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NUMERICAL INVESTIGATION FOR EFFECT OF HOLE ON THERMAL ANALYSIS OF RECTANGULAR PLATE

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Abstract

The temperature distribution over a plate is one of the most fundamental aspects of any investigation in engineering and science, and it has implications in many different sectors. Mechanisms of heat transfer within a solid plate are of extreme importance for many fields, such as aerospace engineering, electronics, materials science, and energy systems. The ability to more accurately model and predict temperature distributions within a plate may allow for new thermal management strategy development, material selection optimization, and overall system optimization. This work investigates the numerical study of thermal behavior in rectangular plates with and without a central circular hole during steady-state heat transfer conditions. This paper aims at making a thorough analysis of the temperature distribution and heat flux on a solid plate and a hole-containing plate by changing geometric configurations and patterns of the boundary conditions, while emphasizing the impact of hole presence on the thermal performance of the plate. The presence of the aperture introduces regions of stress concentration and changes the transfer mechanism, which is the cause for localized fluctuations in temperature as well as changes in the flux of heat, too. Numerical study is made using the finite element method. Two different cases are simulated: a solid square plate with no perforation and a square plate having a central circular hole of different diameters. Several parameters, including the geometry of the plates, hole diameters, and the thermal conductivities of materials with different types of boundary conditions, affect the distribution of temperatures and heat flux in the setup. The following temperature contour and heat flux vector plots provide further insights into thermal dynamics of this setup. The results presented here are expected to improve the design and thermal performance of perforated rectangular plates, irrespective of the perforations, and hence help facilitate progress in both thermal efficiency and structural integrity.

Keywords: *Ansys, Temperature Distribution, Steady State, Heat Flux, Thermal Conductivity.*

1. INTRODUCTION

The research on thermal stresses in perforated plates constitutes a very highly relevant area of inquiry within the domain of thermo-elasticity, strongly overlapping with numerous areas of engineering. The subject has grown with time and has been able to encompass more and more sophisticated geometries and material characteristics: isotropic to anisotropic materials; simple circular apertures to complex ones. In fact, in this period, the foundation for the study of thermal stress in plates was laid. Mindlin [1] discussed some of the basic ideas in mechanics; he could have been concerned with material stress-strain relations. In this study, one might see some new mathematical representations or analytical methods which are said to explain how materials behave when put under a variety of

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Vol: 62 | Issue: 04 | 2025

different loads. It may provide an important foundation upon which further breakthroughs could be made in applied mechanics and materials science. This paper by Florence and Goodier [2] discusses thermal stresses around spherical cavities and circular holes in materials under uniform heat flow. The work they carried out was the development of mathematical models that would enable them to predict the stress distributions within those specific configurations. This investigation has significant importance in understanding how structural discontinuities impact the thermal stress distributions and might be valuable for engineering design and material selection. A similar work extended by Florence et al. [3] is taken from the earlier one, that is, by studying the thermal stress around an insulated, ovaloid hole in a direction of uniform heat conduction. On the basis of this probably, geometrical complexity that is associated with the aperture comes into consideration, and hence, further complex mathematical forms are put to use.

Their results open up the possibility that hole-geometry effects are quite significant in the description of the thermal stresses bearing upon design considerations in specific applications sensitive to heat. Probably the most comprehensive reference on the effect of holes on the distribution of stress in materials is Savin's work, [4] "Stress Concentration Around Holes," published in 1961. The text probably covers a wide range of hole geometries, dimensions, and orientations as well as provides analytical methods and practical case studies. A new landmark study into structural integrity testing and material failure analysis, authored for engineers as well as the researcher, includes this 1968 research by Lekhnitskii [5] on anisotropic plates where a whole treatment of stress as well as deformation problems of materials depending on anisotropic direction is included that might involve such mathematical models applied as well as analytic techniques being appropriate to those anisotropic materials. This research could have significant implications in the understanding and utilization of high-performance materials, including composites and certain types of crystalline structures. Greszczuk's [6] work in 1971 was on the practice of mechanics in the aerospace industry, possibly stress analysis of aircraft structures or materials. The research could be on developing new analytical or experimental techniques that might be used to better understand material behavior under aerospace conditions.

This research would have allowed progress on the subtopics of airframe design and material selection pertinent to aerospace work. In the year 1974, Deb Nath [7] performed a research work that established new discoveries inside the mechanical field. This study entailed a stress analysis using material behavior including the subtopic of structural mechanics and novel analytical methods to bring to light subtleties of mechanical events. Tauchert et al. [8] (1985) studied the effect of temperature fluctuation on stress distributions in materials or structures. It included mathematical models with relevant experimental data for thermo-elasticity. This kind of research is important in the designing of structures or components to be used within different thermal environments. Zimmermann [9] (1986) researched the compressibility of properties of two-dimensional cavities having varied geometrical configurations. The author discussed analytical methods to calculate the distortion of these cavities when pressure is applied. Potentially, this study could be very important in the context of geo-mechanics, materials science, and fluid dynamics to understand the geometry of a void in a material and compressibility of a material. Chandrashekhara et al. [10] (1989) reported detailed work on the analysis and design methods for composite materials. New models and experiment results of this work related to stress, deformation, and failure mechanisms of composite structure are analyzed in the paper. High chances exist that such diverse composite materials engineering will start launching with applications relevant to aerospace and automobile industry fields. Hwu [11] (1990) discussed thermal stresses in anisotropic plates containing elliptic holes or cracks. The current study will emphasize the development of the mathematical models in the lines of predicting stress distributions within complex structural systems. The current study holds great importance in explaining how material anisotropy

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Vol: 62 | Issue: 04 | 2025

and geometric discontinuities interact with each other to affect distributions of thermal stress and so might have implications in the development of advanced materials and optimization of the structural design.

