INFLUENCES OF FRICTION CONDITIONS ON SHEET HYDROFORMING USED IN AUTOMOBILE INDUSTRIES +

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Abstract:

Sheet hydroforming (SHF) or hydro-mechanical deep drawing (HDD) has been emerged as one of the desirable manufacturing processes particularly in automobile industries. This importance is appeared due to its capability of producing complex mechanical components in few steps. It also presents further advantages such as improved structural strength, stiffness, and more efficient material usage. The SHF depends directly on many factors, and the most important one is a friction. The friction plays an important role in SHF operation processes; therefore, different values of coefficient of friction between the die and sheet were considered in the present paper. These values were varied from 0.01 up to 0.35, and hence the obtained results showed that higher values of coefficient of friction led to a low expansion capabilities and more thickness alteration. This means that the friction between die walls and the employed sheet was increased when a bead force is created a bead force and it is dependent directly on the contacted surfaces and expanded plastic zone. Finally, some preliminary results on the effect of friction on this type of high pressure forming and choosing best working conditions, as well as effect on sheet thickness are presented with some experimental results.

Key words: Sheet hydroforming, Mechanical deep drawing, High pressure forming.

تاثير ظروف الاحتكاك على تشكيل الصفائح الهيدروميكانيكي المستخدمة في صناعة السيارات

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المستخلص:

تعتبر عملية تشكيل الصفائح او ما تسمى عملية التشكيل الهيدروميكانيكي العميق من العلميات الهندسية المهمة في عمليات التصنيع وخصوصا صناعة السيارات وهذه الاهمية تكمن في امكانية انتاج اشكال هندسية معقدة من المعدات الميكانيكية وبخطوات عملية قليلة وكذلك تمتلك هذه العملية ايجابيات اخرى مثل تحسين القوة الهيكيلية والجساءة للمنتجات وتتيح استخدامات كفوءة للمعدن.

تعتمد عملية تشكيل الصفائح على العديد من العوامل ومن اهمها هو الاحتكاك حيث يلعب الاحتكاك دوراً مهما في عملية التشكيل وعليه تم الاعتماد في هذا البحث على قيم مختلفة من معامل الاحتكاك الفاصل بين القالب المستعمل والصفيحة المشكلة حيث كانت تتراوح بين 0.01 الى 0.35 وعليه اظهرت النتائج العملية عند القيم الكبيرة نسبيا لمعامل الاحتكاك تقل امكانية التوسع للصفيحة وعدم انتظام سمك الصفيحة وهذا يعني ان الاحتكاك بين جدران القالب والصفيحة

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المستعملة يزداد عندما تتكون القوة المركزة حيث ان تلك القوة تعتمد مباشرة على نوع ونعومة الاسطح المتلامسة وتكون المنطقة المنطقة المتوسعة اللدنة وأخيرا اظهرت النتائج تاثير الاحتكاك على التشكيل باستخدام الضغوط العالية واختيار وتحديد افضل ظروف اشتغال وكذلك بيان تاثير سمك الصفيحة مع بعض النتائج العملية.

Introduction :

Hydro form is a popular word in sheet metal and tube forming industries. Hydroforming process is used for strengthening the metal; and hydra molding is also produced less "grainy" parts in order to allow for easier metal finishing. In Hydroforming process, high pressurized oil and water are used to forma metal. Sheet-forming process includes a very large variety of shapes and sizes, ranging from simple bends to double curvatures with shallow or deep recesses to very complex shapes. Typical examples are automobile bodies, aircraft panels, appliance bodies, kitchen utensils and beverage cans. Sheet metal process and tube forming process might likely give the fair idea about the strategy of metal forming process.

In sheet hydroforming, there are bladders forming (i.e., there is a bladder that contains the liquid and no liquid contacts with the sheet) and hydroforming where the fluid contacts with the sheet (no bladder). Bladder forming is sometimes called a flex forming. Flex forming is mostly used for low volume productions, as in the aerospace field. Forming with the fluid in direct contact with the part can was done either with a male solid punch (this version is sometimes called hydro-mechanical deep drawing) or with a female solid die. In hydro-mechanical deep drawing, a work piece is placed on a draw ring (blank holder) over a male punch and then a hydraulic chamber surrounds the work piece and a relatively low initial pressure seats the work piece against the punch. The punch is then raised into the hydraulic chamber and pressure is increased to as high as 15000 psi which forms the part around the punch. After that the pressure is released and punch retracted, hydraulic chamber lifted, and the process is complete.

Hydroforming, as shown schematically in figure (1), is a specialized the type of die forming that uses pressurized hydraulic fluid to form typical metallic sheets into a desired shape with a die cavity. Hydroforming is a cost-effective way of shaping malleable metals such as aluminum or brass into lightweight, structurally stiff and strong pieces. Hydroforming process allows complex shapes with concavities to be formed, which would be difficult or impossible to apply with standard solid die stamping. Hydroforming parts can often be made with a higher stiffness to weight ratio and at a lower per unit cost than traditional stamped or stamped and welded parts. Virtually, all metals of cold forming can be hydro formed, including aluminum, brass, carbon and stainless steel, cooper and high strength alloys.

