Stress Corrosion Cracking (Mechanisms)

LECTURE 02

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Proposed mechanisms of SCC

1- Dissolution-based mechanisms

- *atoms at crack tips to be removed preferentially in a direction approximately normal to the applied stress, with only limited dissolution behind the crack tip.*

- *Limited dissolution behind crack tips:*

Formation of protective (or semi-protective) films on fracture surfaces, because :

(i) anodic microstructural/microchemical features have been dissolved,

(ii) stresses/strains are much lower than those at the crack tip,

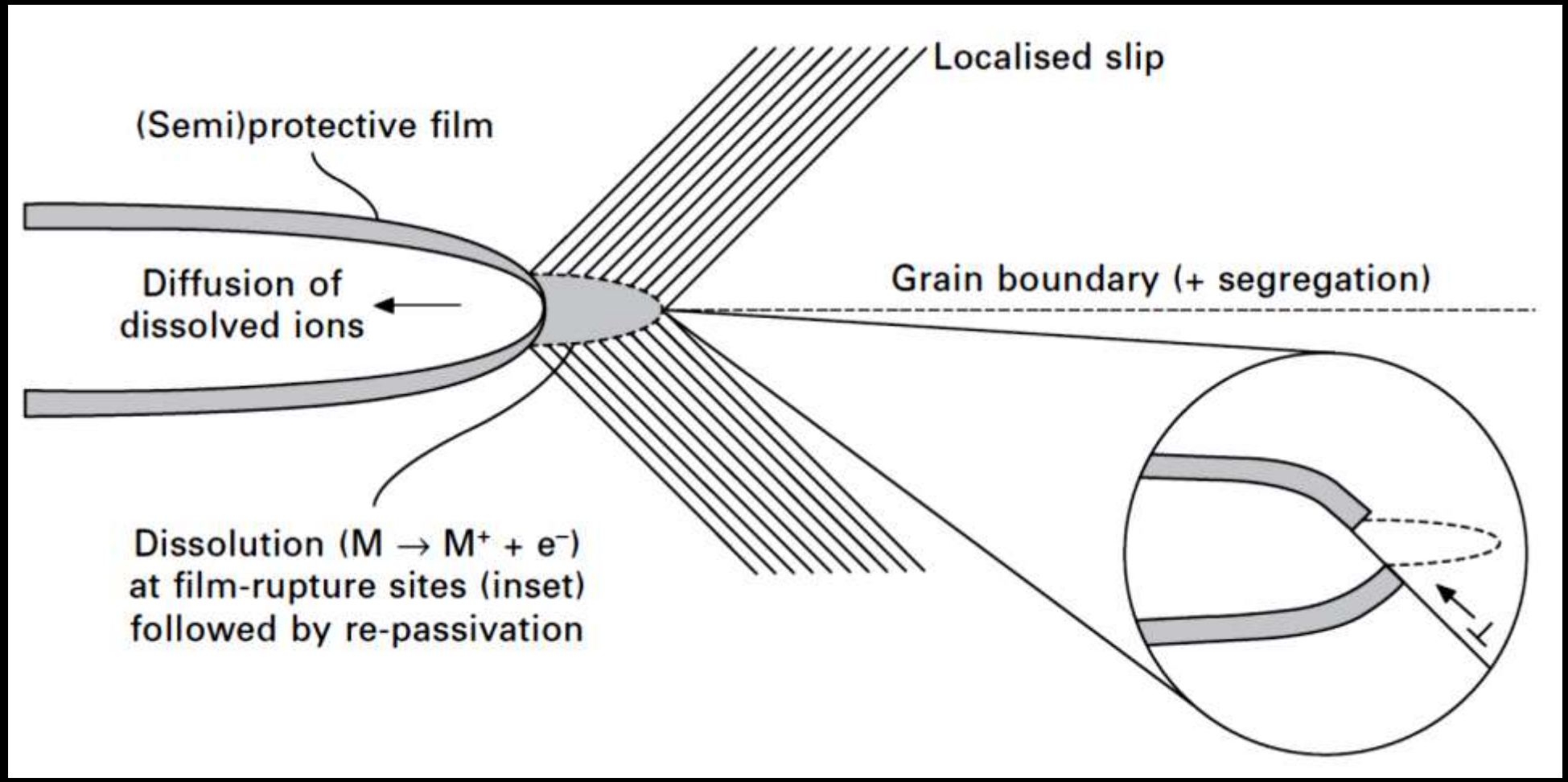
(iii) environments behind crack tips are less aggressive than those at crack tips.

