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WORKING PARTY ON
MECHANICAL PROPERTIES OF INTERFACES

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"High Resolution Electronmicroscope Studies on Interfaces"

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These are preliminary lecture notes, intended only for distribution to participants.

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ATOMIC SCALE INFORMATION AND MECHANICAL PROPERTIES OF INTERFACES IN TiAl INTERMETALLICS AND Al MATRIX COMPOSITES REINFORCED BY WHISKERS

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OUTLINE

Introduction

The Atomic Scale Techniques For Interfaces

Interfaces And Ductility/Toughness of TiAl

Interfacial Reaction Products And Mechanical Properties in Al composites

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1. Introduction

¤ GB, IB and Interfaces can affect properties to a great extent
- Nanocrystal--high toughness
- Multilayer superlattice--"supermodulus effect"
- Ni-Al, Ti-Al intermetallics--B segregation at GB and interface
- Composites--bonding status of interfaces

¤ Progress in characterization of interfaces
- Simple theoretical reasoning
- Crystal defect theory and experimental observations
- Computer and computation techniques

¤ Demands in scientific frontiers
- Surface engineering
- Interface engineering for composites
- Interface design for microelectronic devices

¤ Progress in studies on interface structure
- Metallic G.B.
- Diffraction contrast EM & HREM
- Ceramics G.B.
- Polyphase materials interface boundaries

2. Atomic Scale Techniques for Interface Studies

2.1 CTEM & HREM

- ♦ Instruments are similar
- ♦ Imaging principle is quite different
  - CTEM--Amplitude contrast
  - HREM--Phase contrast

2.2 Basic Requirement for Interface HR Images

- ♦ At least one but preferably both crystals along a zone-axis with the boundary seen end-on
- ♦ The boundary as 2-D medium should be projected to a 1-D image:
  - All displacements are confined in the plane perpendicular to the observation axis and does not depend on the Z coordinate.
  - The distances between atomic columns are larger than resolution limit.
    (Pure tilt G.B.)

2.3 Chemical Lattice Imaging

- ♦ A-priori information:
  - The atomic species which are involved are already known but their exact location is to be found.
  - The relationship between the lattice constant and the composition is supposed to be known,
  - The image pattern should be uniquely and of possible linearly dependant on the chemical composition.

2.4 Limitations

- ♦ Projection problem
- ♦ Relaxation at interfaces
- ♦ Radiation damage

Main application:
- Periodicity at the interface
- Coherency or the loss of coherency with or without interfacial dislocations
- Atomic modeling and positioning at the interfaces
- Roughness of boundaries: steps; facets; chemical gradients

2.5 Study Cases of Atomic Structures in Materials Interfaces

- N.C. G.B.
- Interface boundaries in metallic materials
  δ', S' and Al matrix
- Interfaces in ceramics materials
  TiC/TiB_2
- Heterophase
  Cu-Pd metallic multilayer film with λ=1.4, 2.3, and 3.4 nm on mica substrate and Cu buffer showing partial dendrite crystal structure
- Composite interface
  TiC_p/Ti

2.6 Advantages and Limitations of The Atomic Scale Techniques

Technique	Resolution (struct.)	Resolution (chemical)	Probed thickness	Material limitat.	Specimen require.
HREM	0.16-0.2nm	indirec.1nm	over 20 nm	Radiation damage in ionic materials	20 nm thin foil with boundary end-on
AP-FIM	0.3 nm	0.4 nm atomic sensitive	Surface peeling layer by layer	Best in non-ducti. materials	Wire with tip r=tens nm, high density of boundary
STM	0.2nm L 0.005nm N	0.2 nm	Surface	Conductors	Flat&clean surface with B. end-on

3. Interface and Ductility/Toughness of TiAl

- TiAl intermetallic compounds are the potential materials for use at high-temperature because they exhibit a desirable combination of high modules retention, creep and oxidation resistance with low density.

3.1 Lamellar Structure

- The alloys are usually composed of a lamellar mixture of TiAl(γ-phase) and Ti_3Al (α_2-phase) and always exhibit superior mechanical properties in comparison with the single γ or α_2 phases. It is reasonable to suggest that the interfaces between the γ- and α_2- phases play an important role in improving the ductility and toughness.
- The hierarchy of lamellar mixture structures
  Twins and dislocations in the coarse γ phase
- Terraced interfaces in the coarse lamellar with micrometer scale
- Flat interfaces in the fine lamellar with 20 nm scale

3.2 Fully Lamellar Structure and Mechanical Properties

- Elongation increases with decreasing of the lamellar spacing
- Toughness decreases with coarsening of the lamellar spacing

3.3 Interfaces Are the Easily Deformable Regions

- In the case of the less plastic deformation(2-3%) one set of twins formed and the initial deformation began at γ/α_2 interfaces.
- Larger plastic deformation (6-7%) will induce the second set of twins and the latter causes interfaces twist .
- Finer lamellar, more interfaces and easier to be deformed

3.4 Strengthening of the γ Matrix as the Lamellar Becomes Thinner

- 0.7% expansion in the thin γ slice in comparison with the coarse γ matrix
- Composite defect structure inside the thin γ slices
- γ matrix strengthening may degrade toughness (K1c)

3.5 Atomic Scale Information Provided by HREM Might Be Localized, A full Understanding of Mechanical Properties of Interfaces Should Use Micro-scale Information As Well.

3.6 Phase Transformation Induced By Deformation In The TiAl(Cr) Intermetallics During The Deformation

- The interface regions became difficult to be identified
- γ--α_2 transformation induced by deformation at interfaces

4.Interfacial Reaction Products and Mechanical Properties in Al Composites

- The whisker-reinforced Al composites have been of much interest for their high specific strength, high modulus, high wear resistance and thermal stability.

4.1 Materials

- SiCw/6061Al
- Si_3N_4w/6061Al
- $Al_{18}B_4O_{33}$w/6061Al
- $K_2Ti_6O_3$w/6061Al

4.2 Bending Strength, Micro-Hardness and the Effect of T6 Treatment

- The influence of T6 treatment on bending strength was similar to that on micro-hardness
- Strength increased after T6 for SiC and Si_3N_4 whiskers, however it decreased slightly for oxide whiskers.

4.3 HREM Observations of Whisker/Matrix Interfaces

- There was no chemical reaction which damaged whiskers during T6 treatment for SiCw and Si_3N_{4w}/Al
- Chemical reaction between whisker and Al alloy during T6 treating

4.4 Mg Segregation May Play An Important Role For Interfacial Reaction in Whisker/Al Composites