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Fractographic classification in metallic materials by using computer vision

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ABSTRACT

The first step in the failure analysis is based on the visual inspection of the fracture surface. This is the base for the development of any fractographic process and it represents the main means for fracture classification. In several occasions, this process is carried out by non-suitable personnel in this area, which increases the chances of generating a wrong classification and, therefore, of negatively altering the results of the entire process. By using artificial vision techniques, this document shows the work done for classifying three types of fractures: brittle sudden, ductile sudden, and progressive due to fatigue, all these in metallic materials in order to promote failure analysis on a fracture surface. The employed descriptors: Haralick's features, energy masks, and the fractal dimension (41, overall), were generated from the Gray Level Co-occurrence Matrix (GLCM), the texture energy laws, and the fractal analysis (respectively) applied to obtained full-scale images, different from other studies using SEM for the acquisition of the data set. The Artificial Neural Networks classifiers and the Support Vector Machine performance were analyzed, finding out that the first one obtained the best results. Such results can be compared to the ones obtained by an expert in this field, with an accuracy percentage higher than 80% for the three types of fractures.

1. Introduction

The failure analysis aims to determine the breaking causes of a component and the way to avoid it, either by redesigning the piece or by replacing the used material. The main breaking cause in metallic materials usually lies on the excessive application of pressure on the piece. This overloading is caused by other factors such as the ones to be analyzed [4]. Setting up the relation between the qualitative characteristics of the common elements of the fractures and the mechanical properties of the structure of the material is an important task for the analysis of the real damage [6].

The fractographic analysis on the fracture surface is a stage of the failure analysis consisting on a visual examination to reveal the superficial characteristics on the flaw, allowing to observe the propagation patterns and the fracture origin. Through the fracture surface characterization of the material, it is possible to conduct a preliminary analysis to failure, which will allow to find the causes that generated it. The lack of necessary information about the way the piece failed and behaved makes it impossible to deduct the causes that made it happen. Such analysis begins with the observation of the macroscopic characteristics of the fracture surface, with which the first traces of some of the parameters are obtained. Afterwards, an analysis is carried out under a stereoscope that allows the confirmation of the observations made in the first instance. Zooming the analysis with a scanning electron microscope (SEM), allows the characterization of the microscopic process of fracture propagation, identifying thus:

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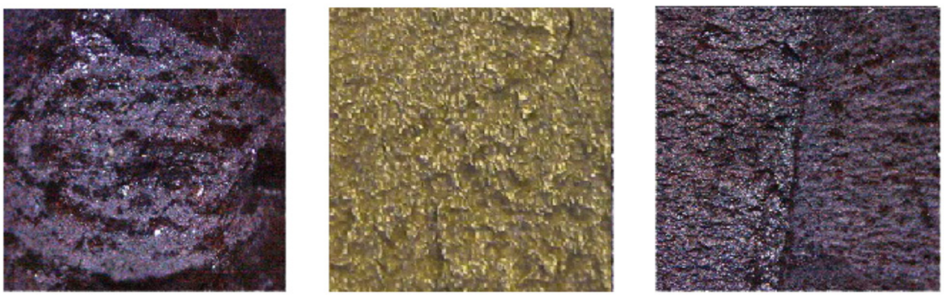
cleavage facets and cavities of transgranular fracture, intragranular fracture affected zones, grain boundary morphology, fatigue striations, corrosion surfaces under tensions or characteristic images such as cavities or solidification porosity [4]. When obtaining the images through SEM, it is important to keep in mind that the quantity of texture elements must be sufficiently representative to factually characterize the texture. It must be approximately homogeneous and the texture characteristics (for the images of a type of fracture) must be alike to the greatest extent [9].

A fracture occurs when a mechanical element separates into two or more fragments, resulting in three phases: *i*) nucleation of one or several cracks, *ii*) propagation of the crack(s) and *iii*) fracture of the element [1]. Depending on the speed in which these phases take place, the fractures can be classified into sudden (if its cracks propagate 0.2–0.4 times the speed of sound in the material) or progressive (if its crack has a slow propagation of, for instance, 1 mm per day). These types of fractures can also be classified into mechanical fractures influenced by the environment or the temperature. In this work, we will present a quite strong simplification of the fracture types, based on the mechanical fractures (i.e. those whose flaws are caused by effort application) so as to focus on the initial development of an expert system. Specifically in three types of fractures (Fig. 1), which are characterized for having different kinds of marks and texture on their surfaces. They are: *i*) brittle sudden fracture, with a granular texture and radial or river-like marks; *ii*) ductile sudden fracture, with a fibrous texture and it presents no marks in its surface; and *iii*) progressive fracture due to fatigue, which is divided into two regions: one closed to the origin with texture of stable propagation texture and with Ratchet marks (the one we analyzed), and another one that can be either brittle or ductile. It is important to highlight that even though the fatigue fracture is divided into two regions (as we can see in Fig. 1(c)), we will only focus on the one with stable propagation texture since, by doing this, the classification problem will be simplified; furthermore, the texture of the other region is already analyzed with the other two kinds of fractures.

An expert system is a computer program that imitates a human expert's behavior and corresponds to one of the most useful applications in the artificial intelligence [2]. Among the main reasons to use this kind of systems, it is found out that in some occasions it is not possible to find an available expert or it would turn out to be highly expensive to hire one, that they optimize time, that they improve the workers' productivity, and that they ease their training [2]. Traditionally, the fractures classification process is a visual exam that takes into account different characteristics for each one of them. Such process can be taken to a classification problem by using computer vision techniques, which will be able to generate great advantages when applying the failure analysis. Computer vision techniques are quite important to make the digital fractographic images processing, since they allow to obtain more information in less time, acquiring thus better results than the ones obtained traditionally [8]. The field of materials and failure analysis has been used to esteem the crack growth rate (CGR), through the texture on surfaces obtained by SEM by means of a fracture surface reconstruction through previously selected subimages, a process known as auto-shape decomposition [5]. In many cases, the images of certain materials are analyzed as it was done in [8], where steel API5L-X52 is worked with in order to classify the microcavities morphology. In [9] and in [6], fractographic texture methods are analyzed so as to reconstruct the fracture-due-to-fatigue trace by means of the relation of the surface texture characteristics and the crack growth rate. For the 3D analysis, the shape reconstruction method from stereoimages through an algorithm that is able to find counterpart points in both of the images [10].The latter gets back its shape through multiple images from the same generated scene, by using a fixed viewing direction and different directions of light sources [7]. The use of the provided information by three-dimensional images allows to determine important quantitative characteristics (such as the local roughness), and allows a deeper comprehension of the flaw mechanisms [11]. The reconstruction process is applied in order to obtain the 3D geometrical mesh model for each region of interest (ROI) [11].

As for the recognition or classification on fracture surfaces, in [13] they work with three types of sintered steel with the purpose of identifying the morphology, measurements, and apparent porosities on the fracture surface. They obtain their images with SEM and they analyze the fractures due to fatigue. Among the obtained characteristics, they calculate the morphological gradient in gray scale images and they take into account the local neighbors to make the classification. In [12] they generate a software that is able to classify six different morphologies on fracture surfaces by using descriptors such as the Fourier Transform,



(a) Strong platinum piece aluminum with ductile sudden fracture.

(b) Steel 4140 screw piece with brittle sudden fracture.

(c) Toughness fracture test tube piece type SENB and steel 5160 with progressive fracture due to fatigue.

Fig. 1. Examples of types of fracture to be analyzed.