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Mechanical and Thermal Analysis of Functionally Graded Rotating Disk Applying Different Profiles and Material Combinations using ANSYS 18.1

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***Abstract*: Functionally graded Materials (or also can say, Functionally Gradient materials) are characterized as an anisotropic material whose physical properties varies continuously as the dimensions varies randomly or strategically, to achieve the desired characteristic. The overall properties of the functionally gradient material are different from the properties of any of the individual parent materials which form it. They can be applied to metals, ceramics and organic composites to generate improved components, they are increasingly being considered in industry for various applications to maximize strengths and integrities of many engineered structures. The study is mainly focused on comprehensive overview of the various production techniques for manufacturing of functionally graded materials; characterizations, advantages and formulation of FGMs as well as recent developments in this field are presented. Material modelling, geometric modelling and finite element modelling is done for the disc and then numerical problem is solved using the finite element software ANSYS 18.1.**

***Keywords*: Applications of FGM, Functionally graded Material, ANSYS 18.1, Mori-Tanaka.**

1. Introduction

Functionally graded materials (FGM): These are multi-phase materials with graded properties. The gradation of material properties in FGMs is achieved by continuously varying the volume fractions of the constituents. The resulting material properties can be tailored so that to fit the requirements posed in a multitude of technically demanding applications. FGMs are a class of advanced composites composed of two or more discrete constituent phases with continuous and smoothly varying composition. These advanced materials with designable gradients of composition can integrate the advantages of constituent phases and show stronger superiority than homogeneous materials made of similar constituents in applications. Often, the accurate information of the shape and distribution of particles may not be available, thus the effective material properties, viz. elastic moduli, shear moduli, density, etc. of the graded composites are being evaluated only by the volume fraction distribution and the approximate shape of the dispersed phase.

2. Rotating disk

Thin disks are modeled and analyzed as two dimensional axisymmetric body and thick disks are modeled as three dimensional axisymmetric body.

A. Formulation and Validation of the problem using ANSYS

A rotating annular disk of Al/ceramic functionally graded material [19] is validated. Properties of Al and ceramic are given in table 1. The property variation of the material in the FG disk along the radial direction is assumed to be power-law and Mori-Tanaka gradation (2.1.1), (2.1.2) and (2.1.3) respectively.

Table 1
Mechanical properties of Al and ceramic [19]

Material	E (GPa)	ρ (g/cm^3)	B (GPa)	G (GPa)
Al	71	2.70	58.333	26.9231
Ceramic	151	5.70	128.333	58.0769

Where E is modulus of elasticity, ρ is density, B is bulk modulus and G is shear modulus of the material.

The effective bulk modulus B and shear modulus G of FG disk evaluated using the Mori-Tanaka estimates.

$$B(r) = \frac{(\mathrm{Bo} - \mathrm{Bi})\mathrm{Vo}}{(1 + (1 - \mathrm{Vo})\frac{3(B_o - B_i)}{3B_i + 4G_i})} + B_i$$

$$G(r) = \frac{(\mathrm{Go} - \mathrm{Gi})\mathrm{Vo}}{(1 + (1 - \mathrm{Vo})\frac{3(G_o - G_i)}{G_i + f_1})} + G_i$$

Where

$$f_1 = \frac{G_i(9B_i + 8G_i)}{6(B_i + 2G_i)}$$

V is the volume fraction of the phase material. The subscripts i and o refer to the inner and outer materials respectively. The volume fraction of the inner and outer phases are related by

$$V_i + V_o = 1$$

And V_o is expressed as

$$V_o = \left(\frac{r - r_i}{r_o - r_i}\right)^n$$

Where n (n>=0) is the volume fraction exponent. The elastic modulus E and the Poisson's ratio v can be found as

$$E = \frac{9BG}{3B + G}$$

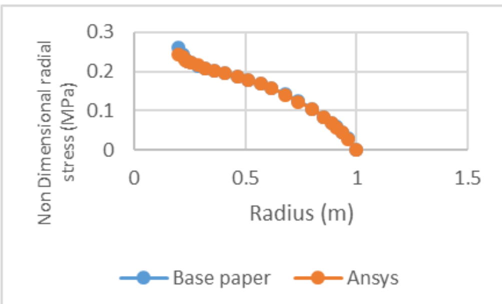

Fig. 1. Comparison of radial stress for concave profile with results of reference

