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Influence of Metal Type on the Deep Drawing Force by Experimental and Finite Element Method

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Abstract

This paper is aimed to study the effect of material type on the drawing force. Three metals are used (low carbon steel 1008 AISI, Austenitic stainless steel 304 AISI, and pure aluminum 1100), as a sheet with thickness of 0.5mm for each one, and they were cutting as a blank with 80 mm diameter, then drawn in a die with 44mm diameter to produce cup. To predict the deep drawing force by finite element method, Hill's yield criteria is used, which examines the effect of anisotropy. Two dimension axisymmetry model of deep drawing were built and analyzed by ANSYS FEM code. The results show that the drawing force for stainless steel is higher than the other two metals due to the difference in metallurgical structure. The numerical results were compared with the experimental; good agreement was found between finite element and experimental results.

Keywords: Deep drawing, Finite element method, ANSYS, Anisotropy

دراسة تأثير نوع المعدن على قوة السحب العميق عمليا وباستخدام طريقة العناصر المحددة

الخلاصة

يهدف البحث الى دراسة تأثير نوع المعدن على القوة اللازمة لعملية السحب العميق حيث ثلاث معادن (فولاذ منخفض الكربون AISI 1008 و فولاذ مقاوم للصدأ AISI 304 والمنيوم نقي 1100 على شكل صفائح بسمك 0,5 ملم لكل معدن . وقد قطعت هذه الصفائح على شكل غفل بقطر 80 ملم ثم سحبت في قالب ذو قطر 44 ملم للحصول على منتج القدح. في هذا البحث تم استخدام معيارية هل(Hill) لحساب قوة السحب العميق لغرض اخذ تاثير اختلاف الخواصanisotropy . تم بناء نموذج متماثل حول المحور للسحب العميق ببعدين وتم تحليله ببرنامج ANSYS . ومن نتائج القوة التي تم الحصول عليها وجد ان القوة اللازمة لسحب الفولاذ الاوستناتي المقاوم للصدأ كانت اكبر من القوة اللازمة لسحب الفولاذ المنخفض الكربون وبعدها الالمنيوم بسبب خصائص المعدن الميتالورجية وحصول اصلاد انفعالي. تم مقارنت النتائج مع طريقة العناصر المحددة وقد وجد تقارب مقبول بينها وبين العملي.

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Introduction

In deep drawing process, sheet metal is formed into a concave part whose thickness is substantially the same as the original material. One of the simplest parts formed by this process is a circular cup. In this process, a flat circular sheet of metal (blank) is placed over the opening in the die and then pushed through and deformed by a moving punch. As the punch moves downward, the outer annulus of the blank, known as the flange, moves radially inward. The flange has a tendency to fold upwards, but is restrained by the blank holder. As the flange moves radially inward, its inner edge bends over the rounded corners of the die transforming a flat blank into a cylinder [1]. An experimental and numerical analysis of deep drawing of relatively thick sheet metal was carried out by Kampus and Kuzman [2]. Young [3] investigated a simulation of deep drawing by finite element method. Jian and Shunpahg[4] are used ABAQUS finite element program to analysis of an axisymmetric deep drawing part forming using reduced forming steps. Esra'a [5] used ANSYS software to simulate the deep drawing process. Hani [6] studied the stresses generation in the deep drawing process with conical die using finite element method. Harth and Shaker [7] studied the earing phenomenon in deep drawing process using finite element method. In the current research experimental and finite element investigation is made to study the effect of the metal type on the deep drawing force.

Anisotropy

It is frequently found that the tensile properties of metal products are not the same in all direction. The

Dependence of properties on orientation is called anisotropy. Deep drawing is the forming process which shows anisotropic material behavior most clearly and for which the effect of anisotropy has been known for the longest time.

The plastic anisotropy is subdivide into normal and planar anisotropy [8 and 9]. The normal anisotropy (r) is defined as the ratio of plastic strain in the width to that in the thickness direction in sheet tensile test. In practical terms (r) is a measure of the resistance to thinning. The normal anisotropy (r) is defined by:

$$r = \frac{\in_w}{\in_t} = \frac{\mathrm{Ln}\, W_o / W_f}{\mathrm{Ln}\, t_o / t_f} \qquad \ldots (1)$$

Where $\in_w$, $\in_t$are the strains in the width and thickness direction respectively

w_o, w_f: are the initial and final width of the specimen, respectively

t_o, t_f: are the initial and final thickness of the specimen, respectively.

