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MATHEMATICAL MODELING OF DRAWING STRESSES OF MAGNESIUM ALLOYS THROUGH HYDROFORMING DEEP DRAWING PROCESS USING HEAVY MACHINE OIL MEDIUM

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Abstract: *The advantages of sheet hydro forming are improving the material formability, reduction of friction force, the accuracy of the forming part and the reduction of forming stages.The hydro formed components are used in the aerospace, automotive and other industries. This paper presents mathematical modeling of drawing stresses of magnesium alloys in hydroforming deep drawing process through heavy machine oil medium. An additional element such as fluid pressure is to be contributes positively in several ways in this process. In hydro forming deep drawing process, the methodology for 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 drawing stresses are produced in the cup wall at die entrance radius along the drawing direction during the formation cup in this process with help of punch force , the shear stresses acted by viscous fluid on the both sides of blank, so apply viscosity phenomenon to this analysis. The blank holder pressure is controlled by the radial pressure of fluid. Drawing stresses are evaluated in terms of process parameters, blank geometry, shear stress and viscosity of heavy machine oil through mathematical modeling. .*

Keywords: *Mathematical modeling, Drawing stress, shear stress, deep drawing Process, hydro forming and viscosity of oil*

I. INTRODUCTION

Hydro forming deep drawing is an important process used for producing cups from sheet metal in large quantities. Hydraulic pressure can enhance the capabilities of the basic deep drawing process for making cups. 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, circumferential compression and Drawing stresses are produced in drawing direction of cup[1-4]. 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 [5-6]. 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 forming deep drawing process the special drawing processes such as hydro-forming [7], hydro-mechanical forming [8], counter-pressure deep drawing [9-10], hydraulic-pressure-augmented deep drawing [11].

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. 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[12-17].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. 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.

In this paper the drawing stresses are determined in terms of dynamic viscosity of fluid, blank geometry and process parameters for magnesium alloys.

II. 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_0 = 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

III. MATHEMATICAL MODELING OF DRAWING STRESS

3.1 Radial Stress

Hydro forming deep drawing Process as shown in fig.1. In the hydro forming deep 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 thick 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 hydro forming deep drawing process. The various stresses acting on the blank element during the process is shown in fig.2.

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 F_1 is given by, $F_1 = 2\tau \times A_c$ Where A_c = fluid contact area of element But $A_c = rdrd\theta + \frac{dr}{2}drd\theta$

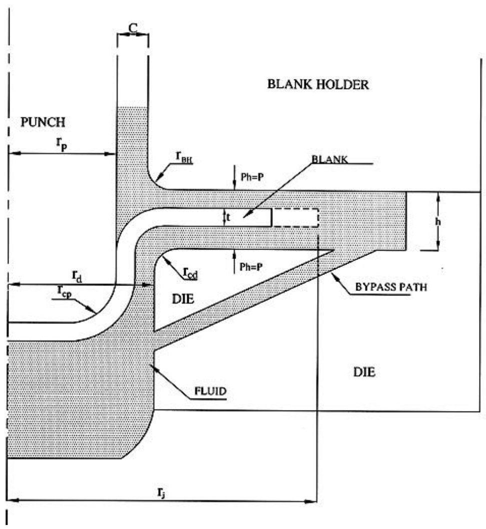

Fig.1 Hydroforming Deep Drawing process

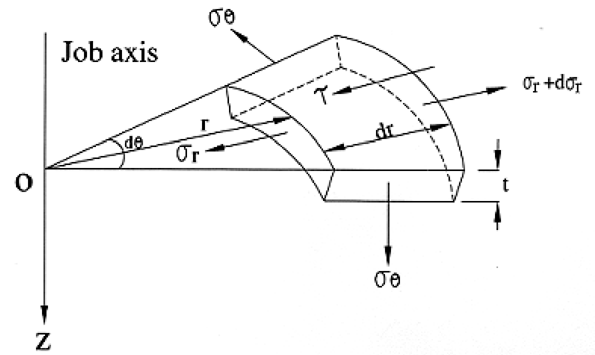

Fig.2. Stresses acting on the element during Drawing process

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

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

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

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

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

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

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

Integrating $\Rightarrow$

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

$$\Rightarrow \sigma_r = \frac{2\tau}{t} r - \sigma_0 \ln r + C \qquad (3)$$

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)

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

This equation (4) represents distribution of radial stresses in the blank during the hydro forming process.

