Thermo Elasticity: A Patent Review

Author Details: Dr. Kiran Bala
Assistant Professor in Mathematics, Govt. College, Barwala (Pkl.)

Abstract:
Thermo elasticity is the change in size and shape of a solid object as the temperature of that object fluctuates. The principles of thermo elasticity have affected the way engineers design a number of different objects. The patent is a limited legal monopoly granted to an individual or firm to make, use and sell its invention and to exclude others from doing so. According to section 3 (k) of Indian patent act, mathematical methods are nonpatentable because these are considered to be acts of mental skill. However, any application of mathematical formula may be patented if it satisfies the qualifications of "invention." This paper reviews recent and important patents related to applications of thermo elasticity within different fields.

Keywords: *Thermo elasticity, patent, application.*

Introduction:

Thermo elasticity deals with the dynamical system whose interactions with the surrounding include not only mechanical work and external work but the exchange of heat also. Changes in temperatures cause thermal effects on materials. Some of these thermal effects include thermal stress, strain, and deformation. Thermal deformation simply means that as the "thermal" energy (and temperature) of a material increases, so does the vibration of its atoms/molecules and this increased vibration results in what can be considered a stretching of the molecular bonds - which causes the material to expand. Of course, if the thermal energy(and temperature) of a material decreases, the material will shrink or contract. Thus, thermo elasticity is based on temperature changes induced by expansion and compression of the test part. Thus, the theory of thermo elasticity is concerned with predicting the thermomechanical behaviour of elastic solids. It represents a generalization of both the theory of elasticity and theory of heat conduction in solids.The theory of thermo elasticity was founded in 1838 by Duhamel [1], who derived the equations for the strain in an elastic body with temperature gradients. Neumann [2], obtained the same results in 1841. However, the theory was based on the independence of the thermal and mechanical effects. The total strain was determined by superimposing the elastic strain and the thermal expansion caused by the temperature distribution only. The theory thus did not describe the motion associated with the thermal state, nor did it include the interaction between the strain and the temperature distributions. Hence, thermodynamic arguments were needed, and it was Thomson [3], in 1857 who first used the laws of thermodynamics to determine the stresses and strains in an elastic body in response to varying temperatures.

There are three types of thermo elasticity, i.e., uncoupled, coupled and generalized thermo elasticity. The theory of classical uncoupled theory of thermo elasticity predicts two phenomena not compatible with physical observations. First, the equation of heat conduction of this theory does not contain any elastic term contrary to the fact that the elastic changes produce heat effects. Second, the heat equation is of parabolic type predicting infinite speeds of propagation for heat waves. The classical uncoupled and coupled thermo elastic theories of Biot[4] and Nowacki[5] have an inherent paradox arising from the assumption that the thermal waves propagate at infinite velocity, and it is a physically unreasonable result.

Generalized thermo elasticity theories have been developed with the objective of removing the paradox of infinite speed of heat propagation inherent in the conventional coupled dynamical theory of thermo elasticity in which the parabolic type heat conduction equation is based on Fourier's law of heat conduction. This newly emerged theory which admits finite speed of heat propagation is now referred to as the hyperbolic thermo elasticity theory since the heat equation for the rigid conductor is a hyperbolic-type differential equation. The first generalized theory of thermo elasticity is due to Lord and Shulman [6] who coupled elasticity with a way in which temperature can travel with a finite wave speed. The approach of Lord and Shulman [6] begins with the full nonlinear equations, but they are mainly interested in developing a linear theory since they begin with "small strains and small temperature changes." The second generalization to the coupled theory is known as the generalized theory with two relaxation times. Muller[7] introduced the theory of generalized thermo elasticity with two relaxation times. A more explicit version was then introduced by Green and Laws [8], Green and Lindsay [9] and independently by Suhubi[10]. In this theory, the temperature rates are considered among the constitutive variables. This theory also predicts finite speeds of propagation for heat and elastic waves similar to the Lord-Shulman theory. It differs from the latter in that Fourier's law of heat conduction is not violated if the body under consideration has a centre of symmetry. Dhaliwal and Sherief[11] extended the Lord and Shulman (L-S) theory for an anisotropic media. Chandrasekharaiah[12]referred to this wave-like thermal disturbance as "second sound." These writers investigate the propagation of a thermal pulse in a thermo elastic shell employing each of the linearized equations for the three thermo elastic theories, Classical, Lord-

