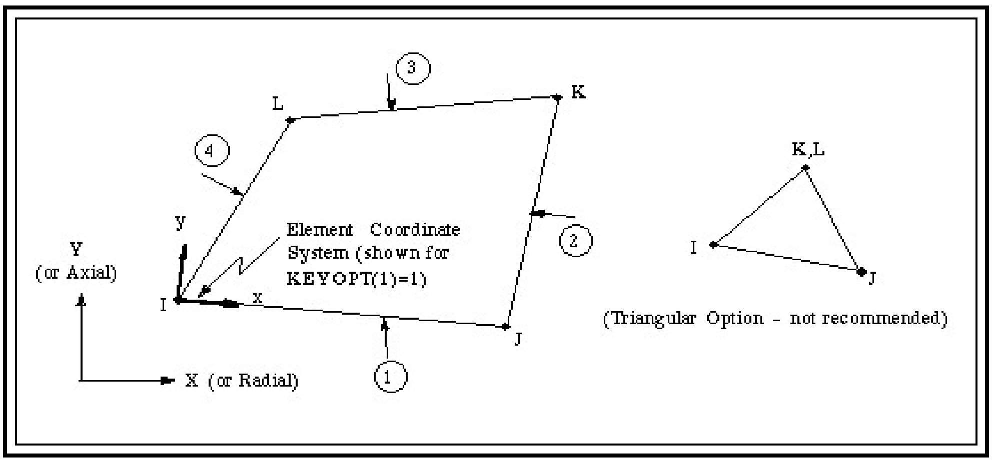

Figure (3). Plane42 2-D structural solid element [4, 5].

❖ Input tools material properties:

Material properties include Young Modulus (220 GPa), Poisson Ratio (0.3), Coefficient of Friction (0.1)

❖ Define contact element:

The element used to represent the contact between the tool set (punch ,die , and blankholder) and the blank is (**CONTAC48 2-D Point-to-Surface Contact)** . This element has two degrees of freedom at each node: translations in the nodal X and Y directions. Contact occurs when the contact node penetrates the target line, Elastic Coulomb friction and rigid Coulomb friction are allowed, where sliding is along the target line. The geometry and node locations are shown in Figure (4).

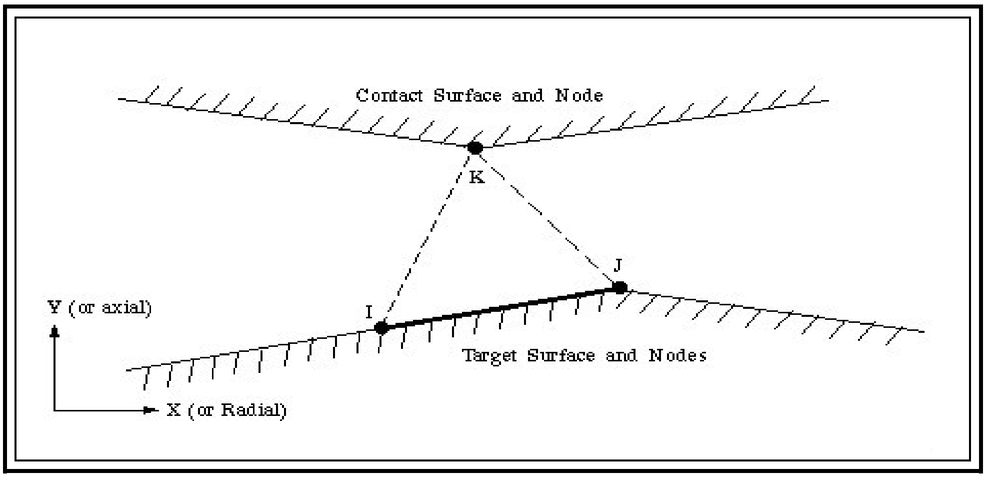

Figure (4). Contact48 2-D node-to-node contact [4,5].

ii. Set Real Constant:

After defining the element type, it needs to select the correct real constants set. The real constant set for each contact surface must be the same as the one used for the corresponding target surface for each contact pair. Each contact pair must refer its own real constant number. In this work "seven" contact pairs are used, i.e. seven real constant values are used.

