Transversal Electrical Resistivity Evaluation of Rod Unidirectional Carbon Fiber-Reinforced Composite Using Eddy Current Method

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This paper aims at proposing a simple approach in which a transversal electrical resistivity of a rod unidirectional carbon fiber-reinforced composites (UD-CFRC) is evaluated . The method is based on eddy current technique. The latter is associated with inverse problem method that consists of minimizing the difference between the computed and measured resistances. The Ant Colony Algorithm (ACA) which is a kind of heuristic minimizing algorithm based on population search, is used to get transversal electrical resistivity. The findings of the work are summarized as the following. First, it was demonstrated that the eddy currents created in the UD-CFRC are independent from the value of longitudinal resistivity. Then, the electrical resistance is computed using direct problem which is formulated with 2-D axisymmetric finite element method. After that, the identified resistivity that obtained with the inverse problem, is introduced in the direct problem to compute resistance. Finally, the confrontation between the computed resistance and the measured one shows a significant concordance between the two.

***Index Terms*—Composite materials, Conductivity measurement, Eddy Currents, Finite Element Analysis, Inverse Problems.**

I. Introduction

Due to their high performances, carbon fiber reinforced composite (CFRC) rods have large applications in the manufacturing industries such as aerospace industry and civil building . They are mainly used to manufacture bridges and cable structures of tower constructions [1]-[2]. A composite can be broadly defined as an arrangement of two or more materials that retain their macrostructure resulting in a material that can be designed to have improved properties than the constituents alone. The rods , which consist of carbon fibers plies backed with a diameter close to a few microns, are glued together in epoxy filled matrix in order to build cylindrical-shape [2].

The defects related to rod CFRC that appear during UD-CFRC rod manufacture such as fiber break and bonding lack, affect directly the construction strength [3]-[4]. Yet, delamination which is due to the fatigue of is the most usual defect in rod CFRC. To detect these defects, non-destructive eddy current method is required .[5]-[6]. To better apply this technique, it is necessary to evaluate the electrical resistivity in each direction of the rod [7].

The longitudinal electrical resistivity can be measured by using a volt-ampere-metric method. However, Due to contact issues it is not easy to evaluate the transversal resistivity using the afore mentioned method.

In this paper, a simple approach is proposed to evaluate the transversal resistivity of UD-CRFC rod, using contactless method based on eddy currents. Firstly, a multi-layer air solenoid coil is performed. Secondly, the electrical resistance of the coil is measured using a precision LCRmeter (Fig. 1). Thirdly, The computed resistance is compared to the measured one, using inverse problem method. until the transversal electrical resistivity is found [7]-[8].

In this context, The Cedrat/Flux 3D software is used to study the value and direction of induced currents in the UD-CFRC rod according to the longitudinal resistivity (Fig. 2). This study shows that, eddy current has the same components as the source current which are independent to the longitudinal resistivity. Therefore, the resistance will be computed using an axisymmetric model. This kind of problem can be easily formulated using magnetic potential vector and solved with 2D finite element method implemented with Matlab®.

The inverse problem goal function is minimized using the Ant Colony Algorithm (ACA).

II. Problem Modeling

The 3D Cedrat/Flux simulation shows clearly that the longitudinal electrical resistivity has no influence to the path of eddy currents created in the UD-CFRP rod and their value.

The numerical model can be expressed in 2D axisymmetric domain and expressed using *A-V* formulation, named potentials successively, magnetic vector and electrical scalar.

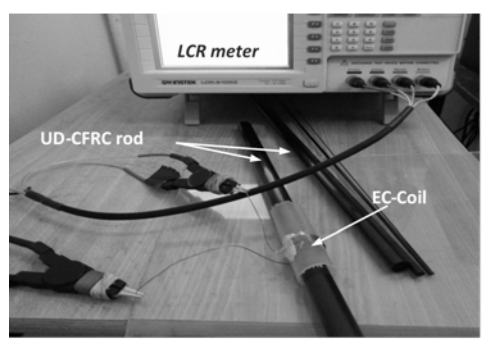


Fig.1. Experimental setup

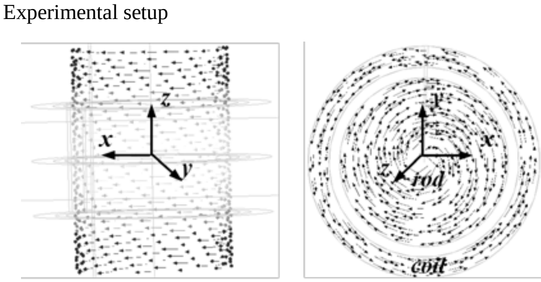
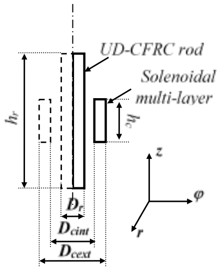


Fig. 2. Eddy current direction in the CFRP-rod



h_r (mm)	h_c (mm)	D_r (mm)	D_{cint} (mm)	D_{cext} (mm)	D_{co} (mm)	N_{turns}	N_{layer}
6.75	150	16.00	22.23	24.40	0.5	24	2

h_r : height of UD-CFRC rod
h_c : height of coil
D_r : UD-CFRC rod diameter
D_{cint} : coil internal diameter
D_{cext} : coil external diameter
D_{co} : diameter of copper wire
N_{turns} : coil turn number
N_{layers} : coil layer number

Fig. 3. Geometric model

Figure 3 shows the geometric model and the characteristic dimensions.

