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THERMO CREEP TRANSITION STRESSES IN A THICK WALLED CYLINDER SUBJECTED TO INTERNAL PRESSURE BY FINITE DEFORMATION

TERMALNI PRELAZNI NAPONI OD PUZANJA U DEBELOZIDNOM CILINDRU POD UNUTRAŠNJIM PRITISKOM KONAČNOM DEFORMACIJOM

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Abstract

Creep stresses and strain rates have been obtained for a thick-walled circular cylinder made of compressible and incompressible material subjected to internal pressure and steady state temperature by using Seth's transition theory. It has been observed that the circumferential stress has maximum value at the external surface of the cylinder made of incompressible material as compared to compressible material, with effects of temperature reducing stresses at the external surface of the cylinder in comparison to pressure effects alone. Strain rates are found to be maximum at the internal surface of the cylinder of compressible material and they decrease with the radius. With the introduction of temperature effect, the creep rates have higher values at the internal surface but lesser values at the external surface as compared to a cylinder subjected to pressure only.

Izvod

Naponi usled puzanja i brzine deformacija su dobijeni za debelozidni kružni cilindar od stišljivog i od nestišljivog materijala, opterećen unutrašnjim pritiskom i ravnomernom temperaturom, primenom Setove teorije prelaznog naponskog stanja. Uočava se da obimski napon ima maksimalnu vrednost na spoljnoj površini cilindra od nestišljivog materijala, u poređenju sa cilindrom od stišljivog materijala, i sa uticajem temperature kojom se smanjuju naponi na spoljnoj površini cilindra u poređenju sa uticajem samo pritiska. Brzine deformisanja su maksimalne na unutrašnjoj površini cilindra od stišljivog materijala, i smanjuju se sa radijusom. Uvođenjem uticaja temperature, brzine puzanja su veće na unutrašnjoj površini, ali su manje na spoljnoj površini, u poređenju sa cilindrom pod uticajem samo pritiska.

INTRODUCTION

A thick-walled circular cylinder is widely used commonly either as pressure vessel intended for storage of industrial gases or a media transport of high pressurised fluids. Creep of the thick-walled cylinder under internal pressure has been discussed by many authors /1-5/. Rimrott /3/ analysed the above problem by considering large strain. This author made the following assumptions:

1. The volume of the material is constant, or

$$\dot{\varepsilon}_r + \dot{\varepsilon}_\theta + \dot{\varepsilon}_z = 0$$

2. The ratios of the principal shear strain rates to the principal shear stresses are equal, i.e.,

$$\frac{\dot{\varepsilon}_{\theta\theta} - \dot{\varepsilon}_{rr}}{\sigma_{\theta\theta} - \sigma_{rr}} = \frac{\dot{\varepsilon}_{rr} - \dot{\varepsilon}_{zz}}{\sigma_{rr} - \sigma_{zz}} = \frac{\dot{\varepsilon}_{zz} - \dot{\varepsilon}_{\theta\theta}}{\sigma_{zz} - \sigma_{\theta\theta}}$$

3. The axial strain rate is zero, i.e.,

$$\dot{\varepsilon}_z = 0$$

4. There is a significant stress versus rate of true strain relationship which coincides with the true stress versus creep rate relationship in simple tension, for example Norton's Law.

5. The creep deformation is infinitesimally small.

Seth's transition theory /6/ does not require any of these assumptions like a yield condition, incompressibility condition and thus poses and solves a more general problem from which cases pertaining to the above assumptions can be worked out. This theory utilises the concept of generalized strain measure which not only gives the well known strain measure but can also be used to find the stresses in plasticity and creep problems by determining the asymptotic solution at transition points of the governing equations defining the deformed field.. It has successfully been applied to a number of creep problems /8-12, 16-23/.

Seth /7/ has defined the generalized principal strain measure as:

$$e_{ii} = \int_0^{e_{ii}^A} \left[1 - 2e_{ii}^A\right]^{\frac{n}{2}-1} de_{ii}^A = \frac{1}{n}\left[1 - \left(1 - 2e_{ii}^A\right)^{\frac{n}{2}}\right], \ (i = 1,2,3) \quad (1)$$

where 'n' is the measure.

In this paper, the problem of creep stresses and strain rates for a thick-walled circular cylinder subjected to internal pressure and steady state temperature by using Seth's transition theory is investigated. Not only is the solution for compressible material obtained, but also is shown, as a particular case that assumptions (2) and (3) stated above come out from the solution itself.

GOVERNING EQUATIONS

We consider a thick-walled circular cylinder of internal radius a and external radius b, respectively, subjected to internal pressure p and steady state temperature Θ on the inner surface $r = a$. The displacement components in cylindrical polar co-ordinates are given by /7/:

$$u = r(1-\beta);\quad v = 0;\quad w = dz \tag{2}$$

where β is function of $r = \frac{d}{dr}(\log R) = \frac{1}{r\left[1-(P+1)^n\right]}\left\{nP(2-c)-c\left[1-(P+1)^n\right]+\frac{nc\xi\overline{\theta_0}}{2\mu\beta^n}\right\}$ only, and d is a constant.

The strain components for finitesimal deformation are given by /7/:

$$e_{rr}^A = \frac{1}{2}\left[1-\left(r\beta'+\beta\right)^2\right],$$

$$e_{\theta\theta}^A = \frac{1}{2}\left[1-\beta^2\right],$$

$$e_{zz}^A = \frac{1}{2}\left[1-\left(1-d\right)^2\right],$$

$$e_{r\theta}^A = e_{\theta z}^A = e_{zr}^A = 0 \tag{3}$$

where $\beta' = d\beta/dr$ and the meaning of the superscript "A" is for Almansi.

