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Dynamic analysis of nonlocal thermoelastic diffusive solids under ramp-type thermal sources

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Abstract. This study investigates the dynamic behavior of nonlocal thermoelastic solid with diffusion subjected to Ramp type thermal source, with a focus on the influence of nonlocal parameter on the material. To examine this we consider nonlocal thermoelastic solid with diffusion. The governing equations are solved using Integral transforms to analyze the nonlocal parameter response of the thermoelastic solids with diffusion. Our findings show that change in nonlocal parameter resulted in the variations of normal stress, shear stress, mass concentration and temperature. The study highlights the importance of nonlocality in determining the stress, temperature and concentration fields in nonlocal thermoelastic- diffusive solids due to ramp type heat. The results provide valuable insights for applications in advanced materials science, micro- and nano-scale engineering, and dynamic load analysis, where understanding the coupled effects of nonlocality, thermoelasticity, and diffusion is essential.

Keywords: angular ferequency; fourier transformation; nonlocal; stress; thermoelastic; thermomechanical

1. Introduction

Nonlocal thermoelasticity with diffusion is a rapidly evolving research area that extends classical thermoelasticity to account for small-scale effects, heat and mass transport, and mechanical inter- actions in solid materials. The incorporation of diffusion and thermal sources further enhances the complexity of the problem, making it essential for applications in materials science, geophysics, and engineering.

Eringen (1972) introduced the nonlocal elasticity theory, which incorporates the effect of long-range interactions and nonlocal stress fields in continuum mechanics. Later, this concept was extended to thermoelasticity, addressing limitations of classical models.

Nowacki (1974) proposed the theory of thermoelastic diffusion, which takes into account mass transport caused by concentration gradients and temperature differences. A more general this model was incorporated by him where temperature displacement and diffusion fields in elastic solids are coupled. Sadeghi and Kiani (2022) extended their investigation of the thermoelastic diffusional model using generalized thermoealsticity with Lord-Shulman(LS) theory as well as Green Lindsay(GL) model. Marin *et al*. (2014a) expanded the idea of how far effects can spread in a material to include cases involving micropolar thermoelastic diffusion. They showed that the temperature and chemical potential P do not cause any changes or disturbances outside a certain limited area during a given period of time.

Marin *et al*. (2014b) demonstrated that the presence of microstretch has no impact on the fundamental behavior of the mixed initial-boundary value problem in thermoelastic bodies. Hobiny *et al.* (2022) examine how the radial displacement, carrier density, conductive and heat-related temperatures, and stresses behave in a semiconductor material that has a spherical hole.

Marin *et al.* (2021) performed numerical analysis of a nonlinear hyperbolic bioheat equation under different boundary conditions, focusing on its application in the medical treatment of tumor cells.

Saeed and Abbas (2022) used mathematical models of bioheat transfer to investigate the temporary heat behavior in spherical tissue caused by a laser heat source. Abbas (2015a)analyzed the solution of a thermoelastic interaction problem in a functionally graded material subjected to thermal shock, using the fractional order three-phase lag model

Photo-thermal-elastic interactions in an infinite semiconductor medium with a cylindrical hole are studied using the coupled theory of thermoelasticity and plasma waves under a hyperbolic two- temperature model. (Abbas *et al.* 2021). The effect of two temperatures on an axially moving microbeam exposed to ramp-type heating is investigated using the generalized thermoelasticity theory with one relaxation timeCarrera *et al*. (2015)

The propagation of plane waves in a thermo-microstretch elastic half-space is examined using both the Lord–Shulman model and the classical coupled dynamical theory by Abbas and Othman (2012)

Abbas (2015b) studied thermoelastic interactions in a microscale beam exposed to a moving heat source using Green and Naghdi's type III theory. Abbas and Youssef (2015) investigated a two-dimensional problem involving a porous material using the fractional order generalized thermoelasticity theory with one relaxation time.

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Abouelregal *et al.* (2022) described the coupling between heat transfer and diffusion in thermoelastic materials by developing a thermal diffusion model. Abouelregal *et al.* (2025b) proposed a novel thermoviscoelastic model that combines nonlocal elasticity theory with the KelvinVoigt viscoelastic model and a Klein–Gordon-type nonlocal elasticity approach. Atta *et al.* (2024) investigated the interaction between thermal processes and diffusion in thermoelastic solids.

Abouelregal *et al.* (2025a) investigated photothermal processes in rotating semiconducting materials using the MGT framework, which incorporates finite thermal wave speeds. This approach overcomes the limitations of classical heat conduction models like Fourier's law by employing the tempered generalized Caputo fractional derivative.

Abouelregal and Sedinghi (2021) developed a new model to describe diffusion in thermoelastic solids and compared the resulting strain, temperature, and mass diffusion fields. Bhattacharya and Kanoria (2014) Studied two-temperature thermoelastic diffusion mdels on and mass transport in solids. The relevance of these to theincorporation of diffusive effects in nonlocal thermoela thermoelasticity was built upon by ours. Chandel *et al.* (2025) introduced a nonlocal thermoelastic diffusion model incorporating memory-dependent effects. (Li *et al.* 2022) studied effects of nonlocality in thermoelastic diffusion for nano structures.

Singh *et al.* (2020) detection of transitive capitulations in nonlocal thermoelastic diffusion solids affected by timeharmonic thermalsources. This confirmed the effect of external heat inputs on tem- perature distributions,resistance to diffusions and stress wave propagations in radiative solid mate- rials. Recent advances in computational modeling, fractional calculus and machine learning have enabled more sophisticated simulations of nonlocal thermoelastic diffusion problems. Kong *et al.* (2023) designed a mechanical-electromagnetic radiation (EMR) testing system to investigate how thermal treatment influences the mechanical degradation of coal, as well as its deformation and frac- ture behavior under thermo-mechanical coupling conditions.

Abbas *et al.* (2024) have developed nonlocal thermoelastic models incorporating fractional time derivatives. These models use Eringen's nonlocal elasticity theory and show that fractional-order derivatives significantly impact wave propagation, thermal stress distribution, and displacement in the material. The Laplace transform method has been used to solve governing equations analytically, highlighting how ultrashort laser pulses influence temperature variations. The influence of relaxation time on a two-dimensional thermoelastic medium with a doubly porous structure was analyzed under the effects of diffusion and gravity. By applying normal mode analysis, the analytical expressions for the physical variables, presented in exponential form were derived (Othman and Mansour 2023).

(Marin *et al.* 2024) explored wave propagation in unbounded thermoelastic materials under nonlocal effects. The study extends the Lord and Shulman generalized thermoelastic model with integral transform techniques, showing that the nonlocal parameter and relaxation time alter displacement and temperature distributions. The study of nonlocal thermoelastic media with diffusion under a thermal source is crucial for understanding the coupled interactions of mechanical, thermal and diffusive fields particularly in nanoscale materials. Classical thermoelasticity fails to capture size-dependent effects, necessitating the use of nonlocal theories to describe wave propagation, stress distribution, and diffusion behavior more accurately. Recent research has introduced fractional-order derivatives to improve the modeling of memory-dependent thermal responses (Abbas *et al.* 2024)

Furthermore, experimental validation of nonlocal thermoelastic diffusion models is lacking, making it difficult to apply these theories to nanotechnology, aerospace, and energy materials. Addressing these gaps requires more computationally efficient models, deeper exploration of external thermal and mechanical loads, and the development of experimental techniques to validate theoretical findings. The study of nonlocal thermoelastic materials with diffusive solids has received a lot of attention in recent years because of its applications in advanced materials science, such as micro and nano materials and biomechanics. The frequency-dependent response of such materials under different loading is an important field of study. This study summarizes significant contributions to the area emphasizing theoretical and computational advances (Srinivasa and Reddy 2017).