Shulman and Green-Lindsay. Their numerical results typically demonstrate that Classical theory leads to a smooth pulse while that of Lord-Shulman is less smooth showing discontinuities in derivatives. The theory of Green and Lindsay [9] leads to strong pulse behaviour displaying distinct jumps such as to the behaviour of stainless steel run tanks which holds cryogenic liquids for rocket fuel at NASA's John C. Stennis Space Centre, the strong pulse solution is definitely of interest.

Green and Naghdi[13-15] proposed three new thermo elastic theories based on entropyequality than the usual entropy inequality. The constitutive assumption for the heat flux vector is different in each theory. Thus they obtained three theories which are called thermo elasticity of type I, thermo elasticity of type II and thermo elasticity of type III. Green and Naghdi[15] postulated a new concept in generalized thermo elasticity which is called the thermo elasticity without energy dissipation. The principal feature of this theory is that in contrast to the classical thermo elasticity, the heat flow does not involve energy dissipation. Also, the same potential function which is defined to derive the stress tensor is used to determine the constitutive equation for the entropy flux vector. In addition, the theory permits the transmission of heat as thermal waves at finite speeds. Dhaliwal and Wang [16] formulated the heat-flux dependent thermo elasticity theory for an elastic material with voids. This theory includes the heat-flux among the constitutive variables and assumes an evolution equation for the heat-flux. Hetnarski and Ignaczack[17] examined five generalizations to the coupled theory and obtained a number of important analytical results. The literature on generalized thermo elasticity is available in the books like "Thermo elastic Solids" by Suhubi[10], "Thermo elastic Deformations" by lesan and Scalia[18], "Thermo elastic Models of Continua" by Iesan [19], "Thermo elasticity with Finite Wave Speeds" by Ignaczak and Ostoja-Starzewski [20], etc. Many reviews on this topic are already published. However, to my knowledge, there is no report on patented innovations on the application of thermo elasticity. In order to address the importance of patented innovations, in this article, the current status of patents is reviewed.

Methodology Used:

A patent search was conducted in February 2017, and a total of 7040 results were found on patents on the application of thermo elasticity. In this study, the *Google patent search* website[21] was used to search for patents. It collects published patent applications from 6th March 1894 to today and from many countries. Accessing the Google Patent Search website, an advanced search using keywords in patent titles and abstracts was carried out. A search for applications of thermo elasticity patents was conducted using (i) title keywords of thermo elasticity, applications, and (ii) combination keywords of applications of thermo elasticity in various fields. The abstracts or the whole patents of all those found were carefully reviewed.

Limitations of the study:

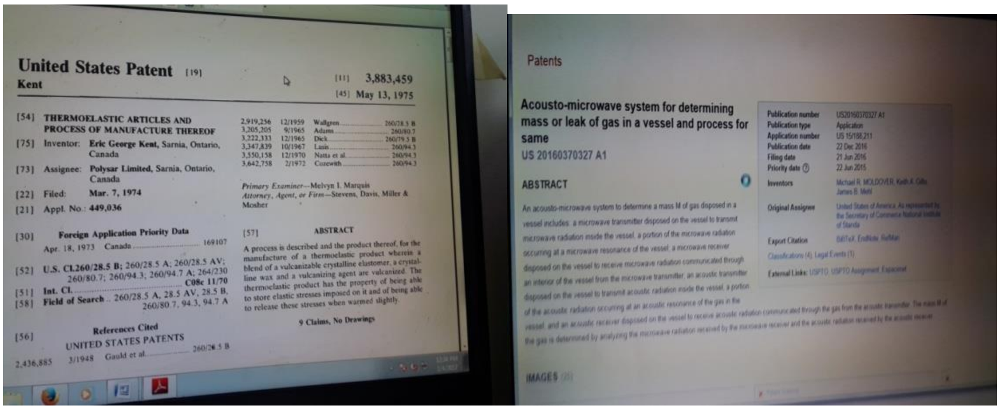
Patents that were not in the Google Patent Search [21] were not included. Patents for application of thermo elasticity that were not mentioned in the patent title and abstract were not included; a search for full texts (claims and description) of all the patents was not possible due to limitations of the database.

