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Impact of nonlocal and two temperature parameters on a transversely isotropic thermoelastic solid due to ramp type heat

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Abstract. This study examines the effects of nonlocality and two temperature on a transversely isotropic thermoelastic solid subjected to a ramp type heat source. The governing field equations are formulated within the framework of Green-Naghdi heat conduction theory of type-II and further solved using the Laplace and Fourier transform techniques. Analytical expressions for displacement components, stress components and conductive temperature have been obtained in the transformed domain. The numerical inversion technique has been employed to produce findings in the physical domain. The effects of nonlocal and two temperature parameters on the displacement components, conductive temperature and components of stress have been depicted graphically.

Keywords: laplace and fourier transform; nonlocal; ramp type heat; transversely isotropic thermoelastic solid; two temperature

1. Introduction

Thermoelasticity theory combines the principles of elasticity and heat conduction to describe the coupled interaction between thermal and mechanical fields in deformable solids. It is concerned with the influence of temperature variations on the deformation of an elastic medium as well as the effect of deformation on the thermal state of the material. Thermal stress arise when a medium is subjected to transient heat sources or time dependent thermal boundary conditions, resulting in coupled interactions between thermal and mechanical fields. The classical theory of thermoelasticity, introduced by Duhamel [1], is an uncoupled theory that describes a phenomena rather than true physical properties of the medium. However, this theory has two major limitations. First, the state of the elastic body did not rely on temperature. Furthermore, the parabolic heat equation indicates that temperature can flow at any speed, which contradicts empirical evidence. To address these restrictions, Biot [2] proposed the theory of coupled thermoelasticity. In this theory, heat conduction equations are linked to equations of elasticity. Despite this, this theory also predicts heat waves propagating at infinite speed. Later, Lord and Shulman [3] developed the

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generalised thermoelasticity hypothesis with a single relaxation time. According to this theory, the hyperbolic heat equation predicts a finite speed of temperature propagation. Recently, Tounsi et al. [4] investigated the wave propagation analysis of the imperfect functionally graded (FG) sandwich plates. Mudhaffar et al. [5] applied a four-known quasi-3D shear deformation theory to investigate the bending behavior of a functionally graded plate. Tounsi et al. [6] studied the thermoelastic flexural analysis of silicon carbide/Aluminum graded (FG) sandwich 2D uniform structure (plate). Furthermore, Boulahbal et al. [7] investigated the bending behavior of non-homogeneous beams under small scale and nonlinear hygro-thermo-mechanical loading. Gourdache et al. [8] discussed the hygrothermal-thermodynamic free vibration response of bio-inspired helicoidal laminated composite plates. Some significant studies on thermoelasticity theory also have been discussed by [9-18].

The two temperature theory of thermoelasticity for deformable bodies, which incorporates the thermodynamic temperature and the conductive temperature was introduced by Chen and Gurtin [19] and Chen et al. [20-21]. For time independent scenarios, the difference between thermodynamic temperature and conductive temperature is proportional to the amount of heat supplied and these temperatures are equal when no heat is supplied. For time dependent situations, the difference between these temperatures is non zero and independent of heat supply. When the two temperature parameter is zero, the two temperature thermoelasticity theory reduces to the coupled theory of thermoelasticity [2].

According to the nonlocal thermoelasticity theory, the different physical quantities depend on the values of independent constitutive factors for the entire system, not just at that particular site. Consequently, nonlocal effects play a dominant role in the thermoelastic response of the material. Additionally, the conclusions are comparable to those of the classical theory if the effects of strains at locations other than the reference point are ignored. Kroner [22] established a continuum theory for elastic materials to account for long range cohesive forces, thereby demonstrating the significance of range effects. Later, Edelen and Laws [23] developed a theory of nonlocal interactions, which agreed with Kroner's definition of nonlocality. In addition, Edelen et al. [24] derived the constitutive equations for the theory of nonlocal elasticity known as proto-elasticity. Eringen and Edelen [25] created the nonlocal elasticity hypothesis by applying global balance principles with the second law of thermodynamics. Wang and Dhaliwal [26] established a reciprocity relationship, addressed specific concerns of nonlocal thermoelasticity and further extended the concept of nonlocality. Artan [27] demonstrated the superiority of nonlocal theory by comparing its results with those of the classical theory. Marin [28] determined the uniqueness of thermoelastic solids with voids while Polizzotto [29] improved the Eringen model of nonlocal elasticity theory. Later on, Eringen [30] proposed nonlocal continuum field theories. Paola et al. [31] introduced a mechanical based approach to three-dimensional nonlocal elasticity theory and illustrated that the findings are strongly dependent on size. Vasiliev and Lurie [32] discussed various nonlocal elasticity theories. According to Marin and Craciun [33], micro structured composites exhibit nonlocal effects. Lata and Singh [34] analysed Rayleigh wave propagation in a nonlocal magneto-thermoelastic material with hall current and rotation. Several researchers studied various problems involving both nonlocal and two temperature theory e.g., Li et al. [35], Saeed and Abbas [36], Ailawalia and Marin [37], Singh and Lata [38], Marin et al. [39], Kaushal et al. [40], Abbas and Sur [41], Paswan et al. [42], Han et al. [43], Guo et al. [44], Sobolev and Kudinov [45], Ailawalia et al. [46], Ma and Wang [47], Alzahrani and Abbas [48], Makkad et al. [49], Sharma et al. [50], Hafed and Zenkour [51], Li and Zhou [52], Li et al. [53].

