ACTA STEREOL 1994; 13/2: 305-310
PROC 6ECS PRAGUE, 1993
ORIGINAL SCIENTIFIC PAPER

FOURIER ANALYSIS OF AUSTENITE PARTICLES SHAPE IN A DUPLEX STAINLESS STEEL

Jerzy BYSTRZYCKI[1], Grzegorz ŻEBROWSKI[2]
Krzysztof J. KURZYDŁOWSKI[2] and Krzysztof JASEK[1]

[1] Department of Metallurgy and Metal Technology
Military University of Technology,
01-489 Warsaw, Kaliskiego 2, Poland
[2] Department of Materials Science and Engineering,
Warsaw University of Technology,
02-524 Warsaw, Narbutta 85, Poland

ABSTRACT

The paper describes two methods for quantitative characterization of shape of particles or other 3-dimensional elements of materials microstructures. The methods are based on studies of particle sections revealed in a cross-sections of the material. The first method utilizes the concept of radius vector. In the second method particle contours are defined by the angle of the tangent line and the reference direction. An example of application is presented to studies of austenite particles in austenitic-ferritic duplex stainless steels.

Key words: Fourier analysis, particles shape, duplex steel.

INTRODUCTION

A precise quantitative characterization of shape particles, or other 3-dimensional elements of the materials microstructures such as grains in polycrystalline aggregates, is an important part of material description required by modern materials science. The shape of particles is important factor providing information on processes taking place in the microstructure. It has also an influence on the mechanical properties of the materials. The quantitative information on the shape of particles can be obtained by means of Fourier transformations (Ralph, 1984). Strojny et al.,(1987) have presented applications of the Fourier analysis (FA) of shape in the investigations of biological objects. They described two methods with one of them applicable for the case of convex figures and the other for figures of any shape (convex and concave). These methods are based on the Fourier transformations of the functions which describe the shape contour of the sections of analyzed objects. In the first method the contour is described by the rotating radius vector. This method, simpler in implementation, is restricted to convex figures. In the second method, the contour function is defined in terms of the tangent direction and its angle with the reference direction. In this case, any shape of grains can be analyzed.

THE METHOD

According to the Fourier theorem, any continuous and period function F(x) with the period T can be represented in the form of a series of sinus and cosines functions. These series are defined as the Fourier series of the function F(x) and are given by the following formulae:

$$F(x) = A_0 + \sum_{n=1}^{\infty} A_n \cos\frac{2\pi nx}{T} + \sum_{n=1}^{\infty} B_n \sin\frac{2\pi nx}{T}, \qquad (1.1)$$

$$F(x) = A_0 + \sum_{n=1}^{\infty} C_n \cos\left(\frac{2\pi nx}{T} - \varphi_n\right), \qquad (1.2)$$

where:

$$C_n = \sqrt{A_n^2 + B_n^2}, \qquad (1.3)$$

$$\varphi = arctg\frac{B_n}{A_n}, \qquad (1.4)$$

$$A_0 = \frac{1}{T}\int_0^T F(x)\, dx, \qquad (1.5)$$

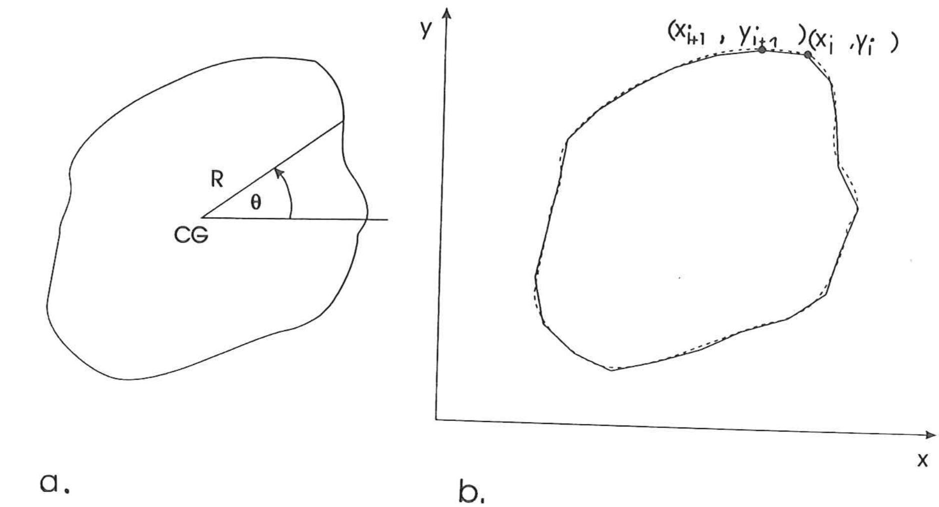
$$A_n = \frac{2}{T}\int_0^T F(x) \cos\frac{2\pi nx}{T} dx, \qquad (1.6)$$