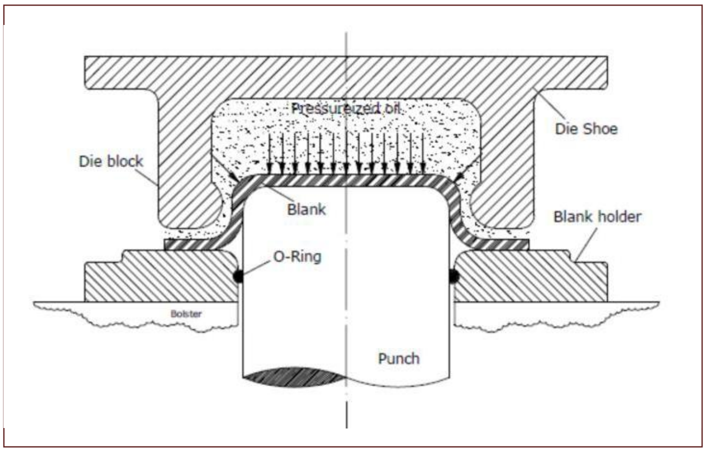

Figure (1): Schematic setup of Sheet Hydroforming

Metal forming using liquid media, or hydroforming, is broadly classified into sheet and tube hydroforming, as shown in figure 2. Sheet hydroforming is further classified into sheet hydroforming with a punch (SHF-P) and sheet hydroforming with a die (SHF-D), which is depending on whether a male (punch) or a female (die) tool will be used to form the part. SHF-D is auxiliary classified into hydroforming of single blanks and double blanks, depending on the number of blanks being used in the forming process.

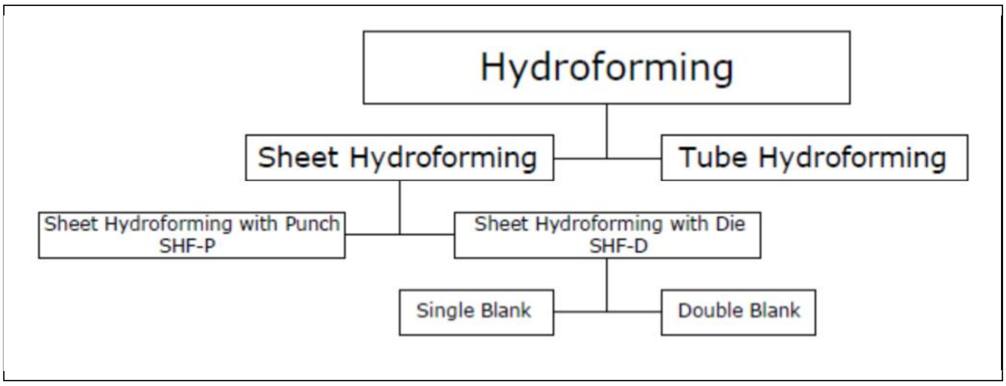

Figure (2): Classification of Hydroforming

Sheet hydroforming process is an alternative to drawing process in which either punches or die is replaced by hydraulic medium, which generates the pressure and forms the part. In SHF-P, the hydraulic fluid is replaced with the die, while in SHF-D the hydraulic fluid is replaced with the punch. In case of an absence of either punch or die in SHF process reduces the tooling cost, and this is fact [1].

Recently, some new sheet hydroforming processes have been introduced in manufacturing industries. Thiruvarudchelvan and Lewis [2], Anwar Kandil [3], and Zhang and Danckert [4] studied the standard hydroforming process. Figure (1) illustrates the basic tool set-up for this process. An essential part of this set-up is a rubber diaphragm that seals the liquid in the pressure chamber. During this process, the flange of the part is kept pushed against the blank holder by the fluid pressure transmitted through the diaphragm. There are many advantages for the standard hydroforming process, such as better surface quality and forming of complex shapes. In the meantime, it has some disadvantages, such as the requirement of heavy presses. The fluid pressure is very important in this process because wrinkles would be appeared if the pressure is not sufficiently high. But, if the pressure is too high, the blank may be damaged by rupture [4].The hydro mechanical deep drawing process has been developed by researchers on the basis of the standard hydroforming technology [2, 3]. The fluid pressure in this process can be produced by the downward movement of the punch, or is supplied by a hydraulic system. This is because there is no rubber diaphragm is used. The tool device in this process is similar to that in a conventional deep drawing. An O-ring is used to prevent the flow out of the fluid on the flange. By using this process, more local deformation are increased the drawing ratio and forming of complicated parts are realized [2]. But, in this method the blank holder force is not adequate to prevent the complex shapes from wrinkling. In addition, the fluid pressure is very high that causes high clamping force, and thus heavy presses are required. In another investigation, Groche and Metz [5, 6] used an active-elastic blank holder system for high-pressure forming. Figure (5) illustrates the simplified schematic of this system. In this method, an elastic blank holder with a circular groove was used under the blank. The active-elastic blank holder system showed improvements with respect to the material flow in the flange area and reduced sheet thinning in critical corner regions of the work piece. In this method the die set-up is complicated and the forming pressure is high.