Despite these developments, studies addressing the combined effects of nonlocality and two temperature in transversely isotropic thermoelastic solids remain limited. Motivated by this observation, the present work investigates a two-dimensional transversely isotropic thermoelastic medium without energy dissipation in the presence of nonlocal and two temperature effects under ramp type heat source. The governing equations are solved using the Laplace and Fourier transform techniques to obtain the displacement components, conductive temperature and stress components. Numerical computations are carried out through a numerical inversion technique and the resulting physical fields are presented graphically. The proposed model provides a framework for understanding the coupled influence of nonlocality and two temperature on thermoelastic wave propagation and may be useful in the analysis of advanced composite materials, micro scale structures and other engineering applications where size dependent and thermo-mechanical effects play an important role.

2. Basic equations

According to the two temperature theory introduced by Youssef [54] and Eringen's nonlocal elasticity theory [30], the governing equations for a nonlocal transversely isotropic thermoelastic solid with two temperature are given as follows:
Nonlocal constitutive relation is given by

$$(1-\epsilon^2\nabla^2)t_{ij} = C_{ijkl}e_{kl} - \beta_{ij}T, \quad i,j = 1,2,3. \tag{1}$$

The nonlocal equation of motion without body force is

$$(1-\epsilon^2\nabla^2)t_{ij,j} = \rho(1-\epsilon^2\nabla^2)\ddot{u}_i; \;\; i,j = 1,2,3. \tag{2}$$

Now, substituting Eq. (2) in Eq. (1), gives

$$C_{ijkl}e_{kl,j} - \beta_{ij}T_{,j} = \rho(1-\epsilon^2\nabla^2)\ddot{u}_i, i,j = 1,2,3. \tag{3}$$

Following Youssef [54], the nonlocal heat flux relation is given by

$$(1-\epsilon^2\nabla^2)q_i = -K_{ij}\vartheta_{,j}, \qquad \text{where } \dot{\vartheta} = \varphi, i,j = 1,2,3 \tag{4}$$

Energy equation excluding external heat source [2] is given by

$$-q_{i,i} = \beta_{ij}T_0\dot{e}_{ij} + \rho C_E\dot{T} \quad i,j = 1,2,3. \tag{5}$$

By substituting Eq. (5) into Eq. (4) and taking derivative w.r.t. t both sides, we get

$$K_{ij}\varphi_{,ij} = (1-\epsilon^2\nabla^2)\beta_{ij}T_0\ddot{e}_{ij} + \rho C_E\ddot{T}, \quad i,j = 1,2,3. \tag{6}$$

The strain-displacement relations are

$$e_{ij} = \frac{1}{2}\left(u_{i,j} + u_{j,i}\right), \quad i,j = 1,2,3, \tag{7}$$

where

$$T = \varphi - a_{ij}\varphi_{,ij}, \quad i,j = 1,2,3, \tag{8}$$

represents two temperature equation
and

$$\beta_{ij} = C_{ijkl}\alpha_{ij}, \quad i,j = 1,2,3, \tag{9}$$

is the thermal tensor relation.

$C_{ijkl}\left(C_{ijkl}=C_{klij}=C_{jikl}=C_{ijlk}\right)$ represents elastic parameters, q represents heat flux, ϑ is thermodynamical temperature, φ is the conductive temperature, T_0 represents the reference temperature, e_{kl} are components of strain tensor, t_{ij} are the components of stress tensor, u_i are the displacement components, T is the temperature, ρ is the density, K_{ij} is the thermal conductivity, C_E is the specific heat, α_{ij} represents coefficient of linear thermal expansion, a_{ij} are the two temperature parameters and ϵ represents nonlocal parameter.

3. Formulation of the problem

We consider a homogeneous and nonlocal transversely isotropic thermoelastic medium which is subjected initially at uniform temperature T_0. We employ a rectangular Cartesian coordinate system (x_1, x_2, x_3) with x_3 axis pointing normally into the half space, indicated by $x_3 \geq 0$. We assume the plane such that all particles on a line parallel to x_2 axis are equally displaced, so that the field component $u_2 = 0$ and u_1, u_3, φ are independent of x_2. Following Slaughter [56] and using appropriate transformations on the set of Eqs. (1)-(9) to derive the equations for nonlocal transversely isotropic thermoelastic solid with two temperature and without energy dissipation. Furthermore, restricting our analysis to a two-dimensional problem with $\vec{u} = (u_1, 0, u_3)$, yields

$$c_{11}\frac{\partial^2 u_1}{\partial x_1^2}+c_{44}\frac{\partial^2 u_1}{\partial x_3^2}+(c_{13}+c_{44})\frac{\partial^2 u_3}{\partial x_1\partial x_3}-\beta_1\frac{\partial}{\partial x_1}\left\{\varphi-\left(a_1\frac{\partial^2\varphi}{\partial x_1^2}+a_3\frac{\partial^2\varphi}{\partial x_3^2}\right)\right\}=\rho(1-\epsilon^2\nabla^2)\frac{\partial^2 u_1}{\partial t^2}, \tag{10}$$

