Investigation of Mechanical and Thermal Loading in Gas Turbine Blade with Different Materials

R. Ramani
PG Scholar
Department of Aeronautical Engineering,
Nehru Institute of Engineering and Technology
Coimbatore, Tamil Nadu

P. Maniiarasan
Professor
Department of Aeronautical Engineering
Nehru Institute of Engineering and Technology
Coimbatore, Tamil Nadu

***Abstract*— The objective of this project is to investigate the mechanical and thermal loading and its effect in gas turbine blade with functionally graded materials (FGM). In the present work turbine blade was designed with layers of FGM materials. The blade has been designed and analyzed with multiple layers which gives better results on increasing the layers of the blade. The material property varies at each layer due to its own physical property. FGM is composed of Nickel and Zircon. And Carbon fiber is used to reduce the amplitude of vibration of the blade. FGM often used layer by layer, an attempt has been made to investigate the effect of temperature and induced stresses on the turbine blade. The mechanical properties off the blade are grated in the thickness direction according to a displacement and stress is obtained using Finite element method (FEM) and the thermal analysis investigate the direction of the temperature flow which is been developed due to thermal loading. An attempt is also made to suggest the best material for a turbine blade by comparing the results obtained for this materials to common material.**

Keywords--- FEM, FGM, induced stress, temperature effect, turbine blade.

I. INTRODUCTION

Composite materials have been used in the aerospace industry over the past three decades. Still, their wider utilization is hampered by the long delay and high cost of certification testing. Composite materials will fail under extreme working conditions through a process called delamination (separation of fibers from the matrix). This can happen in high temperature application. The main constituents of structural composites are the reinforcements and the matrix. The reinforcements, which are stronger and stiffer, are dispersed in a comparatively less strong and stiff matrix material. The strength and stiffness of such composites are, therefore, controlled by the strength and stiffness of constituent fibers. The matrix also shares the load when there is not much difference between the strength and stiffness properties of reinforcements and matrices.

A. Functionally Graded Material (FGM)

Functionally Graded Material (FGM) belongs to a class of advanced material characterized by variation in properties as the dimension varies. The overall properties of FGM are unique and different from any of the individual material that forms it. There is a wide range of applications for FGM and it is expected to increase as the cost of material processing and fabrication processes are reduced by improving these processes. In this study, an overview of fabrication processes, area of application, some recent research studies and the need to focus more research effort on improving the most promising FGM fabrication method (solid freeform SFF) is presented. The main purpose is to increase fracture toughness, increase in strength because ceramics only are brittle in nature. Brittleness is a great disadvantage for any structural application. These are manufactured by combining both metals and ceramics for use in high temperature applications.

B. Gas Turbine Blade

A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor. A turbine blade is the individual component which makes up the turbine section of a gas turbine. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings.

C. Fibre

The composite's properties are mainly influenced by the choice of fibers. Fibers constitute the main bulk of reinforcements that are used in making structural composites. There are carbon, glass and aramid fibres and the composite is often named by the reinforcing fibre, e.g. CFRP (Carbon Fibre Reinforced Polymer). They have different properties, including price, which make one more suitable then the other for different purposes. For strengthening purposes carbon fibres are the most suitable and will therefore be focused on in the following.

D. Carbon fiber

Carbon fibres have a high modulus of elasticity, 200 – 800 Gpa. The ultimate elongation is 0.3 – 2.5 % where the lower elongation corresponds to the higher stiffness and vice versa. Carbon fibres do not absorb water and are resistant to many chemical solutions. They withstand fatigue excellently, do not stress corrode and do not show any creep or relaxation compared to low relaxation high tensile pre-stressing steel strands. Carbon fibre is electrically conductive and, therefore might give galvanic corrosion in direct contact with steel. The properties of carbon fibers, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion, make them very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared to similar fibers, such as glass fibers or plastic fibers.

Fig. 1. Fibre

Carbon fibers derived from Polyacrylonitrile (PAN) are turbostratic, whereas carbon fibers derived from mesosphere pitch are graphitic after heat treatment at temperatures exceeding 2200 °C. Turbostratic carbon fibers tend to have high tensile strength, whereas heat-treated mesosphere-pitch-derived carbon fibers have high Young's modulus (i.e., high stiffness or resistance to extension under load) and high thermal conductivity.