Probably, in that paper, presented by Hsu et al. [12] in 1993, they were looking for further application of the method at the boundary within engineering analysis; probably comes up with the new method overcoming complexities arising when these methods would be considered applied within structural mechanics, or heat transfer problems. Perhaps, the paper could also present methods of ways to improve computational techniques towards understanding distribution of stress and thermal behaviors in materials. Maybe this research finds important things further to enhance better engineering design process and the methodological approaches put in structural analyses. The one done by Lin and Hwu [13] in 1993 dealt on how an elliptical rigid inclusion could influence heat flow through the anisotropic elastic matrix for uniformity. Most probably they also recommend in such studies, the mathematical models intended to compute temperature and stress distribution about the inclusion. The study can explain the thermal behavior exhibited by composite materials or structures that contain an embedded part of great significance. The results might be highly applicable to designing the heat management system as well as for predicting the thermal stresses in the complex materials. The article from Shiau and Wu [14] in Composite Structures, 1996, may be discussing the analysis or design issues concerning the composite material under some sort of conditions. Their work is probably providing new modeling or experimental observation that would relate to the behavior of the composite structure.

The benefit regarding distribution, deformation, as well as stress states and modes of failure. The result might be highly significant for the relevant applications in bringing composite material design up to increased standards as well as overall improvements in the behavior of structures consisting of composites in a whole large range of structural applications. In the work of Qin [15] from the year 2000, an integrated solution is developed for the solution of thermos-piezoelectric materials with heterogeneously hole configurations under conditions of thermal loading. It might also be a report on advanced mathematical models introduced to predict the inter-coupled thermal, electrical, and mechanical responses given by the materials. The work has a huge potential to continue the development in knowledge and designs of advanced smart materials and sensor technologies. The results can have great influence on the design of more efficient energy-harvesting devices or adaptive structural systems. The paper presented by Chao and Gao [16] in 2001 deals with mixed boundary-value problems for two-dimensional anisotropic thermoelectricity, specifically on elliptic boundaries. Their work may describe analytical methods used to solve these complex problems. This work may explain the distribution of stress and temperature in anisotropic materials having non-circular inclusions or boundaries. Results can be of some significance in the design and analysis of advanced composite structures and microelectronic devices.

Wang and Chao, [17] in their 2002 paper, have considered the perturbation solutions for nearly circular inclusion problems under the plane thermoelectricity. Their work likely gives a rough analytical means of estimating stress and temperature distribution around nearly noncircular inclusions. This research may give even more practical approaches to analyzing geometries in the field of thermos-elastic material. The outcomes may be quite concerning for the engineers in many applications that have taken into consideration accounting for a slight non-circularity of geometries. The paper by Gao et al. [18] in the year 2002 is considered a precise analysis about elliptic hole problems in relation to thermo-piezoelectric media. His work most likely yields some excellent, detailed mathematical solutions to forecast the coupled fields of thermal, electrical, and mechanics around some elliptical voids. This paper promises to unveil a lot to enlighten upon the behavior of advance multifunctional materials characterized through structural discontinuity. There are broader impacts of the material

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Vol: 62 | Issue: 04 | 2025

work in engineering sensor, actuators or devices for energy harvesting based on thermos piezoelectric material responses. Advanced dynamic material concepts for micro-electromechanical system, published year 2002 by Vel, Batra [19] for International Journal of Solids and Structures, which might include even the structural analyses into detailed complexities of material responses. New analysis may include advanced analytical or even numerical techniques developed specifically for the hard problems to come out in the discipline of solid mechanics. This investigation can further be contributory to the understanding of material behaviors under various kinds of loading. Results obtained in this research may go a long way in improving the design of the structure, selecting the material, and developing more refined analysis techniques for engineering applications. Zhang et al. [20] have conducted the study in the year 2003 about the thermal stresses that exist around a circular hole in a functionally graded plate. Their work likely explains analytical or numerical procedures which predict stress distributions in such advanced materials. Such work holds good potential significance for the explanation of the effect that material property gradients have on the appearance of thermal stress patterns. Possible implications from these results may be significant to the development of structures that show enhanced resilience at high temperatures.

The research work from Simetière and Zidi [21] of the International Journal of Solids and Structures on complexity problems on solid mechanics from the year 2004 is likely dealing with these topics. This paper can give out some novel analytical models or new methods for computing within material behavior. It might give better knowledge in phenomena involving stress and deformation on advanced materials or structural systems. Conclusions obtained as a result of this work might have importance in designing advanced techniques for structural designs and material determining of many types of engineering applications. Recent research done by Hwu and Lee [22] in the year 2004 has considered the thermal influence on singular behavior of a multi-bonded anisotropic wedge study. Perhaps their work gives some mathematical models to estimate the stress concentrations across material interfaces under conditions of thermal loading. This study can give an understanding of failure modes related to composite structures and bonded materials. Perhaps it may be important insights to improve design concerning multi-material systems that function under a very broad range of temperatures.

Hasebe and Wang [23] published an article in 2005 that deals with a new method of handling thermal stress, achieved by complex variable methods. Their research probably develops new analytical techniques in the calculation of temperature and stress distributions in materials. This paper may contribute significantly to better analytical methods for thermal stress analysis in complex geometrical setups. Huge practical implementations are expected from the outcomes both in thermal management and structural design engineering fields. In Bhullar's [24] work from the year 2006, an experimental work was carried out on a hexagonal domain having an elliptic aperture. Analytical or numerical methods may be provided for the research to predict the stress distributions within the given geometric arrangement. The kinds of research can be done that can give valuable information about hole geometry and orientation that are affecting thermal stress distributions in non-circular structural arrangements. The result obtained can be of importance for designing heat-resistant components or structures that have complex geometries. Such exploration probably reveals stress and deformation analysis regarding a uniform heat flux subjected upon rigid and stiffened surfaces through dynamics or simulation using analytical approach on rigid-inclusion liner cracks by Hasebe et al. [25] in the year 2007, predicting specific numerical or mathematical model relating stress intensity for stress under particular load such cases as can describe how one such material failed while subjected on this nature type. The results could be of great importance in enhancing the strength of the material under mechanical and thermal loads. Sharma et al. [26] published a paper in 2007 in the Journal of Thermal Stresses, allegedly to explore advanced topics on the subject of thermal stress analysis. New Analytical Techniques This research could trigger new analytical techniques or experimental data related to material stresses due to temperature-induced effects or their structural configurations. Such a study would be able to enhance the knowledge regarding the effects of thermal load on material responses and structural reliability. The significance of this finding could be greater for enhancing thermal management methods in a variety of engineering applications. Aseeri's [27] 2008 study used Goursat functions to examine the behavior of an isotropic plate with a curvilinear hole. The most probable outcome of this study will be analytical solutions regarding the stress distributions around non-circular apertures. Such a study may lead to the development of new mathematical methodologies for solving intricate boundary value problems in the field of elasticity. Such a study may find findings to be of great paramountcy to stress analysis of structures characterized with unregular shapes of their openings or inclusions.