$$(c_{13}+c_{44})\frac{\partial^2 u_1}{\partial x_1\partial x_3}+c_{44}\frac{\partial^2 u_3}{\partial x_1^2}+c_{33}\frac{\partial^2 u_3}{\partial x_3^2}-\beta_3\frac{\partial}{\partial x_3}\left\{\varphi-\left(a_1\frac{\partial^2\varphi}{\partial x_1^2}+a_3\frac{\partial^2\varphi}{\partial x_3^2}\right)\right\}=\rho(1-\epsilon^2\nabla^2)\frac{\partial^2 u_3}{\partial t^2}, \tag{11}$$

$$k_1\frac{\partial^2\varphi}{\partial x_1^2}+k_3\frac{\partial^2\varphi}{\partial x_3^2}=T_0(1-\epsilon^2\nabla^2)\frac{\partial^2}{\partial t^2}\left(\beta_1\frac{\partial u_1}{\partial x_1}+\beta_3\frac{\partial u_3}{\partial x_3}\right)+\rho C_E(1-\epsilon^2\nabla^2)\frac{\partial^2}{\partial t^2}\left\{\varphi-\left(a_1\frac{\partial^2\varphi}{\partial x_1^2}+a_3\frac{\partial^2\varphi}{\partial x_3^2}\right)\right\}, \tag{12}$$

$$t_{11}=c_{11}e_{11}+c_{13}e_{33}-\beta_1 T,\ t_{33}=c_{13}e_{11}+c_{33}e_{33}-\beta_3 T,\ t_{13}=2c_{44}e_{13}, \tag{13}$$

where

$$e_{11}=\frac{\partial u_1}{\partial x_1},\ e_{33}=\frac{\partial u_3}{\partial x_3},\ e_{13}=\frac{1}{2}\left(\frac{\partial u_1}{\partial x_3}+\frac{\partial u_3}{\partial x_1}\right),\ T=\varphi-\left(a_1\frac{\partial^2\varphi}{\partial x_1^2}+a_3\frac{\partial^2\varphi}{\partial x_3^2}\right), \\ \beta_1=(c_{11}+c_{12})\alpha_1+c_{13}\alpha_3,\quad \beta_3=2c_{13}\alpha_1+c_{33}\alpha_3. \tag{14}$$

In above equations, we use the contracting subscript notations $(1\to 11, 2\to 22, 3\to 33, 4\to 23, 5\to 31, 6\to 12)$ to relate c_{ijkl} to c_{mn}.

The initial and regularity conditions are given by

$$u_1(x_1,x_3,0)=0=\dot{u}_1(x_1,x_3,0),\quad u_3(x_1,x_3,0)=0=\dot{u}_3(x_1,x_3,0), \tag{15}$$

$$\varphi(x_1,x_3,0)=0=\dot{\varphi}(x_1,x_3,0)\ \text{for}\ x_3\geq 0,\quad -\infty<x_1<\infty, \tag{16}$$

$$u_1(x_1,x_3,t)=u_3(x_1,x_3,t)=\varphi(x_1,x_3,t)=0\ \text{ for } t>0\ \ when\ x_3\to\infty. \tag{17}$$

To facilitate the solution, following dimensionless quantities are introduced:

$$x_1' = \frac{x_1}{L},\ x_3' = \frac{x_3}{L},\ u'_1 = \frac{\rho c_1^2}{L\beta_1 T_0}u_1,\ \ u'_3 = \frac{\rho c_1^2}{L\beta_1 T_0}u_3,\ T' = \frac{T}{T_0},\ t' = \frac{c_1}{L}t,\ t'_{11} = \frac{t_{11}}{\beta_1 T_0},\ t'_{33} = \frac{t_{33}}{\beta_1 T_0},\ t'_{31} = \frac{t_{31}}{\beta_1 T_0},\ \ \varphi' = \frac{\varphi}{T_0},\ \ a'_1 = \frac{a_1}{L^2},\ a'_3 = \frac{a_3}{L^2},\ \ \epsilon' = \frac{\epsilon}{L} \tag{18}$$

where $c_1^2 = \frac{c_{11}}{\rho}$ and L is a constant of dimension of length.

Using the dimensionless quantities defined by Eq. (18) into Eqs. (10)-(12), suppressing the primes and thereafter applying Laplace and Fourier transforms defined by

$$\bar{f}(x_1, x_3, s) = \int_0^\infty f(x_1, x_3, t)\, e^{-st}\, dt, \tag{19}$$

$$\hat{f}(\xi, x_3, s) = \int_{-\infty}^\infty \bar{f}(x_1, x_3, s)\, e^{i\xi x_1}\, dx_1, \tag{20}$$

we obtain a system of three homogeneous equations. These resulting equations have non trivial solutions if the determinant of the coefficient $(\widehat{u_1}, \widehat{u_3}, \widehat{\varphi})$ vanishes, which yield to the following characteristic equation

$$\left(P\frac{d^6}{dx^6} + Q\frac{d^4}{dx^4} + R\frac{d^2}{dx^2} + S\right)(\widehat{u_1}, \widehat{u_3}, \widehat{\varphi}) = 0, \tag{21}$$

