Investigation of hydrostatic counter pressure effect on thickness distribution in Hydromechanical deep drawing process with hemispherical punch

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Abstract:
In this paper, effect of hydrostatic pressure on thickness distribution in the Hydromechanical deep drawing process (HDD) has been analysed numerically . HDD process of hemispherical Cups with material AL6111-T4 has been investigated . Simulation of process with finite element code ABAQUS/Explicit has been done and Forming Limit Diagram(FLD) damage criterion has been used for determining rupture instability . In addition anisotropy , using anisotropic Hill criterion for the plate is considered and material behavior by uni-axial tensile test is obtained . Results showed an optimized maximum counter-pressure profile for best thickness distribution . Also thickness distribution has 4.25% improvement by using HDD process in compare to conventional deep drawing process .

Key-words **:** Hydromechanical deep drawing; Thickness distribution; Hemispherical cup; Finite element; Forming limit diagram; Counter pressure

1. Introduction

Recently , the traditional sheet metal forming process can not be used for variety of productions . Advanced sheet metal forming such as HDD is used specially in many industries. Conventional deep drawing process is applied for mass production parts but HDD more is used for single and batch production type [1]. In conventional deep drawing of hemispherical cups, the blank will be wrinkled because large region between punch contact location and blank holder is unsupported. Also thickness distribution and quality of pieces produced using conventional deep drawing is worse than parts produced with HDD process. Higher economic efficiency and flexibility can be achieved by using HDD process. Part quality and thickness distribution obtain by using Hydromechanical deep drawing process is also better than conventional deep drawing process. This is because the blank to the punch surface is compressed due to hydraulic counter pressure. Desirable friction force between the punch and blank created. That will cause blank to be adherence to the punch surface and prevent from stretch and thinning in the cup wall. A corollary of this is that the thickness distribution of parts has been more uniform [2] , and in addition there is a good control in the wall of the cup due to applied hydraulic counter pressure, for this reason the HDD process have a more appliance in produce sensitive aerospace parts [3,4].

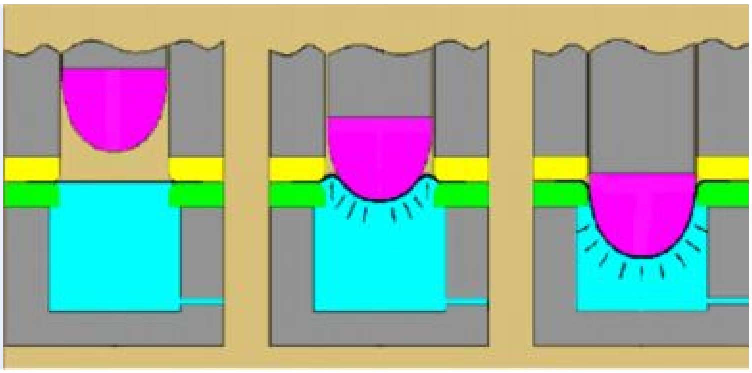

Fig 1 : Hydromechanical deep drawing process of hemispherical punch

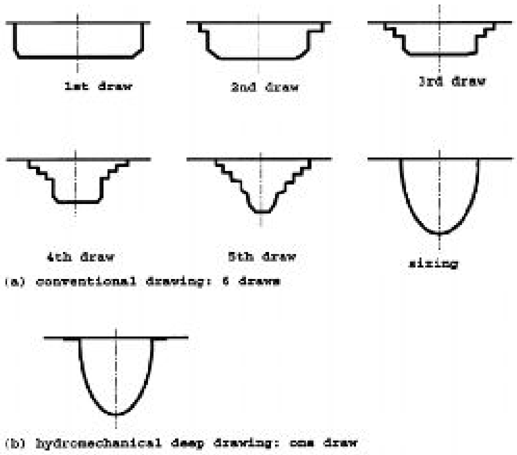

Fig2. Deep drawing of hemispherical or conical parts [4]

Hydromechanical deep drawing process is an efficient method for production of complicated parts. Number of production stage can be reduced to one stage by using HDD method, for example one draw is sufficient to form a hemispherical part in the HDD process, where as five draws and a sizing are needed for conventional deep drawing (see Fig2) [4].