iii. Generation of Geometric Model:

The model generated using, key points, lines, area, and area meshing.

iv. Set Contacts:

❖ Contact between punch and blank (three "node – to – surface" contacts)

❖ Contact between blankholder and blank (one "node – to – surface" contact)

❖ Contact between die and blank (two "node – to – surface" contacts)

❖ Contact between die and blankholder (one "surface – to – surface" contact).

v. Boundary conditions:

Set the geometry to be axisymmetric around y= 0 (axis y-y) and set blankholder load = 15 KN and fixing the die at points (1,2,3) (no displacement in both x & y directions) as shown in Figure (5).

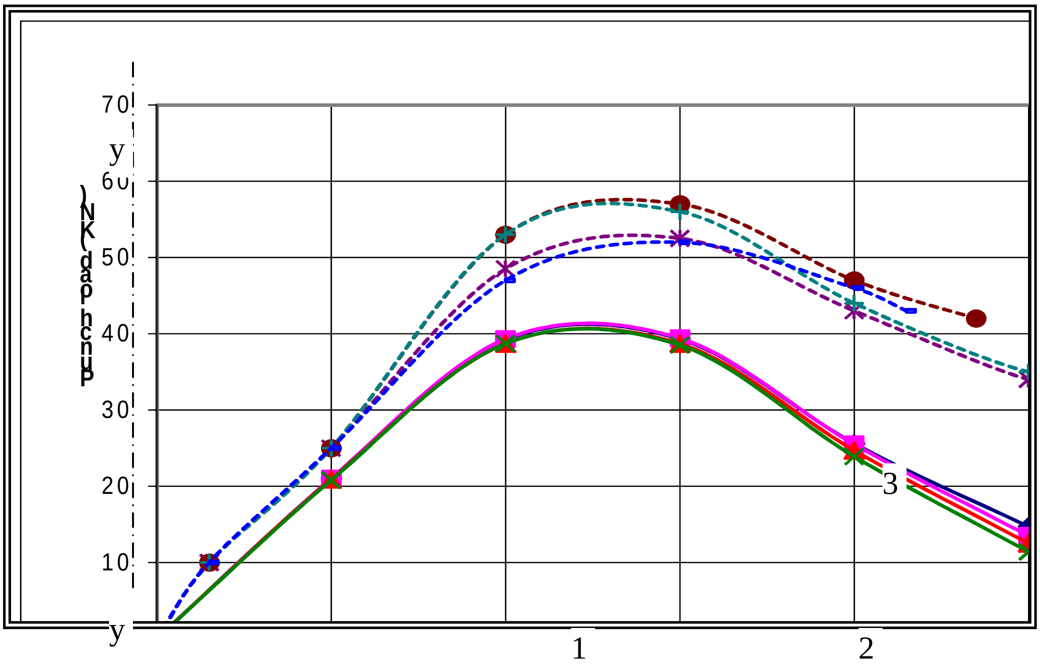

Figure (5). FEM model.

vi. Applying displacement to punch:

Punch moves downward to draw the blank inside the die to produce a cup, this movement consists of (11 steps) (maximum), in each step the punch moves a distance of (5) mm, to reach a maximum total displacement of (55) mm. Punch speed equal to (10) mm/ min.

Speed (v) = displacement (u)/ time (t) (7)

3-4-2 Computational analysis:

The data set prepared in preprocessing stage is used as input to the finite elements code itself, which construct and solve a system of non-linear algebraic equations.

4- Results and discussion

4-1- Implementation

Figure (6) shows a screen used to input cup dimensions which are; cup diameter = (120) mm, cup thickness (0.42) mm, while cup height is deeper here and equal to (400) mm.

Figure (7) illustrates blank material properties screen. This screen contains information about properties of the blank to be drawn, like metal type , the type of the used metal is “ Mild Steel” , and metal designation in two international classifications (US) and (DIN) , the used metal designation in (US) is (SAE 1006) , and (RRSt 14) using (DIN). Also this screen contains yield stress, which is equal to (220 N/mm2), and ultimate tensile stress which is equal to (350 N/mm2). and draw ratio for first draw, first redraw with annealing , and first redraw without annealing ,and their values are as follows (2, 1.7, and 1.3) respectively. The proper lubricant of this type of metal is also displayed in this screen. At this stage data is retrieved form a database file[7].

