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THE CONCEPT OF AUTOMATIC PROFILOMETRIC FRACTURE SURFACE MEASUREMENTS

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The concept of semi-automatic fracture surface profilometric measurements for determination of a fractal dimension has been tested. The results of four testing methods: manual, with the help of digitizer and image analyzer with micro and macro camera, respectively, were visualized on diagrams. The investigations have been preceded by testing selected methods on the "Koch triadic" profile with the D value being known.

1. Introduction

Material itself and applied heat treatment determine the structure of material which in turn decides on a mechanism of fracture, thus, also on a morphology of a fracture surface.

Solution to a problem of quantitative fracture surface description becomes indispensable for a proper direction of searching for basic relations between chemical composition, technology, structure and material properties, respectively.

Fractography, as a method of material testing has been focused so far on a qualitative topography description of a fracture surfaces. More often, attempts have been recently made to describe quantitatively characteristic features of a fracture surface. Finding a "numerical language" for description of a fracture surface would create an essential progress in seeking for interrelations between given decohesive mechanisms and characteristic features of materials, determined by the fracture mechanics methods. Recently, so called self-similar curves that reflect a configuration and shape observed, independently of magnification applied, have been adopted to fractography.

A new quantity can be introduced for self-similar figures (fractals). It is defined as such a number D, that the whole figure can be divided into $N = n^D$ parts similar according relation $r = 1/n$ to the whole figure. If such a partition is possible, thus, this figure can also be divided into N^k parts similar according relation r^k. Then

$$D = \frac{\ln N}{\ln \frac{1}{r}} \tag{1.1}$$

where N is a natural number.

It turns out, that the profile of the fracture surface can be considered as a fractal figure (cf Schwarz and Exner, 1980; Przerada and Bochenek, 1989, 1990). Taking measurements of the fracture surface profile line length using the finite measuring steps, than plotting the relation between measured lengths $L(\eta)$ and a quantity η in double log diagram the straight line can be obtained. From this line the value of D can be determined from the relation

$$\log L(\eta) = (1 - D) \log \eta \tag{1.2}$$

where

$L(\eta)$ – profile length

η – measuring step value

$(1 - D)$ – line slope.

Each fractal graph for a fracture surface has two asymptotes: $R_1 = 1$ for very high values of a measuring step η and $R_1 = R_1(0)$ for an infinitely small measuring step. Knowledge of these properties is necessary for a proper selection of a measuring step, length of which relates to the given structural unit (grain size, bundle, domain). Using an incorrect measuring step may in volve an improper value of fractal dimension.

2. The problem formulation and the way of its solution

The methods of a fractal dimension D determination that have been utilized up till now, required taking the series of measurements. These measurements were made with the help of micro-photographies containing the profile line of the cross section taken perpendicularly to the fracture surface. Main disadvantages of the described methods were an expensive preparation process of the specimen and the necessity of making numerous micro photographies. The multiple manual profile length measurements, using different length of the measuring step, made the procedure even more discomfortable.

Thus, an attempt to the partial automation of the measuring operation has been made. Two directions have been selected.

- *The first direction*

The manual multiple adding up of the profile length with the help of a divider was replaced by a single data concerning the tested profile input, using a digitizer tablet coupled with a microcomputer by the RS connector. A suitable designed algorithm and a computer program allowed for a multiple automatic adding up of the profile length basing on a single data input.

The number of steps selected by the program are limited by an s-shaped fractal curve and the computer working time only.

- *The second direction*

Using the automatic image analyzer allows the simulation of the manual procedure by application of the morphological binary image convertion method. Herein, two various possibilities of investigations have been selected. The first one takes place when the profile image is transmitted to the analyzer (Magiscan) through the microscope directly from the tested specimen (fracture profile line). The second possibility is based on the analysis of the image profile that is transmitted by camera from the micro photographies used earlier during a manual procedure.

The various methods proposed allow for the comparison of results obtained by different procedures. The efficiency of the methods used can be measured by: total time that is necessary to obtain the D-value and accuracy of the D-value estimation.

