INFLUENCE OF OXYGEN ON THE MICROSTRUCTURAL DEVELOPMENT OF Ti-46.5Al-0.8Ta (at.%) ALLOY PRODUCED BY SPS

Presenting author: *P.V. Cobbinah*

Co-authors: *W.R. Matizamhuka, R. Machaka, M.B. Shongwe and Y. Yamabe-Mitarai*

Vaal University of Technology

Department of Metallurgical Engineering

Faculty of Engineering and Technology

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Outline

- Introduction
- Experimental procedure
- Results and discussions
- Conclusions

Introduction

- Nickel-based superalloys (NBSAs) are the most successfully used high-temperature alloys over the last five decades[1].

- Properties of NBSAs[1]
  - ➢NBSAs maintain their face-centred cubic structure (FCC) phase form from room temperature (RT) to their melting point (1455 °C).

  - ➢Beyond 800 °C, NBSAs have proved to withstand significantly required conditions of loading under static, fatigue, creep and tolerate severe operating environments.

Introduction

- For some specific stress and temperature range, a competent replacement of the heavier NBSAs (~8 $g.cm^{-3}$) with lighter materials is imperative to improve performance.

- Titanium aluminide (TiAl) alloys[2]
  - ordered α_2(Ti_3Al) phase with a hexagonal crystal structure (DO_{19})

  - γ(TiAl) phase with a face-centred tetragonal structure ($L1_0$) , analogous to that of NBSA's $L1_2$ ordered FCC phase

Introduction

- Thermo-physical properties of TiAl alloys[3]
  - low density (3.9 - 4.2 $g.cm^{-3}$)
  - high melting point of 1460 °C
  - high elastic moduli
  - low diffusion coefficient
  - good corrosion and oxidation behaviour by forming a surface alumina passivating layer
  - are ductile at their service temperatures while also maintaining good structural stability

Introduction

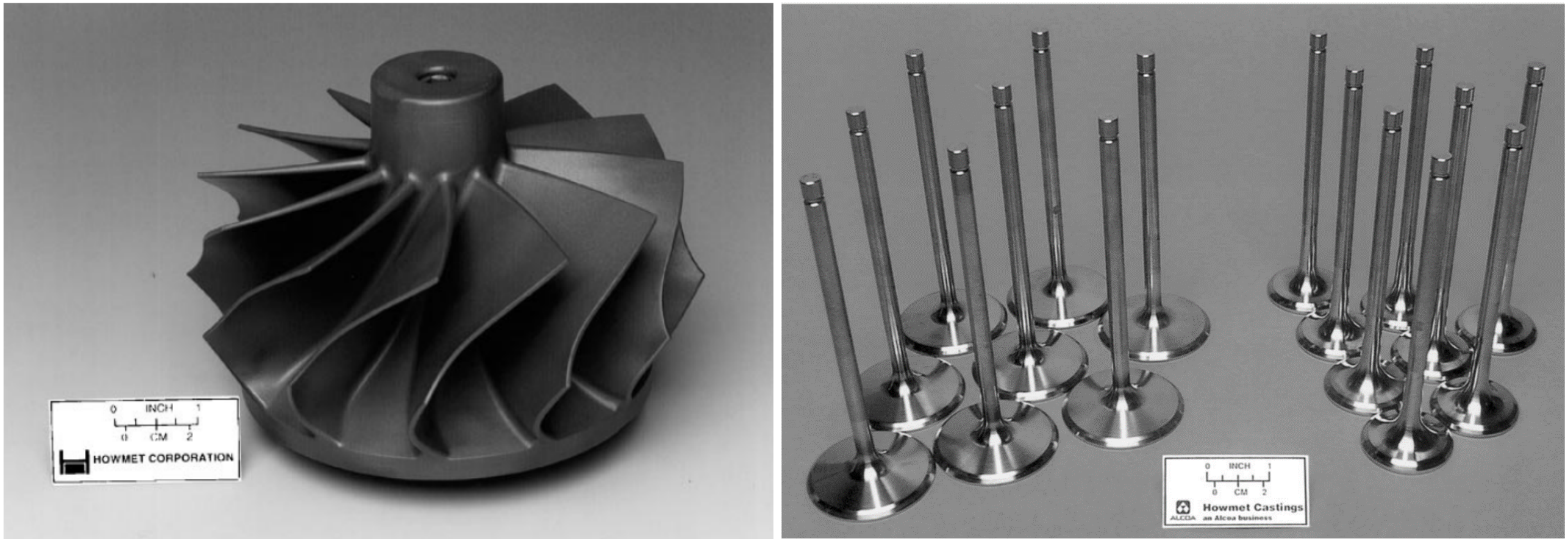
- Applications of TiAl alloys
  - Aerospace industry

(a) (b)

Figure 1: (a) Photograph of TiAl low-pressure turbine (LPT) blade as used in the last stage of GEnx engine and (b) an assembly of TiAl LPT blades after an engine test as used in the GE CF6 test engine[4].

