Fracture surface characterization of porous materials:

Fractal geometry vs. AMT (Angle Measure Technique)

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Extended abstract

Investigation of deformation structures and fracture for porous metals and materials under plastic deformation allows us to understand these processes in detail and to delineate the most effective operative conditions. Fracture surfaces display structures like dislocations, micro-, mezo- and macro-cracks, depending on the stage of deformation. Study of these types of structures gives us the ability to determine dependencies of materials deformation characteristics on physical and mechanical properties of these materials. Thus, investigation of the deformation structure is an important task for material science.

The most issue relates to how to obtain a quantitative description of the fracture surfaces, which usually have a distinctly non-uniform structure. This is even more complicated regarding complex multiphase materials with a very heterogeneous internal structure such as, for example, the porous materials. The known approaches allow us to solve this problem could be divided on two parts:

- Statistical approaches (i.e. Mean Absolute Deviation).
- Non-traditional approaches, dealing with structure peculiarities at a *hierarchical* scale system

Fractal analysis (FA) is a well-known non-traditional method which is very widely used. The basic ideas of fractal geometry methods were published by B. Mandelbrot [1]. The main concept of FA is that a fractal dimension can be considered as a quantitative measure of object surface heterogeneity *because* of its inherent self-similarity features. In a simplified representation, one could interpret the fractal dimension as a measure of heterogeneity of a set of points on a plane, or in space. If we deal with a fracture surfaces, the fractal dimension is viewed as a measure of surface roughness etc. There are several papers which report fractal characteristics of deformation structure of porous metal materials and how these depend on the physical and mechanical material properties [3, 4]. These results show that in some cases there are correlations between the fractal dimension of the materials fracture surface and the deformation stages and conditions. However, it was found that FA does not give good results if the surfaces are relatively smooth ($D \sim 2.1\text{-}2.2$). Moreover, these are also the cases, in which we cannot calculate D with a satisfactory accuracy. This is because of the non-linearity of the plot that presents the dependence between the numbers of measure functions covering a set of points, which are used in the box-counting algorithm versus their scale factor. Moreover, fractal analysis fails when we dealing with significantly noisy surfaces images.

In this connection, our main task is to look for other, complementary or alternative methods for quantitative analysis of the heterogeneous structures and to compare them with fractal analysis.

We have considered a viable and promising different approach to hierarchical structural analysis, in which we pay special attention to *simplicity*, *efficiency* as well as *conceptual closeness* to FA. The AMT (Angle Measure Technique [5]) scores very high for all these attributes, in fact AMT was originally developed precisely for characterization structures (1-D, 2-D, 3-D), for which the conventional FA failed, when encountering varying and *scale-correlated* fractal dimensions.

The Angle Measure Technique is a rather new method, e.g. for geo-morphological analysis, for technological measurement series characterization and for image processing a.o. AMT was developed by the American physical geographer ***Robert Andrle***, as an alternative to FA for characterizing the complexity of "geomorphic lines". At present, AMT is now widely applied in chemometrics as a general method for analysis and characterization of 1-D and 2-D complex signals [6].

Experimental

For check the effectiveness of AMT method for analysis of difficult fracture surfaces, we first apply this technique for classification of surfaces, which were simulated *with* - and *without* noise. 225 stochastic fractal surfaces were produced (*D* values ranging from 2.1 to 2.9) using the Diamond-Square Algorithm [7]. The surfaces images are in a 512• 512 pixel size format.

Surface analysis comprise two stages: 1) Calculation of AMT's "Mean Angle" (MA) and "Mean Y-difference spectra" (MDY) [6], followed by 2) PCA analysis of these spectra for surface discrimination. Two first principal components describe 98% of the total variance among the 225 spectra. From corresponding *score plots* for surfaces with value of *D* in the entire range of $2.1 < D < 2.9$ one may conclude that AMT easily allows discriminating the samples with different values of *D* (all systematic results will be presented).