3. Tests and results

In order to determine the advantage of proposed methods the test problem has been solved. It is based on testing of the profile with a known D-value. The fractal line known as a "triadic Koch flake" was selected. Three different stages of evolution A, B, C, of this line are shown in Fig.1. The value of fractal dimension D of the "triadic Koch flake" is given by relation

$$D = \frac{\log 4}{\log 3} = 1.2619... \tag{3.1}$$

We will refer to the above value comparing our results.

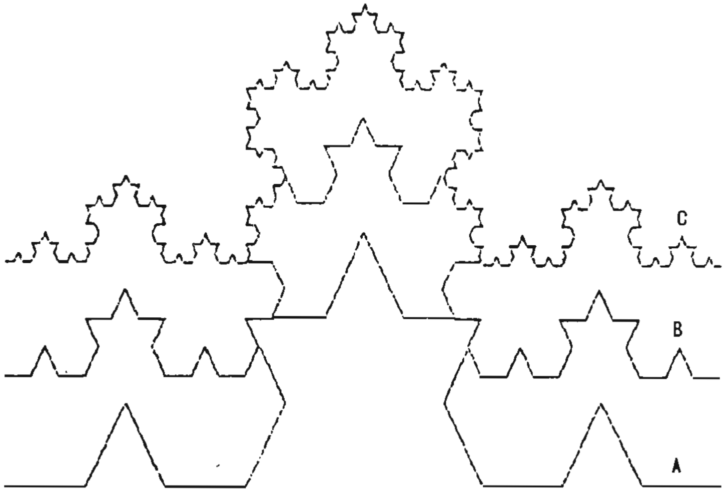

Fig. 1. Profile lines of the "triadic Koch flake" at different levels of their evolution (A, B, C)

The following methods were tested:

1. Manual method with the help of pair of dividers
2. Semi-automatic measurements with the help of digitizer tablet
3. Semi-automatic method using the Magiscan analyzer.

The magnitude of measurement error depends on the accuracy of the tool used.

The accuracy of the first method is limited by a diameter of a pin hole (determined by a divider) that is equal to 0.3 mm. For the second method the resolution of the digitizer tablet (Cosmo Graphic) is equal to 0.1 mm. Finally the accuracy of the third method is determined by a possibility of representation of the profile shape by binary video image that is limited by the screen size $(512 \times 512$ pixels) and the accuracy is equal to 0.27 mm. According to Eq (1.2) the measuring steps η should be selected properly and they should depend on characteristic sizes of a profile line and on arrangement of measuring tools. The most complex procedure of the measuring step selection takes place when the Magiscan video image analyzer is used. It follows from the adaptation of the procedure of subsequent profile smoothing of tested specimen with the help of technique usually called the dilation technique. This technique as one of morphological transformation operations takes its roots from the "coating" analogy of the tested profile of arbitrary fixed width by a layer of material. It simulates, with a high precision, an increase in the measuring step η. The width of the layer w can be transformed, according to (cf Flook, 1978 and 1982; Alexander, 1990), into the equivalent value of a measuring step η_e by the following relation

$$\eta_e = \sqrt{\frac{A_w}{\pi}} \tag{3.2}$$

where $A_w = 7w^2 + 4w + 1$.

The results of investigations carried out for three different levels of smoothing of the "Koch triadic line" (Fig.2) at five steps of the dilation procedure (1, 3, 8, 20, 60) led to determination of a fractal dimension value D.

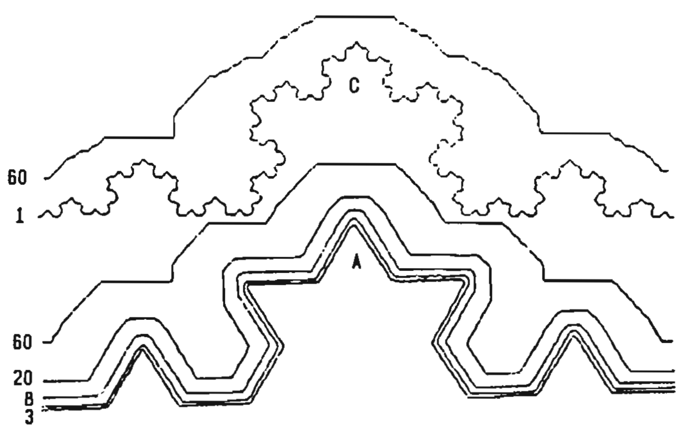

Fig. 2. The "triadic Koch" slope lines variation after dilation process from 1 to 60 layers of width w

As it was expected the profile line became smoother when the smoothing process had been completed. However, the final effect does not satisfy expectations. If the degree of dilatation is too high (> 50) the shape of transformed line remains unchanged. Most lines are inclined at 45 and 90 degrees. It is a result of the octaedric system of representation of a basic element within the Magiscan analyzer. This effect was a main source of errors during the measuring procedure.