slip-dissolution mechanism

- *(film-rupture/anodic dissolution mechanism)*

- *rupture of protective films by slip bands intersecting the crack tip, then dissolution along grain boundaries or low-index crystallographic planes, until repassivation occurs*

slip-dissolution mechanism



2- Adsorption-based mechanisms

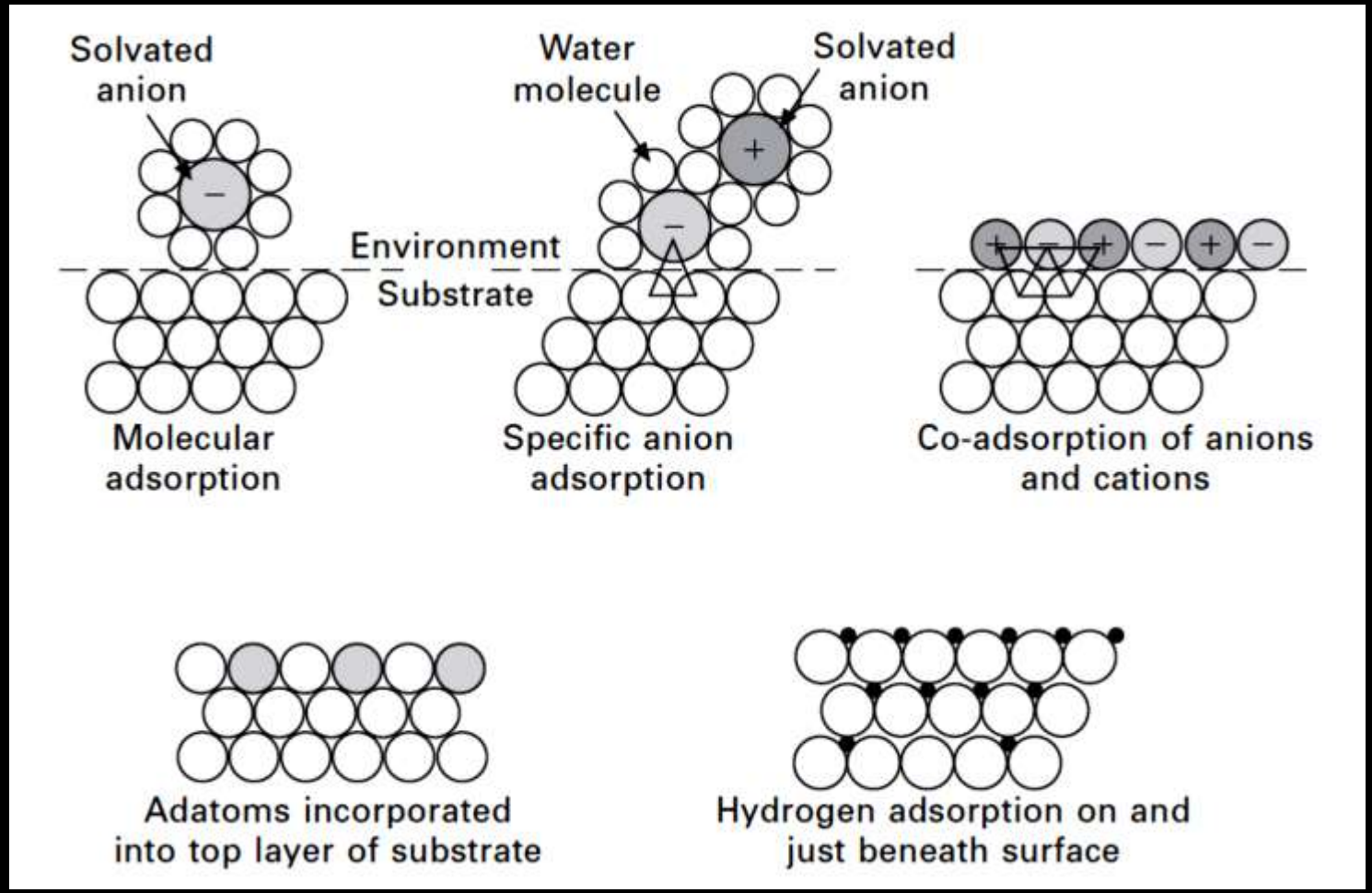
- *adsorption-active media could affect deformation and fracture of solids due to decreases in the surface energy*