The study of time-harmonic interactions in nonlocal thermoelastic diffusion solids integrates mul- tiphysics phenomena critical for advanced materials in nanotechnology and aerospace engineering. Nonlocal elasticity theory, pioneered by (Eringen 1972), accounts for long-range atomic interactions, essential at nanoscales. Coupling thermoelasticity with diffusion introduced by (Nowacki 1974) enables analysis of materials under simultaneous thermal, mechanical and mass transport loads. Recent advances focus on dynamic responses to time-harmonic thermal sources, vital for optimizing high-frequency devices.

Thermoelasticity deals with how materials deform under temperature changes and how mechanical changes affect temperature. Material's behavior is also affected by diffusion processes. The material's response involves mechanical deformation, thermal effects and diffusion, all considered in a nonlocal framework. The focus is on how a thermal source (like a heat input) influences these interactions under time-harmonic conditions (Sharma and Grover 2011).

Eringen (1972) proposed the idea of nonlocal elasticity, which has been critical in understanding material behavior at tiny scales, where traditional continuum mechanics fails to describe size dependent phenomena. Eringen's nonlocal theory states that stress at a given place is determined by the strain field at all other sites in the body, making it appropriate for modeling nanomaterials and structures with intrinsic heterogeneity. Recent research has expanded this theory to incorporate thermal and diffusive effects, resulting in a more complete framework for studying coupled phenomena (Karami *et al.* 2018).

Alimoradzadeh and Akbas (2023) conducted a study on the nonlinear vibration behavior of a composite beam reinforced with carbon nanotubes, supported by a nonlinear viscoelastic foundation, employing Hamilton's principle. The nonlinear partial differential equations governing the motion were formulated using the Euler- Bernoulli beam theory. Nonlocal thermoelasticity delves into exploring how mechanical deformation and thermal influences interact in materials where the traditional notion of interaction doesn't apply anymore. This perspective takes into consideration size effects that become notable in materials with characteristics. In the realm of thermoelasticity, the behaviors of both the mechanical and thermal domains are dictated by constitutive equations that encompass a global perspective. The correlation between stress and strain, in a context usually involves a length scale factor that determines the extent of connectivity among adjacent material locations (Zarei and Pilla 2023).

Singh and Lata (2023) studied the effect of two temperature parameters on the axisymmetric deformation in a two-dimensional nonlocal homogeneous isotropic thick circular plate without energy dissipation. They used Laplace and Hankel transforms and found the analytical solutions to the problem. Lata and Singh (2020a, b, c) studied nonlocal effects on various models.(Abbas *et al.* 2023) examined the impact of three thermal relaxation times on living tissue within the framework of the Three-Phase-Lag (TPL) bioheat model. By applying Laplace transforms, analytical solutions for tissue temperature and the associated thermal damage are derived.

Song *et al.* (2025) examined the constant normal stiffness (CNS) boundary condition within deep rock engineering structures, highlighting it as a more precise reflection of the stress environment in jointed rock masses, grounded in the theory of statically determinate beams. Their findings demonstrated that both the CNS boundary condition and anchorage have a substantial impact on the shear mechanical properties. Singh and Lata (2024) had studied the thermomechanical deformations that appear in a nonlocal homogeneous isotropic thick circular plate through the frequency domain with- out energy dissipation and solved the problem through Hanker transformation techniques.Existing studies on nonlocal thermoelastic diffusion primarily focus on transient or time-domain analyses, often over- looking the complexities introduced by fully coupled field equations. This study focuses on how nonlocal effects influence stress, temperature, and mass concentration under Ramp type thermal loading. There is a critical need for advanced mathematical modeling and analytical techniques to accurately capture these interactions. This gap will lead to more precise predictions and enhanced material design in thermoelastic diffusion systems, ultimately improving their practical applications.

2. Basic equations

Following (Eringen 2002) the stress tensor at arbitrary point x of a nano material body not only depends up on the stress tensor at x, but also depend on all points of the body. The nonlocal stress tensor for a homogeneous isotropic elastic material in the absence of body force can be expressed a

$$\sigma_{ij}(x) = \int_{v} \alpha(|x - x'|, \xi) t_{ij}(x) dV(x')$$

By employing Eringen's nonlocal formulation, the nonlocal stress tensor $\sigma_{ij}(x)$ can be expressed as

$$(1 - \xi^2 \nabla^2)\sigma_{ij}(x) = t_{ij}(x)$$

The constitutive equation for coupled thermoelastic diffusion medium while neglecting the body forces can be expressed as

$$\begin{aligned}(1 - \xi^2 \nabla^2)\sigma_{ij}(x) &= 2\mu e_{ij} + \delta_{ij}(\lambda e_{kk} - \gamma_1 T - \gamma_2 C),\\ P &= -\gamma_2 e_{kk} - aT + bC\end{aligned}$$

Following (Eringen 1974), (Ram *et al.* 2008) and (Malik *et al.* 2023) the basic equations in isotropic nonlocal thermoelastic media with diffusion can be given by

$$(\lambda + \mu)\nabla . \nabla \boldsymbol{u} + \mu \nabla^2 \boldsymbol{u} - \gamma_1 \nabla T - \gamma_2 \nabla C + \rho(1 - \xi^2 \nabla^2)\vec{F} = \rho(1 - \xi^2 \nabla^2)\ddot{\boldsymbol{u}} \tag{1}$$

$$\begin{aligned}(K \frac{\partial}{\partial t} + K^*)\nabla^2 T &= \rho\,(1 - \xi^2 \nabla^2)\frac{\partial^2}{\partial t^2}(\rho C_E T \\ &\quad + \gamma_1 T_0 u_{i,j} + a T_0 C)\end{aligned} \tag{2}$$

$$(1 - \xi^2 \nabla^2)\dot{C} = d\nabla^2 (bC - \gamma^2 e_{kk} - aT) \tag{3}$$

$$\text{Where } \gamma_1 = (3\lambda + 2\mu)\alpha_t, \quad \gamma_2 = (3\lambda + 2\mu)\alpha_c \tag{4}$$

In Eqs. (1)-(3) T is temperature, ρ is density, α_t is the coefficient of linear thermal expansion, α_c is the coefficient of diffusion expansion, K is coefficient of thermal conductivity, K^* is the materialistic constant, a is coefficients of thermoelastic diffusive effects ,b is coefficient of diffusive effects, σ_{ij} are components of stress tensor, C is concentration distribution, u_i is displacement vector, λ and μ are Lame's constants, C_E is specific heat at constant strain, T_0 is temperature of the medium in its natural state assumed, that $|T / T_0| < 1$, d is diffusion constant, ξ are nonlocal parametrs, $e_{ij} = 1\,2\,(u_{i,j} + u_{j,i})$; $i, j\ are\ 1, 2, 3, \nabla$ is gradient and ∇^2 is Laplacian operator.