Some advantages of sheet hydroforming are improving the material formability, reduction of friction force, the accuracy of the forming part and the reduction of forming stages because of improvement of limiting drawing ratio (LDR) [6,7]. Analysis of tearing phenomenon in hydroforming was studied by Zhang *et al.*(2000), Lang *et al.*(2005) and Dechang *et al.*(2005). [8,9,10]. Generally, two kinds of material failure caused by inappropriate fluid pressure were identified. The failure by wrinkling at the flange area (The area that the blank is contact with die and blankholder) result from insufficient fluid pressure and the failure by rapture on the top of the cup results from excessive fluid pressure [11]. Numerous researchers have attempted to explain theoretically the critical condition of rapture in hydroforming process. Yossifon and Tirosh (1985,1991) predicted rapture by using the criterion of plane strain failure and wrinkling instability by energy method, they also obtained tearing and wrinkling diagrams for a process with radial pressure [12,13]. Sy-wei *et al.*(1993) extended the results of Yossifon and Tirosh (1991) for hemispherical cups [11]. Wu et al.(2004) and Khandeparkar and Liewald (2008) obtained rapture and wrinkling diagram for stepped punches by finite element simulation and experiments [14,15]. Thiruvarudchelvan and Tan (2006) performed theoretical analysis and experimental approach from hydraulic pressure-assisted deep drawing process [16].

Hama *et al.*(2007) developed an elasto-plastic finite element method for the sheet hydroforming of elliptical cups [17]. Zhang et al .(2003) investigated effect of anisotropy and prebulging on the dimension accuracy and thickness distribution in hydromechanical deep drawing of hemispherical mild-steel cups by finite element simulation and experiments [18].

In this paper, the effect of hydrostatic pressure on thickness distribution in the Hydromechanical deep drawing process of hemispherical AL-alloy 6111-T4 cups has been studied numerically and the counter pressure profile was applied according to experimental work [19], also an optimal maximum counter pressure profile for best thickness distribution was obtained and the thickness distribution of part in conventional deep drawing and Hydromechanical deep drawing with optimized maximum counter pressure profile, was compared.

2. Conditions

Fig.3 shows the true stress-strain in rolling direction for material behavior of Al6111-T4 obtained from uniaxial test based on ASTM E8 standard and anisotropic characteristics (r-values) obtained according ASTM E517 standard .

Optimized counter-pressure profile generate by try and error method with using experiments or simulation approach. Appropriate thickness distribution is obtained by using the following counter-pressure profile shown in (Fig.4) which is adopted from experimental work [19].

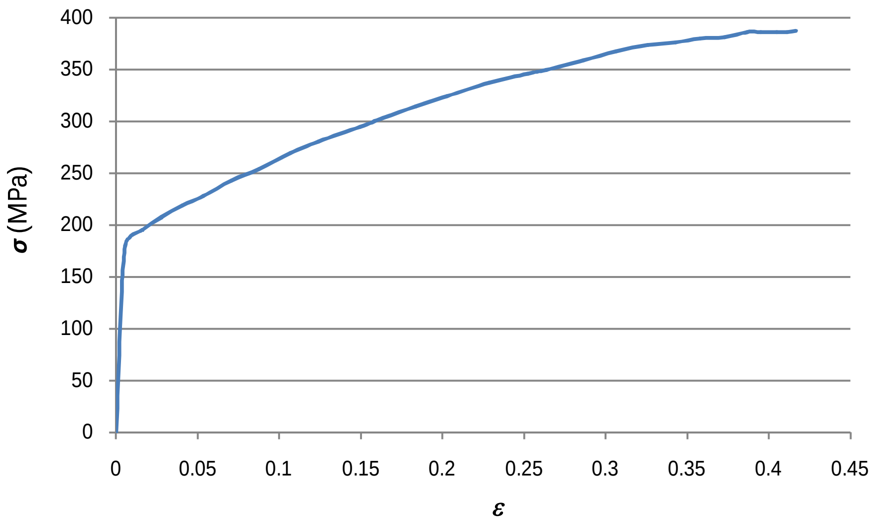

Fig 3. True stress-strain in rolling direction for AL6111-T4 obtained from uniaxial test