In Figure (8), the results are as follows; Clearance between punch and die equal to (0.55) mm (1.309*t), die and punch profile radii are equal to (10, 10) mm respectively. Blank diameter here is larger and is equal to (454.31) mm, since the cup is deeper, thus more metal is needed.

In Figure (9), number of draws will be displayed and equal to “Four draws”, since (h/d) ratio which is acceptable and equal to (3.33) is more than (3.0) and less than (4.5).

Cup diameter and height for the first, second, third and fourth draws are (272.58, 190.80, 137.38, 120) mm, and (121.15, 246.93, 385.03, 400) mm respectively.

Figure (10) shows tool geometry and loads will be determined and the blank with diameter (D) that become a completely drawn cup in four stages .Results for the first draw are as follows; punch diameter = (272.58) mm , die diameter = (273.68) mm, punch load = (121.68) KN, blankholder load = (40.56) KN , and total load = (162.24) KN.

Results for the second draw are as follows; punch diameter = (190.80) mm, die diameter = (191.90) mm, punch load = (64.20) KN, blankholder load = (21.40) KN, and total load = (85.60) KN.

Results for the third draw are as follows; punch diameter = (137.38) mm, die diameter = (138.48) mm, punch load = (43.7) KN, blankholder load = (14.56) KN, and total load = (58.26) KN.

Results for the fourth draw are as follows; punch diameter = (120) mm, die diameter = (121.1) mm, punch load = (25.16) KN, blankholder load = (8.38) KN, and total load = (33.55) KN.

By clicking on “Connect to AutoCAD” button, AutoCAD will be automatically launched, and by clicking on “Plot 1st die” and “Plot 2nd die” and “Plot 3rd die” and “Plot 4th die” buttons, first, second, third and fourth deep drawing dies will be plotted directly as shown in Figure (11).

The whole results of the computer-aided design system are listed in details in Table (2). It can be concluded that, if the product (cup) needs more than one stage (draw) to be completely drawn, punch load, blankholder load, total load, and (LDR) will be decreased with subsequent stages.

The developed system showed how to design for deep drawing process which is a time consuming and tedious work can be accomplished automatically. Also it is not violated by human errors; these benefits will be next reflected on the quality of the produced part.

4-2 Finite elements analysis

FE method is used to simulate the drawing operation, the result were compared with experimental results found by (Al-bassam) [1] and the theoretical results found by Mithaq [5].

The maximum punch stroke was set as (55) mm to ensure that the product (cup) is completely drawn. Boundary conditions utilized by FEM were as follows, coefficient of friction (μ) = 0.1, blankholder force (BH. F.) = (15) KN, Poisson ratio (υ) = 0.3, punch speed = 10 mm / min.

To investigate the effect of radial clearance between punch and die on the drawing operation, one punch with profile radius of (15) mm, and with diameter of (120) mm, and four dies with die profile radius of (6) mm , and diameter of (120.9 , 121, 121.1, 121.14) mm. This tool set gave the best drawn cups with less wrinkles and earing experimentally.

the radial clearances were taken as follows: C1= 0.45 mm (107 %), C2 = 0.5 mm (116 %), C3 = 0.55 mm (130.9 %) , and C4 = 0.57 mm (135.7%).

Figure (11) represents the effect of radial clearance on punch load. Both FEM and experimental results are included. It is clear that the punch load increases slightly with the decrease of radial clearance between punch and die. This occur since the gap between punch and die decreases, thus the contacted area between the blank and tools will be larger an the friction higher. Also the Figure shows that experimental loads are higher than FEM loads , this may occur since in the experimental circumstances , the lubricant could be inefficient, and this causes the friction between the blank and tools to be higher.

It is clear that cup thickness remains stationary at the cup bottom. At the next region (under punch profile radius), the thickness decrease, because of stretching applied to this region. At the cup edge, the cup wall thickness has a proportional relation with radial clearance, this is caused by the hoop stress applied to this area and also the gap between punch and die acting to size the blank.