Substituting Eqs.(3) in Eq.(1), the generalized components of strain are:

$$e_{rr} = \frac{1}{n}\left[1-\left(r\beta'+\beta\right)^n\right],$$

$$e_{\theta\theta} = \frac{1}{n}\left[1-\beta^n\right],$$

$$e_{zz} = \frac{1}{n}\left[1-(1-d)^n\right],$$

$$e_{r\theta} = e_{\theta z} = e_{zr} = 0 \tag{4}$$

The stress-strain relations for isotropic material are given by /13/,

$$T_{ij} = \lambda\delta_{ij}I_1 + 2\mu e_{ij} - \xi\theta\delta_{ij},\quad (i,j=1,2,3) \tag{5}$$

where T_{ij} are the stress components, λ and μ are Lame's constants, $I_1 = e_{kk}$ is the first strain invariant, δ_{ij} is Kronecker's delta, $\xi = \alpha(3\lambda + 2\mu)$, α being the coefficient of thermal expansion, and θ is the temperature. Further, θ has to satisfy:

$$\nabla^2\theta = 0 \tag{6}$$

Substituting the strain components from Eq.(4) in Eq.(5), the stresses are obtained as:

$$T_{rr} = \lambda I_1 + \frac{2\mu}{n}\left[1-\left(r\beta'+\beta\right)^n\right]-\xi\theta,$$

$$T_{\theta\theta} = \lambda I_1 + \frac{2\mu}{n}\left[1-\beta^n\right]-\xi\theta,$$

$$T_{zz} = \lambda I_1 + \frac{2\mu}{n}\left[1-\left(1-d\right)^n\right]-\xi\theta,$$

$$T_{r\theta} = T_{\theta z} = T_{zr} = 0 \tag{7}$$

where $I_1 = \frac{1}{n}\left[3-\left(r\beta'+\beta\right)^n-\beta^n-\left(1-d\right)^n\right]$ and $\beta' = d\beta/dr$.

The temperature field satisfying Eq.(6) and $\theta = \theta_0$ at $r = a$, $\theta = 0$ at $r = b$, where θ_0 is constant, is given by:

$$\theta = \frac{\theta_0\log(r/b)}{\log(a/b)}. \tag{8}$$

The equations of equilibrium are all satisfied except:

$$\frac{dT_{rr}}{dr} + \frac{T_{rr}-T_{\theta\theta}}{r} = 0. \tag{9}$$

Using Eqs.(7) in Eq.(9), one gets a non-linear differential equation in β as:

$$nP(P-1)^{n-1}\beta\frac{dP}{d\beta} + nP(P+1)^n + (1-C)nP - \left[1-(P+1)^n\right]C + \frac{nc\xi\overline{\theta_0}}{2\mu\beta^n} = 0 \tag{10}$$

where C is the compressibility factor of the material in terms of Lame's constant, and the other variables are given by: $c = 2\mu/\lambda + 2\mu$, $r\beta' = \beta P$, and $\overline{\theta_0} = \theta_0/\log(a/b)$.

Transition points of β in Eq.(10) are $P \to \pm\infty$, -1.

The boundary conditions require that:

$$T_{rr} = -p \text{ at } r = a$$
$$T_{rr} = 0 \text{ at } r = b \tag{11}$$

The resultant force transmitted by the wall in axial direction is equal to $\pi a^2 p$, that is

$$2\pi\int_a^b rT_{zz}\,dr = \pi a^2 p. \tag{12}$$

TRANSITION THROUGH THE PRINCIPAL STRESS DIFFERENCE

It has been shown that the asymptotic solution through the principal stress difference /8-12, 16-23/ at the transition point $P \to -1$, gives the creep stresses. We define the transition function R as:

$$R = T_{rr} - T_{\theta\theta} = \left(\frac{2\mu}{n}\right)\beta^n\left[1-(1-P)^n\right] \tag{13}$$

Taking the logarithmic differential of Eq.(13) with respect to r and using Eq.(10), one gets:

$$\frac{d}{dr}(\log R) = \frac{1}{r\left[1-(P+1)^n\right]}\times \left\{nP(2-c)-c\left[1-(P+1)^n\right]+\frac{nc\xi\overline{\theta_0}}{2\mu\beta^n}\right\} \tag{14}$$

Taking the asymptotic value of Eq.(14) at $P \to -1$, and after integration:

$$R = T_{rr} - T_{\theta\theta} = A r^{-2n+c(n-1)} \exp f \qquad (15)$$

where A is a constant of integration, which can be determined by boundary conditions and

$$f = \frac{\alpha \bar{\theta}_0 (3-2c) r^n}{D^n} .$$

The asymptotic value of β as $P \to -1$ is D/r; D being a constant.

By substituting Eq.(15) in Eq.(9), one gets:

$$T_{rr} = -A \int F dr + B \qquad (16)$$

where $F = r^{-2n+c(n-1)-1} \exp f$ and B is a constant of integration, which can be determined by boundary conditions.

Constants A and B are obtained by using boundary conditions given by Eq.(11) in Eq.(16) as:

$$A = \frac{-p}{\int_a^b F dr} \quad \text{and} \quad B = A \int F dr \quad \text{at } r = b.$$

By substituting the values of A and B into Eq.(16):

$$T_{rr} = -p \frac{\int_r^b F dr}{\int_a^b F dr} \qquad (17)$$

The value of $T_{\theta\theta}$ and T_{zz} are obtained from Eqs.(15) and (7) respectively as:

$$T_{\theta\theta} = T_{rr} + \frac{prF}{\int_a^b F dr} \qquad (18)$$

$$T_{zz} = \left(\frac{1-c}{2-c}\right)(T_{rr} + T_{\theta\theta}) + E e_{zz} - E\alpha\theta \qquad (19)$$

where $E = \left[\frac{3-2c}{2-c}\right] 2\mu$.

The term e_{zz} is obtained by using Eq.(19) in Eq.(12) as:

$$e_{zz} = \frac{\dfrac{ca^2 p}{(2-c)} + E\alpha\bar{\theta}_0 \left[a^2 \log(b/a) + \dfrac{\left(a^2 - b^2\right)}{2} \right]}{\left(b^2 - a^2\right)} \qquad (20)$$

Eqs.(17)–(19) give the thermal creep stresses for a thick-walled circular cylinder under internal pressure.

By introducing the following non-dimensional components as:

$$R = \frac{r}{b},\ R_0 = \frac{a}{b},\ \sigma_r = \frac{T_{rr}}{p},\ \sigma_\theta = \frac{T_{\theta\theta}}{p},\ \sigma_z = \frac{T_{zz}}{p} \text{ and } E_1 = \frac{E}{p},$$

Eqs.(17)–(20) in non-dimensional from become:

$$\sigma_r = -\frac{\int_R^1 F_1 dr}{\int_{R_0}^1 F_1 dr} \qquad (21)$$

$$\sigma_\theta = \sigma_r + \frac{R^{-2n+c(n-1)} \exp f_1}{\int_{R_0}^1 F_1 dr} \qquad (22)$$

$$\sigma_z = \left(\frac{1-c}{2-c}\right)(\sigma_r + \sigma_\theta) + E_1 e_{zz} - E_1 \alpha\theta \qquad (23)$$

$$\text{where } E_1 e_{zz} = \frac{\dfrac{cR_0^2}{(2-c)} + E_1 \alpha\bar{\theta}_0 \left[R_0^2 \log(1/R_0) + \dfrac{(R_0^2 - 1)}{2} \right]}{(1 - R_0^2)} \qquad (24)$$

and $F_1 = r^{-2n+c(n-1)-1} \exp f_1$, and $f_1 = \dfrac{\alpha\bar{\theta}_0 (3-2c)(bR)^n}{D^n}$.