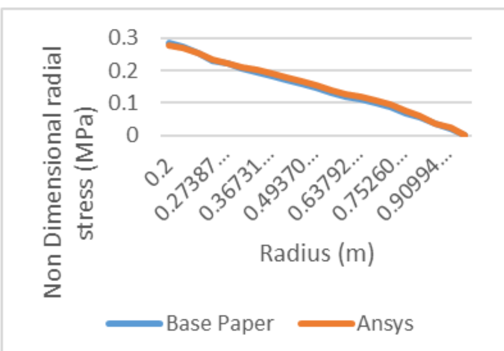

Fig. 2. Comparison of radial stress for uniform profile with results of reference

B. Comparative study based on combination of different materials

In this section ceramic material combination (silicon carbide, aluminum nitride, silicon nitride, zirconia) with metal (aluminum) is studied. Since stress is not dependent on material but strain is a dependent variable on material therefore, by varying different ceramic materials deformation or strain will change

1) SiC (Silicon carbide)

An annular disc comprising of aluminum and titanium carbide (FGM) will be analyzed, the mechanical properties are shown in table 2.

Table 2
Mechanical properties of SiC

Material	E (GPa)	ρ (g/cm^3)	α (/ ^{0}C)
SiC	410	3.10	4×10^{-6}

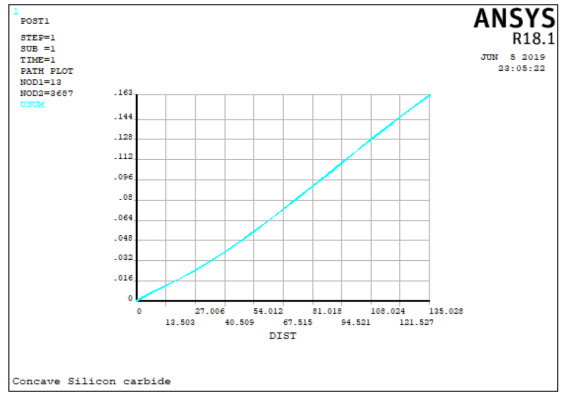

Fig. 3. Variation of summation of all displacement for concave thickness disk for Al SiC material, fix-free boundary condition

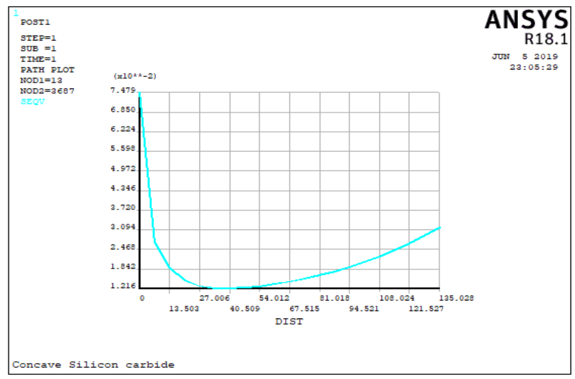

Fig. 4. Variation of von mises stress for concave thickness disk for Al-SiC material, fix-free boundary condition

2) AlN (Aluminum nitride)

An annular disc comprising of aluminum and alumina (FGM) will be analyzed, the mechanical properties are shown in table 3.

Table 3
Mechanical properties of AlN

Material	E (GPa)		ρ (g/cm^3)	α (/ ^{0}C)
AlN	330		3.26	4.5×10^{-6}

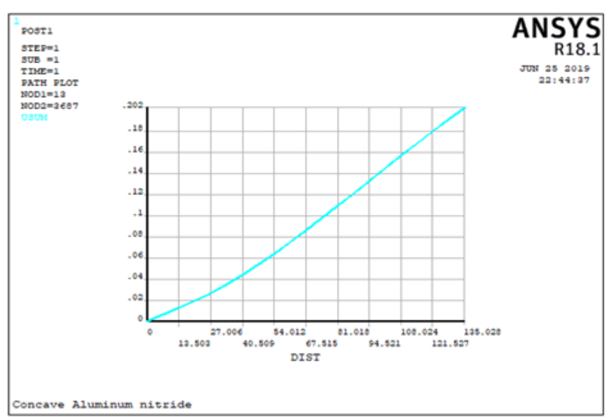

Fig. 5. Variation of summation of all displacement for concave thickness disk for Al-AlN material, fix-free boundary condition