Theoretical Basis :

Figure (3-A) illustrates sheet or strip drawing. A force (F) pulls a strip through a pair of wedges. The strip width (w) is much greater than the thickness (t); as a result, the width does not change and plane strain prevails. The drawing stress is $\sigma_d = F/wt_e$. Figure (3-B) shows the differential slab element. Pressure (P) is normal to the die, and it acts on two areas of $wdx/\cos\alpha$, and the corresponding component of force in the x-direction is $2Pwdx(\sin\alpha/\cos\alpha)$. The normal pressure also causes a frictional force on the work metal, $2\mu wPdx/\cos\alpha$, with a horizontal component $2Pwdx(\cos\alpha/\cos\alpha)$, where μ is the coefficient of friction. Both of these forces act in the positive x-direction. The drawing force, $\sigma_x wt$ acts in the negative x-direction, while the force in the positive x-direction is $(\sigma_x + d\sigma_x)(t+dt)w$. the x-direction force balance gives:

$$(\sigma_x + d\sigma_x)(t+dt)w + 2w\tan(\alpha)Pdx + 2\mu Pwdx = \sigma_x wt \quad \text{.................. (1)}$$

Simplifying and neglecting second order differentials,

$$\sigma_x t + \sigma_x dt + tdx + 2\tan(\alpha)Pdx + 2\mu Pdx = \sigma_x t \quad \text{............................ (2)}$$

Substituting $2dx = \dfrac{dt}{\tan(\alpha)}$ and $B = \mu\cot(\alpha)$, $Pdt + \sigma_x dt + td\sigma_x + \mu\cot(\alpha)Pdt = 0$ or,

$$td\sigma_x + \{\sigma_x + P(1+B)\}dt = 0 \quad \text{.. (3)}$$

$$\frac{d\sigma_x}{\sigma_x + P(1+B)} = -\frac{dt}{t} \quad \text{... (4)}$$

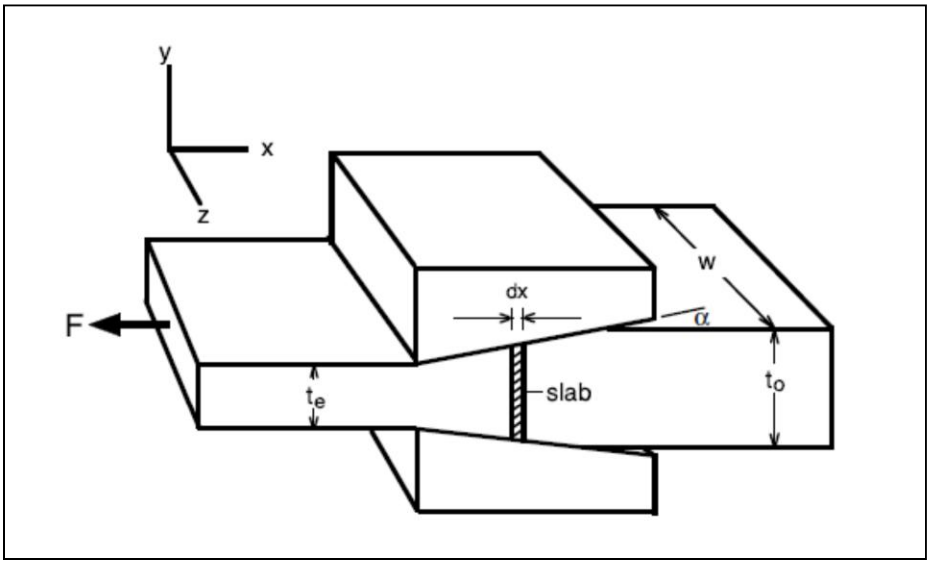

Figure (3-A): Forming (Drawing) of a metallic sheet

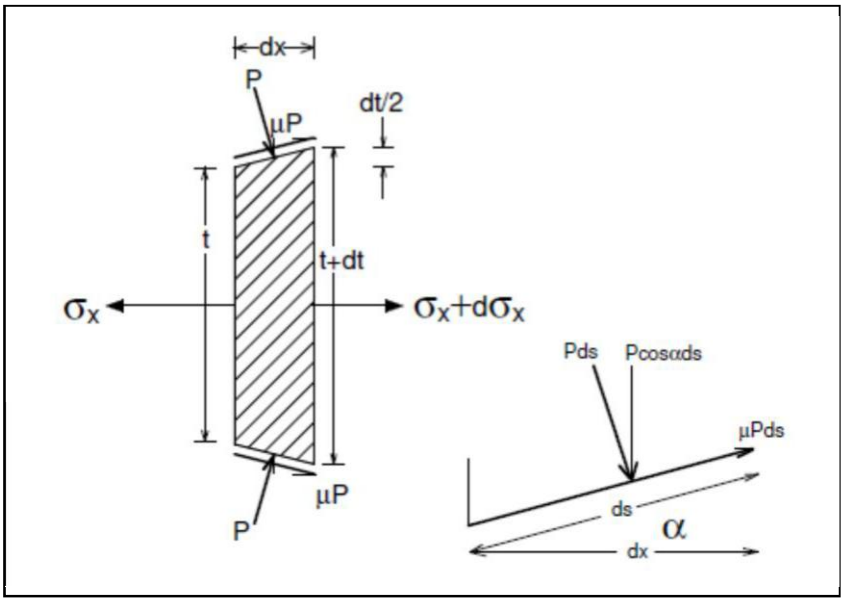

Figure (3-B): Forces Equilibrium in sheet forming

To integrate equation 4, the relation between P and σ_x must be found. The fact that P does not act in the direction normal to x, this will be ignored and P will be taken as a principal stress, P $= -\sigma_x$. For yielding in plane strain, $\sigma_x - \sigma_y = 2k$ where k is the yield strength in shear. For Tresca 2k = Y and for Von Misses $2k = (2/\sqrt{3})Y$. Substituting P = 2k $-\sigma_x$ into equation 4:

$$\frac{d\sigma_x}{B\sigma_x - 2k(1+B)} = \frac{dt}{t} \quad \text{.........} (5)$$