- *chemisorption of specific ions,*

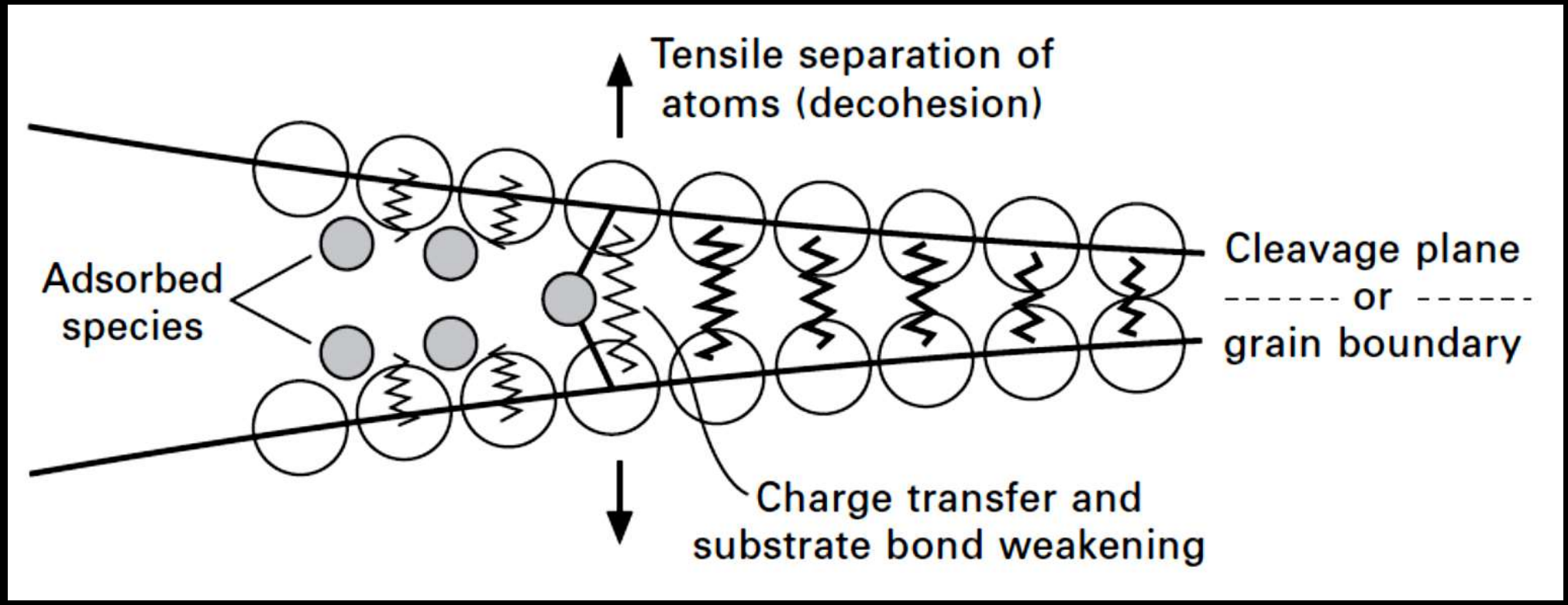
  e.g. complex Cu-NH3 ions for SCC of a-brass, weakened the strained interatomic bonds at crack tips, promoting crack growth by decohesion along a cleavage plane or a grain boundary

various types of adsorption:

- *The type of adsorption and degree of charge transfer will determine the extent of substrate–substrate bond weakening*



