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A Comparison of Strain Deformation Mechanism of Al, Mo, MgO & CaO in Harper-Dorn Creep

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ABSTRACT

Harper-Dorn creep Mechanism is studied for Al, Mo, MgO and CaO. The normalized grain size for each material is compared by using Langdon-Mohamed Type deformation mechanism maps [7]. Al is an F.C.C. metal, Mo is a B.C.C. metal, whereas CaO and MgO are non-metallic oxides, they all have different physical properties and hence this case study has a wide range of spectrum.

Key Terms:Harper-Dorn Creep, Creep deformation mechanism, Creep deformation maps.

1. INTRODUCTION

A new mechanism was developed for Harper-Dorn creep[3], in which the creep rate ε_{HD} is given by

$$\varepsilon_{HD} = A_{HD}\left[\frac{D_1 Gb}{kT}\right](\frac{\sigma}{G}) \qquad (1)$$

Where: D_1 is the diffusion co-efficient, G is the shear modulus, b is the Burger's vector, k is Boltzmann's constant, T is absolute temperature, σ is the normal stress and A_{HD} is a constant given by

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$$A_{HD} = \frac{1.4\pi(\frac{\tau_p}{G})^2}{-\ln(\frac{\tau_p}{G})} \quad (2)$$

Where τ_p is the Peierl's stress,

Since the magnitude of τ_p varies significantly between materials with different crystallographic structures, the effect of structure was investigated by constructing maps [4,5,&7] for Al (typical f.c.c metal), Mo (typical b.c.c. metal), CaO and MgO (typical non-metallic oxides) [2]. The values of τ_p / G, T_m and A_{HD} for different materials are given in Table 1, [3].

Maps were constructed by using the relationships for Nabarro-Herring creep, power law creep at high temperature, and Harper-Dorn creep (figures 1-5). The relationships for Coble creep and power law at low temperature were not included in the analysis. The values of A_1 and 'n' for each material are given in Table 2.

2. DEFORMATION MECHANISMS

The dominant deformation mechanisms occurring at high temperature creep are briefly described as below:

Dislocation Glide

A dislocation moves across a slip plane thereby deforming the crystal by deforming glide. This deformation is observed at stress level below the strength and where there no effects from diffusion.

Dislocation Climb

A pure edge dislocation can move in a direction perpendicular to its length. However it may move perpendicular to the glide plane, by a process known as climb.

Power Law Creep

When the steady-state creep-rate is proportional to some power greater than unity, it is called Power Law Creep. Furthermore power law creep can be divided according to the nature of the transport mechanism for the vacancies. First, there is a high temperature creep and the transport mechanism occurs by lattice diffusion. Second, there is low temperature creep and the transport creep and the mechanism occurs along the dislocation core.

Diffusion Creep

Diffusion creep represents the stress-directed diffusion of vacancies under the action of an imposed stress, and this may either be through the lattice (Nabarro-Herring) [5] or along the grain boundaries (Coble) creep [6]. This leads to strain rate linearly proportional to stress and inversely proportional to the grain size raised to the power of either 2 (N-H creep) or 3 (Coble creep).

Harper-Dorn creep

Harper-Dorn creep [1,8] is a deformation mechanism at high temperature and low stress levels which is different from diffusion creep and power law creep. The precise nature of the physical process appears to occur by dislocation climb under saturated condition.

3. METHOD OF CONTRUCTION

The governing equations used to draw the mechanism are given below:

<u>Mechanism</u> Constitution equations for creep ε (s^{-1})

Nabarro-Herring $$\varepsilon_{NH} = A_{NH} D_o e^{-Q_1/RT} (Gb/kT)(b/d)^2 (\sigma/G) \quad (3)$$

Coble $$\varepsilon_{Co} = A_{Co} D_o e^{-Q_{gb}/RT} (Gb/kT)(b/d)^3 (\sigma/G) \quad (4)$$

Harper-Dorn $$\varepsilon_{HD} = A_{HD} D_{o(1)} e^{-Q_o/RT} (Gb/kT)(\sigma/G) \quad (5)$$

Climb (L. T.) $$\varepsilon_C = 50 A_1 D_{o(c)} e^{-Q_c/RT} (Gb/kT)(\sigma/G)^{n+2} \quad (6)$$

