A New Fuzzy Geometrical Approach to Classify Defects in Composite Materials

Matteo Cacciola, DICEAM Department, University of Reggio Calabria, Reggio Calabria, Italy
Salvatore Calcagno, DICEAM Department, University of Reggio Calabria, Reggio Calabria, Italy
Fabio La Foresta, DICEAM Department, University of Reggio Calabria, Reggio Calabria, Italy
Mario Versaci, DICEAM Department, University of Reggio Calabria, Reggio Calabria, Italy

ABSTRACT

It is well known that in the Non Destructive Testing/Evaluation (NDT/E) context, Ultrasonic Echoes (UEs) and Tests (UTs) are intensively exploited to identify and characterize defects in the Carbon Fiber Reinforced Polymer (CFRP). This paper examines the localization and the classification of defects in this material from a fuzzy geometrical point of view. In particular, starting from an experimental campaign of measurements carried out in our Lab (Laboratory of Electrical Engineering & Non-Destructive Tests and Evaluations, “Mediterranea” University of Reggio Calabria), fuzzy subsethood calculus is taken into account to translate the characterization of a defect in CFRP into a sort of “fuzzy distance” among UEs. Finally, the floor is open for any questions related to the comparison with a higher computational complexity heuristic technique.

Keyword: Classification Problems, Composite Materials, Fuzzy Calculus, Non Destructive Testing/Evaluation (NDT/E), Ultrasonic Echoes (UEs)

1. INTRODUCTION

During the production and life-cycle of manufactured CFRPs articles, loads and vibrations can be reason of compromising functionality and integrity requesting, imperatively, the evaluation and the testing by non-destructive inspection. In this context, UTs play a very crucial role especially in civil and industrial domains where it is necessary to guarantee the integrity of the elements under stimuli by means of approaches with a good resolution and versatility (Haapalainen & Leskela, 2012). Unfortunately, the industrial production of CFRP articles generates several kinds of defects (delaminations, inclusions and porosity) with

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different levels of danger. Then, it is imperative to design a sort of “check procedure” on the integrity and functionality of CFRPs articles in terms of detection and classification of defects starting from NDT/E approaches (Haapalainen & Leskela, 2012; Raišutis, Kažys, Žukauskas, & Maželis, 2011; Yun, Choi, & Seo, 2012).

Unfortunately, in the UTs domain, distinct defects can give similar signals generating an ill-posed problem for which the visual inspection of UT signals is not sufficient to characterize defectiveness. In the scientific literature, the classification problem was resolved by means of experimental heuristic approaches, but characterized by a higher computational complexity (Hea, Pana, Luoa, & Tianb, 2011; Cacciola, Calcagno, Megali, Pellicano, Versaci, & Morabito, 2010; Morabito, Labate, La Foresta, Bramanti, Morabito, & Palamara, 2012; Mamnone, La Foresta, & Morabito, 2012). Nevertheless, for on-line applications it is required a procedure with a low computational complexity. In such cases, the authors’ experience in the soft computing field, even in applications different from the NDT/E, (Versaci & Morabito, 2003; Labate, La Foresta, Inuso, & Morabito, 2011; Labate, La Foresta, Inuso, & Morabito, 2011; Costantino, Morabito, Praticò, & Versaci, 2012), plays a determining role for the putting into effect of a methodology with requirements of reduced processing times of data affected by uncertainty and/or imprecision (Cacciola, Calcagno, Megali, Pellicano, Versaci, & Morabito, 2010; Cacciola, Megali, Calcagno, Morabito, Pellicanò, & Versaci, 2009; Angiulli & Versaci, 2003; Angiulli & Versaci, 2002). Due to the sampling and noising, UT signals can be affected by imprecisions and uncertainty. So, according to the Italian PRIN Project (prot. 2009TCLKNF_002) (Italian PRIN Project), it appears natural to treat the classification problem as a sort of fuzzy classification for which, thinking that signals with a kind of defect are affected by similar ranges of statistical values, they can be treated as elements of a particular class. So, the classification problem is formulated by a fuzzy geometrical approach where each class of defect is considered as a particular fuzzy set (hyper-rectangle into a unit hyper-cube). A signal with an unknown defectiveness is visualized by a point into the unit hyper-cube and it is classified by means of computation of the minimum among the point and hyper-rectangles. The paper is organized as follows: the next section explains the structure of the exploited experimental database. Then, an overview of the proposed fuzzy geometrical approach is developed in terms of fuzzy Subsethood Operator. After that, results and some comments are shown and, finally, some conclusions are drawn.

2. MATERIALS AND METHODS

• The experimental dataset: For our purpose, an artificial panel of CFRP has been made in the Laboratory of Electrical Engineering and Non-Destructive Testing and Evaluation of “Mediterranea” University of Reggio Calabria (Italy) in which different defects take place (Figure 1). UTs signals have been carried out by means of UTs and pulse reflection methods. For each type of defect a set of maps with benchmark for the unflawed area has been made by means of localization of probe at different sites of it. Table 1 shows the dataset characteristics; particularly, for each defect (delamination, inclusion and porosity) number of samples and physical parameters are reported for training and testing evaluation procedures respectively. By visual inspection of a signal, it is possible to detect the presence of a defect by means of the information carried out by the two peaks in the signal: top-echo and bottom-echo (phenomenon of reflection of ultrasonic wave on top and bottom surfaces, shown as well in Figure 2). If any further peak takes place between the top- and bottom-echo peaks, it shows the presence of a defect. It is very important to note that: 1) the visual inspection of a signal can detect the presence of a defect, but it is not able to give us its typology; 2) there are defects that are considered more dangerous

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