Spheroidization of Cementites Platelets in SK85 Heat-Treated High Carbon Steel

Lateef O. Mudashiru,Sunday O.Adetola,Emmanuel O. Olafimihan and Wasiu A. Raheem

Abstract–The change of fractal dimension is the representation of material internal properties which are closely related to deformation conditions. Consequently, many natural structures cannot be described by conventional methods, because they are complex and irregular. A new approach is the application of fractal geometry. In this work, the relationship between fractal dimension and sphericity on the spheoridization of cementites platelets in 30% and 40% cold-rolled SK85 high carbon steel, heat-treated for 1hr and 16hrs at 720 ºC respectively was studied. The best spheroidized platelets was found in 40% cold-rolled specimen, having weighted average sphericity and fractal dimension β = 0.8951 ± 0.0012 and D =1.1891 ± 0.0107, close to that of a perfect shape. Thus, a few hours of exposure time during heat-treatment condition may favor the growth and dispersion of spheroidization platelets rather than long period of heat-treatment.

Keywords –Fractal dimension, Sphericity, Spheroidization, High carbon steel, SK85.

1. INTRODUCTION

High carbon steels generally contains carbon contents ranging from 0.3 to 1.2 % in weight percent. These alloyed materials were generally considered very important in fabricating parts of automobiles, industrial machines and machining tools. In the production of high carbon steel, spheoridization heat treatment is crucial to guarantee formability and quality of products. Spheroidization heat treatment is conducted by soaking the steel with ferrite/martensite microstructure at a high temperature so that the shape of carbides or cementites in ferrite matrix becomes spherical by the diffusion of carbon atoms [1] [2]. Spheroidized microstructure is the most stable one in steels and well known to give rise to a good ductility.

[3] revealed that controlled rolling process enables a production of the materials with a fine microstructure and better mechanical properties than conventional production processes. However, accelerated carbide spheroidization and refinement (ASR) carried out in their study aimed at produce steel work pieces with a microstructure consisting of a fine-grained ferrite matrix and globular carbide particles. It was found that this microstructure has higher yield strength and toughness than the conventional ferritic-pearlitic microstructure. [4] found that by increasing number of cycles of heat treatment in ultra-high carbon steel (UHCS) the size of carbides and ferrite reduces and become finer.

In the study conducted by [5] on the spheroidized carbide dissolution and elemental partitioning in a high carbon bearing steel 100Cr6. Scanning electron micrographs revealed that around 14 vol.% spheroidized carbides are formed during soft annealing and only 3 vol.% remain after dissolution into the austenitic matrix by austenitization at 1123 K (850 °C) for 300s. However, spheroidization behavior of cementite in low carbon steel processed by the equal channel angular pressing technique was investigated by [6]. The results indicated that the application of the severe plastic deformation improved the kinetics of spheroidization significantly. In this work, fractal analysis was used to numerically characterize the area fraction of spheroidized cementite in the study conducted by [1], were spheroidized cementite was measured with an image analyzer as a function of cold reduction ratios and duration times.

2 METHODOLOGY

2.1 Material and Methods

[1] observed that as spheroidization annealing proceeded, fragmentation of cementite plates, spheroidization of the cementites platelets and coarsening were observed consecutively. These may however, have positive or negative effects on the resulting microstructure and consequently on the mechanical properties of the material.

The chemical compositions of SK85 high carbon steel (HCS) in the study conducted by [1] were 0.83C, 0.2Si, 0.43Mn, 0.008P and 0.001S in weight fraction. The thickness of plates was 4mm and the microstructure observation revealed nearly bainite structure. (Fig. 1) show the micrograph that revealed the appearances of cementites and (Fig. 2) show the fractal geometry of the spheriods of four selected specimens during spheroidization heat treatment taken from the 40%-cold-rolled fine pearlite (FP) specimens annealed for 1hr and 16 hrs, and the 30%-cold-rolled coarse pearlite (CP) specimens annealed for 1hr and 16hrs respectively.