Climb (H.T) $\varepsilon_c = A_1 D_{o(1)} e^{-Q_1/RT}(Gb/kT)(\sigma/G)^n$ (7)

Equations (3) and (5) give values of (d/b) which separates Harper-Dorn and Nabarro-Herring by horizontal line:

$$d/b = (28A_{HD})^{1/2} \quad (8)$$

Equations (5) and (7) give values of σ/G which which separates Harper-Dorn and Power law creep (H. T.)

$$\sigma/G = (A_{HD}/A_1)^{\frac{1}{n+1}} \quad (9)$$

On double logarithmic plot the slope of the line separating Nabarro-Herring and Power law creep is calculated by equation (10)

$$Slope = \frac{1-n}{2} \quad (10)$$

The values of (d/b), σ/G and slopes calculated for each material are listed in Table 3.

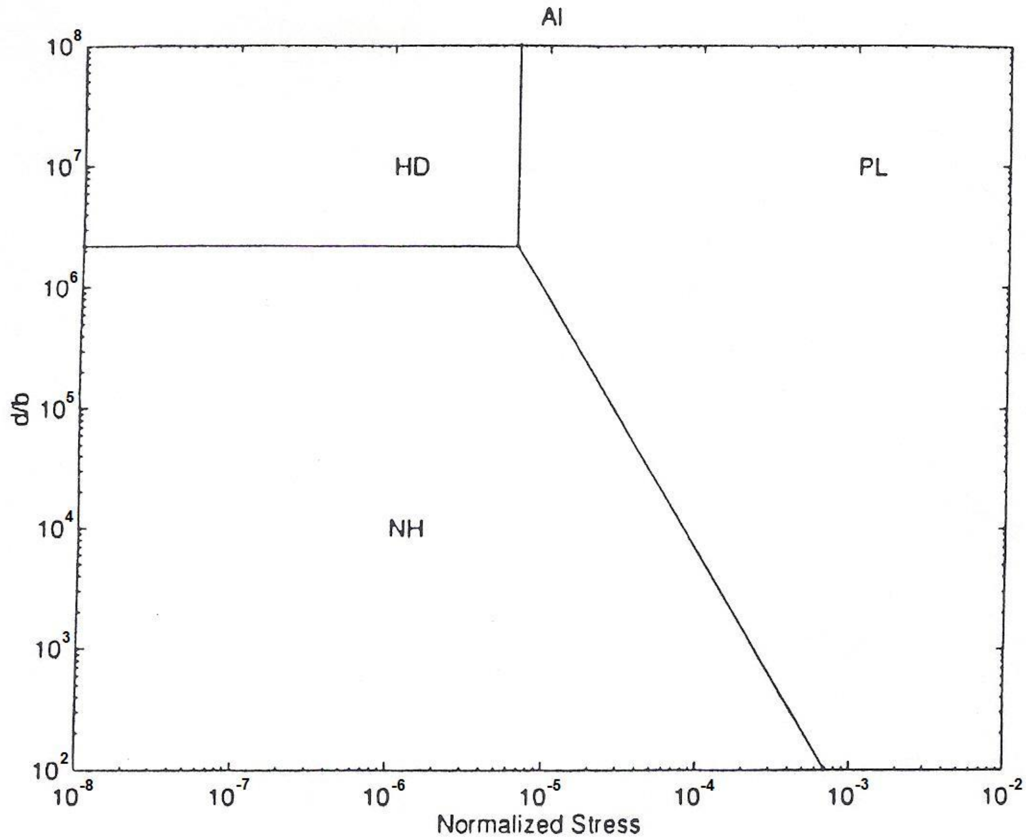

Figure 1: Harper-Dorn creep for Aluminum

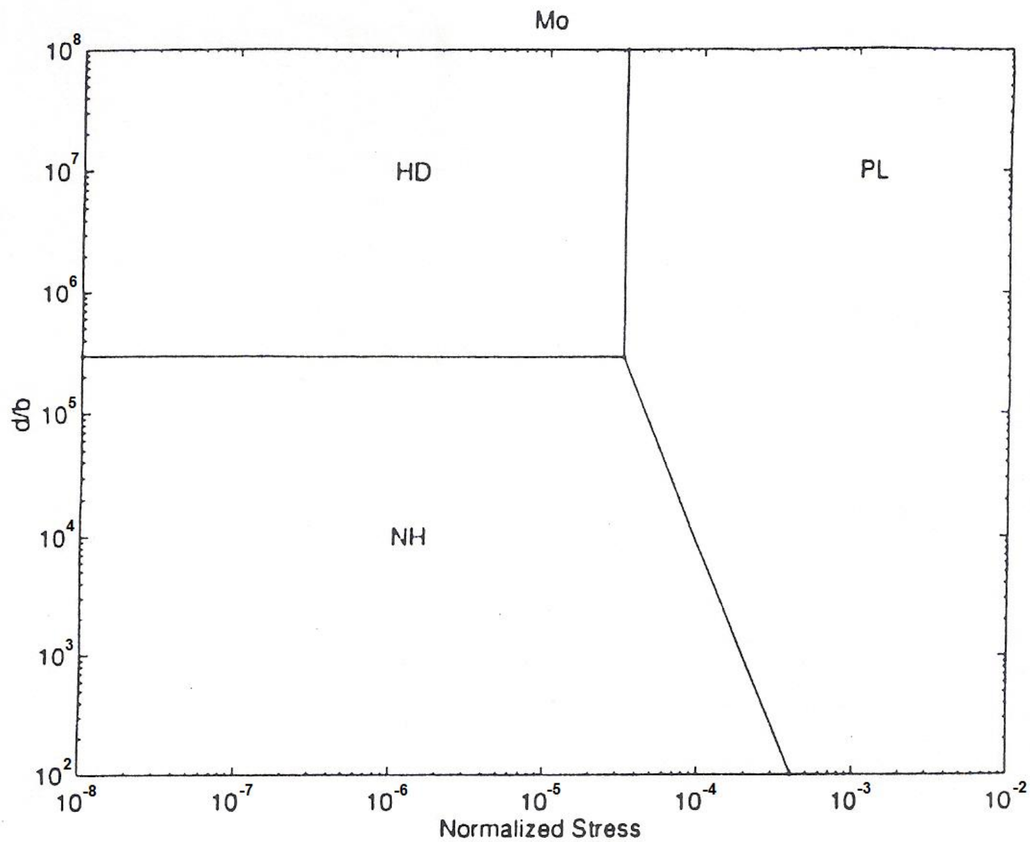

Figure 2: Harper-Dorn creep for Mo

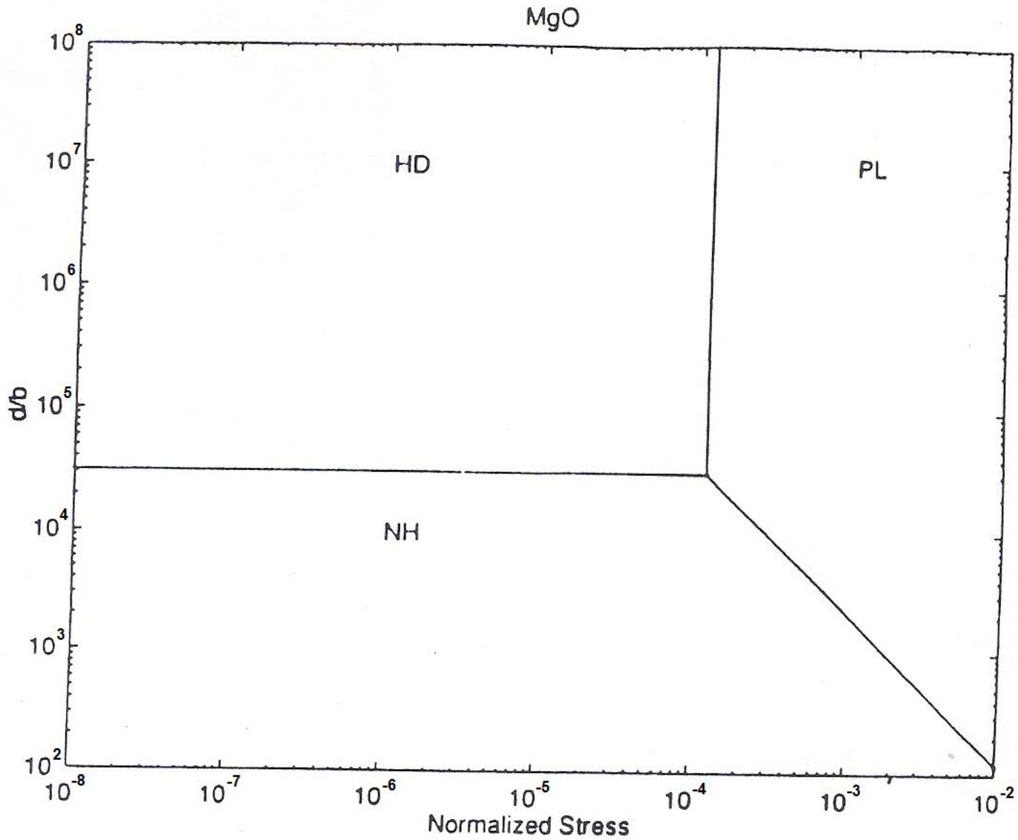

Figure 3: Harper-Dorn creep for MgO

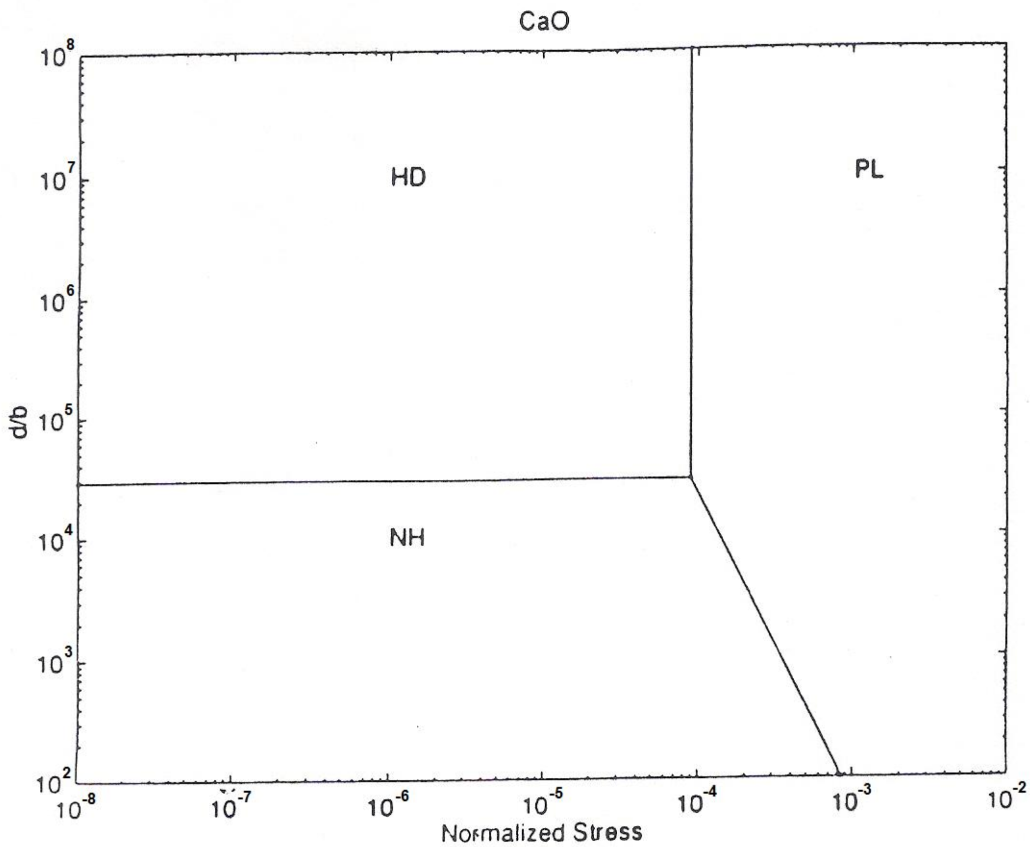

Figure 4: Harper-Dorn creep for CaO

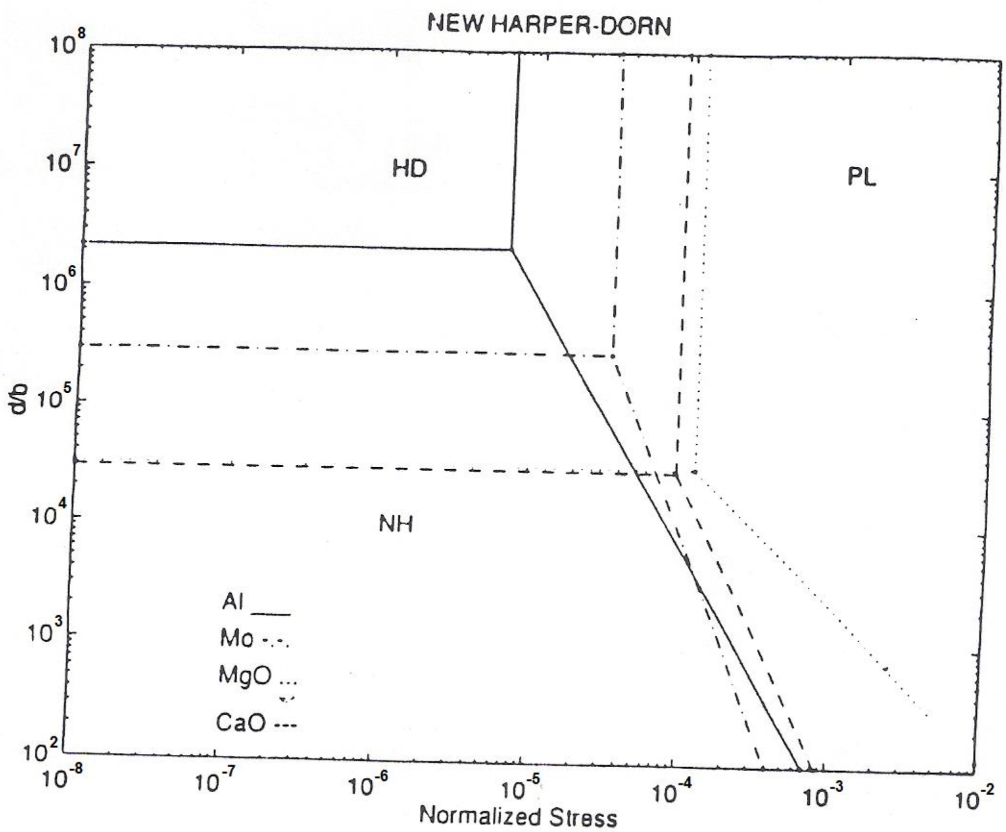

Figure 5: A comparison of Al, Mo, MgO, and CaO in Harper-Dorn creep.

Table 1: The values of τ_p/G, Temperature and A_{HD} for different materials

Material	τ_p/G	Temperature	A_{HD}
Al	$4x10^{-6}$	$0.98\ T_m$	$5.66x10^{-12}$
