CHAPTER 7

INVESTIGATIONS ON DRAWING STRESSES IN MAGNESIUM ALLOYS BLANKS

7.1 INTRODUCTION

In the fluid assisted deep drawing process the blank slides along the die corner with fluid contact. The Coefficient of friction between the blank and both the blank holder and die surface is negligible, hence frictional force is zero. The drawing stress in the cup wall at die entrance radius along the drawing direction is equal to radial stress occurred in the beginning of die corner which is obtained in radial direction. The radial stresses are determined at the radius of die opening $r_d = 40\text{mm}$ and these are equating to drawing stresses in the cup wall at die entrance radius along the direction of drawing.

In this process drawing stresses are studied on blanks made of magnesium alloys for different radii of blanks with heavy machine oil medium at different thickness of blanks.

7.2 RESULTS AND DISCUSSION

7.2.1 Drawing Stresses

The drawing stress distribution along the magnesium alloys blanks during the fluid assisted deep drawing process is given in eq.(3.20). The geometry of process, process parameters and yield strength of magnesium alloys are considered for evaluation of drawing stresses with given fluid for successful formation of cup in fluid assisted deep drawing process. The following parameters are considered for the analysis
\[
\begin{align*}
    r_p &= 35\text{mm} \\
    r_d &= 40\text{mm} \\
    P &= 35\text{N/m}^2 \\
    P_b &= 35\text{N/m}^2
\end{align*}
\]

fluid medium:

Heavy machine oil

\[
\begin{align*}
    \mu &= 0.453\text{N-s/m}^2 \\
    \rho &= 986\ \text{kg/m}^3
\end{align*}
\]

\[
\begin{align*}
    r_j &= 80\text{mm,85mm,90mm,95mm and 100mm} \\
    t &= 1.5\text{mm, 2.5mm and 3.5mm}
\end{align*}
\]

and remaining data of the process and various parameters is given in 3.16. The fluid pressure is obtained from Flotran CFD for heavy machine oil is 35 N/m^2. This pressure of the fluid is applied radially on periphery of blank and it is equal to blank holding pressure.

Substitute the geometry and process parameters in eq.(3.20), to get generalized equations for results, which are given in eq.(7.1), eq.(7.2) and eq.(7.3) with respect to \( r_d = 40\text{mm} \) and at \( t = 1.5\text{mm, 2.5mm and 3.5mm} \) respectively.

\[
\begin{align*}
    \Rightarrow \sigma_z &= \sigma_0 \ln \left( \frac{r_j}{40} \right) - 1.15 \left( r_j - 40 \right) \quad [7.1] \\
    \Rightarrow \sigma_z &= \sigma_0 \ln \left( \frac{r_j}{40} \right) - 0.762 \left( r_j - 40 \right) \quad [7.2] \\
    \Rightarrow \sigma_z &= \sigma_0 \ln \left( \frac{r_j}{40} \right) - 0.609 \left( r_j - 40 \right) \quad [7.3]
\end{align*}
\]
Fig. 7.1 shows the variation of drawing stresses in blank made of magnesium alloys with heavy machine oil obtained using theoretical and finite element simulation. From theoretical analysis, the range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are 15249233.7 N/m² – 20158392 N/m², 142095126 N/m² – 187839531 N/m² and 103972031.1 N/m² – 137443540.8 N/m² respectively.

From Finite Element analysis, the range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are 160116950.4 N/m² – 213275757.7 N/m², 149199882.3 N/m² – 198734223.8 N/m² and 109170632.7 N/m² – 145415266.2 N/m² respectively.
In theoretical analysis the drawing stresses are maximum at \( r_j = 100\text{mm} \) for AZ61A-F alloy is 201583892N/m\(^2\) and in AZ31B-0 alloy which is 137443540.8N/m\(^2\). At \( r_j = 80\text{mm} \) the least variation observed for AZ61A-F alloy is 152492333.7N/m\(^2\), AZ31B-0 alloy is 103972031.1 N/m\(^2\). High drawing stresses are found in AZ61A-F magnesium alloy and least in AZ31B-0 magnesium alloy and within these drawing stresses for HK31A-H24 magnesium alloy are observed.