For incompressible material ($c \to 0$) Eqs.(21) to (24) become:

$$\sigma_r = -\frac{\int_R^1 F_2 dr}{\int_{R_0}^1 F_2 dr} \qquad (25)$$

$$\sigma_\theta = \sigma_r + \frac{R^{-2n} \exp f_2}{\int_{R_0}^1 F_2 dr} \qquad (26)$$

$$\sigma_z = \frac{(\sigma_r + \sigma_\theta)}{2} + E_1 e_{zz} - E_1 \alpha\theta \qquad (27)$$

$$\text{where} \quad e_{zz} = \frac{\alpha\bar{\theta}_0 \left[R_0^2 \log(1/R_0) + \dfrac{(R_0^2 - 1)}{2} \right]}{(1 - R_0^2)} \qquad (28)$$

and $F_2 = r^{-2n-1} \exp f_2$, and $f_2 = \dfrac{3\alpha\bar{\theta}_0 (bR)^n}{D^n}$.

Particular case:

When there is no thermal effect ($\theta_0 = 0$), creep stresses from Eq.(21) to (23) become:

$$\sigma_r = -\frac{\left[R^{-2n+c(n-1)} - 1\right]}{\left[R_0^{-2n+c(n-1)} - 1\right]} \qquad (29)$$

$$\sigma_\theta = \sigma_r + \frac{R^{-2n+c(n-1)}\left(-2n + c(n-1)\right)}{\left[R_0^{-2n+c(n-1)} - 1\right]} \qquad (30)$$

$$\sigma_z = \left(\frac{1-c}{2-c}\right)(\sigma_r + \sigma_\theta) + E_1 e_{zz} \qquad (31)$$

$$\text{where} \quad E_1 e_{zz} = \frac{cR_0^2}{(2-c)(1-R_0^2)} \qquad (32)$$

These equations are the same as obtained by Gupta, /10/.

For incompressible material ($c \to 0$) Eqs.(29) to (31) become:

$$\sigma_r = -\frac{\left[R^{-2n} - 1\right]}{\left[R_0^{-2n} - 1\right]} \qquad (33)$$

$$\sigma_\theta = \sigma_r - \frac{2nR^{-2n}}{\left[R_0^{-2n} - 1\right]} \tag{34}$$

$$\sigma_z = \frac{(\sigma_r + \sigma_\theta)}{2} \tag{35}$$

These equations are the same as obtained by Finnie & Heller /1/, and Odqist /14/.

Strain Rates:

When the creep sets in, the strains should be replaced by strain rates. The stress-strain relations can be written as:

$$\dot{e}_{ij} = \frac{1+\nu}{E} T_{ij} - \frac{\nu}{E}\delta_{ij} T + \alpha\theta \tag{36}$$

where $\dot{e}_{ij}$ is the strain rate tensor with respect to flow parameter t, $T = T_{11} + T_{22} + T_{33}$, and $\nu = 1 - c/2 - c$.

By differentiating Eq.(3) with respect to time t, one gets:

$$\dot{e}_{\theta\theta} = -\beta^{n-1}\dot{\beta} \tag{37}$$

For SWAINGER measure ($n = 1$), from Eq.(37) it follows:

$$\dot{\varepsilon}_{\theta\theta} = \dot{\beta} \tag{38}$$

The transition value of Eq.(13) as $P \to -1$ gives

$$\beta = \left[\frac{n(3-2c)}{(2-c)}\right]^{\frac{1}{n}} (T_{rr} - T_{\theta\theta})^{\frac{1}{n}} . \tag{39}$$

By substituting Eqs.(37), (38) and (39) into Eq.(36), one gets:

$$\dot{\varepsilon}_{rr} = \frac{1}{E_1}\left[\frac{n(\sigma_r - \sigma_\theta)(3-2c)}{E_1(2-c)}\right]^{\frac{1}{n}-1}\left[\sigma_r - \nu(\sigma_\theta + \sigma_z) + \alpha\theta E_1\right],$$

$$\dot{\varepsilon}_{\theta\theta} = \frac{1}{E_1}\left[\frac{n(\sigma_r - \sigma_\theta)(3-2c)}{E_1(2-c)}\right]^{\frac{1}{n}-1}\left[\sigma_\theta - \nu(\sigma_r + \sigma_z) + \alpha\theta E_1\right], \tag{40}$$

$$\dot{\varepsilon}_{zz} = \frac{1}{E_1}\left[\frac{n(\sigma_r - \sigma_\theta)(3-2c)}{E_1(2-c)}\right]^{\frac{1}{n}-1}\left[\sigma_z - \nu(\sigma_r + \sigma_\theta) + \alpha\theta E_1\right]$$

where $\theta = \theta_0 \log R / \log R_0$.

From Eqs.(40), one gets:

$$\frac{\dot{\varepsilon}_{\theta\theta} - \dot{\varepsilon}_{rr}}{\sigma_{\theta\theta} - \sigma_{rr}} = \frac{\dot{\varepsilon}_{rr} - \dot{\varepsilon}_{zz}}{\sigma_{rr} - \sigma_{zz}} = \frac{\dot{\varepsilon}_{zz} - \dot{\varepsilon}_{\theta\theta}}{\sigma_{zz} - \sigma_{\theta\theta}} \tag{41}$$

For incompressible material ($c \to 1/2$) without thermal effects, the creep strain rates Eq.(40) using Eq.(35) become:

$$\dot{\varepsilon}_{rr} = -\left(\frac{1}{E_1}\right)^{\frac{1}{n}} (-n\sqrt{3})^{\frac{1}{n}-1}\left(\frac{\sqrt{3}}{2}\right)^{\frac{1}{n}+1} (\sigma_r - \sigma_\theta)^{\frac{1}{n}}$$

$$\dot{\varepsilon}_{\theta\theta} = -\left(\frac{1}{E_1}\right)^{\frac{1}{n}} (-n\sqrt{3})^{\frac{1}{n}-1}\left(\frac{\sqrt{3}}{2}\right)^{\frac{1}{n}+1} (\sigma_\theta - \sigma_r)^{\frac{1}{n}} \tag{42}$$

$$\dot{\varepsilon}_{zz} = 0 .$$

These constitutive Eqs.(42) are same as obtained by Odquist /14/ provided we put $E_1 = (-n\sqrt{3})^{n-1} = \sigma_c$ and $n = 1/N$.

