

(*SuperForge*)

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(precision forging)

(lateral extrusion)

hhaghighat@razi.ac.ir

[] Juneja Grover [] Bhutta Chitkara [] Dean Abdul

[] Shabara El-Domaity [] Bhutta Chitkara .

Hsu [] Yohngjo Chitkara [] Bhutta Chitkara

Cho [] Choi .

Plancak .
(gear like elements)

[] Can .

Can

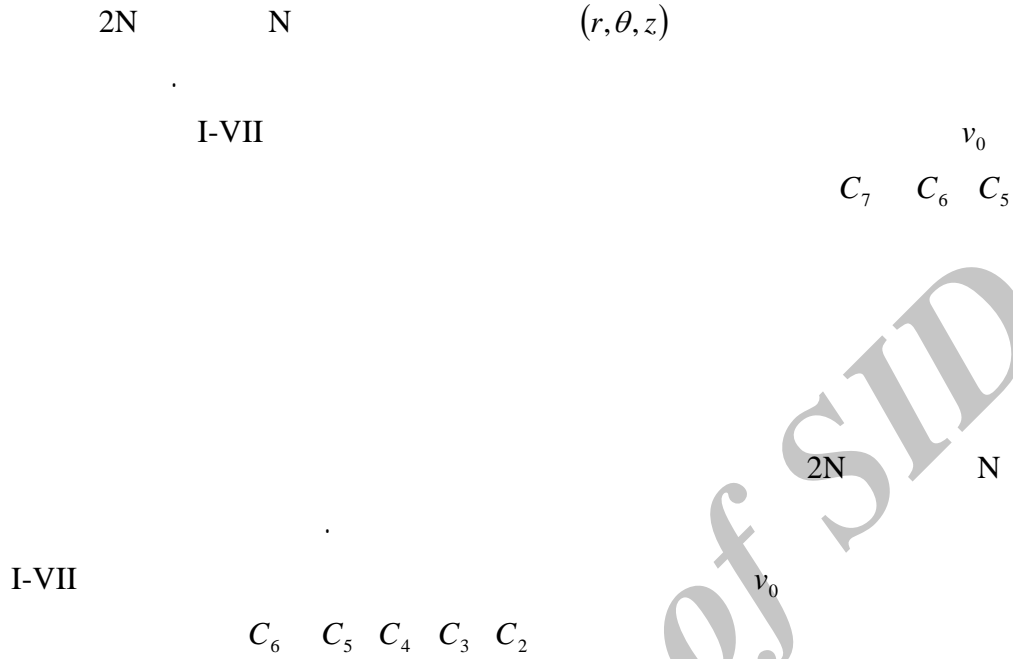
[] Can Altinbalik .

[]

(SuperForge

$$\dot{\epsilon}_{rr} + \dot{\epsilon}_{zz} + \dot{\epsilon}_{\theta\theta} = 0 \quad ()$$

-
-



:

$$\begin{aligned}
 \dot{\epsilon}_{rr} &= \frac{\partial U}{\partial r} r, \\
 \dot{\epsilon}_{\theta\theta} &= \frac{1}{r} \left(\frac{\partial U}{\partial \theta} \theta + U_r \right), \\
 \dot{\epsilon}_{zz} &= \frac{\partial U}{\partial z} z, \\
 \dot{\epsilon}_{r\theta} &= \frac{1}{2} \left(\frac{\partial U}{\partial r} \theta - \frac{U}{r} + \frac{1}{r} \frac{\partial U}{\partial \theta} r \right), \\
 \dot{\epsilon}_{rz} &= \frac{1}{2} \left(\frac{\partial U}{\partial z} r + \frac{\partial U}{\partial r} z \right), \\
 \dot{\epsilon}_{\theta z} &= \frac{1}{2} \left(\frac{\partial U}{\partial z} \theta + \frac{1}{r} \frac{\partial U}{\partial \theta} z \right)
 \end{aligned}
 \tag{ }$$

:

$$\dot{\varepsilon} = \sqrt{\frac{2}{3}} \sqrt{\dot{\varepsilon}_{ij} \dot{\varepsilon}_{ij}} \quad ()$$