where

$$P = (\rho_1 + \varepsilon^2 s^2)[(\rho_4 + \varepsilon^2 s^2)\{p_3 + \zeta_3 s^2\varepsilon^2(1 + a_1\xi^2) + \zeta_3 s^2 a_3(1 + \varepsilon^2\xi^2)\} + \zeta_2 s^2\varepsilon^2 p_5(1 + a_1\xi^2) + \zeta_2 s^2 p_5 a_3(1 + \varepsilon^2\xi^2)] + \xi^2\rho_2[\rho_2\zeta_3 s^2 a_3\varepsilon^2 - \zeta_1 s^2\varepsilon^2 p_5 a_3] - \xi^2 a_3[\rho_2\zeta_2 s^2\varepsilon^2 - \zeta_1 s^2\varepsilon^2(\rho_4 + \varepsilon^2 s^2)] + (\xi^2 + s^2 + \xi^2\varepsilon^2 s^2)[(s^2\varepsilon^2)(\zeta_3 s^2 a_3\varepsilon^2) + \zeta_2 s^2\varepsilon^2 p_5 a_3],$$

$$Q = -(\xi^2 + s^2 + \xi^2\varepsilon^2 s^2)[(\rho_4 + \varepsilon^2 s^2)\{p_3 + \zeta_3 s^2\varepsilon^2(1 + a_1\xi^2) + \zeta_3 s^2 a_3(1 + \varepsilon^2\xi^2)\} + a_3\varepsilon^2(-\xi^2\rho_1 - s^2 - \xi^2\varepsilon^2 s^2) + \zeta_2 s^2\varepsilon^2 p_5(1 + a_1\xi^2) + \zeta_2 s^2 p_5 a_3(1 + \varepsilon^2\xi^2)] + (\rho_1 + \varepsilon^2 s^2)[(\rho_4 + \varepsilon^2 s^2)\{-\xi^2 - \zeta_3 s^2(1 + a_1\xi^2)(1 + \varepsilon^2\xi^2)\} + \zeta_2 s^2 p_5(1 + a_1\xi^2)(1 + \varepsilon^2\xi^2)] + \xi^2\rho_2[\rho_2\{p_3 + \zeta_3 s^2\varepsilon^2(1 + a_1\xi^2) + \zeta_3 s^2 a_3(1 + \varepsilon^2\xi^2)\} + \zeta_1 s^2\varepsilon^2 p_5(1 + a_1\xi^2) + \zeta_1 s^2 p_5 a_3(1 + \varepsilon^2\xi^2)] + \xi^2(1 + a_1\xi^2)[\rho_2\zeta_2 s^2\varepsilon^2 - \zeta_1 s^2\varepsilon^2(\rho_4 + \varepsilon^2 s^2)] - a_3\xi^2[-\rho_2\zeta_2 s^2(1 + \varepsilon^2\xi^2) + \zeta_2 s^2(1 + \varepsilon^2\xi^2)(\rho_4 + \varepsilon^2 s^2) - \zeta_1 s^2\varepsilon^2(-\xi^2\rho_1 - s^2 - \xi^2\varepsilon^2 s^2)],$$

$$R = -(\xi^2 + s^2 + \xi^2\varepsilon^2 s^2)[(\rho_4 + \varepsilon^2 s^2)\{-\xi^2 - \zeta_3 s^2(1 + a_1\xi^2)(1 + \varepsilon^2\xi^2)\} + (-\xi^2\rho_1 - s^2 - \xi^2\varepsilon^2 s^2)\{p_3 + \zeta_3 s^2\varepsilon^2(1 + a_1\xi^2) + \zeta_3 s^2 a_3(1 + \varepsilon^2\xi^2) - \zeta_2 s^2 p_5(1 + a_1\xi^2)(1 + \varepsilon^2\xi^2)] + (\rho_1 + \varepsilon^2 s^2)[(-\xi^2\rho_1 - s^2 - \xi^2\varepsilon^2 s^2)\{-\xi^2 - \zeta_3 s^2(1 + a_1\xi^2)(1 + \varepsilon^2\xi^2)\}] + \xi^2\rho_2[\rho_2\{-\xi^2 - \zeta_3 s^2(1 + a_1\xi^2)(1 + \varepsilon^2\xi^2)\} - \zeta_1 s^2 p_5(1 + a_1\xi^2)(1 + \varepsilon^2\xi^2)] + \xi^2(1 + a_1\xi^2)[-\rho_2\zeta_2 s^2(1 + \varepsilon^2\xi^2) + \zeta_1 s^2(1 + \varepsilon^2\xi^2)(\rho_4 + \varepsilon^2 s^2) - \zeta_1 s^2\varepsilon^2(-\xi^2\rho_1 - s^2 - \xi^2\varepsilon^2 s^2)] + a_3\xi^2[\zeta_1 s^2(1 + \varepsilon^2\xi^2)(\xi^2\rho_1 + s^2 + \xi^2\varepsilon^2 s^2)],$$

$$S = -(\xi^2 + s^2 + \xi^2\varepsilon^2 s^2)[(-\xi^2\rho_1 - s^2 - \xi^2\varepsilon^2 s^2)\{-\xi^2 - \zeta_3 s^2(1 + a_1\xi^2)(1 + \varepsilon^2\xi^2)\}] + \xi^2(1 + a_1\xi^2)[\zeta_1 s^2(1 + \varepsilon^2\xi^2)(-\xi^2\rho_1 - s^2 - \xi^2\varepsilon^2 s^2)].$$