$$B_n = \frac{2}{T}\int_0^T F(x) \sin\frac{2\pi nx}{T} dx, \qquad (1.7)$$

The Fourier representation of a given functions F(x) can be limited to first n elements of Fourier series. This yields a function that approximates F(x). The higher is n the better is precision of approximation.

In the quantitative metallography approach shape of particles is usually studied via examination of their 2-dimensional sections. In this case the particles are represented as a single or multiple loops. In the case of convex contours each loop can be described by the vector R(Θ) function. This is the function defining position of particle contour in a cylindrical system of coordinates (r,Θ) attached to the gravity center of a given particle (Fig.1).
The R(Θ) function is periodic, with a period 2Π and can be represented in the form:

$$R(\theta) = R_0 + \sum_{n=1}^{\infty} R_n \cos(n\theta - \varphi_n), \qquad (1.8)$$



CG - a geometrical centre of gravity

Fig.1. a) Schematic explanation of R(θ) function for convex figures; b) A polyhedron approximating contour of a 2-dimensional figure.

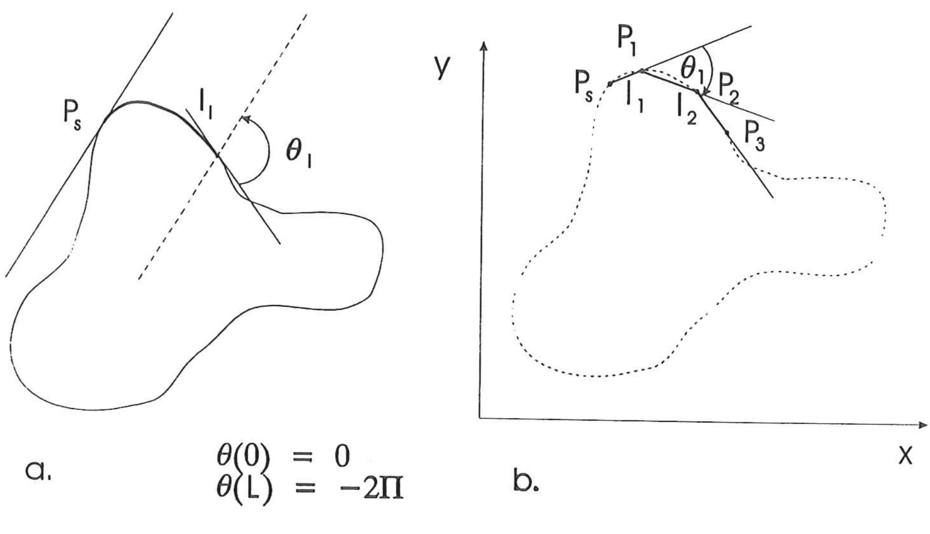


Fig.2. a) Schematic explanation of θ(L) function that can be used for figure of a general shape; b) A polyhedron approximating contour of a 2-dimensional concave figure.

where: R_0 - radius of the circle of the same area as the particle,
R_n - n-th harmonic figure of n bulges,
ϕ_n - orientation of the harmonic figure with respect to the references axis.