:

$$\dot{W}_i = \int_V \sigma_0 \dot{\varepsilon} dV \quad ()$$

:

$$\dot{W}_s = \frac{\sigma_0}{\sqrt{3}} \int_S |\Delta V| dS \quad ()$$

ΔS

$|\Delta V|$

:

$$\dot{W}_f = \frac{m\sigma_0}{\sqrt{3}} \int_S |\Delta V| dA \quad ()$$

$|\Delta V|$

m

dA

:

$$\dot{W} = \sum \dot{W}_i + \sum \dot{W}_f + \sum \dot{W}_s \quad ()$$

Matlab

N

F_{ave}

:

$$\dot{W}_{total} = 2N\dot{W} \quad ()$$

$$F_{ave} = \frac{\dot{W}_{total}}{v_0} \quad ()$$

SuperForge

SolidWorks

Al99,5

[] $\bar{\sigma} = 152.49 \bar{\epsilon}^{0.292}$ [MPa]

(...)

Al99,5

($m = 0.1$) [] $\bar{\sigma} = 152.49 \bar{\epsilon}^{0.292}$ [MPa]

()

SuperForge

SuperForge

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$m = 0.6$ $m = 0.1$

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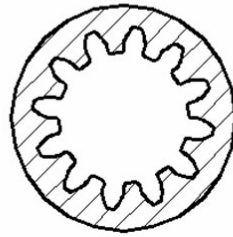
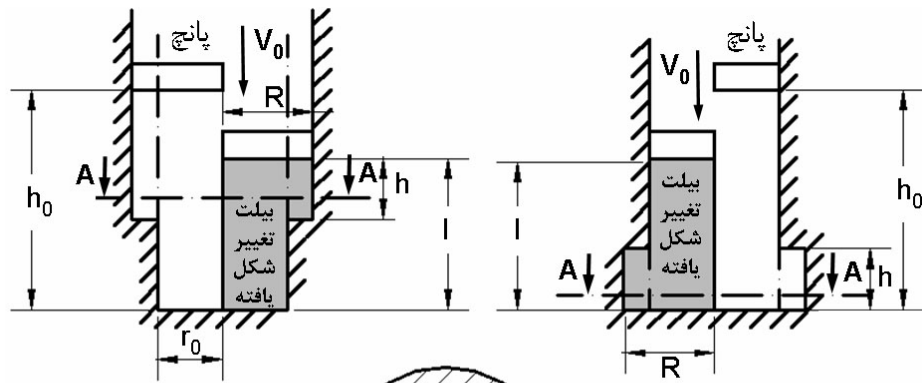
: m : M : N : r m/s : v_0 r : U_r

θ	: U_θ
z	: U_z
m^3	: V
N.m/s	: \dot{W}_i
N.m/s	: \dot{W}_s
N.m/s	: \dot{W}_f
	: z
1/s	: $\dot{\epsilon}$
rad	: θ
Pa	: σ_0