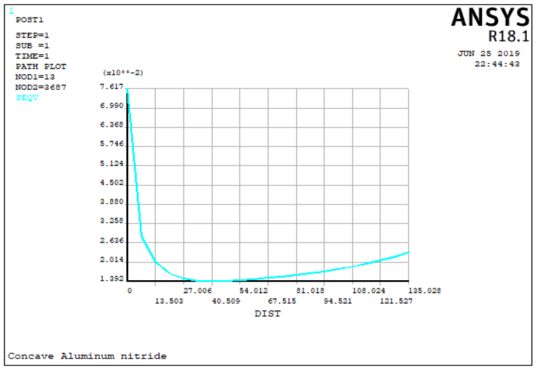

Fig. 6. Variation of von mises stress for concave thickness disk for Al-AlN, fix-free boundary condition

3) Si_3N_4(Silicon nitride)

An annular disc comprising of aluminum and silicon nitride (FGM) will be analyzed, the mechanical properties are shown in table 4.

Table 4
Mechanical properties of Si3N4

Material	E (GPa)	ρ (g/cm^3)	α (/ ^{0}C)
Si_3N_4	310	3.26	3.3×10^{-6}

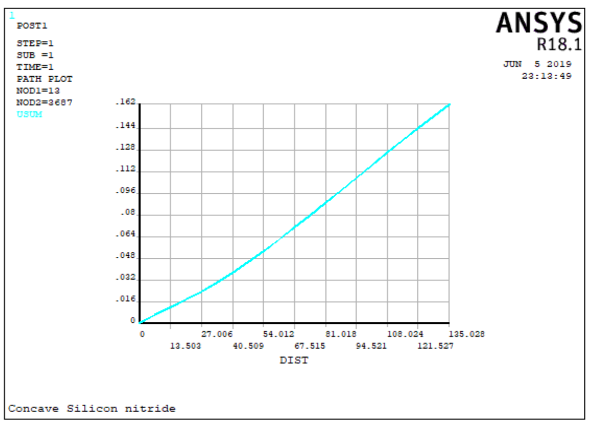

Fig. 7. Variation of summation of all displacement for concave thickness disk for Al- Si3N4, fix-free boundary condition

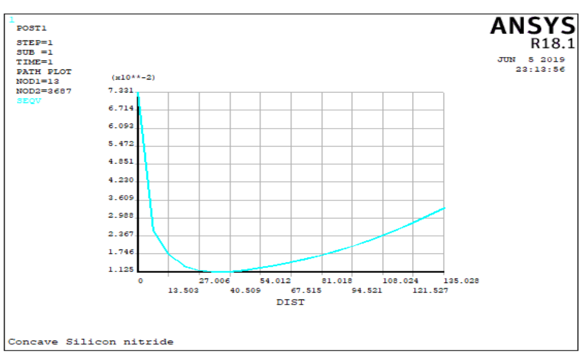

Fig. 8. Variation of von mises stress for concave thickness disk for Al-Si3N4, fix-free boundary condition

4) ZrO3 (Zirconia)

An annular disc comprising of aluminum and zirconia (FGM) is already analyzed under validation now a comparative analysis of variation of summation of all displacement for different ceramic materials will be analyzed.

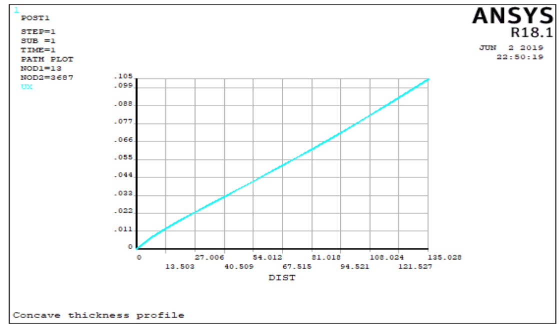

Fig. 9. Variation of radial displacement for concave thickness disk for Al-zrO3, fix-free boundary condition

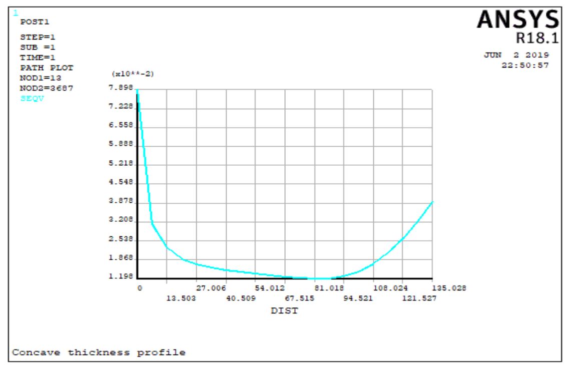

Fig. 10. Variation of summation of all displacement for concave thickness disk for Al-zrO3, fix-free boundary condition

5) Comparative study based on the division of material properties in FGM

In this section division of material properties is studied i.e. the gradation of material from start to end will vary with respect from fine to coarse. The disc is of 150mm length while the hole is of 15mm therefore the effective length for FGM disc in this case is 135mm so if material properties if varies after every 1mm (which is considered in all the above cases), 0.5mm, 0.33mm what are the differences in terms of radial displacement and von mises stress.