Introduction

- Automotive industry



(a) (b)

Figure 2: (a) Turbine wheel casting of γ-TiAl for automotive turbochargers (b) Cast γ-TiAl exhaust valves in testing for high-performance cars by Howmet Corporation[4].

Drawback of TiAl alloys

- A major challenge associated with TiAl alloys is its low ductility at ambient temperatures.

- Attempts to improve the low ductility of TiAl alloys have included:
  - microalloying to form ternary or quaternary alloys[5]
  - grain refinement through the powder metallurgy processing route or by rapid solidification[6].
  - alteration of the morphology, volume fraction and distribution of constituent phases by heat treatment[7].

Introduction

Aim of study

To evaluate the influence of oxygen on the microstructural development of Ti-46.5Al-0.8Ta (at.%) alloy produced by spark plasma sintering (SPS).

Experimental procedure

Elemental powders

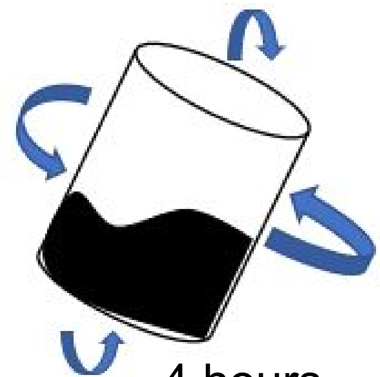
Ti
99%, <45 μm

Al
(99.5%, 7-15 μm)

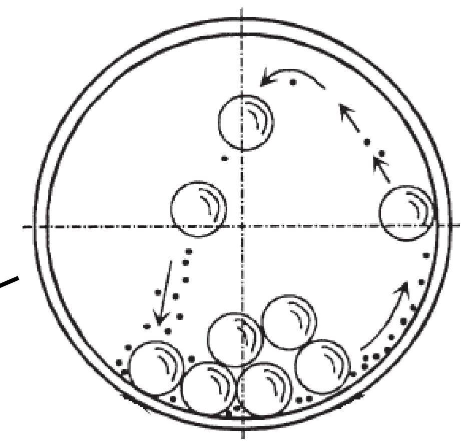
Milled in ethanol
4 hours

2 wt.% Stearic acid
6 hours

Ti-46.5Al-0.8Ta (at.%)