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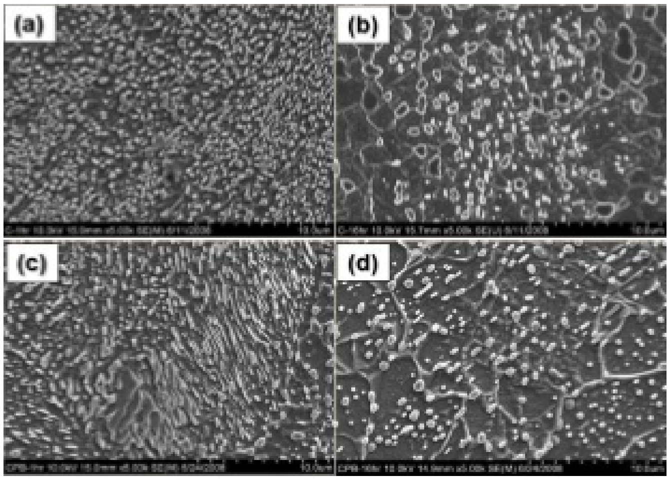

Fig. 1: Micrograph of Sk85 HCS Specimens; 40%-cold-rolled for (a) 1hr and (b) 16 hrs; 30%-cold-rolled for (c) 1hr and (d) 16hrs each at 720 °C.

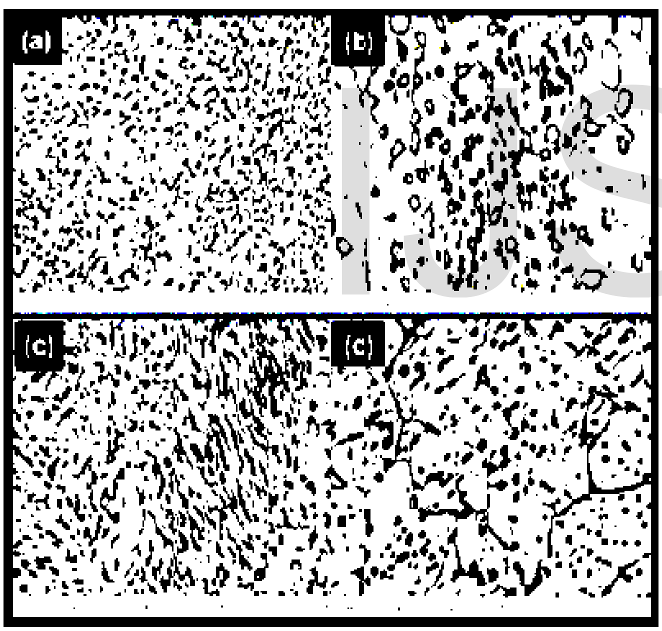

Fig. 2: Fractal geometry of spheroid cementites: 40%-cold-rolled for (a) 1hr and (b) 16 hrs; 30%-cold-rolled for (c) 1hr and (b) 16hrs each at 720 °C

Fractal Analysis Approach

Fractal analysis is a useful tool to quantify the inherent irregularity of nature [7] [8] [9]. Fractals are self-similar and infinitely detailed, and the related fractal dimension (D), sphericity (β) and lacuranity parameter (Γ) are index of its morphometric variability and complexity. Moreover, fractal analysis has been applied to a variety of natural objects [8] [9] [10] [11]. Thus, among the different methods of fractal analysis calculation, the box-counting method is one of the most appropriate in landscape structural estimation because it can be apply to fractal patterns with or without self-similarity.

In this work, the mathematical basis for measuring chaotic objects with the power law is adopted. The basic equation is as follows:

$$P = P_e\, \delta^{D-1} \qquad (1< D < 2 \text{ and } \delta_m < \delta < \delta_M) \qquad \text{………..…} (1)$$

where "P_e" is the measured perimeter, "P" is the true perimeter, "δ" is the yardstick, "δ_m and δ_M" are the upper and lower limits respectively for any shape and "D" is defined as the fractal dimension. The fractal dimension "D" describe the complexity of the contour of an object which can be more practically called roughness. Sphericity "β", on the other hand is used with fractal dimension "D", to describe the shape of the platelets formed [7] [10]. It can be expressed as:

$$\beta = 4\pi AT/P^2 \qquad (0 < \beta <1 \text{ and } 1 < D < 2) \qquad \text{……………} (2)$$

From the equations above:

$$\beta = (4\Pi a_T/P^2)\, \delta^{2(1-D)} (0 < \beta < 1 \text{ and } 1 < D < 2) \qquad \text{………….}(3)$$

where "A_T" is the total platelet area. When β = 1 and D = 1, a perfect circular shape is formed by the platelet in the microstructure. As β decreases, the shapes become more elongated showing a departure from perfect sphere.