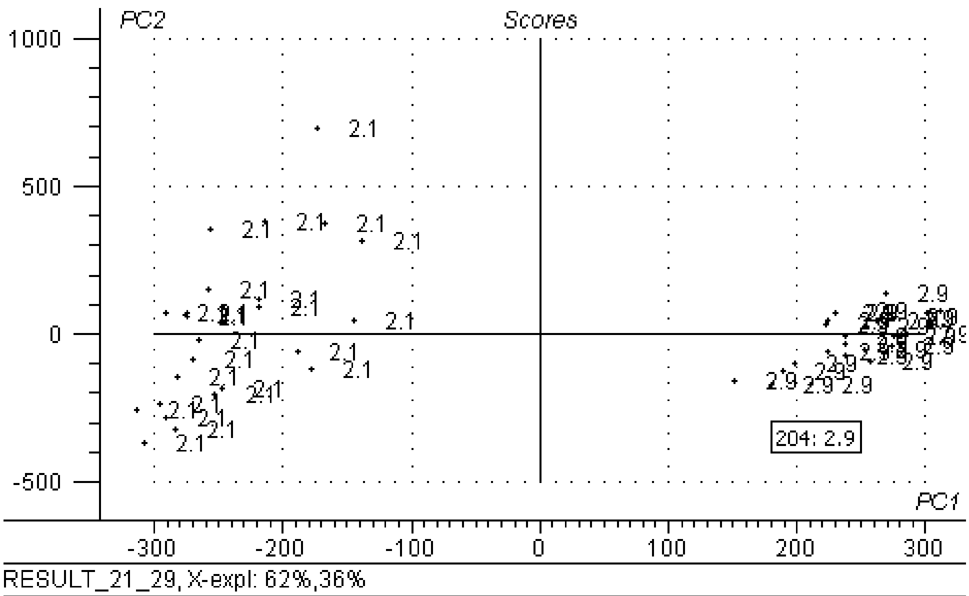

Fig. 1. Score plot of AMT-spectra of end-members with D 2.1 and 2.9 respectively. No noise.

As we can see in Fig.1, application of the PCA discrimination feature to the AMT-spectra for the two extreme end-members gives a very clear distinction. In this case PC1 corresponds to the overall *D* (first-order feature) while PC2 describes second-order, more subtle smoothness property differences between the surfaces realized, attesting to AMT's versatile sensitivity of the detailed fractal properties of objects, which are indeed *correlated* to the scale hierarchy (systematic results and interpretations will be presented).

Real-world fracture surface images, obtained with microscopes, video and photographic equipment, differ from simulated surfaces, first of all because of the presence of significant amounts of stochastic noise superposed on the first- and second-order fractal features. The second part of this work is devoted to investigations of noise-influences in this type of images and to characterizing and discrimination ability of FA *versus* AMT. For this purpose, various systematic fractions of white Gauss noise (varying levels and variances) are added to the above images of simulated surfaces. Again both FA as well as AMT-spectra are calculated and compared.

Examples of such “noised surfaces”, as well as their initial and calculated fractal dimensions are shown in figure 2. Obviously, noise makes the surfaces more heterogeneous, and the calculated fractal dimensions no longer correspond to the embedded true dimensions. In this case, we cannot perform surface roughness characterization etc. using fractal analysis.

