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NUMERICAL AND EXPERIMENTAL STUDY ON THE EFFECT OFDIE DESGIN ON SHEET HYDROFORMING PROCESS

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ABSTRACT

In this paper, a FEM is used to determine the effect of die design on sheet hydroforming process. The hydraulic deformation is a process for sheet forming by applying hydraulic pressurized liquid on the sheet. This process is characterized by its ability to give homogenous strain distribution along the blank with highly mechanical properties. To simulate deformation process and analyze the results theoretically, a special programmer for finite elements (Ansys15) has been used. To prove rightness of numerical simulation, a die with the same dimensions of used die in research has been built. The simulation of the sample deformation process has been performed by using circular plate of aluminum alloy (1435) with two different thickness (1)mm using four profile radius for lower die (2,4,6,8,10)mm and under effect of (10) KN blank holder force(BHF). These parameters have been used to know the effect of die profile radius and blank holder force on the product in term of stresses distribution and wrinkling and tearing and average of thickness change along the length from the center of the sample to the final edge on the accuracy and the shape of final product.

Key words: Finite Element Simulation , Sheet Hydroforming , hydraulic pressurized liquid , die design , die profile radius.

دراسة تحليلية وتجريبية لتصميم القالب في عملية التشكيل الهيدروليكي للصفائح المعدنية

الدكتور.عبد الكريم جليل كاظم رائد سلمان سعيد

الخلاصة :

التشكيل الهيدروليكي هو عملية تشكيل الصفائح بواسطة تسليط ضغط هيدروليكي للسائل على الصفيحة حيث تمتاز هذه العملية بأنها تعطي توزيع انفعال متجانس على طول العينة وكذلك خواص ميكانيكية عالية . ولمحاكاة عملية التشكيل وتحليل النتائج نظريا فقد تم استخدام برنامج خاص بتقنية العناصر المحددة (ANSYS 11) وللإثبات صحة المحاكاة العددية تم بناء قالب بنفس إبعاد القالب المستخدم في البحث . تمت محاكاة عملية تشكيل لنموذج باستخدام قرص من سبيكة الألمنيوم (1435) بسمك (1و2) ملم مع خمسة أنصاف أقطار الحافة القالب السفلي هي (10,8,6,4,2) ملم وتحت تأثير ثلاثة قوى مختلفة للمسك هي (15,10,5) كيلو نيوتن ،حيث تم استخدام هذه المتغيرات لمعرفة تأثير سمك المعدن ونصف قطر حافة القلب ومقدار قوة المسك على المنتج بدلالة توزيع الاجتهادات والانبعاج ومعدل تغير السمك على طول المسافة من مركز النموذج إلى الحافة النهائية على دقة وشكل المنتج. كشفت النتائج التي تم الحصول عليها أن الفشل بالانفجار هو السائد عند استخدام سمك (1ملم) في حين أن الفشل بالتجاعيد يكون سائدا عند استخدام سمك (2ملم) ، كذلك فأن الفشل بالتجاعيد يزداد عند استخدام قوة مسك اقل أو تساوي (5 كيلو نيوتن) ، أما بخصوص الاستنتاجات فقد وجد انه كلما قل قطر حافة القالب زادت الاجتهادات المتكونة لذلك فأن أفضل تصميم لقطر حافة القالب والتي معها يكون تغيير السمك

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قليل وقيمة الاجتهادات الناتجة قليلة وموزعه بانتظام هو عند استخدام قالب بنصف قطر حافة (8ملم) مع قوة مسك (10 كيلو نيوتن) وذلك لصفيحة بسمك (1ملم) ، أما عند استخدام صفيحة بسمك (2ملم) فأن أفضل تصميم لنصف قطر حافة القالب هو (10ملم) مع قوة مسك (15كيلو نيوتن) . تضمن الجانب العملي صناعة جهاز التشكيل الهيدروليكي مع عدة قوالب سفلية متغيرة في قطر الحافة واستخدام قرص من سبيكة الألمنيوم (1435) بقطر (80ملم) كعينة لعمل وعاء شبه كروي ومن ثم مقارنة التغير في السمك مع النتائج العددية . أعطت النتائج العملية موافقة جيدة مع النتائج العددية وكانت اعلي نسبة تفاوت بين النتائج العملية والنتائج العددية هي (5.7%) .

INTRODUCTION

Metal hydroforming is the technology used for shaping metal and alloys to make useful products by various forming processes as sheet hydroforming, tub hydroforming. Sheet metal forming using pressurized fluid media is called sheet hydroforming(SHF) .Sheet hydroforming is defined as Sheet Hydroforming with Punch (SHF-P) and Sheet Hydroforming with Die (SHF-D)as **Fig.1** based on the male (punch) or the female (die) tool that has the shape/impression to be formed. SHF-P is the same as ‘Hydro mechanical Deep Drawing’ (HMD). Similarly, SHF-D is synonymous with ‘High pressure Sheet hydroforming'. The SHF-D is further classified into hydroforming of single and double blank depending on number of blanks being used in the forming process. as **Fig.2.** Sheet metal hydroforming (SHF) is a special kind of hydroforming processes. It involves flanging, punching, bending, stamping, deep drawing, and other processes, which allow the production of large quantities of metal portions with various complexities.

