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Isogeometric analysis of laminated composite and sandwich plates using a layerwise deformation theory

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ABSTRACT

We present an isogeometric finite element formulation for static, free vibration and buckling analysis of laminated composite and sandwich plates. The idea behind this work is to associate an isogeometric analysis (IGA) with a layerwise theory [*A.J.M. Ferreira. Analyis of composite plates using a layerwise deformation theory and multiquadrics discretization. Mech Adv Mater Struct 2005;12(2):99–112*]. Isogeometric analysis based on non-uniform rational B-spline (NURBS) basic functions were recently proposed to preserve exact geometries and to enhance very significantly the accuracy of the traditional finite elements. B-splines basic function (or NURBS) is used to represent for both geometric and field variable approximations, which provide a flexible way to make refinement and degree elevation. They enable us to achieve easily the smoothness with arbitrary continuity order compared with the traditional FEM. The layerwise theory assumes a first-order shear deformation theory in each layer and the imposition of displacement continuity at the layers interfaces. This permits to remove shear correction factors and improves the accuracy of transverse shear stresses. Intensive numerical studies have been conducted to show the highly efficient performance of the proposed formulation.

1. Introduction

Composite and sandwich structures have extensively been used in various engineering disciplines such as aerospace engineering, automotive engineering, and civil engineering. Laminated composite structures are often made of several orthotropic layers with different materials stacked together to achieve superior properties such as high stiffness and strength-to-weight ratios, long fatigue life, wear resistance, and lightweight [1,2]. On the other hand, the sandwich structures are a special case of laminated composite structures in which the difference of material properties between core and face sheets are very large. To use them effectiveness, a good understanding of the bending behavior, stresses distribution, dynamic response and buckling loads of the plates [1] are necessary.

Several laminate plate theories have been applied for analysis of composite and sandwich plates. The classical laminate plate theory (CLPT) [3] is only suitable for thin plates, which the shear deformation effect is neglected. The first-order shear deformation theory (FSDT) [4] can be applied for both moderately thick and thin plates but the accuracy of solutions strongly depends on shear correction factors. To bypass the limitations of FSDT, the higher-order shear deformation theories (HSDTs) [5–7] have been developed. These theories disregard shear correction factors and yield highly accurate solutions for displacements and transverse shear stresses for thick plates. Classically, first-order and higher-order theories use the equivalent single-layer models (ESLs), which consider the same degrees of freedom for all laminate layers. However, in the practical application of sandwich plates, the difference of strength between core and face sheets are often large. These theories can face certain drawbacks to predict accurately the bending behavior and dynamic response. In fact, most of them do not correctly represent the transverse shear stresses and high frequencies. Alternatively, layerwise theories [8–10], regarding independent degrees of freedom for each layer, have been devised. Herein, the generalized layerwise model proposed by Reddy [9] is perhaps the most popular. As the simplified Reddy's model, a layerwise displacement model reported in [11] is adopted in this study. The proposed model assumes a first-order shear deformation theory in each layer and the imposition of displacement continuity at the layers interfaces. Also, several other equivalent-single-layer models for laminated plates have been proposed accounting for zig-zag effects and fulfillment of interlaminar continuity. Among these the one by Mau [12], Chou and Carleone [13], Di Sciuva [14], Toledano and Murakami [15] and Ren [16] are herein mentioned. Mixed layer-

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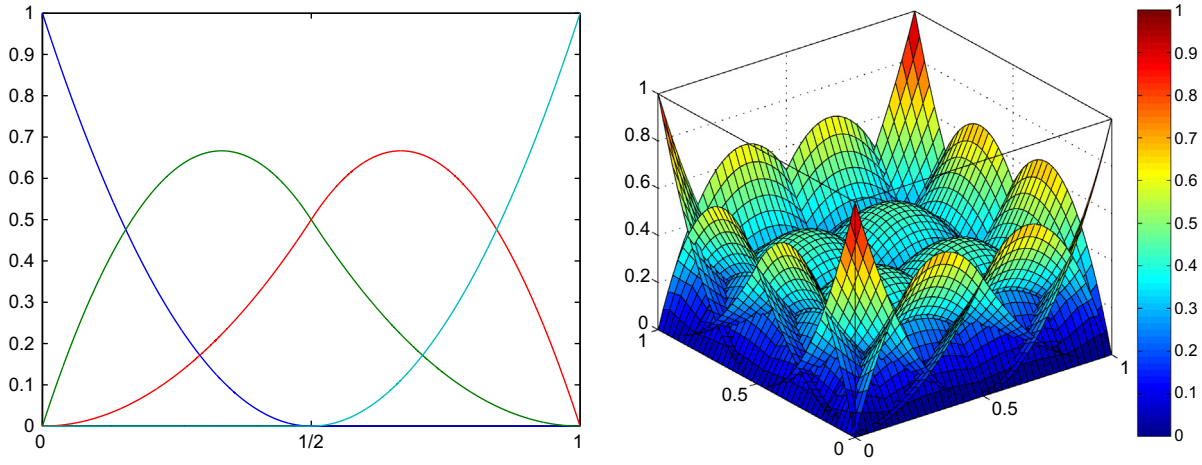

Fig. 1. 1D and 2D quadratic B-spline basis functions.

