International Journal of Applied Research in Mechanical Engineering

Volume 1 | Issue 4 Article 2

April 2012

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Recommended Citation

UDAY KUMAR, R. (2012) "EFFECT OF BLANK RADIUS ON RADIAL STRESSES IN HYDROFORMING DEEP DRAWING PROCESS," *International Journal of Applied Research in Mechanical Engineering*: Vol. 1 : Iss. 4 , Article 2.
Available at: https://www.interscience.in/ijarme/vol1/iss4/2

EFFECT OF BLANK RADIUS ON RADIAL STRESSES IN HYDROFORMING DEEP DRAWING PROCESS

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Abstract : This paper presents evaluation and effect of blank radius on radial stresses through mathematical formulations in hydroforming deep drawing process using castor oil medium. Hydraulic pressure can enhance the capabilities of the basic deep drawing process for making cups. In hydroforming deep drawing process, applying the hydraulic pressure on blank periphery in radial direction. It is obtained through the punch movement within the fluid chamber, which is provided in punch and die chambers. These two chambers are connected with the bypass path and it is provided in the die. During the process punch movement within the fluid chamber the pressure is generated in fluid and it is directed through the bypass path to blank periphery, the fluid film is created on the upper and lower surfaces of the blank and subsequently reduces frictional resistance and is to reduce tensile stresses acting on the wall of the semi drawn blank. The blank is taking at centre place in between blank holder and die surface with supporting of high pressurized viscous fluid. The radial stresses are produced in the blank in radial direction due to punch force applied on it, the shear stresses acted by viscous fluid on the both sides of blank, so apply viscosity phenomenon to this analysis. The radial stresses are determined in terms of viscosity of castor oil, blank geometry and process parameters for magnesium alloys.

Keywords: *radial stress, shear stress, deep drawing process, hydro forming, viscosity*

1. INTRODUCTION

Hydroforming deep drawing is one of sheet metal forming process to produce seamless shells, cups and boxes of various shapes. In this forming process, additional element such as fluid pressure is to be contributes positively in several ways. Amongst the advantages of hydraulic pressure forming deep drawing techniques, increased depth to diameter ratio's and reduces thickness variations of the cups formed are notable. In addition, the hydraulic pressure is applied on the periphery of the flange of the cup, the drawing being performed in a simultaneous push-pull manner making it possible to achieve higher drawing ratio's then those possible in the conventional deep drawing process. Deep drawing is an important process used for producing cups from sheet metal in large quantities. In deep drawing a sheet metal blank is drawn over a die by a radiused punch. As the blank is drawn radially inwards the flange undergoes radial tension and circumferential compression [1]. The latter may cause wrinkling of the flange if the draw ratio is large, or if the cup diameter-to-thickness ratio is high. A blank-holder usually applies sufficient pressure on the blank to prevent wrinkling [2]. Radial tensile stress on the flange being drawn is produced by the tension on the cup wall induced by the punch force. Hence, when drawing cups at larger draw ratios, larger radial tension are created on the flange and higher tensile stress is needed on the cup wall. Bending and unbending over the die radius is also provided by this tensile stress on the cup wall. In addition, the tension on the cup wall has to help to overcome frictional resistance, at the flange and at the die radius. As the tensile stress that the wall of the cup can withstand is limited to the ultimate tensile strength of the material, in the field of hydro form deep drawing process the special drawing processes such as hydro-forming [3], hydro-mechanical forming [4], counter-pressure deep drawing [5], hydraulic-pressure- augmented deep drawing [6] .

The process is an automatic co-ordination of the punch force and blank holding force, low friction between the blank and tooling as the high pressure liquid lubricates these interfaces and elimination of the need for a complicated control system [7-12]. The pressure on the flange is more uniform which makes it easiest to choose the parameters in simulation. The pressure in the die cavity can be controlled very freely and accurately, with the approximate liquid pressure as a function of punch position, the parts can drawn without any scratches on the outside of the part and also obtained in good surface finish, surface quality, high dimensional accuracy and complicated parts. In the fluid assisted deep drawing process the pressurized fluid serves several purposes are supports the sheet metal from the start to the end of the forming process, thus yielding a better formed part, delays the on set of material failure and reduces the wrinkles formation.

In this paper the radial stresses are evaluated in terms of viscosity of fluid, blank geometry, and process parameters for magnesium alloys and studied using above process theoretically. The viscosity phenomenon is considered for evaluation of the process.