Adsorption-based mechanisms



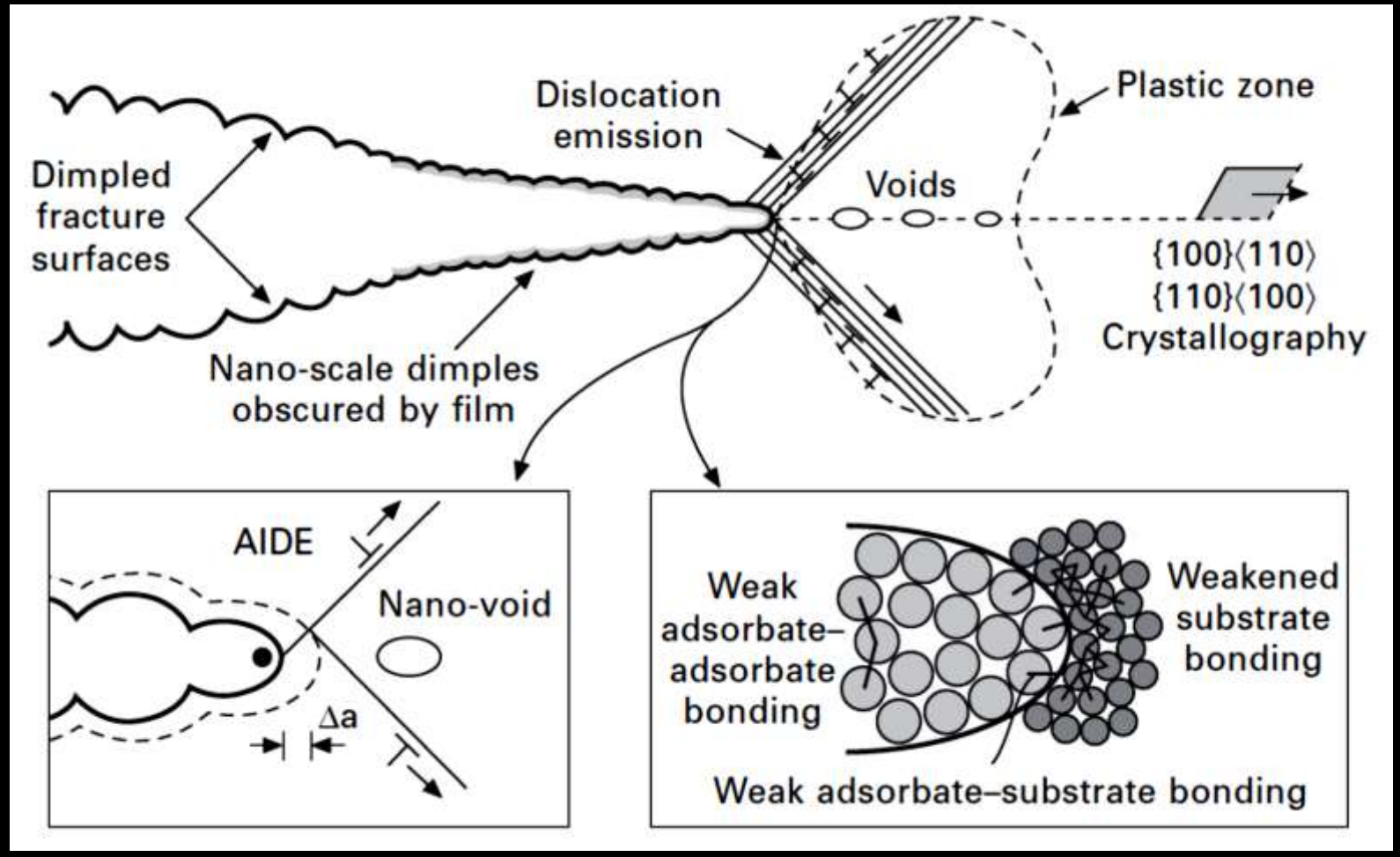
Adsorption-based mechanisms

- *adsorption-induced dislocation-emission (AIDE) mechanism for SCC, HE and LME (involving various adsorbed species, hydrogen, and metal atoms*

- *adsorption weakens interatomic bonds at crack tips and thereby facilitates the nucleation of dislocations rather than decohesion.*

- *Cleavage-like cracking along low-index crystallographic planes is explained in terms of the AIDE process*

- *adsorption-induced dislocation-emission (AIDE) mechanism for transgranular SCC involving coalescence of cracks with nano-voids (or microvoids) in the plastic zone ahead of crack tips.*



