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Short communication

Stabilization of nanostructured materials using fine inert ceramic particles

S.S. Razavi Tousi [a,*], M.B. Rahaei [a], M.S. Abdi [b], S.K. Sadrnezhaad [a,c]

[a] *Ceramic Department, Materials & Energy Research Center, P.O. Box 31787/316, Karaj, Iran*
[b] *Ceramic Engineering Department, Malayer University, Malayer, Iran*
[c] *Center of Excellence for Advanced Processes of Production and Shaping of Materials, Department of Materials Science and Engineering, Sharif University of Technology, Tehran, Iran*

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Abstract

Modified versions of the Zener drag equation were obtained by evaluating a non-random distribution of incoherent ceramic particles in a nano-crystalline material. Analytical investigation of particle-boundary correlation indicates that the limiting grain size would be proportional to $f_V^{-1/3}$ for f_V larger than 2.96%. The limiting grain size can be obtained by a combination of random and non-random Zener drag pressure in the case of volume fractions smaller than 2.96%.

Keywords: A. Grain growth; B. Grain size; Nanostructures; Fine ceramic particles

1. Introduction

Nanostructured materials are thermodynamically unstable due to the presence of a large fraction of interface boundaries. Stabilization of the fine grained structure is of critical importance if the unique structures and properties of nanostructured materials are to be retrained. The distribution of inert ceramic particles in a nano-crystalline (NC) matrix and thus the effect of Zener drag can be employed as a useful method for stabilization of grain size [1–4]. Experimental investigations reported the marked effect of second phase particles on the stagnation of grain growth in NC materials [5–7]. In spite of its name, Zener never published any paper on this effect and his contribution was made through a personal communication to Cyrile Stanley Smith [8]. However, the effect has become known under Zener's name, and in the last 60 years since its discovery, several extensive modeling and simulation studies have been completed. These studies have focused chiefly on the effects of particle shape, volume fraction, coherency, distribution, particle correlation with the boundary.

Several studies, experimentally [9,10] or theoretically [11–15], have shown that the number of particles correlating with boundaries is much higher than the value estimated using a random approach. The assumption of a random distribution of precipitates at grain boundaries does not seem to be representative of the real materials. Specially in NC matrixs, the presence of a high amount of grain boundary phase causes a non-random distribution of particles. Within the framework of this paper it is our intention to firstly explain the classical Zener relationship and then by means of some changes in the stated assumptions, obtain a modified equation for NC materials.

2. The drag pressure due to a random distribution of particles

For a volume fraction f_V of random distributed spherical particles of radius r, the number of particle per unit volume (N_V) is given by

$$N_V = \frac{3 f_V}{4\pi r^3} \tag{1}$$

The number of particles intersecting unit area of boundary is then

$$N_S = 2rN_V = \frac{3 f_V}{2\pi r^2} \tag{2}$$

The drag pressure caused by the particles on unit area of the boundary is given by

$$P_Z = F \cdot N_S \tag{3}$$

* Corresponding author. Tel.: +98 9151100483; fax: +98 261 6201888.
E-mail address: s.razavitousi@gmail.com (S.S. Razavi Tousi).

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