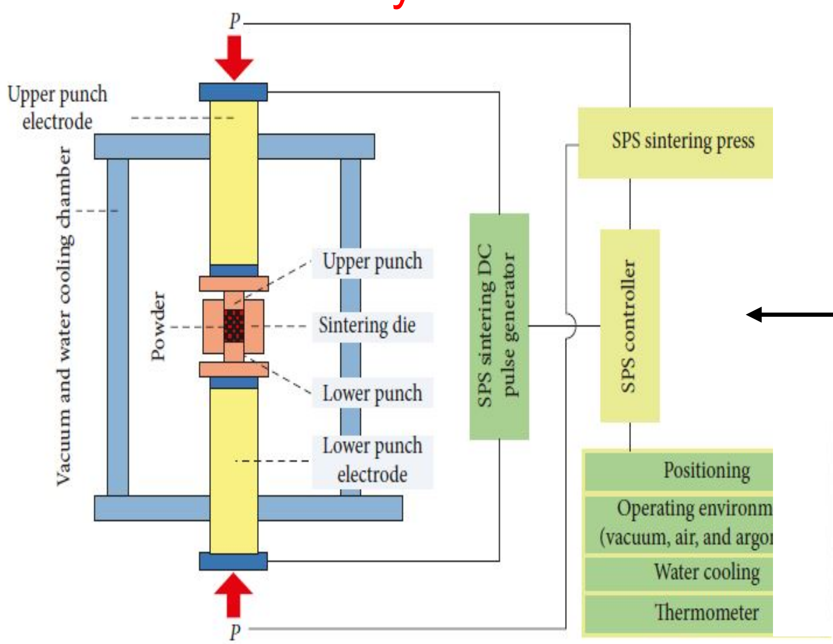
4 hours

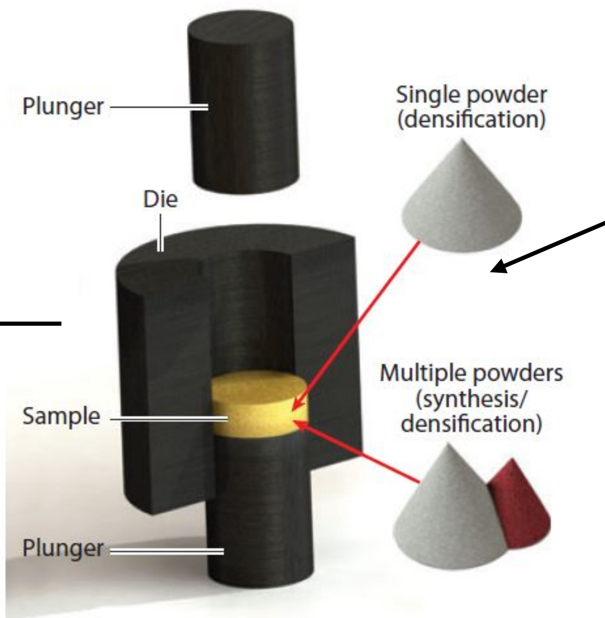


Mechanical alloying

BPR, 10:1
350 rpm