In the case of non-convex particles the contours can be defined in terms of the angle θ between the tangent to the particle contour and some reference direction (Fig.2). This angle changes with the position of the tangency point and can be analyzed as a function of a distance l from a starting point P_0. In this way the shape is described by $\theta(l)$ function. This function is, however, not periodical one. To make it independent of L, contour length, it is transformed in the following way:

$$\theta^*(t) = \theta\left(\frac{Lt}{2\pi}\right) + t, \tag{1.9}$$

where:

$$t = \frac{2\pi l}{T}.$$

The two described methods have been implemented in the form of a software developed for micro-computers. The software has been written in Turbo PASCAL 6.0. It has been successfully verified on some model figures with the results shown in Fig.3-5.
The programs developed can be used to process directly the images acquired with a help of a simple system for image acquisition. They approximated the studied contour by a finite number of points selected in an automatic way or manually be the operator.

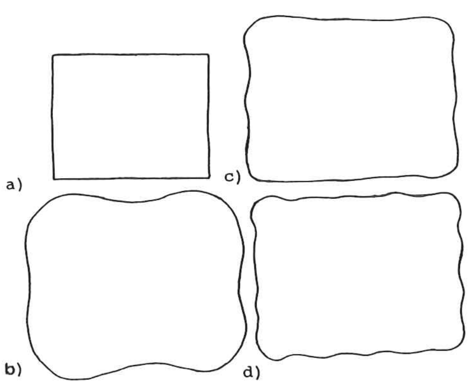


Fig.3. An example of Fourier transformation of a convex particle shape:
a) the particle,
b) its approximation with 5 harmonics,
c) with 10 harmonics,
d) with 40 harmonics.

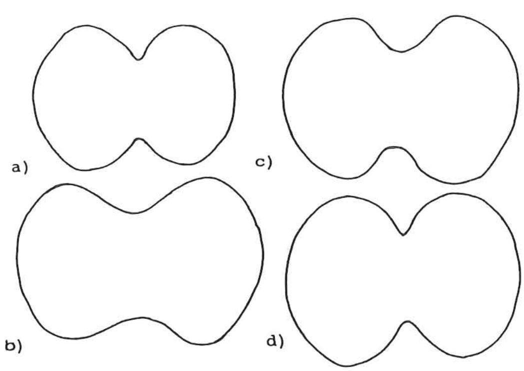


Fig.4. An example of Fourier transformation of a concave particle shape:
a) the particle,
b) its approximation with 5 harmonics,
c) with 10 harmonics,
d) with 40 harmonics.

THE MATERIAL

The software developed has been utilized in studies of particles in a two-phase material. A duplex stainless steel of the composition given in Table I was used. The material was plastically deformed by cold working and subsequently annealed at 1050°C for one hour.

Table I. Chemical composition of the material

Element	C	Mn	Si	P	S	Cr	Ni	Mo
Concentration [%]	0.03	0.87	0.98	0.03	0.008	21.3	4.9	1.4

Cylindrical specimens of the material have been strained to fracture in a tensile tests carried out at room temperature. Microstructure observations were conducted on longitudinal sections on shoulder sections, in some distance from and directly inside the neck.
The applied heat treatment produced a microstructure consisting of austenite particles in a ferritic matrix (Fig.6). The particles of austenite are agglomerates of austenite grains and frequently assume non-convex shapes. Consequently, the second method has been used to quantify their shape.

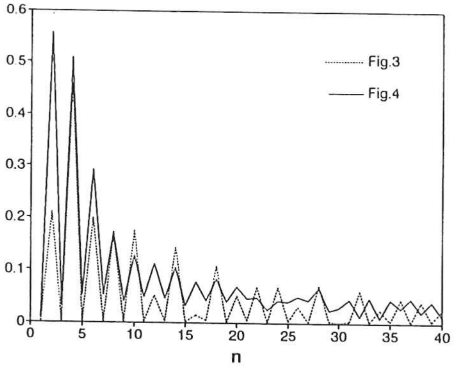


Fig.5. The amplitudes of the harmonics for the contours in Fig .3 and 4.