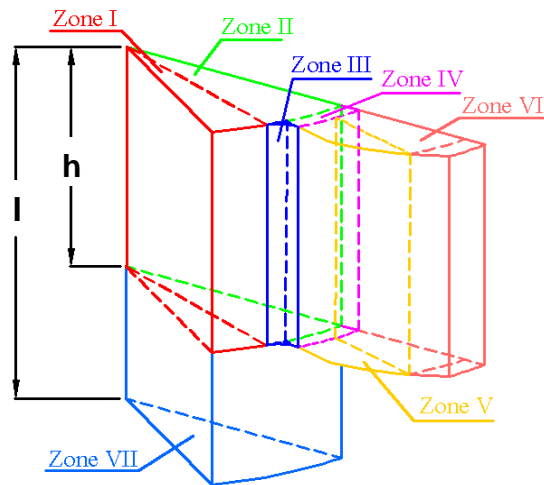
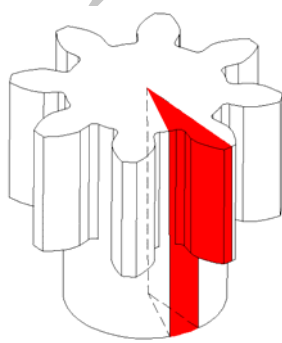
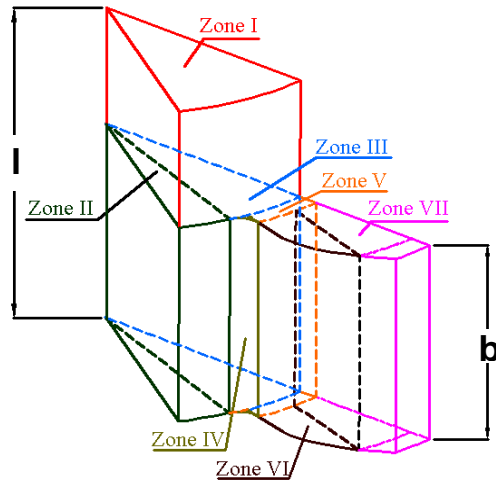
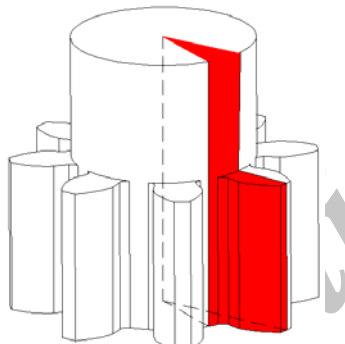
<p>Zone I: $0 \leq \theta \leq \alpha$ $0 \leq r \leq r_r$ $b \leq z \leq l$</p>	$U_r = 0$ $U_\theta = 0$ $U_z = -v_0$
<p>Zone II: $0 \leq \theta \leq \theta_1$ $0 \leq r \leq r_r$ $0 \leq z \leq b$</p>	$U_r = 0$ $U_\theta = \frac{v_0 \theta}{b} r$ $U_z = -\frac{v_0}{b} z$
<p>Zone III: $\theta_1 \leq \theta \leq \alpha$ $0 \leq r \leq r_r$ $0 \leq z \leq b$</p>	$U_r = \frac{v_0 r}{2b} \left(\frac{\alpha}{\alpha - \theta_1} \right)$ $U_\theta = \frac{v_0 \theta_1}{b} r \left(\frac{\alpha - \theta}{\alpha - \theta_1} \right)$ $U_z = -\frac{v_0}{b} z$
<p>Zone IV: $\theta_1 \leq \theta \leq \theta_s$ $r_r \leq r \leq r_b$ $0 \leq z \leq b$</p>	$U_r = \frac{v_0}{2b} \left(\frac{\alpha}{\alpha - \theta_1} \right) \frac{r_r^2}{r}$ $U_\theta = \frac{v_0}{2b} \left(\frac{\alpha}{\alpha - \theta_1} \right) \frac{r_r^2}{r} \left[\frac{r_b^2 - r^2}{\sqrt{-r^4 + [4(r_r + r_f)^2 - 2r_b^2] r^2 - r_b^4}} \right]$ $U_z = 0$

