PREDICTION OF HIP PARAMETERS

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INTRODUCTION

During hot isostatic pressing (HIPping) plastic flow, power law creep, NH-creep, Coble creep, grain boundary diffusion, bulk diffusion /1/ and grain boundary sliding /2/ may contribute to densification. Which of these mechanisms is dominating the shrinkage and neck growth rates depends on a number of parameters connected to the powder (size, grain size, current geometry, bulk material properties, interface properties) and to parameters connected to processing (pressure, temperature, time). To predict HIP parameters required for densification of a particular material HIP diagrams have been developed some years ago /3,4/. These theoretical predictions lack of sufficient experimental verification up to now, since most published work on HIPping describes only the sufficient but not the necessary conditions to obtain completely dense material. Very little is known about the reduction of porosity during HIPping itself /5/. In addition the construction of these HIP diagrams requires a variety of material data which are often not available. In this paper a method is described which provides some of the required material data and which allows the prediction of the HIP behaviour at lower densities.

EXPERIMENTS

Glass containers were filled with powders superior sphericity and a narrow size distribution (range < 25µm). After evacuating to 10^{-6} bar the containers were sealed and HIPped. For comparison, single powder spheres were uniaxially deformed under well controlled load as shown schematically in fig.1. For the calculation it was assumed that the material of the deformation zones (dark areas) distributes homogeneously on the free surface of the particles and that the radius of the particle R is increasing during deformation. The radius of the contact area x is connected to the reduction of the distance between the particle center and the contact area by

$$(1) \qquad R = \sqrt{\left(\frac{2}{3} R_o^3 + \frac{(R_o-h)^3}{3}\right) \frac{1}{R_o-h}}$$

$$(2) \qquad x = \sqrt{2|h+(R-R_o)|R-|h+(R-R_o)|^2}$$

The resulting stress at the contact zone is

$$\tau = \frac{f}{\pi x^2} \qquad (3)$$

The deformation of the single sphere between two parallel plates was transformed into an equivalent densification during HIPping by taking into account the increasing number of contacts per particle during densification /6/ by

$$D = \frac{D_o}{1 - \left(\frac{(7,3+8,573\frac{x^2}{R_o^2})h^2 (3R_o - h)0.32}{3R_o^3} \right)} \qquad (4)$$

The relation between HIP pressure p and the force on the single particle f is calculated with

$$p = \frac{ZD}{4\pi R_o^2} f \qquad (5)$$

(z = Coordination number)

RESULTS AND DISCUSSION

Figure 2a and b shows microstructures of C1018 after HIPping at 1000°C at 50MPa for 20min. Figure 2b shows a sample made of powders which were coated by thin layers of fine Al_2O_3 particles before HIPping. The presence of the inert fine particles at the grain boundaries in the contact areas partly suppresses grain boundary diffusion. As a consequence, pores with sharp edges remained during HIPping. Since similar sharp pore edges were observed in the sample made of uncoated powder it is concluded that densification and pore rounding by grain boundary and surface diffusion was also negligible during HIPping of these samples. Figure 2c and d shows microstructures of C1018 after HIPping for 10 and 20min at 20MPa. The densities were 0.86 and 0.88, respectively. The sharp edges of the pores in both samples indicate power law creep to be the dominant densification mechanism. The known yield strength values disclose plastic flow.

The deformation experiments with a single spherical particle showed the expected dependence of the deformation behavior on the particle size (fig.3). The influence of particle size must not be confused with the pronounced influence of the grain size in the polycrystalline particle on deformation (fig.4). Spherical Cu particles of 170µm in diameter were produced with internal grain sizes of 10, 40 and 170µm (single crystal). Grain boundary sliding is thought to result in the pronounced dependency of the deformation rate on grain size. The deformation rate of C1018 at different loads is shown in fig.5. From these diagrams the stress dependency of power-law creep can be determined (creep exponent). It is also possible to obtain the temperature dependency of power-law creep if diagrams for other temperatures are made too. The dashed line indicates the transition from HIP stage I to HIP stage II at a density of 90% /4/.