6 hours

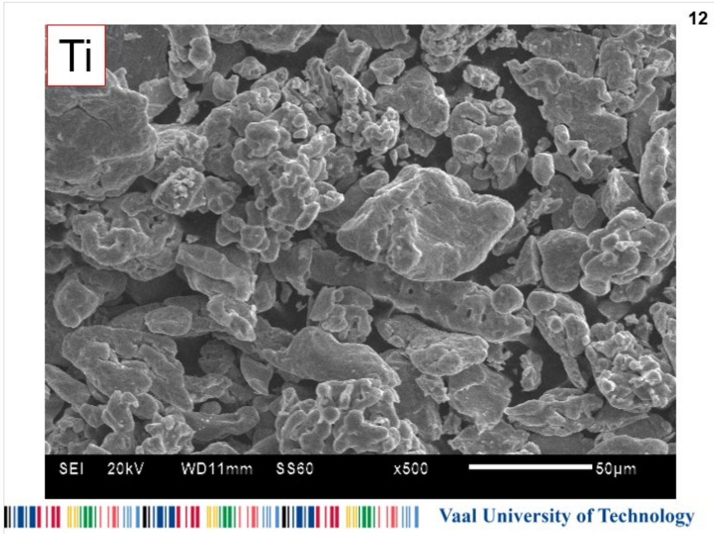
FCT H-HP D25 hybrid

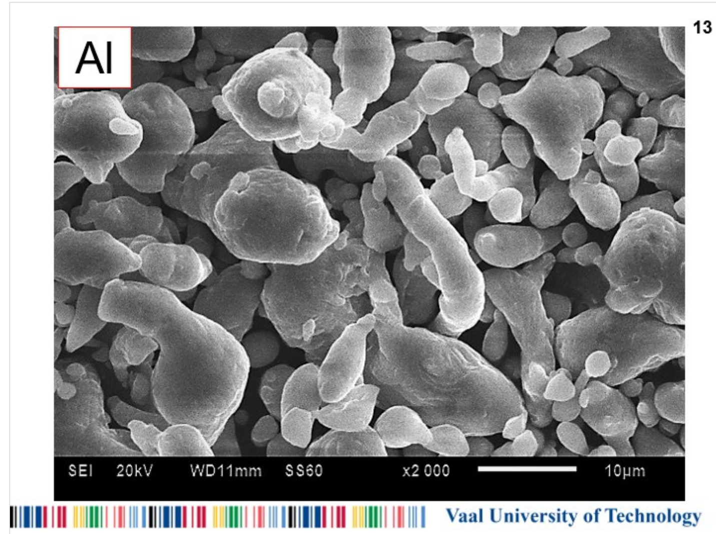




Results and discussions