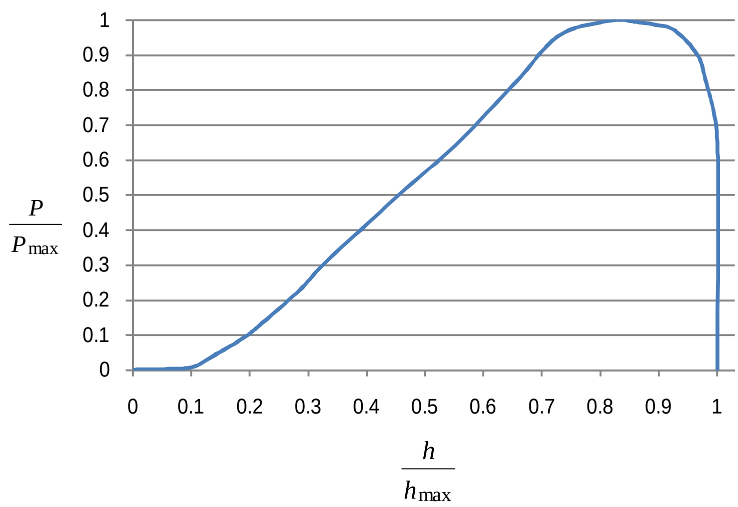

Fig 4 . Normalized counter-pressure profile adopted from experimental work

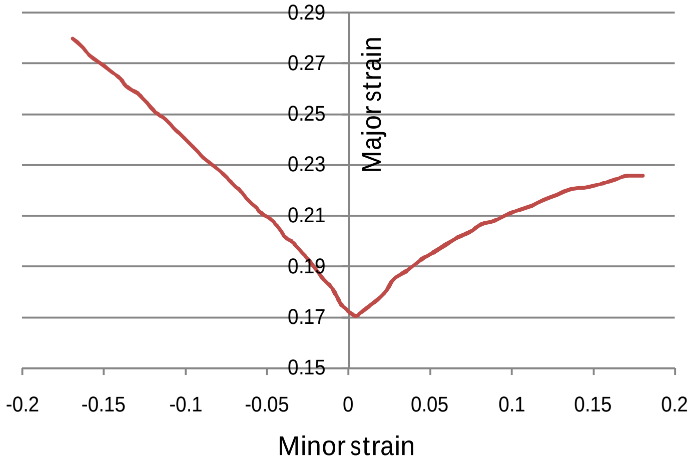

Fig 5. Forming limit diagram (FLD) of AL6111-T4

Table 1. Mechanical material properties and process parameters for the simulation

Material	AL6111T4
Blank Diameter ,R_0(mm)	177.8
Thickness,t_0(mm)	1
Poisson ratio , μ	0.33
Young's modulus ,E (Mpa)	71000
Density (g/cm^3)	2.7
Yield stress (Mpa)	180
Ultimate tensile strength , (Mpa)	370
Strain hardening exponent, n	0.210
Strength coefficient , K	456.688
Punch travel ,h_{max}(mm)	57
Punch Diameter,(mm)	101.6
Inner Diameter Of Blank Holder,(mm)	103.6
OuterDiameter Of Blank Holder,(mm)	200
Inner Diameter Of Draw binder,(mm)	103.6
OuterDiameter Of Die,(mm)	210
Die profile radius ,(mm)	8
Gap Between Die and Blank holder,(mm)	1.1
Friction Coefficient (Blank and Punch)	0.15
Friction Coefficient (Blank and Blank Holder)	0.05
Friction Coefficient (Blank and Die)	0.05
Anisotropy ,R_0	0.832
Anisotropy ,R_{45}	0.861
Anisotropy ,R_{90}	1.422

3. Finite element analysis

3.1 Finite element simulation

Modeling of Hydromechanical deep drawing process was developed using Abaqus/CAE and commercial explicit software of Abaqus was used in the 3D simulation. All tools (i.e punch , die and blankholder) were modeled using a discrete rigid type R3D4 and the material were modeled using S4R (a 4-node quadrilateral in-plane general purpose shell, reduced integration). Also in order to obtain desired mesh size and element geometry, the blank was partitioned to three region and 3456 elements on blank was established by using structured mesh strategy.

