#### **Perfect and real crystals**

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# SOLID SOLUTIONING

- Metals usually form homogenous liquid solutions in their liquid state.
- Even after to solid crystalline state, the metals retain their homogeneity and consequently their solubility, this is called **solid** solution.
- There are two types of solid solution:-
- 1) Substitutional( (a)disordered and (b)ordered)
- 2) Interstitial

#### SUBSTITUTIONAL SOLID SOLUTION

In this there is a direct substitution of one type of atom for the another so that the solute atoms (Cu) enter the crystals to take the position normally occupied by solvent atoms.(Ni)

- In **disordered substitutional solution** the atoms do not occupy any paticular position and are disordered.
- In ordered solution, the alloy is in disordered condition and if i is cooled slowly, it undergoes rearrangment of atoms due to diffusion that takes place due to cooling.

# INTERSTITIAL SOLID

•It is formed when solute atoms are very small as compared to solvent atoms, they are unable to substitute solvent atoms(because of large difference in diameters) and can only fit into the interstices or spaces in the crystal lattice of the solvent atom.



e.g., Ni, Al (hi-T yield strength),

Al<sub>s</sub>(Li,Zr) (strengthening)

Ordered Substitutional and Interstititials Compounds

e.g., small impurities, clays ionic crystals, ceramics.

#### Grain boundary strengthening

- Is a method of strengthening materials by changing their average crystallite (grain) size.
- It is based on the observation that grain boundaries impede dislocation movement and that the number of dislocations within a grain have an effect on how easily dislocations can traverse grain boundaries and travel from grain to grain.
- So, by changing grain size one can influence dislocation movement and <u>yield strength.</u>
- For example ,heat treatment after plastic For example,heat treatment after plastic deformation and changing the rate of solidification are ways to alter grain size. Ideformation and changing the rate of solidification are ways to alter grain size.



#### **GRAIN BOUNDARY STRENGTHENING**

# **DISPERSION HARDENING**

- Dispersion hardening is a mean of strengthening a metal by creating a fine dispersion of insoluble particles within the metal.
- So metals containing finely dispersed particles are much stronger than the pure metal matrix.
- This effect depends on the size, shape, concentration and physical characteristics of particles.
- Dispersion hardened materials can be produced with the help of powder metallurgy- a process in which powder(of materials) of required shape, size and distribution are mixed in desired proportions and then compacted and sintered at the appropriate temperature.



## PARTICULATE STRENGTHENED SYSTEMS

- The difference between particulate and dispersion strengthened systems are in the size of dispersed particles and their volumetric concentration.
- In dispersion strengthening the particle size are small as compared to particulate strengthened systems
- Because of their size the particle can not interfere with dislocations and exhibits a strengthening effect by hydrostatically restraining the movement of the matrix close to it.
- Particulate composites sre made mainly by powder metallurgy techniques that may involve solid or liquid state sintering(atomic diffusions preferably at high temperatures) or even impregnation by molten metals
- Examples are Tungsten-nickel-iron system obtained as a liquid sintered composite.



When a material is stressed **below** its elastic limit:

When a material is stressed **beyond** its elastic limit:

**Crystals** 



<u>Deep drawing of a cylindrical cup</u>. (a) Before drawing; (b) after drawing

#### **Crystals** Simulation of deep

draw

Ζ

х



Plastic deformation may take place by:

- Dislo. Slip
- <u>Twinning</u>
- Grain boundary sliding
- Diffusional creep
- Phase transformation



Slip bands on Copper surface







 $\begin{array}{c} info.lu.farmingdale.edu/dept \\ s/\\met/met205/Image257.g \\ if \end{array}$ 

http://www.seismo.unr.edu/ftp/pub/louie/class/plate/diffusion creep.GIF



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Deformation (engineering strain) vs. dislocation density









slip lines on the surface of a nickel single crystal by Atomic Force Microscopy

**Slip band** 

**Crystals** 

Slip plane **Plastic Deformation:** 

1."Slip along close-packed planes";

2.Shear force instead of tension or compression along plane is required for deformation



Phil Mag. Lett., Vol. 77, No. 1, pp. 23- 31, 1998 A. Schwab, et al



If dislocation don't move, plastic deformation doesn't happen. ?

#### Chapter II The Plastic Deformation of Metal Crystals

A specific orientation relationship bet. slip lines and stress direction  $\mathbf{h} \boldsymbol{\sigma}$ 

<u>Slip</u>

system?



