EFFECT OF NANOSCALE ON THE HALL-PETCH RELATIONSHIP

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Abstract: We are going to discuss about the set of effects,that are going to show up when we go to the nanoscale for mechanical properties. We look at the effect of the Nanoscale on the Hall-Petch Relationship. Strength is a function of grain size for conventional grain size samples. In nano-scale, volume fraction of interfaces is nearly equal to that of the volume fraction of the grain hardness is a function of grain size for coarse grained samples (5µm to 25µm) and also for fine grained samples (5nm to 25nm). We see the effect of temperature on variation of strength, equi-cohesive temperature and diffusion creep.
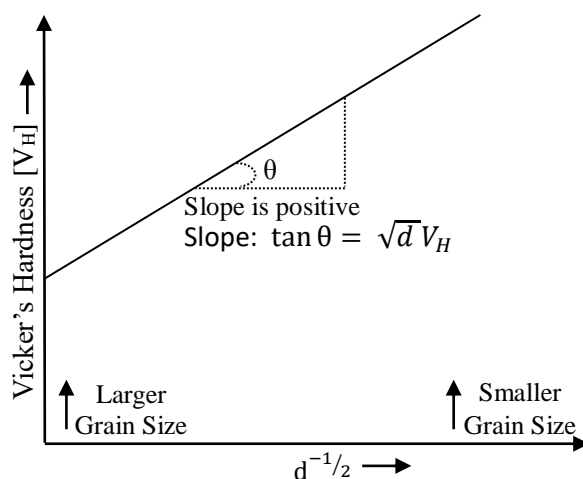
IndexTerms: Hall-Petch plot, Hall and Petch Relationship, Diffusion Creep, Diffusion Co-efficient, Strain Rate, Grain Boundary Sliding, Hardness.

I. INTRODUCTION

We see in 1989 publication in the sort of the earlier days of studies into nano-materials and nanotechnology and so on. In the early 1950s Hall and Petch demonstrated their respective measurement made on Iron and Steel materials.
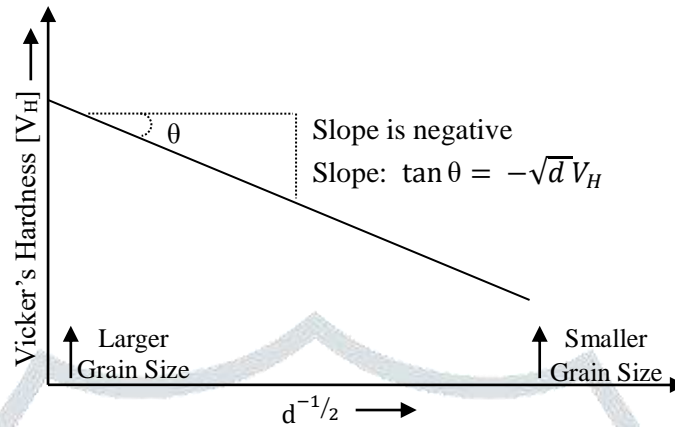
$$\sigma_y = \sigma_\circ + \frac{k_y}{\sqrt{d}}$$, where 'd' is average grain size

Hall-Petch relationship gives the yield strength as a function of the grain size and there are constants here. Also there is a lattice friction constant, hence there are two constants. The above relationship is valid over a wide range of grain sizes below 1 Micron size, this relation is not valid. Hall-Petch relationship gave important contribution in the field of material science. Deviation from this relationship is also very important. The idea that is relevant to the nanoscale is the primary idea thatmakes a difference from the perspective of size scales. Volume fraction of the interfaces is comparable to that of the volume fraction of the grain itself. At atomic lavel, atomic order begins to start getting bit disrupted. At the interface you have some bonds which are sort of broken and they're not complete and so on. Interface should be ideally be thought of as a two dimensional structure. We can assume a certain volume over which its effect is perceived or felt. The primary difference between the macro scale and the nano-scale which are associated with the boundary even though they had some impact not zero, it had even in the case where the grain sizes were large but the extent of the impact was minimum so, the idea of the nanoscale is relevant with respect to the mechanical property.

Graph between Vicker's Hardness and grain sizes.

The above graph represents Vicker's Hardness with respect to average grain size. If we go from left to right we get large grain size to smaller grain size. Positive slope represents linear behavior. In classic Hall-Petch behaviour coarse grain size is in the range of 5 microns to 25 microns, below this range this relationship does not hold. We see the behaviour as hardness as a function of green size for fine grained simples.

Graph between Vicker's Hardness and grain sizes.

This graph shows that when we go from large grain size to smaller grain size than Vicker's hardness decreases. Slope is negative no longer positive. In the 5 μm to 25 μm range Vickers hardness decreases from large grain size to a small grain size. For smaller grain size hardness increases, that is proportional to yield strength. When the grain size is going down then the field strength is going up of that material so, it can be decided for stronger material. For nano grained size material. It is found that opposite the slope is negative. When size is about 25 nanometer to 5 nanometer than strength actually decreases. Therefore slope will be negative. This behaviour is called inverse Hall-Petch behaviour. It is very important to know because in all of science that is basically what we do? The grain size related impact on yield strength explained by the Hall-Petch equation.