THEORETICAL BACKGROUND

In this paper the sheet hydroforming simulations are carried out by using explicit FEM. The force necessary to form a cup is applied to the blank by the fluid characteristic of pressure distribution. This pressure is distributed in the blank as stress causing plastic flow of the material . The cup of the shell can be considered as a ring as shown in **Fig.(3)** .The stresses on an element at radius r are shown in **Fig.(3.a)** the equilibrium equation for this element, with neglecting friction is.

$$(\sigma r + d\sigma r).\ (t + dt).\ (r + dr)\ d\theta = \sigma r\ .t\ .r\ .d\theta + \sigma\theta.\ t\ .dr\ .d\theta \qquad (1)$$

Equation (1) reduces to,

$$\frac{d\sigma_r}{dr} + \frac{\sigma_r dr}{tdr} - \frac{\sigma_\theta - \sigma_r}{r} = 0 \qquad (2)$$

(σ_r) radial stress

(σ_θ) circumferential stress ,(r) radius

In **Fig.(3.b)** in the external edge, point A, there is a free surface and σr (radial stress) = 0, the stress is therefore one of uniaxial compression (circumferential stress) in which σθ = −σf, where σf is the present flow stress. At some intermediate radius, point B, the radial stress will be opposite and equal to the hoop stress, while at the internal edge, point C, the radial stress will be a maximum. The stress states and the corresponding strain are shown on the Von Misses yield locus; **Fig 4** shows stress state and strain vectors for different points on the flange. At the external edge A the blank will thicken as it deforms, while there will be no change in thickness at point B . At the internal edge C the sheet will be thin. The total effect is that in deforming, the total area of the material which initially in the flange will not change too much . This is a useful approximation when blank sizes are determined.

EXPERIMENTAL PROCEDURE

Designing and manufacturing the testing rig.

In this stage, all parts of the sheet metal hydroforming (SHF) rig have been designed according to numerical results and manufactured. The testing rig for (SHF) process consisted of the following parts:

a. Fluid compressor.

b flange.

c. Die Housing.

d. Lower Die .

e. Base .

Fluid medium

The viscous medium used in this study was provided by Extrude Hone and it is marketed under the commercial name(C-11). The fluid medium is modeled as a “Newtonian” fluid, i.e. a strain-rate sensitive material, due to its rather complicated and poorly understood material properties. The flow stress of a Newtonian fluid can be expressed as

$$\sigma = k.\ \varepsilon \text{ (MPa)} \quad (3)$$

where $k = 3\eta\times10^{-6}$, η is the viscosity of the medium (Pas), which can be easily determined by an upsetting experiment,(ε) strain-rate sensitive.

Operation sequence for the SHF tooling

Sheet hydroforming has been put in compressor test device which is characterized by. a) max load (200KN). b)ram velocity(0.5mm/min), the purpose behind using compressor test device is to apply force on the piston of SHF .

The whole operation can be summarized in three steps:

Step1: filling the cylinder of(SHF) with oil (c-11). Then , a circular blank has been put between the die and the blank holder. After that, BHF has been applied by using a screw bolt and a torque arm that prevents wrinkling.

Step2 : moving the piston by using composer test device , the continuous falling of the piston leads to increase in oil pressure which causes deforming of the blank.

Step 3: releasing the force of the compressor test device and removing (BHF) and by that they formed piece can be extracted . with this final step SHF process has been completed**.** **Fig.(5**)show the compressor test device with rig.

TENSILE TESTING

The data obtained from the mechanical testing were used to calculate specimens mechanical properties, such as: Young’s modulus, yield strength and tangent modulus. The average mechanical properties of Aluminum (1435) in different rolling directions are listed in **Table.(1)**.

NUMERICAL RESULTS AND DISCUSSIONS FOR 3DMODEL

To simulate the SHF process, the (ANSYS program15) has been used . The parameters used and discussed are:

