SPS densification kinetics of TiAl determined from powder constitutive relations

J.P. Monchoux[1*], Z. Trzaska[2], A. Couret[1], L. Durand[1], T. Voisin[3], M. Thomas[4]

1 CEMES-CNRS UPR 8011, Université de Toulouse, 31055, France; 2 LSMP-CNRS UPR 3407, Université de Paris 13, Villetaneuse, 93430, France; 3 Lawrence Livermore National Laboratory, CA 94550, USA; 4 ONERA, Châtillon, 92322, France.

**Corresponding author: monchoux@cemes.fr*

Highlights

- Activation parameters for densification have been determined.
- Influence of microstructure on activation parameters is shown.
- SPS densification kinetics is well reproduced.

1. Introduction

The spark plasma sintering (SPS) method becomes increasingly employed to elaborate materials in complex geometries [1-3]. To perform this efficiently with metals, which densify by plastic deformation of the powder particles at high temperatures, it appears more and more important to accurately characterize the mechanical behaviour of the powder, by a precise evaluation of the activation parameters [4]. Here, we have determined these data in the case of TiAl by two methods: (i) compression at high temperatures of bulk samples, and (ii) isothermal densification of a powder by SPS. We show the influence of the deformation microstructure of the alloy (characterized by transmission electron microscopy, TEM) on these parameters, and how it impacts the anisothermal densification by SPS (100°C/min), calculated from simple literature models.

2. Methods

The compression and SPS experiments have been carried out on recrystallized bulk samples and powder, respectively, both exhibiting initially a near-gamma microstructure of 4 µm in grain size. This insured that the initial microstructures of the powder particles and of the bulk samples were as close as possible. Compression experiments have been carried out for deformation rates varying from 2×10^{-4} s^{-1} to 2×10^{-2} s^{-1}, and for temperatures between 900°C and 1080°C. SPS isothermal densification curves have been performed for uniaxial pressures between 25 MPa and 75 MPa, and for temperatures 865°C and 969°C. The activation parameters for the SPS experiments have been determined using the Arzt and Helle model [5,6].

3. Results and discussion

Significant differences of activation parameters between TiAl bulk and powder have been obtained (Fig. 1a). Activation energies were close (300 kJ/mol and 308 ± 20 kJ/mol, respectively), but stress exponent (slope of the curves in Fig. 1a) quite different ($n = 3.2\text{-}5.5$ and $n = 1.9 \pm 0.3$, respectively). The reason for this discrepancy is not yet understood, but it can be noted that literature data obtained with TiAl alloys of different microstructures exhibit large scattering, pointing on a strong influence of microstructure on the kinetics. However, data obtained with a close initial microstructure (Ti-48Al-2Nb-2Cr, near-gamma [4]) and our results are strongly divergent. It is then highly necessary to study accurately the microscopic mechanisms to account for the macroscopic behavior. TEM studies showed that the microscopic plasticity mechanisms were controlled by dislocation climb, which elementary mechanism is Al bulk diffusion. The activation energy of this mechanism (360 kJ/mol [7]) accounts wells for the values obtained in our study. Moreover, the observation of recrystallization processes (Fig. 1b) is coherent with the superplastic behavior of the alloy. Finally, using the activation energy of the powder, anisothermal densification kinetics have been accurately reproduced in different conditions (20°C/ and 100°C/min).

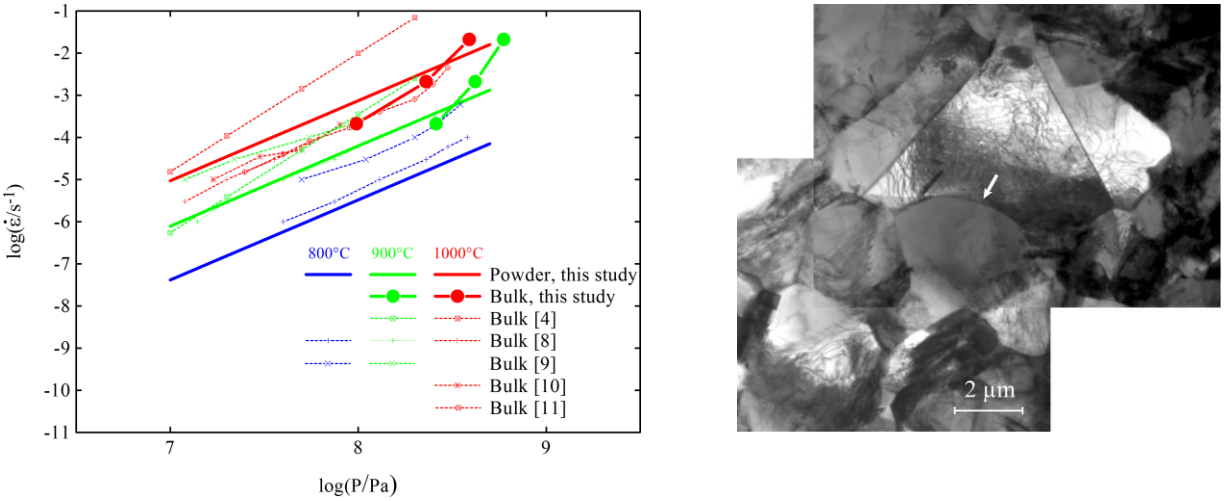

Figure 1. (a) Strain rate-stress relations for TiAl powder and bulk, compared with literature data. (b) TEM image of the microstructure of a TiAl bulk sample deformed of 20 % at 900°C. The arrow shows a recrystallization nucleus, which grain boundary moves towards the strongly deformed region situated above.

4. Conclusions

Accurate mastering of the microstructure is necessary to determine the pertinent densification activation parameters. Even in this case, however, significant discrepancies may occur, if the latter are determined from bulk specimens. Better results seem to be obtained with activation parameters obtained from densification of powders.

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