It is clear that the equivalent strain over the cup wall increase with deeper punch movement and the change of radial clearance does not affect the equivalent strain.

The effect of radial clearance seems to be very small using both the experimental method or FEM, since the difference in range of the used clearances is very small, it is difficult to determine the optimum one, thus C3 (1.309 t) can be considered as best clearance.

In the experimental method the optimum die design was concluded depending on normal (thickness) strain, in addition to punch load, while using finite element method in this work, the optimum die design is predicted depending on equivalent (effective) strain and stress which represent the resultant of strain and stress in the normal , radial, and circumferential directions , and this proves that predicting the optimum die design using finite elements methods is accurate than the experimental method.

Optimum die design, using FEM, can be concluded to have a tool set with r_p equal to (10 or 15) mm , and r_d equal to (6 or 10) mm, and clearance of (0.55) mm (130.9 % t), and this gives a good match with the experimental results.

5- Conclusions

- It has been observed that the computer – aided deep drawing design system aids designers in providing an automated easy tool for working faster and more accurate.; these benefits will be next reflected on the quality of the produced part.
- If the product (cup) need more than one stage (draw) to be completely drawn, punch load, blankholder load, total load, and (LDR) will decreased with subsequent stages.
- It was concluded, using FEM, that it is possible to produce successful cups.
- Finite elements method is more accurate than the experimental method in predicting the best die design the experimental method ,since predicting of best die design, using FEM, as show in Figure (12)

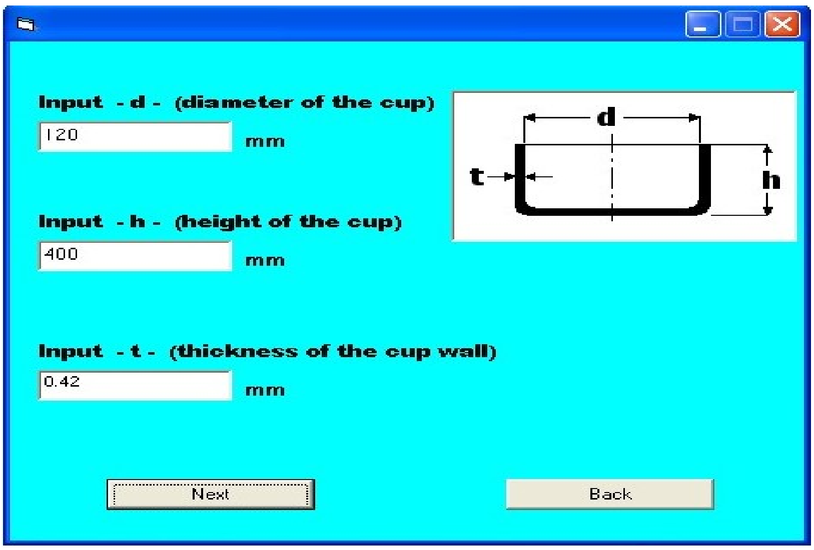

Figure (6). Cup geometry screen.

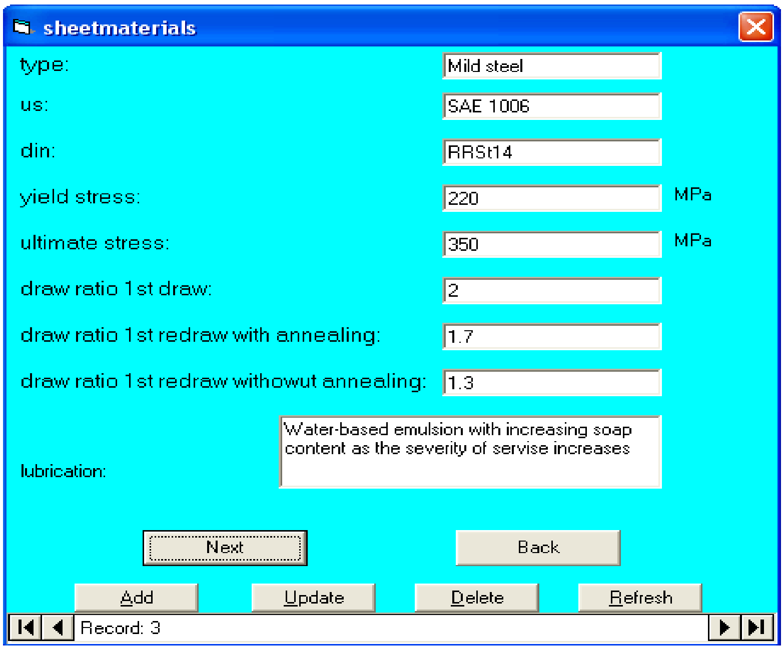

Figure (7). Blank metal properties screen.