THE EFFECT OF DIE PROFILE RADIUS WITH (10)KN BHF ON STRESS VON-MISES FOR 1MM THICKNESS

From **Fig.(7)** and **Fig.(8)** show the von- Mises stress distribution along the(1mm)thickness aluminum sheet with (10)KN BHF and different die profile radius. From these figures ,it can be seen that the entire material is plastically deformed, the stress is not uniform along the length . the maximum value of stress on aluminum plate with thickness(1mm) and 10KN BHF is (1.49GPa) when using die profile (2mm) and the minimum value of stress on plate with thickness(1mm) is (0.28Gpa) when using die profile (2mm). These value don't exceed the yield stresses when applied 10KN BHF and using die profile (10mm) (in such state the deformation will not occur and the plate will return to its original shape) , and (10)KN BHF is not enough to strongly hold. the aluminum plate with thickness(1mm)and die radius(10mm) with 10KN BHF .(all die profile radius which are less than 10 mm are suitable to form 1mm thickness and 10KN BHF). Figure (9) show from nodal solution the relation between the von- Mises stress on the upper surface and the distance from the center of cup for (1mm) thickness with die radius(2,4,6,8,10)mm with 10KN BHF. **Fig.(10)** show the Von-Mises stress distribution along the length of (1mm) aluminum sheet thickness with(2mm) die profile radius and(5,10,15KN) BHF. **Fig (11)** show the Von-Mises stress distribution along the length of (1mm) aluminum sheet thickness with(4mm) die profile radius and(5,10,15KN) BHF. **Fig.(12)** show the Von-Mises stress distribution along the length of (1mm) aluminum sheet thickness with(10mm) die profile radius and(5,10,15KN) BHF. From these result, it can be concluded that the aluminum plate with (1mm)thickness can be deformed when use die profile radius (2,4,6,8mm) with 5,10,15KN BHF this BHF enough to avoid wrinkling defect, but for (10mm) die radius only 15BHF enough to occur deformation and avoid wrinkling defect, so the batter BHF to hold the aluminum plate with die radius (2,4,6,8) is 5,10,15 KN BHF and for (10mm) die profile radius is 15 KN.

SIMULATE THE (SHF) PROCESS FOR 2D MODEL

To simulate the (SHF) process for 2D model , the (ANSYS program15) has been used as shown in **Fig(13)**. **Fig.(14)**and **Fig.(15)** show simulate the (SHF) process for 3D model .

CONCLUSIONS

Extensive experimental and numerical simulation of SHF process have been implemented in this research. The thickness variation along the X- axis is investigated numerically and experimentally along the distance from the center of sheet metal plate. The stress distribution along the distance from the center of sheet metal plate were investigated numerically. The influence of plate with different thickness , BHF and die profile radius are analyzed. The numerical results obtained during this work lead to the following conclusions:

1-The best plate thickness to get a cup of the aluminum plate1435 is 1mm, while the wrinkling in the cup is observed at 2mm thickness of aluminum, and the fracture in cup 1mm.

2-The best design for profile radius for lower die to produce a cup of aluminum (1435) with 1mm plate thickness is when using (8mm) die profile radius with (10KN) BHF.

3- The best design for die profile radius for lower die to produce a cup of aluminum (1435) with 2mm plate thickness is when using (10mm) die profile radius with (15KN) BHF.

4- Thickness variation along X- axis decreases when increasing die profile radius so maximum value is recorded when using 2mm die profile radius and minimum value when using 10mm.

5-The Von- Mises stress of the aluminum plate1435 with 1mm thickness is greater than that of 2mm thickness.

6-Increasing BHF causes increase in von-miss stress and stress along X-direction, so the best BHF in this work is (10KN).

7- Thickness variations obtained by the experimental work are coincide with that obtained by the numerical method .

Table (1) : The Mechanical Properties of Aluminum Alloy 1435

Modulus of elasticity	Poison's ratio	Yield stress	Tangent modules
69.5GPA	0.33	130MPA	0.1GPA

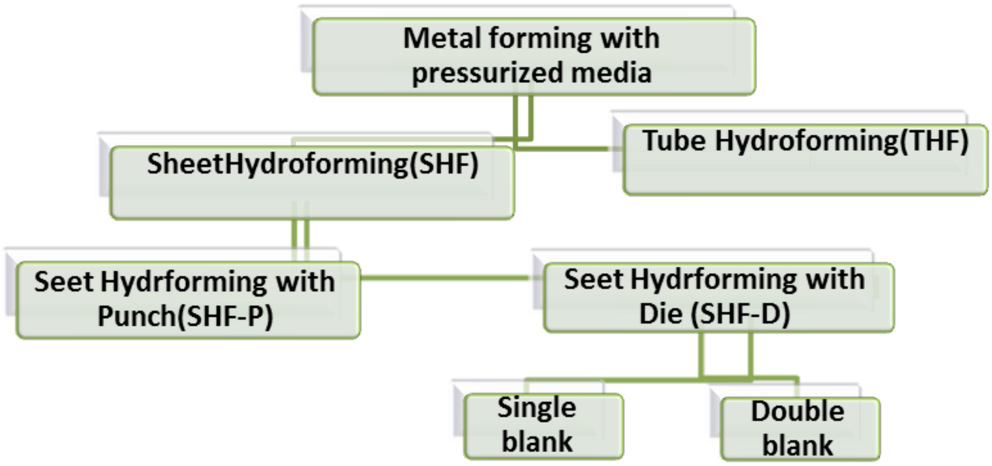

Figure.(1) Classification of metal forming processes using fluid pressurized media.

