Recognition of Oriented Structures by 2D Fourier Transform

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Abstract

Oriented structures in metallography are usually evaluated by the intersection method or on the base of comparison against a series of standard micrographs. In this paper is introduced a new method for assessment of structures formed by elongated grains using the Fourier transform technique: The image is transformed into reciprocal (Fourier) space and use is made of the fact that the Fourier transform is very sensitive to the orientation distribution of grains. The Fourier transform of the micrograph is a specific pattern, which bears a clear relation to the original micrograph and can be evaluated both qualitatively and quantitatively.

Introduction

Plastic deformation may strongly influence the properties of products. So, pearlite banding has a negative effect on hydrogen induced cracking [1], anisotropy is intentionally introduced into transformer and dynamo sheets [2], etc. On the other hand, by annealing, anisotropy disappears [3] and ferrite may acquire the form of equiaxial grains.

The light microscopy enables observation of the shape of individual grains (crystals) after their etching. Mostly, three basic methods are used to evaluate such structures:

1) The oldest one is the comparison of a series of standard micrographs with the micrograph of the sample under consideration [4] (e.g. cold-rolled sheets and strips). Workers´ experience affect the results obtained in this way, which are only qualitative.
2) In a more suitable and exact way, the evaluation is performed so that the original image is overlaid by a line grid and the number of intersections with grain boundary is counted [5]. The degree of orientation is then defined as the ratio of the oriented boundary surfaces to the total boundary surface [6]. The main disadvantage of this method is its laboriousness.
3) Other, more developed techniques of image analysis, have appeared recently [7,8] such as the diameter (Feret´s ratio) method [1] based on size distribution in defined directions (perpendicular directions of drawing and rolling). Here, the precision of the results is greater than with manual evaluation, thanks to the use of digital image processing [8].

In our paper, we shall introduce another procedure for evaluation micrographs of oriented structures by Fourier analysis [9].

Fundamentals

All the conventional techniques mentioned above operate within the (obvious) "real" space. For our purposes, we shall introduce another, abstract, mathematical space, the so-called "reciprocal" space, which is the space of (spatial) frequencies of periodic components

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of patterns (pictures) observed in the real space. By spatial frequency we mean here, e.g., the number of intersections of grain boundaries with overlaid straight line per unit length. While the unit length is meter, the spatial frequency is $(\text{meter})^{-1}$, i.e. "reciprocal" meter and this is why we say that the space of spatial frequencies is "reciprocal" with respect to the "real" space. The image, as observed in the real space, is coded as (expressed in term of) grey level f(x,y) at position (pixel) (x,y). Next the function is expanded into its harmonical components by the Fourier transform.

A deformation like rolling or drawing may result in elongation of grains in one direction and their shortening in other direction. So, the spatial frequencies in different directions will diverge: they will be smaller in the directions in which the grains have been elongated and greater in the direction in which they were compressed. As a consequence of this, the Fourier transform of the micrograph, which is (usually) a (simple patch-like) pattern in the reciprocal space, becomes anisotropic, elliptical, contrary to the case of equiaxial grains: here, the spatial frequencies are the same in all directions, and, therefore, the Fourier transform of the micrograph (image) of such a structure will be isotropic, circular. Anisotropy of the Fourier transform F(u,v) of the micrograph under analysis reflects anisotropy of the structure as perceived directly on the micrograph (image) of the structure f(x,y). But the Fourier spectrum F(u,v) (or power spectrum $|F(u,v)|^2$) is much simpler than image f(x,y), and, therefore, evaluating Fourier transform of images is easier and gives more (detailed, exact) information on deformed structures than evaluating directly the (image of the) micrograph [10].

Fourier analysis

The majority of the present-day Machine Aided Image Analysis (MAIA) software packages contain routines for doing Fourier transform, i.e. converting the image under inspection into reciprocal space (Fourier space) – to express the image in terms of spatial frequencies. The anisotropy of these patterns adequately reflects the anisotropy of the original micrographs: the greater anisotropy of the structure, the greater the anisotropy of the corresponding power spectrum.