3.2. Radial stress at die corner (σ_{rd})

Radius of die opening = r_d at $r = r_d \Rightarrow \sigma_r = \sigma_{rd}$ we know that from eq. (4) ,

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

$$\Rightarrow \sigma_r\big)_{r=r_d} = \sigma_{rd}$$

$$\therefore \sigma_{rd} = \sigma_0 \ln\left(\frac{r_j}{r_d}\right) - \frac{2\tau}{t}(r_j - r_d) \qquad (5)$$

The equation (5) represents radial stress distribution in the blank at die corner and is acting in radial direction during the drawing process.

3.3 Drawing stress

In hydro forming deep drawing process, the blank slides along the die corner during drawing process with fluid contact media. The radial stress at beginning of die corner in this process is given by eq.5. The Coefficient of friction between the blank and both the blank holder and die surface is negligible, so frictional force is zero. To develop the relation between drawing stress at die throat along the drawing direction σ_z and radial stress at die corner in radial direction σ_{rd} . This relation can be evaluated by using simple belt pulley analogy. In this analysis the fluid friction is considered and also these stresses are already in terms of fluid viscosity are defined. The relation between σ_z and σ_{rd} with fluid contact is shown in fig.3.

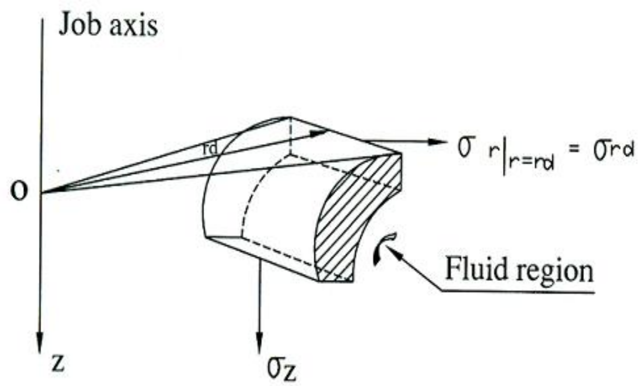

Fig.3.The drawing stress [σ_z] and radial stress at die corner [σ_{rd}] during drawing process in fluid medium

In conventional deep drawing process the above analogy is given by $\frac{T_1}{T_2} = e^{\mu\theta}$ where T_1 and T_2 are tensions , θ = Included angle at center of pulley made by T_1 and T_2 (or) Contact angle , μ = coefficient of friction between pulley and belt. This eq. is apply to this hydro forming process with considerations of $T_1 = \sigma_z$ x A* and $T_2 = \sigma_{rd}$ x A*, where A* = contacting area of σ_z and σ_{rd} & it is same and μ = 0 (Coefficient of friction between the blank and both the blank holder and die surface & no direct contact between the blank and both the blank holder and die surface) , $\theta = \frac{\pi}{2}$

$$\Rightarrow \frac{\sigma_z \, x \, A^*}{\sigma_{rd} \, x \, A^*} = e^{\mu\theta} \Rightarrow \frac{\sigma_z}{\sigma_{rd}} = e^{0 \, x \frac{\pi}{2}} = e^{0} = 1 \Rightarrow \frac{\sigma_z}{\sigma_{rd}} = 1 \Rightarrow \sigma_z = \sigma_{rd}$$

$$, \quad \therefore \sigma_z = \sigma_{rd} \qquad (6)$$

so in hydro forming deep drawing process, The drawing stress in the cup wall at die entrance radius along the drawing direction is equal to radial stress occurred at beginning of die corner in radial direction. But we know that radial stress at die corner in radial direction from eq.[5]

$$\Rightarrow \sigma_Z = \sigma_{rd} \quad \Rightarrow \sigma_Z = \sigma_0 \ln\left(\frac{r_j}{r_d}\right) - \frac{2\tau}{t}(r_j - r_d) \qquad (7)$$

This equation represents the distribution of drawing stress in the cup wall at die entrance radius along the drawing direction in the process.