6) 0.5mm spacing between two gradation

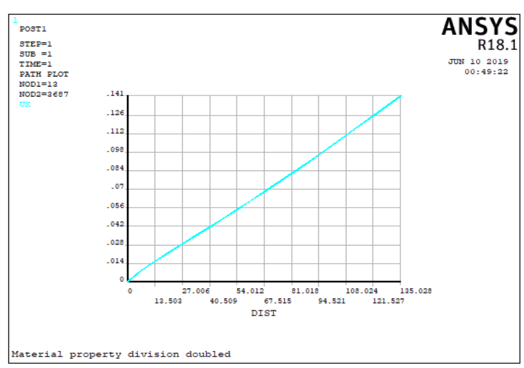

Fig. 11. Variation of radial displacement for concave thickness disk for 0.5mm, fix-free boundary condition

In this case the rotating disc material property changes after every 0.5mm according to the exponential law of FGM, radial displacement and von mises stress is monitored to note the differences in both the cases considered.

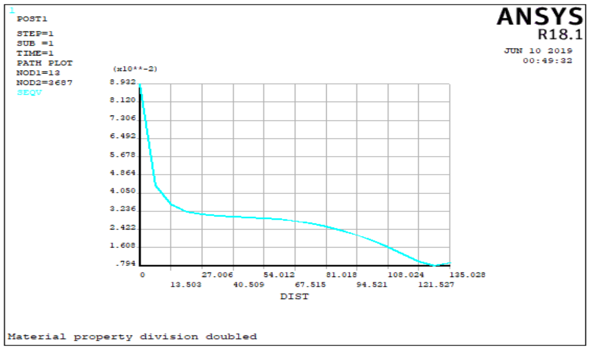

Fig. 12. Variation of von mises stress for concave thickness disk for 0.5mm, fix-free boundary condition

7) 0.33mm spacing between two gradation

In this case the rotating disc material property changes after every 0.33mm according to the exponential law of FGM, radial displacement and von mises stress is monitored to note the differences in both the cases considered.

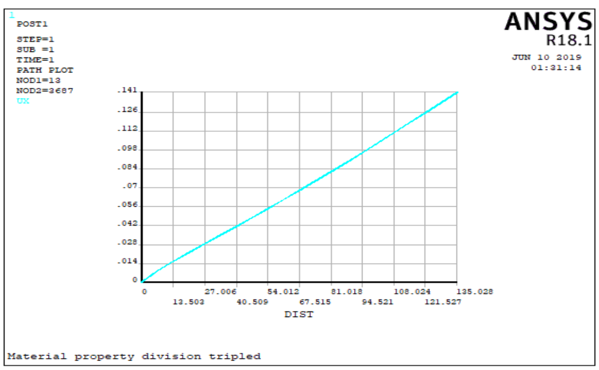

Fig. 13. Variation of summation of all displacement for concave thickness disk for Al-zrO3, fix-free boundary condition

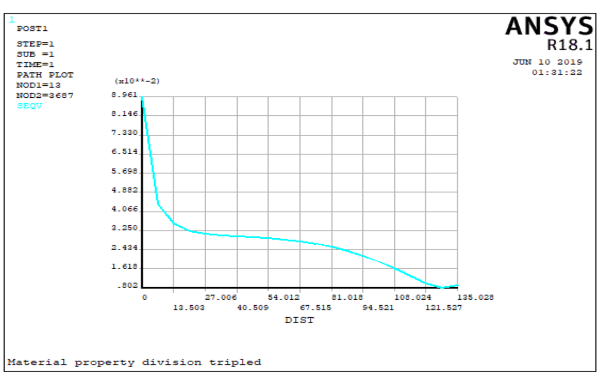

Fig. 14. Variation of summation of all displacement for concave thickness disk for Al-zrO3, fix-free boundary condition

