

Effect Of Viscosity On Radial Stresses In Hydroforming Manufacturing Process

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ABSTRACT

Hydro forming manufacturing process, an additional element such as fluid pressure is to be contributes positively in several ways. Hydro forming deep drawing is one of sheet metal hydro forming process to produce seamless shells, cups and boxes of various shapes. 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, olive oil, shear stresses, blank geometry and process parameters for magnesium alloy. The study on these stresses in these two oils medium with its viscosity.

Keywords : Viscosity, Hydro forming , Radial stress, Shear stress, Deep drawing process,

1. INTRODUCTION

Hydro forming is new development in the manufacturing of various products in the field of engineering. In the manufacturing area one of the hydro forming process is Hydro forming deep drawing. In general sheet metal blank is drawn over a die by a radiused punch in deep drawing process. 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. Hydraulic pressure can enhance the capabilities of the basic deep drawing process for making cups. 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 than 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 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 hydro forming 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 onset 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 alloy 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			
σ_o	=	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	=	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. HYDROFORMING PROCESS - DETERMINATION OF RADIAL STRESSES

Hydro forming deep drawing process is a non conventional deep drawing process. The Hydro forming 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 evaluation of 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 F₁ is given by, F₁ = 2τ x A_c Where A_c = fluid contact area of element , But $A_c = r dr d\theta + \frac{dr}{2} dr d\theta$

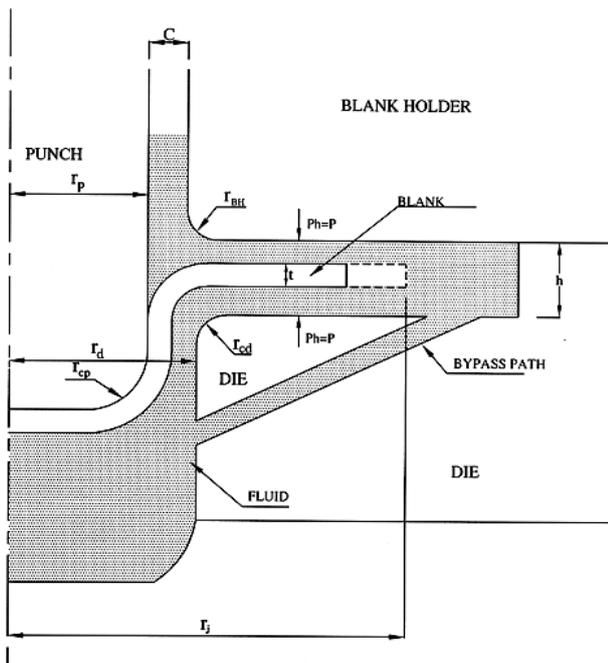


Fig.1 Hydro forming Deep drawing process

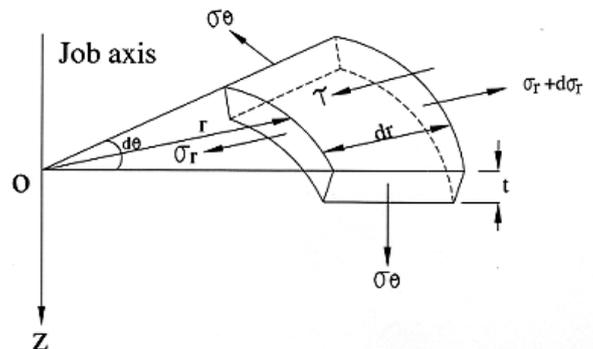


Fig.2. Stresses acting on the element during

Drawing process

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

$$\Rightarrow \sum_{\rightarrow} F_r = 0, \quad \Rightarrow (\sigma_r - \sigma_\theta) dr + r d\sigma_r = \frac{2\tau}{t} r dr \quad (1)$$

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

$$\sigma_r - \sigma_\theta = \sigma_0 \quad (2)$$

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

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

Integrating

$$\begin{aligned} \Rightarrow \int d\sigma_r &= \int \frac{2\tau}{t} dr - \int \sigma_0 \frac{dr}{r} \\ \Rightarrow \sigma_r &= \frac{2\tau}{t} r - \sigma_0 \ln r + C \end{aligned} \quad (3)$$

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

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

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)

$$\Rightarrow \sigma_r = \sigma_0 \ln\left(\frac{r_j}{r}\right) - \frac{2\tau}{t} (r_j - r) \quad (4)$$

This equation (4) represents distribution of radial stresses in the blank with respect to shear stresses of fluid during the hydro forming deep drawing process.