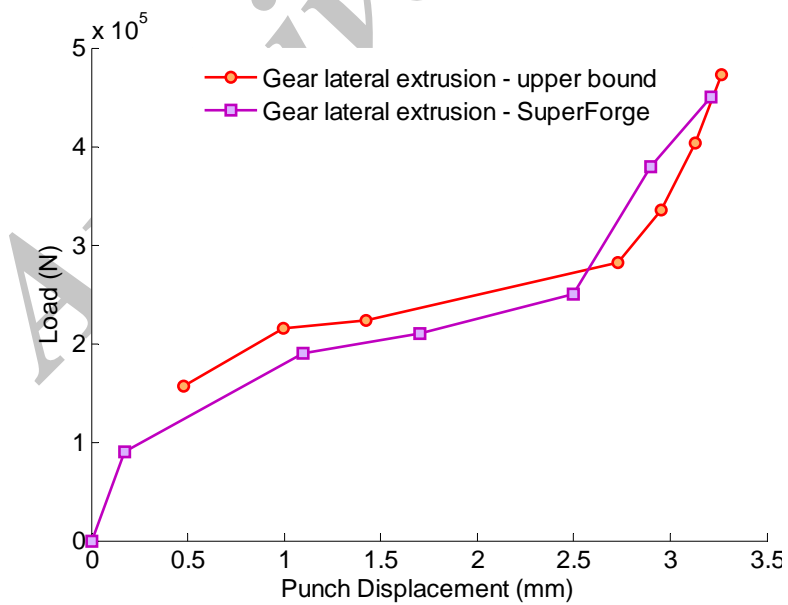
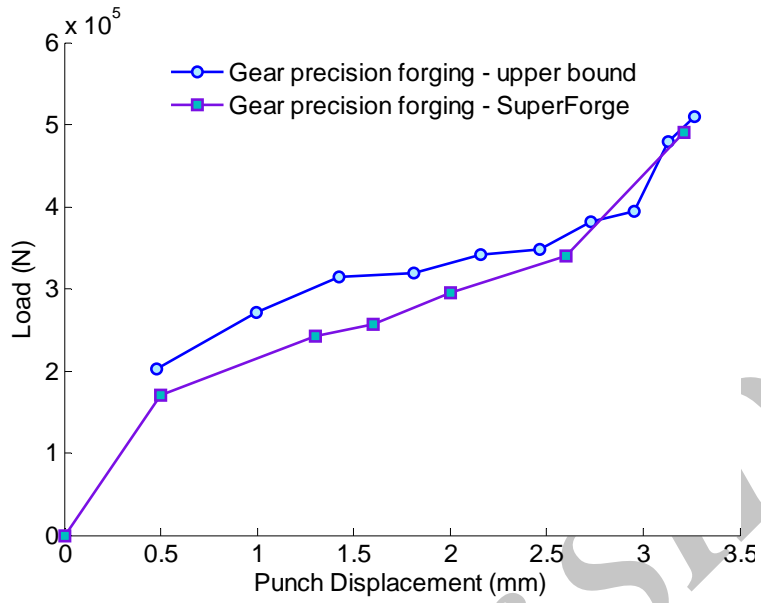
<p>Zone V: $\theta_s \leq \theta \leq \alpha$ $r_r \leq r \leq r_b$ $0 \leq z \leq b$</p>	$U_r = \frac{C_5}{r} + \frac{v_0}{4b} \left(\frac{\alpha}{\alpha - \theta_s} \right) \frac{r_r^2}{r} \tan^{-1} \left[\frac{-2r_b^4 + (-2r_b^2 + 8r_f r_r + 4r_f^2 + 4r_r^2) r^2}{2r_b^2 \sqrt{-r^4 + [4(r_r + r_f)^2 - 2r_b^2] r^2 - r_b^4}} \right]$ $- \frac{v_0}{4b} \left(\frac{\alpha}{\alpha - \theta_s} \right) \frac{r_r^2}{r} \tan^{-1} \left[\frac{r^2 + r_b^2 - 4r_f r_r - 2r_f^2 - 2r_r^2}{\sqrt{-r^4 + [4(r_r + r_f)^2 - 2r_b^2] r^2 - r_b^4}} \right]$ $U_\theta = \frac{v_0}{2b} \left(\frac{\alpha}{\alpha - \theta_1} \right) \frac{r_r^2}{r} \left[\frac{r_b^2 - r^2}{\sqrt{-r^4 + [4(r_r + r_f)^2 - 2r_b^2] r^2 - r_b^4}} \right] \left(\frac{\alpha - \theta}{\alpha - \theta_s} \right)$ $U_z = 0$
<p>Zone VI: $\theta_s \leq \theta \leq \text{inv}\phi_R$ $r_b \leq r \leq R$ $0 \leq z \leq b$</p>	$U_r = \frac{C_6}{r}$ $U_\theta = \frac{C_6}{r} \frac{\sqrt{r^2 - r_b^2}}{r_b}$ $U_z = 0$