3. Formulation of problem

Considering a two-dimensional homogeneous nonlocal isotropic thermoelastic body initially at undeformed state at initial temperature T_0. We take a rectangular coordinate system (x, y, z) having origin on the surface $z = 0$ with $z - axis$ pointing vertically downward into the medium is introduced. The surface of half space is subjected to a ramp type thermal source. For two-dimensional problem in xz plane we take.

$$\boldsymbol{u} = (u, 0, w),\quad u = u(x,z,t),\quad \boldsymbol{w} = w(x,z,t),\quad T = T(x,z,t)\ and\ C = C(x,z,t)$$

From Eqs. (1)-(3) the component form of the equations are derived as

$$(\lambda + \mu)\frac{\partial e}{\partial x} + \mu\nabla^2 u - \gamma_1\frac{\partial T}{\partial x} - \gamma_2\frac{\partial C}{\partial x} + \rho(1 - \xi^2\nabla^2)F_1 = \rho(1 - \xi^2\nabla^2)\ddot{u} \tag{5}$$

$$(\lambda + \mu)\frac{\partial e}{\partial z} + \mu\nabla^2 w - \gamma_1\frac{\partial T}{\partial z} - \gamma_2\frac{\partial C}{\partial z} + \rho(1 - \xi^2\nabla^2)F_3 = \rho(1 - \xi^2\nabla^2)\ddot{w}, \tag{6}$$

$$\left(K\frac{\partial}{\partial t} + K\right)\nabla^2 T = \rho(1 - \xi^2\nabla^2)\frac{\partial^2}{\partial t^2}\left(\rho C_E\frac{\partial T}{\partial t} + \gamma_1 T_0 e + a T_0 C\right) \tag{7}$$

$$(1 - \xi^2\nabla^2)\frac{\partial C}{\partial t} = d\left[b\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial z^2}\right) - \gamma_2\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial z^2}\right)\left(\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z}\right) - a\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2}\right)\right] \tag{8}$$

The condition of variables at initial are given by the following forms

$$\begin{gathered} u(x,z,0) = 0 = u'(x,z,0),\\ w(x,z,0) = 0 = w\,(x,z,0),\\ T\,(x,z,0) = 0 = T\,(x,z,0),\\ C(x,z,0) = 0 = C\,(x,z,0), \quad \text{for}\ \ x \geq 0,\\ -\infty < x < \infty,\\ u(x,z,t) = w(x,z,t) = T\,(x,z,t) = C(x,z,t) = 0\, for\ t > where, \quad x \to \infty \end{gathered} \tag{9}$$

In our calculation we used the following dimensionless quantities for simplicity

$$\begin{gathered} x' = \frac{{\omega_1}^*}{c_1}x,\ z' = \frac{{\omega_1}^*}{c_1}z,\ t' = {\omega_1}^* t\ ,\ u' = \frac{{\omega_1}^*}{c_1}u,\\ a' = \frac{{\omega_1}^*}{c_1}a\ ,\ C' = \frac{\gamma_2}{\rho {c_1}^2}C,\ T' = \frac{\gamma_2}{\rho {c_1}^2}T,\ F_1' = \frac{F_1}{\gamma_1 T_{0,}},\\ F_3' = \frac{F_3}{\gamma_1 T_{0,}}\ ,\ e' = e\ ,\ {c_1}^2 = \frac{\lambda + 2\mu}{\rho},\ \omega_1' = \frac{\rho C_E {c_1}^2}{K} \end{gathered} \tag{10}$$

We express the displacement variables $u(x,z,t)$ and $w(x,z,t)$ in terms of dimensionless potential functions Ψ_1 and Ψ_2 as

$$u = \frac{\partial\psi_1}{\partial x} - \frac{\partial\psi_2}{\partial z},\qquad w = \frac{\partial\psi_1}{\partial z} + \frac{\partial\psi_2}{\partial x} \tag{11}$$

The general solution of the problem in Laplace transform is given by

$$F(x,z,s) = \int_0^\infty f(x,z,t)e^{-ts}dt \tag{12}$$

The Fourier transformation is given as follow

$$f(\zeta,z,\omega) = \int_{-\infty}^{\infty}(\psi_1,\psi_2, T, C)(x,z,t)e^{-i\zeta x}dx \tag{13}$$

By using the concept of Fourier transformation; from Eqs. (5)-(8) after substitute Eq. (11) in them, we get the following

$$\left(A_1(D^2 - \zeta^2) + \omega^2(1 - \xi^2\nabla^2)\right)\hat{\psi}_1 - \widehat{T} - \hat{C} = 0 \tag{14}$$

$$\left(A_2(D^2 - \zeta^2) + (1 - \xi^2\nabla^2)\omega^2)\right)\hat{\psi}_2 = 0 \tag{15}$$

$$A_3(1 - \xi^2\nabla^2)(D^2 - \zeta^2)\hat{\psi}_1 + A_4(1 - \xi^2\nabla^2) - A_5(D^2 - \zeta^2))\widehat{T} + A_6(1 - \xi^2\nabla^2)\hat{C} = 0 \tag{16}$$

$$A_9(D^2 - \zeta^2)^2\hat{\psi}_1 + A_{10}(D^2 - \zeta^2)\widehat{T} + \left(A_7(1 - \xi^2\nabla^2) - A_8(D^2 - \zeta^2)\right)\hat{C} = 0 \tag{17}$$

where

$$A_1 = \frac{(\lambda + 2\mu}{\rho {c_1}^2},\quad A_2 = \frac{\mu}{\rho {c_1}^2},\ A_3 = \rho S^2\gamma_1 T_0,\ , A_4 = \frac{S^3\rho^3 {c_1}^2 {\omega_1}^* C_E}{\gamma_1},$$

$$A_5 = \frac{\rho c_1(K{\omega_1}^* S + K^*)}{\gamma_1},\ A_6 = \frac{S^2\rho^2 {c_1}^3 T_0 a'}{{\omega_1}^*\gamma_2},\ A_7 = \frac{S\rho{\omega_1}^*{c_1}^2}{\gamma_2},\quad A_8 = db\frac{\rho{\omega_1}^{*2}}{\gamma_2},$$

$$A_9 = d\gamma_2\frac{{\omega_1}^{*2}}{{c_1}^2},\quad A_{10} = db\frac{\rho{\omega_1}^{*2}}{\gamma_1},\quad A_{11} = \frac{{\omega_1}^{*2}\xi^2}{{c_1}^2},\quad A_{12} = \gamma_1 T_0,\quad A_{13} = \frac{\rho{\omega_1}^* c_1}{\gamma_1}$$

$$A_{14} = \gamma_2 T_0,\quad A_{15} = \frac{\rho{\omega_1}^* c_1}{\gamma_2},\ A_{16} = \frac{A_{12}}{A_{13}},\quad A_{17} = \frac{A_{14}}{A_{13}}$$

The Eqs. (14)-(17) pocess a non-trivial solution if determinant of their cofficients vanishes. By simplifying the equation formed from them, we have the following polynomial equation with respect to $\hat{\psi}_1$, $\hat{\psi}_2, \widehat{T}, \hat{C}$

$$(D^6 R_1 + D^4 R_2 + D^2 R_3 + R_4)\,(\hat{\psi}_1\ ,\ \widehat{T}, \hat{C}) = 0 \tag{18}$$

$$(D^2 + r)\hat{\psi}_2 = 0,\qquad r = \frac{R_6}{R_5} \tag{19}$$

Where

$$\begin{gathered} M_1 = A_4 A_7\omega^2,\quad M_2 = A_1 A_4 A_7 + A_4 A_8\omega^2 - A_5 A_7\omega^2 - A_6 A_{10}\omega^2 + A_3 A_7,\\ M_3 = -A_1 A_4 A_8 + A_5 A_8\omega^2\ ,\ M_4 = A_1 A_5 A_7 + A_1 A_6 A_{10} + A_3 A_8 + A_9 A_6 + A_3 A_{10} - A_4 A_9,\\ M_5 = A_1 A_5 A_8 - A_5 A_9\quad ,\quad M_6 = A_2 {A_{11}}^2 + {A_{11}}^3 M_1 + M_4 A_{11} + M_5,\quad M_7 = M_1 {A_{11}}^2 - 2A_{11}M_2 - A_{11} - M_4\ ,\\ M_8 = M_2 + M_3 - 3M_1 A_{11},\quad M_9 = M_1\ ,\ R_1 = M_6\ ,\quad R_2 = -3M_6\zeta^2 + M_7,\\ R_3 = 3M_6\zeta^4 - 2M_7\zeta^2 + M_8,\quad R_4 = M_7\zeta^4 - M_6\zeta^6 + M_9 - M_8\zeta^2,\quad R_5 = A_2 - A_{11}\omega^2,\\ R_6 = -A_{11}\omega^2\zeta^2 - A_2\zeta^2 - 1 \end{gathered} \tag{20}$$