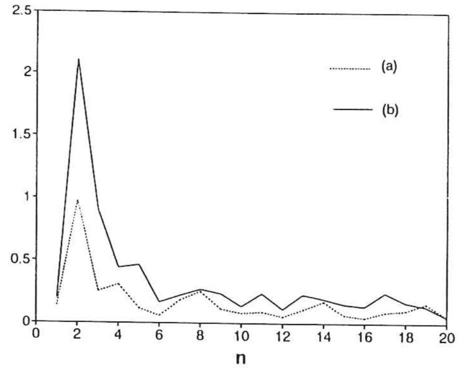


Fig.7. The average values of the amplitudes for particles of austenite in the strained and un-strained material.

RESULTS AND DISCUSSION

Some of the results of the particle shape studies are depicted in Fig. 7 and 8. These results show that the shape of austenite particles is a function of their position with respect to the strained specimen neck and in turn the amount of plastic deformation. This is an indication that these particles play an important role in the accommodation of the plastic straining in the material.
The amplitudes of the harmonic functions for individual particles studied have been subsequently averaged to obtain typical shapes of particles as a function of the absorbed plastic strain.

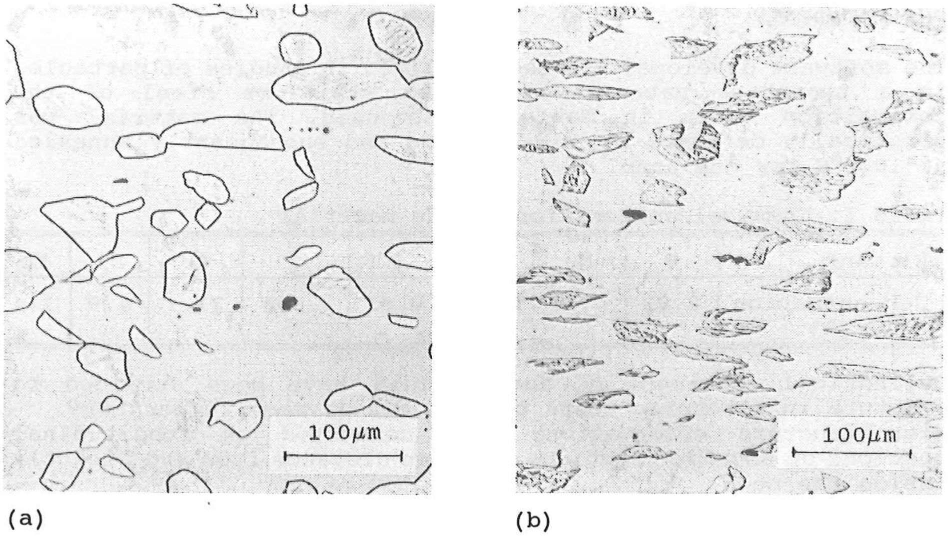


Fig.6. Microstructure typical of: (a) un-deformed material and (b) the material in the strained specimen neck.

On that basis the contribution of austenite to the deformation of the material has been found to be a factor controlling the plasticity of the duplex steel.

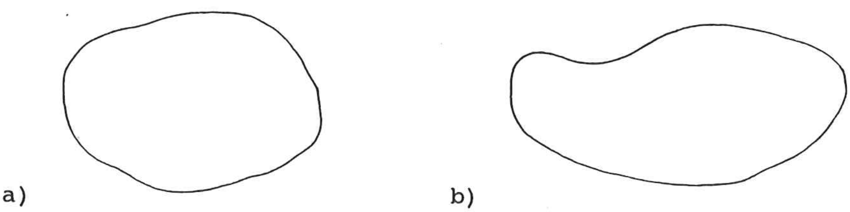


Fig.8. The averaged shapes of particles as a function of their distance from the specimen neck: (a) un-deformed materials and (b) the material in the strained specimen neck.

The performed analysis of the shape of particles makes it also possible to automatically separate them into individual grains. This is, however, subject of a different publication currently under preparation.

ACKNOWLEDGEMENTS

This work has been supported by grant from Polish Committee for Scientific Research.

REFERENCES

Ralph B. Application of image analysis to the Measurement of particle size and shape. Anal. Proc. 1984: 21: 506-508.

Strojny P, Ostrowski K, Dziedzic-Gocławska A. Application of the Fourier analysis of shape in the investigations of cell images and other biological objects. Postępy Biologii Komórki. 1987; 3: 149-156.