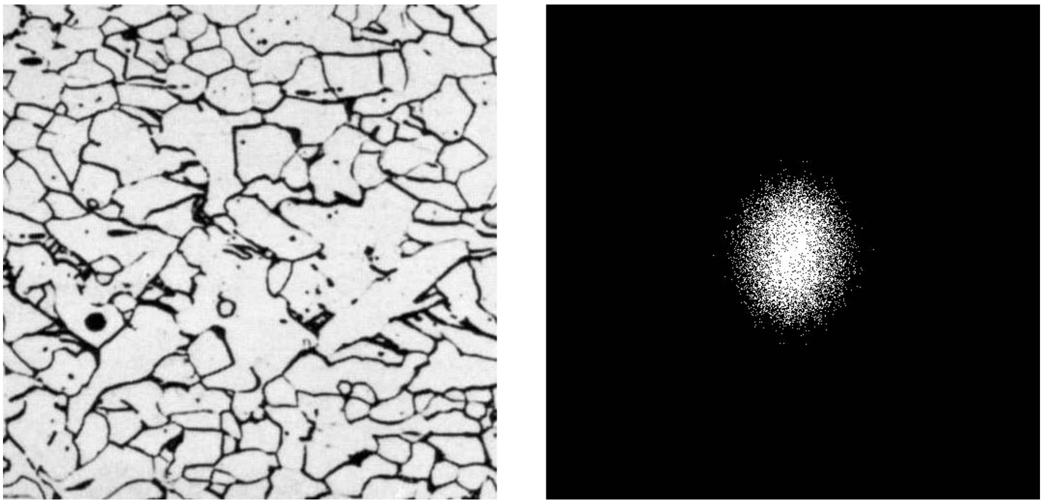
In a deformed structure, the number of grain boundaries intersecting the vertical (y-) axis is much greater than the number of grain boundaries intersecting the horizontal (x-) axis: the spatial frequencies in the vertical direction are greater than those in the horizontal direction. That is why the corresponding spectrum is stretched in the vertical direction and squeezed in the horizontal direction. So, the anisotropy of the power spectrum can be used as a measure of the anisotropy of the original image (microstructure). And, due to the fact that the power spectrum is a simple pattern, its assessment is easier than the direct analysis of the micrograph. We evaluated the anisotropy of the (shape of) the power spectra.

Software for recognition of the degree of deformation of materials

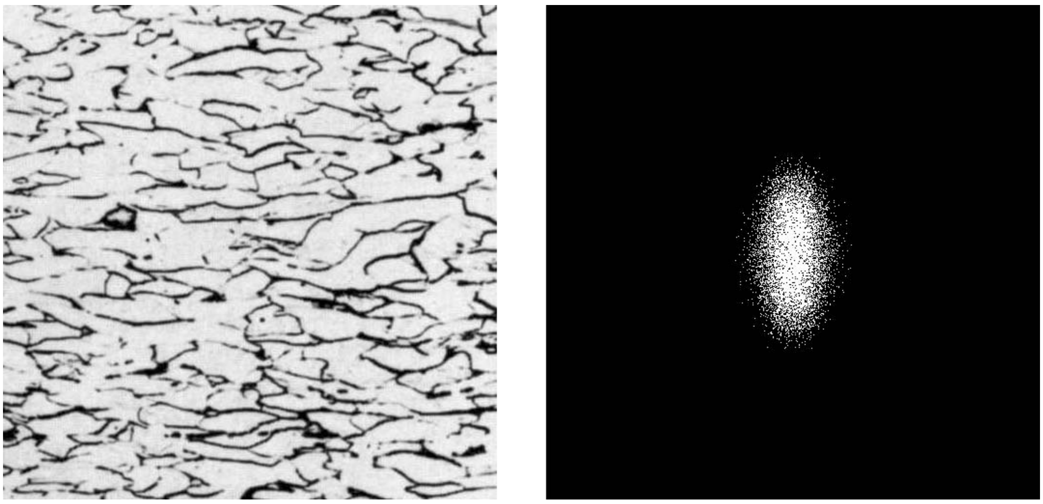
For the first simulation and verification of methods is used software system MATLAB. Two programs are developed in MATLAB now.