4. PHENOMENA OF VISCOSITY

In this hydro forming deep drawing process, the blank is interaction with the fluid, then the viscosity is comes into the picture. During the process due to viscosity of fluid 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 and also the blank is taking place at middle of the gap with supporting of fluid. 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.

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

$$\therefore (dy)_1 = (dy)_2 = (dy) \Rightarrow dy = \frac{h-t}{2}, \quad \text{but } \tau_1 = \tau_2$$

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

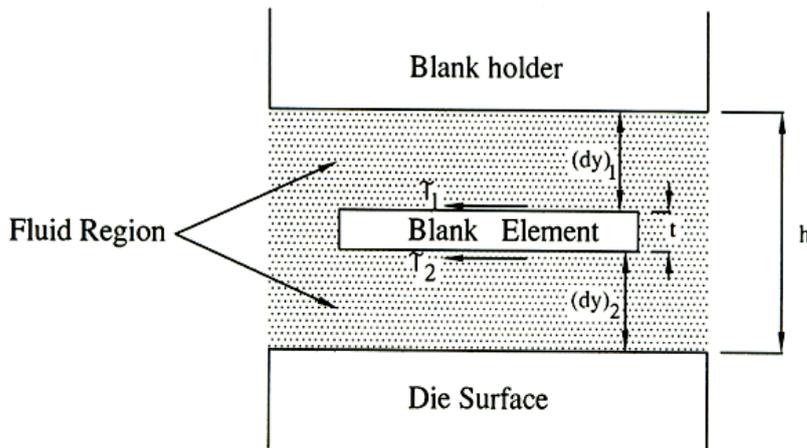


Fig.3.The blank element between blank holder and die surface within oil medium

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

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

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

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

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

$$\therefore \tau_A = 2\tau = 2\mu \left(\frac{du}{dy}\right) = 2 \frac{\mu u}{\left(\frac{h-t}{2}\right)} = \frac{4\mu u}{h-t}$$

$$\tau_A = 2\tau = \frac{4\mu u}{h-t} \quad (5)$$

Now we have to determine the radial stresses in terms of viscosity.

5. RADIAL STRESSES IN TERMS OF VISCOSITY

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

$$\sigma_r = \sigma_0 \ln\left(\frac{r_j}{r}\right) - \frac{2\tau}{t}(r_j - r) \quad \text{and} \quad 2\tau = \frac{4\mu u}{h-t} \quad \text{we get}$$

$$\sigma_r = \sigma_0 \ln\left(\frac{r_j}{r}\right) - \frac{4\mu u}{h-t} \cdot \frac{(r_j - r)}{t} \quad (6)$$

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

$$\Rightarrow \sigma_r \Big|_{r=r_j} = 0 \quad (7)$$

The equation (6) represents the to evaluation radial stresses in the blank during hydroforming deep drawing process.

6. MAGNESIUM ALLOYS

Magnesium is the highest of the commercially important metals, having a density of 1.74 gm/cm³ 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. 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 imparting adequate connection resistance, this property has been improved markedly with the development of high purity alloys. For this analysis Magnesium alloy considered namely AZ31B-O and HK31A-H24. Magnesium AZ31B-O : Composition (%): 3.5 Al, 0.6 Mn , 1.0Zn and Tensile strength 240MPa, Yield strength 150MPa and HK31A - H24: Composition (%): 3.2Th, 0.7Zr and Tensile strength 228MPa, Yield strength 205MPa

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 value of magnesium alloy are considered for evaluation of radial stresses of magnesium alloys with different fluids for successful formation of cup in hydroforming deep drawing process.

$r_p = 30$ mm, $r_d = 35$ mm, $C = 5$ mm, Radial pressure of fluid = P, Punch speed $u = 12$ mm/sec, $h = 12$ mm, thickness of blank $t = 2$ mm, radius of blank $r_j = 90$ mm, type of materials used: Magnesium alloys AZ31B-O and HK31A-H24, type of fluids used : Castor oil, viscosity $\mu = 0.985$ N–sec/m² and olive oil viscosity $\mu = 0.081$ N–sec/m². Yield stress value (σ_0) of magnesium alloy: AZ31B-O $\sigma_0 = 150 \times 10^6$ N/m² and HK31A-H24 $\sigma_0 = 205 \times 10^6$ N/m² .