An interactive MatLab program was developed to obtain the numerical values of the fractal dimension "D" and the sphericity "β". In this work, the box counting method was used with a counter incorporated into the program and the small boxes or pixels occupied by the platelets outlines were counted. In all, four pixels (2×2 pixels, 4×4 pixels, 8×8 pixels and 16×16 pixels) and four grid sizes (200×200, 100×100, 50×50 and 25×25) were selected. The selections were made for better resolution and to obtain accurate results. The spatial point pattern method (Fig. 3) and the spheroidization platelet distribution map (Fig. 4) [12] were used to describe the patterns displayed by the platelets after heat treatment. The spheroidization platelet distribution map can further be used to identify the shapes of the spheroid platelets and their dispersion from regular shapes.

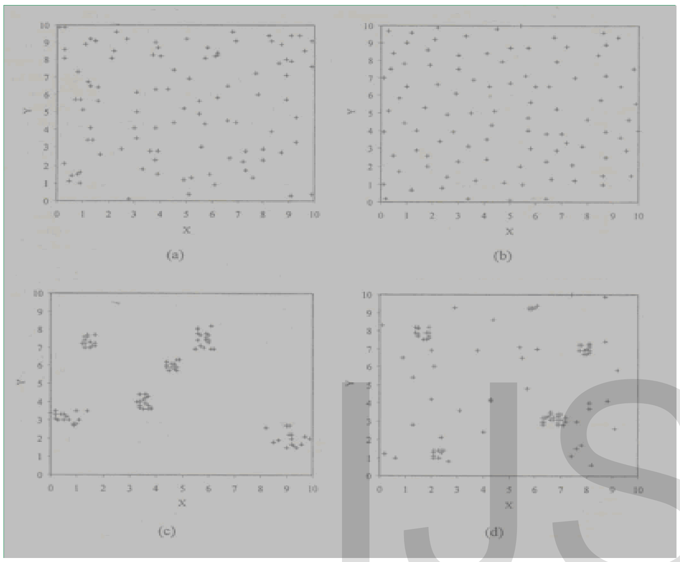

Fig. 3: The four common types of spatial point patterns (a) random; (b) regular;(c) clustered; and (d) clustered superimposed on random background.

Fig. 4: Illustration of development of irregular shape based upon Euclidean circle or rectangle.

3.RESULT AND DISCUSSION

A typical result of such a fractal analysis for the spheroidization heat treatment samples for 40%-cold-rolled Fine Pearlite (FP) specimens annealed for 1hr and 16 hrs, and the 30%-cold-rolled Coarse Pearlite (CP) samples annealed for 1hr and 16hrs respectively were shown in Fig. 5 (a-d). Each point in the map corresponds to an individual spheroid platelet described by two numbers, Sphericity "β" and Roughness "D". It is expected that a higher value of "D" indicates a more complex spheroid platelet perimeter shape.

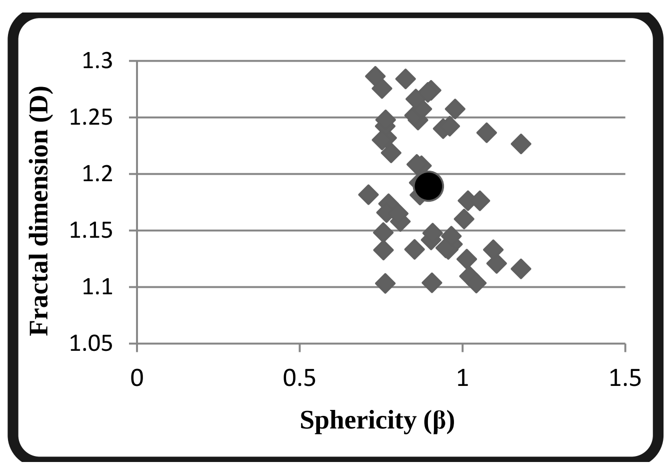

Fig. 5a: Spheroidization of platelet distribution map for 40% cold-rolled sample for 1hr at 750 ^{o}C

Presented in Fig. 5a, is the spheroidization platelet distribution map for 40% cold-rolled sample for 1hr at 720 ^{o}C. Weighted average sphericity and fractal dimension β =

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0.8951 and D =1.1891 were obtained. The platelets are said to be fairly randomly distributed. The Roughness values lie between 1.1031 < D < 1.2863 which is an indication that the material can sustain a high load in tension for a long period of time prior to failure. However, heat treatment of the same sample for high period of time Fig. 5b, does not favor the distribution of spheroidization as the platelets become more clustered.

Presented in Fig. 5c is the spheroidization platelet distribution map for 30% cold-rolled sample for 1hr at 720 ^{o}C. Using spatial point data analysis, the platelets are said to be clustered superimposed on random background with weighted average sphericity and fractal dimension β = 0.775 and D = 1.1449. Also, shown in Figure 5d is the spheroidization platelet distribution map for 30% cold-rolled sample for 16hr at 720 ^{o}C. Clustering of the spheroidized cementite platelets was observed.