3. Conclusion

Since, silicon nitride is showing the least deformation of all the above ceramic materials when made FGM with aluminum Silicon nitride, silicon carbide is showing signs of strain hardening in von mises stress curve thus increasing its hardness thus more susceptible to failure whereas zirconia tends to fall along the length of the disc which can be predicted as a sign of failure. therefore, silicon nitride can be chosen as the material for FGM with aluminum but as per application cost is also needed to be analyzed to come down to the best ceramic material. Comparative study based on spacing of gradation for FGM reveals that radial displacement remains unchanged with the variation of spacing of gradation and radial stress also remains unchanged with the variation of spacing of gradation. Therefore, spacing of gradation for FGM has negligible effect and 1mm spacing can be considered for spacing of gradation.

References

[1] Rasheedat M. Mahamood, Esther T. Akinlabi, Mukul Shukla and Sisa Pityana, 2012. Functionally Graded Material: An Overview. Proceedings of the World Congress on Engineering, Vol. 3, 2012.
[2] Zahra Sharif Khodaei, 2005. Preliminaries to Modeling and Analysis of Functionally Graded Materials. Czech Technical University in Prague.
[3] J.D. Claytona, J.J. Rencisb, 2000. Numerical integration in the axisymmetric finite element formulation. Advances in Engineering Software, 31: 137–141.
[4] Ahmet N. Eraslan, 2003. Elastic–plastic deformations of rotating variable thickness annular disks with free, pressurized and radially constrained boundary conditions. IJMS, 45: 643–667.
[5] Ashraf M. Zenkour, Daoud S. Mashat, 2011. Stress Function of a Rotating Variable-Thickness Annular Disk Using Exact and Numerical Methods. SCIRP Engineering, 3: 422-430.
[6] J. N. Sharma, Dinkar Sharma, Sheo Kumar 2011. Analysis of Stresses and Strains in a Rotating Homogeneous Thermoelastic Circular Disk by using Finite Element Method. International Journal of Computer Applications, Volume 35, No.13, 2011
[7] Hasan Callioglu, 2011. Stress analysis in a functionally graded disc under mechanical loads and a steady state temperature distribution. Sadhana Vol. 36, Part 1: 53–64.
[8] Maruthi B H, M. Venkatarama Reddy, K. Channakeshavalu, 2012. Finite Element Formulation for Prediction of Over-speed and burst-margin limits in Aero-engine disc. International Journal of Soft Computing and Engineering (IJSCE), Volume 2, Issue 3, 2012.
[9] M. Shariyat, R. Mohammadjani, 2013. Three-dimensional compatible finite element stress analysis of spinning two-directional FGM annular plates and disks with load and elastic foundation non uniformities. LAJSS, 10: 859 – 890.
[10] Mohammad Zamani Nejad, Mehdi Jabbari, Mehdi Ghannad, 2015. Elastic analysis of FGM rotating thick truncated conical shells with axially-varying properties under non-uniform pressure loading. Composite Structures, 122: 561–569.
[11] J N. Sharma, Dinkar Sharma, Sheo Kumar, 2012. Stress and strain analysis of rotating FGM Thermo elastic circular disk by using FEM. International Journal of Pure and Applied Mathematics, Volume 74 No. 3: 339-352.
[12] Abdur Rosyid, Mahir Es-Saheb, Faycal Ben Yahia, 2014. Stress Analysis of Nonhomogeneous Rotating Disc with Arbitrarily Variable Thickness Using Finite Element Method. Research Journal of Applied Sciences, Engineering and Technology, 7(15): 3114-3125.
[13] Nguyen Dinh Duc, Vu Thi Thuy Anh, Pham Hong Cong, 2014. Nonlinear axisymmetric response of FGM shallow spherical shells on elastic foundations under uniform external pressure and temperature. European Journal of Mechanics A/Solids, 45: 80-89.