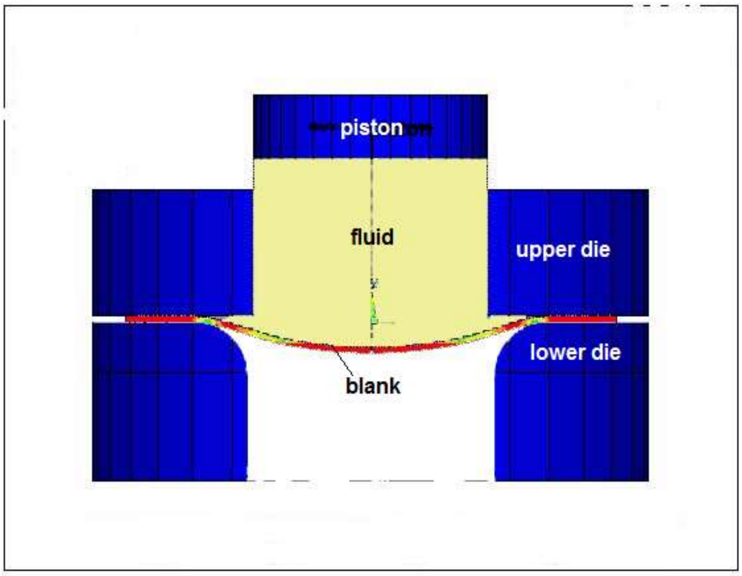

Figure.(2) Sheet Hydroforming (SHF).

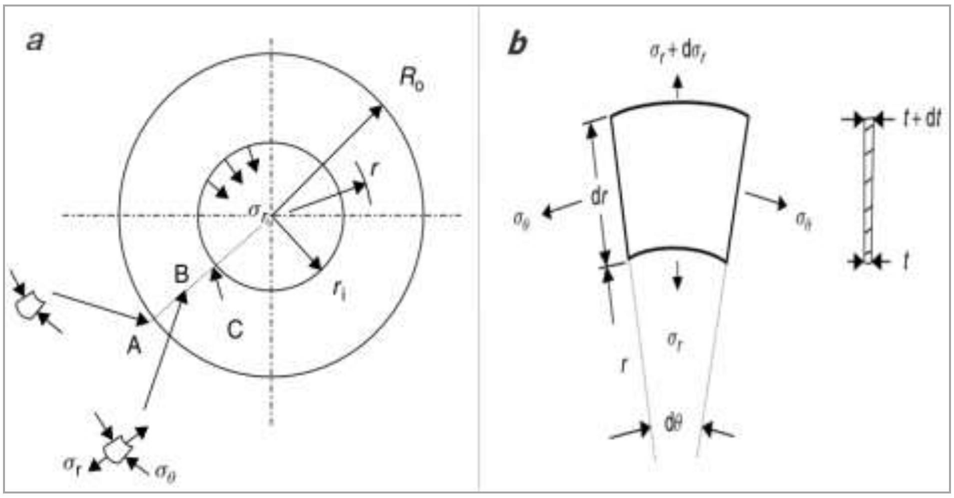

Figure.(3) a-ring cup of a hydroforming. b-Element in the ring flange[20] .

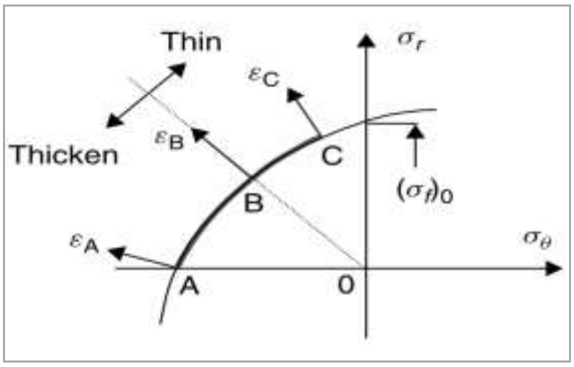

Figure.(4) Stress state and strain vectors for different points on the flange.