When we solve Eqs. (18) and (19) we get their roots $\pm r_i$, $(i = 1, 2, 3)$. We have also at infinity the solutions are vanishes or as $z \to \infty$, the solutions of these equations tend to zero, therefore general solutions of each variable are given in the following form

$$\begin{gathered}\hat{\psi}_1 = B_1 e^{-r_1 z} + B_2 e^{-r_2 z} + B_3 e^{-r_{3z}}, \\ \hat{T} = d_1 B_1 e^{-r_1 z} + d_2 B_2 e^{-r_2 z} + d_3 B_3 e^{-r_{3z}} \\ \hat{C} = l_1 B_1 e^{-r_1 z} + l_2 B_2 e^{-r_2 z} + l_3 B_3 e^{-r_{3z}}, \\ \hat{\psi} = B_4 e^{-r_4 z}\end{gathered} \tag{21}$$

Where

$$d_i = \frac{r_i^{\,6} M_{13} + r_i^{\,4} M_{14} + r_i^{\,2} M_{15} + M_{16}}{r_i^{\,4} M_{10} + r_i^{\,2} M_{11} + M_{12}}, \quad i = (1, 2, 3) \tag{22}$$

$$l\,i = \frac{r_i^{\,6} M_{17} + r_i^{\,4} M_{18} + r_i^{\,2} M_{19} + M_{20}}{r_i^{\,4} M_{10} + r_i^{\,2} M_{11} + M_{12}}, \quad i = (1, 2, 3) \tag{23}$$

$$\begin{gathered}N_1 = A_1 - s^2 A_{11},\; N_2 = (A_1 + s^2 A_{11})\zeta^2 + \omega^2, \\ N_3 = -A_3 A_{11},\; N_4 = A_3 + 2A_3 A_{11}\zeta^2, \\ N_5 = A_3 A_{11}\zeta^4 + A_3\zeta^2,\; N_6 = -A_4 A_{11} - A_5,,\; N_7 = A_4 + A_4 A_{11}\zeta^2 + A_5\zeta^2,\; N_8 = A_6 A_{11}, \\ N_9 = A_6 A_{11}\zeta^2 + A_6,\; N_{10} = A_9,\; N_{11} = 2A_9\zeta^2,\; N_{12} = A_9\zeta^4,\; N_{13} = A_{10},\; N_{14} = A_{10}\zeta^2,\; N_{15} = -A_7 A_{11} - A_8, \\ N_{16} = (A_7 A_{11} + A_8)\zeta^2 + A_7,\; N_{17} = A_2 - A_{11}s^2, \\ N_{18} = (A_2 - A_{11}\omega^2)\zeta^2 + \omega^2,\; M_{10} = N_6 N_{15} + N_8 N_{13}, \\ M_{11} = N_6 N_{16} + N_7 N_{15} - N_9 N_{13} - N_8 N_{14},\; M_{12} = N_7 N_{16} + N_9 N_{14},\; M_{13} = -N_3 N_{15} - N_8 N_{10},\; M_{14} = N_9 N_{10} - N_3 N_6 - N_4 N_{15} + N_9 N_{10} + N_8 N_{11},\; M_{15} = N_4 N_{16} - N_5 N_{15} - N_9 N_{11} - N_8 N_{12},\; M_{16} = N_5 N_{16} + N_8 N_{12},\; M_{17} = -N_3 N_{13} - N_6 N_{10},\; M_{18} = N_6 N_{11} - N_7 N_{10} + N_4 N_{13} - N_3 N_{14},\; M_{19} = N_7 N_{11} - N_6 N_{12} - N_5 N_{13} - N_4 N_{14}, \\ M_{14} = N_5 N_{14} - N_7 N_{12}\end{gathered} \tag{24}$$

4. Boundary conditions

On the half-space $z = 0$, a ramp type thermal source is applied. We consider the appropriate boundary condition as

$$(1 - \xi^2\nabla^2)\sigma_{zz} = 0 \tag{25}$$

$$(1 - \xi^2\nabla^2)\sigma_{zx} = 0 \tag{26}$$

$$\frac{\partial}{\partial z} T(x, z, t) = F(t)\, \psi(x) \tag{27}$$

$$\frac{\partial}{\partial z} C(x, z, t) = 0 \tag{28}$$

Where $\psi(x)$ is the source distribution function and

$$\mathrm{F}(t) = \begin{cases} 0, if\ t \le 0 \\ T\dfrac{t}{t_0}, if\ 0 < t \le t_0 \\ T \quad if\ t > t_0 \end{cases}$$

The Laplace and Fourier transformations defined by Eq. (12) on the set of equations Eqs. (25)-(28) we obtain

$$M_{21}B_1 + M_{22}B_2 + M_{23}B_3 + M_{24}B_4 = 0 \tag{29}$$

$$M_{25}B_1 + M_{26}B_2 + M_{27}B_3 + M_{28}B_4 = 0 \tag{30}$$

$$M_{29}B_1 + M_{30}B_2 + M_{31}B_3 = A_{16}\hat{F}_2(s) \tag{31}$$

$$M_{32}B_1 + M_{33}B_2 + M_{34}B_3 = 0 \tag{32}$$

$$\hat{\mathrm{F}}(s) = T\left(\frac{1 - e^{-st}}{ts^2}\right) \tag{33}$$

where

$$\begin{gathered}M_{21} = A_{11}\lambda(r_1^{\,2} - \zeta^2) - \lambda A_{11}^{\,2}(r_1^{\,4} - 2\zeta^2 r_1^{\,2} + \zeta^4) - 2\mu r_1 + 2\mu A_{11} r_1^{\,3} - 2\mu A_{11}\zeta^2 r_1 - A_3 d_1 - A_{11}A_3 r_1^{\,2} d_1 + A_{11}A_3\zeta^2 d_1 - A_3 l_1 - A_{11}A_3 r_1^{\,2} l_1 + A_{11}A_3\zeta^2 l_1,\; M_{22} = A_{11}\lambda(r_2^{\,2} - \zeta^2) - \lambda A_{11}^{\,2}(r_2^{\,4} - 2\zeta^2 r_2^{\,2} + \zeta^4) - 2\mu r_2 + 2\mu A_{11} r_2^{\,3} - 2\mu A_{11}\zeta^2 r_2 - A_3 d_2 - A_{11}A_3 r_2^{\,2} d_2 + A_{11}A_3\zeta^2 d_2 - A_3 l_2 - A_{11}A_3 l_2 r_2 + A_{11}A_3\zeta^2 l_2,\; M_{23} = A_{11}\lambda(r_3^{\,2} - \zeta^2) - \lambda A_{11}^{\,2}(r_3^{\,4} - 2\zeta^2 r_3^{\,2}) + \zeta^4) - 2\mu r_3 + 2\mu A_{11} r_3^{\,3} - 2\mu A_{11}\zeta^2 r_3 - A_3 d_3 - A_{11}A_3 r_3^{\,2} d_3 + A_{11}A_3\zeta^2 d_3 - A_3 l_3 - A_{11}A_3 l_3 r_3 + A_{11}A_3\zeta^2 l_3,\; M_{24} = i\zeta - A_{11} i\zeta r_4^{\,2} + A_{11} i\zeta r_4^{\,2}, M_{25} = \mu\big(-r_1 + A_{11}(r_1^{\,3} - \zeta^2 r_1)\big),\; M_{26} = \mu\big(-r_2 + A_{11}(r_2^{\,3} - \zeta^2 r_2)\big),\; M_{27} = \mu\big(-r_3 + A_{11}(r_3^{\,3} - \zeta^2 r_3)\big), M_{28} = \mu\big(i\zeta - A_{11}(i\zeta r_4^{\,2} - i\zeta^3)\big),\; M_{29} = -r_1 d_1, \\ M_{30} = -r_2 d_2, M_{31} = -r_3 d_3,\; M_{32} = r_1 l_1, \\ M_{33} = r_2 l_2, M_{34} = r_3 l_3\end{gathered} \tag{34}$$