2. NOTATION

r_p = Radius of punch
r_{cp} = corner radius on punch
r_d = radius of die opening

r_{cd} = corner radius on die

t = thickness of blank

r_j = radius of blank

σ_r = radial stress

σ_θ = hoop stress

$d\theta$ = angle made by element at job axis

P_h = blank holder pressure

P = radial pressure of fluid

τ = Shear stress acting by the fluid on each side of element

2τ = Total Shear stress acted by the fluid on the Element

dr = width of element

r = radial distance of blank element from job axis

σo = yield stress

σ_{rd} = Radial stress at die corner.

C = clearance between die and punch = $r_d - r_p$

$(dy)_1$ = distance between upper surface of the blank element and blank holder

$(dy)_2$ = distance between lower surface of the blank element and die surface

dy = distance maintained by blank element from both blank holder and die surface

τ_1 = shear stress acted by fluid on upper surface of the blank element

τ_2 = shear stress acted by fluid on lower surface of the blank element

du = velocity of the blank element relative to blank holder and die surface

μ = dynamic viscosity or absolute viscosity or Viscosity of fluid

τ_A = 2τ, the total shear stress acting by the fluid on the blank element

h = height of the gap = thickness of fluid

3. MATHEMATICAL MODELING

3.1 Evaluation and Effect of blank radius on Radial Stresses

The Hydroforming deep drawing Process as shown in fig. 1. In this drawing Process, a high pressure is produced in the fluid by the punch penetration into the fluid chamber. This pressurized fluid is directed to the peripheral surface of the blank through the bypass holes and also this high pressure fluid leak out between the blank and both the blank holder and die. This creates a fluid film on upper and lower surface of the flange and subsequently reduces frictional resistance. During the process the shear stresses are acting by fluid on the both sides of semi drawn blank at a gap, which is provided between the blank holder and die surface and the semi drawn blank is taking place at middle of the gap. The height of the gap is more than the thickness of the blank. The radial stresses are generated in the blank in radial direction due to punch force applied on it So these stresses are generated in circular blank material during in the hydroforming deep drawing process. The various stresses acting on the blank element during the process is shown in fig.2.

For mathematical modeling, evaluation and effect of blank radius on radial stresses , let us consider a small element of blank '*dr*' in between blank holder and die surface in radial direction at a distance ' *r*' from the job axis of the circular blank with in the fluid region (fig. 2.). The viscous fluid contact on the both sides of blank element, due to this, the viscous force is acted by fluid on the both sides of the blank element. The total shear stress acting by the fluid on the element = 2τ (i.e. shear stress τ is acting by the fluid on the each sides of element and it is same).Then shear force F_1 is given by, $F_1 = 2\tau \times A_c$ Where A_c = fluid contact area

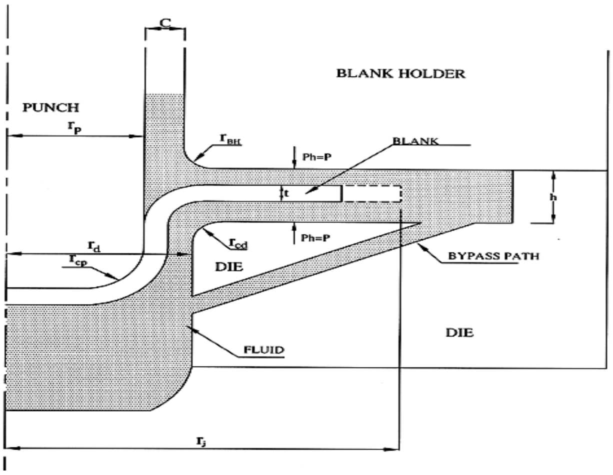

Fig.1 Hydroforming Deep Drawing process

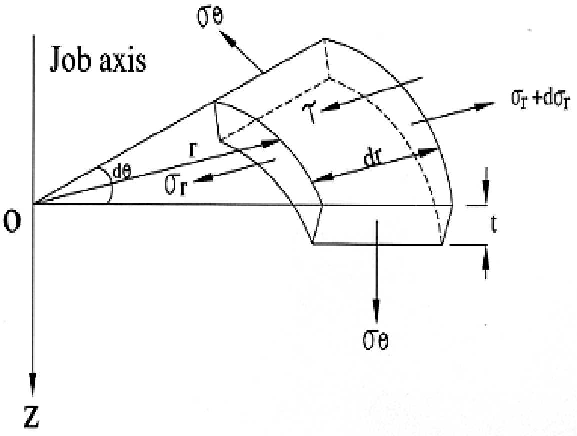

Fig.2. Stresses acting on the element during Drawing process

Apply the equilibrium condition in radial direction, i.e. Net forces acting on the element in the radial direction equal to zero.