It has been shown in Eqs.(41) and (42) that the assumptions (2) and (3) stated above come out from the solution itself, whereas these were assumed by the author /1-5, 14/ prior to the solution.

RESULTS AND DISCUSSION

For calculating stresses, strain-rates distribution based on the above analysis, the following values have been taken: $n = 1, 1/3, 1/7$ (i.e. $N = 1, 3, 7$); $c = 0.75, 0.25, 0.00$; $\alpha = 5.0 \times 10^{-5}$ degF^{-1} (for Methyl Methacrylate) /15/; $\theta_0 = 0$ and 700°F; $\theta_1 = a\theta_0 = 0.00$ and 0.035; and $D = 1$.

In classical theory measure N is equal to $1/n$. Definite integrals in Eqs.(21)–(23) have been solved by using Simpson's rule.

Curves have been drawn in Figs. 1 and 2 between stresses σ_r, σ_θ, σ_z and radii ratio $R = r/b$ for Methyl Methacrylate material /15/ with and without steady state temperature. For $n = 1/7$ (or $N = 7$), it can be seen that the circumferential stress is maximum at the external surface of a cylinder made of incompressible material as compared to that of compressible material. For measure $n = 1/3$ (or $N = 3$) even though the circumferential stress has maximum value at the external surface, yet it has lesser values as compared to measure $n = 1/7$ or ($N = 7$). It has been seen that the introduction of steady state temperature reduces the stresses at the outer surface. For measure $n = 1$, it gives elastic stress distribution.

In Figs. 3(a, b and c), curves are drawn for creep strain rates along the radius for measure $n = 1/3$ (or $N = 3$) and $E_1 = E/p = 0.1$, 1.0 and 1.5 respectively. It has been observed that for a thick-walled cylinder made of compressible material $E_1 < 0$ (i.e. Young's Modulus of the material is less than the pressure applied) the creep rates have larger values at the internal surface as compared to $E_1 \geq 1.0$. These values further increase at the internal surface as n decrease ($n = 1/7$) or N increases ($N = 7$) and $E_1 < 1.0$ (see Fig. 4(a)). With the introduction of the effect of temperature, the creep rates at the internal surface have much higher values for $n = 1/7$ as compared to $n = 1/3$. It means that a thick-walled cylinder made of compressible material subjected to both pressure and temperature has large creep rates at the internal surface for measure $n = 1/7$ (or $N = 7$) and $E_1 < 1.0$ as compared to $n = 1/3$ (or $N = 3$), and the cylinder made of incompressible material.

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Nomenclature

a, b – internal and external radii of the disc, (m)
T_{ij}, e_{ij} – stress (kg·m^{-1}·s^{-2}), strain rate tensors
c – compressibility factor (-)
ε_{ij} – Swainger strain components (-)
u, v, w – displacement components (m)
ν – Poisson's ratio (-)

Greek letters

θ – temperature (°F)

σ_r – radial stress component (T_{rr}/p) (-)

σ_θ – circumferential stress component ($T_{\theta\theta}/p$) (-)

σ_z – axial stress component (T_{zz}/p) (-)

$R = r/b$, $R_0 = a/b$ (radii ratio) (-).

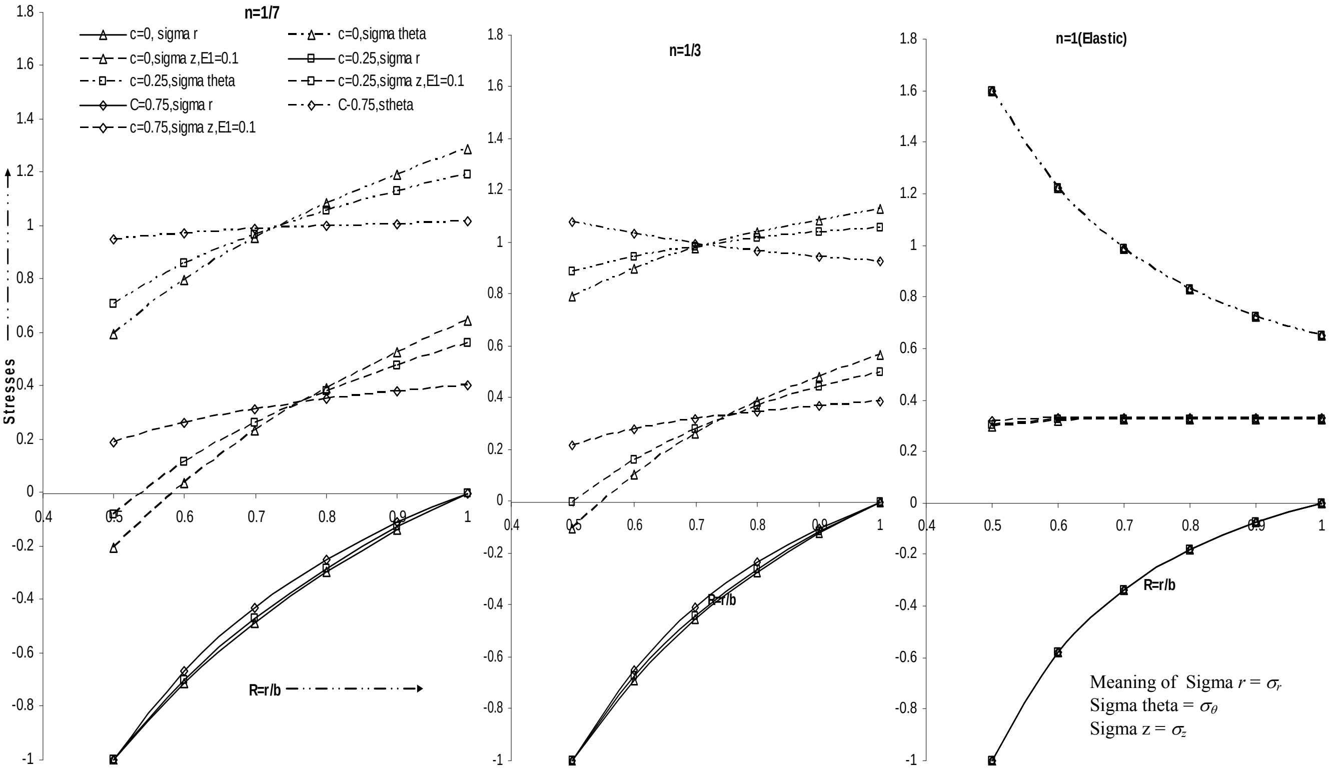

Figure 1. Creep stresses for a thick-walled circular cylinder subjected to internal pressure along radius $R = r/b$ under steady state temperature.
Slika 1. Napon puzanja kod debelozidog kružnog cilindra pod unutrašnjim pritiskom duž radijusa $R = r/b$ sa ravnomernom temperaturom