Patents on applications of thermo elasticity:

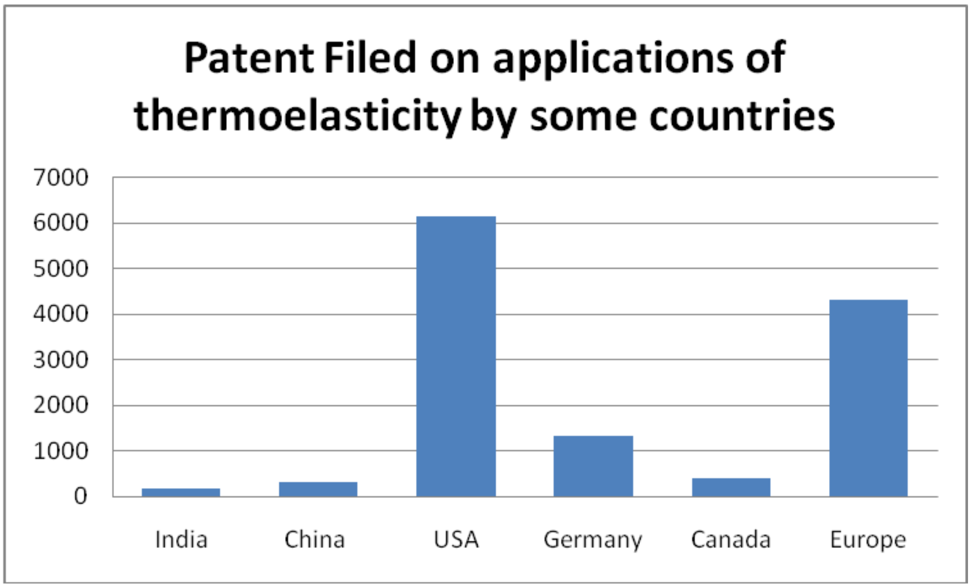
From the Google **Patent Search, we found that many applications of thermo elasticity have been patented.**

- A cooling system based on thermo elastic effect is the US patented in which the system comprises a heat sink, a refrigerated space and a regenerator coupled to the refrigerated space and to the heat sink to pump heat from the refrigerated space to the heat sink. The regenerator comprises solid thermo elastic refrigerant materials capable of absorbing or releasing heat.
- **Inverted radial back-curling thermo elastic ink jet printing mechanism,**K Silverbrook, G McAvoy - US **Patent** 6,247,790, 2001 - Google **Patents**
- **Method of manufacture of an inverted radial back-curling thermo elastic ink jet** K Silverbrook - US **Patent** 6,267,904, 2001 - Google **Patents**
- **Method of manufacture of a thermo elastic bend actuator ink jet printer** K Silverbrook - US **Patent** 6,294,101, 2001 - Google **Patent**
- **Planar thermo elastic bend actuator ink jet printing mechanism** K Silverbrook - US **Patent** 6,213,589, 2001 - Google **Patent**
- **Method of manufacture of high Young's modulus thermo elastic inkjet printer** K Silverbrook - US **Patent** 6,254,793, 2001 - Google **Patent**

- **Blend of thermo elastic polymers with block radial polymers used as a pharmaceutical sealing and resealing materials** EL Hillier, GH Graham, WE Eichelberger - US **Patent** 4,048,255, 1977 - Google **Patents**
- **Foamable thermo elastic ionomer composition** D Brenner, RD Lundberg - US **Patent** 4,164,512, 1979 - Google **Patents**
- **Age hardenable, nickel-iron-chromium-titanium alloy possessing controlled thermo elastic properties** US **Patent** 2,266,482, 1941 - Google **Patents**
- **Thermo elastic articles and process of manufacture thereof** EG Kent - US **Patent**