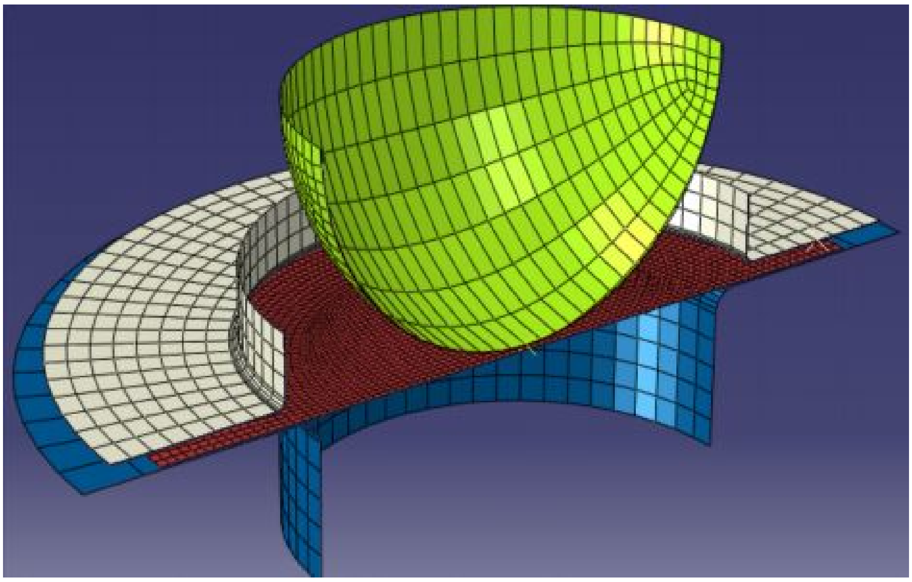

Fig 6. Simulated model by Abaqus/CAE

3.2 Validation of analysis

Generally the kinetic energy should be a small fraction of the internal energy (less than 5 to 10%) until the dynamic effect become least and the analysis procedure will be Quasi-static [20]. Fig 7 shows the internal energy and kinetic energy during process analysis and it is obviously observed that the kinetic energy is very less than five percent of internal energy therefore the problem was solved with quasi-static procedure and simulation results are accurate and valid.

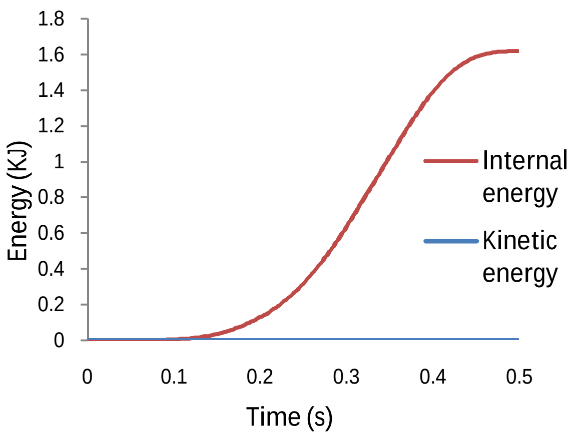

Fig 7. The histories of total kinetic energy and internal energy

Another important energy output variable in finite element simulation is the artificial energy which is substantial fraction (approximately 3%) of the internal energy in this analysis (see Fig8). Usually the artificial energy should be a small fraction of the internal energy (about 5%) until hourglass phenomenon did not occur during the analysis [20].

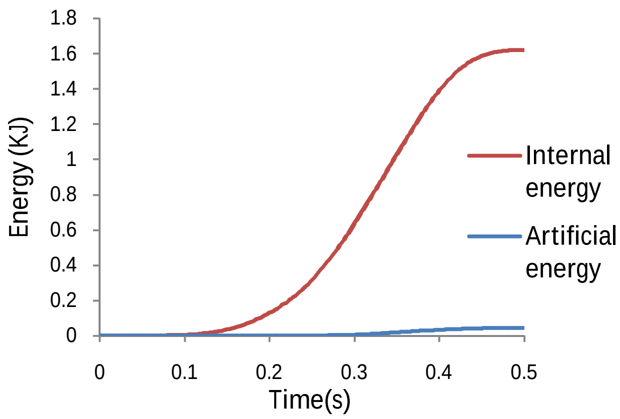

Fig 8. Comparison between artificial energy and internal energy during FEM analysis

