CHARACTERISTIC GRAIN SIZE: PART II
MEASURING PRINCIPLES*

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Abstract The principles for measuring characteristic grain sizes of materials, such as fully-dense single phase materials, porous materials and materials with isolated second phase particles, are developed on the basis of its definition associated closely with the surface area per unit volume, Sv, of grain. The focus of the measuring principles of the characteristic grain size is put on determining Sv of grains. Unlike the measurement of average grain size commonly used, G, correcting factors such as grain shape and grain size distribution factors, will not be applied to the determination of the characteristic grain size, Go, due to its unique geometric meaning and the measure precision of Sv being guaranteed by quantitative stereological technique and gas adsorption method. The measurement of Go can be directly carried out on the polished and etched cross section of materials, similar to the measurement of the average grain size using the Heyn intercept method.

Key words characteristic grain size; measuring principle; gas adsorption technique; porous material; fully-dense single phase materials; material with isolated second-phase particles

Grain size is one of the most important material microstructural parameters due to its significance in material processing and quality control. It is well known that the currently-used methods for grain size measurements are mainly based upon the information from polished and etched cross sections of materials although grains possess three-dimensional features. To relate these data obtained from the two dimensional planes of material microstructure to the sizes of grains, some simplified assumptions about grain shape are required. In most cases, grain shape is assumed to be spheric. But for the requirement of cell space-filling, grains are mainly in polygon form. However, as described in previous paper, the characteristic grain size not only indicates the size of grain, but also considers the effect of grain shape. According to its definition, the characteristic grain size relies on surface area per unit volume of grain, Sv, which can be determined exactly on the cross sections of materials with quantitative stereological technique. Therefore, relatively precise values of grain size would be obtained. In this paper, we will give an emphasis on the measuring principles for determining the characteristic grain sizes of fully-dense single phase materials, porous materials and the materials with isolated second-phase particles.

1 MEASURING PRINCIPLES

As mentioned above, Sv, the ratio of the surface area to the volume of grain, or the surface area per unit volume of grain, can be measured out directly on polished and etched cross sections of materials without introducing any assumptions about grain shape. According to the definition of characteristic grain size, Go is given by
the definition of characteristic grain size, \(G_c\), is given by
\[
G_c = \frac{6}{S_g} \quad (1)
\]

Therefore, in the subsequent sections, emphasis will be put on the determination of \(S_g\).

For fully-dense single phase materials, the value of \(S_g\) can be obtained directly by the quantitative stereological technique as
\[
(S_g)^r = 2(N_r) \quad (2)
\]

Where \((S_g)^r\) is the ratio of the surface area to the volume of grain, and \((N_r)\) is the number of interceptions of grain per unit length of test line. Consequently, the expression of \(G_c\) in this case is given by
\[
G_c = \frac{3}{(N_r)^r} \quad (3)
\]
or
\[
G_c = \frac{3}{(L_m)^r} \quad (4)
\]

where \((L_m)^r\) is the average linear intercept length of grains. These two expressions are available for calculating the characteristic grain size of fully-dense single phase materials. However, in the cases of porous materials and materials containing isolated second-phase particles (oxide dispersion strengthened alloys and precipitation hardened alloys are taken for examples), the expressions (3) and (4) are invalid for calculating \(G_c\) values of the matrices because \((S_g)^r\) is not equal to \(S_g\). In what follows, we will first focus on the \(G_c\) of porous materials. Similarly, we have
\[
(S_g)^F = 2(N_L)^F \quad (5)
\]

where the superscript \(F\) represents the features including grains and pores intercepted by the test line, \((S_g)^F\) is the ratio of the total interface area to the test volume, \((N_L)^F\) is the number of the interceptions of the features per unit length of test line. If the pores in materials are interconnected, the grain-pore interface area or free surface area of grains per unit test volumes, \((S_g)^p\), can be determined with the gas adsorption technique as
\[
(S_g)^p = d \cdot S_m \quad (6)
\]

where \((S_g)^p\) and \(S_m\) are the surface areas per unit volume and per unit mass of the porous materials, respectively, and \(d\) is the apparent density. The grain boundary area per unit test volume, \((S_g)^b\) is
\[
(S_g)^b = (S_g)^F - (S_g)^p \quad (7)
\]

Since each grain boundary is shared by two grains, the total surface areas of all the grains is expressed as
\[
S_T = (S_g)^F V_s + 2(S_g)^p V_s = [2(S_g)^F - S_m d] V_s \quad (8)
\]

where \(V_s\) is the total test volume. If the total volume of all the grains is \(V_m\), we obtain
\[
(S_g)^F = S_T/V_m = \frac{[2(S_g)^F - dS_m]}{\rho} \quad (9)
\]

where \(\rho = V_m/V_s\). Combining this expression with the Eqs. (1) and (5), gives
\[
G_c = \frac{6\rho}{[2(N_L)^F - dS_m]} \quad (10)
\]

This expression is available for the porous materials, whose porosity is larger than 15%. As the porosity is less than 15%, in which most or some of the pores become isolated or closed, the gas adsorption technique is not effective any more and in this case, the expression of \((S_g)^p\) is
\[
(S_g)^p = 4(N_L)^p \quad (11)
\]

where \((N_L)^p\) is the number of interceptions of pores per unit length of test line. Accordingly, the characteristic grain size \(G_c\) is written as
\[
G_c = \frac{3\rho}{[2(N_L)^p - 2(N_L)^p]} \quad (12)
\]

The Eqs. (10) and (12) are useful for the determination of the characteristic grain size of porous materials if they are adopted jointly. However, another measuring method of determining the \(G_c\) values of porous materials is based on the information of the polished and etched cross sections of materials from image analyser. According to this method, if a specific programme is designed for summing up the intercept length of the \(N\) testing grains, denoting \(L_T\), the mean linear intercept length is \((L_m)^F\) and \(G_c\) is given as
\[
G_c = \frac{3\rho}{[2(N_L)^F - 2(N_L)^F]} \quad (13)
\]

This equation is quite similar to the Eq. (4) in form as we image that the porous materials have not pores, because the pores are excluded during the measurement. As for the materials with isolated second-phase particles, the grain size of their matrix is given by the expression similar to that for the porous materials with porosity less than 15%, only \((N_L)^F\) being superseded by \((N_L)^b\), and the expression is
\[
G_c = \frac{3\rho}{[2(N_L)^b - 2(N_L)^b]} \quad (14)
\]

where \((N_L)^b\) is the number of interceptions of the isolated second phase particles per unit length of test line. Similarly, the Eq. (13) is also available in the case of determination of \(G_c\) of matrix of materials containing the isolated second phase particles by means of the image analyser.

2 DISCUSSION

\(S_g\), the ratio of the surface area to the volume of grain is the basis for the measurement of the characteristic grain size, \(G_c\), and can be exactly determined by the Heyn intercept method. In the cases of fully dense single phase materials and materials with isolated second phase particles, contrasted with the determination of average grain size, the measurement of the characteristic grain size is easi-