As the thickness of the specimen is very small compared to its width, the relative errors of measurement of the two strains will be quite different. Taking into account the condition of volume constancy. Equation (1) can be rewritten in the form:

$$V_o = V_f$$

$$W_o.t_o.L_o = W_f.t_f.L_f$$

$$\frac{t_o}{t_f} = \frac{w_f.L_f}{w_o.L_o}$$

$$\backslash\ r = \frac{\mathrm{Ln}(W_o / W_f)}{\mathrm{Ln}(L_f.W_f / L_o.W_o)} \qquad \ldots (2)$$

Where L_o and L_f are the initial and final length of the specimen, respectively.

When drawing with a high r-value material the change in thickness of the flange as it is drawn towards the die opening is less than for a low r-value material and the thickness of the resulting cup will is more uniform, also the use of sheet material with large r-value, will produces less wall thinning in the transition region from the cup bottom to the wall and also reduces the drawing load and increasing limiting drawing ratio. [10,11, and 12]. In general the (r-value) is not generally constant in the sheet plane but changes with inclination from the rolling direction. A measure for the change of anisotropy (planar anisotropy), that is, the change of r-value in the sheet plane. The test piece for determining the ΔR value are cut from the sheet at different angles (0^o, 45^o, 90^o) to the rolling direction.

$$DR = \frac{r_o - 2r_{45} + r_{90}}{2} \qquad \ldots (3)$$

To estimate the deep drawing behavior of sheets one commonly uses average r-value (r'), which is calculated from the r-values measured at angles of (0^o, 45^o, 90^o) to the rolling direction.

$$r' = \frac{(r_o + 2r_{45} + r_{90})}{4} \qquad \ldots (4)$$

Sheet metal with good deep drawing characteristics should have a high (r') and small planar anisotropy ΔR. (Fig. (1).

Experimental work

Material Selections

Three types of metals; low carbon steel (1008-AISI), austenitic stainless steel 304 AISI and pure Aluminum 1100 are chosen as the materials for the majority of the work, table (1) shows the chemical composition of these materials. The three sheet metal are with thickness, t_o =0.5 mm.

Material Characterizations

Material properties in the sheets are determined with three directions , firstly parallel 0° , and then with 45° and last with 90° according to the rolling direction. Table (2) shows the results of tensile test for three materials at different angles (0^o, 45^o and 90^o) with respect to the rolling direction.(the specimen of tensile test is done according DIN 1700). Also, hardness test is made through Vickers method on BROK apparatus with 9.8 kg, three reading is taken and the average is dependent as shown in the table (3).The true strain is measured to predict the plastic anisotropy in the sheet, the sheet would be cut parallel to 0^o, to 90^o and 45^o to the rolling direction. The values of the Lankford coefficient (r-value), normal anisotropy coefficient ($\bar{r}$-value), and planer anisotropy (Δr) for two materials are calculated by using equations(2), (3), (4) respectively, the results are shown in table (4).

Deep Drawing Test

Table (5) shows the parameters of deep drawing process. The number of drawings [13] which are represented by the relation between the ratio of length to the diameter, can be found equal to one drawing as shown in table (6).

Numerical Simulations

The deep drawing process involves extensive plastic deformation together with large strains and rotations. The description of the process is further complicated by highly nonlinear boundary conditions, namely contact and frictional effects. There were a number of early attempts at analytical models of deep drawing. However, due to the complex nature of these models, numerical approaches, dominated by finite element method, are now in widespread use. With the availability of ANSYS software, sheet metal forming simulation has become increasingly prevalent. Finite element analysis permits the modeling of complex geometries, boundary conditions and material behavior which are commonly found in deep drawing processes. In Finite element modeling of sheet forming processes, the robustness and stability of the solution are important requirements. Computational time and convergence issues can become significant due to the complexity of the geometry and the boundary conditions. Both implicit and dynamic explicit FEM codes are available to analyze sheet forming processes [14 and 15] .

Finite element model

Nonlinear Finite Element Formulation can be expressed mainly by three type of nonlinearities: Geometric nonlinearly, Material nonlinearly and Contact nonlinearly. The entire process of performing a finite element analysis of a metal forming operation. The input data for an ANSYS analysis are prepared using a preprocessor. The general preprocessor (PREP7) contains powerful solid modeling and mesh generation capabilities, and is also used to define all other analysis data geometric properties (real constants), material properties, constraints, loads, etc. [16]. The 2-D 8-node structural plane element of PLANE82 was used for blank. The tool set punch, die and blank holder were modeled as rigid bodies. Three different types of nonlinearity evident in the current study are Geometric nonlinearity where Lagrangian procedure can be used to analyze geometric nonlinear (NLGEOM,ON), nonlinear boundary conditions which results from contact and frictional effects where contact procedure in ANSYS was used to model the complex interaction between the blank and tooling. For rigid (tool set)-flexible (blank) contact, 2D 2-node CONTAC48 is used, to represent 2D target (tool set) surfaces which were associated with the deformable body (blank) represented by 2D 8-node PLANE82. The movement of the punch was defined using a pilot node; this node was also employed to obtain the drawing force during the simulation and material nonlinearity, which results from the nonlinear relationship between stresses and strains, Hill's theory is used to represent the material behavior (TB,Hill) [16]. Only one quarter of the tooling and the part are modeled because of the axisymmetry. The finite element model, as shown in Fig.(2).

