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ON THE FINITE ELEMENT IMPLEMENTATION OF THE ELASTIC GRADIENT INHERENT TO FGMs

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The assignment of material properties in the finite element (FE) model must reflect the property distribution in the FGM specimen being simulated. However, most of the FE approaches concentrate on homogeneous (or piecewise homogeneous) materials. Accordingly, the elastic gradient inherent to FGMs is usually implemented by assigning properties to elements individually, even though this leads to a discontinuous step-type variation in properties and requires a uniform mesh in the direction of material property variation.

Santare and Lambros [1] developed a formulation for *graded* elements, which automatically interpolate material properties within the element. These can substantially improve the solution quality based on the same mesh density, especially for higher-order graded elements. Kim and Paulino [2] have also investigated elements with an internal property gradient adopting a generalized isoparametric formulation: the same shape functions are used to interpolate the unknown displacements, the geometry and the material parameters. This procedure is known as the nodal values approach and has been implemented in the research codes WARP3D and FGM-FRANC2D. With the aim of extending the use of graded elements to commercial FE software, Rousseau and Tippur [3] developed a technique to assign spatially varying properties at integration points by defining properties as a function of temperature and providing the model with an initial temperature distribution that matches the elastic modulus variation desired. This methodology enjoys great popularity since it can be used in most of the commercial FE packages although it is not suitable for thermomechanical analyses and does not allow for differences between the gradient profiles of the Young's modulus and the Poisson's ratio.

In the present work, with the aim of overcoming the limitations of the aforementioned procedures, a novel technique is developed that allows for a direct definition of the material properties in the Gauss integration points. The proposed methodology is implemented in the commercial FE code ABAQUS by means of a USDFLD user subroutine and, in order to assess its capabilities, several boundary value problems with known analytical solutions are solved. As seen in the figure for the case of a very coarse mesh and an exponential variation of the elastic properties, the present technique achieves a better performance, especially at the integration points. Results also show that, on the contrary of what is often assumed, Rousseau and Tippur's technique is not able to define a non-linear variation of the elastic properties in those FE codes that have a temperature interpolation criterion that ensures a compatible variation of thermal and mechanical strain.

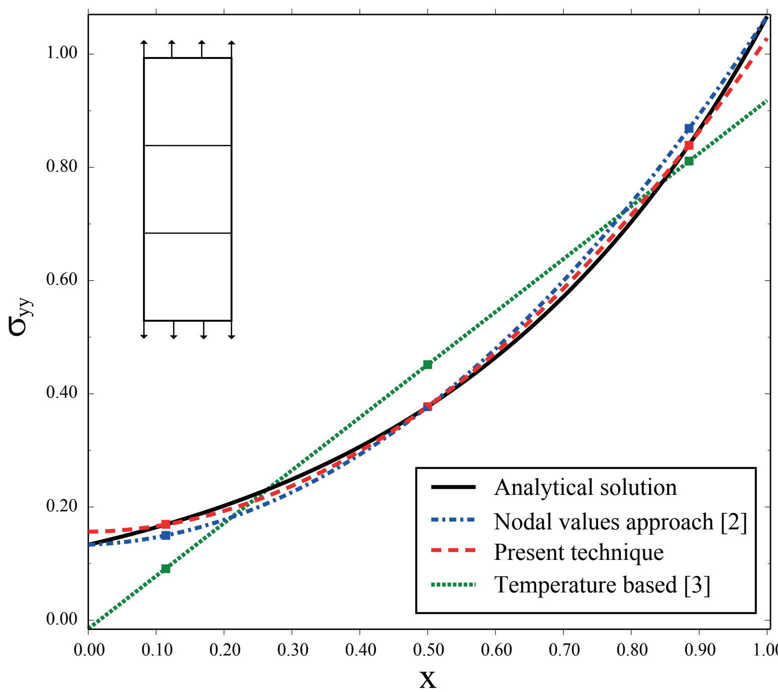

Figure 1: Stress distribution σ_{yy} using quadratic elements (CPS8) in a FGM plate subjected to uniform displacement in the direction perpendicular to material gradation

Results obtained for different kinds of meshes, elements, loads and orientations of the elastic gradient confirm that the present methodology allows for an accurate implementation of the elastic gradient in commercial FE software, which could be particularly relevant in fracture problems, where local stress values may be of critical importance.

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