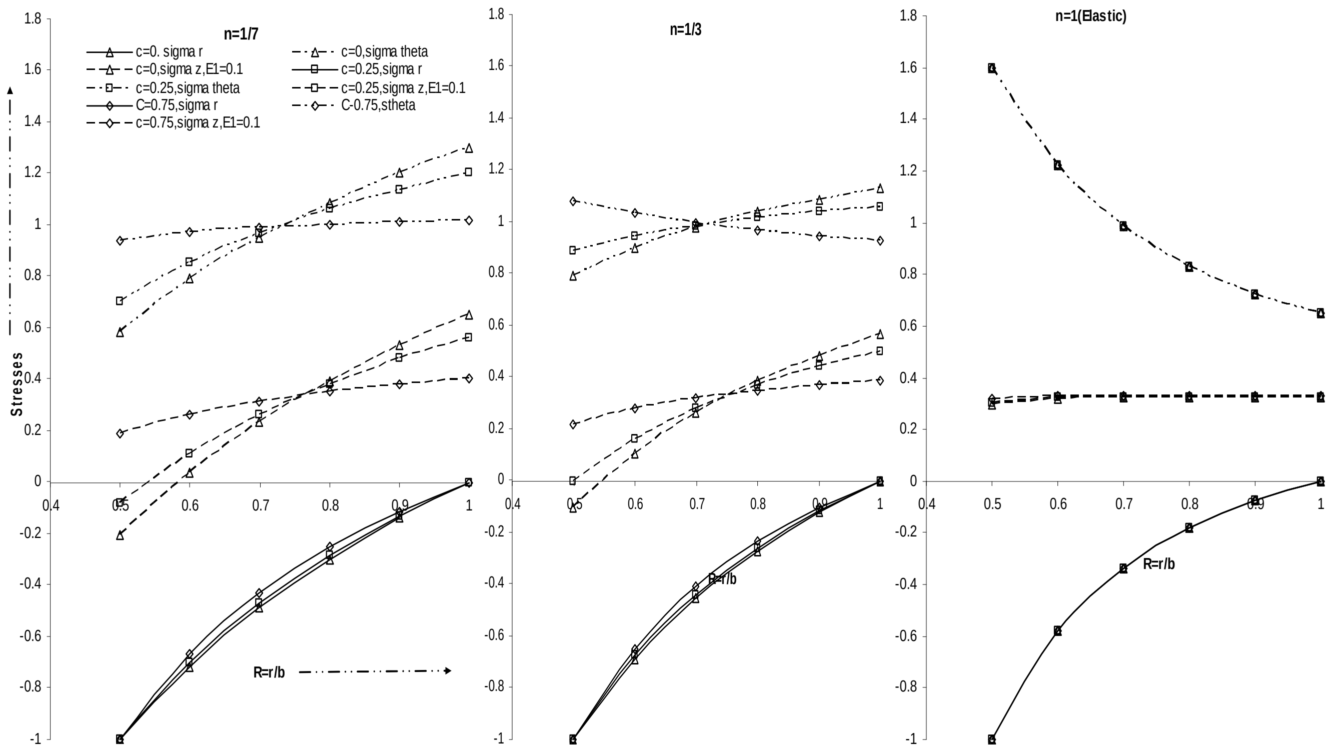

Figure 2. Creep stresses for a thick-walled circular cylinder subjected to internal pressure along radius $R = r/b$.
Slika 2. Naponi puzanja kod debelozidnog kružnog cilindra pod unutrašnjim pritiskom duž radijusa $R = r/b$