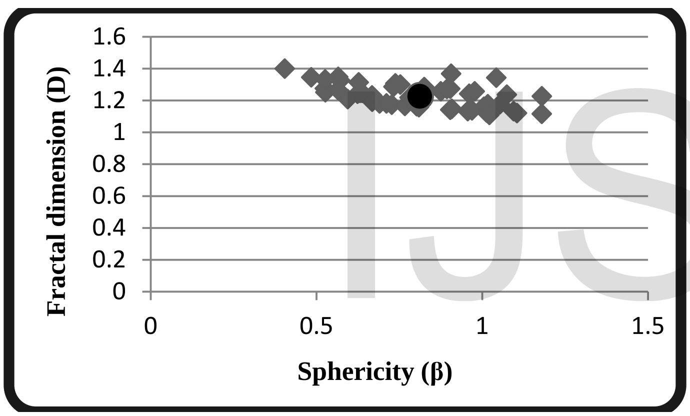

Figure 5b: Spheroidization of platelet distribution map for 40% cold-rolled sample for 16hr at 750 ^{o}C

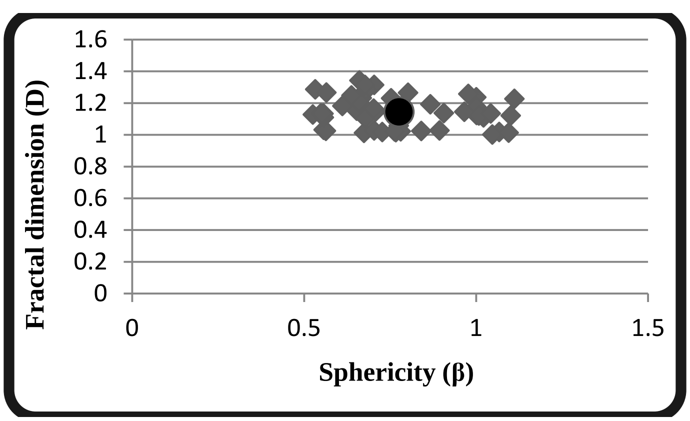

Figure 5c: Platelet distribution map for sample cold-rolled for 1hr at 750 ^{o}C

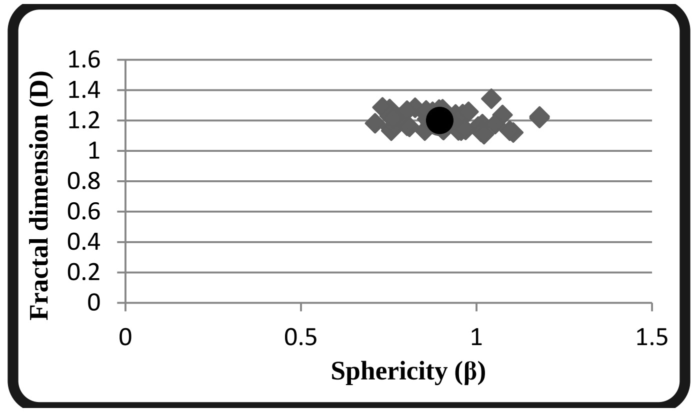

Figure 5d: Spheroidization of platelet distribution map for 30% cold-rolled sample for 1hr at 750 ^{o}C

4. CONCLUSION

Fractal analysis can be applied to the spheroidization measurement to describe the shapes of the platelets formed in high carbon steel after heat treatment using two dimensionless parameters, Roughness "D" and Sphericity "β". With 40% cold-rolled annealed for 1hr, the sphericity value was tending towards being the perfect shape. It is evidence that increased heat treatment time might result in coarsening of carbide particles dominated over fragmentation. Thus, further work can be carried out on 40% cold-rolled samples with heat treatment period of less than 8hrs to ascertain the optimum spheroid platelets shapes.

Acknowledgments

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I. Lateef Mudashiru
Senior Lecturer
Ladoke Akintola University of Technology,Ogbomosho, Oyo State, Nigeria. Department of Mechanical Engineering.
E-mail: lomudashiru@lautech.edu.ng

II. Sunday Adetola
Lecturer I
Ladoke Akintola University of Technology,Ogbomosho, Oyo State, Nigeria. Department of Mechanical Engineering
E-mail: soadetola@lautech.edu.ng

III.Emmanuel Olafimihan
Senior Lecturer