Two-Temperature Generalized Thermoelastic Infinite Medium with Cylindrical Cavity Subjected To Time Exponentially Decaying Laser Pulse

Eman A. N. Al-Lehaibi

Department Mathematic, College of Science and Arts Sharoura, Najran University, KSA

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The present work is devoted to a study of the induced temperature and stress fields in an elastic infinite medium with cylindrical cavity under the purview of two-temperature thermoelasticity. The medium is considered to be an isotropic homogeneous thermoelastic material. The bounding plane surface of the cavity is loaded thermally by time exponentially decaying laser pulse. An exact solution of the problem is obtained in Laplace transform space, and the inversion of Laplace transforms have been carried numerically. The derived expressions are computed numerically for copper, and the results are presented in graphical form.

1. INTRODUCTION

In-depth research has been conducted on generalized thermoelasticity theories in solving thermoelastic problems in place of the classical uncoupled/coupled theory of thermoelasticity. The absence of any elasticity term in the heat conduction equation for uncoupled thermoelasticity appears to be unrealistic, since the produced strain causes variation in the temperature field due to the mechanical loading of an elastic body. The parabolic type of heat conduction equation results in an infinite velocity of thermal wave propagation, which also contradicts the actual physical phenomena. By introducing the strain-rate term in the uncoupled heat conduction equation, the analysis to incorporate coupled thermoelasticity has been extended by Biot.[1] Although the first paradox was over, the parabolic type partial differential equation of heat conduction remains, which leads to the paradox of infinite velocity of the thermal wave. To eliminate this paradox, generalized thermoelasticity theory was developed subsequently. Due to the advancement of pulsed lasers, fast burst nuclear reactors, and particle accelerators, which can supply heat pulses with a very fast time-rise, Bargmann.[2] and Boley[3] generalized thermoelasticity theory is receiving serious attention. Chandrasekharaiah reviewed the development of the second sound effect.[4] Recently, mainly two different models of generalized thermoelasticity are being extensively used: one proposed by Lord and Shulman and the other proposed by Green and Lindsay.[5,6] Lord and Shulman theory (L-S) suggests one relaxation time, and according to this theory, only Fourier's heat conduction equation is modified; however, Green and Lindsay theory (G-L) suggests two relaxation times, and both the energy equation and the equation of motion are modified.

The so-called ultra-short lasers are those with pulse duration ranging from nanoseconds to femtoseconds in general. In the case of ultra-short-pulsed laser heating, the high-intensity energy flux and ultra-short duration laser beam, have introduced situations where very large thermal gradients or an ultra-high heating speed may exist on the boundaries, according to Sun et al.[7] In such cases, as pointed out by many investigators, the classical Fourier model, which leads to an infinite propagation speed of the thermal energy, is no longer valid for Tzou.[8,9] The non-Fourier effect of heat conduction takes into account the effect of mean free time (thermal relaxation time) in the energy carrier's collision process, which can eliminate this contradiction. Wang and Xu have studied the stress wave induced by nanoseconds, picoseconds, and femtoseconds laser pulses in a semi-infinite solid.[10] The solution takes into account the non-Fourier effect in heat conduction and the coupling effect between temperature and strain rate. It is known that characteristic elastic waveforms are generated when a pulsed laser irradiates a metal surface.

The two-temperatures theory of thermoelasticity was introduced by Gurtin and Williams,[11] Chen and Gurtin,[12] and Chen et al.,[13,14] in which the classical Clausius-Duhem inequality was replaced by another one depending on two temperatures; the conductive temperature φ and the thermodynamic temperature T, the first is due to the thermal processes, and the second is due to the mechanical processes inherent between the particles and the layers of elastic material, this theory was also investigated by Iean.[15] Abbas solved many problems that discussed the two-temperature theory of thermoelasticity and also the thermoelastic medium with cylindrical cavity.[16–20]

Only in the last decade has the theory of two-temperature thermoelasticity been noticed, developed in many works, and found its applications mainly in the problems in which the discontinuities of stresses have no physical interpretations. Among the authors who contribute to this theory, Quintanilla studied existence, structural stability, convergence, and spatial behavior for this theory.[21] Youssef introduced the generalized Fourier law to the field equations of the two-temperature theory of thermoelasticity and proved the uniqueness of solution for homogeneous isotropic material.[22,23] Puri and Jordan recently studied the propagation of harmonic plane waves,[23] and Magaa and Quintanilla[24] have studied the uniqueness and growth solutions for the model proposed by Youssef.[25]

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