Hasebe et al. [28] study of 2010 touches upon heat conduction phenomena and thermal stress produced by an electric current in a thin plate containing an elliptic hole and edge crack. Probably, their work introduces coupled electro-thermo-mechanical models to address this complicated scenario. This study may carry significant significance to explain the failure mechanisms related to electronic components or conductive materials. The results may have major implications in the creation of more dependable electrical systems or for more resistant conductive materials. Hwu's [29] 2010 work on anisotropic elastic plates probably presents detailed analysis on stress and deformation within anisotropic materials that are sensitive to direction. It may encompass a variety of loading conditions, boundary value problems, and analytical methods that can be classified into the category of the anisotropic elasticity field. It may act as some kind of source that is highly important to scholars and practitioners working in the fields of the study and application of advanced materials. It could potentially lead to insightful benefits, together with methodology improvements towards the designing as well as an analysis of composite and crystal-like material-containing structures. This must obviously be some highly technical paper in International Journal of Mechanical Sciences by Jain and Mittal [30] for the year 2011 that deals with very advanced topics under the head of solid mechanics or the behavior of materials. Their study may present some new analytical or numerical techniques to overcome some complex problems which may originate in the field of structural analysis. Such a study is likely to develop a better understanding of material behavior under various kinds of loading. The results of the present study can have important consequences for the betterment of the design methodologies for structures or analytic techniques in applications of engineering. Tang and Shen's [31] research publication in the 2013 version of Composite Structures likely describes one of the analytical aspects of advanced composites material or designing structure.

Presumably, an experimental or original model can result in this document as related information regarding composite characteristics under specific conditions for certain types. It is significant in further progress within the body of knowledge at the frontiers in composite engineering towards better insight with stress distribution mechanisms, deformation capabilities, and patterns of failure processes. The result may be of significant importance for enhancing the performance of composite structures in many industrial applications. Abbas [32] in his work in 2014 applied a fractional order generalized Newtonian model for the study of the thermos-elastic interactions, which in this case was in an infinite fiber-reinforced anisotropic plate with a circular aperture. Such a work will have the appearance of opening up new mathematical approaches toward predicting the stress and temperature distributions in such a complex material system. The investigation could potentially reveal new information in the behavior of advanced composite materials under thermal loading conditions. These results would then carry very essential implications for designing improved fiber-reinforced structures sustainable under high-temperature conditions. In the second Abbas [33] work published in 2014, Abbas investigates a three-phase lag model for thermos-elastic interactions in an

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Vol: 62 | Issue: 04 | 2025

unbounded fiber-reinforced anisotropic medium with a cylindrical cavity. Work probably applies developed mathematical models of advanced kinds accounting for non-Fourier heat conduction in composite materials. Therefore, the more precise description of thermal behavior of complex material systems may be ensured. The results may find applications in developing better thermal management strategies for fiber-reinforced composites in engineering. Duc and Cong's [34] paper in the European Journal of Mechanics - A/Solids, published in 2015, should cover advanced topics in structural mechanics or material behavior. Their work may introduce new analytical or numerical methods for dealing with complex deformation or stress states in materials. This research may help one better understand material responses to different loading conditions. The findings of this research may be useful in refining structural design or analysis techniques used in engineering. Jafari et al. [35] investigate, in 2016, the stress distribution around triangular holes in metallic plates subjected to uniform heat flux. Most probably, they present parametric analyses to understand the effect of hole geometry and material properties on the thermal stress pattern.

This study could be important in the optimization of design for structures that include stress concentration under thermal loading. The results might be applied in enhancing the thermal performance and longevity of parts that have non-circular apertures. The 2016 paper by Jafari et al. [36] in European Journal of Mechanics A/Solids studies the thermal stresses of metallic plates containing non-circular holes, under uniform heat flux. Their work most likely describes numerical or analytical methods for predicting stress distributions around complex hole geometries. Such studies might be important for the understanding of how hole shape affects thermal stress patterns in structural components. Findings may find their applications in the optimization of designs for heat-resistant structures with non-circular openings. In 2016, Rasouli and Jafari [37] studied thermal stresses in infinite anisotropic plates with elliptical holes under uniform heat flux. The paper likely discusses mathematical models for predicting stress fields in such directionally dependent materials. This study may help understand how material anisotropy and hole geometry interact to influence thermal stress distributions. The results may be applied to the design of more efficient heat management systems for advanced materials. The paper Zhang and Wang [38] prepared in 2016 contains explicit solutions to the elliptical hole or crack problem in thermoelectric materials. This most likely represents an analytical solution to determine coupled thermal, electrical, and mechanical fields that surround such a discontinuity. The findings are quite relevant to an attempt at trying to understand the failure mechanism of a thermoelectric device. They can assist in achieving greater reliability and efficiency for a thermoelectric energy conversion system. In 2017, Chao et al. [39] studied the effects of thermal stresses caused by a remote uniform heat flow that interacted with two circular inclusions. The research probably utilizes some analytical or numerical methods in forecasting the stress fields developed within such a complex geometry. This paper can be considered to be a building block for insight into the distribution of thermal stress in composite or multi-component inclusion-containing systems. Their study may be extended to design the more robust phase materials for a high temperature condition.