$$\Rightarrow \quad \sum_{\xrightarrow{+}} F_r = 0,$$

$$\Rightarrow \quad (\sigma_r - \sigma_\theta)dr + r\,d\sigma_r = \frac{2\tau}{t}\, r\,dr$$

(1)

As σ_r, σ_θ are the two principle stresses, the equation is obtain by using Tresca's yield criteria

$$\sigma_r - \sigma_\theta = \sigma_0$$

(2)

Combined eq. (2) and eq. (1)

$$\Rightarrow \quad \frac{dr}{r} + \frac{d\sigma_r}{\sigma_0} = \frac{2\tau}{\sigma_0 t} dr$$

$$d\sigma_r = \frac{2\tau}{t} dr - \sigma_0 \frac{dr}{r}$$

Integrating

$$\Rightarrow$$

$$\int d\sigma_r = \int \frac{2\tau}{t} dr - \int \sigma_0 \frac{dr}{r}$$

$$\Rightarrow \quad \sigma_r = \frac{2\tau}{t} r - \sigma_0 \ln r + C$$

(3)

Where C is constant, it is obtained from boundary condition.

That boundary condition : at $r = r_j$, $\sigma_r = 0 \quad (\because \mu = 0)$

Where μ is the coefficient of friction between blank and both the blank holder and die surface

The boundary condition is Sub. in eq. (3) we get

$$C = -\frac{2\tau}{t} r_j + \sigma_0 \ln r_j$$

Component C is sub. in eq.(3)

$$\Rightarrow \quad \sigma_r = \sigma_0 \ln\left(\frac{r_j}{r}\right) - \frac{2\tau}{t}(r_j - r)$$

(4)

This equation (4) represents mathematical modeling and distribution of radial stresses, effect of radius of blank on radial stresses during the hydroforming deep drawing process.

4. PHENOMENA OF VISCOSITY

In this hydroforming deep drawing process, the blank is interaction with the fluid, then the viscosity is comes into the picture. During the process the shear stresses and shear forces are acting by the fluid on the blank in the gap, which is the region between blank holder and die surface. During the hydroforming deep drawing process, the blank is taking place at middle of the gap. The effect of viscosity phenomenon in this process as shown in below fig.3. Newton's law of viscosity is introduced to this process for evaluation of stresses in terms viscosity, then the study of effect of viscosity of influence on these stresses is incorporated.

Let us consider a small element of blank in between blank holder and die surface with in the fluid region i.e gap. as shown in fig.3.

But $(dy)_1 = (dy)_2$, because the blank element is taking place at middle of the gap

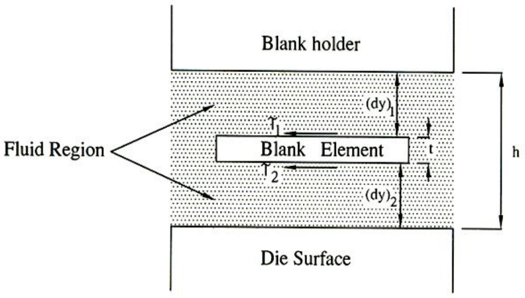

Fig.3.The blank element between blank holder and die surface within the fluid region

$$\therefore \quad (dy)_1 = (dy)_2 = (dy)$$

$$\Rightarrow \quad dy = \frac{h - t}{2}$$

but $\tau_1 = \tau_2$

Because $\left(\frac{du}{dy}\right)_1 = \left(\frac{du}{dy}\right)_2$, According to Newton's law of viscosity $\tau_1 = \mu\left(\frac{du}{dy}\right)_1$, $\tau_2 = \mu\left(\frac{du}{dy}\right)_2$

Let us $\tau_1 = \tau_2 = \tau$

The total shear stress acting by the fluid on the blank element

$$\tau_A = \tau_1 + \tau_2 = 2\tau_1 = 2\tau$$

$$\therefore \quad \tau_A = 2\tau$$

But $\tau = \mu\left(\frac{du}{dy}\right)$, Where $du = u - 0 = u$

$$\therefore \quad \tau_A = 2\tau = 2\mu\left(\frac{du}{dy}\right)$$

$$= 2\frac{\mu u}{\left(\frac{h-t}{2}\right)} = \frac{4\mu u}{h-t}$$

$$\tau_A = 2\tau = \frac{4\mu u}{h-t}$$

(5)

Now we have to determine the radial stresses in terms of viscosity, then the study of effect of viscosity of influence on these stresses is incorporated.