The results of taken measurements are shown in a graphical form in Fig.3 and Fig.4. The relationship between dilation layer width w and equivalent step size η_e, Eq (3.2), enables a comparison of all results obtained with the help of various testing methods. It is made in Table 1 and Table 2.

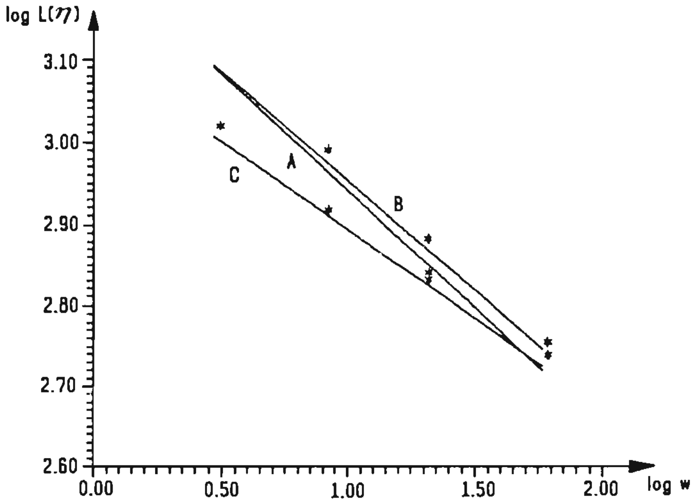

Fig. 3. Dependence of the fractal dimension D on the level of profile evolution, w – number of dilations

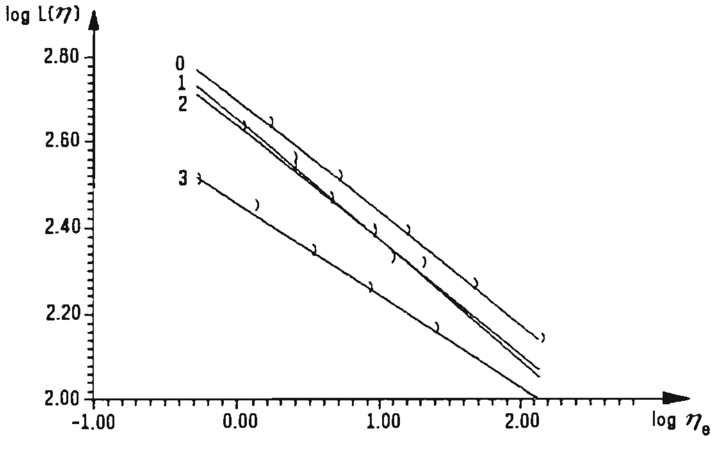

Fig. 4. Dependence of the fractal dimension D on the applied measuring method

Table 1

Symbols of flakes	D-values
A	1.269
B	1.286
C	1.218

Table 2

	method	D-value	accuracy [%]	computing time [min.]
0	analytical	1.2617	0.03	5
1	divider	1.2816	7.56	30
2	digitizer	1.2663	6.56	10
3	Magiscan	1.2131	18.60	40

The high scatter of the estimated D-values is observed. The smallest error (6.5%) was noticed for the digitizer method. The highest estimation error (18.6%) was obtained for the Magiscan image analysis method. Moreover this method takes 40 min. of computing time. Thus, the most optimum procedure of estimation of the D-value seems to be the digitizer method.

After completion of the test with the "triadic Koch flakes" the investigations of real fracture surfaces have been launched. Three profiles were selected with different degrees of roughness. They represented the fracture surfaces of the SENB specimens. The microstructure of materials was controlled by quenching with various cooling rate after austenization process. The specimen M had a ferrite – pearlitic structure. The structure of specimen R was a ferrite – bainitic one and the specimen O had a bainite – martensitic structure. To test the fracture surfaces the following methods were used.