Results and Discussion

The experimentally measured forming load-displacement curves for the three metals and finite element results are shown in Fig.(3). The overlapping curves indicate that there is a variation between experimental and FE results, so the discrepancies between the experimental and finite element results for maximum deep drawing forces shown in table (7). The discrepancies between the finite element and experimental results can be accounted for by possible errors in both analyses. In the experiment, possible errors were due to misalignment of the blank over the ring die, insufficient blank lubrication, and blank thickness variation. Also, errors in measurement of the forming loads. Finite element analysis determines an approximate solution of the problem modeled which have errors, these errors generally result from simplifications to the geometry, boundary conditions, material properties, loading and friction and fitting the die profile to a circular arc instead of a generalized cubic spline as well as the discretization errors are a consequence of representing a continuum by a finite number of elements. A mesh refinement study was conducted to determine an optimal FE mesh. Finally the round-off errors which are a result of the finite precision of the computer used. Fig.(3) indicates that the stainless have higher drawing force than the other materials (low carbon, Aluminum) due to the differences in the metallurgical structure.

Conclusions

The following conclusion can be drawn from this research.

1. The simulation results with Hill's model could describe the drawing process more accurately than with Von Mises model.
2. The ability of the Hill's model to capture anisotropic behavior is evident in the variations in the cup height with material direction.
3. The Austenitic stainless 304 AISI have higher drawing force than the other materials (low carbon steel 1008 AISI and Aluminum 1100).
4. Despite the numerous assumptions and simplifications made to the numerical model, very good agreement between the experimental and FE results were found.

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Table (1) Chemical composition of 1008-AISI Low Carbon Steel, austenitic stainless steel 304 AISI and pure Aluminum 1100

Metal	**Composition**								
%	**C**	**Mn**	**P**	**S**	**Si**	**Ni**	**Cr**	**Ti**	
Actual value 1008	0.2	0.65	0.03	0.05	0.06	0.077	0.021	0.008	
Standard value 1008	0.18-0.23	0.3-0.6	0.04	0.05	0.01	-	-	-	
Actual value 304L	0.09	1.1	0.041	0.026	0.38	10	20	-	
Standard value 304L	0.06	1.5	-	-	0.75	10	19	-	
Metal	**Composition**								
%	**Cu**	**Mn**	**Mg**	**V**	**Si**	**Zn**	**Ti**	**Fe**	**Al**
Actual value Al 1100	0.05	0.009	0.029	0.055	0.14	0.035	0.035	0.24	Rem.
Standard value Al 1100	0.05	0.03	0.03	0.05	0.25	0.05	0.03	0.35	Rem.

Table (2) Results of tensile test

Material type	**Rolling direction**	σ_y **N/mm^2**	σ_u **N/mm^2**	**Elongation mm**
Low carbon AISI (1008)	0	170	321	22
	45	170	339	23
	90	163	434	24
Stainless steel (304)	0	188	550	42
	45	185	500	44.3
	90	195	650	48.2
Aluminum 1100	0	69.5	100.9	37.9
	45	66.	94.1	35.7
	90	62	98	35.6

Table (3) Results of hardness test

Material type	**Hardness kg/mm^2**
Low carbon AISI (1020)	92.8
Stainless steel (304)	137.7
Aluminum 1100	32

Table (4) The value of anisotropy index of three materials with respects to rolling direction.