The first program reads an input image with a structure of material under inspection and performs a 2D Fourier Transform [11] on this data. Then the FFT magnitude is calculated for each point of the image and thresholded to levels 0 or 1. Finally, a new image, composed from the thresholded FFT magnitudes, is saved on hard disk. Figure 1 shows input images (material structure for different deformations) and output images (Fourier spectra) obtained by this program.

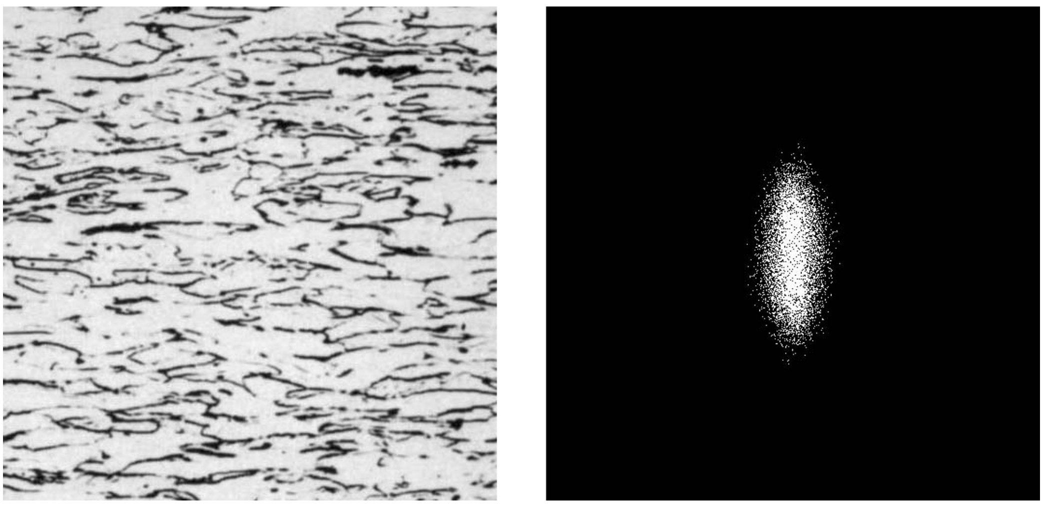
The second program uses the image of the Fourier spectra as an input image and realizes two methods for the recognition of the degree of material deformation. These methods use vertical and horizontal histograms or histograms in polar coordinates.



a) 10% deformation



b) 40% deformation



c) 60% deformation

Figure 1: Material structures and their spectrum obtained by the 2D Fourier Transform

Horizontal and vertical histograms

This method is based on the calculation of the horizontal histogram and the vertical histogram. The horizontal (vertical) histogram is calculated as the number of white pixels in rows (columns). Then a width of the main peak is extracted from each histogram. The width is measured in a level which is manually set. In our case the level is set to 70%. A parameter H/V is a ratio of the width of the main peak in the horizontal histogram and the width of the main peak in the vertical histogram. A minimum of the parameter H/V is 1. When this parameter is near 1 that means small or no deformation. Figure 2 shows the thresholded frequency spectrum of the input image (deformation 40%) and the horizontal and the vertical histograms obtained from this frequency spectrum.