The agreement of equivalent HIP densities calculated from the deformation of a single sphere and the densities measured from HIP experiments is shown in fig.6. The deformation rates of a Ni based superalloy AP1 showed a certain surprise (fig.7). The plastic deformation during heating up to temperature was much more pronounced when heating up to 1180°C than to heating up to 1120°C. During subsequent isothermal annealing, however, the deformation rate was higher at 1120°C than at 1180°C. The total deformation at 1120 and 1180°C became equal after annealing isothermally for 40min.

CONCLUSIONS

The deformation of a single spherical powder particle provides profound information on the deformation mechanisms and densification rates which are expected during HIPping at densities < 90%. Extrapolation to higher densities is possible. The internal grain size of the powder particles is a major factor determining the densification behaviour during HIPping.

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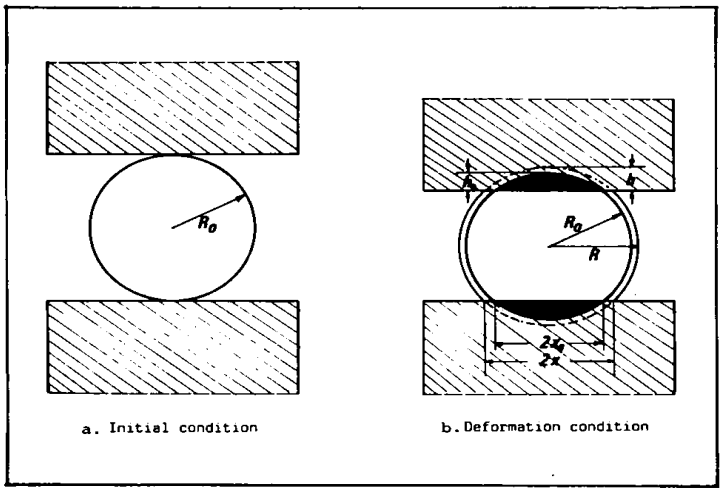

Fig.1: Deformation of a single sphere between two parallel plates.