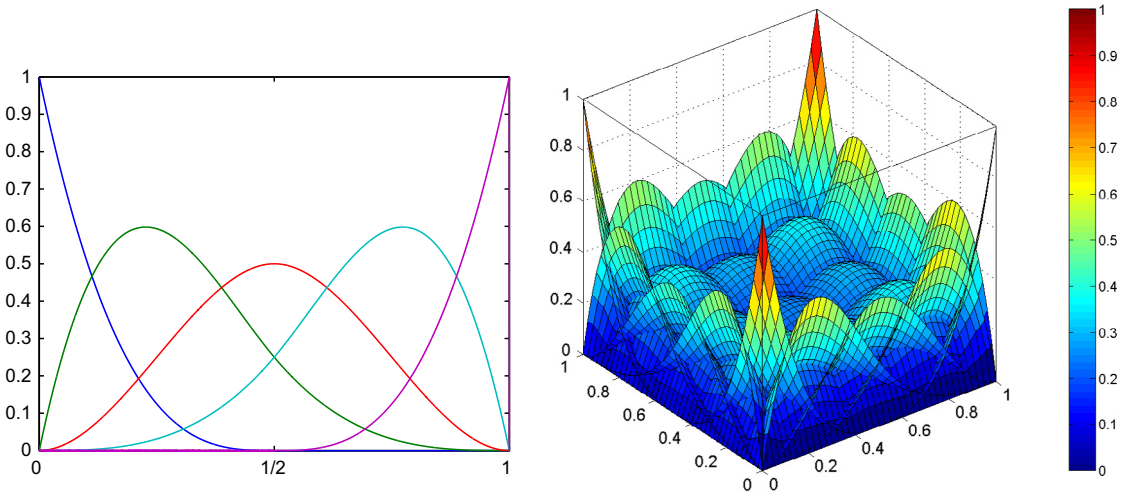

Fig. 2. 1D and 2D cubic B-spline basis functions.

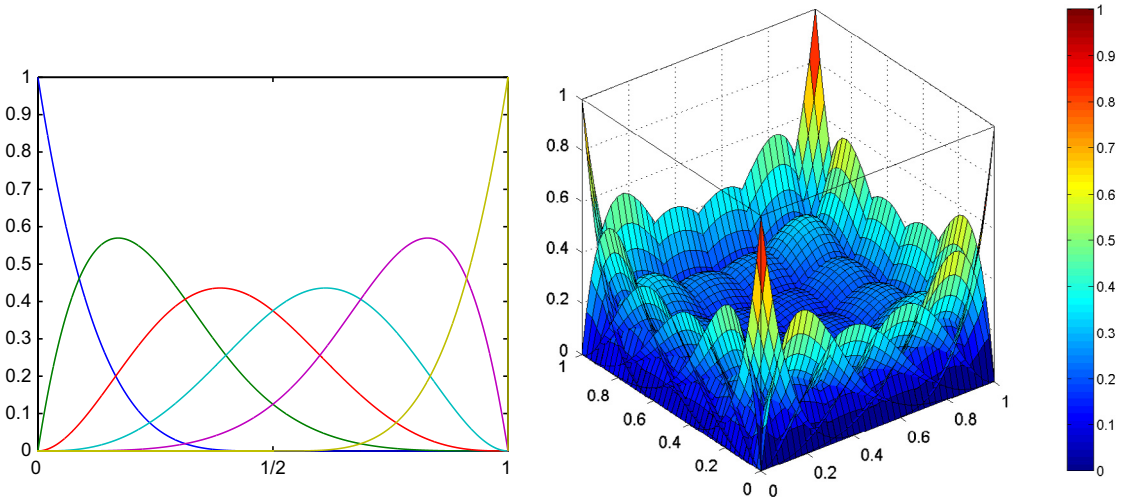

Fig. 3. 1D and 2D quartic B-spline basis functions.

wise and equivalent-single-layer theories based on Reissener Mixed Variational Theorem have been discussed by Carrera [17–19]. A historical review encompassing early and recent developments of advanced theories for laminated beams, plates and shells was revisited in [20]. Interested readers are addressed to that last paper for a more complete review on relevant topics. In addition, Batra and Vidoli [65] have developed a higher-order shear and normal deformable plate theory that considers both tangential and normal