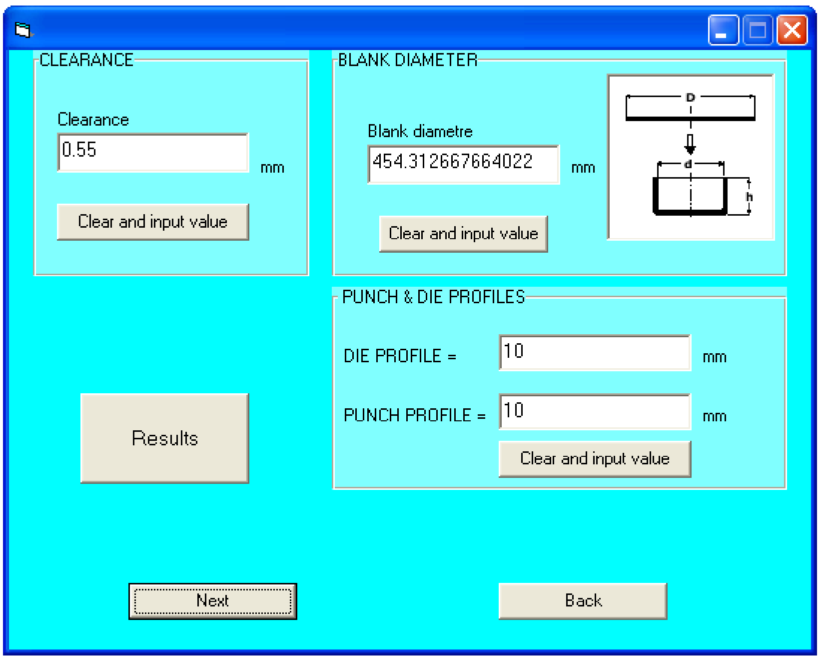

Figure (8). Blank diameter and tool geometry.

