

## Hygro-thermo-mechanical bending response of FG plates resting on elastic foundations

Bouid Merazka<sup>1,2</sup>, Abdelhakim Bouhadra<sup>1,2</sup>, Abderrahmane Menasria<sup>1,2</sup>, Mahmoud M. Selim<sup>3</sup>, Abdelmoumen Anis Bousahla<sup>4</sup>, Fouad Bourada<sup>1,5</sup>, Abdeldjebbar Tounsi<sup>1</sup>, Kouider Halim Benrahou<sup>1</sup>, Abdelouahed Tounsi<sup>\*1,6,7</sup> and Mesfer Mohammad Al-Zahrani<sup>7</sup>

<sup>1</sup>Materials and Hydrology Laboratory, University of Sidi Bel Abbès, Faculty of Technology, Civil Engineering Department, Algeria

<sup>2</sup>Department of Civil Engineering, Faculty of Science & Technology, Abbes Laghrour University, Khenchela, Algeria

<sup>3</sup>Department of Mathematics, Al-Aflaj College of Science and Humanities, Prince Sattam bin Abdulaziz University, Al-Aflaj 710-11912 Saudi Arabia

<sup>4</sup>Laboratoire de Modélisation et Simulation Multi-échelle, Université de Sidi Bel Abbès, Algeria

<sup>5</sup>Département des Sciences et de la Technologie, université de Tissemsilt, BP 38004 Ben Hamouda, Algérie

<sup>6</sup>YFL (Yonsei Frontier Lab), Yonsei University, Seoul, Korea

<sup>7</sup>Department of Civil and Environmental Engineering, King Fahd University of Petroleum & Minerals, 31261 Dhahran, Eastern Province, Saudi Arabia

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**Abstract.** The aim of this work is to study the hygro-thermo-mechanical bending responses of simply supported FG plate resting on a Winkler-Pasternak elastic foundation. The effect transverse shear strains is taken into account in which the zero transverse shear stress condition on the top and bottom surfaces of the plate is ensured without using any shear correction factors. The developed model contains only four unknowns variable which is reduced compared to other HSDTs models. The material properties of FG-plate are supposed to vary across the thickness of the plate according to power-law mixture. The differential governing equations are derived based on the virtual working principle. Numerical outcomes of bending analysis of FG plates under hygro-thermo-mechanical loads are performed and compared with those available in the literature. The effects of the temperature, moisture concentration, elastic foundation parameters, shear deformation, geometrical parameters, and power-law-index on the dimensionless deflections, axial and transverse shear stresses of the FG-plate are presented and discussed.

**Keywords:** FG plates; Winkler–Pasternak foundations; shear and normal strains; hygrothermal and mechanical response

### 1. Introduction

Functionally graded materials (FGMs) are a new category of composites that are of great interest to engineering design and manufacture (Mantari and Guedes Soares 2013, Daouadji and Hadji 2015, Attia 2017, Ahmed *et al.* 2019, Jalaei and Civalek 2019, Zouatnia and Hadji 2019, Selmi 2020, Merzoug *et al.* 2020, Gafour *et al.* 2020, AlSaid-Alwan and Avcar, 2020, Karami and Janghorban 2020, Abdulrazzaq *et al.* 2020, Ghandourah and Abdraboh 2020, Hadji and Avcar 2021). These types of materials have desirable properties for specific applications, particularly for aerospace, automobile, civil and other engineering structures and applications under stress concentration, high thermal and residual stresses. FGM is advantageous due to the particular properties of resistance to high temperature gradients, high mechanical performance and reduce risk of catastrophic fracture (Birman and Byrd 2007, Yang *et al.* 2012, Rachedi *et al.* 2020).

The Physical properties such as the Young module, the Poisson ratio, the elasticity shear module, Material density and thermal and moisture expansions vary smoothly and continuously through the FG plates and are acquired by combining different materials to meet specific requirements. The considerable advantages offered by the functional quality materials (FGM) compared to the conventional materials of the improvements generating changes as a result of the properties of the materials, eliminating the discontinuities at the interfaces while the characteristics of the constituent materials are preserved (Birman and Byrd 2007, Mantari and Guedes Soares 2013). These components often represented the engineering alloys of aluminum, magnesium, titanium, copper, steel, tungsten, etc. and the advanced compositions ceramics such as alumina, zirconia, tungsten-carbide and silicon-carbide (Birman and Byrd 2007, Carrera *et al.* 2008 and 2011, Yang *et al.* 2012, Mantari and Guedes Soares 2013, Madenci 2019, Hadji 2020, Vinyas 2020). The favor of using FGM is that it can continue in a high thermal gradient environment, while maintaining its structural integrity. Several studies on FGMs have been limited to thermal stress analysis, thermal buckling, fracture mechanics and optimization (Sepahi *et al.* 2010, Kasaeian *et*

\*Corresponding author, Professor  
E-mail: [abdelouahed.tounsi@yonsei.ac.kr](mailto:abdelouahed.tounsi@yonsei.ac.kr)