Li et al. [40] 2017 develops a three-dimensional fundamental solution for a penny-shaped crack in an infinite thermo-magneto-electro-elastic medium with transverse isotropy. Most probably, the work describes more advanced mathematical models for such a complex multi-physics problem. This research could provide new tools for fracture mechanics analysis of smart materials that involve coupled field responses. The output can be of interest to design more advanced sensors or actuators with improved reliability. Moure et al. [41] 2017, in a paper discuss the development of crack matrix in open-hole laminates under applied thermomechanical loads. Their work probably encompasses both experimental and theoretical analysis to predict damage progression in composite materials. The study may be useful in explaining failure mechanisms in composite structures that are further

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Vol: 62 | Issue: 04 | 2025

subjected to a combination of thermal and mechanical stresses. The findings might help in increasing the durability of the components made of composites from aerospace or automobile industries. Wang and Wang [42] 2017 considered thermoelectric fields and thermal stresses developed due to an inclined elliptic hole in thermoelectric material. In all likelihood, their study shall propose analytical or numerical techniques to predict the distributions of coupled fields around non-circular holes. Such research can reveal how orientation affects the pattern of stress and electric fields within a thermoelectric device. Applications can lie in the design optimization of a thermoelectric generator or cooler. In Zenkour and Radwan's [43] 2018 Journal of Thermal Stresses article, possibly discussed here, would include higher level considerations into the realm of thermal stress analysis. Probably discussing composites or functionally graded materials, it would bring in novel methods for predicting analytical solutions or new numerical models with temperature-induced stresses on more complicated material systems. Material heterogeneity, it seems, may now find ways that relate the latter's impact onto distributions in the system under concern. The study might have implications for improved thermal management strategies in advanced structural applications. Zhang et al. [44] 2020 could have focused on high-performance composites and/or composite structure thermal and/or mechanical responses. Their research work does indeed uncover some new methodologies for modeling some stress analysis technique or outcome of an experimental pertaining to a predictive failure within a composite. Perhaps, this constitutes the crucial part of optimization of composite design especially with regard to a certain form of loading along with exposures. The findings can be exploited for optimizing composite structures, both in performance and reliability aspects.

Especially if this work has the industrial exploitation capability, probably there are descriptions in the paper Liu et al. [45] 2021, from Composites Part B: Engineering concerning probably problems advanced composite materials-new processing routes-new material systems-or something similar to the new composites-their experimental evidence or theoretical models about the new composites about their mechanical as well as their thermal behavior. This research may assist in developing materials with tailored performance for certain applications in engineering. Results may initiate efficiency or durability improvement in composite structures under extreme conditions. Most probably, the article by Chen and Wang [46] in International Journal of Solids and Structures 2022 addresses some challenging problems in solid mechanics, such as wave propagation or dynamic response of materials. Their work could represent a way of analytical examination in analytics or computational means toward determining material response to a variety of loading. In fact, one might discover knowledge on simple mechanical mechanisms within higher-performance materials and structures. Outputs could aid optimizations of dynamic circumstances involving structures and selection of the ideal materials.

The 2023 publication of Hassan and Mahmoud [47] in Thin-Walled Structures perhaps contains work relative to mechanical behavior or stability concerning thin-walled components or structures. The latter could have advanced predictive stress distribution or buckling behavior of structures through newly found analytical models or numerical simulation; this contributes much toward understanding geometric parameter influence in terms of the functionality and performance of a lightweight structure. These results can be applied to the optimization of thin-walled structures for the aerospace, automotive, or civil engineering industries. For sure Xu et al. [48]'s paper in Composite Structures in 2024 is one of the new contributions to one of the modern topics in composites or structures. Their contribution could be some new methodology of manufacturing, some experimental results, or a theory for mechanical and/or multifunctional properties in advanced composites. Such projects will help towards gaining insight regarding the next generation of composite structures or other radical structural designs. Such concepts and ideas will help find proper usage in new-generation high-performance, light structures.

DOI: 10.5281/zenodo.15166801
Vol: 62 | Issue: 04 | 2025

2. PROBLEM DEFINITION

This paper is an attempt to numerically study the thermal performance and stress distribution characteristics of a rectangular plate, considering configurations both with and without perforations, and employing isotropic as well as composite materials. In this case, the plate will be exposed to three sides at uniform temperature, and another side of the plate will be of different temperature. The application of FEA is recommended for the modeling of heat transfer phenomena and the distribution of thermal stress within the system under investigation. This study examines the effects of hole dimensions, positioning, and material characteristics on the thermal performance of rectangular plates. The ultimate aim is to develop design guidelines that make it possible to optimize thermal management in such structures with perforations.

3. MODELLING CONSIDERATIONS

The dimensions of the rectangular plate are based on standards set for commercial purposes. The plate is such that it is about 5% of the total width. There is a set of isotropic materials used together with the orthotropic material called Glass Fibre Reinforced Polymer (GFRP). This is due to the good light weight property, and favorable characteristics of the material in terms of mechanical strength.

3.1 Materials Used

The geometries of the plate and the cut-outs were constructed using parametric modeling software. The parameters and dimensions of the geometries being considered are provided in the following tabular format. An investigation into the thermal stress has been carried out for both the orthotropic as well as isotropic materials to present the temperature distribution and heat flux within the plate.

Table 1: Rectangular plate with Hole dimensions

S. No.	Parameters	Dimensions
1	Length	20 m
2	Width	10 m
3	Thickness	1 m
4	Cutout (Circular)	0.5 m

The two-dimensional meshed models of the rectangular plates with and without holes used in this study, are given below in Figure 1,2.

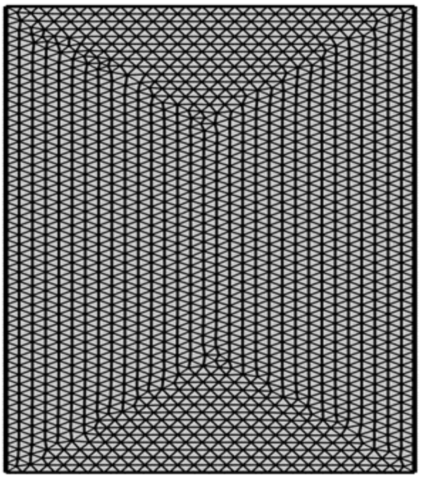


Figure 1: Meshed Rectangular Plate

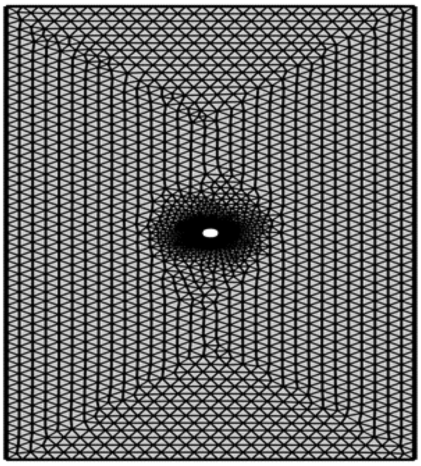


Figure 2: Meshed Rectangular Plate with Hole

DOI: 10.5281/zenodo.15166801
Vol: 62 | Issue: 04 | 2025

The materials used in this study and their respective mechanical properties are given in the tables below.