<p>Zone VII: $\text{inv}\phi_R \leq \theta \leq \alpha$ $r_b \leq r \leq R$ $0 \leq z \leq b$</p>	$U_r = \frac{\sqrt{r^2 - r_b^2}}{r_b} \frac{C_6}{(\alpha - \text{inv}\phi_R) r} + \frac{C_6}{(\alpha - \text{inv}\phi_R) r} \tan^{-1} \left(\frac{r_b}{\sqrt{r^2 - r_b^2}} \right) + \frac{C_7}{r}$ $U_\theta = \frac{C_6}{r} \frac{\sqrt{r^2 - r_b^2}}{r_b} \left(\frac{\alpha - \theta}{\alpha - \text{inv}\phi_R} \right)$ $U_z = 0$
<p>Zone I: $0 \leq \theta \leq \theta_1$ $0 \leq r \leq r_r$ $1 - h \leq z \leq l$</p>	$U_r = 0$ $U_\theta = \frac{v_0 r}{h} \theta$ $U_z = -\frac{v_0}{h} z$
<p>Zone II: $\theta_1 \leq \theta \leq \alpha$ $0 \leq r \leq r_r$ $1 - h \leq z \leq l$</p>	$U_r = \frac{v_0 r}{2h} \left[1 + \frac{\theta_1}{(\alpha - \theta_1)} \right] + \frac{C_2}{r}$ $U_\theta = \frac{v_0 \theta_1}{h(\alpha - \theta_1)} r (\alpha - \theta)$ $U_z = -\frac{v_0}{h} z$
<p>Zone III: $\theta_1 \leq \theta \leq \theta_s$ $r_r \leq r \leq r_b$ $1 - h \leq z \leq l$</p>	$U_r = \frac{ur}{2h} + \frac{C_3}{r}$ $U_\theta = \left[\frac{ur}{2h} + \frac{C_3}{r} \right] \frac{r_b^2 - r^2}{\sqrt{-r^4 + (4(r_r + r_f)^2 - 2r_b^2) r^2 - r_b^4}}$ $U_z = -\frac{v_0}{h} z$