- Morphologies of as-received powders





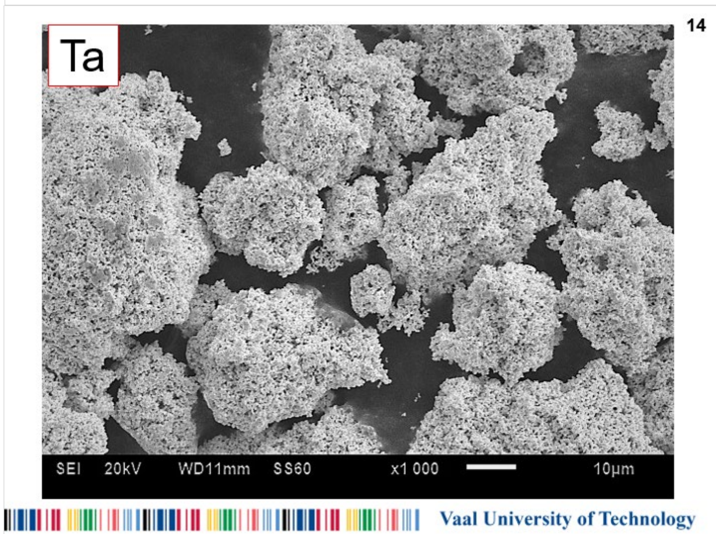
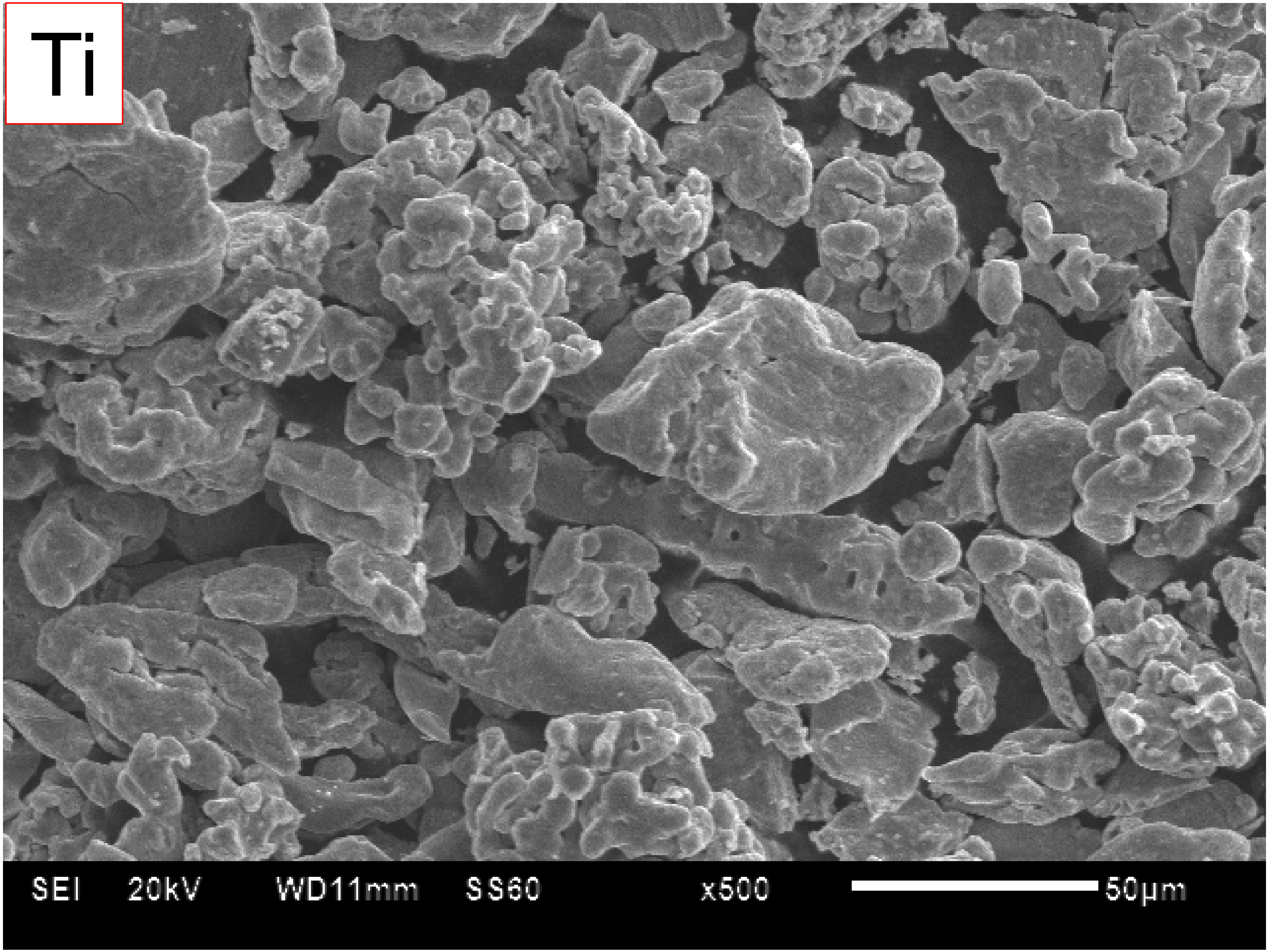