The evaluation of values of Radial stresses (σ_r) in the blank of magnesium alloys with different fluids at a radial distance from job axis for a given radius of blank at constant thickness 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 various viscosity of fluids for blank of magnesium alloys are at constant thickness and radius.

$$\text{at } \mu_{olive\ oil} = 0.081\text{N-sec/ m}^2$$

$$\sigma_r = \sigma_0 \ln\left(\frac{90}{r}\right) - 0.194[90 - r]$$

$$\text{at } \mu_{castor\ oil} = 0.985\text{N-sec/ m}^2$$

$$\sigma_r = \sigma_0 \ln\left(\frac{90}{r}\right) - 2.364[90 - r]$$

The radial stresses of magnesium alloy is presented in fig. 4 and 5, at $t = 2$ mm with radius of blank $r_j = 90$ mm within the range of radial distance $r = 45$ mm to 65mm using olive oil and castor oil medium. From the figures, due to viscosity of oils, 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 alloy and olive oil and castor oil pressure.

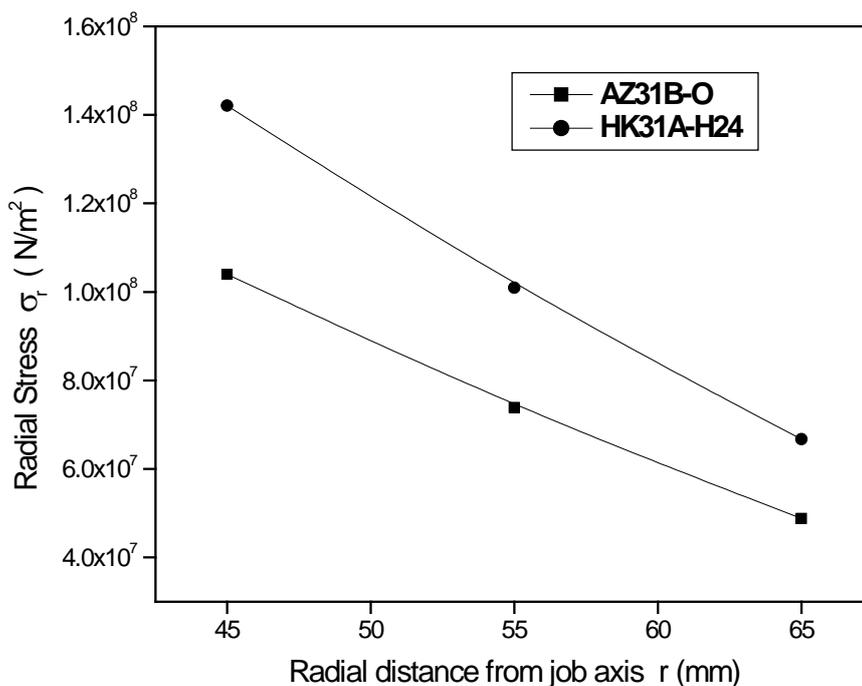


Fig.4. Radial stress distribution in magnesium alloy olive oil viscosity

From 4, the magnesium alloy at $r_j = 90\text{mm}$ with olive oil medium, the range of radial stresses of AZ31B-O is $48813355.21\text{N/m}^2 - 103972068.4 \text{ N/m}^2$ and HK31A– H24 is $66711587.24 \text{ N/m}^2 - 142095163.3 \text{ N/m}^2$. The order of radial stresses as $\text{AZ31B-O} < \text{HK31A-H24}$. Among these alloys, for a lower radial distance from the job axis of blank is 45mm, the radial stress is higher value in HK31A-H24 and lowest in

