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Densification mechanisms made during creep techniques applied to the hot isostatic pressing

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Abstract

Hot isostatic compression involves the simultaneous application of pressure and elevated temperature to materials. The pressure applied, usually by a gas, is isostatic because it's developed in a suitable pressurized vessel by a fluid. Therefore in principle no alteration in component geometry occurs. Under these conditions of heat and pressure, internal pores or defects within a solid body or a powder compact collapse and weld up. Encapsulated powder and sintered components densify easily and faster than due to sintering alone. Therefore HIP is today used for a lot of applications, like upgrading castings (removing shrinkage pores in interdendritic space), densifying pre-sintered components, consolidation of powders and interfacial bonding.

The paper presents some technical data regarding to densifying mechanism made by different creep techniques.

Key words: HIP, compression mechanism, full density, creep.

1. Introduction

Creep can occur either by the process of diffusion, or through propagation of crystal defects, known as intracrystalline slip. There are a number of scenarios for creep such as:

• Creep by diffusion-controlled dislocation climb occurs when obstacles are overcome by climb of edge dislocation from one to another of a set of, parallel, glide planes. Since climb requires the removal or addition of a row of atoms from the extra half-plane associated with the dislocation, thus we find the process is intertwined with solid-state diffusion, which occurs by exchange of atoms for vacancies in the crystal lattice. We also find that diffusion is proportional to temperature, thus dislocation climb is favoured under high temperature.

• Haper-Dorn creep is a particular case of climb-controlled flow in which dislocation density is stress-independent, for which is only possible at low stresses and therefore lower dislocation densities.

• Creep by cross-slip of screw dislocations occur where obstacles are overcome by thermally activated cross-slip.

• Diffusion creep involves flow which is achieved by migration of vacancies between grains boundaries e.g., grain boundary sliding, fluid phase transport, and pressure solution are particular cases. Diffusion plays a role in dislocation-climb controlled by creep.

The main densification mechanisms during hot isostatic pressing are: plastic yielding, power law creep, densification by diffusion and Nabarro-Herring and Coble creep.

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The paper presents some theoretical data for calculating densification mechanisms during Nabarro-Herring and Coble creep.

2. Nabarro-Herring Creep

We find that at temperatures greater than 60% of the fusion temperature, or melting point, deformation is thought to occur through diffusive mass transfer or creep. Nabarro-Herring creep is a process by which atoms vacancies or defects exchange through the lattice. This form of creep is also known as bulk diffusion.

At high temperatures and low stresses diffusion creep instead of power-law creep becomes the dominating deformation process in the contact zone. The stresses are then of the order $\sigma/G < 10\text{-}4$.

The origin of both mechanisms is stress-directed diffusion motion of vacancies and of atoms. The mechanism is depicted schematically in Fig. 1.

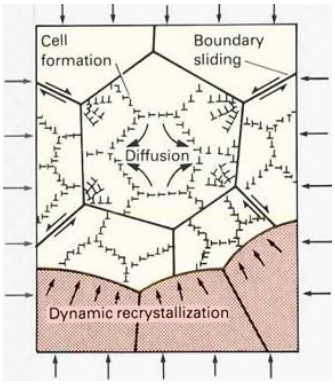

Figure 1. Scheme of atomic transport in Nabarro-Hering creep

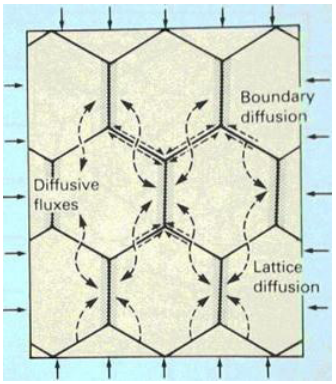

Figure 2. Indication of Coble creep, diffusion along grain boundaries

3. Coble Creep

Coble creep is a process where diffusion occurs along grain boundaries (Fig. 2). Hence we observe that the grain boundaries provide an enhanced diffusivity path for diffusion to occur.

Stress changes the chemical potential of atoms on the surface of the grains in a policrystal which is the subjected to stress. The atoms of the crystal lattice at the side faces are shifted by the tensile stress a little bit apart from each other, where the lattice of the top and bottom surface are a little bit squeezed together.