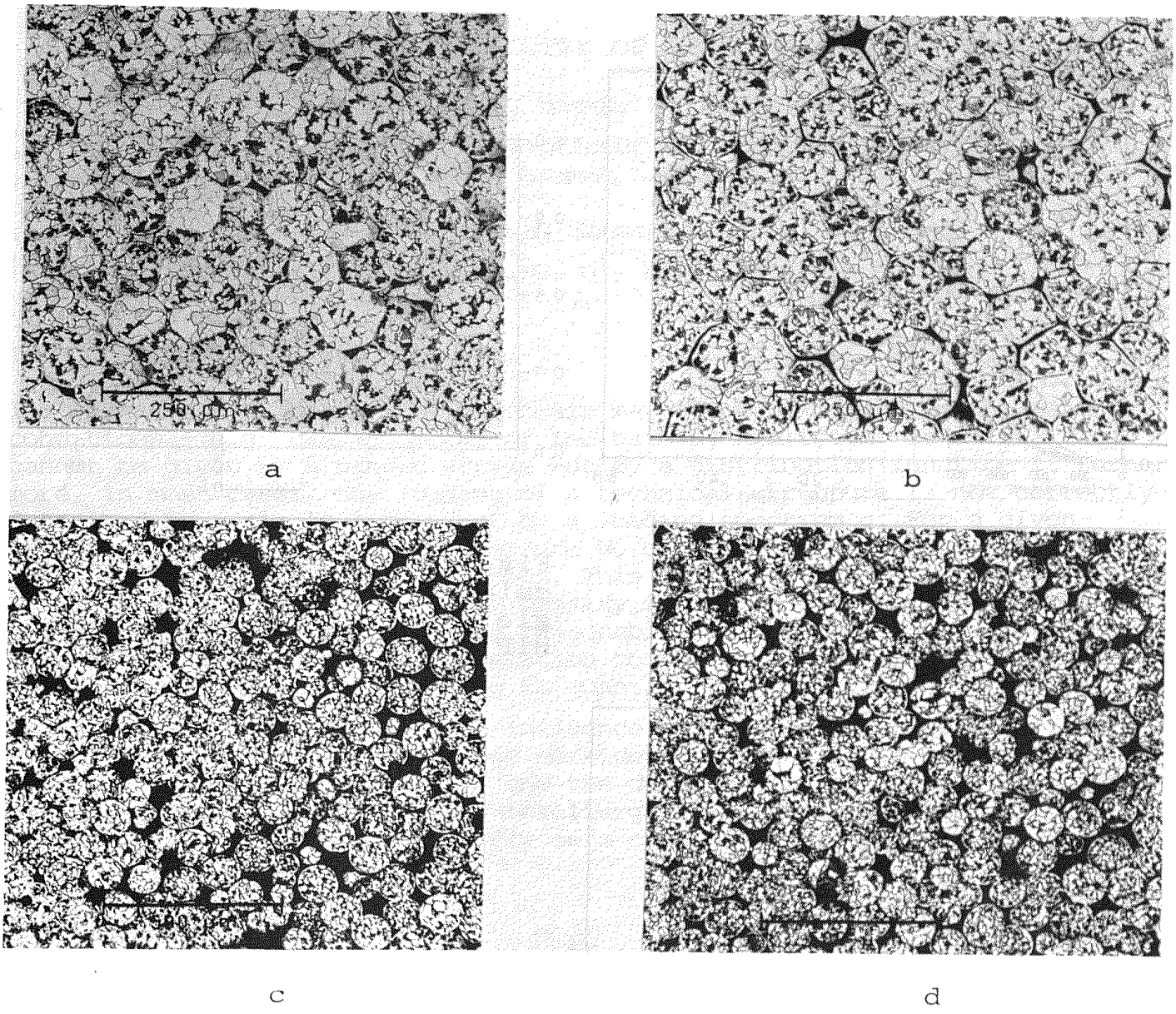

Fig.2a-d: Microstructure of C1018 after HIPping at 1000°C, a.)50MPa, 20min. b.)50MPa,20min.,Al_2O_3 coated c.)20MPa, 10min. d.)20MPa, 20min.

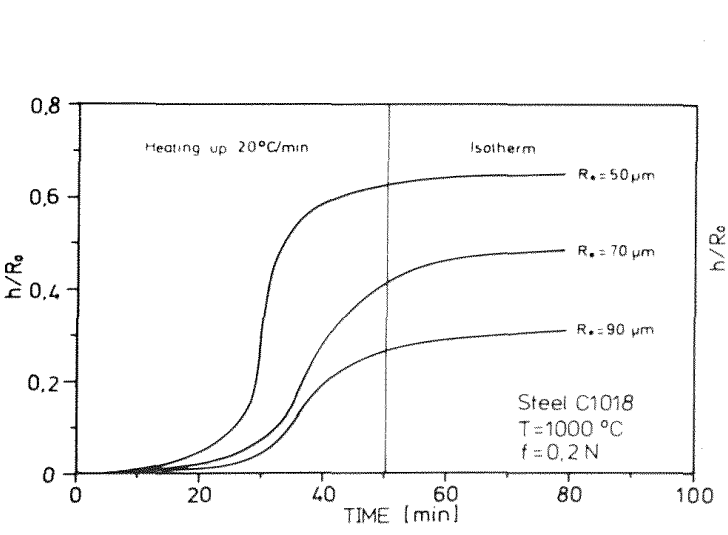

Fig.3: The influence of particle size on the deformation rate.

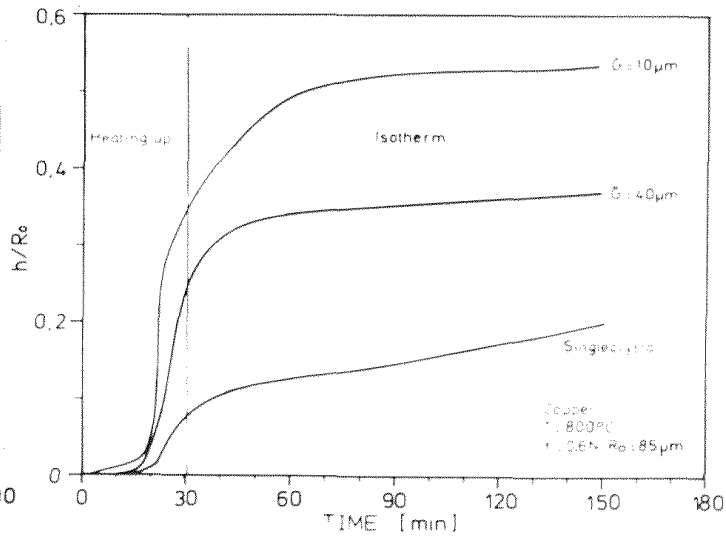

Fig.4: The influence of grain size on the deformation rate.