Integrating between $\sigma_x = 0$ and $\sigma_x = \sigma_d$ between $t = t_o$ to t_e and solving for σ_d :

$$\frac{\sigma_d}{2k} = \frac{(1+B)}{B}\left[1 - (\frac{t_e}{t_o})^B\right] \quad \text{.........} (6)$$

Finally substituting $\varepsilon_h = \ln(\frac{t_o}{t_e})$ as the homogeneous strains,

$$\frac{\sigma_d}{2k} = \frac{(1+B)}{B}\left[1 - e^{(-B\varepsilon_h)}\right] \quad (7)$$

Several assumptions are involved in the derivation of equation 7. First, it is assumed that 2k is constant, which is not true if the material work hardens. The effect of work hardening can be approximated by using an average value of 2k. Another way is that the friction coefficient is constant. The assumption that P is a principal stress is reasonable for low die angles and low coefficients of friction, but the assumption gets progressively worse at high die angles and high friction coefficients. Figure (4) shows a specimen with h<b is being compressed with a constant coefficient of friction (μ). This is making a force balance on the differential portion, $\sigma_x h + 2\mu P dx - (\sigma_x + d\sigma_x)h = 0$ this simplifies to:

$$2\mu P dx = h d\sigma_x \quad (8)$$

Again take $\sigma_y = -P$ and σ_x as principal stresses and realize that for plane strain, $\sigma_x - \sigma_y = 2k$ so $d\sigma_x = dP$. Equation (8) becomes $2\mu P dx = h dP$ or:

$$\frac{dP}{P} = \frac{2\mu dx}{h} \quad (9)$$

Integrating from P=2k at x=0 to P at x= $\ln(P/2k) = 2\mu x/h$

$$\frac{P}{2k} = e^{\left(\frac{2\mu x}{h}\right)} \quad (10)$$

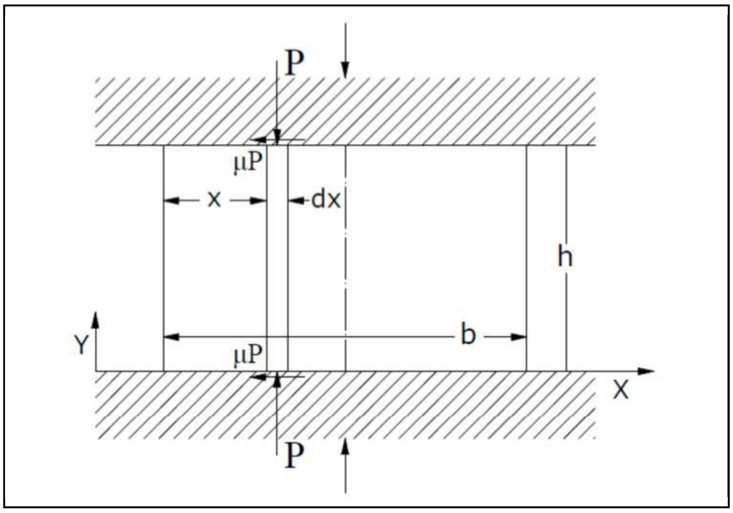

Figure (4): Definition of friction analysis.

Equation (10) predicts a friction hill, which is illustrated in figure (5) below:

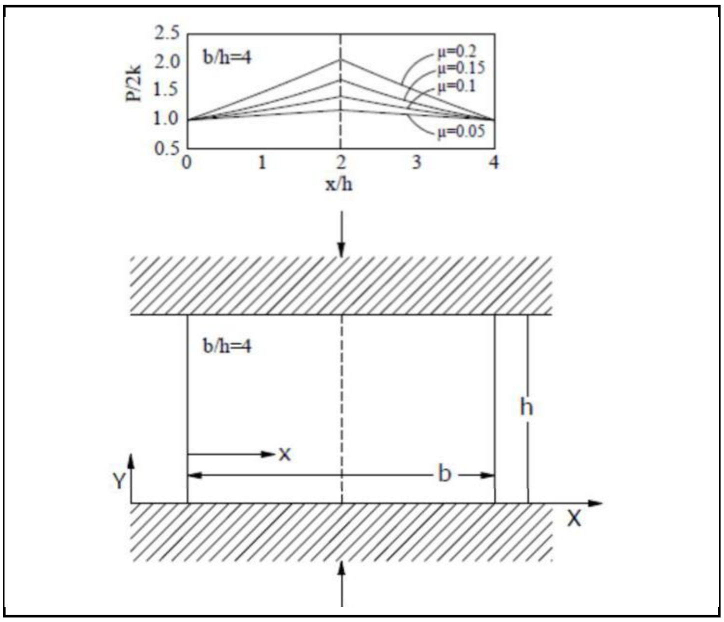

Figure (5): Friction hill in SHF with constant coefficient of friction (μ).

