ON THE IDENTIFICATION OF RESIDUAL IMPACT PROPERTIES OF MATERIALS BY ACOUSTO-ULTRASONICS
— A PATTERN RECOGNITION APPROACH

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ABSTRACT: This paper deals with the application of Acousto-ultrasonics, in conjunction with Pattern Recognition and Classification techniques, to the identification of residual impact properties of a class of polymeric material, namely, Polyvinylchloride (PVC). PVC specimens of different low-energy repeated impact damage states are processed by Acousto-ultrasonics (AU) to retrieve AU signals in the form of digitalized records. These AU signals are grouped as distinct classes, each pertaining to a known level of repeated impact damage. Describing features of these AU signals are used to build Pattern Recognition (PR) Classifiers. These classifiers are used to identify unknown damage states in other PVC specimens by classifying the retrieved AU signals as belonging to one of the classes. The obtained results indicate that Acousto-ultrasonics in combination with Pattern Recognition and Classification techniques can be used for the quantitative non-destructive identification of damage states in PVC specimens of unknown low-energy repeated impact conditions.

KEY WORDS: pattern recognition, acousto-ultrasonics, impact damage, quantitative non-destructive examination

I. INTRODUCTION

Low-energy repeated-impact constitutes an important degrading factor in the residual ability of solid polymers to withstand static and/or dynamic loadings. Since this type of polymer degradation is likely to affect in-service structural components, Quantitative Non-destructive Examination (QNDE) techniques are often considered to assess repeated-impact damage in polymeric material systems.

Acousto-ultrasonics (AU) is a relatively new Quantitative Non-destructive Examination technique that combines aspects of conventional Ultrasonic and Acoustic Emission practices. It has been proven to be a suitable approach to quantify microstructural and morphological states of materials and the related mechanical properties[1]. The technique has been recently used to test solid polymers, which characteristically show high attenuation of ultrasonic waves[2].

In the AU practice, the interactions of the ultrasonic-wave with the tested material microstructure usually result in complicated waveforms that are quite difficult to analyze. A new approach to the analysis of AU signals consists of the use of Pattern Recognition and Classification Methodologies. By this approach, Acousto-ultrasonic waveforms are identified as belonging to a class, while each class represents one of different states of the tested

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material-property. To this purpose, each waveform is mathematically treated as a multi-parametric entity, which is called a "pattern vector".

Each component of such a vector represents a value of a parameter, also called "feature", which is used for the identification of the AU signal. In PR practice, pattern classification is performed by means of a computer-based Pattern Recognition System. This system, labelled “Pattern Recognition Classifier”, is designed on the basis of AU signals pertaining to known material states.

Classification of unknown patterns is based on the so-called "decision functions". There are two main approaches to generate these decision functions, i.e., deterministic and statistical. The former comprises decision rules that are established by the assumption that a minimum of a function of generalized distance between a pattern and a class indicates that the pattern belongs to the class\[3\]. The statistical approach, however, is based on the maximization of the probability of classifying a pattern as belonging to a class, when it appears to belong, at the same time, to another\[4\].

Decision functions are usually determined by the limited-size samples of pattern vectors that are selected for the design of the Pattern Recognition system. In this context, arbitrary decision functions are initially assumed and, then, through a sequence of iterative learning steps, these decision functions are made to approach satisfactory forms. This procedure is called “learning and estimation” of decision functions\[6–7\].

This paper describes the application of Acousto-ultrasonics in conjunction with Pattern Recognition and Classification techniques for the identification of different low-energy repeated impact damage states in PVC specimens. The retrieved AU signals from the material specimens are grouped as classes pertaining to known levels of repeated-impact damage. Some selected describing features of these AU signals are used to build a number of Pattern Recognition Classifiers. These classifiers are tested for their performances concerning classification when identifying damage states in PVC specimens as belonging to one of the classes.

II. ACOUSTO-ULTRASONICS TECHNIQUE

Acousto-ultrasonics (AU) may be understood as "acoustic emission simulation with ultrasonic sources"\[8\]. The working hypothesis of the AU technique is that more efficient stress-energy transfer and strain redistribution, in the microstructure of the material specimen, during mechanical loading, would correspond to higher mechanical strength of the material.

In the AU practice, a broadband transducer sends a repetitive series of ultrasonic pulses into the test specimen. A receiving transducer is located at a specific distance, on the same side of the specimen, from the sending transducer. Both transducers are coupled at normal incidence to the surface of the test specimen. The transmitted ultrasonic wave into the material specimen is considered to be affected by the microstructural and morphological properties that determine the mechanical performance. Therefore, as mentioned earlier, the captured AU signal should contain information concerning the overall mechanical response of the material specimen.

Experimental work on polymers by Lee and Williams\[9\] and Iyer and Haddad\[2\], on metals by Tanary\[10\], and on different classes of composites by Vary\[11\] and Williams and