II. PROBLEM DESCRIPTION

A. Project Approach

Designing of the turbine blade is quite a complicated process. For designing a gas turbine blade, firstly the very required blade parameters is checked and verified for the designing. The blade parameters are as in table I.

TABLE I. BLADE PARAMETERS

PARAMETER	VALUE	UNIT
Blade height, **h**	0.081833	m
Chord width, **c**	0.02727	m
Pitch, **s**	0.02264	m
Number of blades	69	
Mean radius, **r**	0.2475	m

These parameters are used appropriately in CATIA V5 software in order to obtain the design of turbine blade in a step by step manner. Each parameters are given as input at the places required.

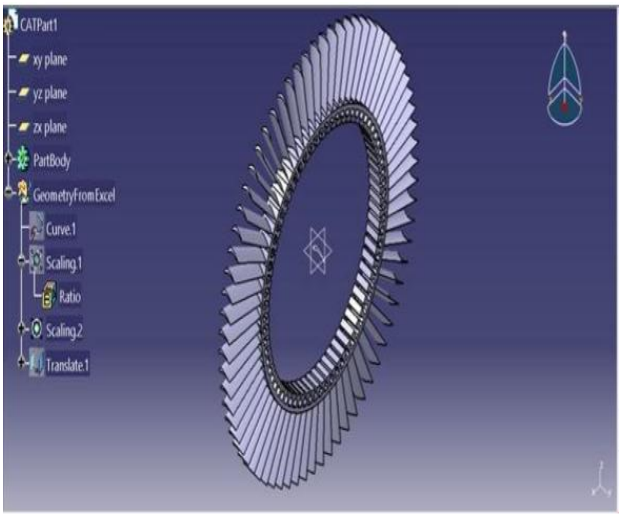

Fig. 2. gas turbine blade set

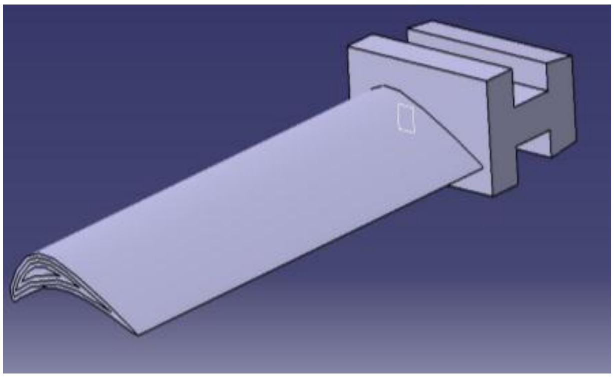

Fig. 3 Single blade geometry

B. Material Properties

The material properties of Functionally Graded Material is calculated using Rule of Mixtures. Since, FGM is a type of composite which varies through its volume fraction or dimension.

The Volume Fraction equation is given by

$$V_C + V_M = 1 \quad (1)$$

Where,

V_C – Volume fraction of Ceramic

V_M – Volume fraction of metallic

The Elastic properties of FGM can be calculated using Power Law

$$P(Z) = \{(P_C - P_M) * (V_C) n\} + P_M \; V_C = \{(1/2) + (z/h)\} n \quad (2)$$

Where,

P_C – Material property of Ceramic

P_M – Material property of Metallic

z – Thickness co-ordinate

h - Thickness

n – Volume fraction exponent (≥ 0)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 06, June-2016

C. Analysis of Gas Turbine Blade

Analysis of Gas Turbine Blade is carried out using commercial FEA software. The material properties were applied according the calculation which is carried to thermal-stress simulation so the concept of this analysis is to be the complete combusted gas with high pressure and temperature will hit the turbine blade. So the main important thing is here is the blade cooling and strength due to high pressure. That's what I take different layer with zircon, metal, composite mixtures

The Gas Turbine blade has undergone through structural and thermal investigation. The analysis is first carried out for the layered plate in order to know the problems that could occur during the layered analysis. Since, the current research is to be establish the balanced material properties.

