International Journal of Engineering and Applied Physics (IJEAP)
Vol. 4, No. 3, September 2024, pp. 1077~1082
ISSN: 2737-8071

The effective Young's modulus of porous exponential functionally graded material

Lan Hoang That Ton*
* Dept. of Civil Engineering at HCMC University of Architecture, Vietnam.

Article Info

Article history:

Received Jan 30, 2024
Revised July 15, 2024
Accepted Aug 10, 2024

Keywords:

Young's modulus
Exponential functionally graded material
Porosity

ABSTRACT

The effective Young's modulus of porous exponential functionally graded material is presented in this article. Matlab software is used to plot the change in value of this quantity along the thickness of the structure related to this material.

Corresponding Author:

Lan Hoang That Ton,
Department of Civil Engineering,
HCMC University of Architecture, Vietnam.
Email: tltechonlinesom@gmail.com

1. INTRODUCTION

Materials have always served the purpose of meeting human needs related to every aspect of life, be it daily living things to the aircraft, aerospace, and automotive industries. Materials have always been an integral part of human beings. Specific properties lead to specific applications. Materials possess excellent light weight and high strength for aircraft and aerospace applications. Functionally graded materials (FGM) are a completely unique concept in terms of their ability to have innovative features and superior properties that cannot be achieved by standard traditional materials [1]. It can be effectively fabricated using additive manufacturing [2, 3]. Mechanical performance is crucial for FGM structures, and the impact of porosity on their mechanical performance must be investigated [4, 5]. The study [6] comprehensively investigated the natural frequency analysis of a shear-deformable functionally graded porous plate with cutouts, utilizing an FE-based multilayered FGM model. Analyzing natural frequencies was vital to prevent catastrophic failure in porous plates, particularly in cooling plates. Cutouts in cooling plates enhanced heat dissipation, improved airflow, reduced weight,... This study employed an FE-based multilayered FGM model that considered three distinct porosity distributions (even, uneven, and sinusoidal) and incorporated a power law distribution based on a modified rule of mixture to derive the effective material properties of the FGM porous plate. The paper [7, 8] presented the behaviors of FGM plates and beams with porosities related to the third-order shear deformation theory or the differential transformation method. The maximum deflection of a functionally graded sandwich conoidal shell with porous core was studied in [9]. Two types of porosity distribution was listed to study the effect of porosity in the core layer of the shell. The modified power law was used and the governing equations were considered based on an isoparametric Q9 element having 63 dofs. The studies [10–12] were given in the mechanical behaviors of FGM nanoplates, thin annular plates, or rectangular plates with porosities. The articles [13-15] were carried out to investigate the combined effect of porosity and temperature on the FGM sandwich structures. These studies relied on high-order shear deformation theories, a modified power law function as well as focusing on the interplay of gradient index, aspect ratio, porosity index, and boundary conditions. Furthermore, the forced vibration analysis of a viscoelastic spherical cavity with double porosity had been presented in the context of the Nunziato and Cowin model as in [16]. The articles [17-20] focused on the design and production of titanium-based materials with better mechanical properties and improved the connection between the implant and the bone and so on.

To initiate these studies, the value of the effective Young's modulus needs to be considered, especially for exponential functionally graded material with porosity. This is also the goal of this article.

2. FORMULATION

The effective Young's modulus of exponential functionally graded material is given by

$$E(z) = E_m e^{\left[\ln\left(\frac{E_c}{E_m}\right)\times\left(\frac{z}{h}+\frac{1}{2}\right)\right]} \tag{1}$$

with porosity effect, the effective Young's modulus of exponential functionally graded material is rewritten as

$$\text{Type 1:} \quad E(z) = E_m e^{\left[\ln\left(\frac{E_c}{E_m}\right)\times\left(\frac{z}{h}+\frac{1}{2}\right)\right]} - \frac{\alpha}{2}(E_c + E_m) \tag{2}$$

$$\text{Type 2:} \quad E(z) = E_m e^{\left[\ln\left(\frac{E_c}{E_m}\right)\times\left(\frac{z}{h}+\frac{1}{2}\right)\right]} - \frac{\alpha}{2}(E_c + E_m)\left(1 - \frac{2|z|}{h}\right) \tag{3}$$