The roots of the Eq. (21) are $\pm\lambda_i$ $(i = 1,2,3)$ using the radiation condition that $\widehat{u_1}, \widehat{u_3}, \widehat{\varphi} \to 0$ as $x_3 \to \infty$ the solution can be written as

$$\widehat{u_1} = A_1 e^{-\lambda_1 x_3} + A_2 e^{-\lambda_2 x_3} + A_3 e^{-\lambda_3 x_3}, \tag{22}$$

$$\widehat{u_3} = d_1 A_1 e^{-\lambda_1 x_3} + d_2 A_2 e^{-\lambda_2 x_3} + d_3 A_3 e^{-\lambda_3 x_3}, \tag{23}$$

$$\widehat{\varphi} = l_1 A_1 e^{-\lambda_1 x_3} + l_2 A_2 e^{-\lambda_2 x_3} + l_3 A_3 e^{-\lambda_3 x_3}, \tag{24}$$

where

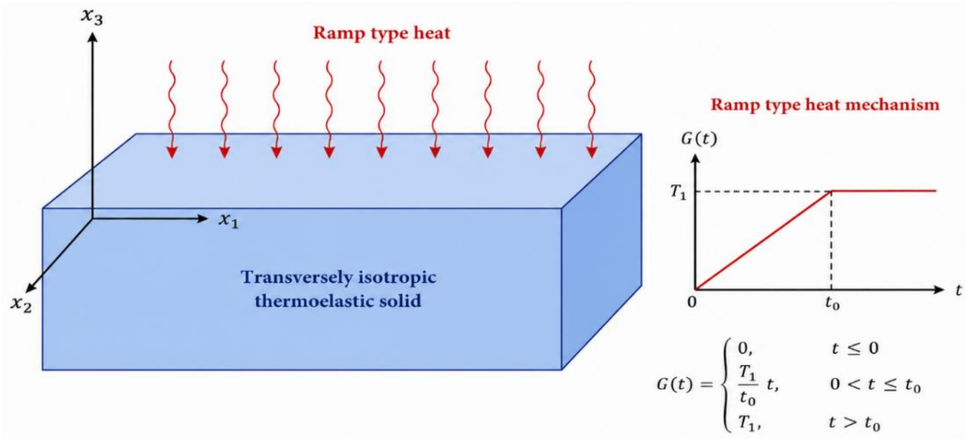

Figure 1. Schematic representation of the transversely isotropic thermoelastic solid subjected to ramp type heat

$$d_i = \frac{-\lambda_i^3 P^* - \lambda_i Q^*}{\lambda_1^4 R^* + \lambda_1^2 S^* + T^*} \quad i = 1,2,3, \tag{25}$$

$$l_i = \frac{\lambda_i^2 P^{**} + Q^{**}}{\lambda_1^4 R^* + \lambda_1^2 S^* + T^*} \quad i = 1,2,3, \tag{26}$$

where

$$\begin{gathered} P^* = i\xi\, [\zeta_1 s^2 \varepsilon^2 p_5 (1 + a_1 \xi^2) + \zeta_1 s^2 p_5 a_3 (1 + \varepsilon^2 \xi^2) + \rho_2 \{p_3 + \zeta_3 s^2 \varepsilon^2 (1 + a_1 \xi^2) + \\ \zeta_3 s^2 a_3 (1 + \varepsilon^2 \xi^2)\}], \\ Q^* = i\xi\, [-\zeta_1 s^2 p_5 (1 + a_1 \xi^2)(1 + \varepsilon^2 \xi^2) + \rho_2 \{-\xi^2 - \zeta_3 s^2 (1 + a_1 \xi^2)(1 + \varepsilon^2 \xi^2)\}], \\ R^* = [(\rho_4 + \varepsilon^2 s^2)\{p_3 + \zeta_3 s^2 \varepsilon^2 (1 + a_1 \xi^2) + \zeta_3 s^2 a_3 (1 + \varepsilon^2 \xi^2)\}] + (-\xi^2 \rho_1 - s^2 - \\ \xi^2 \varepsilon^2 s^2)(-\zeta_3 s^2 \varepsilon^2 a_3) + \zeta_2 s^2 \varepsilon^2 p_5 (1 + a_1 \xi^2) + \zeta_2 s^2 p_5 a_3 (1 + \varepsilon^2 \xi^2), \\ S^* = (\rho_4 + \varepsilon^2 s^2)\{-\xi^2 - \zeta_3 s^2 (1 + a_1 \xi^2)(1 + \varepsilon^2 \xi^2)\} + (-\xi^2 \rho_1 - s^2 - \xi^2 \varepsilon^2 s^2)\, \{p_3 + \\ \zeta_3 s^2 \varepsilon^2 (1 + a_1 \xi^2) + \zeta_3 s^2 a_3 (1 + \varepsilon^2 \xi^2)\} - \zeta_2 s^2 p_5 (1 + a_1 \xi^2)(1 + \varepsilon^2 \xi^2), \\ T^* = (-\xi^2 \rho_1 - s^2 - \xi^2 \varepsilon^2 s^2)\{-\xi^2 - \zeta_3 s^2 (1 + a_1 \xi^2)(1 + \varepsilon^2 \xi^2)\}, \\ P^{**} = i\xi\, [-\rho_2 \zeta_2 s^2 (1 + \varepsilon^2 \xi^2) + (\rho_4 + \varepsilon^2 s^2)(1 + \varepsilon^2 \xi^2)\zeta_1 s^2 - \zeta_1 s^2 \varepsilon^2 (-\xi^2 \rho_1 - s^2 - \\ \xi^2 \varepsilon^2 s^2)], \\ Q^{**} = i\xi\, [-\zeta_1 s^2 (1 + \varepsilon^2 \xi^2)(-\xi^2 \rho_1 - s^2 - \xi^2 \varepsilon^2 s^2)], \end{gathered} \tag{27}$$