This is only valid from the edge (x=0) to the center line (x=b/2). The average pressure P_a , can be found by integrating P over half of the block to find the force and dividing that by the area of the half block.

$$F_y = \int_0^{b/2} P dx = \int_0^{b/2} 2ke^{\left(\frac{2\mu x}{h}\right)} dx = 2k\left(\frac{h}{2\mu}\right)\left[e^{\left(\frac{\mu b}{h}\right)} - 1\right] \quad \text{.......................} \quad (11)$$

$$\frac{P_{av}}{2k} = \left(\frac{h}{\mu b}\right)\left[e^{\left(\frac{\mu b}{h}\right)} - 1\right] \quad \text{...} \quad (12)$$

A simplified approximation solution can be found by expanding

$$e^{\left(\frac{\mu b}{h}\right)} - 1 = \left(\frac{\mu b}{h}\right) + \frac{(\mu b/h)^2}{2} + ...etc \text{ for small values of} \left(\frac{\mu b}{h}\right),$$

$$\frac{P_{av}}{2k} \approx 1 + \frac{\mu b}{2h} \quad \text{...} \quad (13)$$

<u>Experimental Procedure :</u>

Aluminum sheet materials are used in hydro forming applications. Aluminum is preferred due to the uncomplicated formability and high elongation. In experiments, it was used **Al 5754** aluminum alloy sheet materials with 1 mm thickness. Mechanical properties of the employed Al 5754 sheet are given in Table 1.

Table (1): Mechanical properties of (Al-5754) sheets used in this research

Specification	Rates	Unites
Density	$2.66*10^3$	Kg/m^3
Modulus of Elasticity	70	GPa
Poisson ratio	0.3	--
Yield strength	100	MPa
Tangent modulus	416	MPa
Sheet width	300	mm
Sheet length	600	mm
Sheet thickness	**1**	mm
No. of sheets	40	--

The sheet hydroforming process parameters used in this investigation are illustrated in table (2) below:

Table (2): SHF parameters used in the experimental part

Specification	Rates	Unites
Tool material	Medium carbon steel	--
Forming time	10	Seconds
Forming force	4800	KN
Forming pressure	266	Bars

Table (3) shows the obtained Al-sheet hydroforming results of height and radius of the notched profile on the hydroformed aluminum sheet.

Table (3): The obtained Al- SHF results

No. of tests	1	2	3	4	5	6	7	8
Designed profile height (mm) Die	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Measured profile height (mm) Al-sheet	3.7	3.9	4	4.18	4.36	4.5	4.6	4.7
Differences in heights (mm)	1	0.8	0.7	0.52	0.34	0.2	0.1	0
Designed profile radius (mm) Die	6	6	6	6	6	6	6	6
Measured profile radius (mm) Al-sheet	9.3	8.8	8.52	7.9	7.52	6.8	6.32	6
Differences in radiuses (mm)	3.3	2.8	2.52	1.9	1.52	0.8	0.32	0
Coefficient of friction	0.35	0.3	0.25	0.2	0.15	0.1	0.05	0.01

Results and Discussions :

Figure (6) illustrates the manufactured cross sectional V-notched profile with 4.7 mm height, 6 mm radius and 8 mm die thickness with 1 mm thickness of Al sheet. The main goal of this research is how to get the best fitting between the die and Al sheet; or in other words, how to hydro form Al sheet according to the prepared V-profile.

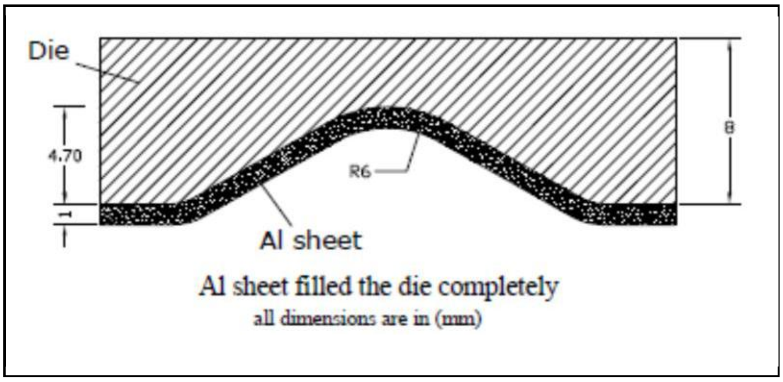

Figure (6): Manufactured V-notched profile die

Figure (7) highlights on many repeated tests by using constant value of oil pressure for each case but with different values of coefficient of friction between all contacted surfaces which is vary from 0.01 up to 0.35. Thus, it is seen that there is gap between the inner surface of the active die and Al- sheet and this gap thickness (offset) starts from zero at μ=0.01 up to maximum value of 1 mm approximately at μ=0.35. Therefore, this gives a clear idea about behavior of the used Al sheet with different values of coefficient of friction to get rid of the gap, i.e. how to reach to the complex shapes in hydroforming process by varying the coefficient of friction under an appropriate oil pressure that ensuring best forming and no cracks, wrinkling, folding, earing in Al sheet.