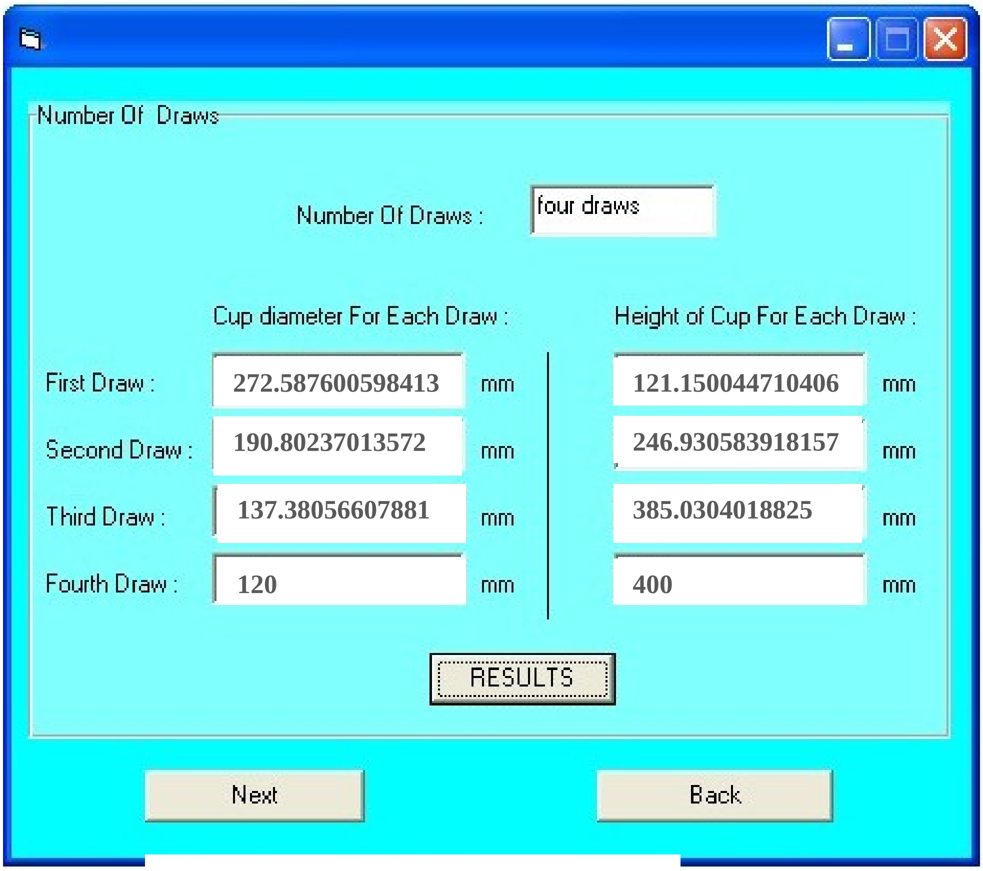

Figure (9). Number of draws screen.

