Composite Material Characterization using Eddy Current by 3D FEM Associated with Iterative Technique

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Abstract

In this paper, an iterative technique, employing the $\vec{T}$-formulation associated with the finite element method, based on Maxwell equations and the Biot and Savart law, is used for analyzing the density of eddy currents in composite carbon fiber reinforced polymer (CFRP) materials. For this purpose, a code has been developed for solving an electromagnetic 3D non-destructive evaluation problem. This latter permits the characterization of this CFRP and determinate of fibers orientation using the impedance variation which is implanted in polar diagram. Firstly, the obtained results are compared with those of the analytical model. This comparison reveals a high concordance which proves the validity of the proposed method. Secondly, three different applications are shown for illustrating the characterization of unidirectional, bidirectional and multidirectional piece using a rectangular coil plotted in normalized impedance variation diagram.

Key words: Composite, Carbon Fiber Reinforced Polymer, Eddy Current, 3D Finite Element Method, T- Formulation, $\vec{T}$ -iterative, Pancake Sensor, Rectangular Sensor, non-Destructive Testing.

1. Introduction

Nowadays, carbon fiber composite materials (CFRP) occupy a privileged place in industrial fields, [1] and are more and more popular compared to isotropic materials, because of their mechanical properties, such as high mechanical tensile strength, light weight, corrosion resistance and ability to adapt to complex geometric shapes. This is what makes their use widespread in several industrial sectors such as: aerospace, air transport, maritime and rail, health, sports, wind turbines, aircraft fuselage and many others, [2-6].

Nevertheless, contrary to the above advantages of CFRP materials, these can be altered in many ways during manufacturing, assembly and life stages by a variety of different damages and / or structural failures. As a result, the wide applicability of these materials has created the need for the development of fast and reliable systems for non-destructive testing (NDT), both for quality control during a manufacturing process as well as for monitoring the state of their structures in use [1].

The electrical conductivity of carbon fiber composite materials depends on the volume fraction, the structure and the orientation of the fibers in the material. In laminated carbon fibers composite materials Figure 2 (a); each layer contains unidirectional fibers embedded in an insulating matrix.

The electrical conductivity of the CFRP in the transverse direction to the fibers is not zero, [7-9] because there are contacts between the fibers and this is due to the fact that the fibers are not arranged in a perfectly straight way and also some fibers are not completely covered by the insulating matrix [10,11]. This conductivity varies between 10 and 100 S/m in the transverse direction to the fibers and between 5.10^3 and 5.10^4 S/m in the longitudinal direction of the fibers [12]. For the same reasons, there is conductivity according to the thickness of a composite laminated material [10].

Several scientific works, in the literature, use the $\vec{T}$-iterative method for modeling and simulating of problems of Eddy Current non Destructive Testing (EC-NDT) [13-16]. In 2009, [15] exploited this iterative method associated with the finite difference method to characterize the composite carbon fiber materials (CFRP), and in 2012, [16] used the same method coupled with the finite volume method to characterize isotropic materials and CFRP composites possibly containing defects.

In this context, we have developed a Matlab calculation code based on $\vec{T}$-iterative technique solved by 3D finite element method, to solve an EC-NDT problem that contains an absolute circular sensor and unidirectional plate. The obtained results are compared with the analytical model ones in the aim to validate the proposed method [17]. Hence, a second rectangular shape sensor is used with a composite unidirectional and multi directional plate for characterizing the fibers orientations, based on the impedance variation. The mesh of the sensor / plate is made separately using Gmsh software [18].