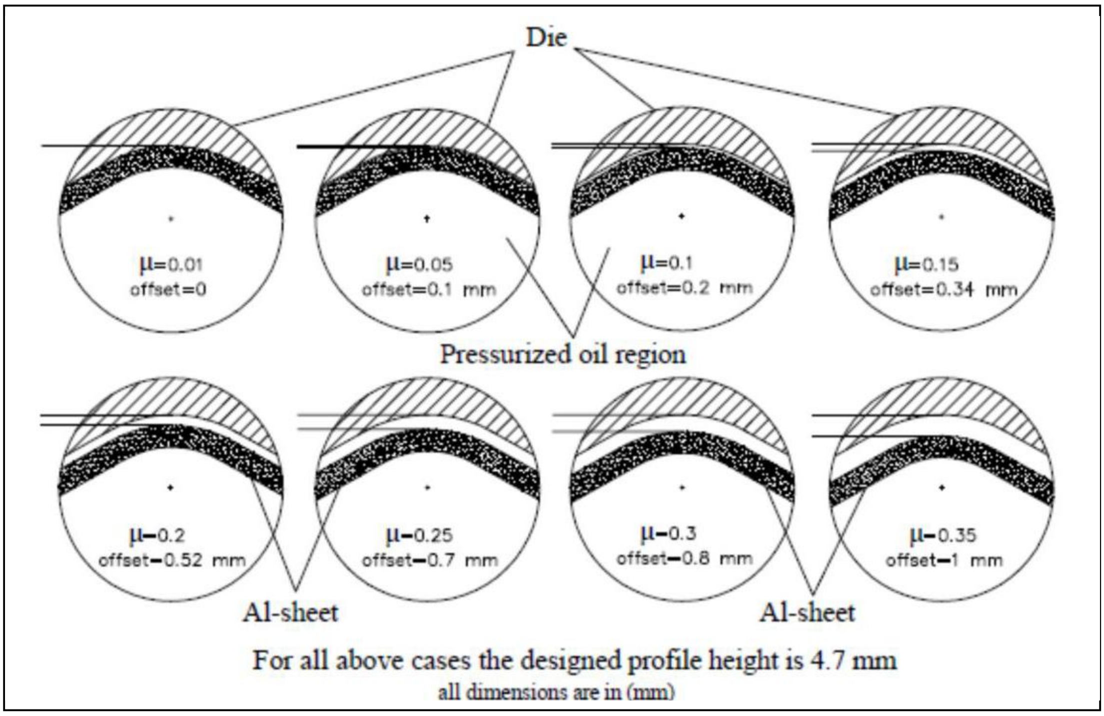

Figure (7): Profile height as a function of coefficient of friction

In figure (8), three cases appear to specify the gained profile as a function of radius of curvature (R) with the associated coefficient of friction. It is showed that as the coefficient of friction increases, the developed radius is increased as well. Base on this result and to get the best fitting, i.e. approximate radius of curvature equal to the standard one 6 mm, the coefficient of friction should be decreased when μ=0.01, offset=0 and R=6 mm meanwhile when μ=0.35, offset = 1 mm and R=9.3 mm. As the coefficient of friction decreased, this allows using Al sheet to flow smoothly throughout the profile, ensuring a proper oil pressure. At this research, a wide range of pressures has been tested to reach the optimum value which saves the sheet from any kind of deformation.

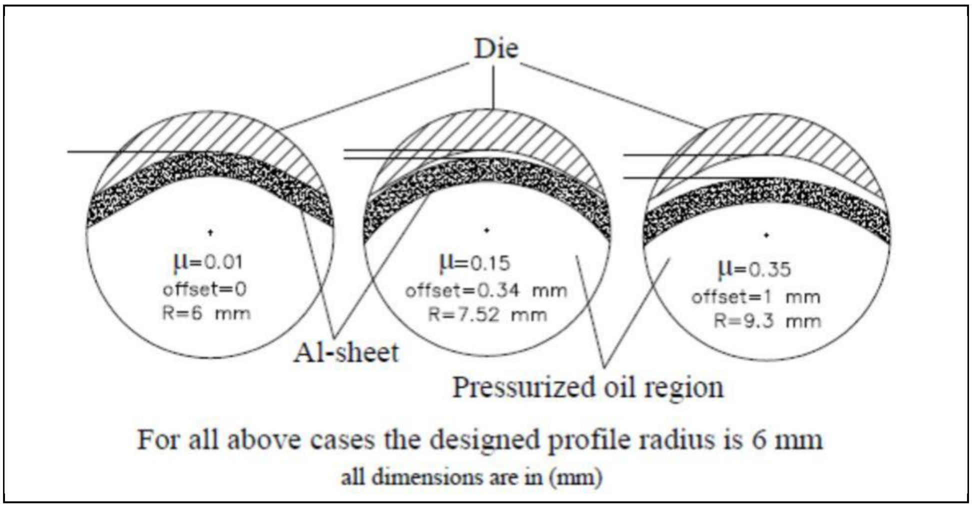

Figure (8): Profile radius as a function of coefficient of friction

The above-mentioned table shows full detailed information of the overall achieved results. It is facilitates the comparison of the measured results with the designed values. All above-mentioned results are totally done under the constant oil pressure but with different values of coefficient of friction. The height versus the coefficient of friction results are presented in figure (9).