D. Meshing

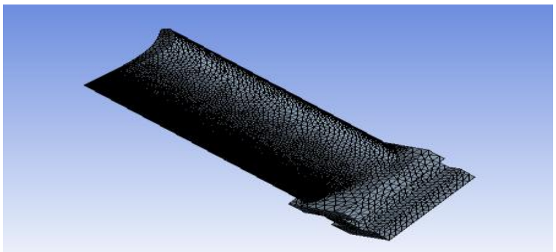

Fig. 4. Gas turbine blade meshed

The blade was defined after the complete geometry section. The next step is meshing the model which process is called as pre-processing. The geometry which includes the points, curves and surface families' creations, clust setting, material definition.

The tetrahedron meshing has been used in this geometry by using patch conforming method. The total number of cell and nodes are 415050 and 620609 respectively. The proximity level should be fine in the small size faces and shorten edges. Here the gas turbine blade was leading and trailing edge, the both of edges was fined according to capture the edge and faces of 0.001 mm tolerance of the mesh.

E. Calculation

For 2 layers,

$$E(Z) = \{(E_C - E_M) * (V_C)\, n\} + E_M \quad (3)$$

Let n = 1,

$$V_C = \{(1/2) + (z/h)\}\, n \quad (4)$$

$$V_C = 1 \quad (5)$$

$$V_M = 1 - V_C \quad (6)$$

Therefore, $V_M = 0$ (7)

$$E_1 = \{(151 - 105.7) * (1)\, n\} + 105.7 \quad (8)$$

E_1 = 151 GPa

Similarly, E_2 = 105.7 GPa

TABLE II. MATERIAL PROPERTIES

S.NO	MATERIAL	YOUNG'S MODULUS, E (GPa)	DENSITY, ρ (kg/m3)	POISSON RATIO	THERMAL CONDUCTIVITY, k (W/mK)	CO-EFFICIENT OF EXPANSION (m/mK)	MELTING POINT 0C
1	CERAMIC (Zircon)	151	3000	0.29	23	5.7x10-6	1855
2	METALLIC (Nickel)	105.7	4429	0.29	91	13.4x10-6	1455
3	CARBON FIBRE	200	1950	0.2	1003	-1.6x10-6	3650

TABLE III. YOUNG'S MODULUS FOR MATERIAL PROPERTY ON n^{th} LAYERS

Material property on nth layer	young's modulus		
0	2nd layer	3rd	4th
1	151	151	151
2	105.7	139.675	139.675
3		117.025	117.025
4			105.7

TABLE IV. DENSITY FOR MATERIAL PROPERTY ON n^{th} LAYERS

Material property on nth layer	Density		
0	2nd layer	3rd	4th
1	3000	3000	3000
2	4429	3357.25	3357.25
3		4071.75	4071.75
4			4429

TABLE V. THERMAL CONDUCTIVITY FOR MATERIAL PROPERTY ON n^{th} LAYERS

Material property on nth layer	Thermal conductivity		
0	2nd layer	3rd	4th
1	23	23	23
2	91	40	40
3		74	74
4			91

F. Boundary conditions

The fixed supports are applicable at the face is fixed to the hub of the blade. So that is constrained at x, y & z directions and the pressure load will takes 24.75×10^5 Pa with 619°C

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 06, June-2016

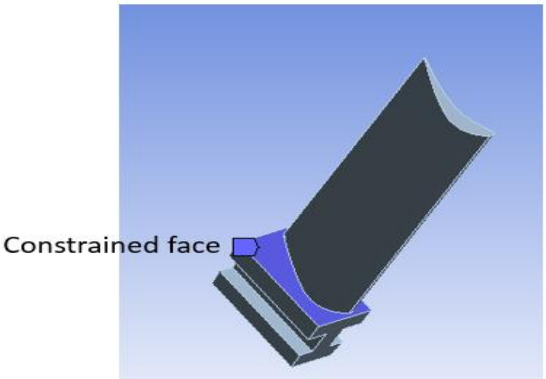

Fig. 5. Constrained boundary condition

Thermal loading of the blade considered as to hit the hot high pressure gas in leading edge of the blades. And the heat will transfer through the medium of solid material is called as convection. So as the thermal loading and convection regions set as per the calculation. And the mechanical loading set as the pressure force of the fluid.