IV. 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.4. Newton's law of viscosity is applied to this process for evaluation of drawing stresses.

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.4.

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

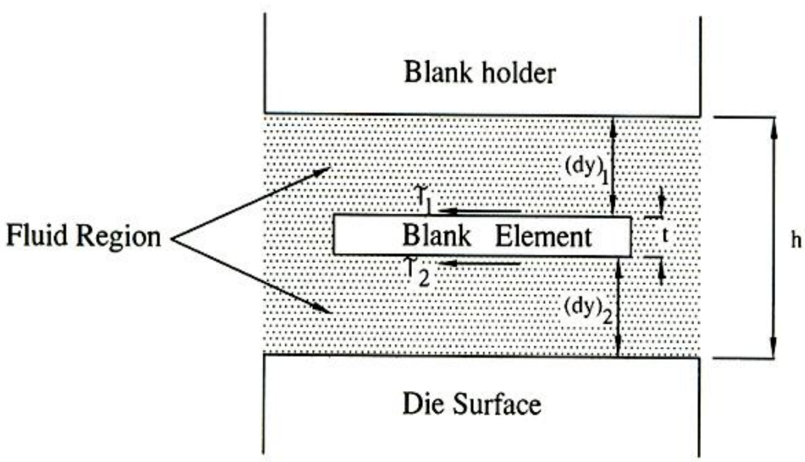

Fig.4.Blank element between blank holder and die surface within fluid region

$$\therefore (dy)_1 = (dy)_2 = (dy) \Rightarrow dy = \frac{h-t}{2}$$

but $\tau_1 = \tau_2$, Because of $\left(\frac{du}{dy}\right)_1 = \left(\frac{du}{dy}\right)_2$,

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 $du = u - 0 = u$

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

$$\tau_A = 2\tau = \frac{4\mu u}{h-t} \qquad (8)$$

4.1 Drawing stress in terms of viscosity

The drawing stress $\sigma_Z = \sigma_0 \ln\left(\frac{r_j}{r_d}\right) - \frac{2\tau}{t}(r_j - r_d)$ (From eq.7) ,

Substitute $2\tau = \frac{4\mu u}{h-t}$, we get drawing stress in terms of viscosity $\Rightarrow \sigma_z = \sigma_0 \ln\left(\frac{r_j}{r_d}\right) - \frac{4\mu u}{h-t}\left(\frac{r_j - r_d}{t}\right)$

(9)

V. MAGNESIUM ALLOYS

Applications for magnesium alloys include use in aircraft, missiles, machinery, tools, and material handling equipment, automobiles and high speed computer parts. 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 us e 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. 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 three types of Magnesium alloys considered namely AZ31B-O and AZ61A-F. Magnesium alloy AZ31B-0: composition (%): 3.5 Al, 0.6Mn, 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.

VI. RESULTS & DISCUSSION

The drawing stress distribution in the blank during the hydroforming deep drawing is given by eq .9

$$\Rightarrow \sigma_z = \sigma_0 \ln\left(\frac{r_j}{r_d}\right) - \frac{4\mu u}{h-t}\left(\frac{r_j - r_d}{t}\right)$$

The following process parameters and yield stress values of magnesium alloys are considered for evaluation of drawing stresses of magnesium alloys with heavy machine oil for successful formation of cup in hydroforming deep drawing process. r_p = 30 mm, r_d = 35mm , c = 5 mm, Radial pressure of fluid = P, Punch speed u =15mm/sec, h =12 mm, Type of materials used :Magnesium alloys, Yield Stress values (σ_0) of Magnesium alloys: AZ31B-O σ_0 = 150MPa and AZ61A-F σ_0=220MPa.Type of fluid used: Heavy machine oil, viscosity μ =0.453N–sec/m^2, radius of blank r_j = 85mm,90mm,95mm,thickness of blanks t = 2mm. The evaluation of values of drawing stresses (σ_z) in the blanks of magnesium alloys with a given fluid and given thickness of blanks at different radius of blanks as follows. Substitute the above values in above σ_z equation we get generalized equations for evaluation of drawing stresses during the process with respect to thickness of blanks of magnesium alloys with heavy machine oil viscosity .

at t = 2 mm $$\Rightarrow \sigma_z = \sigma_0 \ln\left(\frac{r_j}{35}\right) - 1.358\left(r_j - 35\right)$$

The results of drawing stresses for magnesium alloys with respect to radius of blank as r_j =85mm,90mm and 95, at t =2mm with heavy machine oil are presented in fig.5.