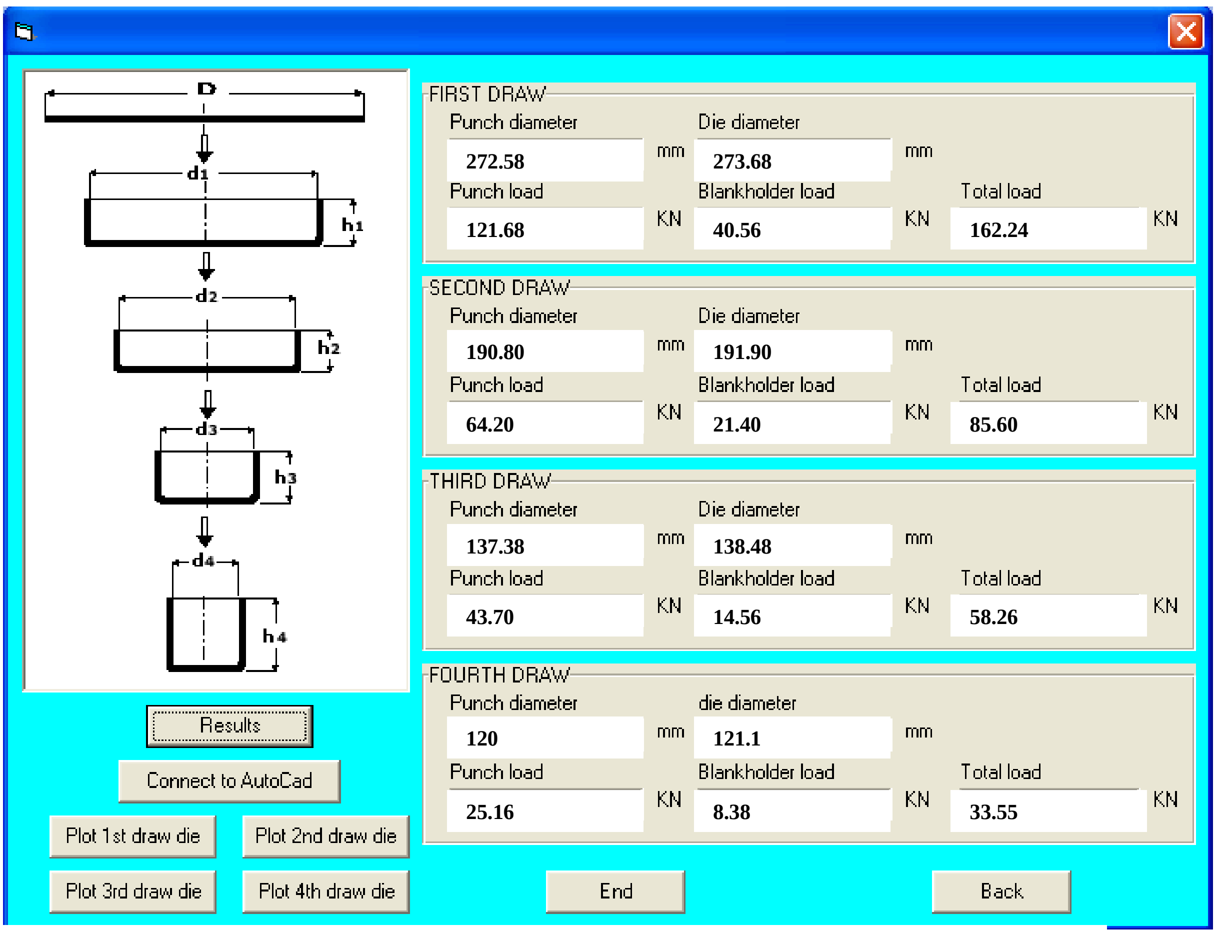

Figure (10). Tool geometry, load, connection to AutoCAD, and auto plot screen.

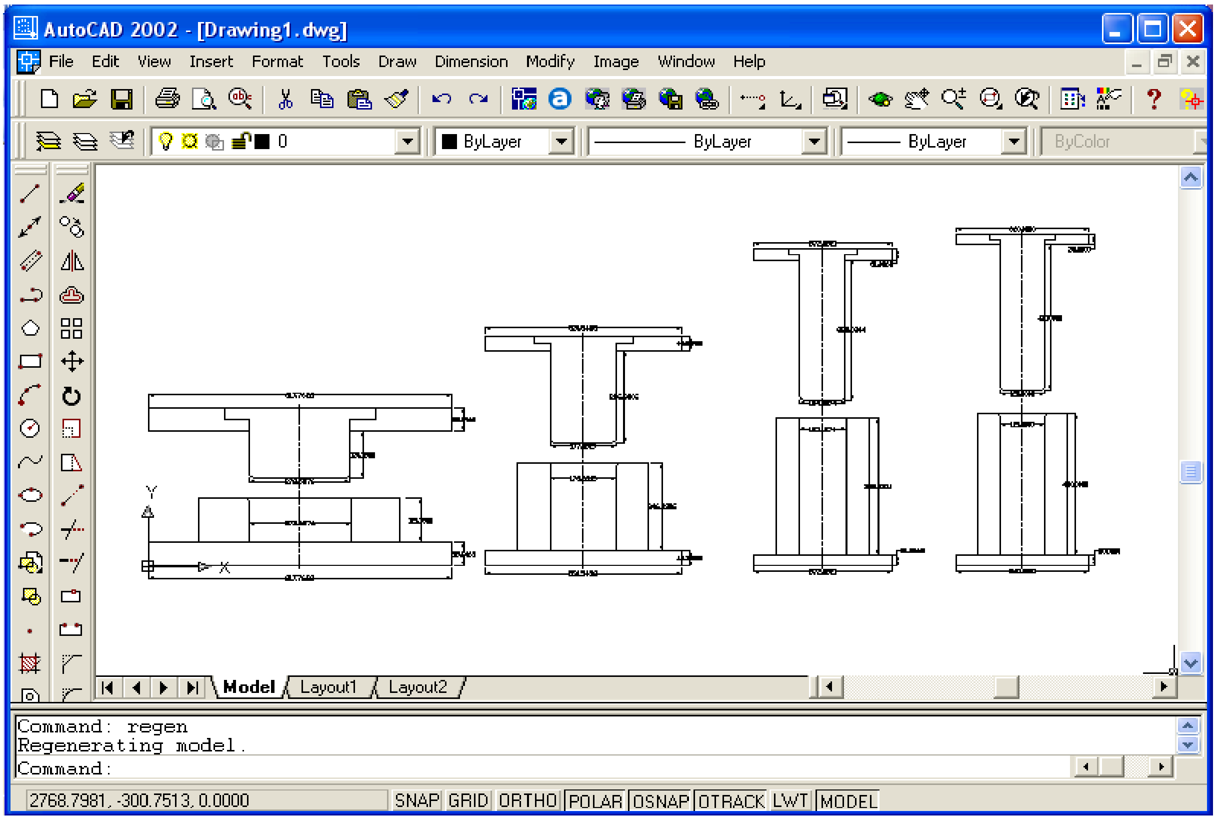

Figure (11). Deep drawing die(s) screen (four draws).