K. Kashihara et al. J. Jap. Inst. Light Metals, vol. 52, p. 107

A specific relationship bet. slip lines



The Plastic Deformation of Metal Crystals Slip system: Slip plane & slip direction

(The combination of a plane and a direction lying in the plane along which slip occurs)



Fig. 3.2(b), Verhoeven



C.f., • Packing density

• interplanar spacing

#### Offset= b for one dislocation slip event





Crystals

Table 3.1 Sip Systems Observed in the Common Metal Crystal   Structures				
Structure	Slip Direction	Slip Planes	Examples	
FCC	(110)	{111}	Cu, Al, Ni, Pb, Au, Ag, Fe	
BCC	(111)	{110}	Fe, W, Mo, brass, Nb, Ta	
BCC	(111)	{211}	Fe, Mo, W, Na	
BCC	(111)	{321}	Fe, K	
HCP	(1120)	(0001)	Cd, Zn, Mg, Ti, Be, Co	
HCP	(1120)	{1010}	Ti, Mg, Zr, Be	
HCP	(1120)	<b>{1011}</b>	Ti, Mg	

Table 3.1, Verhoeven









 $RSS = \boldsymbol{\sigma} \cos\theta \ \cos\lambda$ Shmid factor; m

If a single crystal of an e.g., fcc metal is pulled in tension, slip will be initiated on the first of the 12 slip system that attains a resolved shear stress equal to the CRSS

**Shmid's law:** A single crystal will slip when the resolved shear stress on the slip plane and along a certain slip direction reaches a critical value.



CrystalsTable 3.2.The Critical Resolved Shear Stress for Various Metals

CRSS					
Metal	Lattice	(psi)	$(MN/m^2)$	Slip System	
Ag	FCC	54	0.37	{111}(110)	
Al		114	0.79	11	
Cu		71	0.49	<b>11</b> ,	
Ni		470–1040	3.24-7.17		
Mg	HCP	57-72	0.39-0.50	{0001 <u>}</u> (11 <u>2</u> 0)	
Mg		5900	40.7	{1010}(1120)	
Be		200	1.38	{0001}(1120)	
Be		7600	52.4	{1010}(1120)	
Со		93-100	0.64-0.69	{0001}(1120)	
Ti		1850	12.8	{1010}(1120)	
Zr		93-100	0.64-0.69	{1010}(1120)	
Fe	bcc	4,000	27.6	{ <b>110</b> }, { <b>112</b> }(111)	
Мо		14,000	96.5	{110}, {112}(111)	
Nb		4,900	33.8	{110} (111)	
Та		6,000	41.4	{110} (111)	

Example 1 : A tensile stress that is applied along the [110] axis of a silver crystal to cause slip on the (1 11) [011] critical resolved ystem stress is 6 MPa. Please determine what the tensile stress I4.7 MPa Example 2 : How many favorable slip system are there for tensile stressing along [001] axis? Why?

Crystals



#### CRSS : depend on purity in metals (also see Fig. 5.16, Reed-

TT:11

Metal	Crystal structure	Purity, K	Slip plane	Slip direction	Critical shear stress, MPa	
Zn	hcp	99,999	(0001)	[1120]	0.18	
Mg	hcp	99,996	(0001)	[1120]	0.77	
Cd	hcp	99.996	(0001)	[1120]	0.58	
	hcp	99.99	(1010)	[1120]	13.7	
	•	99.9	(1010)	[1120]	90.1	
Ag	fcc	99.99	(111)	[110]	0.48	
		9 <mark>9.97</mark>	(111)	[110]	0.73	
		99.93	(111)	[110]	1.3	
Cu	fcc	99.999	(111)	[110]	0.65	
		99.98	(111)	[110]	0.94	
Ni	fcc	99.8	(111)	[110]	5.7	
Fe	bcc	<b>99.96</b>	(110)	[111]	27.5	
			(112)			
			(123)			Table 4.4,
Mo	bcc		(110)	[111]	49.0	G.E. Dieter, in 3rd edition

Crystals

<u>Theoretical Shear Strength of a Perfect Crystal</u> **Perfect Crystal**: without any kinds of defects (line, point defects etc) existing in the crystal

Table 3.4	Comparison of Theoretical Shear Stress for Slip to
	Measured Values of CRSS

Metal	Shear Modulus in Slip Direction (×10 <sup>6</sup> psi)	τ <sub>m</sub> (psi)	CRSS (psi)	
Al	3.54	556,000	114	
Ag	3.63	577,000	54	
Cu	5.91	940,000	71	
α-Fe	~10	~1,590,000	4000	
Mg	2.39	381,000	57	

# THANK