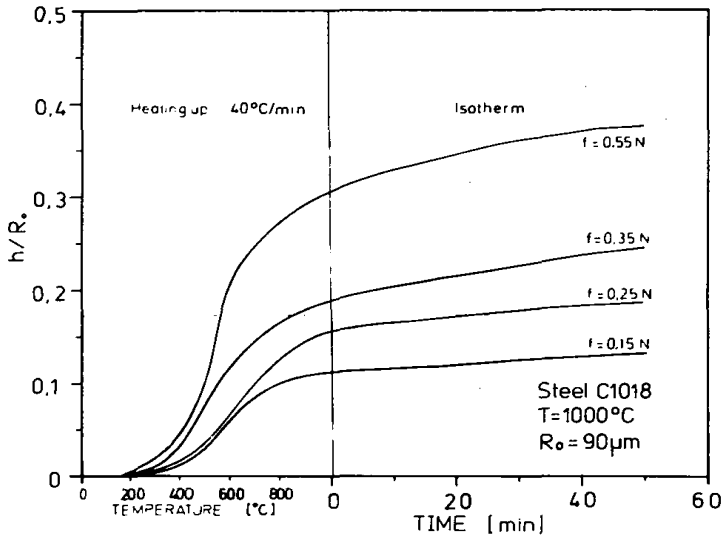

Fig.5: Deformation of spheres with different loads.

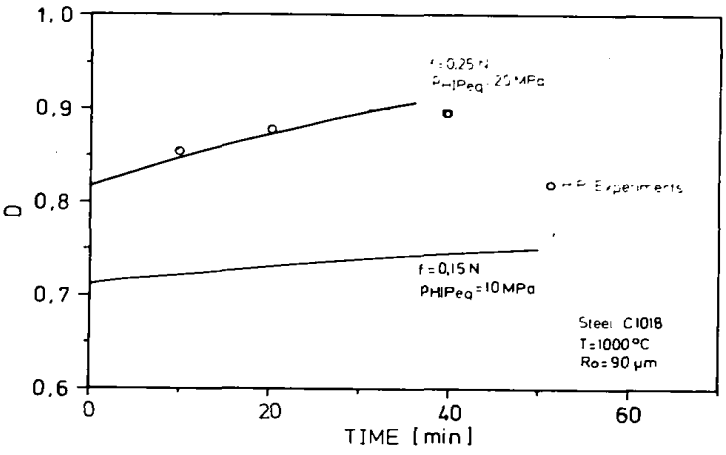

Fig.6: Comparison of calculated densities from single sphere deformation with HIP densities.

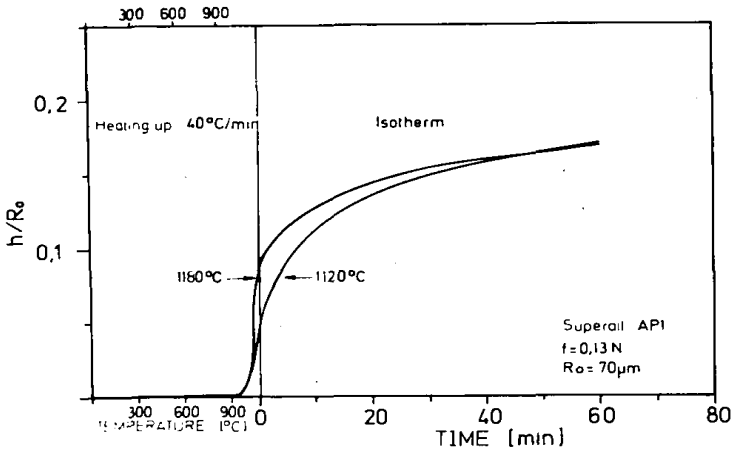

Fig.7: Deformation behaviour of AP1 single spheres.