CHAPTER – VI

CONCLUSION

6.1. ONE END CONSTRAINED WITH A CONICAL DIE (ALUMINIUM)

a) Two barrels namely the top and the bottom were observed when using a die at one end of the specimen.

b) The relationship between the new hoop strain and axial strain conformed to straight line behaviour with a slope of 0.666 for both barrels for aspect ratio 1; however, the slope was different for aspect ratio 0.75 and 1.25 for the top barrel and bottom barrel produced.

c) The calculated and the measured radius of the curvature of both barrels were found to correspond to each other in the ratio of 1:1.

d) The stress ratio parameter and the hydrostatic stress had a direct effect on bulging or barrelling of solid cylinders.

e) A power law relationship between the barrel radius and the new geometrical shape factor exist.

\[ R = C_1 S_1^{-m_1} \]

Where: \( R \) is the barrel radius; \( S_1 \) is the new geometrical shape factor; and \( C_1 \) and \( m_1 \) are empirically determined constants.
ONE END CONSTRAINED WITH A CONICAL DIE (COPPER)

a) Two barrels namely the top and the bottom were observed when using a die at one end of the specimen.

b) The relationship between the new hoop strain and axial strain conformed to straight line behaviour with a slope of 1.00 for aspect ratios 1.25 and 1.00 for top barrels, whereas the slope measured 0.615 for aspect ratio 0.75. Similarly, different slopes were observed for bottom barrels for different aspect ratios. But, it was observed that lubricants applied did not exhibit any major differences in these values.

c) The calculated and the measured radius of the curvature of both barrels were found to correspond to each other in the ratio of 1:1, irrespective of the aspect ratios and lubricant considered.

d) A power law relationship between the barrel radius and the new geometrical shape factor exist.

\[ R = C_{12} S_6^{-m_{12}} \]

Where \( R \) is the radius of curvature of barrel, \( S_6 \) is the new geometrical shape factor, \( C_{12} \) and \( m_{12} \) are the empirically determined constants.

6.2. ONE END CONSTRAINED WITH AN EXTRUSION DIE

(ALUMINIUM)

a) The final shape of the work piece after the upsetting process can be divided in to three geometries namely a extruded portion, a barreled portion and a truncated cone portion.
b) It was observed the height of the truncated cone portion decreases with increase in strain values and also follows a power law relationship viz,

\[ \ln h_t = C_3 S_2^{-m_3} \]

Where \( h_t \) = truncated cone height, \( S_2 \) = New geometrical shape factor \(^{(1)}\) \( C_3 \) and \( m_3 \) are empirically determined constants.

c) The measured radius of curvature matches one to one with the calculated radius, thus establishing the assumption that the radius of curvature of the barrel fits a circular arc. Stresses namely the hoop stress (\( \sigma_0 \)), the effective stress (\( \bar{\sigma} \)) and the hydrostatic stress (\( \sigma_m \)), all found to increase with the increasing level of deformation and different for different barrels. The relationship between the new hoop strain and the axial strain conformed to a straight-line behavior.

d) It was found that the barrel radius followed power relationship, viz,

\[
\begin{align*}
(a) \quad &R = C_4 S_3^{-m_4} \\
(b) \quad &R = C_5 [ (\sigma_m/\bar{\sigma})(h_0 - h_f) ]^{-m_5}
\end{align*}
\]

6.3. BOTH END CONSTRAINED WITH CONICAL DIES (ALUMINIUM)

a) Having the conical die constraint at both the ends of the work piece resulted with two barrels and a boldered part almost at the centre of the work piece irrespective of the aspect ratios and the lubricant
b) The relationship between the new hoop strain and axial strain conformed to a straight-line behavior with a slope of 0.3 for both barrels. The use of lubricant SAE 40 oil does not have much effect on the bulging behavior.

c) The calculated and the measured radius of the curvature of both barrels were found to correspond to each other.

d) The stress ratio parameter and the hydrostatic stress had a direct effect of bulging or barreling of solid cylinders. Except the lubricant SAE 40 oil, all other lubricants had their significant effect on bulging behavior irrespective of aspect ratios.

e) A power law relationship between the barrel radius and the new geometrical shape factor exists.

\[ R = C_6 S_3^{-m_6} \]

Where \( R \) is the radius of curvature of barrel, \( S_3 \) is the new geometrical shape factor, \( C_6 \) and \( m_6 \) are the empirically determined constants.

**CONSTRAINED AT BOTH ENDS WITH CONICAL DIES (COPPER)**

a) Having the conical die constraint at both the ends of the work piece resulted with two barrels and a boldered part almost at the centre of the work piece irrespective of the aspect ratios and the lubricant.

b) The relationship between the new hoop strain and axial strain conformed to a straight-line behavior with a slope of 0.7 for aspect ratio 0.75 for both barrels and 0.6 for aspect
ratio 1.0. It is again noticed that the use of different lubricants has not made any change in the slope value.

c) The calculated and the measured radius of the curvature of both barrels were found to correspond to each other.

d) The stress ratio parameter and the hydrostatic stress had a direct effect on bulging or barreling of solid cylinders. Lubricants used did not exhibit any significant effect on bulging behavior irrespective of aspect ratios.

e) A power law relationship between the barrel radius and the new geometrical shape factor exists.

\[ R = C_{15} S_8^{-m15} \]

Where \( R \) is the radius of curvature of barrel, \( S_8 \) is the new geometrical shape factor, \( C_{15} \) and \( m15 \) are the empirically determined constants.