A similar variation is observed from finite element analysis, maximum at \( r_j = 100\text{mm} \) for AZ61A-F alloy is 213275757.7 N/m\(^2\) and in AZ31B-0 alloy which is 145415266.2N/m\(^2\). At \( r_j = 80\text{mm} \) the least variation is observed for AZ61A-F alloy is 160116950.4N/m\(^2\), AZ31B-0 alloy is 109170632.7N/m\(^2\). High drawing stresses are found in AZ61A-F magnesium alloy and least in AZ31B-0 magnesium alloy and within these HK31A-H24 magnesium alloy are observed.

The average percentage variation between the theoretical and finite element analysis is 5.12%. From this analysis, the order of drawing stresses of magnesium alloys are AZ31B-0 < HK31A-H24 < AZ61A-F obtained.

Fig.7.2 Shows the variation of drawing stresses in blank made of magnesium alloys with heavy machine oil obtained using theoretical and finite element simulation. From theoretical analysis the range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are 152492349.2N/m\(^2\) – 201583915.3N/m\(^2\), 142095141.5N/m\(^2\)-
187839554.3N/m² and 103972046.6N/m² – 137443564.1N/m² respectively.

Fig.7.2 Effect of blank radius on drawing stresses of magnesium alloys at $t = 2.5\text{mm}$

From Finite element analysis range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are $160421951.4\text{N/m}^2$ – $213678950.2\text{N/m}^2$, $149484088.9\text{N/m}^2$ – $199109927.6\text{N/m}^2$ and $109378593.0\text{N/m}^2$ - $145690177.9\text{N/m}^2$ respectively.

The drawing stresses from theoretical analysis are maximum at $r_j = 100\text{mm}$ for AZ61A-F alloy is $201583915.3\text{N/m}^2$ and in AZ31B-0 alloy which is $137443564.1\text{N/m}^2$. At $r_j = 80\text{mm}$ the least variation observed for AZ61A-F alloy is $152492349.2\text{N/m}^2$, AZ31B-0 alloy is $103972046.6\text{N/m}^2$. High drawing stresses are found in AZ61A-F
magnesium alloy and least in AZ31B-0 magnesium alloy and within these HK31A-H24 magnesium alloy are observed.

A similar variation is observed from finite element analysis, maximum at \( r_j = 100 \text{mm} \) for AZ61A-F alloy is 213678950.2 N/m\(^2\) and in AZ31B-0 alloy which is 145690177.9 N/m\(^2\). At \( r_j = 80 \text{mm} \) the least variation is observed for AZ61A-F alloy is 160421951.4 N/m\(^2\), AZ31B-0 alloy is 109378593.0 N/m\(^2\). High drawing stresses are found in AZ61A-F magnesium alloy and least in AZ31B-0 magnesium alloy and within these values for HK31A-H24 magnesium alloy are observed.

The average percentage variation between the theoretical and finite element analysis is 5.3%. From this analysis, the order of drawing stresses of magnesium alloys are AZ31B-0 < HK31A-H24 < AZ61A-F found.

Fig.7.3 Shows the variation of drawing stresses in blank made of magnesium alloys with heavy machine oil obtained using theoretical and finite element simulation. From theoretical analysis the range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are 152492355.4 N/m\(^2\) – 201583924.5 N/m\(^2\), 142095147.7 N/m\(^2\) – 187839563.5 N/m\(^2\) and is 103972052.7 N/m\(^2\) – 137443609.8 N/m\(^2\) respectively.