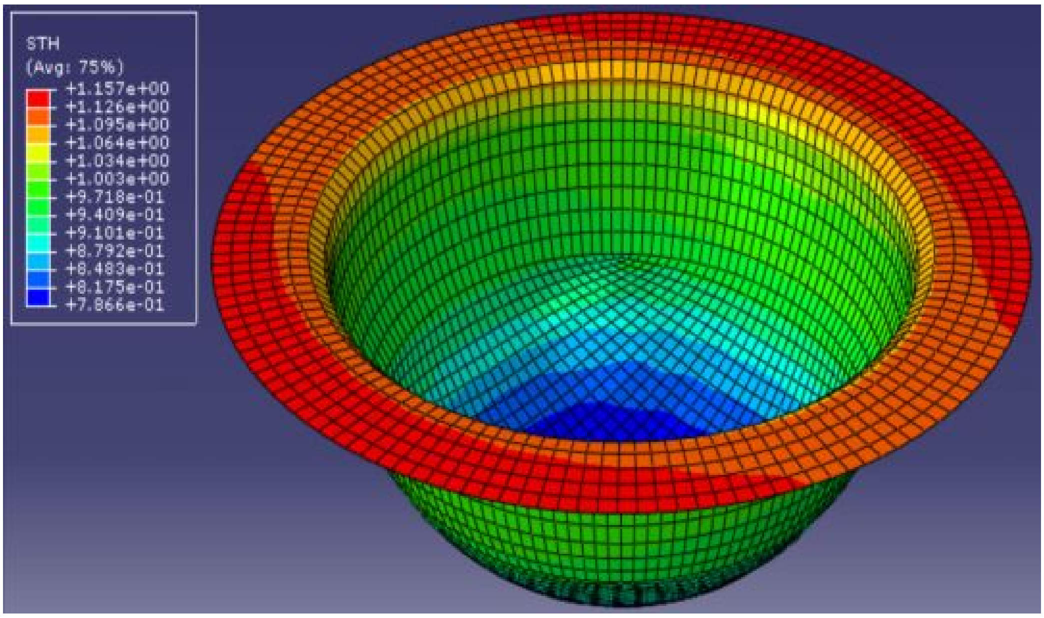

Fig 9. Thickness distribution of part in conventional deep drawing

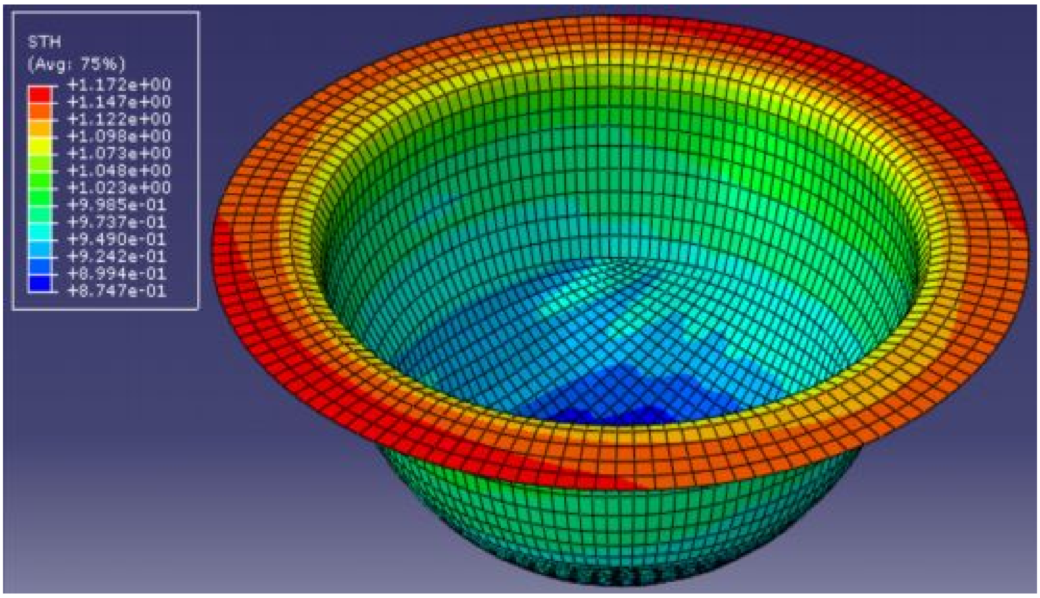

Fig 10. Thickness distribution of part in HDD with 17Mpa maximum counter pressure profile