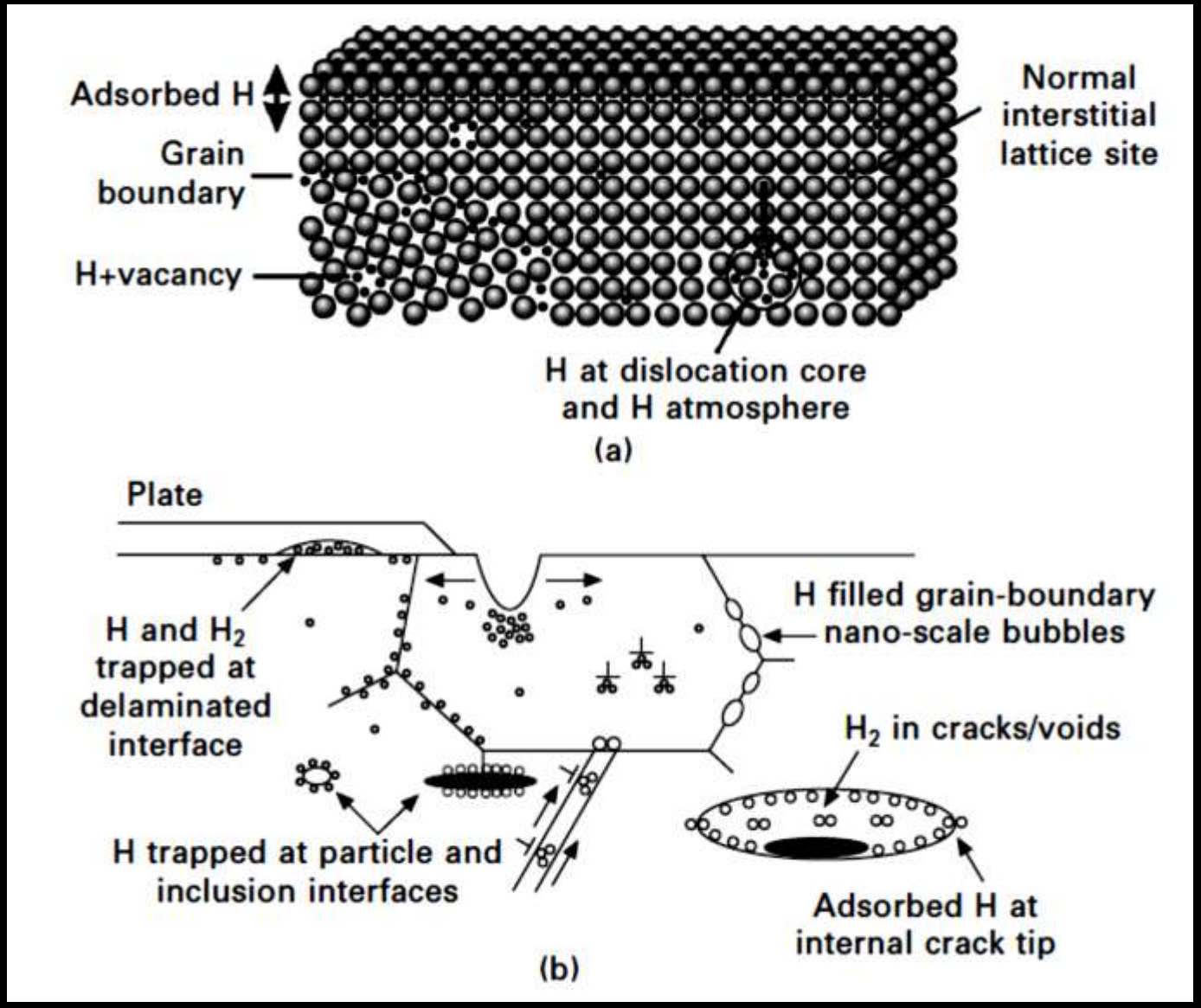
3- Hydrogen-based mechanisms

- *(i) hydrogen can be generated at crack tips by chemical dissociation of water molecules or by electrochemical reactions*

- *(ii) these materials are known to be embrittled by hydrogen (after hydrogen-charging and testing in inert environments or during testing in gaseous hydrogen)*

- *(iii) SCC in some of these materials can occur in moist air where dissolution and some other environmental interactions can be discounted*

sites and traps for hydrogen in materials



Mechanisms based on adsorbed hydrogen

- *weakening of substrate interatomic bonds leading to easier dislocation emission or decohesion at crack tips*

- *However, unlike other adsorbed species, adsorbed hydrogen can readily diffuse ahead of crack tips, so that adsorption of hydrogen could occur not only at external crack tips but also at internal cracks*