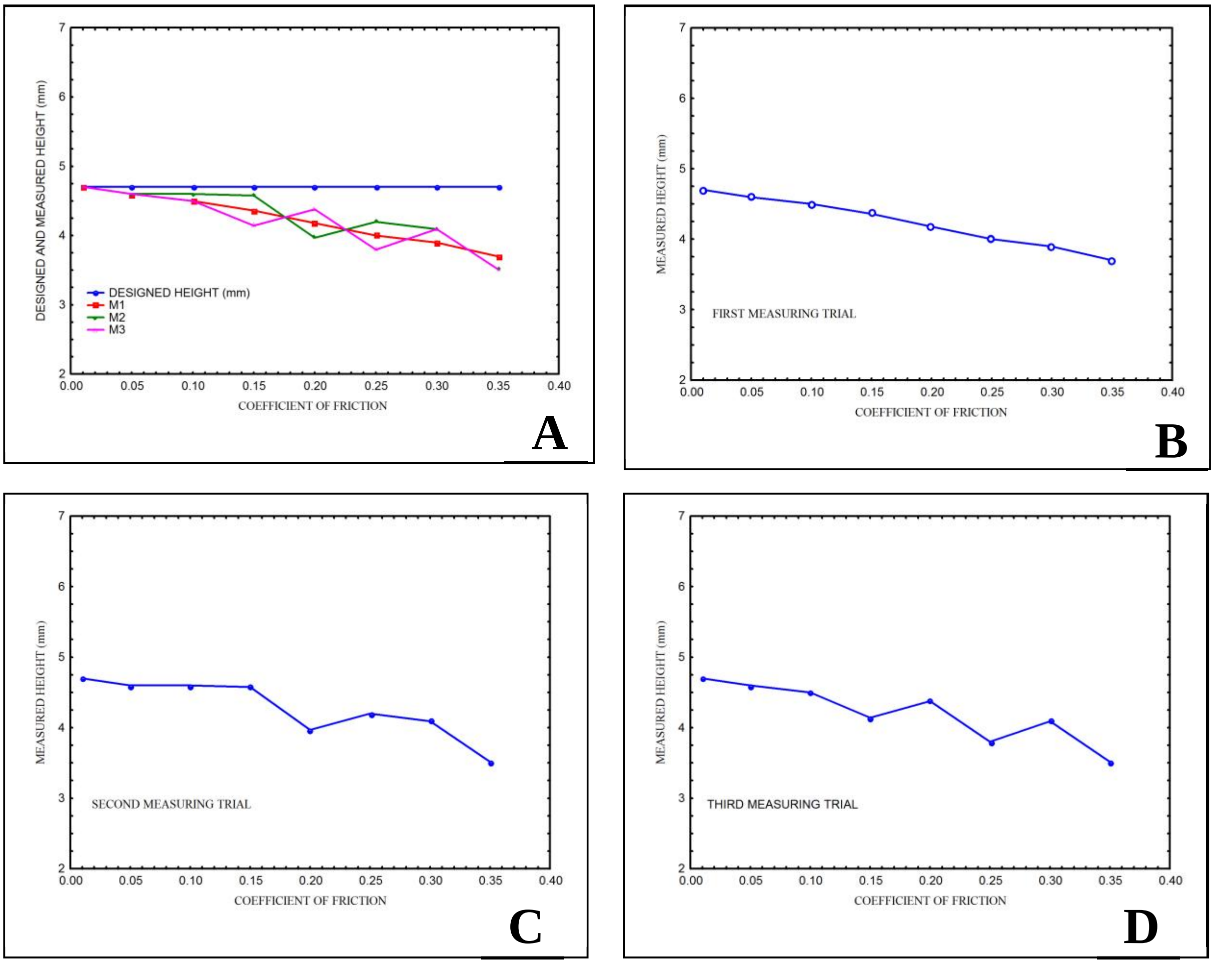

Figure (9): Height versus coefficient of friction

As shown in figure (9-A) there is a comparison between the designed height which equal to 4.7 mm and the three obtained resulted heights, at low values of coefficient of friction there is matching between the heights, but as coefficient of friction increase there will be mismatching and this due to formation of relatively highly friction force between the contacted surfaces that not allow to the employed Al-sheet to flow within the designed profile furthermore the reflect back of the sheet will affect also by deforming the final notched shape, this test was repeated many times with the same boundary conditions as shown in figures (9-B), (9-C) and (9-D) and all give the same divergence in results with increasing coefficient of friction.

The radius versus coefficient of friction results are presented in figure (10-A), the situation in this figure is completely different whereas the coefficient of friction low in value this will associate with acceptable gained radius which very close to the designed one of value of 6 mm and with increasing coefficient of friction the radius will be too much in size and an air gap will form at the tip region, for ensuring this phenomena this test repeated many times keeping the same used parameters and all give approximately same results as indicated in figures (10-B), (10-C) and (10-D). It is so important to mention that this relation between the obtained profiles with coefficient of friction are affected by the nature of Aluminum itself where this metal has critical properties in forming process as like wrinkling, tearing especially at high oil pressure but from another side it is considered as a perfect metal in automobile industries due to its light weight and good strength furthermore excellent appearance, so all aspect have to take into account when choosing Aluminum as raw material in industries.