4. Results and discussion

The part quality was better with more uniform thickness distribution. In the present work, blank thickness was one millimeter . The ideal thickness distribution of the part is obtained in a part for whole region is also one millimeter. In reality one can not reach to this result because there are a circumferential compressive stress in flange area that causes the greater thickness compare to the initial thickness. Also there was a tensile stress in wall of the cup that cause the thickness to decrease from initial thickness. Fig.11 shows the thickness distribution of parts in traditional deep drawing and Hydromechanical deep drawing with different maximum counter-pressure profile obtained from Finite Element Method (FEM) simulation.

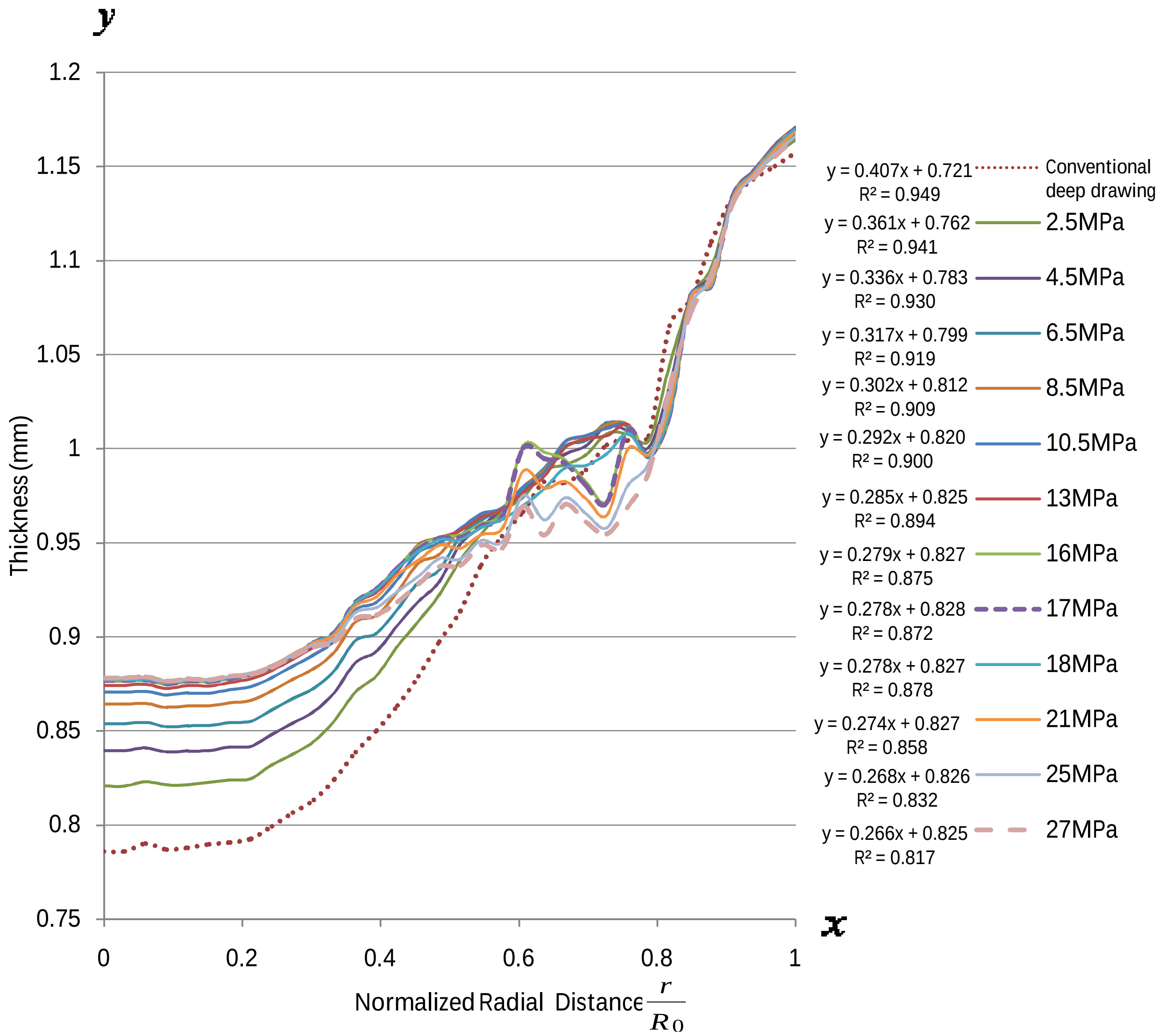

Fig 11. Thickness distribution curves and linear interpolated equations for different maximum counter-pressure profile

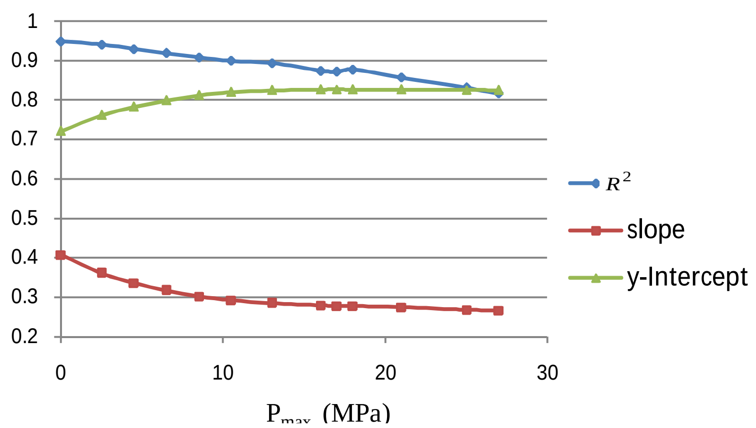

Fig 12. Variation curve of R^2 , slope and y-intercept respect to maximum counter-pressure profile

In order to compare the thickness distribution in different state linear interpolation of each curve was obtained by using least mean square method. A better thickness distribution will be obtain by getting less slop of line and y-intercept close to one. Because the ideal condition of thickness distribution is a horizontal line with equation y=1 (the slop of this line is zero and y-intercept is one). Considering the Fig 12 one can be see that with increasing the maximum counter-pressure profile from zero to 17Mpa، the slop of interpolated lines is reduced and the y-intercept of lines increases also sum of square (R^2) decreases and the thickness distribution is better. With increase maximum counter-pressure profile from 17Mpa to 27Mpa, the slop of