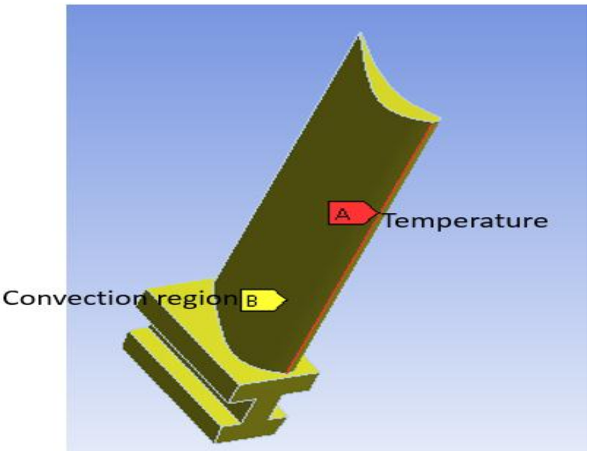

Fig. 6. Contour of Thermal loading

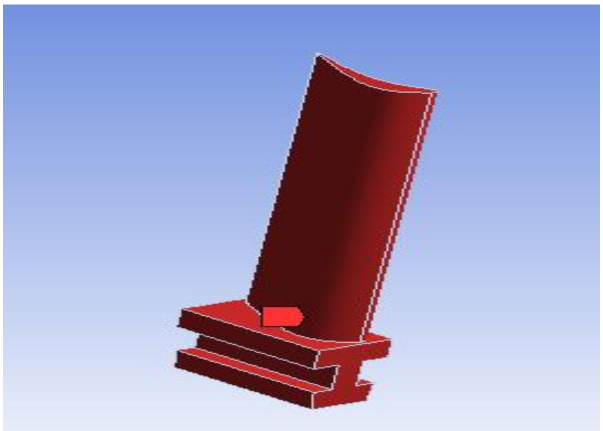

Fig. 7. Contour of Mechanical loading

III. RESULT AND DISCUSION

The analysis is carried on the gas temperature of 619°c, with non-layered, single layer, 3 layer and 4 layers. On analyzing the von-misses stresses occurred on a non-layered gas turbine blade with material properties of ceramic-zircon alone, the maximum von- misses stress that has occurred on it 2.09 x E^{10}pa. The blade has been analysed without applying the material properties of carbon fibre. In temperature analysis, the heat flux of zircon is found to be 1.45 x E^{06} w/m^2 and the temperature and the deformation was 0.036681 m.

The 2 layered blade with the material properties of both zircon and nickel, the maximum von-misses stresses that has occurred on it 1.32 x E^{10} pa. The blade has been analysed without applying the material properties of carbon fibre. In temperature analysis, the heat flux of zircon is found to be 7.37 x E^{06} w/m ^{2} and the temperature and deformation was 0.055633 m.

The 3 layered blade with the material properties of both zircon and nickel with composing the functionally grated material, has tendency of withstanding the maximum von-misses stresses of about 1.30 x E^{10} pa. The blade has been analysed without applying the material properties of carbon fibre. .In temperature analysis, the heat flux of zircon is found to be 8.61 x E^{06} w/m ^{2} and the temperature and deformation was 0.05362 m.

The 4 layered blade with the material properties of both zircon and nickel with composing the functionally grated material, has tendency of withstanding the maximum von-misses stresses of about 1.36 x E^{10} pa. The blade has been analyzed without applying the material properties of carbon fibre. .In temperature analysis, the heat flux of zircon is found to be 7.60 x E^{06} w/m ^{2} and the temperature and deformation was 0.054 m.

When functionally grated materials are used, better capability of withstanding thermal and mechanical loading demonstrated, and it can find the theoretical proof in the layer analysis. For multi-layer blade, the materials are made of 2 completely different things, they own rather different physical properties, which can determine thermal behaviors under specialized condition of high temperature. On one hand, the zircon can prevent the heat from getting too fast into the metal, which means it can also keep heat inside the blade and won't them out. This is useful feature for engine design. On the other hand the nickel is of great elastic ability, which will help to offset the stress created by the physical forces from touching objects. Thus, the composite materials has the two features that counts in engine manufacturing.