or be changed as follows

$$\text{Type 3:} \quad E(z) = E_m e^{\left[\ln\left(\frac{E_c}{E_m}\right)\times\left(\frac{z}{h}+\frac{1}{2}\right)\right]} - \frac{\alpha}{2}(E_c + E_m)\cos\left(\frac{\pi}{2}\frac{z}{h}\right) \tag{4}$$

$$\text{Type 4:} \quad E(z) = E_m e^{\left[\ln\left(\frac{E_c}{E_m}\right)\times\left(\frac{z}{h}+\frac{1}{2}\right)\right]} - \frac{\alpha}{2}(E_c + E_m)\cos\left(\frac{\pi}{2} - \frac{\pi z}{h}\right) \tag{5}$$

3. THE EFFECTIVE YOUNG'S MODULUS

For example, the change of the effective Young's modulus is presented with the material properties as metal *Aluminum* (E_m = 70 GPa) and ceramic *Zirconia* (E_c = 200 GPa).

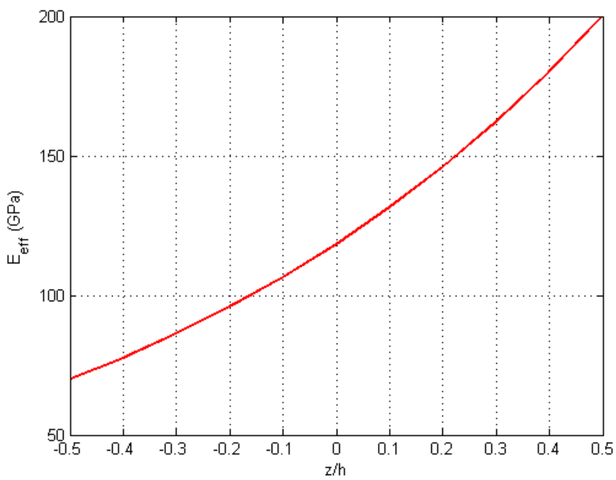
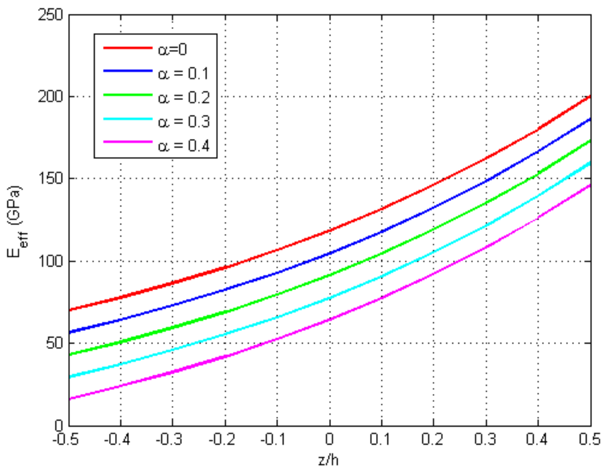
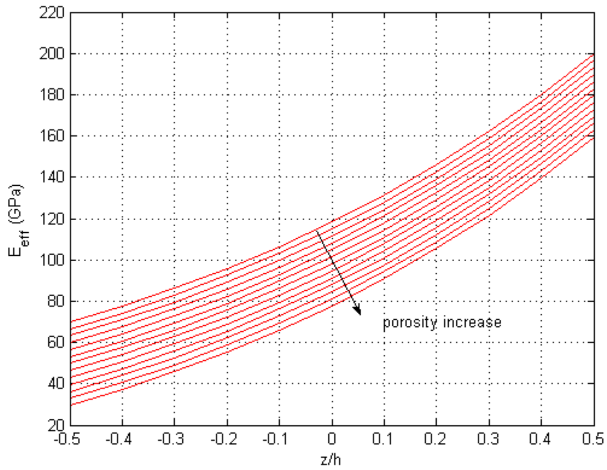


Figure 1. The effective Young's modulus of exponential functionally graded material (*Aluminum / Zirconia)* without porosity.