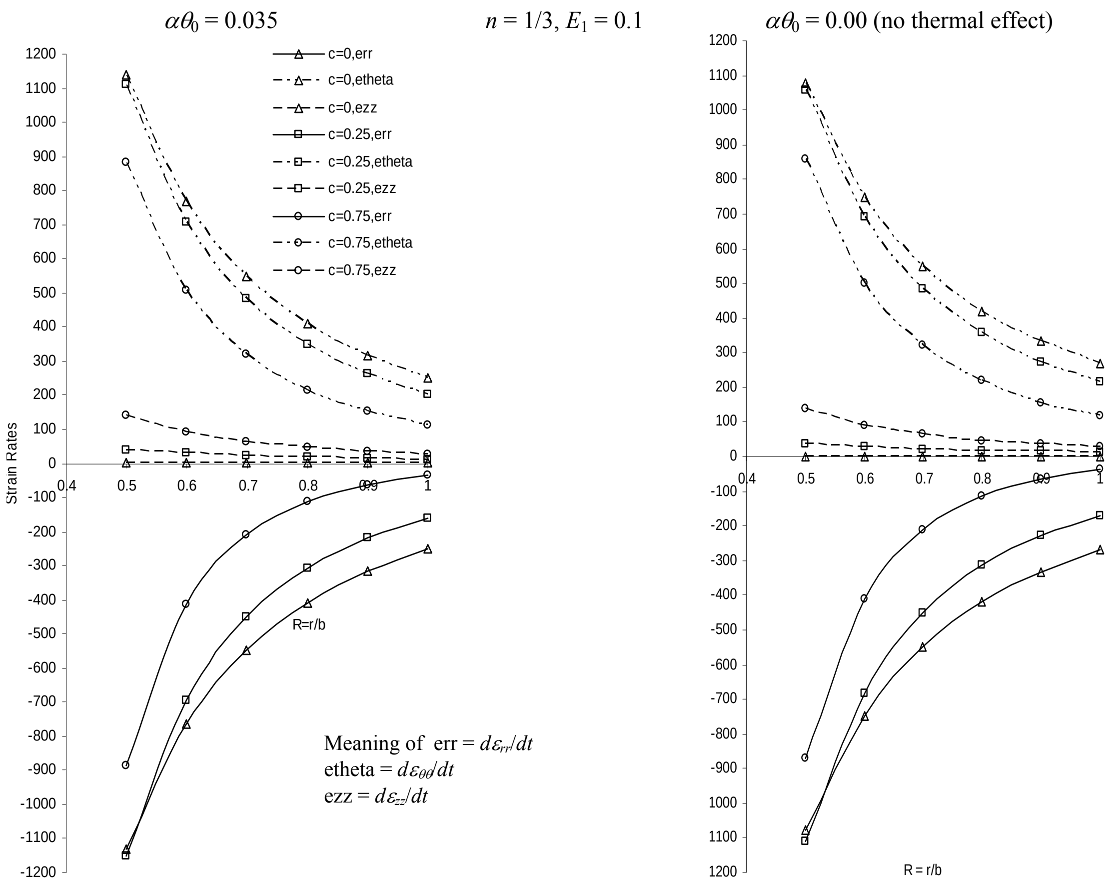

Figure 3(a). Strain rate distribution for a thick-walled circular cylinder subjected to internal pressure for $n = 1/3$ and $E_1 = 0.1$.
Slika 3(a). Raspodela brzine deformacija kod debelozidnog kružnog cilindra pod unutrašnjim pritiskom za $n = 1/3$ i $E_1 = 0,1$

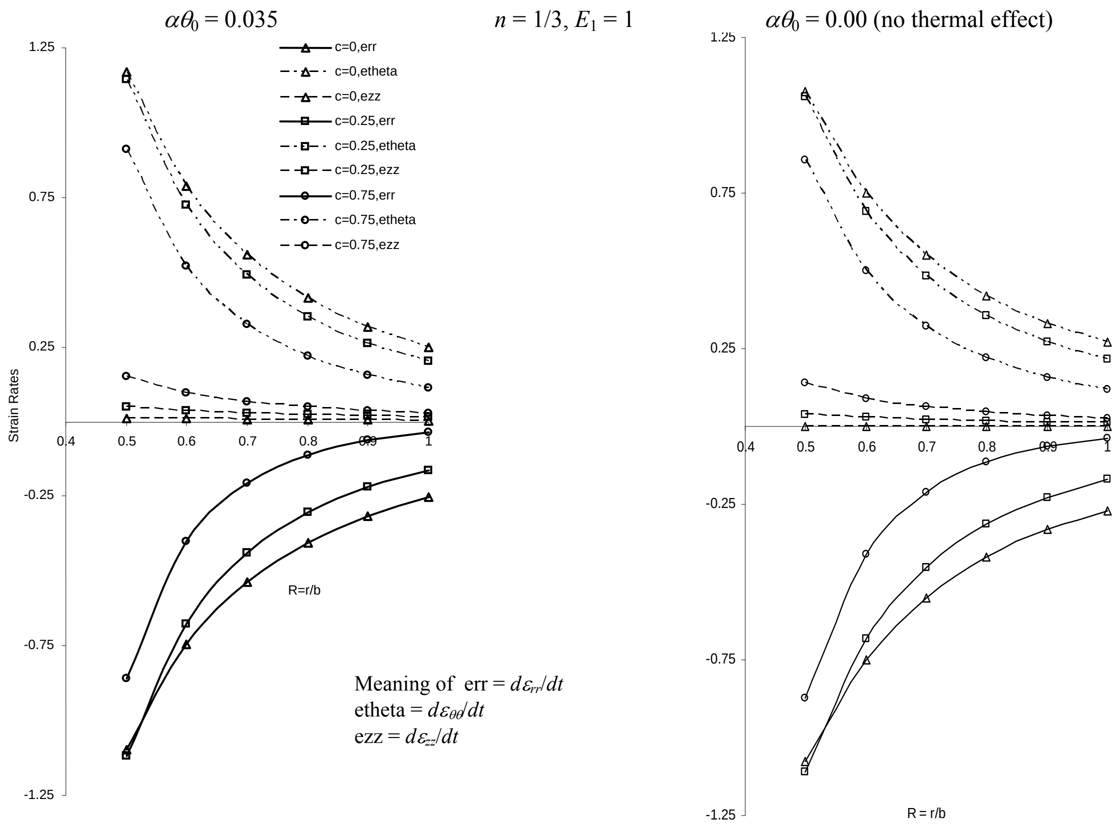

Figure 3(b). Strain rate distribution for a thick-walled circular cylinder subjected to internal pressure for $n = 1/3$ and $E_1 = 1$.
Slika 3(b). Raspodela brzine deformacija kod debelozidnog kružnog cilindra pod unutrašnjim pritiskom za $n = 1/3$ i $E_1 = 1$