- *Ease of hydrogen diffusion, is that high hydrogen concentrations are likely to be present within the first few atomic layers beneath crack tips as well as on the surface*

Mechanisms based on solute hydrogen

- *Where solute hydrogen weakens interatomic bonds and facilitates decohesion (as for adsorbed hydrogen but further ahead of crack tips)*

- *Where solute hydrogen facilitates dislocation activity in the plastic zone ahead of cracks and promotes crack growth by a more localisedslip/microvoid-coalescence process than that which occurs in inert environments*

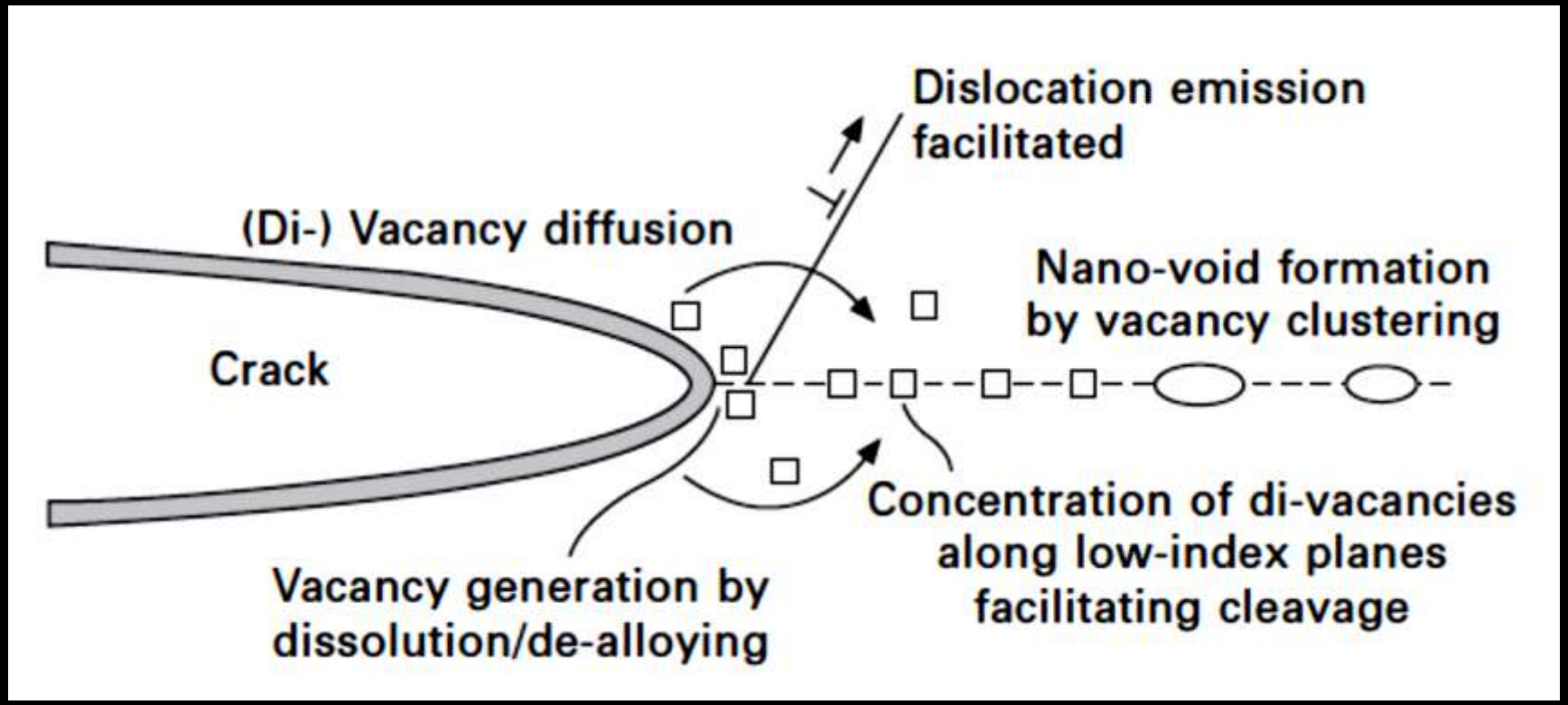
- *Hydrogen-enhanced decohesion (HEDE) mechanisms*
- *Hydrogen enhanced localised-plasticity (HELP) mechanism*