where

$$\delta_1 = \frac{c_{44}}{c_{11}}, \delta_2 = \frac{c_{13} + c_{44}}{c_{11}}, \delta_4 = \frac{c_{33}}{c_{11}}, p_5 = \frac{\beta_3}{\beta_1}, p_3 = \frac{k_3}{k_1}, \zeta_1 = \frac{T_0 \beta_1^2}{k_1 \rho}, \zeta_2 = \frac{T_0 \beta_1 \beta_3}{k_1 \rho}, \zeta_3 = \frac{C_E c_{11}}{k_1}. \tag{28}$$

4. Boundary conditions

We consider that ramp type heat is applied on the half-space ($x_3 = 0$).
The appropriate boundary conditions are as follows:

$$(1 - \epsilon^2 \nabla^2)\, t_{33}(x_1, x_3, t) = 0, \tag{29}$$

$$(1-\epsilon^2\nabla^2)t_{31}(x_1,x_3,t)=0, \tag{30}$$

$$\varphi(x_1,x_3,t)=G(t)\delta(x_1), \tag{31}$$

where $\delta(x_1)$ is an dirac delta function of x_1 and $G(t)$ is a function defined as

$$G(t)=\begin{cases} 0,\ t\le 0 \\ T_1\frac{t}{t_0}, 0<t\le t_0 \\ T_1,\ t>t_0 \end{cases} \tag{32}$$

where t_0 indicates the required time to raise the heat and T_1 is a constant.

Applying the Laplace and Fourier transforms to both sides of Eq. (31), we obtain $\widehat{\varphi}=\bar{G}(s)$ where

$$\bar{G}(s)=T_1\frac{(1-e^{-st_0})}{t_0 s^2}. \tag{33}$$

After applying the Laplace and Fourier transforms defined by Eqs. (19)-(20) on the boundary conditions Eqs. (29)-(31) and with the aid of Eqs. (22)-(24), we obtain the components of displacement, conductive temperature and components of stress as given by

$$\widehat{u_1}=\frac{\bar{G}(s)(1+\epsilon^2\xi^2)}{\varpi}\left(\Omega_{31}e^{-\lambda_1x_3}+\Omega_{32}e^{-\lambda_2x_3}+\Omega_{33}e^{-\lambda_3x_3}\right), \tag{34}$$

$$\widehat{u_3}=\frac{\bar{G}(s)(1+\epsilon^2\xi^2)}{\varpi}\left(d_1\Omega_{31}e^{-\lambda_1x_3}+d_2\Omega_{32}e^{-\lambda_2x_3}+d_3\Omega_{33}e^{-\lambda_3x_3}\right), \tag{35}$$

$$\widehat{\varphi}=\frac{\bar{G}(s)(1+\epsilon^2\xi^2)}{\varpi}\left(l_1\Omega_{31}e^{-\lambda_1x_3}+l_2\Omega_{32}e^{-\lambda_2x_3}+l_3\Omega_{33}e^{-\lambda_3x_3}\right), \tag{36}$$

$$\widehat{t_{33}}=\frac{\bar{G}(s)(1+\epsilon^2\xi^2)}{\varpi}\left(\varpi_{11}\Omega_{31}e^{-\lambda_1x_3}+\varpi_{12}\Omega_{32}e^{-\lambda_2x_3}+\varpi_{13}\Omega_{33}e^{-\lambda_3x_3}\right), \tag{37}$$

$$\widehat{t_{31}}=\frac{\bar{G}(s)(1+\epsilon^2\xi^2)}{\varpi}\left(\varpi_{21}\Omega_{31}e^{-\lambda_1x_3}+\varpi_{22}\Omega_{32}e^{-\lambda_2x_3}+\varpi_{23}\Omega_{33}e^{-\lambda_3x_3}\right), \tag{38}$$

where

$$\Omega_{31}=\varpi_{12}\varpi_{23}-\varpi_{13}\varpi_{22},\ \Omega_{32}=\varpi_{21}\varpi_{13}-\varpi_{11}\varpi_{23},\ \Omega_{33}=\varpi_{11}\varpi_{22}-\varpi_{21}\varpi_{12},$$

$$\varpi_{1j}=\frac{c_{31}}{\rho c_1^2}i\xi-\frac{c_{33}}{\rho c_1^2}d_j\lambda_j-\frac{\beta_3}{\beta_1}l_j+\frac{\beta_3}{\beta_1}a_3l_j\lambda_j^2-\frac{\beta_3}{\beta_1}l_ja_1\xi^2 \quad j=1,2,3,$$

$$\varpi_{2j}=-\frac{c_{44}}{\rho c_1^2}\lambda_j+\frac{c_{44}}{\rho c_1^2}i\xi d_j \qquad j=1,2,3,$$

$$\varpi_{3j}=\lambda_jl_j \qquad j=1,2,3, \qquad\qquad \varpi=\varpi_{11}\Omega_{11}-\varpi_{12}\Omega_{12}+\varpi_{13}\Omega_{13}.$$

5. Particular cases

1. If $a_1=a_3=0$, from Eqs. (34)-(38), we obtain the corresponding expressions for displacements, stresses and conductive temperature for transversely isotropic nonlocal thermoelastic solid without two temperature and without energy dissipation.
2. If $\epsilon=0$, then from Eqs. (34)-(38), we obtain the corresponding expressions for displacements, stresses and conductive temperature for transversely isotropic thermoelastic solid with two temperature and without energy dissipation.