Table 2: Mechanical properties of Isotropic and Other Materials

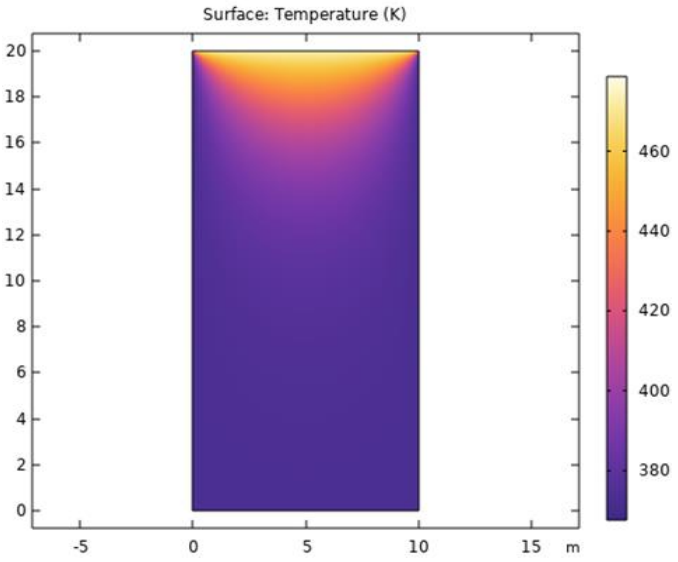
S. No.	Name of Material	Property	Value (W/m k)
1.	Steel	Thermal Conduction	47
2.	Copper	Thermal Conduction	413
3.	Aluminium	Thermal Conduction	237
4.	E-Glass	Thermal Conduction	0.3

4. NUMERICAL ANALYSIS

Numerical analysis was carried out using the commercially available finite element analysis software, ANSYS. This software has an extensive element library to model geometries; it can be used for linear and nonlinear elements. A "Quad solid element" was used to mesh the plate models. The process of meshing was automatic; the Figure shows the meshed model of the plate with central hole created with 1 lakh elements. Thermal stress analysis was carried out by applying temperature boundary conditions to the plate. The left, right, and bottom sides were assigned 100°C, while the topmost side of the rectangular plate was assigned a temperature of 200°C. Meshed models of these boundary conditions are presented in the following figures.

5. THERMAL STRESS ANALYSIS RESULTS

Structural analysis involves the examination and interpretation of the stability of a structure. When assessing the stability of a structure under a temperature change, a heat transfer analysis alone is insufficient. Heat transfer analysis provides only the temperature distribution of the structure, necessitating the subsequent performance of thermal stress analysis to conduct a comprehensive structural analysis for a temperature change. Thermal stress analysis is achieved by applying the temperature distribution obtained through heat transfer analysis as a temperature load. This analysis can be viewed as an examination of the stability of a structure against heat. In certain instances, thermal stress analysis is integrated into the heat transfer analysis process.



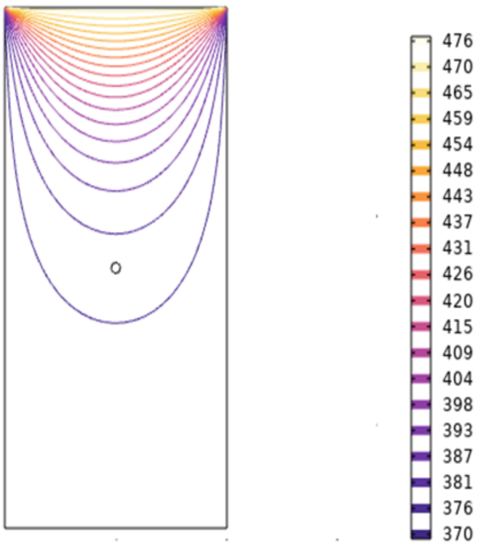


Figure 3: Temperature Distribution on Plate. Figure 4: Temperature Profiles for Plate with Hole

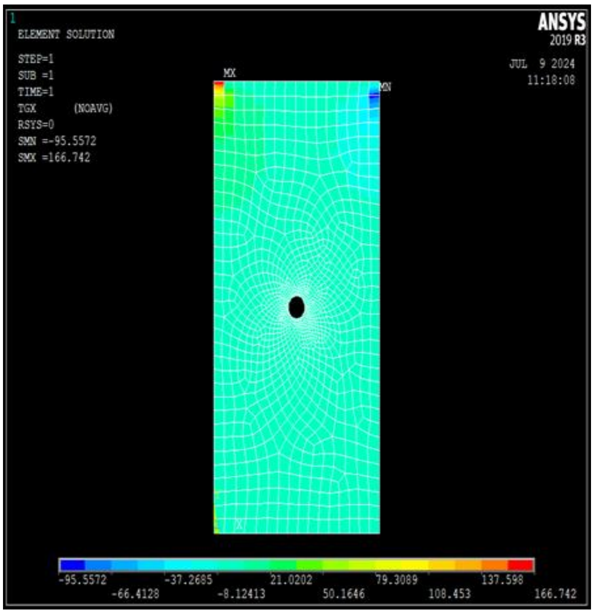


Figure 5: X-component of Thermal Vector.