Mechanisms based on hydride formation

- *hydride-forming materials, such as magnesium, zirconium and titanium alloys, hydrogen production and ingress at crack tips could potentially lead to the formation and brittle fracture of bulk hydrides around crack tips*

4- Vacancy-based mechanisms

- *(i) generation of vacancies at crack tips by dissolution, de-alloying or oxide-film formation*
- *(ii) diffusion of vacancies (or di-vacancies) into the plastic zone ahead of cracks*
- *(iii) vacancy-induced changes to deformation and/or fracture behavior at or ahead of crack tips*

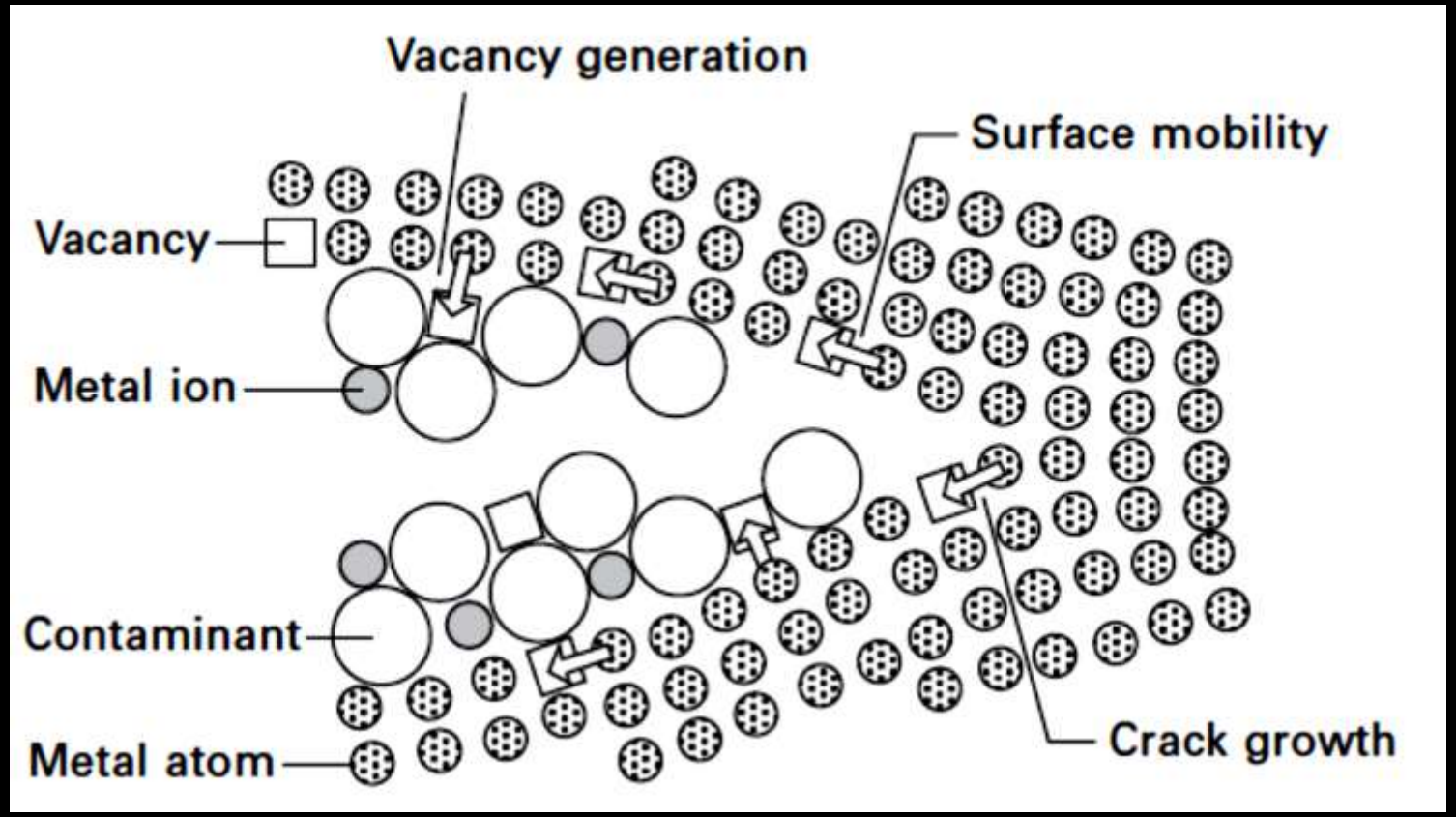

Dislocation emission
facilitated
(Di-) Vacancy diffusion
Nano-void formation
by vacancy clustering
Crack
Concentration of di-vacancies
along low-index planes
facilitating cleavage
Vacancy generation by
dissolution/de-alloying

5- Surface-mobility mechanism

- *surface-diffusion of atoms from an elastically stressed, atomically sharp crack tip to an adjacent vacant lattice site behind the crack tip*

Or

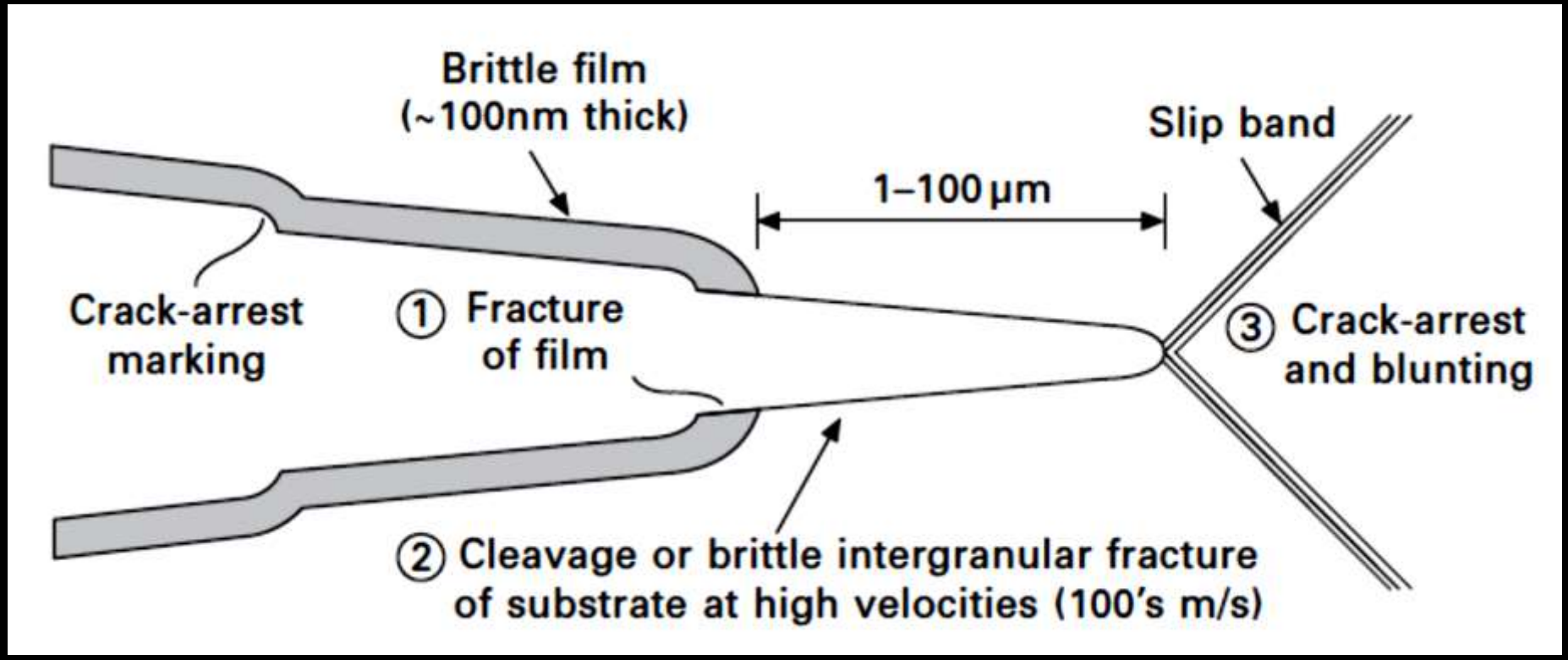
- *crack growth occurs by the capture of vacancies by the stressed lattice at the crack tip*


Vacancy generation
Surface mobility
Vacancy
Metal ion
Contaminant
Metal atom
Crack growth

6- Film-induced cleavage

- *SCC of normally ductile (fcc) materials*

- *(i) the formation of an environmentally induced brittle film at crack tips*
- *(ii) rapid brittle fracture of the film*
- *(iii) continuation of brittle fracture into the underlying substrate for distances that are much greater (10–1000X) than the film thickness*
- *(iv) crack-arrest and blunting*

