QUANTITATIVE FRACTOGRAPHY BEHAVIOR OF FRACTURE PROCESS UNDER ELASTIC-PLASTIC CONDITION

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Abstract. *Fracture surfaces express the sequence of energy release events with crack propagation, showing the relation between structure, stress fields and texture in topology. In metallic alloys, the topology formation can show loading characteristic marks, fracture process dynamics, process and use failures, the degradation effect by environmental factors, etc. Thus, the quantitative fractography can help the investigation of structural faults and enhance manufacturing processes. This work consist on the analysis of fracture surface topography data, obtained by digital image processing for three dimensional reconstruction of broken specimens using the extended depth of field method. Quantitative studies are applied to measure fractal dimension and roughness behavior throughout fracture surface. Proposed materials are the following metallic alloys for aircraft industries: 15-5PH steel and AA 7475 aluminum alloy, with the thermomechanics treatment used for aircraft components. The specimens were fractured under CTOD testing. Image stacks obtained by light microscopy were processed, resulting in several elevation maps of surface fracture used to analyze fractal dimension and roughness, following the progressive advance of crack front during fracture process. Results showed that fractal dimension and roughness could not be related to materials properties under the elastic-plastic condition, but the fracture micromechanism may be related.*

Keywords*: Fractography Quantitative, Fractal Dimension and Roughness*

1. INTRODUCTION

Fracture surfaces express a sequence of events where energy is released by crack propagation, showing the relation among structure components, local tension fields and typical relief formation. In metallic alloys, the evolution of topological formation can indicate the applied loads orientation, failure dynamics and faults under use and process.

Many researchers (Hull, 1999; Cwajna and Roskosz, 2001; Hein, 2001) use fractography quantitative as important tool in investigation of fracture mechanisms. Mandelbrot (1983) found that brittle fracture surface in steels may be described by fractal dimension. The similar results were also reached by other materials, such as molybdenum (Simuyoshi, et al. 1992), aluminum (Horovistiz et al, 2003) and concrete (Carpinteri, 1994).

Fractal geometry is a non-Euclidean geometry, characterized by objects where one portion of them resembles another (self-similarity) and a small portion resembles a large portion (scale invariance). The advantage of fractal geometry is that it describes complex shapes with relatively simple mathematical expressions or numbers (Mecholsky, 1995).

For Williford (1988) and Mecholsky (2006), a fractal dimension can describe mechanical materials properties, such as fracture toughness, but others did not obtain worth of fractal related with fracture toughness (Alexander, 1990). According to other investigations (Balankin 1997), the roughness exponent (fractal dimension) do not depend on mechanical properties, however it depends on the material microstructure, opening new fronts for fractal dimension analysis.

In this paper, fractal maps were made in order to compare the relation between fractal dimension, roughness and displacement on the surface, along crack propagation direction on a compact specimen fracture.

2. METHODOLOGY

Proposed materials are the following metallic alloys for aircraft industry: 15-5PH steel and AA 7475 aluminum alloy, as received, in same thermomechanical conditions for using in aircraft components. The specimens were fractured by CTOD tests, according to ASTM 1290-08. The tests have been performed on compact specimens in order to provide a large fracture surface, using an Instron 8810 servo-hydraulic system.

A quantitative analysis of fractured surface was made to determine the fractal dimension and roughness at different positions. Images from fractured surfaces were acquired using a Nikon Epiphot 200 reflected light microscope, with a Zeiss AxioCam ICc3 digital camera, using long distance objective lens for a total magnification of 500x. The images were acquired to map the center of fractured surface along the crack propagation direction, totalizing 17 positions. The scheme of measured points of maps has been presented in Figure 1.

Figure 1. Scheme of measure points of specimens, the square indicate de analyzed area

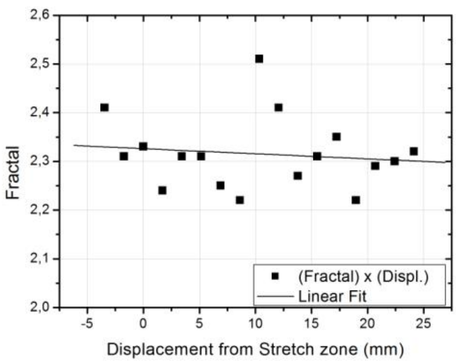
For each position of the map, a stack of images was obtained by a successive displacement, 1 µm. Elevation maps of surface were generated from the process of images stack. This process, used by Horovistiz et al. (2003), consists on a routine of extended depth of field, where the images were processed into a single one, which contains the in-focus parts from each image in the stack (Goldsmith, 2000).

In this study, the images processing for *extended depth of field* reconstruction were made using a plug-in program implemented by Prudencio et al. (2009), based on the algorithm described by Forster et al. (2004). This plug-in generates both the elevation map and the according fully focused picture. Through the elevation maps, the fractal and roughness of surface are calculated, using the plug-ins program "Map Fractal Count" and "SurfCharJ 1II"(Chinga et al, 2007), respectively. The three plug-ins are wrote in Java for NIH Image J (Rasband, 2008), and have open source distribution.