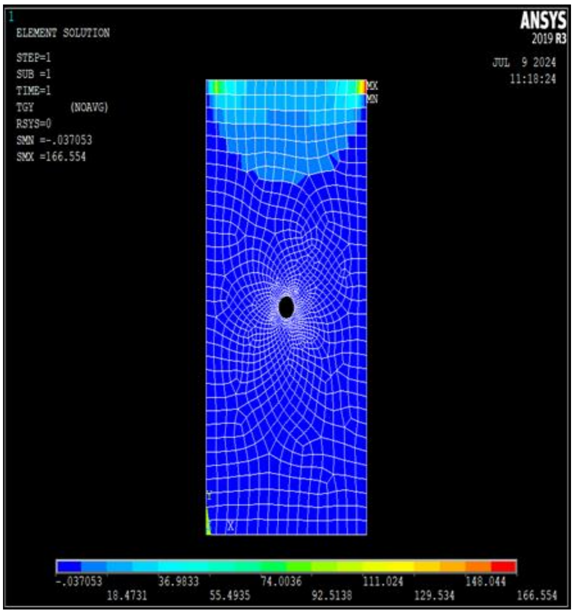


Figure 6: Y-component of Thermal Vector

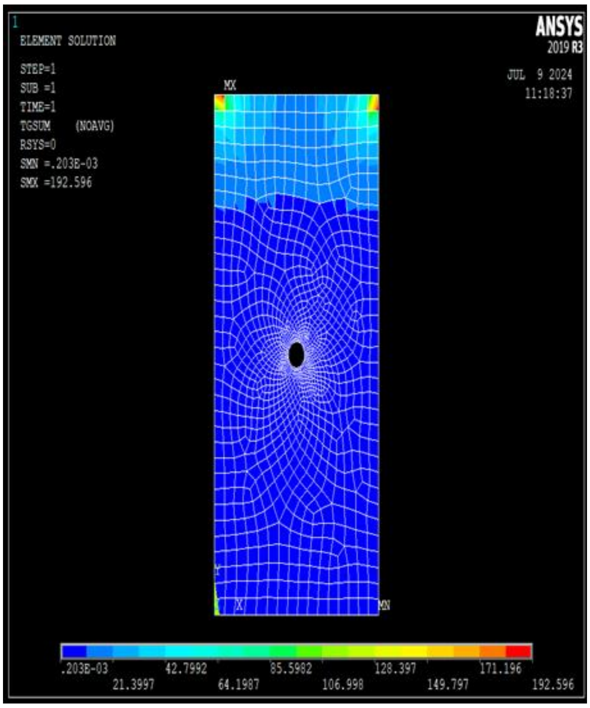


Figure 7: Thermal Gradient Vector.

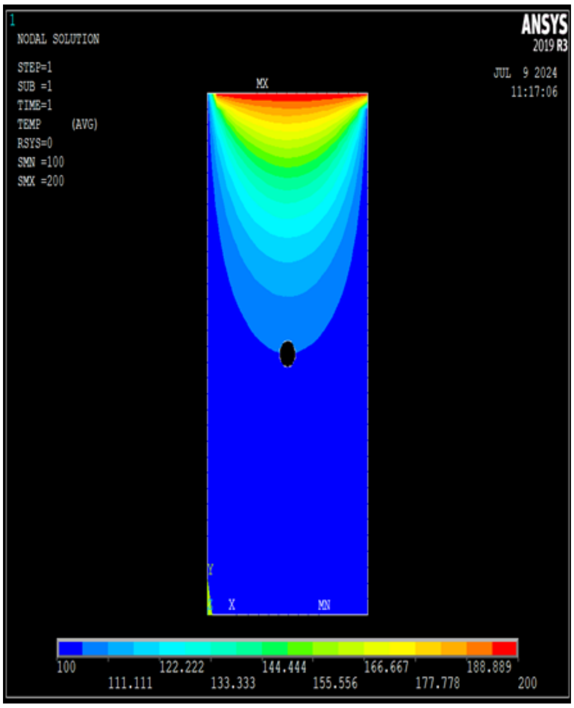


Figure 8: Nodal Temperature Distribution

DOI: 10.5281/zenodo.15166801
Vol: 62 | Issue: 04 | 2025

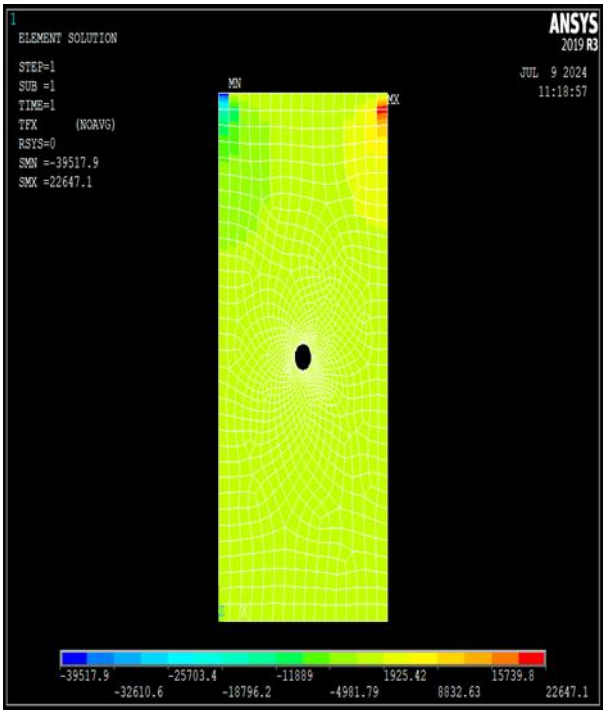


Figure 9: X-Component of Thermal Flux.