Materials	**r0**	**r45**	**r90**	$\bar{r}$	**Δr**
L.C.St	1.56	1.26	2.12	1.55	0.58
304L A.S.St	1.056	0.987	1.15	1.045	0.116
Al 1100	0.95	0.781	1.02	0.883	0.408

Table (5) Deep drawing process parameters

Parameter	**Value**
The Punch diameter (mm)	43
The die diameter (mm)	44
The punch profile radius (mm)	6
The die profile radius (mm)	6
The blank size (mm)	80
Sheet thickness (mm)	0.5
Blank holder force (kN)	10
Drawing speed (mm/min)	200

Table (6) Number of Drawings used to Produce a cup

No. of Drawings	**Ratio of length of cup to its diameter**
1	Up to 0.7
2	0.7-1.5
3	1.5-3
4	3.4-7

Table (7) Discrepancies for max. deep drawing force

	Max. Force (kN) Experimentally	**Max. force (kN) FE analysis**	**Discrepancy %**
L.C.St	46.7	41.3	11.56
304L A.S.St	88.3	78.3	11.32
Al 1100	24.9	20	19.6

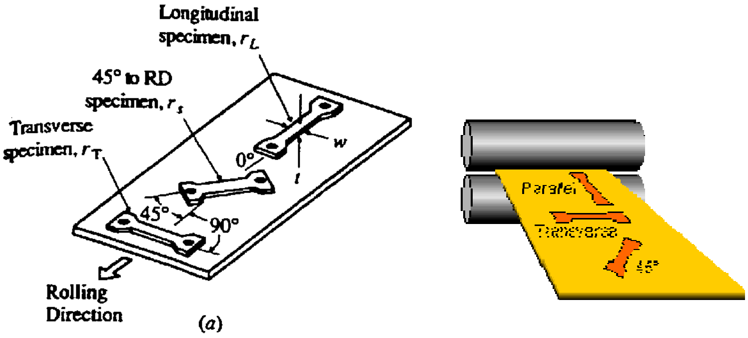

Figure (1) Tensile specimen orientation for determining $\bar{r}$ and Δr

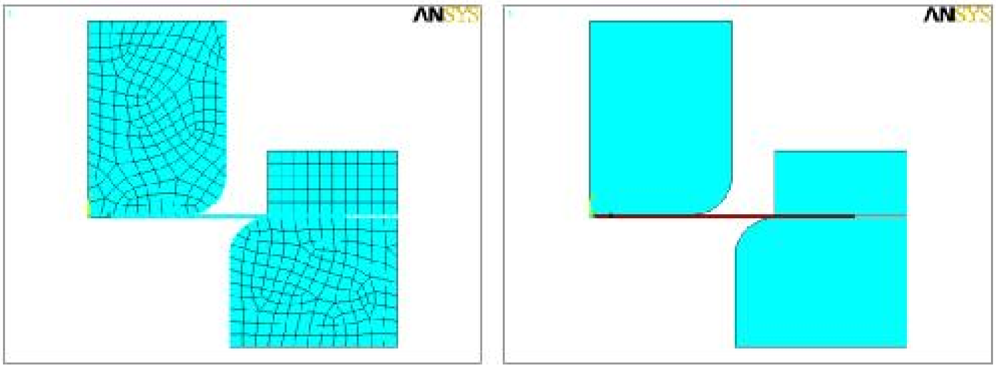

Figure (2) FE Model of axisymmetric deep drawing

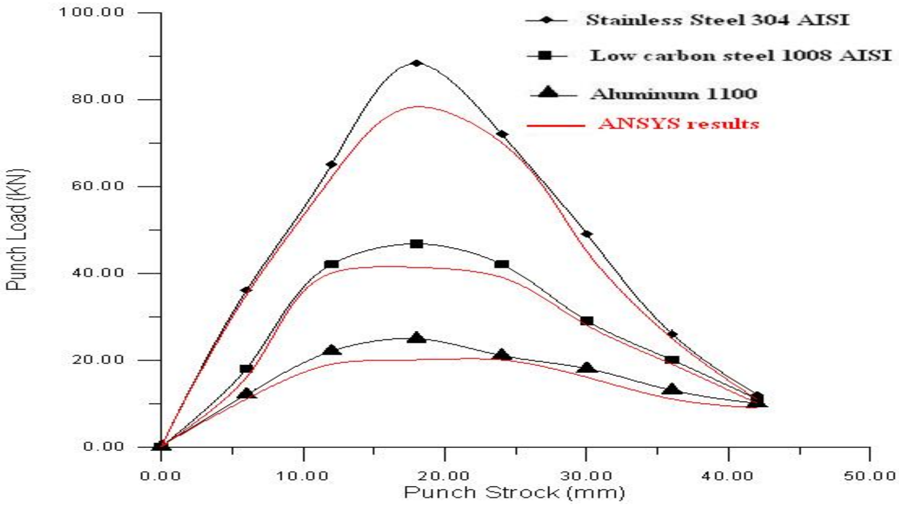

Figure (3) Punch Load vs Punch stroke for three metals