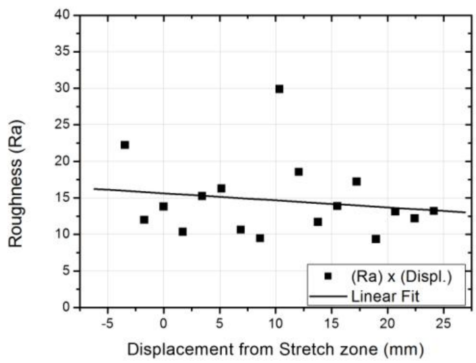
The fractal dimension, roughness and position of fracture data were compared to each other and were compared between both materials.

3. RESULTS AND DISCUSSION

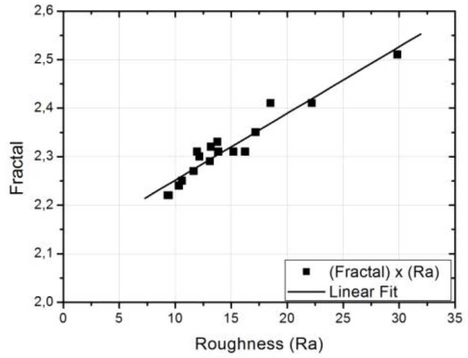
The similar character of the results was obtained for both tested materials. In figure 2 and 3, the graphics that relates the results of fractal, roughness and displacement, from the center of specimen along crack propagation are showed.



(a)

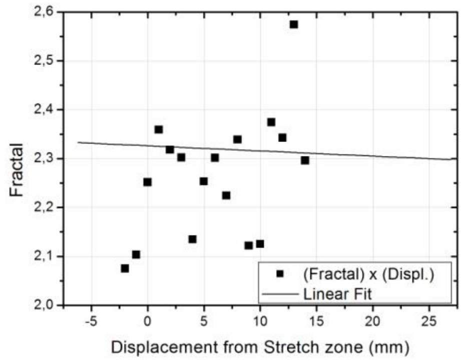


(b)

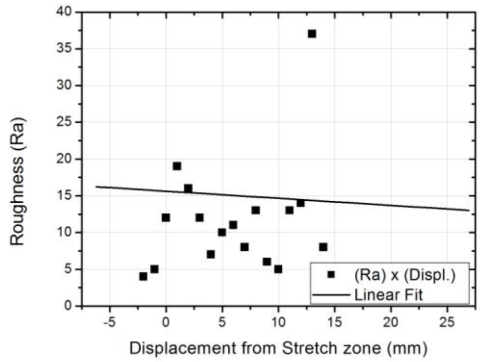


(c)

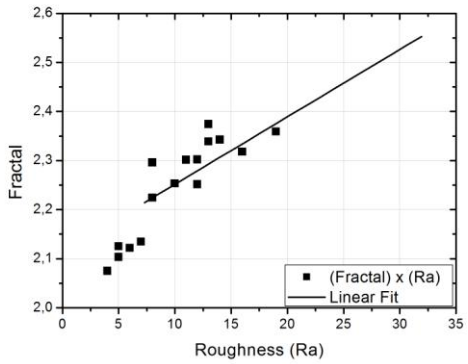
Figure 2. Aluminum alloy AA 7475: a) Fractal versus Displacement; b) Roughness versus Displacement; c) Fractal versus Roughness.



(a)



(b)



(c)

Figure 3. 15-5PH Steel: a) Fractal versus Displacement; b) Roughness versus Displacement; c) Fractal versus Roughness.

Analyzing the results, it was noticed that the range of fractal dimension and roughness in both materials have been a significant scattering in the crack propagation plane, without any linear relation with displacement. The low values of coefficient of correlation (R^2) computed for the relations between “fractal x displacement” and “roughness x displacement”, table 1, show that there is no significant correlation between changes on crack propagation mechanisms, or mechanical properties with fractal or roughness, such as suggested to Mecholski (2006), Maldelbrot (1982), Williford (1988) and others.

Table1. Correlation coefficient (R^2) for each material

	Aluminum Alloy AA7475	15-5PH Steel
Fractal x Displacement	$1,24.10^{-2}$	$2,16.10^{-1}$
Roughness x Displacement	$2,62.10^{-2}$	$8,51.10^{-2}$
Fractal x Roughness	$9,20.10^{-1}$	$8,04.10^{-1}$

Based on Balankin (1997), the scatter of the fractal dimension and roughness could be related to the action of fracture micromechanisms. Fracture micromechanisms could be influenced by the heterogeneity of the microstructure disposed randomly in fracture surface, thus, the fractal dimension and roughness could indicate the presence of different micromechanisms involved on fracture process.

A better correlation (R^2) between fractal and roughness was reached, as showed at Figure 2 “c” and 3 “c” and table 1. Although there is a significant correlation between fractal and roughness to both materials, aluminum alloy had the greatest correlation. The relation showed that both characterization tools have a similar principle and can be applied together with a complementary result.

4. CONCLUSION

This study showed that values of fractal dimension and roughness present no linearity along crack propagation, limiting these tools to characterize mechanical properties of fracture surface, or changes in mechanical loading and tension fields, although there might be a relation with the occurrence of fracture micromechanisms.

On the other hand, a great relation has appeared between fractal and roughness, considering that fractal dimension is related to surface morphology that is directly related to roughness value.

Finally, during the research progress, it was showed that the fractal dimensions are sensible to complex relief formation in fracture process.

5. ACKNOWLEDGEMENTS

This work was supported by FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo), under grant numbers 2008/01788-2 and 2001/09664-1 and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico), under processes 307271/2007-2 and 471749/2008-7.

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