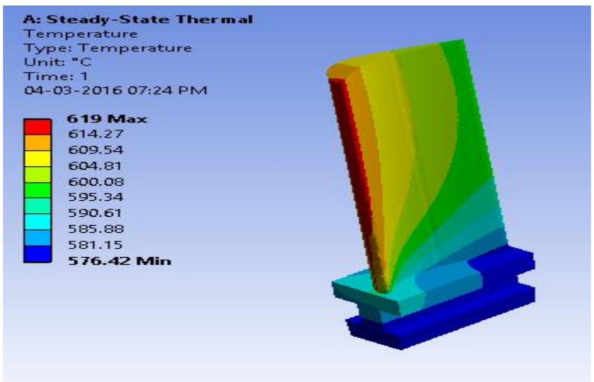

Fig. 8. Steady state temperature effect of turbine blade

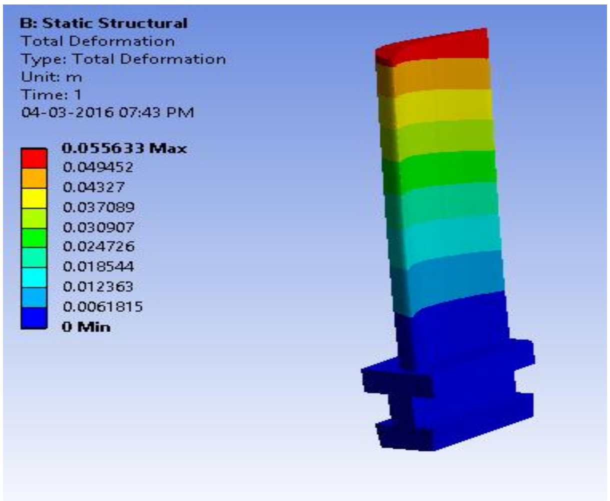

Fig. 9. Deformation of 2 Layers (without Carbon Fibres)

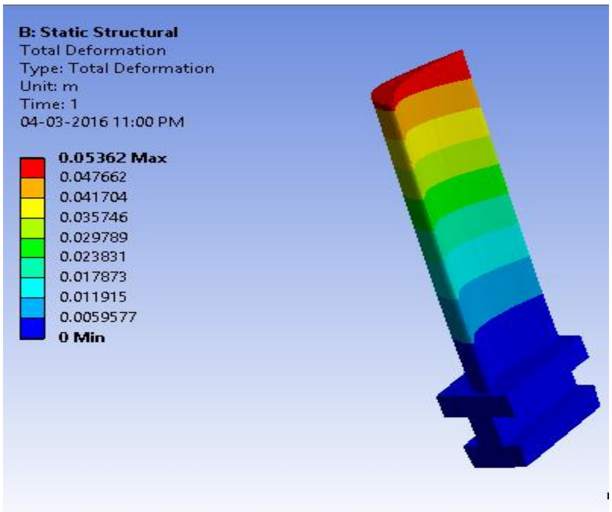

Fig. 10. Deformation of 3 Layers (with Carbon Fibres)

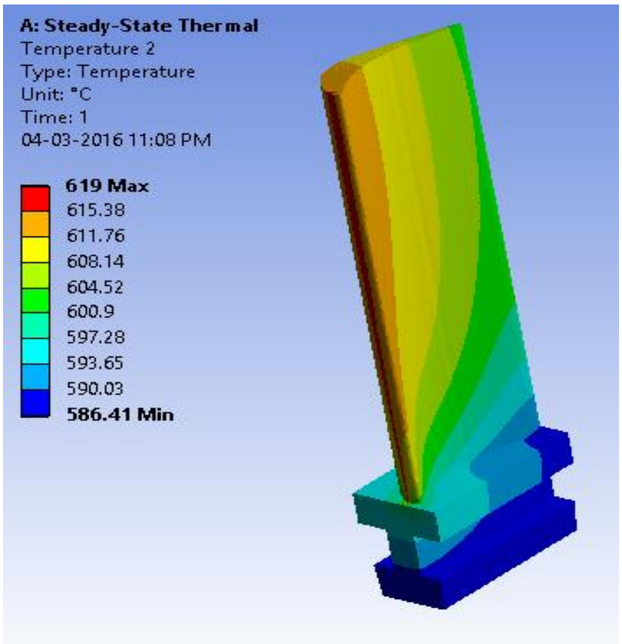

Fig. 11. Steady state temperature effect of 4 Layers (with Carbon Fibres)