Table 1. Physical data for cobalt

Parameters	Value	units	parameters	value	units
c_{11}	3.071	$10^{11}\mathrm{Nm}^{-2}$	β_1	7.04	$10^{6}\mathrm{Nm}^{-2}\mathrm{deg}^{-1}$
c_{12}	1.650	$10^{11}\mathrm{Nm}^{-2}$	β_3	6.90	$10^{6}\mathrm{Nm}^{-2}\mathrm{deg}^{-1}$
c_{13}	1.027	$10^{11}\mathrm{Nm}^{-2}$	k_1	0.690	$10^{2}\mathrm{Wm}^{-1}\mathrm{deg}^{-1}$
c_{33}	3.581	$10^{11}\mathrm{Nm}^{-2}$	k_3	0.690	$10^{2}\mathrm{Wm}^{-1}\mathrm{deg}^{-1}$
c_{44}	1.510	$10^{11}\mathrm{Nm}^{-2}$	ρ	8.836	$10^{3}\mathrm{Kgm}^{-3}$
c_E	4.27	$10^{2}\mathrm{JKg}^{-1}\mathrm{deg}^{-1}$	T_0	298	K

6. Inversion of the transformation

To obtain the solution in the physical domain, the transformed solutions obtained in Eqs. (34)-(38) are first inverted using the inverse Fourier transform, which is expressed as

$$\bar{f}(x_1, x_3, s) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-i\xi x_1}\hat{f}(\xi, x_3, s)d\xi = \frac{1}{2\pi}\int_{-\infty}^{\infty} |\cos(\xi x_1)f_e - i\sin(\xi x_1)f_0 d\xi, \tag{39}$$

where f_e and f_0 are respectively the even and odd parts of $\hat{f}(\xi, x_3, s)$. Afterwards, following Honig and Hirdes [57], the Laplace transform function $\bar{f}(x_1, x_3, s)$ can be inverted to $f(x_1, x_3, t)$ by

$$f(x_1, x_3, s) = \frac{1}{2\pi i}\int_{v-i\infty}^{v+i\infty} \bar{f}(x_1, x_3, s)e^{-st}ds. \tag{40}$$

The last step is to calculate the integral in Eq. (39). The method for evaluating this integral is described in Press et al. [58] which involve the use of Romberg's integration with adaptive step size.

7. Numerical results and discussion

In order to elaborate the effect of two temperature parameters and nonlocal theory, cobalt, a transversely isotropic thermoelastic material, is chosen for the purpose of numerical calculation. Following Eringen [59] and Gupta [60], the corresponding physical data of cobalt are listed in Table 1.

1. The black long dashed line and blue small dashed line represent $a_1 = 0$, $a_3 = 0$ with $\varepsilon = 0$ and $\varepsilon = 0.3$ respectively. Here, $\varepsilon = 0$ denotes absense of nonlocal effects whereas $\varepsilon = 0.3$ represents the presence of nonlocal effect in tranversely isotropic thermoelastic body (without two temperature).
2. The solid red line and solid green line denote $a_1 = 0.3$, $a_3 = 0.06$ with $\varepsilon = 0$ and $\varepsilon = 0.3$ respectively, where $a_1$and a_3 are two temperature parameters.

In Fig. 2, variations in displacement component u_1 with displacement x due to nonlocal and two temperature parameters has been depicted graphically. The graphical representation illustrates how the nonlocal and two temperature parameters affect the behaviour of u_1 in a transversely isotropic thermoelastic medium. It is observed that u_1 behaves oscillatory throughout the considered displacement range. The oscillations are generated by the propagation of thermoelastic waves induced by the ramp type thermal loading. However, in the absence of nonlocal effect within the medium, the magnitude of the oscillations increases, indicating that nonlocality has a