6.4. DIFFERENT FRICTION CONDITIONS AT THE FLAT DIE SURFACES (ALUMINIUM)

a) Among the different surface finish of the platens studied, the grinding finish of the platens established the lowest friction at the interface and hence the barreling is minimum. Whereas the EDM surface finish of the platens exhibited the maximum friction at the interface and the barreling is maximum. The surface finish obtained with milling showed comparatively lower friction than the finish obtained in lathe.

b) The measured radius of curvature matches one to one with calculated, thus establishing the assumption that the radius of curvature of the barrel fits a circular arc.
c) Stresses, namely, the axial, the hoop, the representative and the hydrostatic all found to increase with the increasing level of deformation and different for different barrels. The relationship between the hoop strain and axial strain conformed to a straight-line behavior.

d) It was found that the barrel radius followed power relationship, viz,

\[ R = C_8 S_4^{-m_8}, \quad \text{and} \]
\[ R = C_9 \left[ \left( \frac{\sigma_m}{\bar{\sigma}} \right) (h_0 - h_f) \right]^{m_9} \]

Where,

\( R \) = Radius of curvature, \( S_4 \) = Geometrical shape factor,
\( \sigma_m \) = Hydrostatic stress, \( \bar{\sigma} \) = Representative stress
\( h_0 \) = Initial height of the cylinder,
\( h_f \) = Final height of the cylinder after deformation,
\( C_8, m_8, C_9 \) and \( m_9 \) are experimentally determined constants.

e) The rate of change of radius of curvature with respect to hydrostatic stress was different for different frictional conditions.

f) The rate of change of radius of curvature with respect to stress ratio factor was almost same for different frictional conditions for a given aspect ratio.
DIFFERENT FRICTION CONDITION BETWEEN FLAT DIE SURFACES (COPPER)

a) Among the different surface finish of the platens studied, the grinding finish of the platens established the lowest friction at the interface and hence the barreling is minimum. Whereas the EDM surface finish of the platens exhibited the maximum friction at the interface and the barreling is maximum. The surface finish obtained with milling showed comparatively lower friction than the finish obtained in lathe.

b) The measured radius of curvature matches one to one with calculated, thus establishing the assumption that the radius of curvature of the barrel fits a circular arc.

c) Stresses, namely, the axial, the hoop, the representative and the hydrostatic all found to increase with the increasing level of deformation and different for different barrels. The relationship between the hoop strain and axial strain conformed to a straight-line behavior.

d) It was found that the barrel radius followed power relationship, viz,

\[(a) \quad R = C_13 S_7^{-m13}\]

\[(b) \quad R = C_{14} \left[ \frac{\sigma_m}{\sigma} \right]^{-m14} (h_0 - h_f)\]

Where,

\[R = \text{Radius of curvature}, \quad S_7 = \text{Geometrical shape factor},\]

\[\sigma_m = \text{Hydrostatic stress}, \quad \sigma = \text{Representative stress}\]

\[h_0 = \text{Initial height of the cylinder}\]
$h_f$ = Final height of the cylinder after deformation,

$C_{13}$, $m_{13}$, $C_{14}$ and $m_{14}$ are experimentally determined constants.

e) The rate of change of radius of curvature with respect to hydrostatic stress was different for different frictional conditions.

f) The rate of change of radius of curvature with respect to stress ratio factor was almost same for different frictional conditions for a given aspect ratio.

6.6 DIFFERENTIAL LUBRICATION CONDITION AT THE FACES OF THE SPECIMEN (ALUMINIUM)

a) The final shape of the work piece after the upsetting process can be divided into two geometries namely a barreled portion and a truncated cone portion.

b) It was observed the height of the truncated cone portion decreases with increase in strain values.

c) The measured radius of curvature matches one to one with the calculated radius, thus establishing the assumption that the radius of curvature of the barrel fits a circular arc.

d) Stresses namely the hoop stress ($\sigma_\theta$), the effective stress ($\bar{\sigma}$) and the hydrostatic stress ($\sigma_m$), all found to increase with the increasing level of deformation and different for different barrels. The relationship between the new hoop strain and the axial strain conformed to a straight-line behavior.

e) It was found that the barrel radius followed power relationship, viz,

$$R = C_{10} S_5^{m_{10}}$$

and

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\[ R = C_{11} \left[ (\frac{\sigma_{\text{m}}}{\bar{\sigma}}) (h_0 - h_f) \right]^{m_{11}} \]

Where,

\[ R = \text{Barrel radius}, \quad S_5 = \text{New geometrical shape factor}, \]

\[ \sigma_{\text{m}} = \text{Hydrostatic stress}, \quad \bar{\sigma} = \text{Representative stress}, \]

\[ h_0 = \text{Initial height of the cylinder}, \quad h_f = \text{deformed height}, \]

\[ C_{10}, \quad m_{10}, \quad C_{11}, \quad \text{and} \quad m_{11} \text{ are experimentally determined constants}. \]

f) It was observed that the radius of curvature of the bulge decreases with increasing values of stress ratio parameter irrespective of the aspect ratios and lubricants considered.

f) The rate of change of radius of curvature with respect to stress ratio factor was almost same for different frictional conditions for a given aspect ratio.

6.7. SUGGESTED TOPICS FOR FURTHER INVESTIGATION:

From the considerations of results of the present study, several additional areas may be worth for further investigations.

1. The study may be further extended to other metals having different crystal structures like H. C. P.

2. The study may be extended to other geometrical shape of metals having square, rectangle and hexagonal.

3. The study may be extended to compact sintered powder metallurgy shapes. 4. Extrusion dies may be introduced at both ends and results may be obtained.

5. Modelling and simulating the experiments may be carried out using Finite element techniques and the results may be compared with experimental studies.

6. Further work on cold work effect on (pre strain) barrelling can be carried out.

7. Study may be carried out by varying strain rate under the conditions studied above.