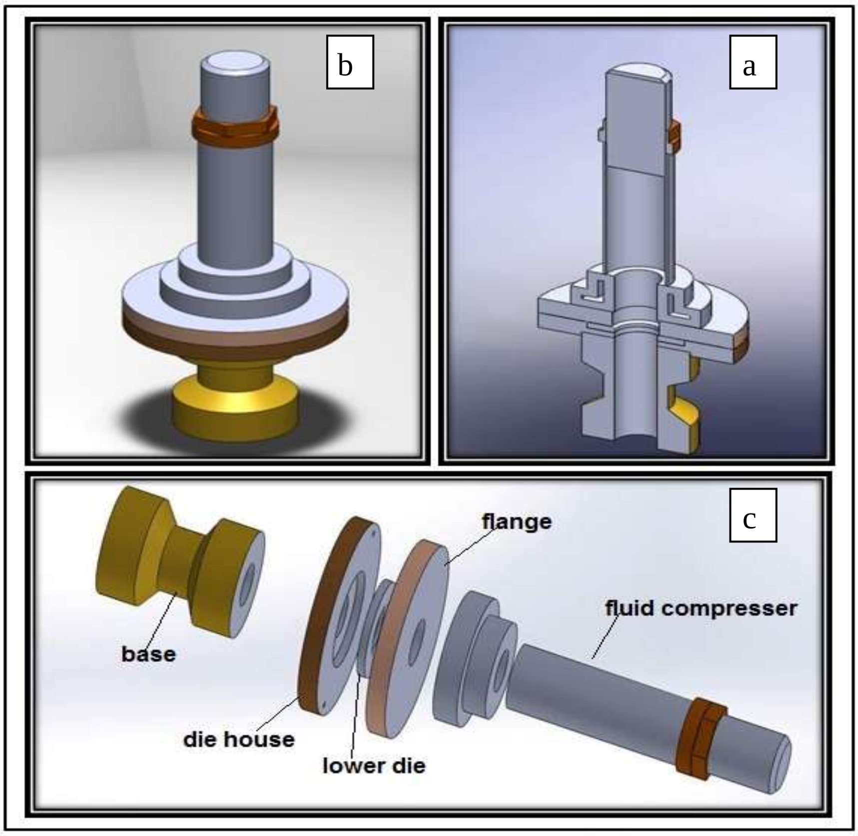

Figure.(5) grid of SHF with all parts

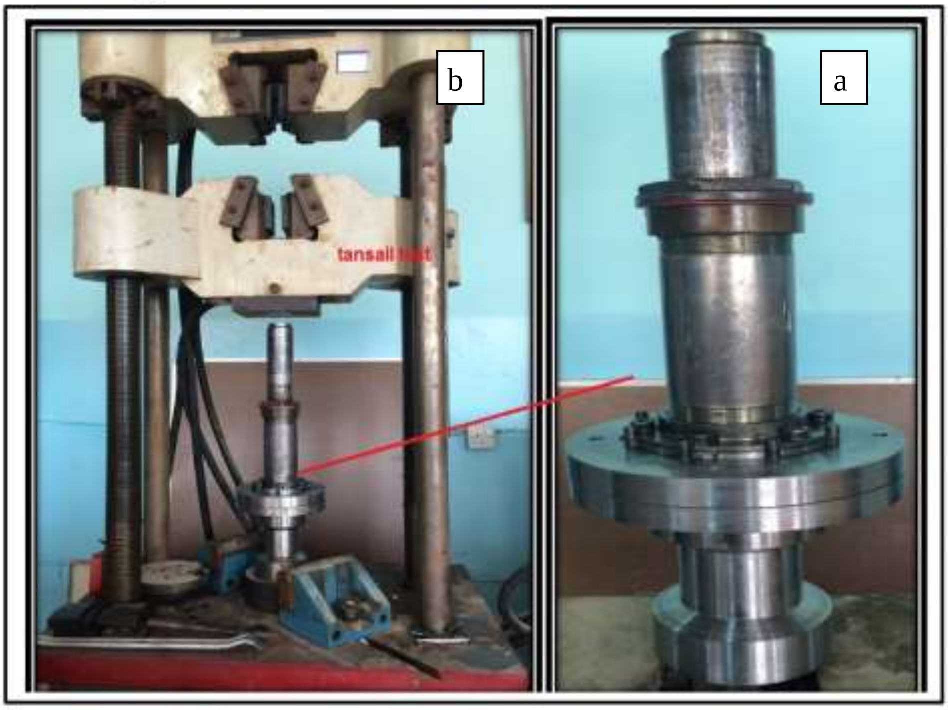

Figure.(6) Compressor test device with grid.

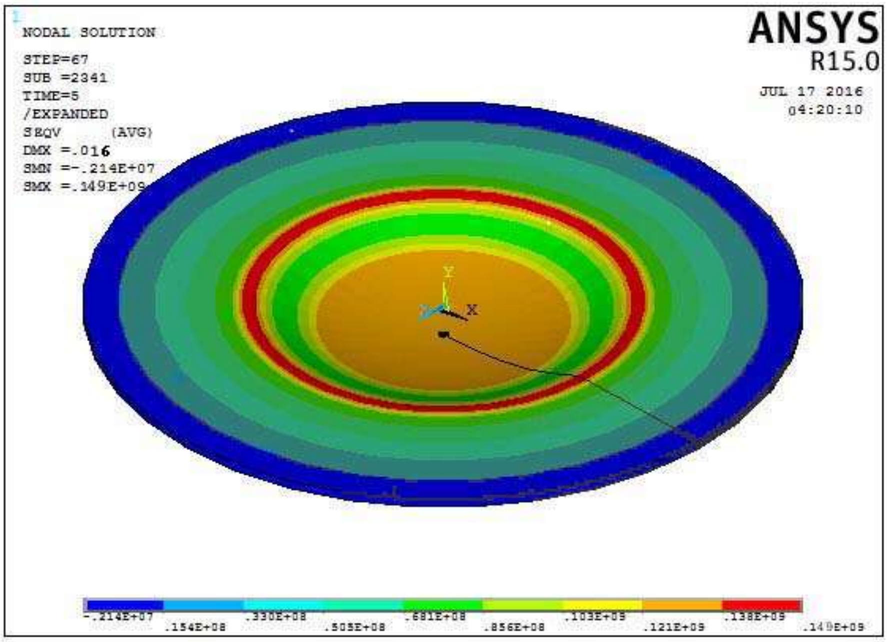

Figure.(7) Von-Mises stress distribution for (1mm) thickness with(2mm) die profile radius and (10)KN BHF.