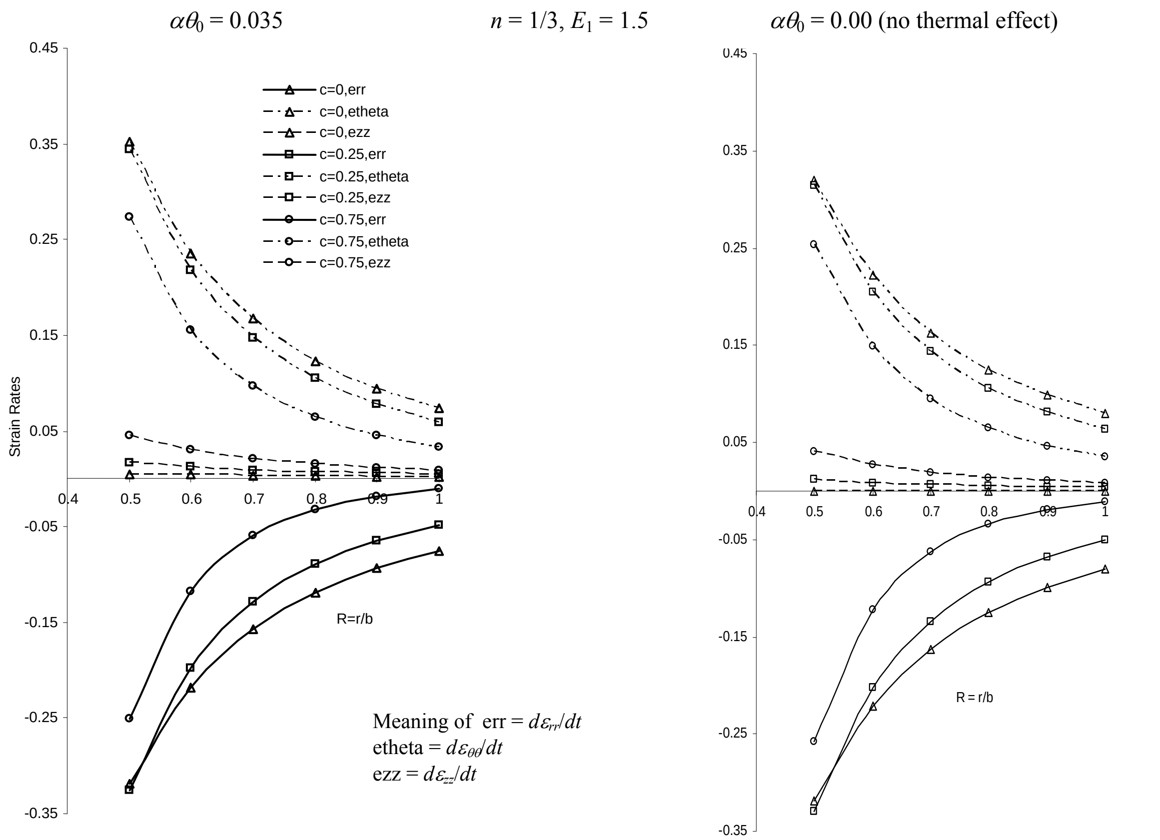

Figure 3(c). Strain rate distribution for a thick-walled circular cylinder subjected to internal pressure for $n = 1/3$ and $E_1 = 1.5$.
Slika 3(c). Raspodela brzine deformacija kod debelozidnog kružnog cilindra pod unutrašnjim pritiskom za $n = 1/3$ i $E_1 = 1,5$

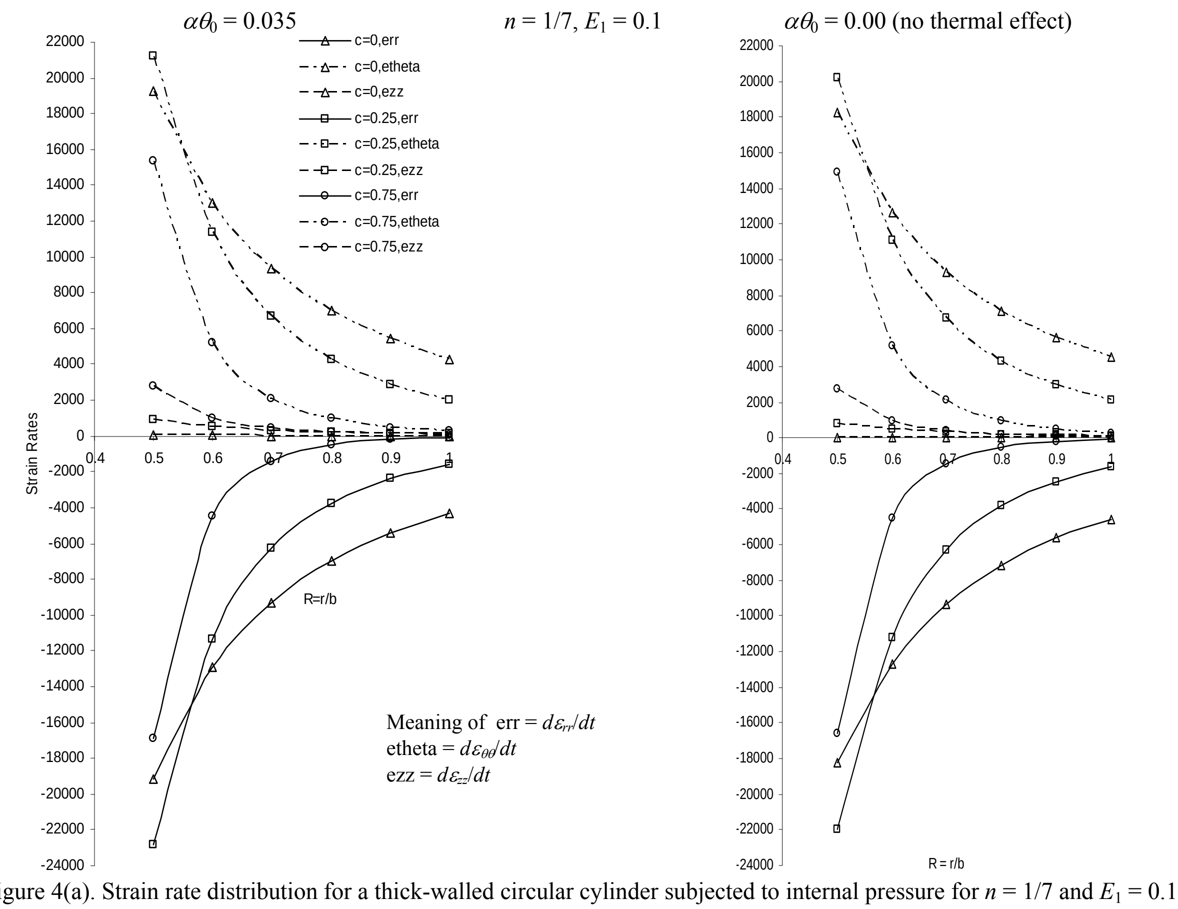

Figure 4(a). Strain rate distribution for a thick-walled circular cylinder subjected to internal pressure for $n = 1/7$ and $E_1 = 0.1$.
Slika 4(a). Raspodela brzine deformacija kod debelozidnog kružnog cilindra pod unutrašnjim pritiskom za $n = 1/7$ i $E_1 = 0,1$