5. RADIAL STRESSES EXPRESSED IN TERMS OF VISCOSITY

We know that radial stresses are produced in the blank at a radial distance ‘ r ’ is given by eq.4

$$\sigma_r = \sigma_0 \ln\left(\frac{r_j}{r}\right) - \frac{2\tau}{t}(r_j - r)$$

and $2\tau = \dfrac{4\mu u}{h-t}$ we get

$$\sigma_r = \sigma_0 \ln\left(\frac{r_j}{r}\right) - \frac{4\mu u}{h-t}\cdot\frac{(r_j-r)}{t}$$

(6)

at the end of the blank (i.e. edges) , put $r = r_j$

$$\Rightarrow \quad \sigma_r\Big)_{r=r_j} = 0$$

(7)

The equation (6) represents the effect of viscosity of fluid on the mathematical modeling and distribution of radial stresses in the blank and also effect of blank radius on radial stresses during hydroforming deep drawing process.

6. DESCRIPTION OF MAGNESIUM ALLOYS

Magnesium is the highest of the commercially important metals, having a density of 1.74 gm/cm^3 and specific gravity 1.74 (30% higher than aluminum alloys and 75% lighter than steel). Like aluminum, magnesium is relatively weak in the pure state and for engineering purposes is almost always used as an alloy. Even in alloy form, however, the metal is characterized by poor wear, creep and fatigue properties. Strength drops rapidly when the temperature exceeds 100^{0}C, so magnesium should not be considered for elevated – temperature service. Its modulus of elasticity is even less than that of aluminum, being between one fourth and one fifth that of steel. Thick sections are required to provide adequate stiffness, but the alloy is so light that it is often possible to use thicker sections for the required rigidity and still have a lighter structure than can be obtained with any other metal. Cost per unit volume is low, so the use of thick sections is generally not prohibitive.For engineering applications magnesium is alloyed mainly with aluminum, zinc, manganese, rare earth metals, and zirconium to produce alloys with high strength – to-weight ratios. Applications for magnesium alloys include use in aircraft, missiles, machinery, tools, and material handling equipment, automobiles and high speed computer parts.On the other positive side, magnesium alloys have a relatively high strength-to-weight ratio with some commercial alloys attaining strengths as high as 300 MPa. High energy absorption means good damping of noise and vibration. While many magnesium alloys require enamel or lacquer finishes to impart adequate connection resistance, this property has been improved markedly with the development of high purity alloys. For this analysis two types of Magnesium alloys considered namely AZ31B-O and AZ61A-F

Magnesium alloy AZ31B-O : composition (%): 3.5 Al, 0.6 Mn , 1.0Zn and Tensile strength 240MPa, Yield strength 150MPa.

Magnesium alloy AZ61A-F: composition (%): 6.5Al, 1.0Zn and Tensile strength 248MPa, Yield strength 220Mpa.

7. RESULTS & DISCUSSION

The radial stress distribution in the blank during the hydroforming deep drawing is given by eq .6

$$\sigma_r = \sigma_0 \ln\left(\frac{r_j}{r}\right) - \frac{4\mu u}{h-t}\cdot\frac{(r_j-r)}{t}$$

The following process parameters and yield stress values of magnesium alloys are considered for evaluation and effect of blank radius on radial stresses of magnesium alloys with given fluid for successful formation of cup in hydroforming deep drawing process.

r_p = 30 mm, r_{cp} = 4mm, r_d = 35mm , r_{cd} = 4mm, r_{BH} = 4 mm, c = 5 mm,

Radial pressure of fluid = P , Punch speed (velocity of blank) u = 12mm/sec, h = 14 mm, thickness of blank t = 2mm, radius of blank r_j = 110mm,115mm,120mm

type of materials used: Magnesium alloys

type of fluid used: castor oil , viscosity μ = 0.985N–sec/ m^2

Yield stress values (σ_0) of magnesium alloys:

AZ31B-O σ_0 = 150 x 10^6 N/m^2

AZ61A-F σ_0 = 220 x 10^6 N/m^2

The evaluation of values of Radial stresses (σ_r) in the blanks of magnesium alloys with a given fluid at a radial distance from job axis for a given radius of blanks at constant thickness of blanks as follows.Substitute the above values in above σ_r equation we get generalized equation for evaluation of radial stresses during the process with respect to different radius of blanks of magnesium alloys with castor oil medium are at constant thickness of blanks t = 2mm.

At r_j = 110mm

$$\Rightarrow \quad \sigma_r = \sigma_0 \ln\left(\frac{110}{r}\right) - 1.97\left[110 - r\right]$$

At r_j = 115mm

$$\Rightarrow \quad \sigma_r = \sigma_0 \ln\left(\frac{115}{r}\right) - 1.97\left[115 - r\right]$$

At r_j = 120mm

$$\Rightarrow \quad \sigma_r = \sigma_0 \ln\left(\frac{120}{r}\right) - 1.97\left[120 - r\right]$$

The radial stresses of magnesium alloys are presented in fig. 4,5,6 at t = 2mm with different radius of blanks r_j = 110mm,115mm,120mm within the range of radial distance r = 55mm to 95mm. From the figure, due to viscosity of fluids, the shear stresses and shear forces are acted on the blank surface during the hydroforming deep drawing process. So the radial stresses are decreases with increasing of the radial distance of the blank from the job axis. Radial stresses are also depends up on process parameters, yield stress of alloys and fluid pressure.

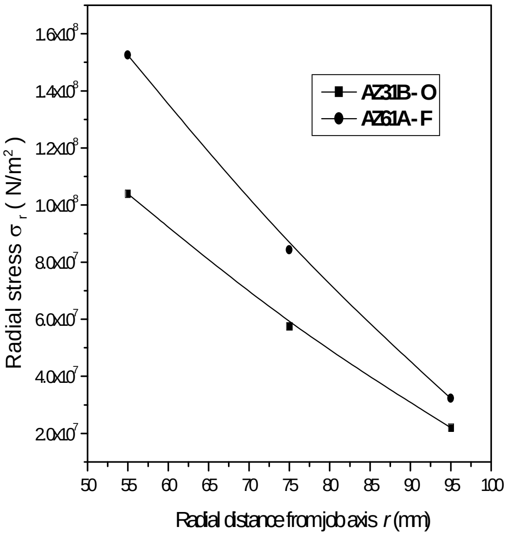

Fig.4. Radial stress distribution in Magnesium alloys at r_j = 110mm

From fig.4 the magnesium alloys at r_j = 110mm with castor oil, the range of radial stresses of AZ61A-F is 32252734.77N/m^2 –152492271.4 N/m^2 and AZ31B–O is21990491.58N/m^2 -103971968.7 N/m^2 , the order of radial stresses of magnesium alloys as AZ31B-O < AZ61A-F.Among these alloys, for a low radial distance from the job axis of blank is 55mm,the radial stress is higher value in AZ61A-F and lowest value in AZ31B-O.

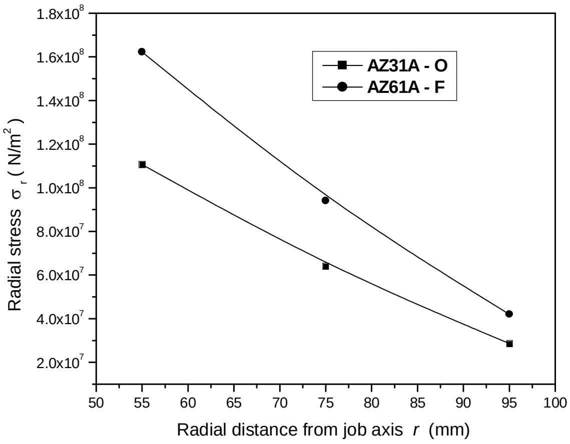

Fig.5. Radial stress distribution in Magnesium alloys at r_j = 115mm

From fig.5 the magnesium alloys at r_j = 115mm with castor oil, the range of radial stresses of AZ61A-F is 42032112.69N/m^2 – 162271649.3N/m^2 and AZ31B–O is 28658246.11N/m^2 -110639723.3 N/m^2 , the order of radial stresses of magnesium alloys as AZ31B-O < AZ61A-F.Among these alloys, for a low radial distance from the job axis of blank is 55mm, the radial stress is higher value in AZ61A-F and lowest value in AZ31B-O.