when we solve the system of Eqs. (29)-(32), we get the nontrivial values of Bi, i = 1, 2, 3, 4 given by

$$B_1 = \frac{A_{16}\hat{F}\,(S)\hat{\psi}_2(\zeta)\Delta_{12}}{\Delta} \tag{35}$$

$$B_2 = \frac{A_{16}\hat{F}\,(S)\hat{\psi}_2(\zeta)\Delta_{22}}{\Delta} \tag{36}$$

$$B_3 = \frac{A_{16}\hat{F}\,(S)\hat{\psi}_2(\zeta)\Delta_{32}}{\Delta} \tag{37}$$

$$B_4 = \frac{A_{16}\hat{F}\,(S)\hat{\psi}_2(\zeta)\Delta_{42}}{\Delta} \tag{38}$$

where

$$\begin{gathered}\Delta_{12} = M_{28}M_{22}M_{34} - M_{28}M_{23}M_{33} + M_{24}M_{27}M_{33} - M_{24}M_{26}M_{34}, \\ \Delta_{22} = M_{24}M_{25}M_{34} - M_{28}M_{23}M_{33} + M_{24}M_{27}M_{33} - M_{24}M_{26}M_{34}, \\ \Delta_{32} = M_{24}M_{26}M_{32} - M_{24}M_{25}M_{33} + M_{28}M_{21}M_{33} - M_{22}M_{28}M_{32}, \\ \Delta_{42} = -M_{23}M_{26}M_{32} + M_{22}M_{27}M_{32} + M_{23}M_{25}M_{33} - M_{21}M_{27}M_{33} - M_{22}M_{25}M_{34} + M_{21}M_{26}M_{34}\end{gathered} \tag{39}$$

Table 1 copper parameters and their values

Constant notation	Value	Constant notation	Value
λ	$7.76{*}10^{10}Nm^{-2}$	μ	$3.86*10^{10}N\,m^{-2}$
α_t	$1.78*10^{-5}K^{-1}$	α_c	$2.65{*}10^{-4}m^3Kg^{-1}$
ρ	$8954kgm^{-3}$	γ_1	0.02s
γ_2	0.2s	K	$386J(msk)^{-1}$
A	$1.2*104m^2KS^2$	b	$0.9*10^6Kgm^5s^2$
T_0	$293K$	C_E	$383.1{*}\mathrm{J}(KgK)^{-1}$
D	$8.5*10^{-9}$	ξ	$3..95*10^{-10}$
ζ	$2*10^{-10}$	K^*	1.2
S	1		

By applying Fourier transform on Eq. (11), substitute from Eq. (21) using Eqs. (35)-(38) we get equations of displacement, stress, temperature and concentration as follow

$$\hat{u}=\frac{\hat{F}(S)A_{16}\hat{\psi}_2(\zeta)}{\Delta}\left(i\zeta\sum_{n=1}^{3}\Delta_{n2}e^{-r_nz}+r_4\Delta_{42}e^{-r_4z}\right) \tag{40}$$

$$\hat{w}=\frac{\hat{F}(S)A_{16}\hat{\psi}_2(\zeta)}{\Delta}\left(\sum_{n=1}^{3}r_n\Delta_{n2}e^{-r_nz}-\Delta_{42}e^{-r_4z}\right) \tag{41}$$

$$\hat{T}=\frac{\hat{F}(S)A_{16}\hat{\psi}_2(\zeta)}{\Delta}\left(\sum_{n=1}^{3}\Delta_{n1}d_ne^{-r_nz}\right) \tag{42}$$

$$\hat{C}=\frac{\hat{F}(S)A_{16}\hat{\psi}_2(\zeta)}{\Delta}\left(\sum_{n=1}^{3}\Delta_{n1}l_ne^{-r_nz}\right) \tag{43}$$

$$\hat{\sigma}_{zz}=\frac{\hat{F}(S)A_{16}\hat{\psi}_2(\zeta)}{\Delta}\left(\sum_{n=1}^{3}\Delta_{n2}(\lambda {r_n}^2-\lambda\zeta^2-2\mu r_n-A_3d_n-A_3l_n)+\Delta_{42}\right) \tag{44}$$

$$\hat{\sigma}_{xz}=\frac{\hat{F}(S)A_{16}\hat{\psi}_2(\zeta)}{\Delta}\left(-2\sum_{n=1}^{3}\Delta_{n2}r_n\mu i\zeta-\Delta_{42}\mu({r_4}^2+\zeta^2)\right) \tag{45}$$

5. Application

5.1 Concentrated Load

The solution due to concentrated normal force on the half space is obtained by setting

$$\psi(x)=\delta(x) \tag{46}$$

Where $\delta(x)$ is dirac delta function. Applying Fourier transform defined by Eq. (13) on Eq. (46)

$$\hat{\psi}(\zeta)=1 \tag{47}$$

Using (47) in the set of Eqs. (40)-(45), we obtain the components of displacement, stress and temperature change and mass concentration.

5.2 Uniformly distributed load

The solution due to uniformly distributed force applied on the half space is obtained by setting

$$\psi(x)=\begin{cases}1\ if\ |x|\le m\\ 0\ if\ |x|>m\end{cases} \tag{48}$$

The Laplace and Fourier transforms of $\psi_1(x)$ and $\psi_2(x)$ with respect to the pair (x,ξ) for the case of a uniform strip load of non dimensional width 2 m applied at origin of co-ordinate system $x_1=x_3=0$ is given by

$$\widehat{\psi(\zeta)}=\left[{}^{2\sin(\zeta m)}/_{\zeta}\right]\qquad \xi\neq 0 \tag{49}$$

Using (49) in the set of Eqs. (40)-(45), we obtain the components of displacement, stress and temperature change and mass concentration.

5.3 Linearly distributed Load

The solution due to linearly distributed force applied on the half space is obtained by setting

$$\psi(x)=\begin{cases}1-\dfrac{|x|}{m}\ if\ |x|\le m\\ 0\ if\ |x|>m\end{cases} \tag{50}$$

Here 2 m is the width of the strip load, using Fourier transform defined by (13) on (50) we obtain

$$\widehat{\psi(\zeta)}=\left[{}^{2\{1-\cos(\zeta m)}/_{\zeta^2m}\right]\qquad \xi\neq 0 \tag{51}$$

Using (51) in the set of Eqs. (40)-(45) ,we obtain the components of displacement, stress and temperature change and mass concentration.