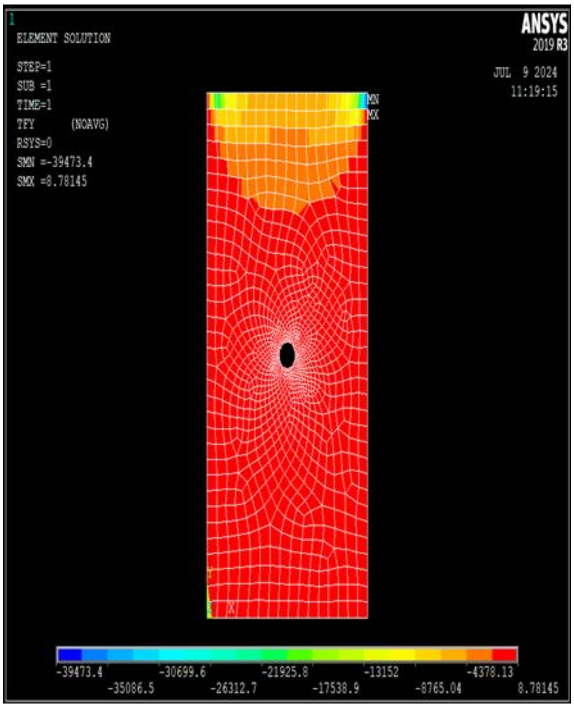


Figure 10: Y-Component of Thermal Flux

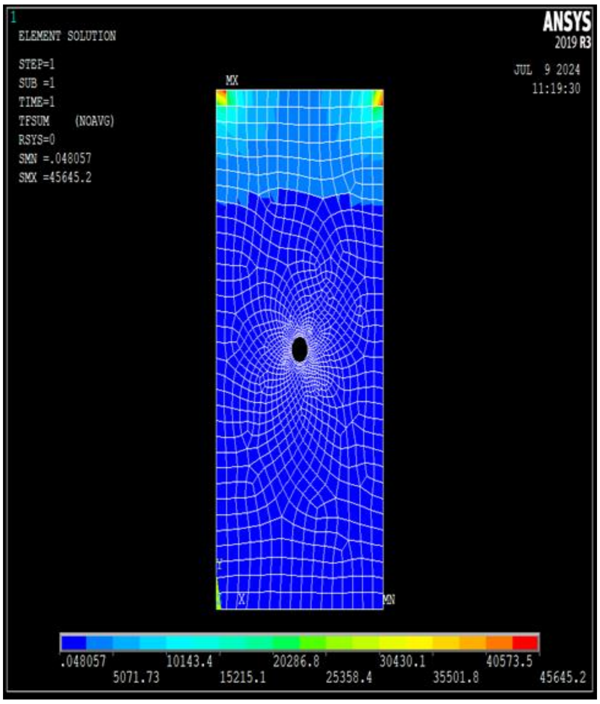


Figure 11: Thermal Flux Vector.

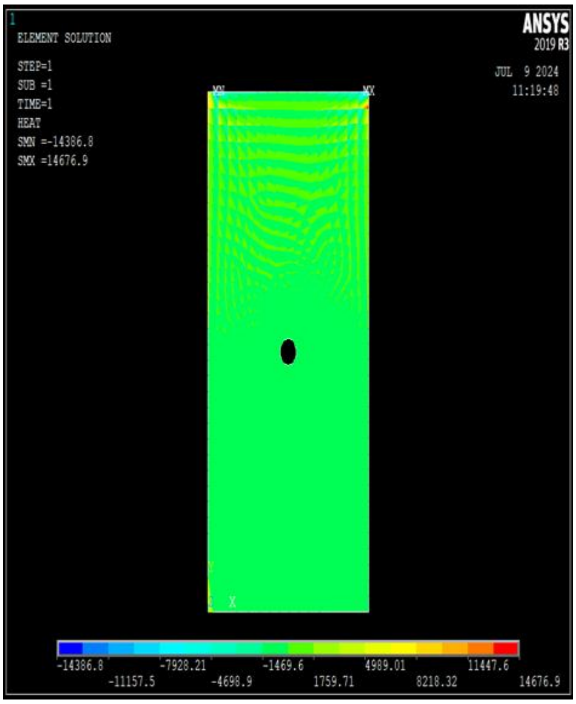


Figure 12: Heat Flux on Plate with Hole

The thermal analysis presented in these figures offers a comprehensive visualization of heat transfer phenomena in a plate with a central hole. Figure 3 depicts a vibrant temperature distribution across the plate's surface, with a striking gradient from high temperature to low temperature regions. Figure 4 complements this with detailed temperature profiles, revealing the intricate thermal landscape around the hole. The thermal vector components (Figures 5 and 6) and gradient vector (Figure 7) illuminate the directional flow of heat, showcasing the complex interplay between the plate's

DOI: 10.5281/zenodo.15166801
Vol: 62 | Issue: 04 | 2025

geometry and thermal behaviour. Figures 8 through 12 delve deeper, presenting nodal temperature distributions and thermal flux components that showcase a picture of heat movement. The heat flux visualization in Figure 12 is particularly captivating, displaying the intensity and direction of thermal energy transfer across the plate's surface. Collectively, these figures weave a tapestry of thermal dynamics, offering invaluable insights into how the presence of a hole influences heat distribution and flow within the plate structure, thus providing a rich foundation for further thermal engineering analysis and optimization.

Table 3: Rectangular plate with No Hole

S. No	Material	Heat Flow (W/m2)	X-Thermal Flux	Y-Thermal Flux	Thermal Flux Vector	X-Thermal gradient	Y-Thermal gradient	Thermal gradient Vector
1.	Steel	2791.99	4419.94	0.0707	7833.41	166.668	166.668	191.981
2.	Copper	24533.9	38839	0.6213	68834	166.668	166.668	191.981
3.	Aluminium	14078.8	22287.9	0.7131	45499.4	166.668	166.668	191.981
4.	E-Glass Epoxy	17.8212	28.212	0.903e-3	57.5942	166.668	166.668	191.981

Table 4: Rectangular plate with d/b=0.1

S. No	Material	Heat Flow (W/m2)	X-Thermal Flux	Y-Thermal Flux	Thermal Flux Vector	X-Thermal gradient	Y-Thermal gradient	Thermal gradient Vector
1.	Steel	2910.61	4491.19	1.741	9051.99	166.742	166.544	192.596
2.	Copper	25576.3	39465.1	15.302	79542	166.742	166.544	192.596
3.	Aluminium	14676.9	22647.1	8.781	45645.2	166.742	166.544	192.596
4.	E-Glass Epoxy	18.578	28.667	0.011	57.778	166.742	166.544	192.596

Table 5: Rectangular plate with d/b=0.2

S. No	Material	Heat Flow (W/m2)	X-Thermal Flux	Y-Thermal Flux	Thermal Flux Vector	X-Thermal gradient	Y-Thermal gradient	Thermal gradient Vector
1.	Steel	2912.35	4491.55	4.122	9130.12	167.39	167.628	194.258
2.	Copper	25591.5	39468.3	36.222	80228.5	167.39	167.628	194.258
3.	Aluminium	14685.7	22648.9	20.786	46039.1	167.39	167.628	194.258
4.	E-Glass Epoxy	18.589	28.6695	0.026	58.277	167.39	167.628	194.258