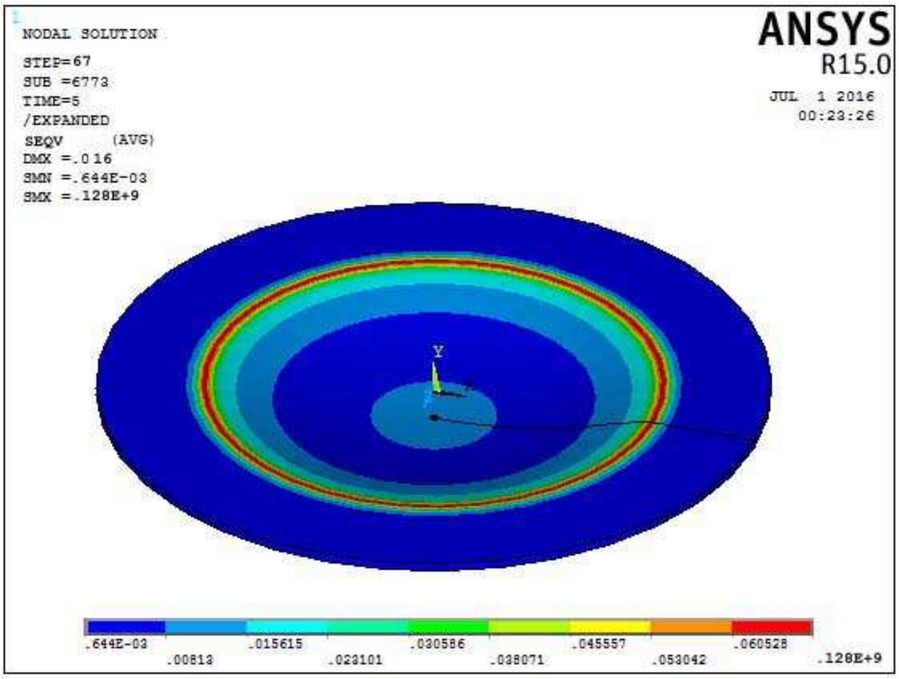

Figure.(8) Von-Mises stress distribution for (1mm) thickness with(10mm) die profile radius and (10)KN BHF.

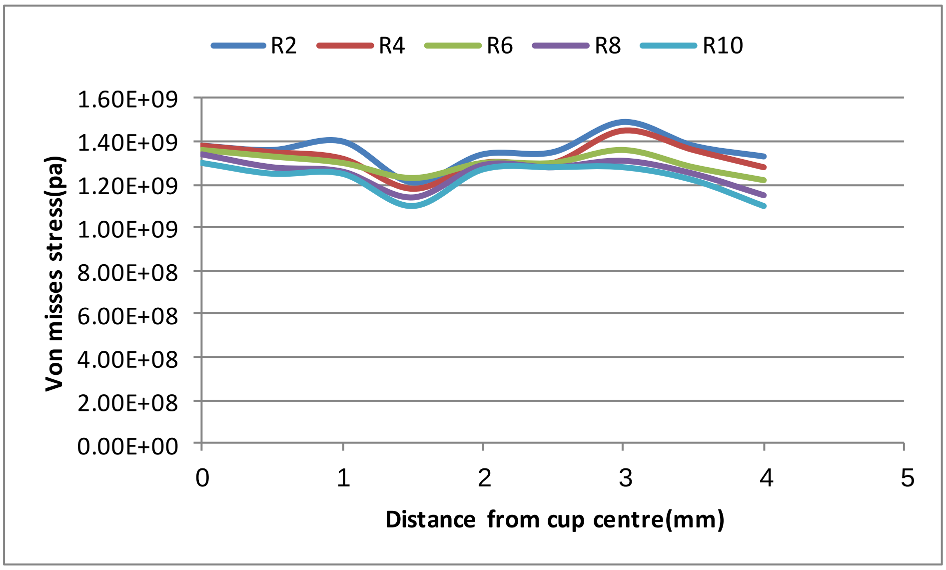

Figure.(9) Von-Mises stress distribution along the length of (1mm) aluminum sheet thickness with(2,4,6,8,10mm) die profile radius and 10KN BHF.