Mo	$2.77x10^{-5}$	$0.91\ T_m$	$3.21x10^{-10}$
CaO	$2.5x10^{-4}$	$0.54\ T_m$	$3.31x10^{-8}$
MgO	$2.33x10^{-4}$	$0.63\ T_m$	$2.85x10^{-8}$

Table 2: The values of different parameters for Harper_Dorn creep

Material	Class	A_{HD}	A_1	n
Al	F. C. C.	$5.66x10^{-12}$	$2.5x10^{6}$	4.4
Mo	B. C. C.	$3.21x10^{-10}$	$1x10^{13}$	6.0
CaO	Ceramic	$3.31x10^{-8}$	$5x10^{6}$	5.0
MgO	Ceramic	$2.855x10^{-8}$	2.0	3.0

Table 3: The values of (d/b), σ/G and slopes for Harper-Dorn creep

Material	d/b	σ/G	slope
Al	$2.2x10^{6}$	$6.45x10^{-6}$	-1.7
Mo	$2.95x10^{5}$	$3.2x10^{-5}$	-2.5
MgO	$3.12x10^{4}$	$1.2x10^{-4}$	-1.0
CaO	$2.91x10^{4}$	$9.0x10^{-6}$	-2.0

4. CONCLUSION

A comparison of Harper-Dorn creep shows that the value of normalized grain size for materials for b.c.c. materials (e.g. Mo) and non-metallic oxides (e.g. MgO and CaO) is smaller than f.c.c. metals (e.g. Al) under the same conditions of stress and temperature.

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6. NOMENCLATURE

T_m	melting temperature	b	Burger's vector
A_1	constant		k Boltzmann's constant
N	index	σ	normal stress
D_1	diffusion co-efficient	B.C.C.	body centered cube
G	shear modulus	F.C.C.	faced centered cube

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