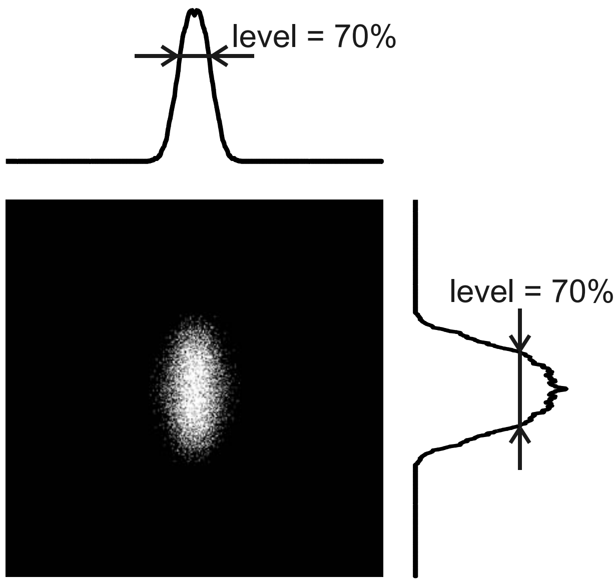


Figure 2: Horizontal and vertical histogram

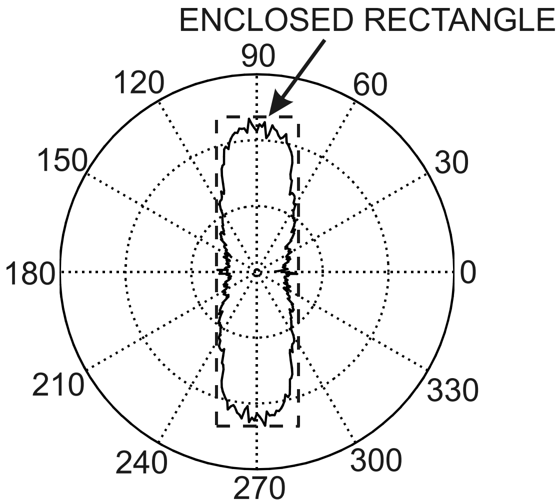


Figure 3: Histogram in polar coordinates with enclosed rectangle

Histogram in polar coordinates

In this method, the histogram in polar coordinates is calculated, that means a calculation of the number of white pixels in each direction (0° to 360°) from the center of the image. Then an enclosed rectangle is constructed and a shape factor (SF) is calculated as a ratio of its sides. A minimum of the shape factor is 1. A SF near 1 means small or no deformation. The figure 3 shows the histogram in polar coordinates for the same input image as figure 2. That means the histogram is calculated from the thresholded frequency spectrum which is shown in figure 2.

At present both methods suppose that the deformation is in the direction of the vertical axis. Some normalization method (e.g. retino-cortical transform) will be involved in the future for independence on the direction of deformation.

Results

The microstructure of deformed steel Capped 1008 with scaled reduction 10% was used for testing. The microstructures obtained by light microscopy are shown in figure 1 (left column). It is evident that the orientation of crystals of the material grows with increasing degree of deformation. At the same time, the frequency spectrum becomes more elongated (see figure 1 – right column). The results of the recognition of the degree of deformation are shown in the graph in figure 4. The deviations from the trend are probably caused by the small number of individual images for each deformation.

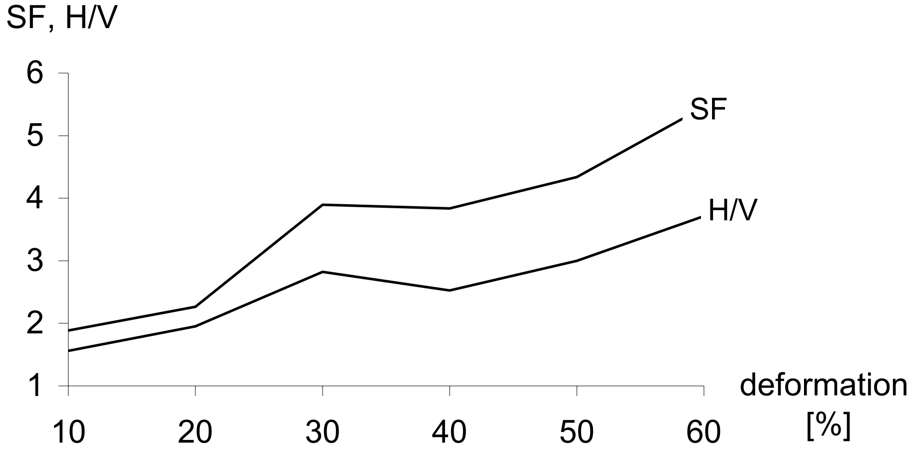


Figure 4: Parameters SF and H/V in dependence on deformation of material

Summary

The Fourier analysis provides an efficient method for the evaluating of the oriented structures. It consists in converting the image (the microstructure) into its power spectrum that is a simple pattern the shape of which reflects the anisotropy of the structure. In comparison with the conventional interception method, the Fourier analysis has a number of advantages:

- the power spectrum of the microstructure under consideration is a simple pattern much easier to analyze than the original micrograph;
- the shape of the power spectrum is very sensitive to the slight differences in the degree of orientation;
- the complete assessment takes only a few seconds per image.

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