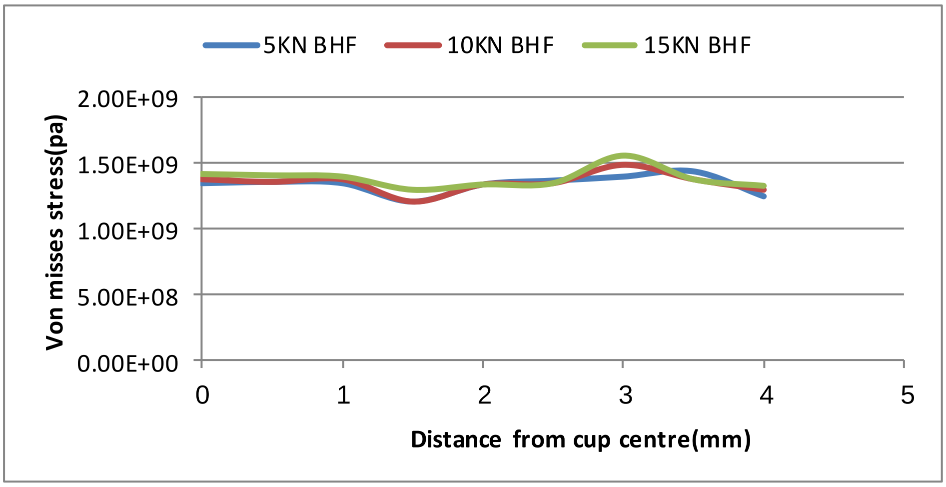

Figure.(10) Von-Misses stress distribution along the length of (1mm) aluminum sheet thickness with(2mm) die profile radius and(5,10,15KN) BHF.

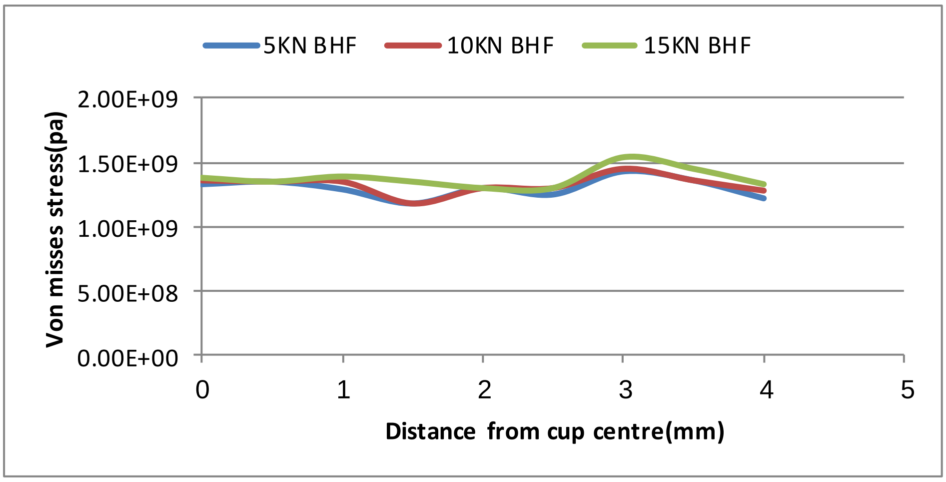

Figure.(11) Von-Misses stress distribution along the length of (1mm) aluminum sheet thickness with(4mm) die profile radius and BHF (5,10,15KN).

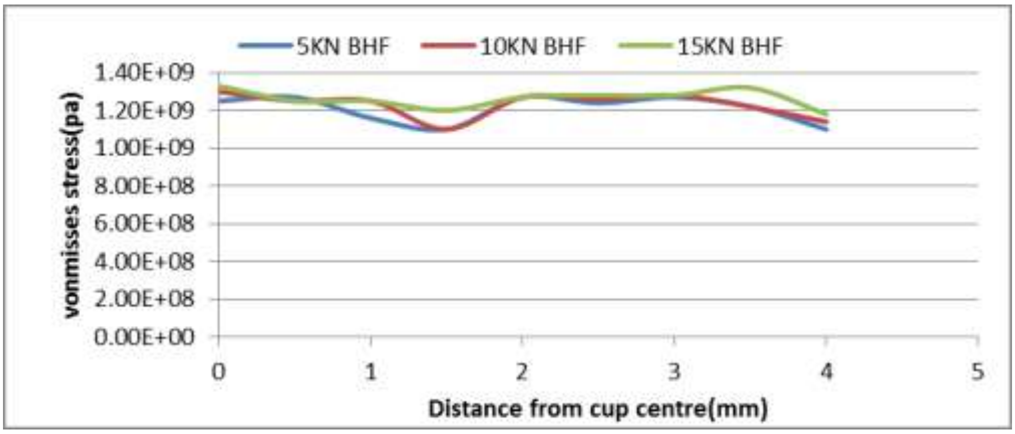

Figure.(12) Von-Misses stress distribution along the length of (1mm) aluminum sheet thickness with(10mm) die profile radius and(5,10,15KN) BHF.