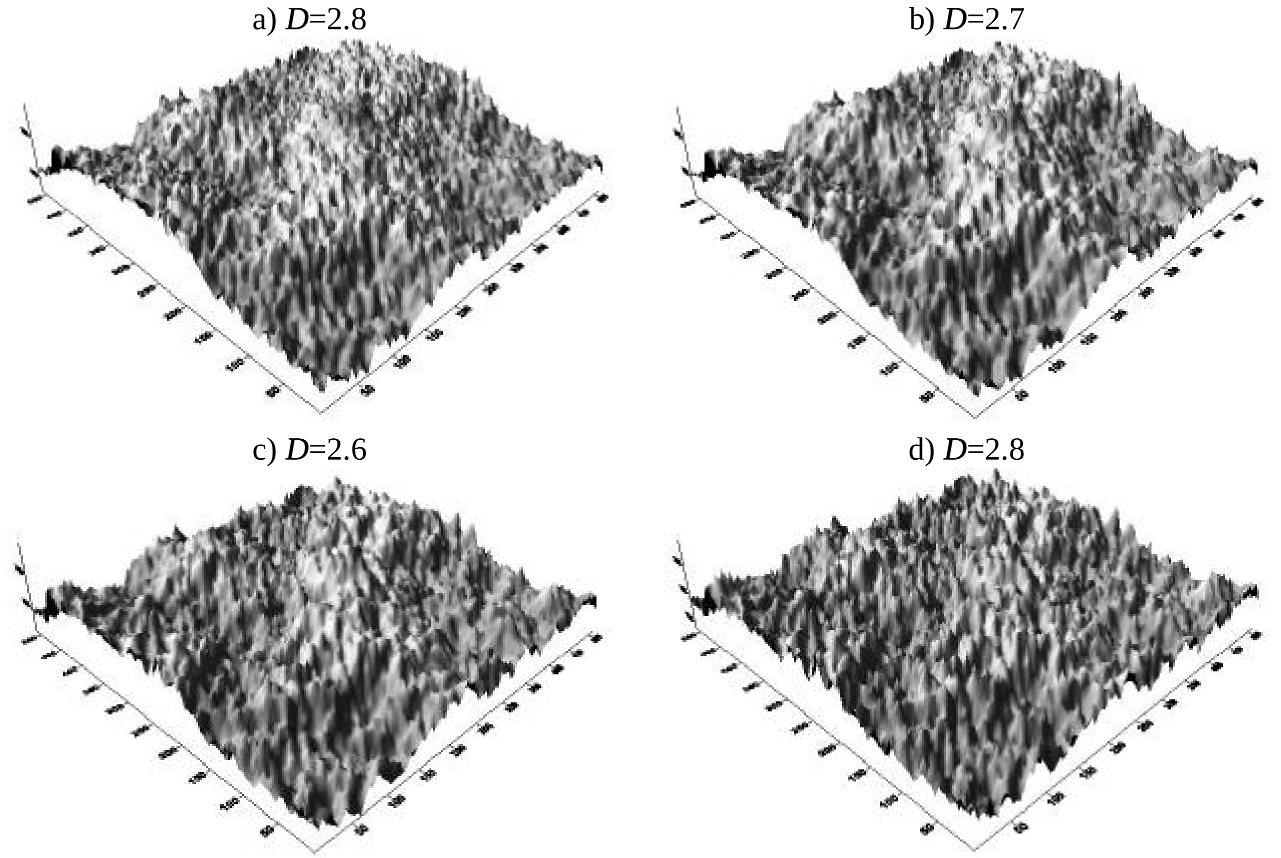

Fig. 2. Samples of “noised surfaces” with initial (***true***) dimensions 2.1 (a), 2.3 (b), 2.5 (c), 2.9(d) and their ***calculated*** fractal dimensions

The corresponding PCA score plot for the alternative AMT spectra, together with the initial (true) dimension *D* from 2.1 to 2.9 is presented on figure 3. PC1 and PC2 now describe 93% of the total variation. Similarly as for the noiseless samples, AMT allows discrimination between surfaces with different fractal dimensions, although clusters representing the different noised realizations with the same D now necessarily also somewhat more overlapping. Fig. 4 again shows the score pots for samples with D = 2.1 and D = 2.9. Nevertheless, from this plot we can see that changing the scale of axis gives us means for discriminations etc. (systematic results and interpretations will be presented).

Conclusions

Summarizing, we can conclude on interesting possibilities for the AMT approach for quantitative surface characterization with different fractal dimensions, especially for D>2.3. Moreover, this method gives clearly superior results for realistic (close to real-world) “noisy surfaces”, for which the conventional fractal analysis fails. It is generally well-known both from theory and applications [1, 6] that AMT indeed is stable w.r.t. additions of noise, which is amply substantiated by our results.

We also present results for even more complex fracture surfaces of porous materials.