6. Numerical results and discussion

To investigate the effect of thermal force on nonlocal thermoelastic material of the nonlocal parameter, we consider the copper material. As mentioned in the studies of (Malik *et al.* 2023), the material constants of copper metal are given by the following table.

The values of constants in copper metal parameters with their standard unit.

6.1 Concentrated load

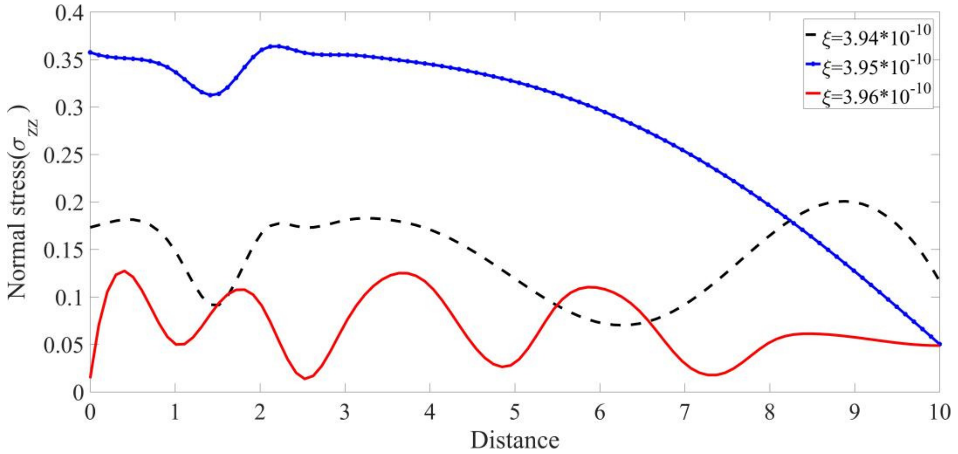

Fig. 1 Variation in normal stress due to ramp type heat (concentrated Load)

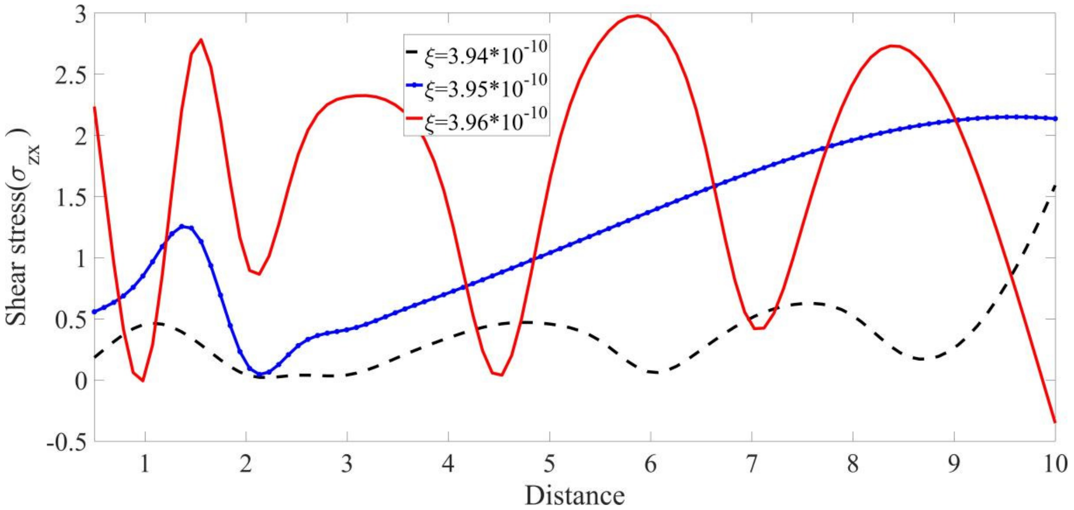

Fig. 2 Variation in shear stress due to ramp type heat (concentrated Load)

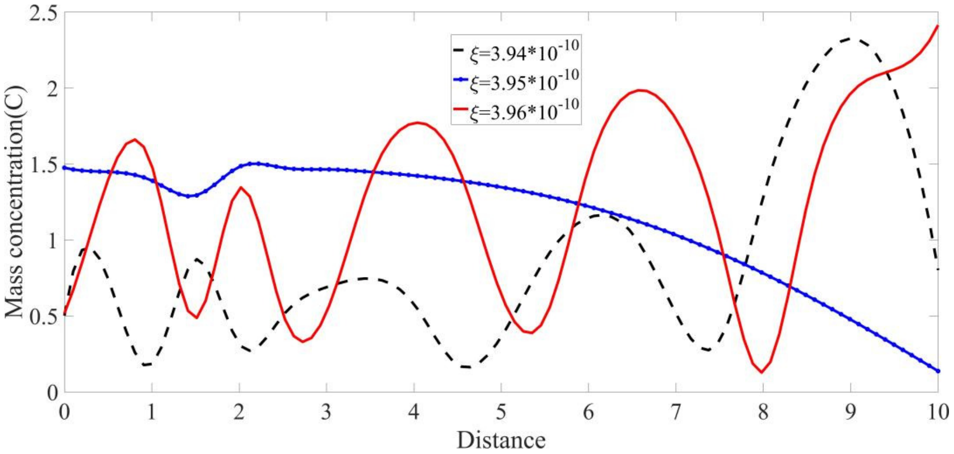

Fig. 3 Variation in mass concentration due to thermal sourcce (concentrated Load)

6.2 Uniformly distributed load

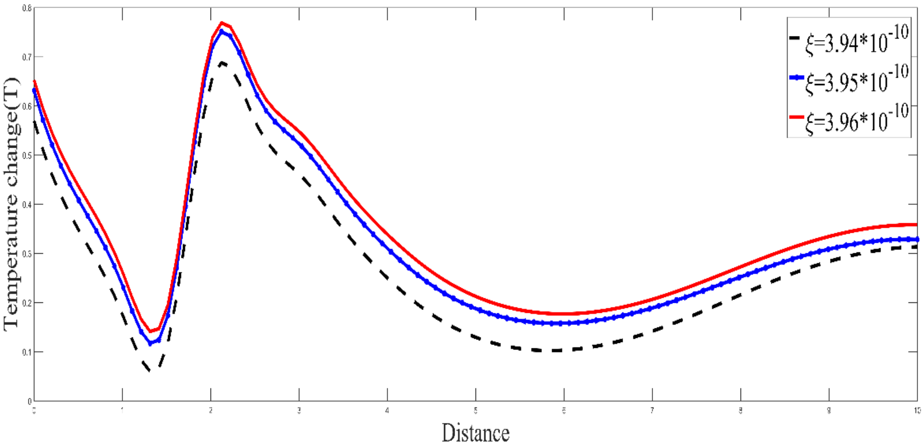

Fig. 4 Variation in temperature change due to ramp type heat (concentrated Load)

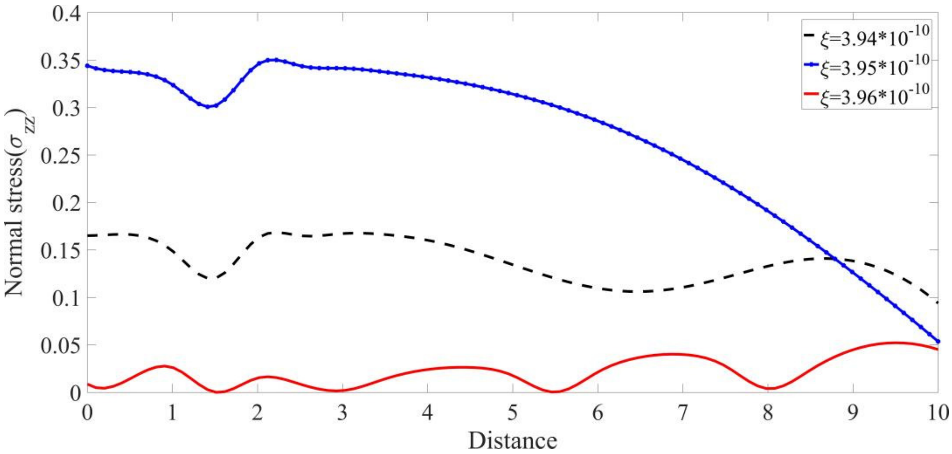

Fig. 5 Variation in normal stress due to ramp type heat (linearly distributed Load)