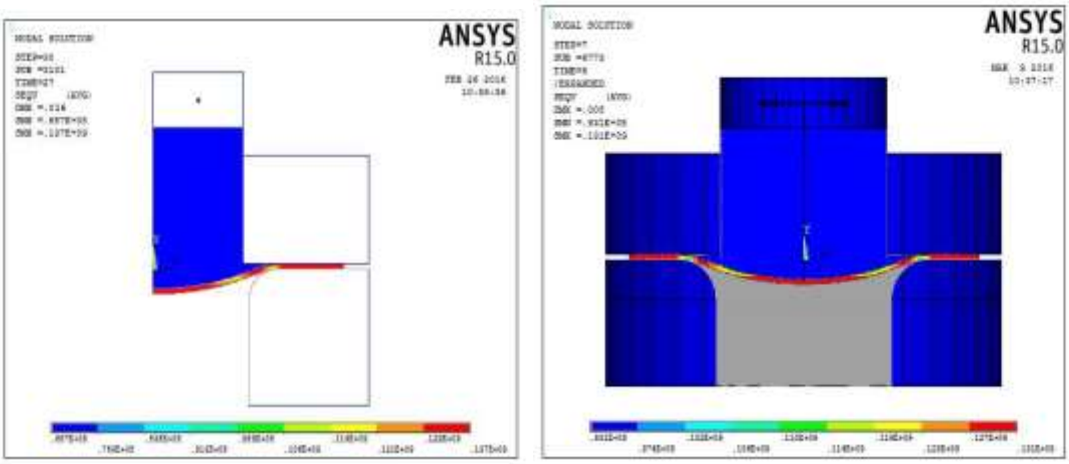

Figure.(13) Stress von-misses distribution for half and full 2D model.

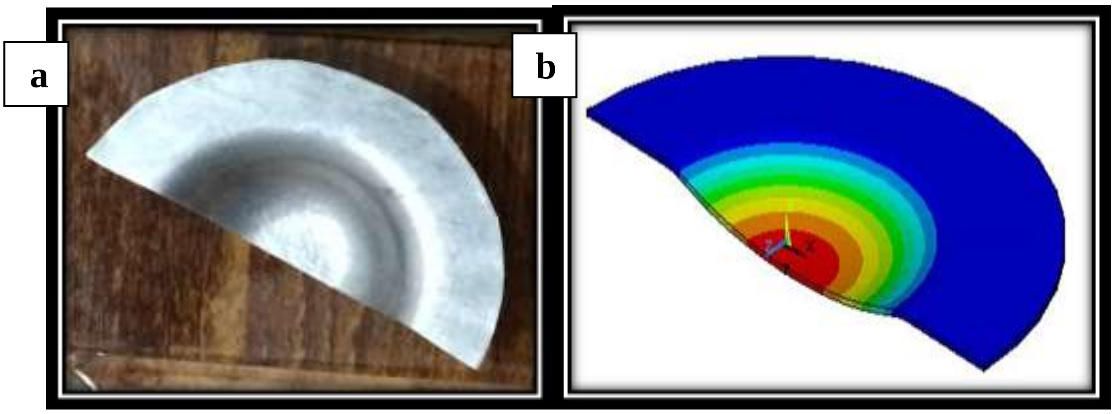

Figure (14) . The deformation results in one half of product:
a) experimentally ,(b)numerically .

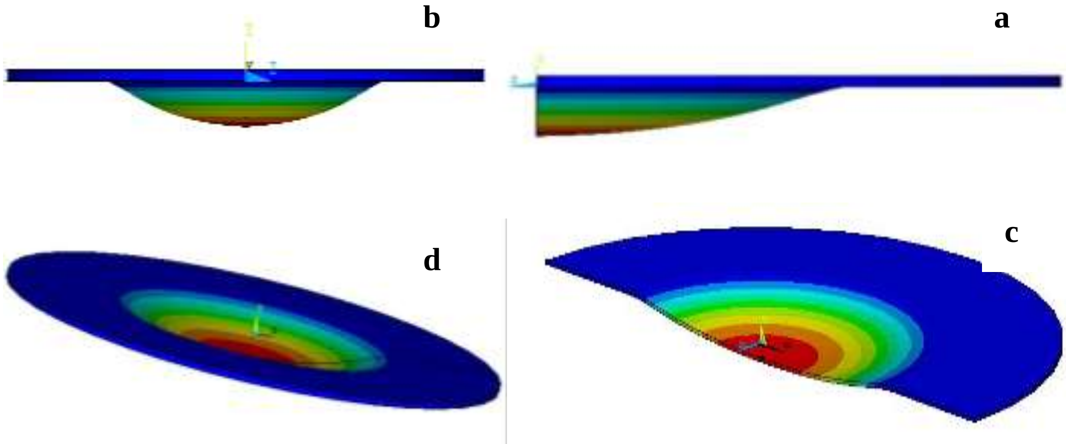

Figure (15) . The SHF product simulation by (Ansys11) program.

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