From Finite element analysis range of drawing stresses for AZ61A-F, HK31A–H24 and AZ31B-0 alloys are 160726942.6 N/m\(^2\) – 214082127.8 N/m\(^2\), 149768285.7 N/m\(^2\) – 199485616.4 N/m\(^2\) and 109586543.5 N/m\(^2\) - 145965113.6 N/m\(^2\) respectively.
Fig. 7.3 Effect of blank radius on drawing stresses of magnesium alloys at $t = 3.5\text{mm}$

The drawing stresses from theoretical analysis are maximum at $r_j = 100\text{mm}$ for AZ61A-F alloy is $201583924.5\text{N/m}^2$ and in AZ31B-0 alloy which is $137443609.8\text{N/m}^2$. At $r_j = 80\text{mm}$ the least variation is observed for AZ61A-F alloy is $152492355.4\text{N/m}^2$, AZ31B-0 alloy is $103972052.7\text{N/m}^2$. High drawing stresses are found in AZ61A-F magnesium alloy and least in AZ31B-0 magnesium alloy and within these HK31A-H24 magnesium alloy are observed.

A similar variation is observed from finite element analysis, maximum at $r_j = 100\text{mm}$ for AZ61A-F alloy is $214082127.8\text{N/m}^2$ and in AZ31B-0 alloy which is $145965113.6\text{N/m}^2$. At $r_j = 80\text{mm}$ the least
variation is observed for AZ61A-F alloy is $160726942.6\text{N/m}^2$, AZ31B-0 alloy is $109586543.5\text{N/m}^2$. High drawing stresses are found in AZ61A-F magnesium alloy and least in AZ31B-0 magnesium alloy and within these HK31A-H24 magnesium alloy are observed.

The average percentage variation between the theoretical and finite element analysis is 5.475%. From this analysis, the order of drawing stresses of magnesium alloys are AZ31B-0 < HK31A-H24 < AZ61A-F found. The nature of graphs linear.

The order of variation of drawing stresses of magnesium alloys with heavy machine oil as medium as follows

$$\sigma_z|_{r=1.5\text{mm}} < \sigma_z|_{r=2.5\text{mm}} < \sigma_z|_{r=3.5\text{mm}}$$

The drawing stresses increase with increase in the radius of blank and also with increase in the thickness of blank. This is due to viscosity and pressure of heavy machine oil.

**7.3 COMPARATIVE STUDIES ON DRAWING STRESSES WITH THREE DIFFERENT FLUID MEDIUM**

The drawing stresses of magnesium alloys evaluated and compared at different radii and constant thickness of blanks by using three fluids such as olive oil, heavy machine oil and castor oil as medium. The radial stresses are evaluated at the radius of die opening $r_d = 45\text{mm}$, which are equating to drawing stresses in the cup wall at die entrance radius along the drawing direction.

**7.3.1 Results and Discussion**

The drawing stress in the cup wall of magnesium alloys at die entrance radius along the drawing direction during the process with
different fluids is given in eq.(3.20).

The following parameters considered for the analysis

\[ r_p = 40\text{mm} \]
\[ r_d = 45\text{mm} \]

Fluids medium:

Olive oil, \( \mu = 0.081\text{N–sec/m}^2 \)

Heavy machine oil, \( \mu = 0.453\text{N–sec/m}^2 \),

castor oil, \( \mu = 0.985\text{N–sec/m}^2 \),

\[ r_j = 90\text{mm, 95mm, 100mm and 105mm} \]

\[ t = 3.0\text{mm} \]

and remaining data of the process and various parameters are given in 3.16.

The pressure (P) obtained in Flotran CFD for different fluids olive oil, heavy machine oil and castor oil are 14.134N/m\(^2\), 58.47N/m\(^2\) and 121.24N/m\(^2\) respectively. This pressure of the fluid is applied radially on periphery of blank and also equal to blank holding pressure.

Substitute the geometry and process parameters in eq.(3.20), the generalized equations for results of drawing stresses at different fluids for magnesium alloys is given in eq.(7.4) to eq.(7.6) at constant thickness \( t = 3.0\text{mm}, r_d = 45\text{mm} \) respectively.