To compute the resistance of coil due to the induced current reaction of the UD-CFRC rod, the following electromagnetic problem must be solved:

$$-\iint_{\Omega}\frac{\partial}{\partial r}\left(\frac{1}{r\mu_0}\frac{\partial A'}{\partial r}\right)-\frac{\partial}{\partial z}\left(\frac{1}{r\mu_0}\frac{\partial A'}{\partial z}\right)+j\frac{\omega}{r\rho_t}=J_{s\varphi} \quad (1)$$

Where, $A'(0, rA_{\varphi}, 0)$ (T.m²) is the modified magnetic vector potential, ρ_t(Ω.m) is the transversal electrical resistivity of the UD-CFRC rod, ω is the electrical pulsation (rad/s), μ_0 is the magnetic permeability of air, and $J_s(0, J_{s\varphi}, 0)$ (A/m^2) is the source current density.

The finite element method formulation can be expressed as:

$$-\sum_{j=1}^{N}(\iint_{\Omega}\frac{1}{\mu_0 r}\vec{\nabla}\alpha_i\vec{\nabla}\alpha_j drdz)A_j + j\omega\sum_{j=1}^{N}(\iint_{\Omega}\alpha_i\alpha_j\frac{1}{r\rho_t}drdz)A_j = \iint_{\Omega}\alpha_i J_{s\varphi}drdz \quad (2)$$

Whereas N is the node number, α_i and α_j are the finite element interpolation functions.
The modified magnetic vector potential *A′* is computed in all regions (rod, air, coil). The coil resistance variation δR_{comp} is computed using following expression:

$$\delta R_{comp} = -2.\pi.\omega.N_{turns}.imag\left(mean\left(A'\right)\right) \quad (3)$$

The inverse problem goal function is written as:

$$\cos t = \frac{1}{2}\left(\frac{\delta R_{comp}-\delta R_{mes}}{\delta R_{mes}}\right) \quad (4)$$

where δR_{mes} is the measured coil resistance variation with and without presence of UD-CFRC rod.

Ant Colony Algorithm (ACA) is applied to minimize the inverse problem goal function in order to get transversal resistivity.

III. Results and Discussions

The value of measured longitudinal resistivity of the UD-CFRC rod given by the two-point method is 50 μΩ.m.
The obtained transversal resistivity value using inverse problem method associated is 0.01316 Ω.m.
This value of resistivity is introduced in a 2-D axisymmetric finite element method to compute the coil resistance variation for frequency range of 0.1MHz up to 2MHz.
The resistance of coil is measured using a precision LCRmeter.

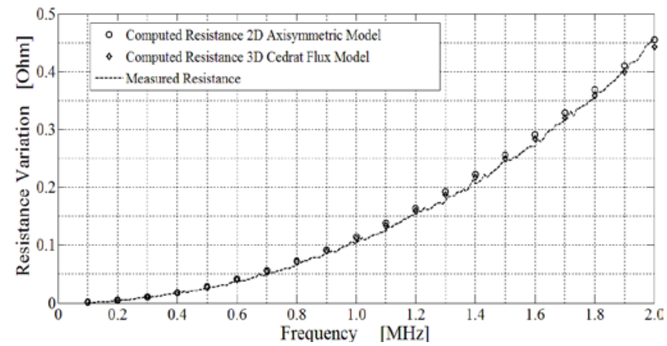


Fig. 4. Coil resistance variation as function of frequency.

The difference between the resistance of coil with and without UD-CFRC have been noticed for the frequency range of 0.8MHz reached to 2 MHz as shown in the fig. 4 due to the influence of the transversal conductivity (skin effect).

Figure 4 shows the comparison between the computed and measured resistance variation of the coil. The maximum error between the computed and measured resistance variation is less than 2%.

IV. Conclusion

In this work, Eddy Current Non Destructive Evaluation technique associated with inverse problem method is used to evaluate the transversal electrical resistivity of unidirectional carbon fiber reinforced composite rods. The two dimensional axisymmetric finite element method is used as a direct model. Ant Colony Algorithm is used to minimize goal function of the inverse problem. The identified resistivity is introduced in the direct model to compute resistance.
The confrontation between the computed resistance and the measured one shows a very good concordance.
One will discuss more about the used methods and give additional results, in the final paper.

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