Thus vacancies from the top and bottom surfaces diffuse to the side faces. This can be expressed mathematically by considering the chemical potential. The chemical potential ($\Delta\mu$) given by the difference between top and bottom due to a tensile stress (s) is:

$$\Delta\mu = s\Omega = \frac{\Delta c}{c_0} k_B T; \tag{1}$$

where: T – temperature,
k_B – Boltzmann constant;
Ω - atomic volume.
s – tensile stress;
c_o – pore concentration;

The concentration difference is:

$$\frac{\Delta c}{c_0} = \frac{s\Omega}{k_B T} \tag{2}$$

The diffusion current density of vacancies can be approximated by:

$$j \cong D\frac{\Delta c}{L/2} = 2Dc_0\frac{s\Omega}{Lk_BT} \tag{3}$$

where: L is the grain size.

The total number of vacancies moving per second is given by:

$$I = L^2 j = 2Dc_0 L\frac{s\Omega}{k_BT} \tag{4}$$

If there is a net flow of vacancies in one direction, there must be an equal net flow of atoms in the opposite direction. Therefore atoms will be removed from the side faces of the grain and deposited on the top and bottom faces. In the course time the grain will change its dimension. The volume removed can be approximately expressed as:

$$L^2\frac{dL}{dt} = I\Omega \tag{5}$$

The strain rate is given by:

$$\dot{\varepsilon} = \frac{1}{L}\frac{dL}{dt} \tag{6}$$

Inserting the expression for the change of grain size yields the equation:

$$\dot{\varepsilon} = \frac{1}{L}\frac{dL}{dt} = \frac{2D\Omega}{L^2\cdot k_BT}s \tag{7}$$

An exact calculation gives:

$$\dot{\varepsilon} = \frac{14D\Omega}{L^2\cdot k_BT}s \tag{8}$$

The difference between Nabarro-Herring creep and Coble creep is simply, that in Coble creep the vacancies or atoms move by grain boundary diffusion. These changes will be expressed with:

$$\dot{\varepsilon} = \frac{14\pi\delta\ D_B\Omega}{L^3\cdot k_BT}s \tag{9}$$

Both equations (8) and (9) can be added up into one expression:

$$\dot{\varepsilon} = \frac{14\Omega}{L^2\cdot k_BT}s\left(D + \frac{\pi\delta\ D_B}{L}\right) \tag{10}$$

If the grain size in the powder material is smaller than the particle size, this deformation adds to power law creep as a way of deforming the contact zone. The same constitutive equation applies as for power law creep, but in this case n = 1 and the constants there must be expressed by those in the NBS - creep equation.

4. Conclusions

It is to note that in Coble Creep, the strain rate dε/dt is proportional to the applied stress; the same relationship is found for Nabarro-Herring Creep. However, the two mechanisms differ in their relationship between the strain rate and grain size.

Commonly are used these relationships to determine which mechanism is dominant in a material - by varying the grain size and measuring how the strain rate is affected and conclude whether Coble Creep or Nabarro-Herring Creep is dominant.

References

Atkinson H.V. & Rickinson B.A. (1991) - Hot isostatic processing, *Adam Hilger Series, Great Britain*, 1991.

Geamăn V. (1995) - Theoretical and experimental researches regarding isostatic processing of poured blanks made from non-ferrous alloys - *Ph.D. Thesis - "Transilvania" University of Braşov*.

Geamăn V. (1996) - Proc. Int. Conf. Hot Isostatic Pressing, Andover – Massachusetts, U.S.A. 221-223.

Ashby M.F. & Jones David R.H. (1980) - Engineering Materials 1: An Introduction to their Properties and Applications. *Pergamon Press*. ISBN 0-08-026138-8.

Frost H.J.; Ashby M.F. (1982) - Deformation-Mechanism Maps: The Plasticity and Creep of Metals and Ceramics. *Pergamon Press*. ISBN 0-08-029337-9.

Turner S. (2001) - Creep of Polymeric Materials. *Oxford: Elsevier Science*. 1813–1817. ISBN 0-08- 043152-6.

Geaman V.; Milosan I. & Stoicanescu M. (2008) - Changes Which Appear In The Ideal Gas Law Under The Temperatures And Pressures Used In Hot Isostatic Processing; *Annals of DAAAM and Proceedings,* 531-532; Conference Title: 19th International Symposium of the Danube-Adria-Association- for-Automation-and-Manufacturing; Trnava SLOVAKIA; ISSN: 1726-9679.