At \( \mu_{\text{olive oil}} = 0.081\text{N–sec/m}^2 \)

\[ \Rightarrow \sigma_z = \sigma_0 \ln \left( \frac{r_j}{45} \right) - 0.12(r_j - 45) \quad [7.4] \]

At \( \mu_{\text{heavy machine oil}} = 0.453\text{N–sec/m}^2 \)
\[ \Rightarrow \sigma_{z} = \sigma_{0} \ln \left[ \frac{r}{45} \right]^{-0.67(r - 45)} \quad [7.5] \]

At \( \mu_{\text{castor oil}} = 0.985 \text{N–sec/ m}^{2} \)

\[ \Rightarrow \sigma_{z} = \sigma_{0} \ln \left[ \frac{r}{45} \right]^{-1.45(r - 45)} \quad [7.6] \]

Fig.7.4 Shows the variation of drawing stresses in blank made of magnesium alloys with olive oil obtained using theoretical and finite element simulation. From theoretical analysis the range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are 152492374.3 N/m² – 186405522.1 N/m², 142095166.6 N/m² - 173696054.2 N/m² and 103972071.7 N/m² – 127094671.9 N/m² respectively.

From finite element analysis the range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are 160726962.5 N/m² – 197589853.4 N/m², 149768305.6 N/m² - 184117817.5 N/m² and 109586563.6 N/m² - 134720352.1 N/m² respectively.

The drawing stresses from theoretical analysis are maximum at \( r_j \) = 105 mm for AZ61A-F alloy is 186405522.1 N/m² and in AZ31B-0 alloy which is 127094671.9 N/m². At \( r_j = 90 \) mm the least variation is observed for AZ61A-F alloy is 152492374.3 N/m², AZ31B-0 alloy is 103972071.7 N/m². High drawing stresses are found in AZ61A-F magnesium alloy and least in AZ31B-0 magnesium alloy and within these values for HK31A-H24 magnesium alloy are observed.
Fig. 7.4 Variation of drawing stresses in magnesium alloys blanks at olive oil medium

A similar variation is observed from finite element analysis, maximum at $r_j = 105$mm for AZ61A-F alloy is $197589853.4$N/m$^2$ and in AZ31B-0 alloy which is $134720352.1$N/m$^2$. At $r_j = 90$mm the least variation is observed for AZ61A-F alloy is $160726962.5$N/m$^2$, AZ31B-0 alloy is $109586563.6$N/m$^2$. High drawing stresses are found in AZ61A-F magnesium alloy and least in AZ31B-0 magnesium alloy and within these values for HK31A-H24 magnesium alloy are observed.

The average percentage variation between the theoretical and finite element analysis is 5.39%. From this analysis, the order of drawing stresses of magnesium alloys are AZ31B-0 < HK31A-H24 < AZ61A-F found.
Fig.7.5 Shows the variation of drawing stresses in blank made of magnesium alloys with heavy machine oil obtained using theoretical and finite element simulation. From theoretical analysis the range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are $152492349.2 \text{N/m}^2 - 186405489.1 \text{N/m}^2$, $142095141.9 \text{N/m}^2 - 173696021.2 \text{N/m}^2$ and $103972046.9 \text{N/m}^2 - 127094638.9 \text{N/m}^2$ respectively.

From finite element analysis the range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are $160421951.4 \text{N/m}^2 - 197217007.5 \text{N/m}^2$, $149484089.3 \text{N/m}^2 - 183770390.4 \text{N/m}^2$ and $109378593.3 \text{N/m}^2 - 134466128.0 \text{N/m}^2$ respectively.
The drawing stresses from theoretical analysis are maximum at \( r_j = 105 \text{mm} \) for AZ61A-F alloy is 186405489.1N/m\(^2\) and in AZ31B-0 alloy which is 127094638.9N/m\(^2\). At \( r_j = 90 \text{mm} \) the least variation is observed for AZ61A-F alloy is 152492349.2 N/m\(^2\), AZ31B-0 alloy is 103972046.9N/m\(^2\). High drawing stresses are found in AZ61A-F magnesium alloy and least in AZ31B-0 magnesium alloy and within these drawing stresses for HK31A-H24 magnesium alloy are observed.