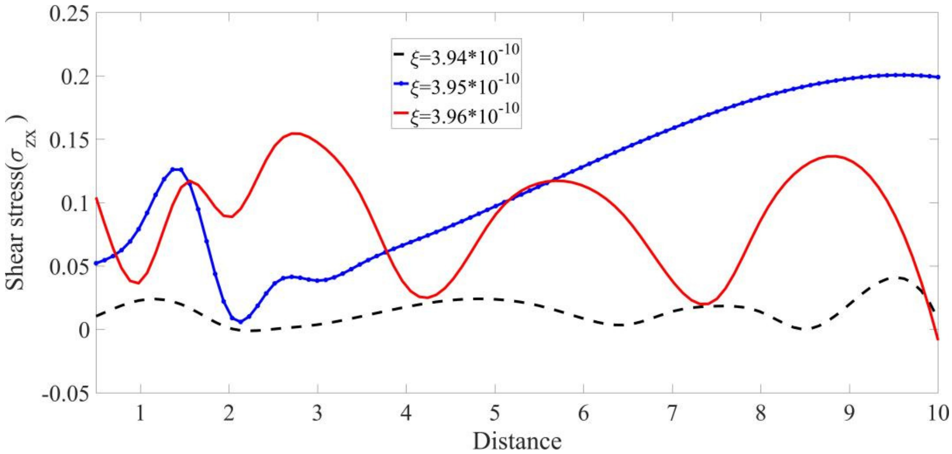

Fig. 6 Variation in shear stress due to ramp type heat (uniformly distributed Load)

6.3 Linearly distributed load

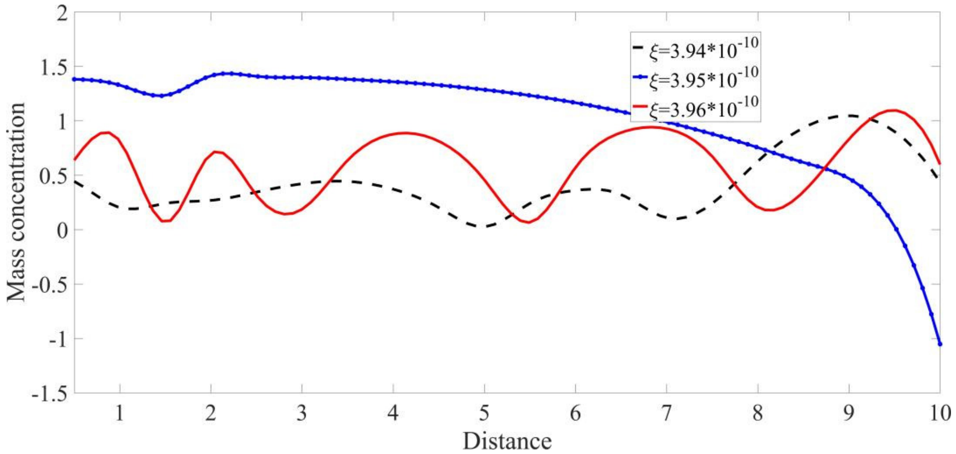

Fig. 7 Variation in mass concentration due to ramp type heat (uniformly distributed Load)

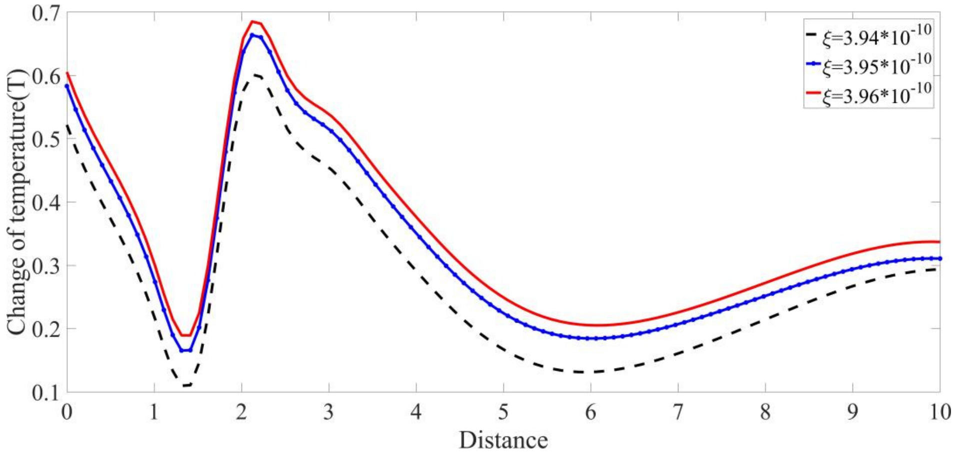

Fig. 8 Variation in temperature change due to ramp type heat (uniformly distributed Load)

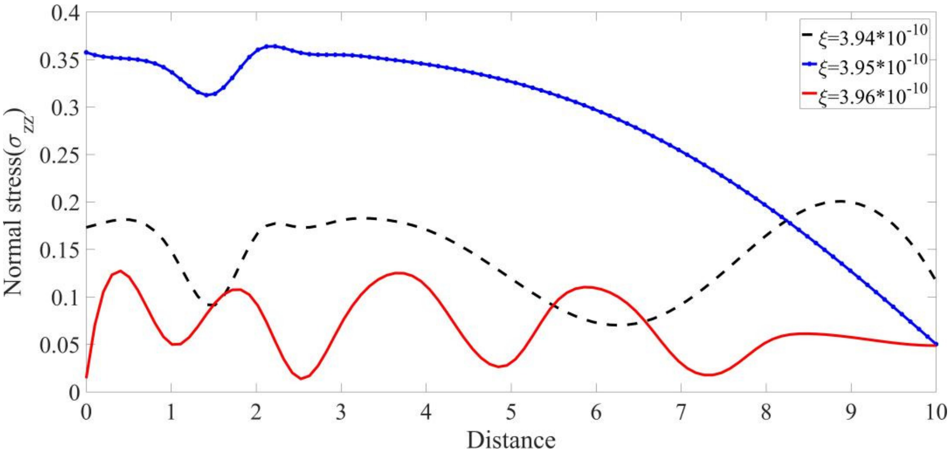

Fig. 9 Variation in normal stress due to ramp type heat (linearly distributed Load)