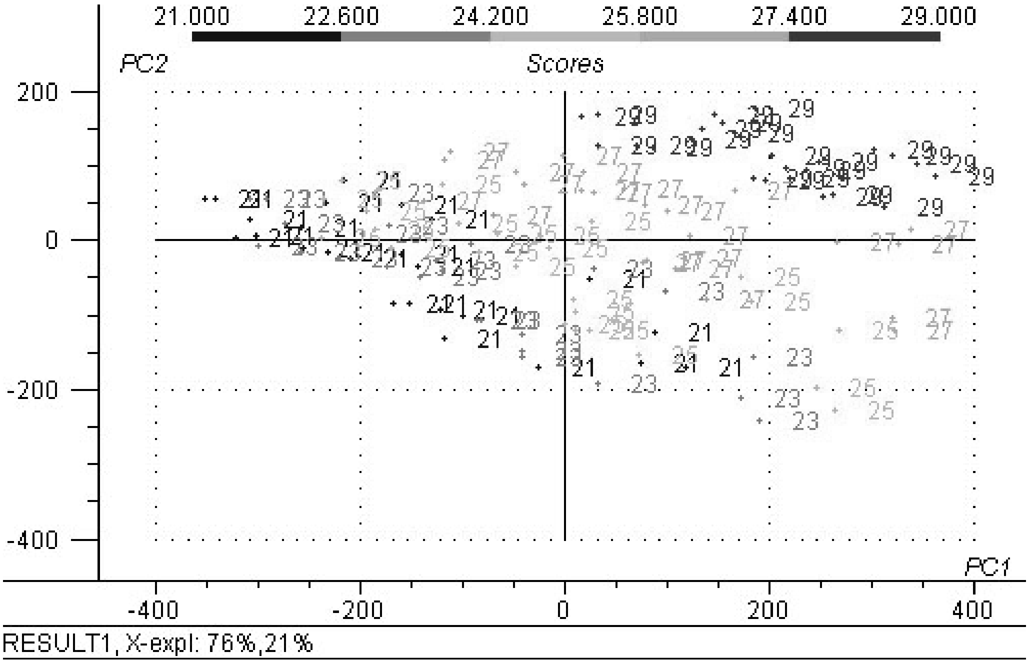

Fig. 3. Score plot of AMT-spectra of “noised surfaces”; cmp. Fig. 1.

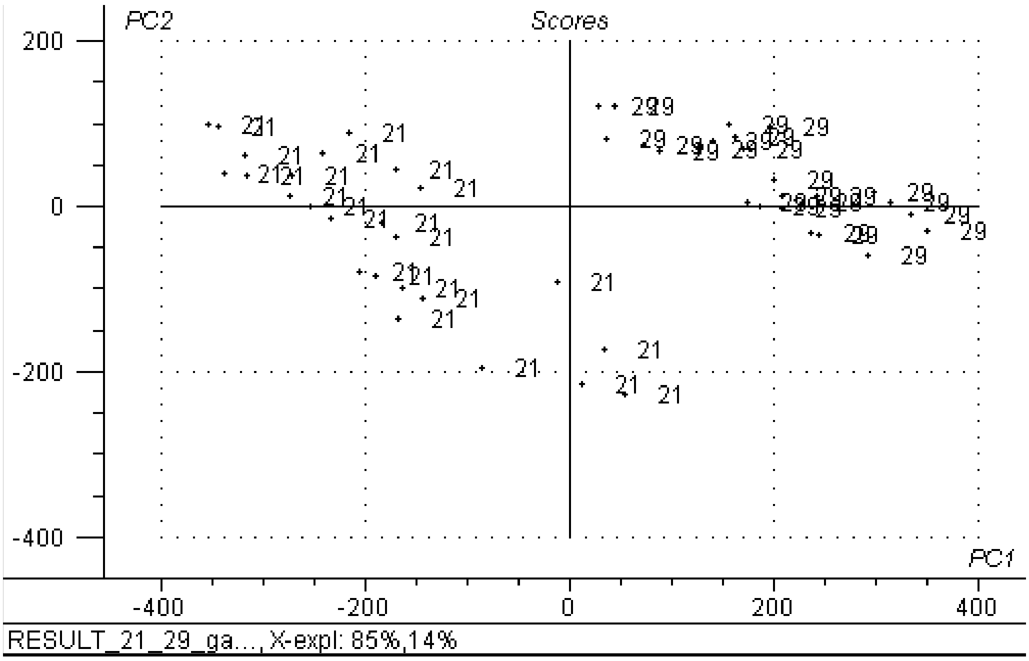

Fig. 4. The scores plots of the AMT spectra of noised surfaces with initial D=2.1 and D=2.9 . Second scale of PC1/PC2 axis

References

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