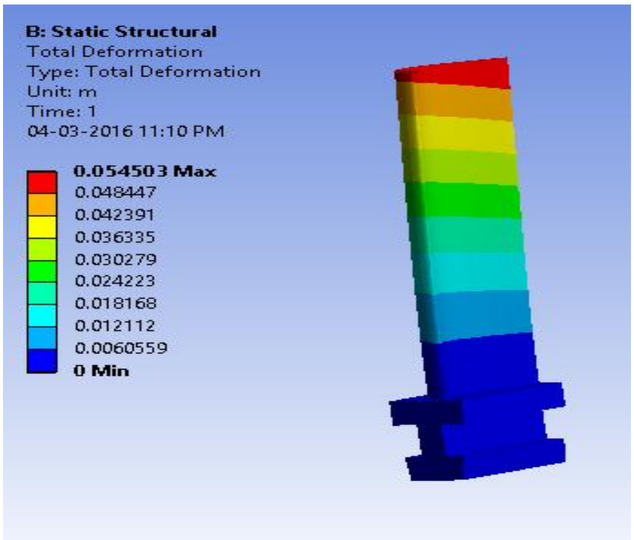

Fig. 12. Deformation of 3 Layers (with Carbon Fibres)

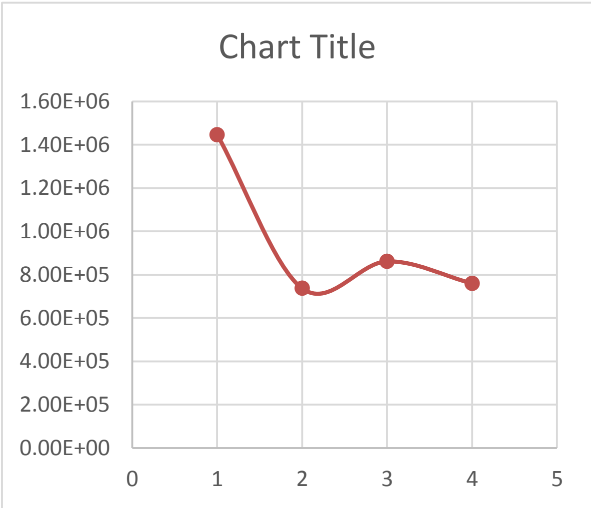

Fig. 13. Heat flux vs. layers

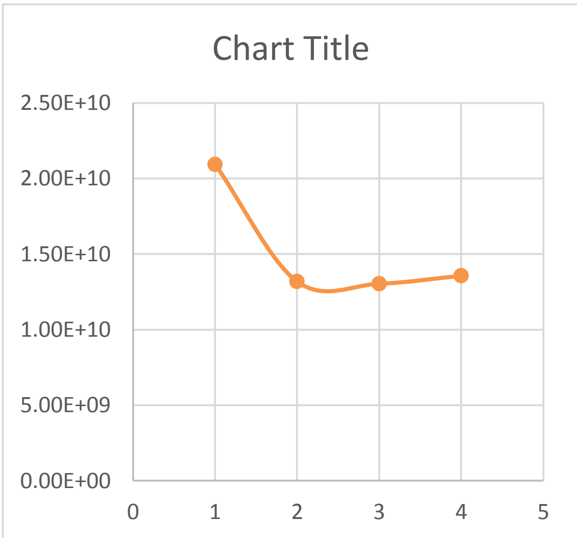

Fig. 14. Von-misses stress vs. Layers

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 06, June-2016

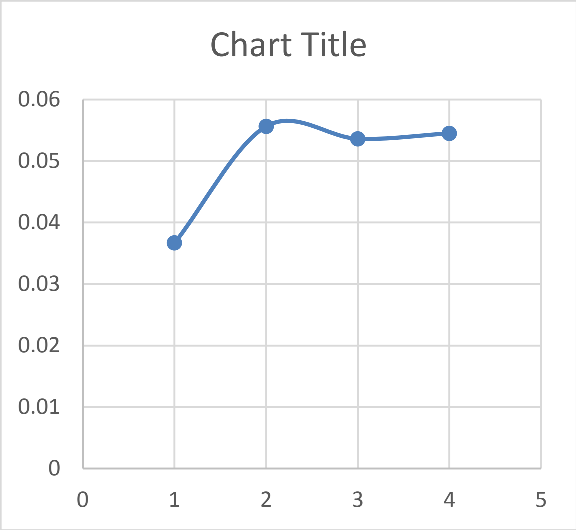

Fig. 15. Deformation vs. Layers

IV. CONCLUSION

From the analysis of the gas turbine blade, various researches are being carried out in FGM based shells, plates & beams. From these researches, the researchers have published many papers concluding that FGM is best suited for extremely high temperature.