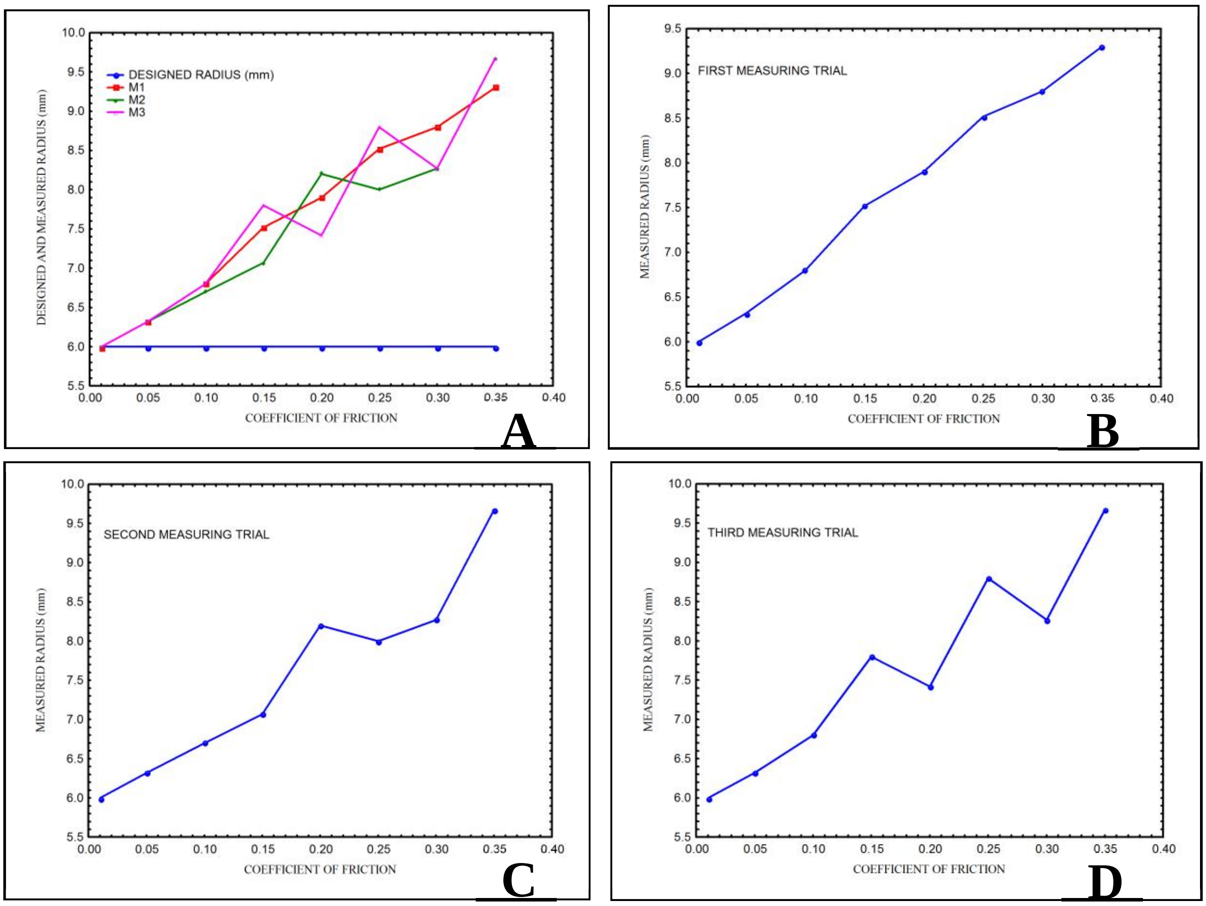

Figure (10): Radius verses coefficient of friction

Conclusions :

Sheet Hydroforming process is a promising technique of advanced manufacturing in the world. This comes since it is a cost-effective way of shaping ductile metals such as aluminum into light weight, structurally stiff and strong pieces. In this paper, Al-5754 aluminum sheets material of 1 mm thickness was hydroformed plastically by using V-notched steel die with different values of coefficient of friction between the directly contacted surfaces. Two parameters were investigated: designed profile height and radius, with each specific values of friction factor. The results showed that as the coefficient of friction increased, this would not allow the aluminum sheet to deform uniformly into the designed shape. Otherwise too much pressure required doing that perfectly but at the same time with this high pressure the sheet will suffer tearing or undesired bulging. Therefore, it must make appropriate equilibrium between applied oil pressure, coefficient of friction, sheet thickness and the desired shape. As the coefficient of friction decreased, this leads to optimum forming with Al-sheet of 1 mm thickness, in addition to giving smooth final surfaces and reducing wear in the forming rig.

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References :

1. Hosseinzade M, Mostajeran H, Bakhshi-Jooybari M, Gorji A, Norouzi S, Hossinipour SJ (2009) Novel combined standard hydro mechanical sheet hydroforming process, IMechE Journal of Engineering Manufacture, 224: 447-457.
2. Thiruvarudchelvan S, Lewis W. (1999) A note on hydroforming with constant fluid pressure. J. Mater Process. Technol., 88:51-56.
3. Kandil A (2003) An experimental study of hydroforming deep drawing. J. Mater Process. Technol., 134:70-80.
4. Zhang S., Danckert J. (1998) Development of hydro mechanical deep drawing. J. Mater Process. Technol., 83:14-25.
5. Groche P, Metz C. (2006) Investigation of active blank holder systems for high pressure forming of metal sheets. Int. J. Mach. Tools Manufacturing 46:1271-1275.
6. Groche P, Metz C. (2005) Hydroforming of unwelded metal sheet using active elastic tools. J. Mater Proc. Tech. 168:195-201.

Nomenclature :

B	Arbitrary constant	t	Thickness (mm)
F	Applied force (N)	t_o	Initial thickness (mm)
FTE	Foundation of Technical Education	t_e	Thickness after drawing
K	Yield strength in shear (MPa)	w	Width (mm)
P	Initial oil pressure (MPa)	x, y	Cartesian coordinates (axes)
P	Average pressure (MPa)	α	Wedge angle (˚)
SCMI	State Company for Mechanical Industries	ε	Strain
Y	Yield strength (MPa)	μ	Coefficient of friction
b	Assumed base of specimen (mm)	σ_d	Drawing stress (MPa)
h	Assumed thickness of specimen (mm)	σ_x	Stress along x-axis (MPa)