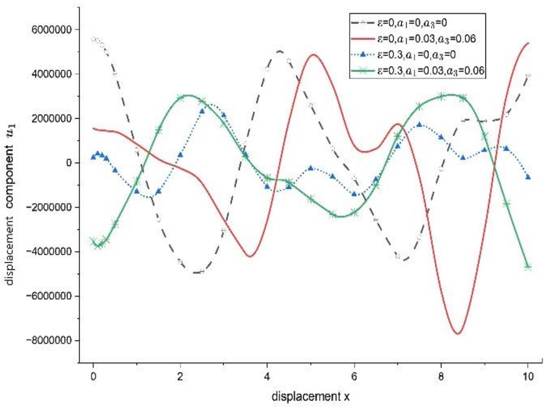

Figure 2. variation of displacement component u_1 with displacement x

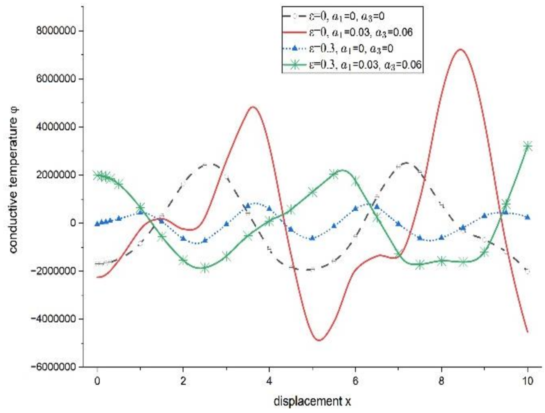

Figure 3. variation of conductive temperature φ with displacement x

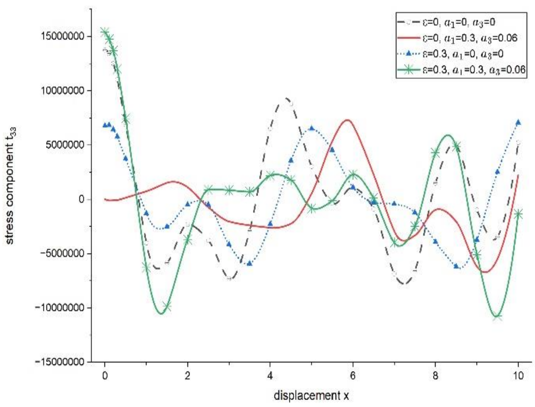

Figure 4. variation of stress component t_{33} with displacement x

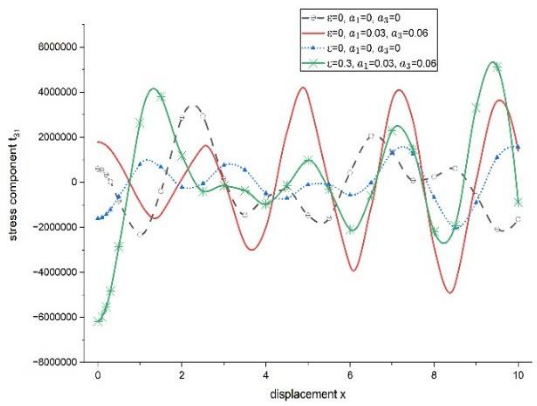

Figure 5. variation of stress component t_{31} with displacement x

significant influence on the material response.

The variation of the conductive temperature φ with respect to displacement x in a transversely isotropic thermoelastic medium due to ramp type heat is illustrated graphically in Fig. 3. It can be seen that the conductive temperature exhibits oscillatory behaviour. The observed oscillations in the conductive temperature arise from the propagation of thermal disturbances generated by the ramp type heat source. The magnitude of φ is lower in the presence of nonlocal effects compared to the local case. However, in the absence of nonlocal parameter i.e., for $\varepsilon = 0$, increasing the two temperature parameters from $a_1 = 0$, $a_3 = 0$ to $a_1 = 0.3$, $a_3 = 0.06$, enhances the amplitude of the oscillations. This indicates that the two temperature parameters significantly influence the thermal response of the medium and modify the conductive temperature distribution.

The variation of the stress component t_{33} with respect to displacement x is shown in Fig. 4. It is clearly visible that t_{33} responds significantly to the combined influence of nonlocality and two temperature. In the absence of two temperature parameters, the variations in t_{33} follow a similar trend for both local and nonlocal cases up to till $0 \leq x \leq 5$, whereas for $5 \leq x \leq 9$, the variations exhibit opposite trends. This behaviour shows that nonlocal effects influence the stress distribution as the thermal disturbance propagates through the material. For $2 \leq x \leq 8$, it can be concluded that increasing $\varepsilon = 0$ to $\varepsilon = 0.3$ and changing the two temperature parameters from $a_1 = 0, a_3 = 0$ to $a_1 = 0.03, a_3 = 0.06$, stablizes the variations of t_{33} within the material.

Fig. 5 illustrates the variation of stress component t_{31} under the influence of nonlocal and two temperature parameters. It is evident that t_{31} exhibits oscillatory behaviour over the entire displacement range. The magnitude of t_{31} increases as the two temperature parameters change from $a_1 = 0$, $a_3 = 0$ to $a_1 = 0.03$, $a_3 = 0.06$ for both the local and nonlocal cases. This indicates that the two temperature parameters have a noticeable effect on the stress distribution within the material. Furthermore, the presence of nonlocal effects reduces the fluctuations in t_{31} for both sets of two temperature parameters, resulting in a comparatively smoother stress response.

8. Conclusions

Based on the obtained results, the following conclusions can be drawn:

1. A nonlocal transversely isotropic thermoelastic solid with two temperature has been investigated within the framework of the nonlocal Green-Naghdi type II heat conduction theory under the ramp type heat source.
2. The physical fields exhibit oscillatory behaviour under ramp type thermal loading.
3. The nonlocal parameter significantly influences the thermoelastic response of the material and alters the amplitudes of the displacement, temperature, and stress distributions.
4. The two temperature parameters have a noticeable impact on the displacement component, conductive temperature and stress components, leading to changes in their oscillatory patterns.
5. The combined action of nonlocality and two temperature modifies the propagation characteristics of thermoelastic disturbances within the transversely isotropic thermoelastic medium.
6. The numerical results demonstrate that nonlocal and two temperature effects should be considered for an accurate prediction of the thermo-mechanical behaviour of transversely isotropic thermoelastic materials subjected to ramp type thermal loading.
7. The present model may be useful in the analysis and design of advanced engineering materials and structures where size dependent effects and thermo-mechanical coupling are pronounced such as composite materials, micro scale devices and geophysics.

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