A similar variation is observed from finite element analysis, maximum at \( r_j = 105 \text{mm} \) for AZ61A-F alloy is 197217007.5N/m\(^2\) and in AZ31B-0 alloy which is 134466128.0N/m\(^2\) N/m\(^2\). At \( r_j = 90 \text{mm} \) the least variation is observed for AZ61A-F alloy is 160421951.4N/m\(^2\), AZ31B-0 alloy is 109378593.3N/m\(^2\). High drawing stresses are found for AZ61A-F magnesium alloy and least in AZ31B-0 magnesium alloy and within these drawing stresses HK31A-H24 magnesium alloy are observed.

The average percentage variation between the theoretical and finite element analysis is 5.21%. From this analysis, the order of drawing stresses of magnesium alloys are AZ31B-0 < HK31A-H24 < AZ61A-F obtained.

Fig.7.6 Shows the variation of drawing stresses in blank made of magnesium alloys with castor oil obtained using theoretical and finite element simulation. From theoretical analysis the range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are 152492314.5 N/m\(^2\) – 186405442.3N/m\(^2\), 142095106.8N/m\(^2\) –
173695974.0 N/m² and 103972011.8N/m² – 127094592.1N/m² respectively.

Fig.7.6 Variation of drawing stresses in magnesium alloys blanks at castor oil medium

From finite element analysis the range of drawing stresses for AZ61A-F, HK31A-H24 and AZ31B-0 alloys are 160116930.2N/m² – 196844147.1N/m², 149199862.1N/m² – 183422948.5N/m² and 109170612.4N/m² – 134211889.3N/m² respectively.

From theoretical analysis the drawing stresses are maximum at \( r_j = 105 \text{mm} \) for AZ61A-F alloy is 186405442.3N/m² and in AZ31B-0 alloy which is 127094592.1N/m². At \( r_j = 90 \text{mm} \) the least variation is observed for AZ61A-F alloy is 152492314.5 N/m², AZ31B-0 alloy is 103972011.8N/m². High drawing stresses are found in AZ61A-F
magnesium alloy and least in AZ31B-0 magnesium alloy and within these values drawing stresses for HK31A-H24 magnesium alloy are observed.

A similar variation is observed from finite element analysis, maximum at \( r_j = 105 \text{mm} \) for AZ61A-F alloy is 196844147.1N/m\(^2\) and in AZ31B-0 alloy which is 134211889.3N/m\(^2\). At \( r_j = 90 \text{mm} \) the least variation is observed for AZ61A-F alloy is 160116930.2 N/m\(^2\), AZ31B-0 alloy is 109170612.4N/m\(^2\). High drawing stresses are found in AZ61A-F magnesium alloy and least in AZ31B-0 magnesium alloy and within these values drawing stresses for HK31A-H24 magnesium alloy are observed.

The average percentage variation between the theoretical and finite element analysis is 5.03%. From this analysis, the order of drawing stresses of magnesium alloys are \( \text{AZ31B-0} < \text{HK31A-H24} < \text{AZ61A-F} \) obtained. The nature of graphs is linear.

The order of viscosity of fluids is

\[
\mu_{\text{olive oil}} < \mu_{\text{heavy machine oil}} < \mu_{\text{castor oil}},
\]

the corresponding order of drawing stresses of magnesium alloys with respect to viscosity of oils is

\[
\sigma_{\epsilon_{\text{olive oil}}} > \sigma_{\epsilon_{\text{heavy machine oil}}} > \sigma_{\epsilon_{\text{castor oil}}},
\]

From this analysis the drawing stresses of magnesium alloys decrease with increase in the viscosity of oils and also increase with the radius of blank. The drawing stresses of magnesium alloys decrease with increase in the pressure of oils. The drawing stresses
obtained in magnesium alloys are higher in olive oil and least in castor oil medium. These effects are due to viscosity of oils, fluid pressure and process parameters. These drawing stresses are used to get good results of formability of magnesium alloys.