# Carbide Grain Growth in Cemented Carbides

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## Abstract

*During sintering of cemented carbides abnormal grain growth is often observed but cannot be understood from the classical LSW-theory. A model based on 2-D nucleation of new crystalline layers and a grain-size distribution function is formulated and the equations are solved numerically. Experimental studies and computer simulations show that the initial grain size distribution has a strong effect on the grain growth behavior. For example, a fine-grained powder can grow past a coarser powder.*

**Keywords** : **Cemented carbide, grain growth, abnormal grain growth, modeling**

## 1. Introduction

During liquid-phase sintering of cemented carbides the average grain size increases by means of coarsening or Ostwald ripening, i.e. large grains grow on the expense of small grains. The classical theoretical analysis of Ostwald ripening was presented by Lifshitz, Slyosov and Wagner (LSW) and the two rate limiting cases, long-range diffusion and interfacial reactions were suggested [1,2]. In the LSW-theory the normalized particle size distribution is stationary and the only change is the increase in average size in time.

Cemented carbides often show a faceted shape which eventually may lead to abnormal grain growth, i.e. a few large grains consume all the small grains. This phenomenon cannot be explained by the LSW-theory.

Grains that are faceted have a singular interface and in the lack of kink and ledge sites a significant energy barrier is needed for atom attachment on the particle surface and the coarsening is therefore controlled by interfacial reactions. Ledge-generating sources as 2-dimensional nucleation of atomic planes or surface defects are necessary for grain growth [3,4,5,6].

## 2. Modeling

A model based on interfacial control by means of a "pill-box" model for nucleation of growth- and shrinkage ledges is implemented in the MatLab environment. If the average carbide grain size is $\bar{r}$ a carbide particle of size $r > \bar{r}$ grows according to:

$$\frac{dr}{dt} = A \exp\left( \frac{-\sigma_d^2 \pi h}{2\sigma_p \left( \frac{1}{\bar{r}} - \frac{1}{r} \right) kT} \right) \qquad (1)$$

The same equation may be used for a shrinking particle, $r < \bar{r}$, if we assume that nucleation of pits is rate controlling:

$$\frac{dr}{dt} = -A \exp\left( \frac{\sigma_d^2 \pi h}{2\sigma_p \left( \frac{1}{\bar{r}} - \frac{1}{r} \right) kT} \right) \qquad (2)$$

The size distribution function $f(r,t)$ obeys the conservation law:

$$\frac{\partial f}{\partial t} + \frac{\partial}{\partial r}\left( \frac{dr}{dt} \cdot f(r,t) \right) = 0 \qquad (3)$$

## 3. Experimental and Results

Samples with a composition of WC-10%Co with WC-powder sizes of 0.25, 0.9 and 2 µm were prepared. The compacts were sintered for a number of different time- and temperature cycles. The samples were polished with usual metallographic techniques and etched with Murakami solution to reveal the grain boundaries. Images for grain size measurements were taken in the scanning electron microscope (SEM) and the magnification was adjusted for every sample to obtain a reasonable number of grains across the field. The equivalent circle diameter was measured with an image analysis program (Leica Qwin) and more than 2000 grains were examined on randomly set fields.

Figure 1 and 2 shows the growth behavior for the three powders. It is seen that a fine-grained powder can result in a coarser structure after sintering than a coarse-grained powder.

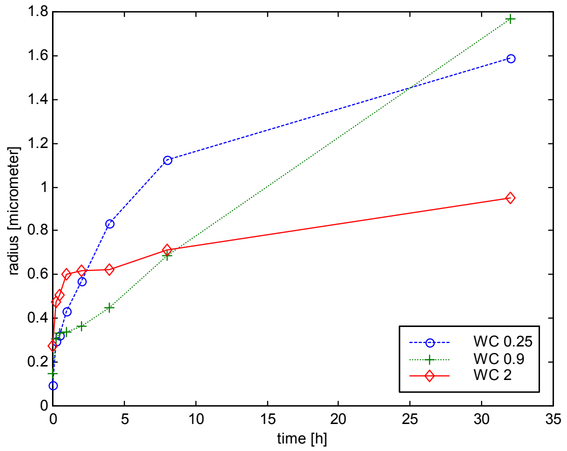

**Fig. 1. Average grain radius as function of sintering time when sintering at 1430 ºC.**

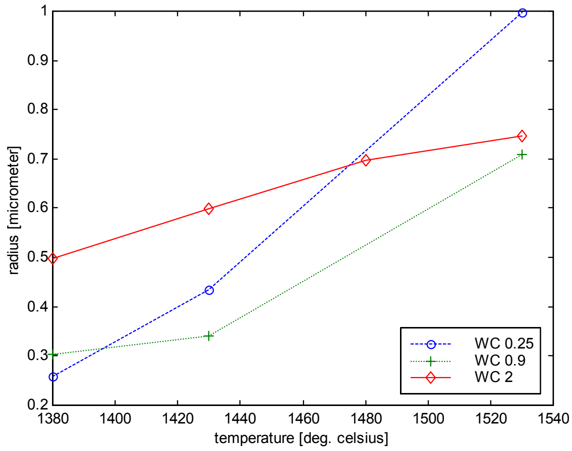

**Fig. 2. Average grain radius as function of sintering temperature when sintered 1 h.**

Computer simulations have also been performed and compared with the experimental results. Figure 3 shows the coarsest powders fit to the experimental data when sintering at 1430 ºC and it is seen that the agreement is satisfactory. Also the effect of adding a small fraction coarse grains or a fine-grain tail has been looked at, figure 3. It is seen that a fraction of large grains dramatically increases the average grain size. A fine-grain tail only slightly increases the growth rate for short times.

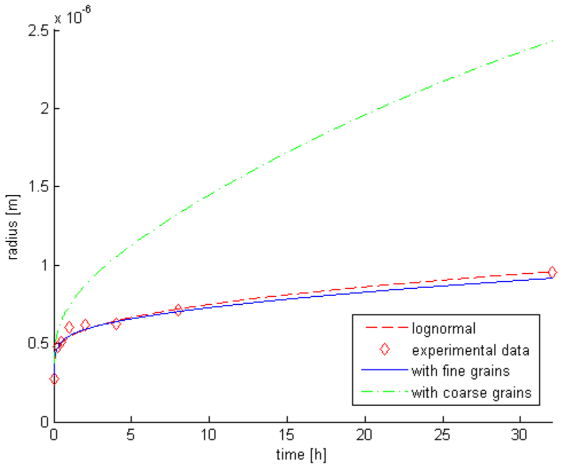

**Fig. 3. Simulated average grain size as function of time for the coarsest powder sintered at 1430 ºC. Fraction coarse grains 0.005 and fraction fine grains 0.4.**

## 4. Summary

The grain growth behavior is strongly influenced by the initial grain size distribution and a more fine-grained powder can grow past a coarser powder. A small fraction of large grains increases the average grain size dramatically due to abnormal grain growth Both an increase in sintering time and sintering temperature has the same effect on the growth behavior.

## 5. References

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