I have been implemented these concepts in the Gas Turbine blade on the basis of FGM properties from the study of various papers.

From the high temperature analysis, it is depicted that FGM in gas turbine blade can withstand high temperature and it will absorb and reduce certain level. Hence it is found to be advantageous of using layered design of gas turbine blade with the usage of FGM.

Functionally graded materials are advanced materials having superior properties of heat resistance, suitability to be used at extreme temperature conditions and having suitable mechanical properties at the same time.

FGMs can be incorporated with FIBRE to produce robust materials that have advanced thermal and mechanical properties making them highly suitable in aerospace vehicles and other structures requiring improved temperature resistance and mechanical strength.

FGM is the material of future which has possibilities for further level of studies and applications. Only lesser experimental studies are conducted in this field and there are only very few practical implementations so far, even though natural examples are many. It is expected that with further studies the acceptability and application of FGM may be further improved.

ACKNOWLEDGEMENT

Anna university support for the work of the authors is greatly acknowledged. It has provided extensive resources and materials for the completion of this research work successfully.

REFERENCES

[1] J. Kubiak , G. Urquiza, J.A. Rodriguez, G. González, I. Rosales, G. Castillo, J. Nebradt, "Failure analysis of the 150MW gas turbine Blades "29 August.

[2] S.E. Moussavi Torshizi, S.M. Yadavar Nikravesh, A. Jahangiri, "Failure analysis of gas turbine generator cooling fan blades", 24 December 2008.

[3] M. Sujata, M. Madan, K. Raghavendra, M.A. Venkataswamy, S.K. Bhaumik,, "Identification of failure mechanisms in nickel base, superalloy turbine blades through microstructural study" 26 May 2010.

[4] Kyung Min Kim, Jun Su Park, Dong Hyun Lee, Tack Woon Lee, Hyung Hee Cho, "Analysis of conjugated heat transfer, stress and failure in a gas turbine blade with circular cooling passages" 8 March 2011.

[5] S. Kargarnejad, F. Djavanroodi, "Failure assessment of Nimonic 80A gas turbine blade" 30 August 2012.

[6] Jui-Sheng Chou, Chien-Kuo Chiu, I-Kui Huang, Kai-Ning Chi, "Failure analysis of wind turbine blade under critical wind loads" 3 September 2012. *(IJIRSE)* International Journal of Innovative Research in Science & Engineering.

[7] R D V Prasad, G Narasa Raju, M S SSrinivasa Rao, N Vasudeva Rao, "Steady State Thermal & Structural Analysis Of Gas TurbineBlade Cooling System" 1, January- 2013.

[8] B.Deeanraju, P.Larence and G.Sankarnarayana, "Theoretical Analysis of Gas Turbine Blade by Finite Element Method" July2011

[9] Sibi Mathew, Silvia Ravelli, David G.Bogard "Evaluation On of CFD Prediction Using Thermal Field Measurements on a Simulated Film Cooled Turbine Blade Leading Edge" Jan 2013.

[10] Hidekazu Iwasaki,Koji Take "Thermal and Fluid Analysis For Turbine Cooled Vane and Blade"

[11] S.Gowreesh, N.Sreenivasalu Reddy and N.V.Yogananda Murthy. "Convective heat transfer analysis of a aero gas turbine blade using ansys", March 2009

[12] P.Kauthalkar, Mr.Devendra S.Shikarwar, and Dr.Pushapendra Kumar Sharma. "Analysis of thermal streses distribution pattern on gas turbine blade using ansys" Nov 2010.

[13] John.V, T.Ramakrishna. "The design and analysis of gas turbine blade" Dec 2012.

[14] V.Raga Deepu, R.P.Kumar Ropichrla. "Design and coupled field analysis of first stage gas turbine rotor blades"

[15] S.Gowreesh, N.Sreenivasalu Reddy and N.V.Yogananda Murthy. "Convective heat transfer analysis of aero gas turbine blade using ansys" march 2009.