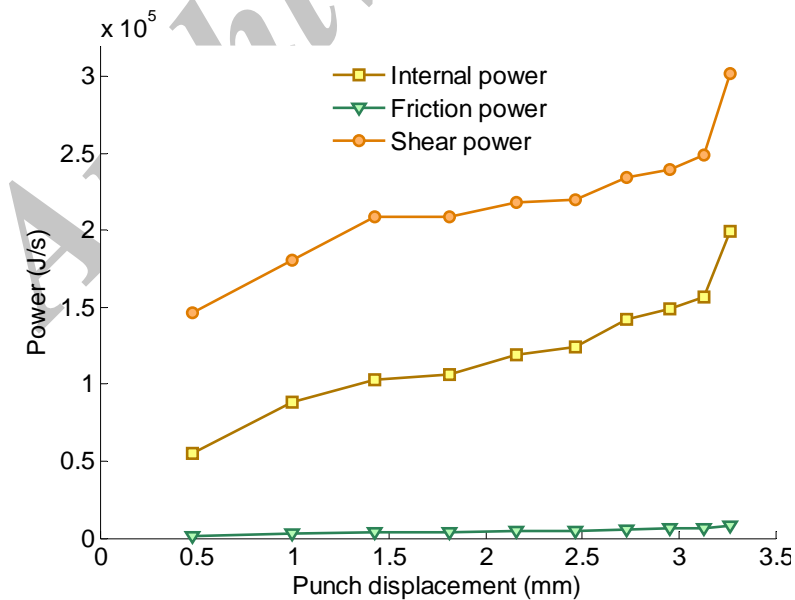
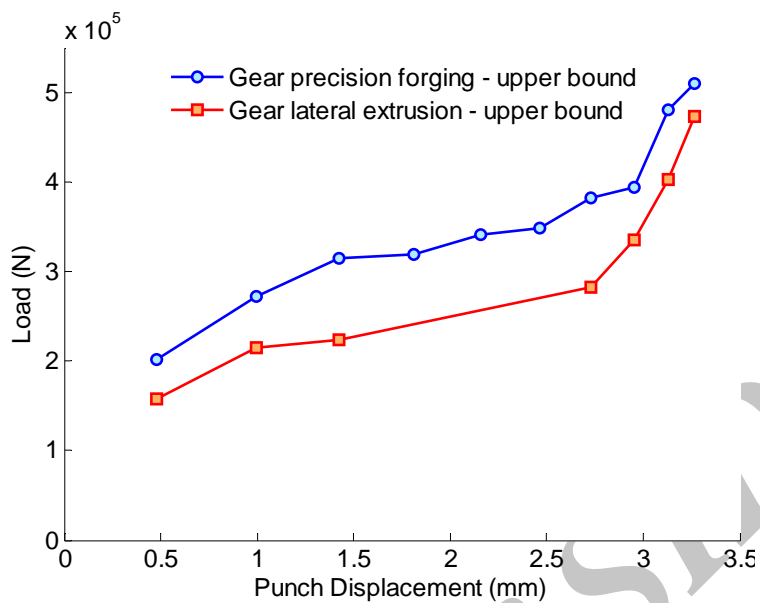
<p>Zone IV: $\theta_s \leq \theta \leq \alpha$ $r_r \leq r \leq r_b$ $1-h \leq z \leq l$</p>	$U_r = \frac{v_0}{4h(\alpha - \theta_s)} \frac{A}{r} + \left[-\frac{v_0(r_r + r_f)^2}{h} + \frac{v_0 r_b^2}{h} - C_3 \right] \frac{B}{2r(\alpha - \theta_s)}$ $+ \frac{C_3}{2r(\alpha - \theta_s)} D + \frac{v_0 r}{2h} + \frac{C_4}{r}$ $U_\theta = \left[\frac{v_0 r}{2h} + \frac{C_3}{r} \right] \left(\frac{\alpha - \theta}{\alpha - \theta_s} \right) \frac{r_b^2 - r^2}{\sqrt{-r^4 + (4(r_r + r_f)^2 - 2r_b^2) r^2 - r_b^4}}$ $U_z = -\frac{v_0}{h} z$
<p>Zone V: $\theta_s \leq \theta \leq \text{inv}\phi_R$ $r_b \leq r \leq R$ $1-h \leq z \leq l$</p>	$U_r = \left[\frac{v_0 r}{2h} + \frac{C_5}{r} \right]$ $U_\theta = \left[\frac{v_0 r}{2h} + \frac{C_5}{r} \right] \frac{\sqrt{r^2 - r_b^2}}{r_b}$ $U_z = -\frac{v_0}{h} z$
<p>Zone VI: $\text{inv}\phi_R \leq \theta \leq \alpha$ $r_b \leq r \leq R$ $1-h \leq z \leq l$</p>	$U_r = \left[\frac{v_0}{6hr} \frac{(r^2 - r_b^2)^{3/2}}{r_b} \right] \frac{1}{\alpha - (\theta_s + \text{inv}\phi_R)} + \left[\frac{C_5 \sqrt{r^2 - r_b^2}}{r r_b} \right] \frac{1}{\alpha - (\theta_s + \text{inv}\phi_R)}$ $+ \left[\frac{C_5}{r} \tan^{-1} \left(\frac{r_b}{\sqrt{r^2 - r_b^2}} \right) \right] \frac{1}{\alpha - (\theta_s + \text{inv}\phi_R)} + \frac{v_0 r}{2h} + \frac{C_6}{r}$ $U_\theta = \left(\frac{v_0 r}{2h} + \frac{C_5}{r} \right) \frac{\alpha - \theta_s}{\alpha - (\theta_s + \text{inv}\phi_R)} \frac{\sqrt{r^2 - r_b^2}}{r_b}$ $U_z = -\frac{v_0}{h} z$
<p>Zone VII: $0 \leq \theta \leq \alpha$ $0 \leq r \leq r_r$ $0 \leq z \leq 1-h$</p>	$U_r = 0$ $U_\theta = 0$ $U_z = 0$