II. THE EFFECT OF TEMPERATURE:

The effect of temperature with change in grain size for many materials. Grain boundaries makes the material weaker at higher temperature the grain as well as the interior of the grain as well as the boundary have roughly the same strength or broad the same contribution to the strength of the material. If we go below a temperature the grain boundary becomes relatively stronger than the grain. Therefore both of them the grain as well as the interior of the grain as well as the boundary have roughly the same strength of their contribution for the strength of the material the temperature is below the grain bond it becomes relatively stronger than grain if temperature is ever have normal temperature the grain becomes stronger than the grain bond Redis is explained by creep diffusion and grain boundary sliding.

Diffusion Creep: It is a group of atoms and vacancies along the grain boundaries. Grain boundary sliding grain boundary sliding means sliding off grain with respect to other for the shape of that simple to change as opposed to dislocation moving through the grain. So the boundary itself is lighting this concept of equation temperature was explained by the diffusion creep and grain boundary is sliding.

Effect of temperature: This is the effect of temperature on a material which has a certain number of grain and grain boundary sliding if grain size is kept fixed and temperature increased gradually or lowering at certain temperature it is seen variation of strength with changes in grain size thus effectively sort of Hall-Petch relationship at one temperature and the Hall-Petch relationship for the same set of samples at higher temperature keeping raising temperature then after certain temperature we see Hall-Petch relationship is inverts and slope changes from positive to negative again it is attributed to grain boundary sliding. Temperature effects on the relative strength of green and grain boundary has been investigated at two different degrees. But at nano-scale higher temperature is avoided, we see the Hall-Petch relationship for higher grain size. Variation of strength depends on grain size at room temperature, slope changes from positive to negative as the size goes to nano-scale. Inverse Hall-Petch relationship works only at room temperature, not at higher temperature. Diffusional creep and transport of vacancies along grain boundary is known as coble creep.

Creep: It is phenomenon in which material appears to have less strength and so changes itself at each even relatively lower load simply at higher temperature it keeps slowly deforming and this is called creeping so this is usually a high temperature phenomenon at room temperature due to the presence of very large number of grain boundary.

$$\frac{d\varepsilon}{dt} = A\,\frac{\delta\sigma\Omega D_{GB}}{d^3 kT}$$

Where,

δ = Grain Boundary Volume
σ = Stress
Ω = Atomic Volume
D_{GB} = Diffusion Coefficient
A = Constant
d = Grain Size
k = Boltzmann's Constant
T = Temperature

There is a lot of parameter here so there is a relative effect of these parameters. Here d^3 is in the denominator, if d is going down from micrometer scale to nanometers scale then there is a huge impact of it. There is something called an equal cohesive temperature, below this temperature the grain boundaries are stronger it is seen that grain boundaries are stronger than the grain.
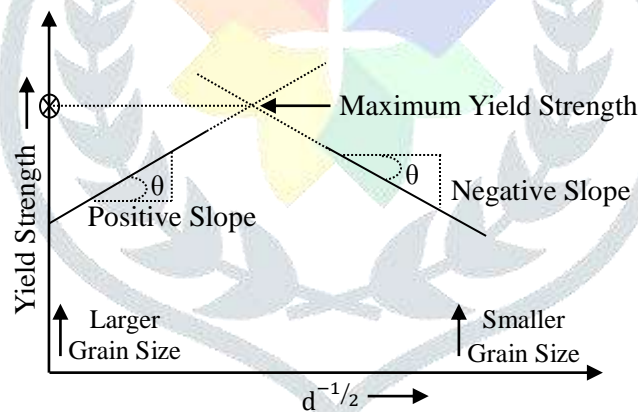
Diffusion coefficient:-If the temperature raises then strain rate decreases for the same stress it shows how quickly the material is deforming when the temperature is increased then we see the opposite effect. So, strain rate goes up because of diffusion coefficient.

$$D_{GB} = D_\circ e^{\frac{-Q}{kT}}$$

Before diffusion atoms in material vibrate. Atoms have to go a barrier and complete the movement and that is thermally activated. Due to rise in temperature the activation energy barrier comes down. For the same activation energy barrier it is possible to push it past that barrier very easily and so, this has significant temperature component associated with it. The above equation shows that the impact of the D which is grain size and we see how it dramatically changes the situation for a small grain size.

Original work you needed about equi-cohesive grain size. Below the normal grain size high temperature behavior is displayed, which means below the grain size material acts as it is sitting at high temperature, so the creep is high and grain boundary is weaker than grain.

III. OVERALL HALL-PETCH PLOT

The above graph shows illustration for large and small grain size. First slope is increasing in strength so it can be sort of extrapolate yield strength is a function of increasing or decreasing grain size there is a certain maximum yield strength that can be obtained by varying the grain size.

IV. DISCUSSION

The brief facts about the above phenomenon are:

- In samples with large grain size, strength increases with increase in grain size [Size Effect].
- In samples with nano-scale grain size, strength decreases with decrease in grain size [Size Effect].
- Diffusional Creep of grain boundaries is responsible for the mechanism suggested to explain the trends observed.

Material scientists are trying to maximize property that can be obtained from material using any process. It is very useful information to know; similarly it can do for other phenomena.

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