

Change in relative density of WC-Co cemented carbides in spark plasma sintering process

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Received 19 October 2006; received in revised form 15 May 2007; accepted 18 May 2007

Abstract

The relative density of WC-Co cemented carbides during spark plasma sintering (SPS) was analyzed. Based on the change in displacement of the ram in the SPS system, the relative densities in the sintering process can be achieved at different temperatures. The results indicated that densification of the samples started at near 900°C, the density rapidly reached its maximum at the increasing temperature stage, in which the temperature was lower than the sintering temperature of 1200°C, and most of the densification took place in the stage. Besides, the theoretical values were consistent with the experimental results.

Keywords: spark plasma sintering; relative density; WC-Co; cemented carbides

1. Introduction

WC/Co cemented carbides are widely applied in many fields, such as cutting and drilling tools, because of their unique combination of high strength, high hardness, high toughness, and moderate modulus of elasticity [1-2]. To obtain excellent materials, the most important working procedure is sintering and the key is the research of the cemented carbides. Sintering is the natural tendency of powder particles to weld together when heated to high temperature.

The conventional explanation for the sintering mechanism of WC/Co contains some of the WC dissolving into the cobalt binder phase, migrating and re-precipitating on the surface of the original WC [3]. The final products compose a three-dimensional skeleton of WC grains with cobalt as a binder phase matrix. The increasing density of the alloy is mostly owing to the viscosity flow and the re-composition of WC particles.

Many authors have researched the density of cemented carbides and found an accordant conclusion; that is, the alloy may get its highest density at the early stage of sintering [4-6].

In this article, the displacement of the ram in a SPS system is investigated to estimate the densification process. The

computing result indicates that most of the densification occurs before the appearance of liquid phase, which is proved in the experiments.

2. Computation model of relative density for SPS

SPS is a new rapid sintering technology of high quality, uniform sintered body at lower temperatures, and in shorter periods compared with conventional sintering methods [7]. During the consolidation process, the dimensional changes of powders were monitored through measuring the position of the lower ram in Fig. 1. Fig. 1 shows a sketch map of the SPS process.

During the SPS process, the invariable pressure P acts on the ram. When the temperature is relatively low, the dimension of a powder compact decreases continuously during densification. When the temperature increases during the sintering process, the volume of the sintered body increases slightly resulting in the displacement of the ram.

If M is the mass of the sintered body, V_0 and V_t are the volume of the sample at the sintering time 0 and t , respectively, A is the cross section area of the sample, and s_t is the displacement of the ram at time t , then the density of the

sintered body can be computed as [8]:

$$D_t = \frac{M}{V_t} = \frac{M}{V_0 - As_t} \quad (1)$$

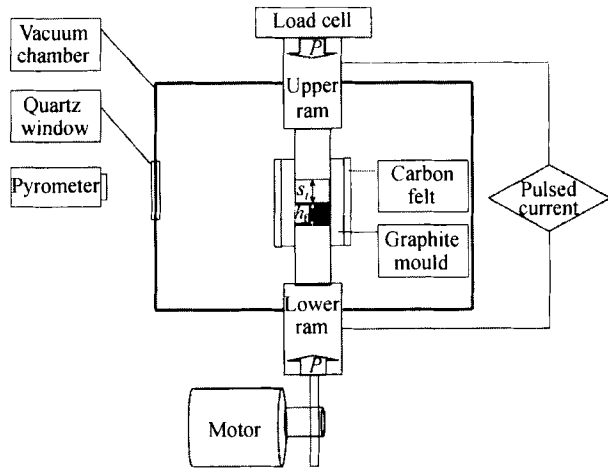


Fig. 1. Sketch map of SPS system.

The original volume of the sample can be obtained as follows:

$$V_0 = A(h_f + s_{\max}) \quad (2)$$

where h_f is the ultimate height of the sintered body after sintering, and $s_{\max}$ is the biggest displacement value in the recording sintering profile.

Thus, the density of the sintered body can be inferred:

$$D_t = \frac{M}{A(h_f + s_{\max} - s_t)} \quad (3)$$

To get the changed tendency of the relative density with the sintering time, the relative density can be denoted as

$$C_t = \frac{D_t}{D_0} = \frac{M}{D_0 A(h_f + s_{\max} - s_t)} \quad (4)$$

where D_0 is the theoretical density; s_t can be gained from the SPS system. From Eq. (4), the relationship amongst the relative density, the sintering time, and the sintering temperature can be gained.

3. Experimental procedure for SPS

Prepared ultrafine WC-11Co, WC-0.3VC-11Co, WC-0.5VC-11Co, WC-0.2Cr₃C₂-11Co and WC-0.4Cr₃C₂-11Co composite powders were consolidated using the SPS system, which was developed by Japan Sumitomo Coal Mining Co. Ltd. The powders were sintered by heat generated through Joule heating and impeded within the powders, which was generated by pulsed current and pressure. Specimens with a diameter of 20 mm and a thickness of 6 mm were densified by the SPS for 5 min at 1200°C under a pressure of 40 MPa in vacuum. The heating rate was maintained as 100°C·min⁻¹.

The consolidation mechanism, which was liquid phase sintering or solid state sintering, was determined by the dimensional changes according to processing temperature as shown in Fig. 1. The changes of temperature and displacement of the four ultrafine cemented carbide powders during SPS are shown in Fig. 2. During the temperature increasing process, the volume of the sintered body decreased continuously through densification; when the temperature continued to increase, however, the volume of the sintered body slightly increased. The reason was as follows. Based on Ref. [1], Co phase can occur expanded in the liquid phase. When the liquid phase was formed during the SPS, the volume of the sintered body slightly increased due to the larger volume of liquid Co compared to that of solid. If the liquid phase was not formed during the sintering process, the dimension of powder compact decreases continuously by densification. At 1100°C, the volume of the sintered body slightly increased. The reason may be that the temperature was lower than the eutectic temperature of WC-Co, so liquid sintering could not form for the coarse particles, but the ultrafine powder WC particles possessed more surface active and dissolubility in the melt state Co through a higher diffusion speed. This resulted in part liquid sintering. Therefore, the volume of the sintered body slightly increased.

From Fig. 2, for the four kinds of ultrafine composite powders, the displacements of the rams were increased at the lower temperature of 1100°C. During the constant temperature stage, the displacement decreased continuously; that is, the volume of the sintered body increased continuously until the end of sintering. Therefore, the density computation only considered the ascending process of the displacement.

4. Results and discussion

4.1. Computation of relative density

During the SPS process, according to Eq. (4), the relative density of samples sintered at different temperatures was attained through computation. Fig. 3 shows the relationship between the temperature and the relative density.

From Fig. 3, the variation tendencies of the relative density were identical for the mixed powders with different proportions. The density of the WC-Co cemented carbide increased with the temperature increasing up to 1100°C. At the beginning of the sintering process, the relative density slightly increased with an increase in temperature. At up to 900°C, densification of the samples started, and the density rapidly reached its maximum at the increasing temperature stage, where the temperature was lower than the sintering temperature of 1200°C. When the sintering was performed

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