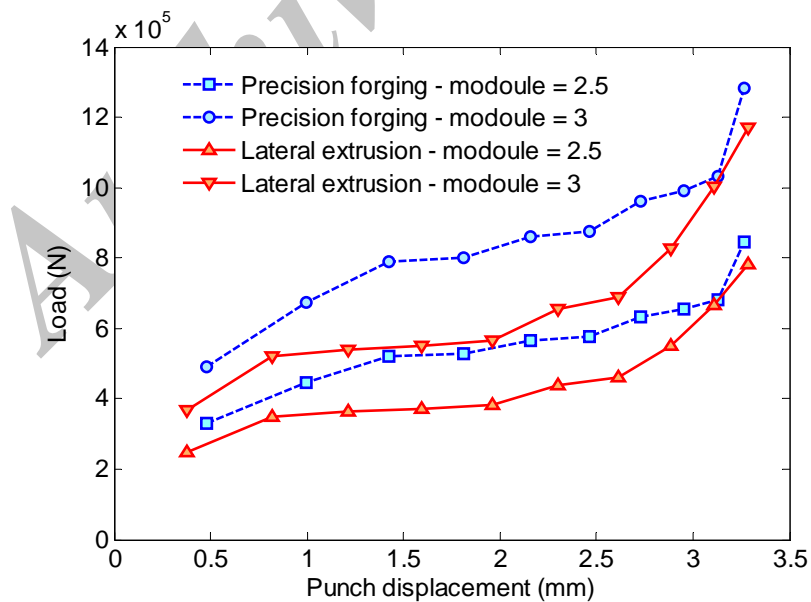
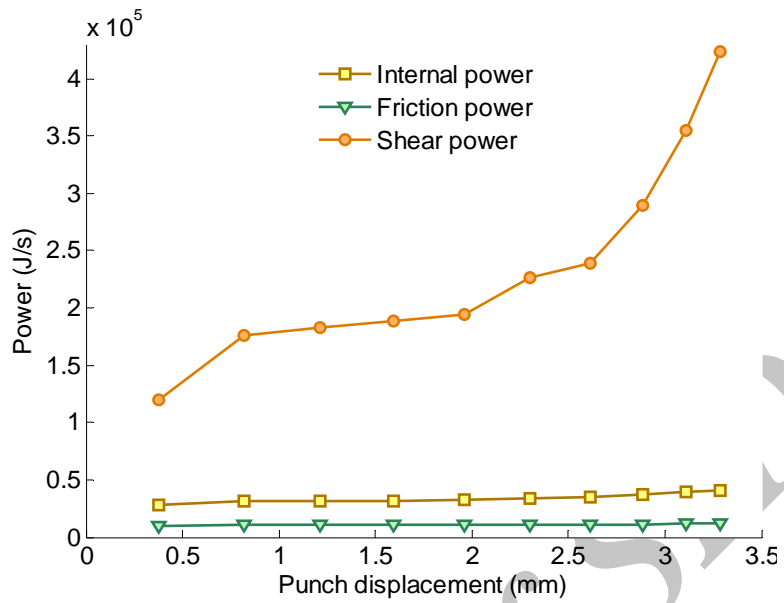