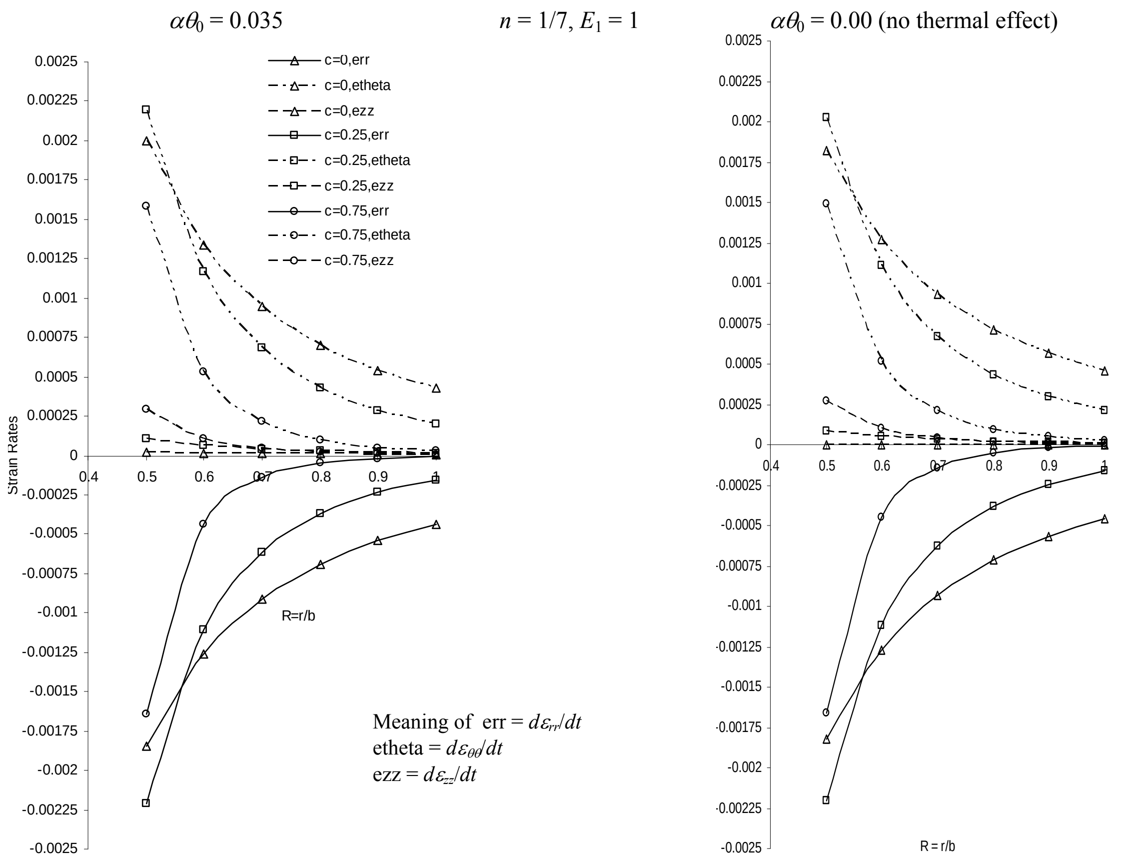

Figure 4(b). Strain rate distribution for a thick-walled circular cylinder subjected to internal pressure for $n = 1/7$ and $E_1 = 1$.
Slika 4(b). Raspodela brzine deformacija kod debelozidnog kružnog cilindra pod unutrašnjim pritiskom za $n = 1/7$ i $E_1 = 1$

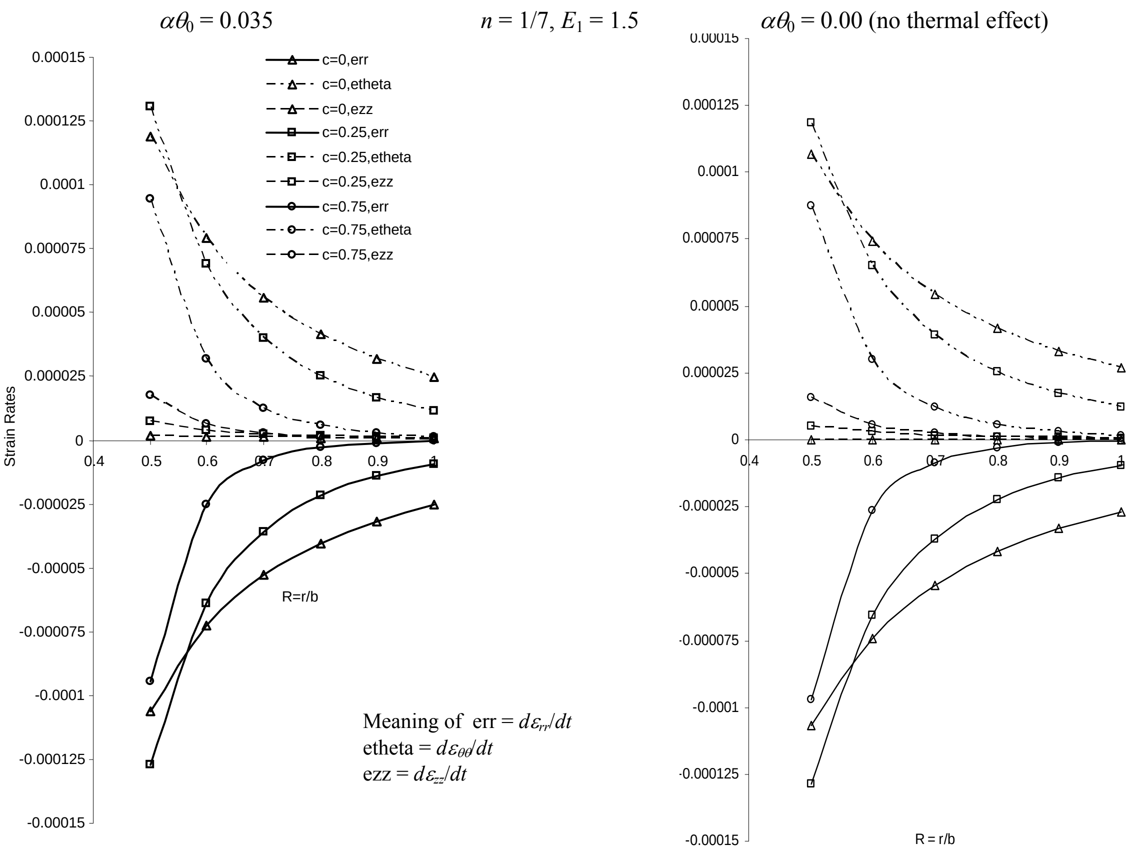

Figure 4(c). Strain rate distribution for a thick-walled circular cylinder subjected to internal pressure for $n = 1/7$ and $E_1 = 1.5$.
Slika 4(c). Raspodela brzine deformacija kod debelozidnog kružnog cilindra pod unutrašnjim pritiskom za $n = 1/7$ i $E_1 = 1,5$

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