Table 6: Rectangular plate with d/b=0.3

S. No	Material	Heat Flow (W/m2)	X-Thermal Flux	Y-Thermal Flux	Thermal Flux Vector	X-Thermal gradient	Y-Thermal gradient	Thermal gradient Vector
1.	Steel	2971.64	4615.7	4.872	9195.88	169.293	168.981	195.657
2.	Copper	26112.5	40559.2	42.819	80806.4	169.293	168.981	195.657
3.	Aluminium	14984.6	23274.9	24.571	46370.7	169.293	168.981	195.657
4.	E-Glass Epoxy	18.967	29.461	0.031	58.697	169.293	168.981	195.657

Table 7: Rectangular plate with d/b=0.4

S. No	Material	Heat Flow (W/m2)	X-Thermal Flux	Y-Thermal Flux	Thermal Flux Vector	X-Thermal gradient	Y-Thermal gradient	Thermal gradient Vector
1.	Steel	2881.55	5564.22	2.544	11190.3	206.402	206.143	238.091
2.	Copper	25320.8	48894.1	22.362	98331.6	206.402	206.143	238.091
3.	Aluminium	14530.4	28057.9	12.832	56427.6	206.402	206.143	238.091
4.	E-Glass Epoxy	18.392	35.516	0.016	71.427	206.402	206.143	238.091

Table 8: Rectangular plate with d/b=0.5

S. No	Material	Heat Flow (W/m2)	X-Thermal Flux	Y-Thermal Flux	Thermal Flux Vector	X-Thermal gradient	Y-Thermal gradient	Thermal gradient Vector
1.	Steel	2800.83	5595.42	1.772	11394.1	210.562	210.715	242.428
2.	Copper	24611.5	49155.9	15.578	100123	210.562	210.715	242.428
3.	Aluminium	14123.3	28208.1	8.939	54755.4	210.562	210.715	242.428
4.	E-Glass Epoxy	17.877	35.706	0.011	72.728	210.562	210.715	242.428

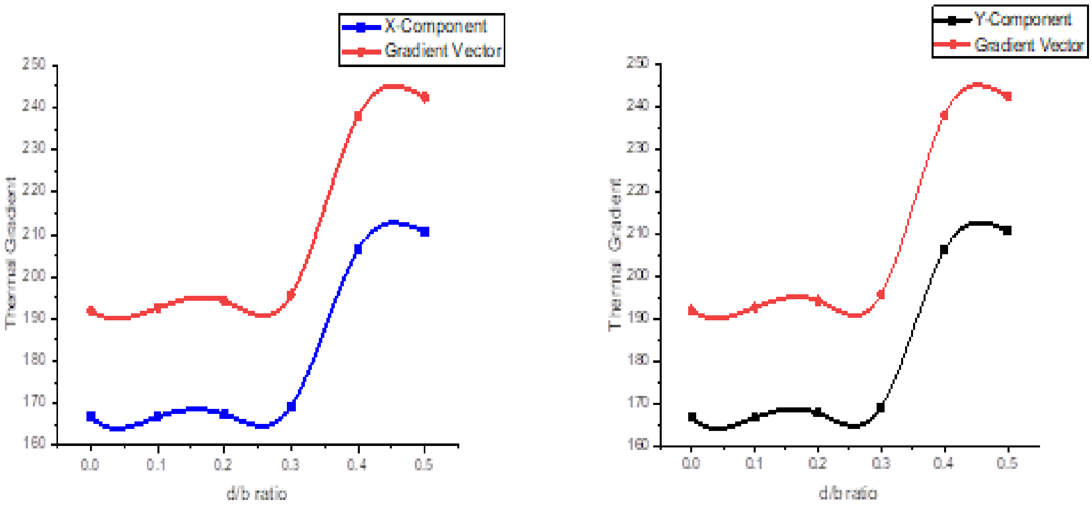


Figure 13: Comparision for Thermal Gradients vs d/b ratio

These tables present a comprehensive analysis of thermal properties for various materials in rectangular plates with different hole sizes. From Table 3 to Table 8, we observe the progression of heat flow and thermal characteristics as the hole diameter-to-plate width ratio (d/b) increases from 0 to 0.5.In this fascinating thermal study, four materials—steel, copper, Aluminium, and E-glass epoxy—are examined under varying conditions. As the hole size grows, we witness intriguing changes in heat flow, thermal flux, and thermal gradients. Copper consistently demonstrates the highest heat flow and thermal flux values, showcasing its superior thermal conductivity. Steel and Aluminium follow, with E-glass epoxy exhibiting the lowest thermal performance, as expected for an insulating material. Notably, the introduction and expansion of the hole generally leads to increased heat flow and thermal flux magnitudes, particularly in the x-direction. This phenomenon likely results from the hole's impact on heat path redistribution. The thermal gradient vectors show a gradual increase as the hole size grows, indicating more intense temperature changes over shorter distances which can be shown in Figure13. This comprehensive dataset provides invaluable insights into how material choice and

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Vol: 62 | Issue: 04 | 2025

structural modifications affect thermal behaviour, offering a solid foundation for thermal management strategies in engineering applications.

6. CONCLUSION

Based on the tabular results and schematic representations provided, the following conclusions can be drawn:

1. The numerical investigation has demonstrated the significant influence of hole size and material properties on the thermal performance of the rectangular plate. As the hole diameter-to-width ratio (d/b) increased from 0 to 0.5, the heat flow, thermal fluxes, and thermal gradients within the plate generally increased. The most notable changes were observed when the hole size increased from d/b = 0.3 to d/b = 0.4, indicating a critical threshold for the impact on thermal performance.
2. Regarding the material comparison, the isotropic materials (steel, copper, aluminum) exhibited substantially higher thermal performance metrics compared to the orthotropic material (E-Glass Epoxy). Among the isotropic materials, copper displayed the highest thermal performance, followed by aluminum and steel.
3. The variations in temperature distribution and thermal gradients due to the changes in hole size and material properties will result in the development of thermal stresses within the plate. These thermal stresses should be analyzed to assess the structural integrity and optimize the design of the perforated plate for various engineering applications.
4. Overall, the findings from this numerical investigation provide valuable insights into the thermal management strategies for rectangular components with perforations, which are commonly encountered in diverse engineering fields.

Declaration of Interest

Authors should reveal any possible conflict of interest in their submitted manuscripts. A competing interest exists when professional judgment concerning the validity of work is influenced by a secondaryinterest, such as financial gain. The author(s) declare(s) that there is no conflict of interest regarding thepublication of this manuscript.

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