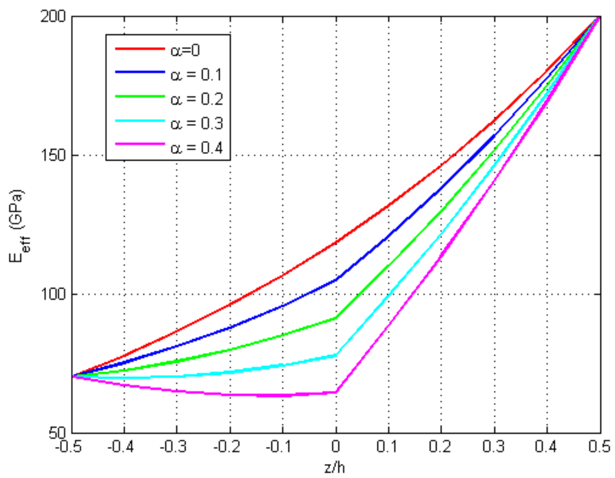
(a)



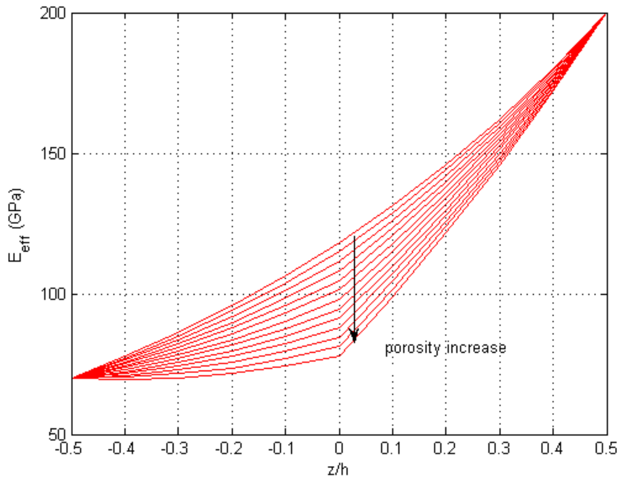
(b)

Figure 2. The effective Young's modulus in Type 1 of exponential functionally graded material (*Aluminum / Zirconia)* with porosity factor α

It can be seen that as the porosity factor increases, the E_{eff} value gradually decreases, corresponding to the first three types of porosity distribution, as shown in Figures 1–4. For type 3, based on a slight change in the porosity distribution, the E_{eff} value increases slightly for the upper and lower face regions of the structure, as depicted in Figure 4a. In Figure 5, for type 4, increasing the porosity reverses the increase and decrease of the E_{eff} value in the region near the upper and lower faces of the structure, respectively.

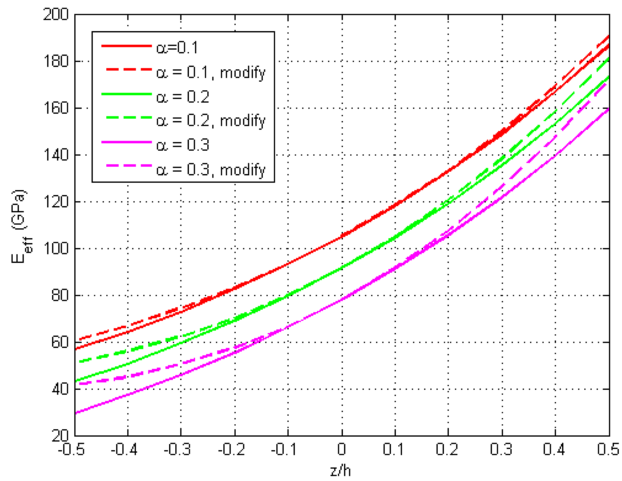


(a)