[14] Minwoo Hong, Ilwook Park, Usik Lee, 2014. Dynamics and waves characteristics of the FGM axial bars by using spectral element method. Composite Structures, 107: 585–593.
[15] Manish Bhandari, Dr. Kamlesh Purohit, 2014. Analysis of Functionally Graded Material Plate under Transverse Load for Various Boundary Conditions. IOSR-Journal of Mechanical and Civil Engineering, Volume 10, Issue 5: 46-55.
[16] Hassan Zafarmand, Mehran Kadkhodayan, 2015. Nonlinear analysis of functionally graded nanocomposite rotating thick disks with variable thickness reinforced with carbon nanotubes. Aerospace Science and Technology, 41: 47–54.
[17] A.M. Afsar, J. Go, 2010. Finite element analysis of thermoelastic field in a rotating FGM circular disk. Applied Mathematical Modelling, 34: 3309–3320.
[18] P. Seshu, 2003. A text book of finite element analysis. PHI Learning Pvt. Ltd. Ch 5, pp. 167-171.
[19] M. Bayat, B. B. Sahari, M. Saleem, E. Dezvareh, A. H. Mohazzab, 2011. Analysis of Functionally Graded Rotating Disks with Parabolic Concave Thickness Applying an Exponential Function and the Mori-Tanaka Scheme. IOP Conf. Series: Materials Science and Engineering, vol: (17). ANSYS help Manual.
[20] Mehdi Bayat, M. Saleem, B.B. Sahari, A.M.S. Hamouda and E. Mahdi, 2009. Mechanical and thermal stresses in a functionally graded rotating disk with variable thickness due to radially symmetry loads. International Journal of Pressure Vessels and Piping, 86: 357–372.
[21] Hasan Callioglu, Numan Behlul Bektas and Metin Sayer, 2011. Stress analysis of functionally graded rotating discs: analytical and numerical solutions. Acta Mech. Sin. 27(6):950–955.
[22] Hasan Callioglu, Numan Behlul Bektas and Metin Sayer, 2011. Stress analysis of functionally graded rotating discs: analytical and numerical solutions. Acta Mech. Sin. 27(6):950–955
[23] Hassan Zafarmand and Behrooz Hassani, 2014. Analysis of two-dimensional functionally graded rotating thick disks with variable thickness. Acta Mech 225, 453–464.
[24] Hasan Callioglu, Metin Sayer, Ersin Demir, 2011. Stress analysis of functionally graded discs under mechanical and thermal loads. Indian Journal of Engineering & Material Sciences, 18:111-118.
[25] Amani Nejad, Majid Abedi, Mohammad Hassan and Mehdi Ghannad, 2013. Elastic analysis of exponential FGM disks subjected to internal and external pressure, Central European Journal of Engineering 3(3): 459-465.
[26] Ashraf M. Zenkour, Daoud S. Mashat, 2011. Stress Function of a Rotating Variable-Thickness Annular Disk Using Exact and Numerical Methods. SCIRP Engineering, 3: 422-430.
[27] J. N. Sharma, Dinkar Sharma, Sheo Kumar 2011. Analysis of Stresses and Strains in a Rotating Homogeneous Thermoelastic Circular Disk by using Finite Element Method. International Journal of Computer Applications, Volume 35, No.13, 2011.
[28] Tirupathi R. Chandrupatla and Ashok D. Belengundu. Introduction to Finite Element in Engineering. PHI Learning Pvt. Ltd.
[29] Lakshman Sondhi, Subhashis Sanyal, Kashi Nath Saha and Shubhankar Bhowmick, 2015. An Approximate Solution to the Stress and Deformation States of Functionally Graded Rotating disks. ICME Conf.
[30] Aidy Ali, M. Bayat, B. B. Sahari, M. Saleem and O. S. Zaroog, 2012. The effect of ceramic in combinations of two sigmoid functionally graded rotating disks with variable thickness. Scientific Research and Essays Vol. 7(25), 2174-2188.
[31] Abdur Rosyid, Mahir Es-Saheb, Faycal Ben Yahia, 2014. Stress Analysis of Nonhomogeneous Rotating Disc with Arbitrarily Variable Thickness Using Finite Element Method. Research Journal of Applied Sciences, Engineering and Technology, 7(15): 3114-3125.
[32] K. Asemi, M.Salehi, M.Akhlaghi, "Post-buckling analysis of FGM annular sector plates based on three dimensional elasticity graded finite elements", International JournalofNon-LinearMechanics67 2014 pp. 164–177.
[33] Javaheri R, Eslami MR. Thermal buckling of functionally graded plates based on higher order theory. J Therm Stress 2011;25(7):603–625.
[34] Navazi H, Haddadpour H. Aero-thermoelastic stability of functionally graded plates. Compos Struct 2007;80(September 2006):580–587.
[35] Bodaghi M, Saidi AR. Thermoelastic buckling behavior of thick functionally graded rectangular plates. Arch Appl Mech 2011;81(11):1555–1572.