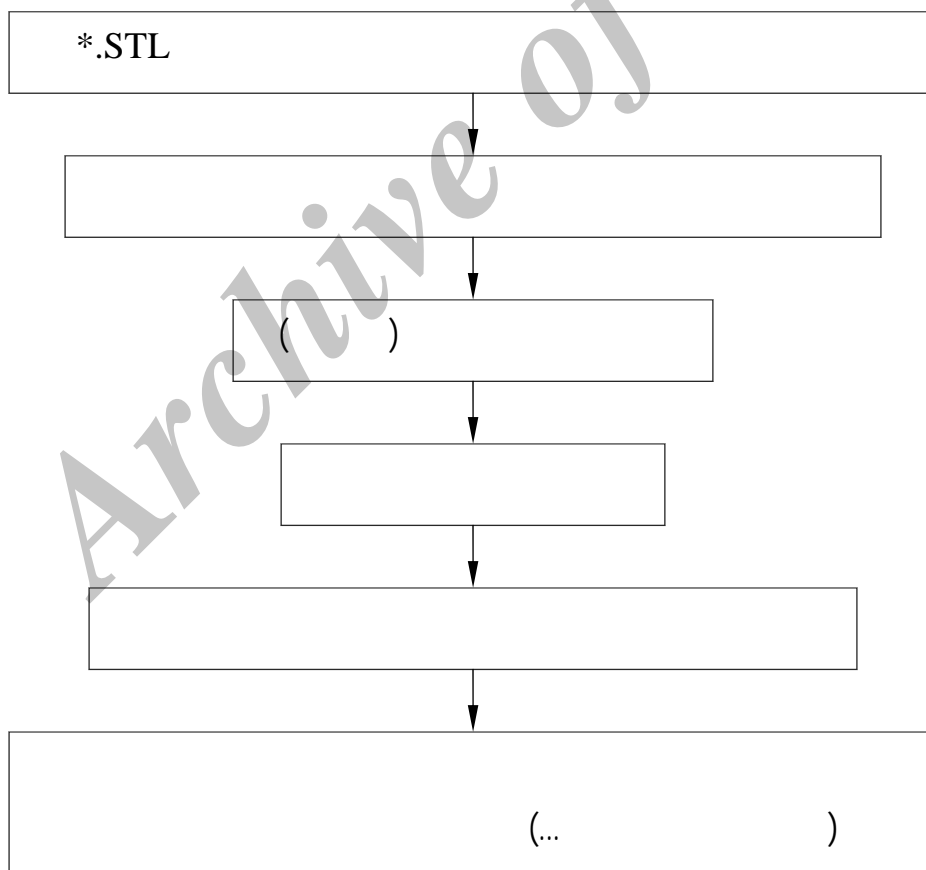
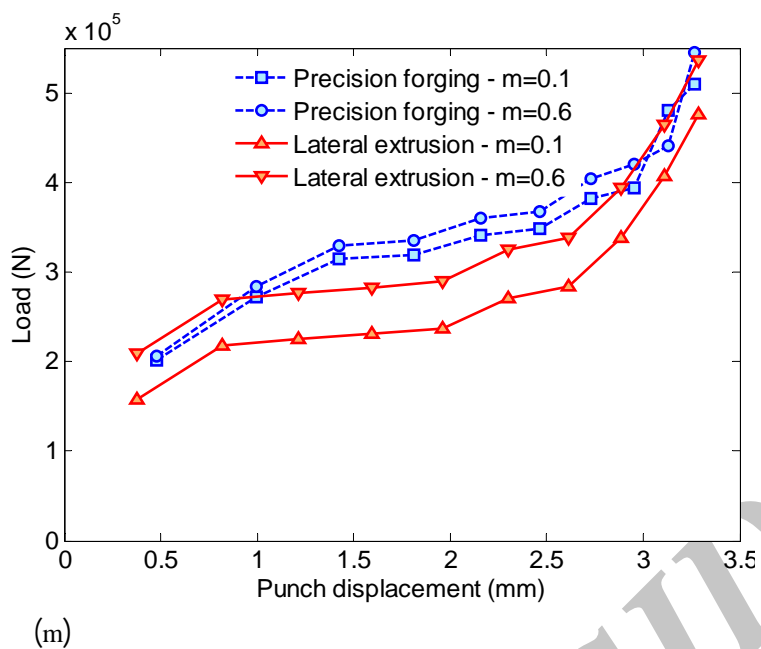
مقطع A-A











SuperForge

Abstract

Precision forging and lateral extrusion are important manufacturing procedure of gears. They have advantages of improved strength, good tolerance, saving billet material, dispensing with the cutting, etc. Upper bound analyses of spur gear shafts lateral extrusion and precision forging have been studied in this paper. The material of solid billet was assumed as rigid-plastic and the involute curve has been used to represent the sides of gear tooth. By means of upper bound analysis, load-displacement diagrams have been determined for lateral extrusion and precision forging. The gear shaft with N teeth was divided to $2N$ deformation units and a deformation unit has been sub-divided to seven deformation zones. Using the present model, various effects of forming parameter such as the friction factor and module upon the forming force have been analyzed. Finally, theoretical obtained load-displacement diagrams of lateral extrusion and precision forging have been compared with each other and have been compared with SuperForge results.

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