interpolated lines is reduced, but the y-intercept decreases, also by increase, maximum counter-pressure from 17Mpa to 18Mpa sum of the squares(R^2) increases and the thickness distribution is worse. Because with increase maximum counter pressure more than 17Mpa the blank will begin to thinning duo to increase friction force between blank and blankholder. If the maximum counter-pressure profile is more than 27Mpa the blank will be ruptured. Thus it the maximum counter-pressure profile that can be optimized for best thickness distribution is 17Mpa.

In addition with considering to interpolated lines equations one can find that the thickness distribution in conventional deep drawing has 7.55% deviation respect to ideal state. While with using maximum counter- pressure profile 17Mpa in Hydromechanical deep drawing has be reach 3.3% deviation from ideal state.

5. Conclusion

The effect of maximum counter-pressure profile on the thickness distribution of part in Hydromechanical deep-drawing has been investigated and the result from this work showed the optimal maximum counter-pressure profile. If the maximum counter-pressure profile will be more than the optimal maximum counter-pressure profile then blank has been thinning due to increasing in friction force between blank and blank holder. In addition with applying higher pressure the blank will be ruptured.

Thinning in the blank is not desirable for thickness distribution because it is localized phenomenon and the best thickness distribution could be obtained by using optimized maximum counter- pressure profile. With comparing Hydromechanical deep drawing and conventional deep drawing one can see, that the thickness distribution will have 4.25% improvement by using optimal maximum counter-pressure profile.

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