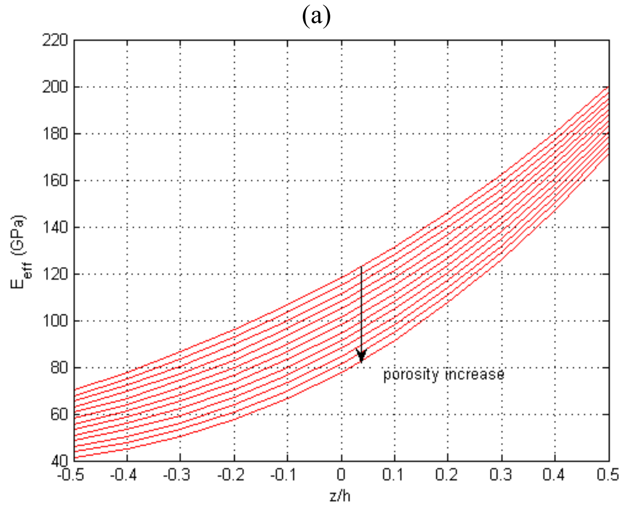


(b)

Figure 3. The effective Young's modulus in Type 2 of exponential functionally graded material (*Aluminum / Zirconia)* with porosity factor α

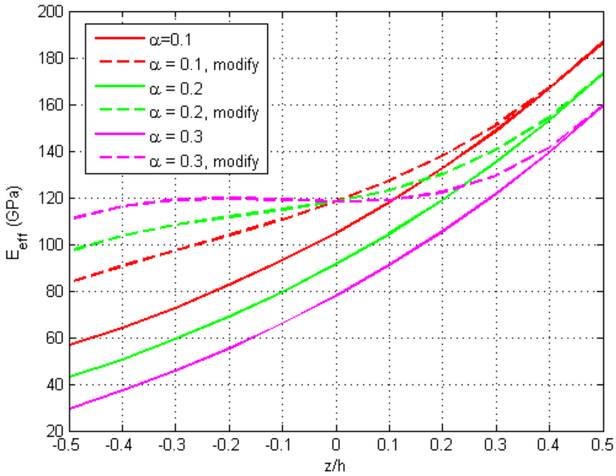


(a)

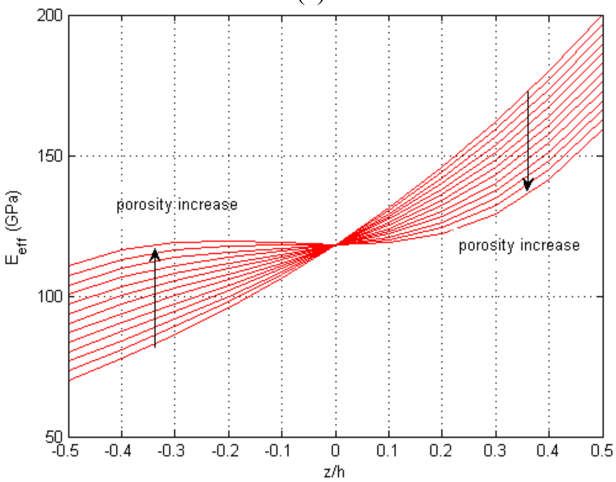


(b)

Figure 4. The effective Young's modulus in Type 3 of exponential functionally graded material (*Aluminum / Zirconia)* with porosity factor α



(a)



(b)

Figure 5. The effective Young's modulus in Type 4 of exponential functionally graded material (*Aluminum / Zirconia)* with porosity factor α

4. CONCLUSION

In this article, the effective Young's modulus of porous exponential functionally graded material is depicted. The main aim is to illustrate this value as applied to the mechanical analysis of structures based on porous exponential functionally graded material in reality.