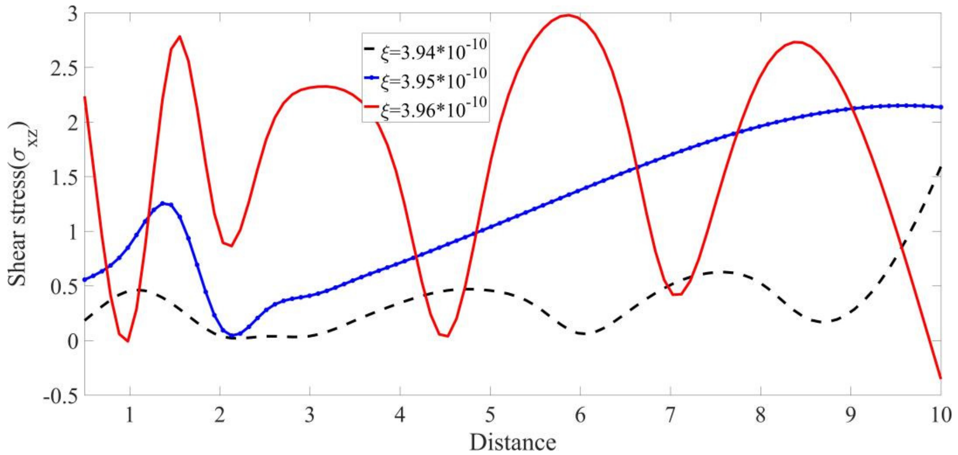

Fig. 10 Variation in shear stress due to ramp type heat (linearly distributed Load)

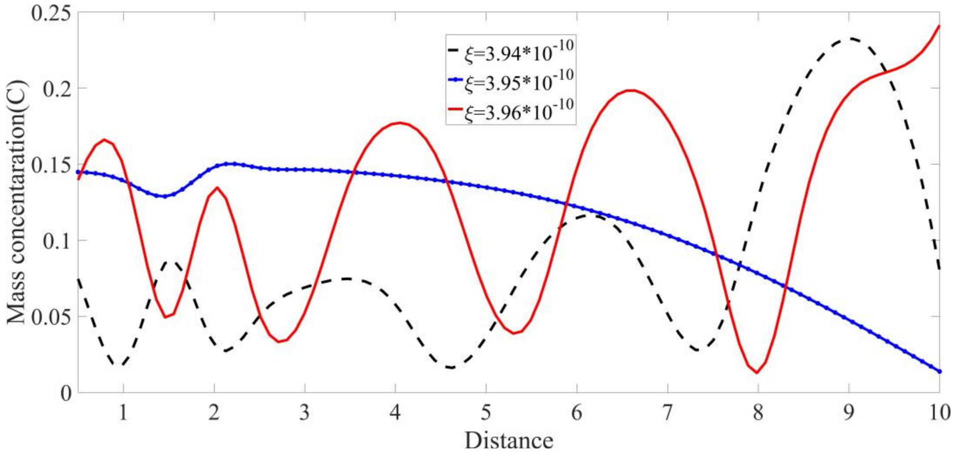

Fig. 11 Variation in mass concentration due to ramp type heat (linearly distributed Load)

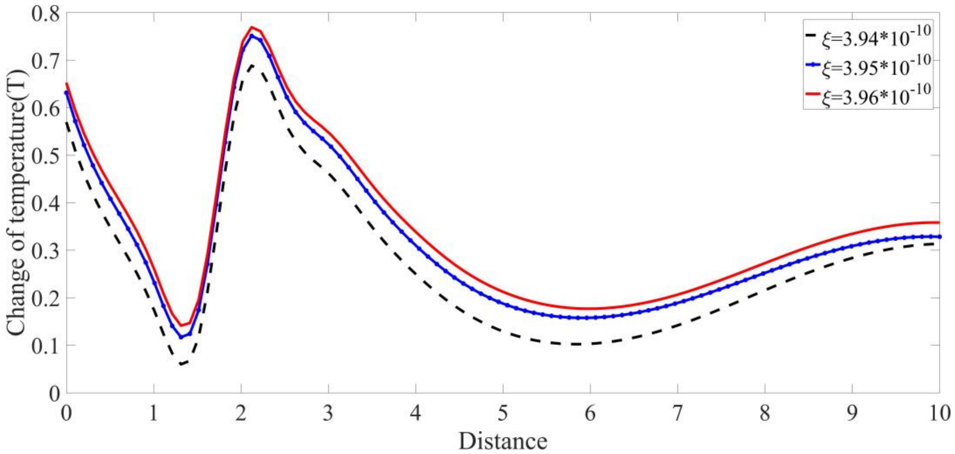

Fig. 12 Variation in temperature change due to ramp type heat (linearly distributed Load)

Figs. 1, 5 and 9 show a similar pattern, but their amplitude and periodicity are different. These differences are caused by the varying values of nonlocal parameters and different types of ramp-type sources. The figures suggest that the thermal source plays a role in changing the normal stress. As the nonlocal parameters change, the effect of the thermal source also changes. This means that both the nonlocal parameters and the type of thermal source influence the normal stress behavior.

Figs. 2, 6 and 10 illustrate the effect of the nonlocal parameter on shear stress under a ramped- type source. These graphs show that shear stress is directly influenced by changes in the nonlocal parameters. The patterns of the graphs are oscillatory, with varying amplitudes and periods de- pending on the type of thermal source and the values of the nonlocal parameters. As the nonlocal parameters change, both the amplitude and periodicity of the shear stress fluctuate. This suggests that the interaction between the ramped-type source and the nonlocal parameter plays a key role in determining the shear stress behavior.

Figs. 3, 7 and 11 demonstrate how the nonlocal parameter influences the mass concentration of materials under ramp type heat. These graphs exhibit an oscillatory pattern with varying amplitudes depending on the values of the nonlocal parameter. Under a concentrated thermal load, the mass concentration decreases along the x-axis from left to right. However, when the load is uniformly or linearly distributed, the mass concentration follows an oscillatory pattern. This indicates that both the type of thermal load and the nonlocal parameter significantly affect the mass concentration behavior.

Figs. 4, 8 and 12 show that the change of temperature under ramp type heat of different loads are affected by nonlocal parameters and all the graphs are started by sharply decreasing then in- creasing and then after oscillated slowly. The shape of the graphs of change of temperature under concentrated, uniformly and linearly distributed loads are looking same but different vertical shift and oscillation periods.

Figs. 4, 8 and 12 illustrate how temperature changes under ramp type heat with different loads are influenced by nonlocal parameters. All the graphs initially show a sharp decrease, followed by an increase, and then gradually transition into a slow oscillatory pattern. While the overall shape of the temperature variation remains similar for concentrated, uniformly, and linearly distributed loads, they differ in vertical shift and oscillation periods. These differences indicate that both the type of thermal load and the nonlocal parameters play a crucial role in determining temperature behavior.

7. Conclusions

In this study we solved the mathematical model of nonlocal thermoelastic diffusive solid due to ramp type heat. The method we use is Laplacian and Fourier transformation methods. Our study show that nonlocal parameters and ramped-type thermal sources has close relations with the change behavior of normal stress, shear stress, mass concentration, and temperature changes in the material. The results indicate that nonlocal parameter alter the amplitude, periodicity and oscillatory patterns of these physical quantities. This means the nonlocal parameter is necessary in distinguishing of qualities of materials. Normal and shear stresses exhibit direct dependency on nonlocal parameters, with variations in amplitude and frequency. Similarly, mass concentration shows different trends based on the type of thermal load, decreasing under concentrated loads and oscillating under uniformly and linearly distributed loads. Temperature changes follow a consistent pattern of sharp initial decrease, rise, and gradual oscillation, with variations in vertical shift and period. The combined effects of nonlocal parameters and ramped-type sources suggest that material responses can be controlled by adjusting these factors. These findings are essential for designing advanced thermoelastic diffusion systems where precise stress, mass concentration and temperature control is required. This study focusses on the effect of nonlocal parameters on the above variables and used secondary data of copper metal. Future work will focus on extending the current model to incorporate anisotropic material behavior, multi-layered structures and time-dependent boundary conditions under ramp-type heat.

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