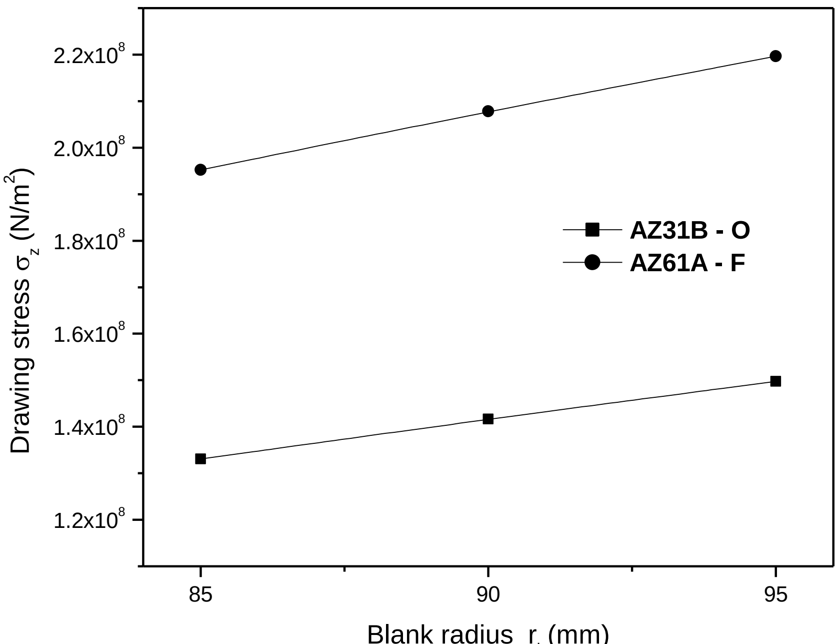

Fig.5. Drawing stresses of Magnesium alloys with heavy machine oil medium at t = 2mm

From this figures the drawing stresses are increasing with increasing the radius of blank. This is due to viscosity of oil and shear stresses acted by this fluid during the process. It is also the function of process parameters, yield stress and fluid pressure. From fig.5 the magnesium alloys at t = 2mm with heavy machine oil viscosity, range of drawing stresses of AZ31B-O is133095411.4 N/m^2 – 149779243N/m^2 and AZ61A-F is 195206635 N/m^2 – 219676261.1 N/m^2 .The increasing order of drawing stresses are AZ31B-O < AZ61A- F. The drawing stress is in higher value when radius of blank is higher value. At lowest radius of magnesium alloys, the drawing stress is higher in AZ61A-F and lower in AZ31B-O

VII. CONCLUSIONS

The drawing stresses are increasing with increasing the radius of blanks. These effects are due to viscosity of heavy machine oil acted on the blank of magnesium alloys during the forming process. In this analysis the drawing stresses are evaluated with in the range of radius is 85mm - 95mm, at constant thickness of magnesium alloys blanks. The highest value of drawing stress occurred in AZ61A-F as 219676261.1N/m^2 at r_j = 95mm and lowest value occurred in AZ31B-O as 133095411.4 N/m^2 at r_j =85mm.The percentage of increase in drawing stresses of each magnesium alloy with in the range of given blank radius and at given thickness is 13%. The order of increased amount of drawing stresses of magnesium alloys as AZ31B-O < AZ61A–F. Higher values of drawing stresses are obtained in high radius of blanks. The higher values of drawing stresses are give the minimizing the drawing time and higher in forming limits. These drawing stresses are used to get good results of deep drawability, surface finish and accuracy in products of magnesium alloys. The wrinkling is reduced due to the blank supported by high pressurized viscous fluid. The drawing stresses are the function of process parameters, yield stress of magnesium alloys and viscosity of heavy machine oil.

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