Table (2). Results of the computer-aided design system.

	First draw	second draw	Third draw	Fourth draw
Blank diameter (mm)	454.31	454.31	454.31	454.31
Cup diameter (mm)	120	120	120	120
Cup height (mm)	400	400	400	400
Cup thickness (mm)	0.42	0.42	0.42	0.42
Clearance (mm)	0.55	0.55	0.55	0.55
Die profile radius	10	10	10	10
Punch profile radius	10	10	10	10
Cup diameter (mm)	272.58	190.80	137.38	120
Cup height (mm)	121.15	246.93	385.03	400
Die diameter (mm)	273.68	191.90	138.48	121.1
Punch Load (KN)	121.68	64.20	43.70	25.16
B. H. Load (KN)	40.56	21.40	14.56	8.38
Total Load (KN)	162.24	85.60	58.26	33.55

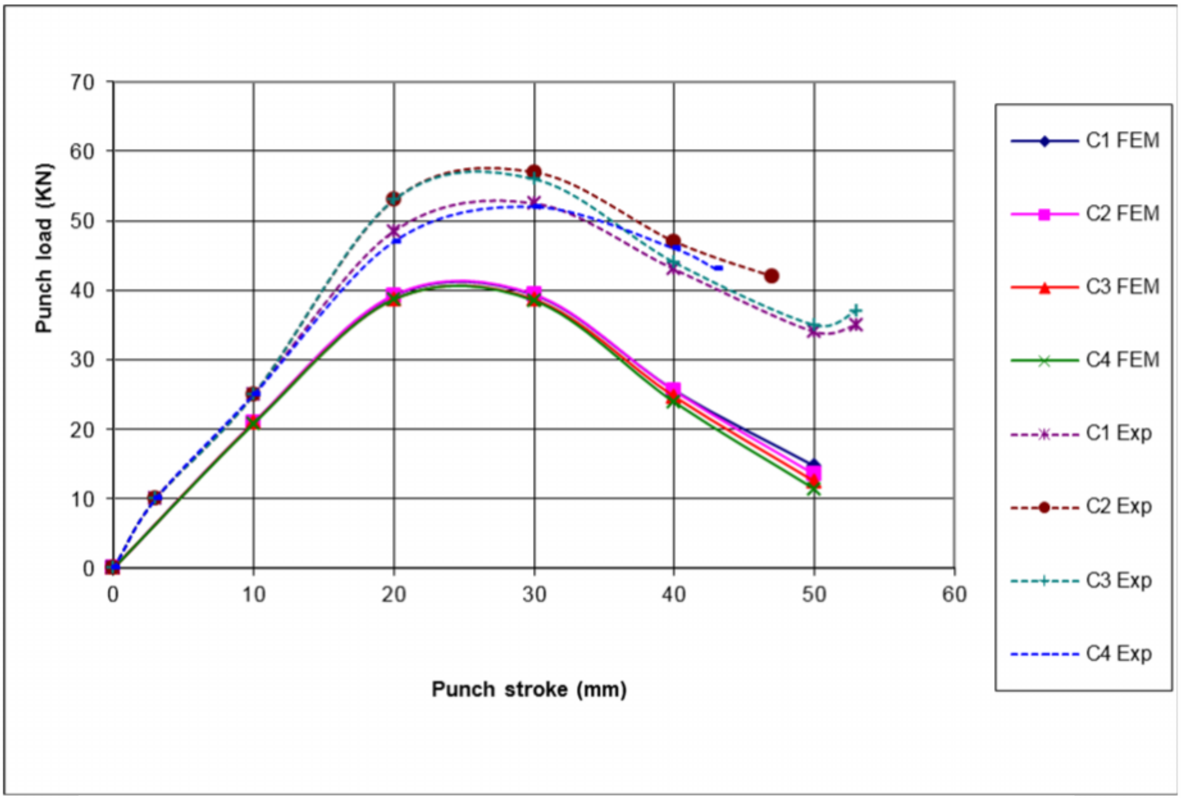

Figure (12). The effect of radial clearance on punch load (p15 d6).

6- References

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