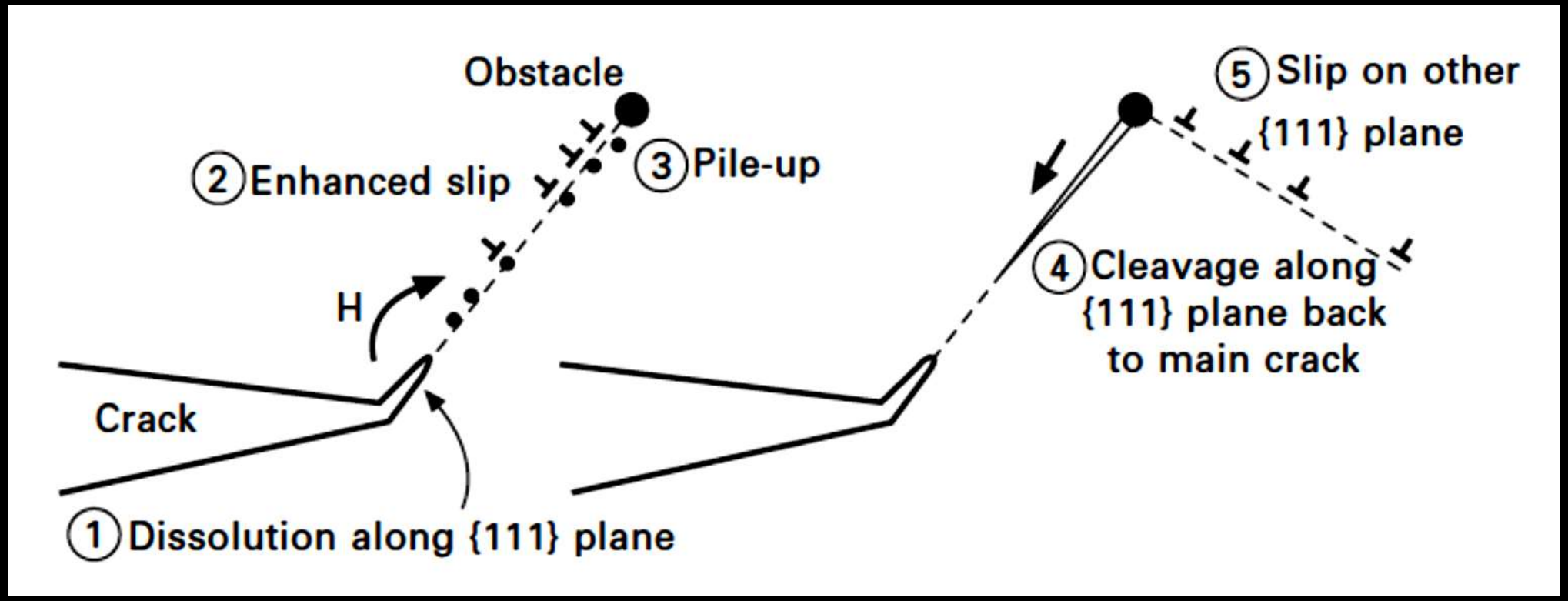


crack growth is discontinuous and that crack-arrest markings should be present on fracture surfaces

7- Corrosion-enhanced localised-plasticity mechanism

- *Transgranular SCC in fcc materials, involving dissolution, adsorbed hydrogen and absorbed hydrogen*

- *1. De-passivation/oxide-rupture*
- *2. Localised dissolution along a {111} slip plane.*
- *3. Localised shearing along this slip plane, promoted by the dissolution slot along the slip plane in conjunction with a lowering of the critical shear stress for dislocation activity due to adsorbed and absorbed hydrogen.*
- *4. Pile-up of dislocations at obstacles, e.g. particles or other dislocations structures such as Lomer–Cottrell locks, which increases local stresses such that decohesion initiates at the head of the pile-up.*
- *5. Propagation of a brittle crack back along a slip plane to link up with the dissolution slot.*
- *6. Crack-arrest and possible re-passivation.*


Obstacle
2 Enhanced slip
3 Pile-up
H
Crack
1 Dissolution along {111} plane
5 Slip on other
{111} plane
4 Cleavage along
{111} plane back
to main crack

8- Other hybrid mechanisms

- *combinations of dissolution/oxidation and mechanical fracture*

- *Dissolution of anodic precipitates and hydrogen embrittlement of regions between the precipitates*
- *Dissolution, occurring irregularly along crack fronts (to produce corrosion slots), plus ductile tearing of ligaments of material between the slots*
- *Internal oxidation along grain boundaries, involving (stress-assisted) oxygen diffusion promoted by vacancies resulting from oxidation, followed by 'brittle' fracture of the weakened boundaries*
- *Dissolution or de-alloying followed by adsorption-induced fracture due to embrittling ions produced by corrosion*