1. Manual measurements with a pair of dividers were taken on micro photographs (magnification 200×)

2. Semi-automatic measurements, using digitizer tablet, were taken on the same microphotographs as in the method 1

3A. Semi-automatic measurements, using the image analyzer with a video camera, were carried out on the same microphotographs as in the methods 1 and 2

3B. Semi-automatic measurements, using image analyzer were performed directly on specimen via microscope (magnification 200×)

The results of the measurements along with the numerical D-values and standard deviations are given in Fig.5 and Table 3. The mean D-values and standard deviations of real profile lines for M, R, O specimens were 1.148 ± 0.0459, 1.1257 ± 0.0317, 1.0909 ± 0.292, respectively.

Table 3

	D-value			
	1	2	3A	3B
M	1.1283	1.2136	1.1423	1.1078
R	1.1312	1.1710	1.1053	1.1025
O	1.0568	1.1283	1.0879	1.0906

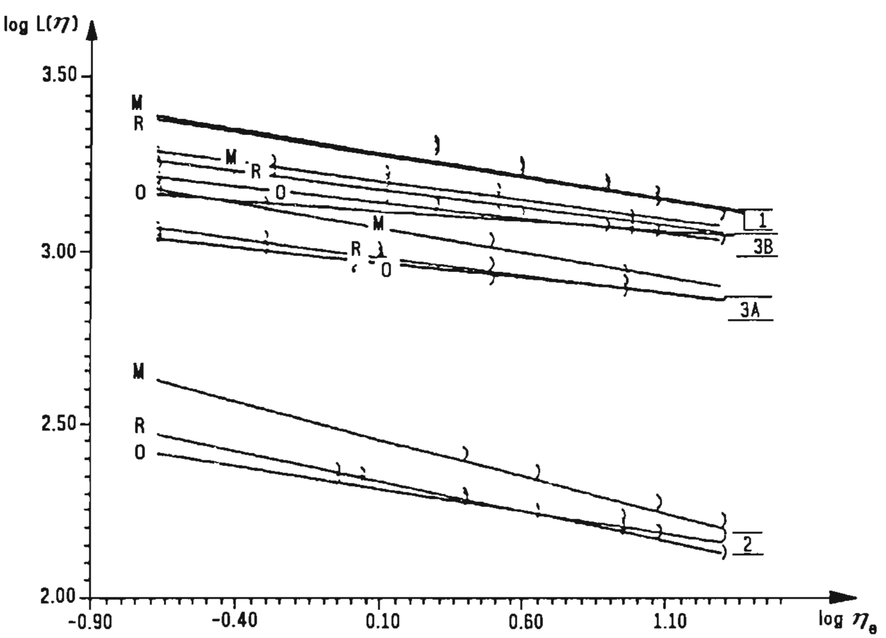

Fig. 5. Dependence of the fractal dimension D for M, R, O specimens on the applied measuring method

It seems that all applied methods of D-value estimation are sufficiently precise and confirm the fracture behavior of tested specimens (Przerada and Bochenek, 1990).

The greatest error of approximation was noticed for the M specimen (5.71 per cent) tested by the second method. The smallest sum of errors for three tested specimens was observed for the 3A. method (2.72 per cent).

In the presented paper the usefulness of all testing methods has been shown. However choice of the particular method should depend on measuring arrangement and computer programs applied.

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Próba zautomatyzowania profilometycznych pomiarów rozwinięcia powierzchni przełomu

Streszczenie

W artykule przedstawiono próbę częściowego zautomatyzowania profilometrycznych pomiarów powierzchni przelomu prowadzonych w celu określenia wymiaru fraktalnego D.

Wyniki zastosowanych metod badawczych (ręcznej, z użyciem digitizera, z użyciem makro i mikro kamery sprzężonej z analizatorem obrazu) przedstawiono w formie graficznej.

Badania rzeczywistych przelomów odniesiono do wyników pomiarów syntetycznego profilu (platka Kocha) o znanej wartości rozwinięcia przelomu D.

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