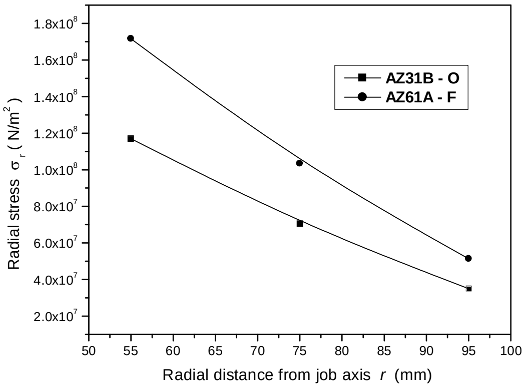

Fig.6. Radial stress distribution in Magnesium alloys at r_j = 120mm

From fig.6. the magnesium alloys at r_j = 120mm with castor oil, the range of radial stresses of AZ61A-F is 51395218.01N/m^2 – 171634754.6N/m^2 and AZ31B–O is 35042178.43N/m^2 -117023655.6N/m^2 , the order of radial stresses of magnesium alloys as AZ31B-O < AZ61A-F.Among these alloys, for a low radial distance from the job axis of blank is 55mm,the radial stress is higher value in AZ61A-F and lowest value in AZ31B-O.

Comparing the above results at caster oil with respect to radius of blanks, the order of radial stresses as

$$\sigma_r \Big|_{r_j=110mm} < \sigma_r \Big|_{r_j=115mm} < \sigma_r \Big|_{r_j=120mm}$$

8. CONCLUSIONS

The Radial stresses are the function of process parameters, yield stress of magnesium alloys and viscosity of caster oil. The radial stresses are decreases with increasing of the radial distance of the blank from the vertical job axis. The radial stresses are increases with increasing the radius of blank of magnesium alloys. These effects are due to viscosity of castor oil acted on the blanks of magnesium alloys during the forming process. The radial pressure of fluid acting on blank surface of alloys is equal to blank holding pressure is to for uniform deformation of blank during the process. The wrinkling is reduced in blank due to the blank supported by high pressurized viscous fluid. Radial stresses of magnesium alloys are determined with in the range of r is 55mm – 95mm with castor oil. For r_j = 110mm, at r = 55mm the highest value of radial stress occurred in AZ61A-F is 152492271.4 N/m^2, lowest value occurred in AZ31B-0 is 103971968.7N/m^2. For r_j = 115mm, at r = 55mm the highest value of radial stress occurred in AZ61A-F is 162271649.3N/m^2, lowest value occurred in AZ31B-O is 110639723.3N/m^2. For r_j = 120mm, at r = 55mm the highest value of radial stress occurred in AZ61A-F is 171634754.6N/m^2, lowest value occurred in AZ31B-O is 117023655.6 N/m^2.

The percentage of decreases of radial stress for these magnesium alloys at r_j = 110mm is 78.8% , r_j = 115mm is 74% and r_j = 120mm is 70%.The decreased amount of radial stresses in magnesium alloys with in the range r is 55-95mm, in AZ31B-O is 81981477.12N/m^2 and in AZ61A-F is 120239536.6N/m^2. So among the order of decrease amount in radial stresses of magnesium alloys as AZ31B-0 < AZ61A– F. The radial stresses are in the magnesium alloys are high at r is 55mm, low at r is 95mm and radial stresses are zero at r is equal to blank radius (at edges of blank). So the radial stresses are inversely proportional to the radial distance of the blank from the job axis were obtained. The radial stresses are directly proportional to the radius of blanks are obtained. The radial stresses are depends on the viscosity, fluid pressure and process parameters. The higher values of radial stresses are gives the minimizing the drawing time and higher in forming limits. These radial stresses are used to get better results of formability of magnesium alloys.

ACKNOWLEDGEMENT

The author (Dr.R.Uday Kumar) thanks the management and principal of Mahatma Gandhi Institute of Technology for encouraging and granting permission to carry out this work.

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