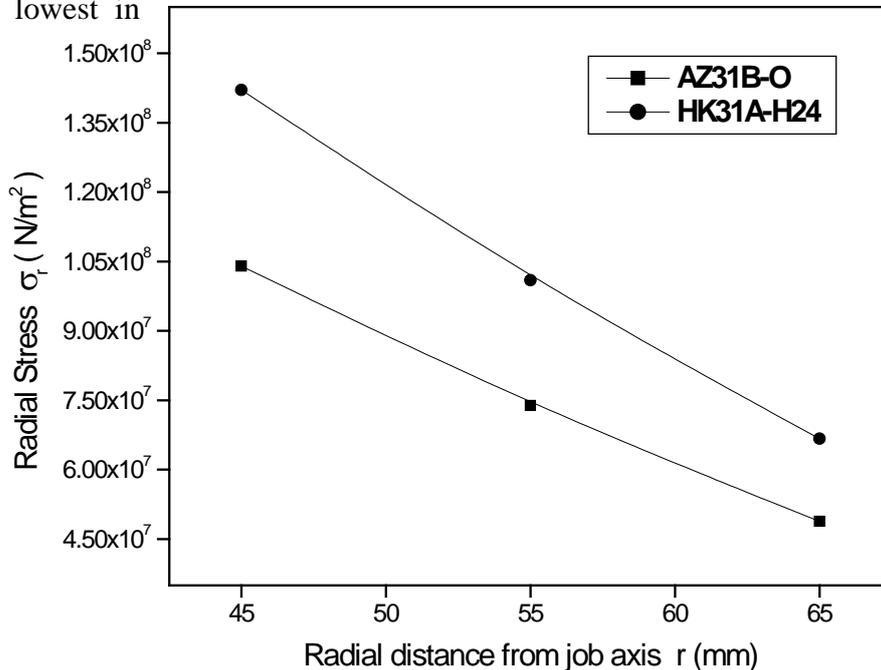


Fig.5. Radial stress distribution in magnesium alloy castor oil viscosity

From 5, the magnesium alloy at $r_j = 90\text{mm}$ with castor oil medium, the range of radial stresses of AZ31B-O is $48813300.96 \text{ N/m}^2 - 103971970.7 \text{ N/m}^2$ and HK31A– H24 is $66711532.99 \text{ N/m}^2 - 142095065.6 \text{ N/m}^2$. The order of radial stresses as $\text{AZ31B-O} < \text{HK31A-H24}$. Among these alloys, for a lower radial distance from the job axis of blank is 45mm, the radial stress is higher value in HK31A-H24 and lowest in AZ31B-O.

Comparing the above results, the order of viscosity of fluids as $\mu_{\text{castor oil}} > \mu_{\text{olive oil}}$ then corresponding the order of radial stresses as

$$\sigma_r \Big|_{\text{castor oil}} < \sigma_r \Big|_{\text{olive oil}}$$

8. CONCLUSIONS

The Radial stresses are the function of process parameters, yield stress of magnesium alloy and viscosity of olive oil and castor oil. The radial stresses are decreases with increasing of the radial distance of the blank of magnesium alloys from the vertical job axis. These effects are due to viscosity of above oils acted on the blanks of magnesium alloy during the forming process. The radial pressure of oil 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 oil. Radial stresses of magnesium alloys are determined with in the range of r is 45mm – 65mm with in the blank radius $r_j = 90 \text{ mm}$. The highest value of radial stress occurred in

HK31A-H24 is $142095163.3 \text{ N/m}^2$ at $r = 45\text{mm}$ with olive oil viscosity and lowest value occurred in AZ31B-O as $48813300.96 \text{ N/m}^2$ at $r = 65\text{mm}$ with castor oil viscosity. The decreased amount of radial stresses in magnesium alloy with in the range r is 45 to 65mm, with olive oil viscosity in AZ31B-O is $55158713.19 \text{ N/m}^2$, HK31A-H24 is $75383576.06 \text{ N/m}^2$ and with castor oil viscosity in AZ31B-O is $55158669.74 \text{ N/m}^2$, HK31A-H24 is $75383532.61 \text{ N/m}^2$. Among these higher in HK31A-H24 and lower in AZ31B-O. The percentage of reduction in radial stresses within the radial distances range 53.05 is obtained. The higher values of radial stresses are occurred in olive oil medium and lowest values of radial stresses are occurred in castor oil medium. So radial stresses are decreases with increasing in viscosity of oils. Higher in viscosity of oil with less in radial stresses. Radial stresses are inversely proportional to viscosity of oils. The radial stresses are in the magnesium alloy are high at r is 45 mm, low at r is 65 mm and radial stresses are zero at r is equal to blank radius. So the radial stresses are inversely proportional to the radial distance from job axis were obtained. The radial stresses are depends on the viscosity, fluid pressure and process parameters. These radial stresses are used to get better results of formability of magnesium alloy.

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