Images of filed Patents



Conclusion: The benefits of the patent system are derived from its roles in promoting innovation, and encouraging investment, economic growth, knowledge sharing and the efficient use of resources. Patents promote knowledge sharing by requiring the details of the patented invention to be placed in the public domain in return for the exclusive right to exploit the invention. In the absence of this exchange, inventors might protect the details of new inventions through secrecy. The disclosure requirements of the patent system are based on the idea that 'scientific and technical openness benefits the progress of society more than do confidentiality and secrecy. There are a lot of patents regarding the application of thermo elasticity. A number of patents filed in some countries are shown graphically. From the graph, it is found that the USA filed a maximum number of patents and India filed a minimum number of patents on thermo elasticity.

REFERENCES

i. *J. M. C. Duhamel,., Me ́moiresur ́lecalcul des actions mol ́eculairesd ́evelopp ́ees par les changements de temp ́eraturedans les corps solides,M ́emoirs par Divers Savans (Acad. Sci. Paris), 5, 1838, 440-498.*

ii. K. E. Neumann, Die Gesetze der Doppelbrechung des Lichts in comprimirtenoderungleichf�ormigerwarmtenunkrystallinischenK�orpern, Pogg. Ann., Physics Chem., 54, 1841, 449-476.
iii. W. Thomson, On the Thermo-Elastic and Thermo-Magnetic Properties ofMatter, Quarterly Journal of Mathematics, 1, 1857, 57-77.
iv. M.A. Biot, Theory of propagation of elastic waves in a fluid-saturated porous solid. I.Low frequency range. II. Higher frequency range, Journal of Acoustical Society of America, 28, 1956, 168-191.
v. W. Nowacki, Couple stresses in the theory of thermo elasticity I, Bulletin L'Academie Polonaise des Science, Serie des Sciences Technology, 14, 1966, 129-138.
vi. H. Lord and Y. Shulman, A generalized dynamical theory of thermo elasticity, Journal of the Mechanics and Physics of Solids, 15 ,1967, 299-309.
vii. I.M.Muller, The Coldness, a universal function in thermo elastic bodies,Archive for Rational Mechanics and Analysis, 41, 1971, 319-332.
viii. A. E. Green and N. Laws, On the entropy production inequality. Archive forRational Mechanics and Analysis, 45, 1972, 47-53.
ix. A. E. Green and K. A. Lindsay, Thermo elasticity, Journal of Elasticity, 2, 1972, 1-7.
x. E. S. Suhubi, A.C.Eringen,Thermo elastic solids in Continuum Physics II, (Ch. 2 ed.). (Academic, Press, New York. ,1975).
xi. R. S. Dhaliwal and H. H. Sherief, Generalized thermo elasticity for anisotropicmedia, Quarterly of Applied Mathematics, 33, 1980, 1-8.
xii. D. S. Chandresekharaiah, Thermo elasticity with second sound : A Review,Applied Mechanics Review, 39 1986, 355-376.
xiii. A. E. Green and P. M. Nagdhi, A re-examination of the basic postulates ofthermomechanics, Proceedings of Royal Society of London: A, 432 ,1991, 171-194.
xiv. A. E. Green andP. M. Naghdi, On undamped heat waves in an elastic solid. J. Thermal Stresses 15,1992, 253–264.
xv. A. E. Green andP. M. Naghdi, Thermo elasticity without energy dissipation,Journal of Elasticity, 31, 1993, 189-209.
xvi. R. S. Dhaliwal and J. Wang,A heat-flux dependent theory of thermo elasticitywith voids, ActaMechanica, 110, 1993, 33-39.
xvii. R. B. Hetnarski and J. Ignaczak, Generalized thermo elasticity, Journal ofThermal Stresses, 22, 1999, 451-476.
xviii. D. Iesan and A. Scalia, Thermo elastic deformations, (Kluwer Academic Publisher, 1996).
xix. D. Iesan, Thermo elastic models of continua (Solid Mechanic and its Applications, Springer, 2004).
xx. J. Ignaczak and M. Ostoja-Starzewski, Thermo elasticity with finite wavespeeds, (Oxford University Press, 2009).
xxi. Website https ://www. google.com/ patents.