REFERENCES

[1] A. Pasha and B. M. Rajaprakash, "Fabrication and mechanical properties of functionally graded materials: A review", *Materials Today: Proceedings*, 52, 379-387, 2022.
[2] E. J. Kim, C. M. Lee and D. H. Kim, "Study on the characteristics of functionally graded materials from Ni-20cr to Ti-6Al-4V via directed energy deposition", *Journal of Alloys and Compounds*, 955, 170263, 2023.
[3] D. D. Singh, S. Arjula and A. R. Reddy, "Functionally graded materials manufactured by direct energy deposition: A review", *Materials Today: Proceedings*, 47, 2450-2456, 2021.
[4] Y. Xiong, Z. Han, J. Qin, L. Dong, H. Zhang, Y. Wang, H. Chen and X. Li, "Effects of porosity gradient pattern on mechanical performance of additive manufactured Ti-6Al-4V functionally graded porous structure", *Materials & Design*, 208, 109911, 2021.
[5] D. Khrapov, M. Kozadayeva, A. Koptyug, T. Mishurova, D. Meinel, R. Surmenev and M. Surmeneva, "Geometrical features and mechanical properties of the sheet-based gyroid scaffolds with functionally graded porosity manufactured by electron beam melting", *Materials Today Communications*, 35, 106410, 2023.
[6] M. Amir, J. Lim, S. W. Kim and S. Y. Lee, "Finite element analysis of natural frequencies of the FGM porous cooling plate with cutouts: A multilayered FGM approach*", Results in Engineering*, 20, 101532, 2023.
[7] C. Tao and T. Dai, "Analyses of thermal buckling and secondary instability of post-buckled S-FGM plates with porosities based on a meshfree method", *Applied Mathematical Modelling*, 89, 268-284, 2021.

[8] N. Wattanasakulpong and V. Ungbhakorn, "Linear and nonlinear vibration analysis of elastically restrained ends FGM beams with porosities", *Aerospace Science and Technology*, 32(1), 111-120, 2014.
[9] M. I. Ansari, A. K. Chaubey and A. Kumar, "Deflection of FGM sandwich conoidal shell with porous core", *Materials Today: Proceedings*, 2023.
[10] M. Sobhy and A. M. Zenkour, "Porosity and inhomogeneity effects on the buckling and vibration of double-FGM nanoplates via a quasi-3D refined theory", *Composite Structures*, 220, 289-303, 2019.
[11] B. Lhoucine, E. Khalid and B. Rhali, "Thermal Behavior Analysis at Large Free Vibration Amplitudes of Thin Annular FGM Plates with Porosities", *Procedia Engineering*, 199, 528-533, 2017.
[12] Z. Hu, Y. Shi, S. Xiong, X. Zheng and R. Li, "New analytic free vibration solutions of non-Lévy-type porous FGM rectangular plates within the symplectic framework", *Thin-Walled Structures*, 185, 110609, 2023.
[13] R. Patil, S. Joladarashi and R. Kadoli, "Effect of porosity and viscoelastic boundary conditions on FG sandwich beams in thermal environment: Buckling and vibration studies", *Structures*, 56, 105001, 2023.
[14] M. A. Kenanda, F. Hammadi, Z. Belabed and M. H. Meliani, "Effect of porosities on mechanical behavior and structural integrity of porous functionally graded plates using a new Quasi-3D trigonometric high order shear deformation theory", *Science Talks*, 9, 100293, 2024.
[15] R. Chintalapudi, G. N. Kannaiyan, B. Pappula and S. Makgato, "The effects of gradient index, aspect ratio, porosity, and boundary conditions on the buckling behavior of functionally graded porous beams: A k-out-of-n system reliability analysis", *Results in Physics*, 60, 107634, 2024.
[16] N. Rana and D. K. Sharma, "Transient wave analysis of viscoelastic spherical cavity with double porosity", *Materials Today: Proceedings*, 2024.
[17] I. Matuła, G. Dercz, A. Barylski and J. Kubisztal, "Porous functionally graded material based on a new Ti-25Nb-5Zr-(2Sn) alloy produced using the powder metallurgy technique", *Journal of Alloys and Compounds*, 982, 173779, 2024.
[18] S. Li, G. Wang, K. Zhang, X. Zhang, L. Zhang, W. Wang and R. He, "Mechanical properties of Al2O3 and Al2O3/Al interpenetrated functional gradient structures by 3D printing and melt infiltration", *Journal of Alloys and Compounds*, 950, 169948, 2023.
[19] M. J. Allah and A. Timesli, "Nonlinear dynamic analysis of viscoelastic FGM with linear and nonlinear porosity distributions", *Materials Today Communications*, 35, 106306, 2023.
[20] A. V. Krysko, L. A. Kalutsky and V. A. Krysko, "Stress-strain state of a porous flexible rectangular FGM size-dependent plate subjected to different types of transverse loading: Analysis and numerical solution using several alternative methods", *Thin-Walled Structures*, 196, 111512, 2024.