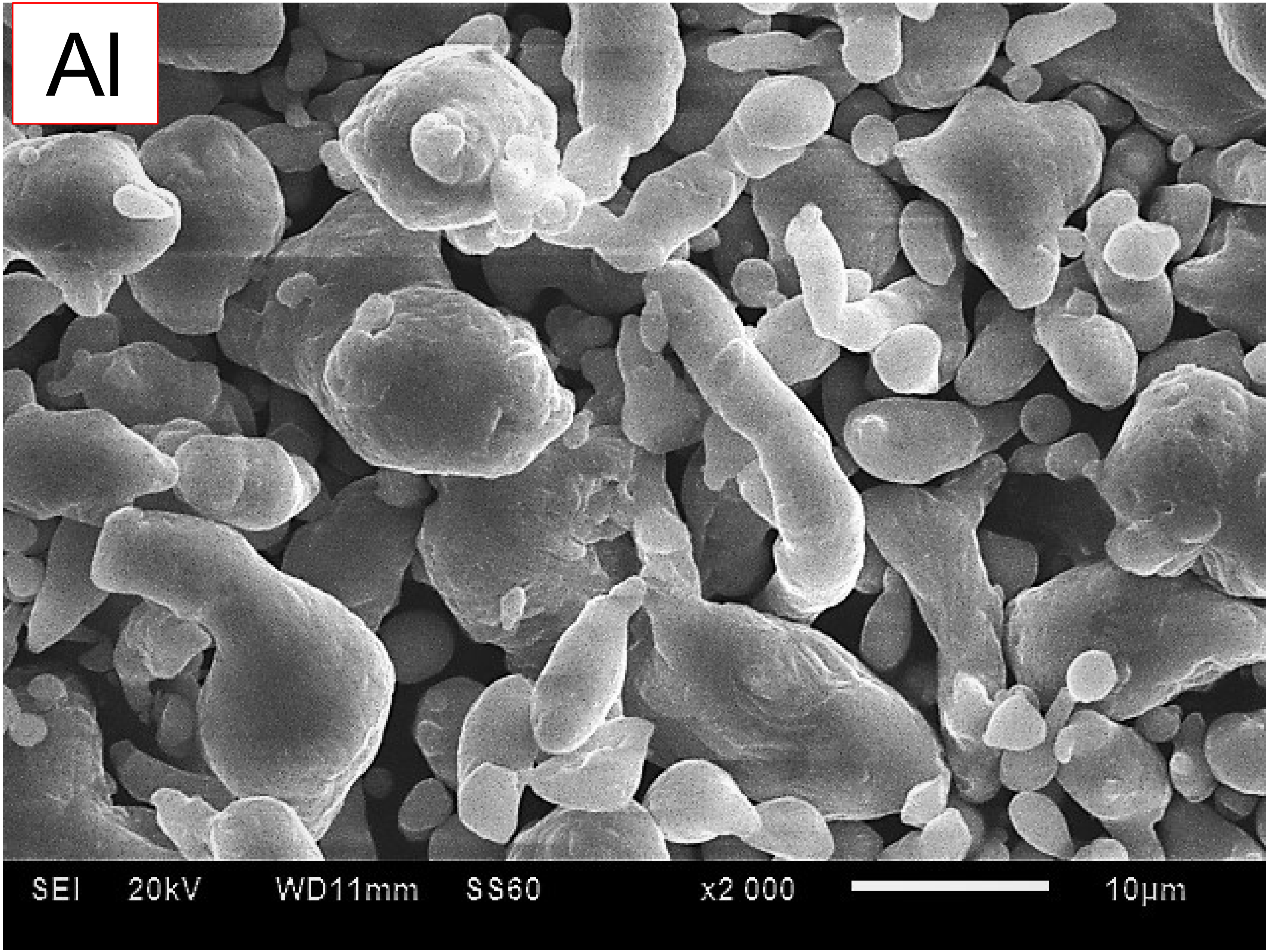
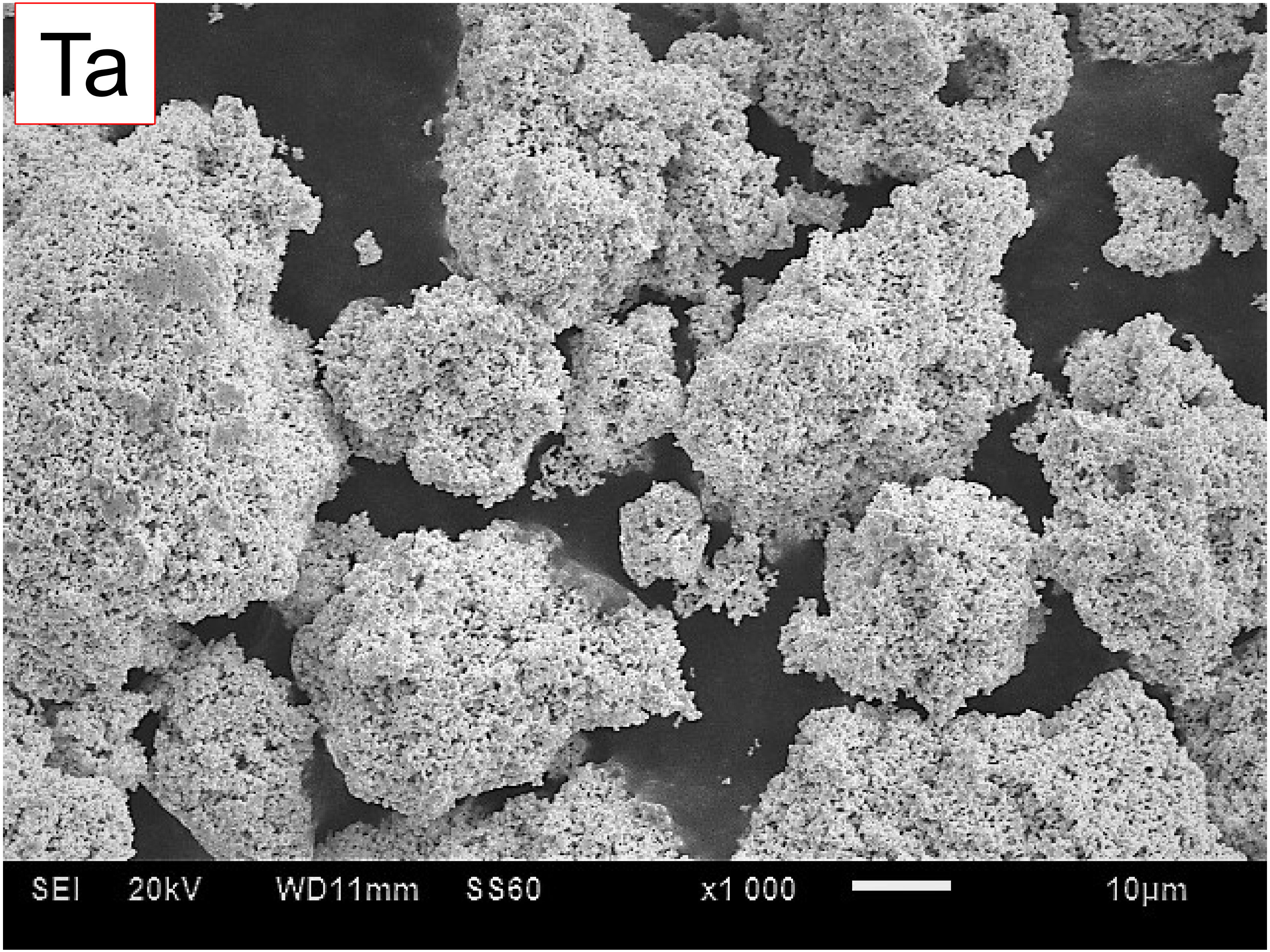


Figure 2: Morphologies of as-received powders

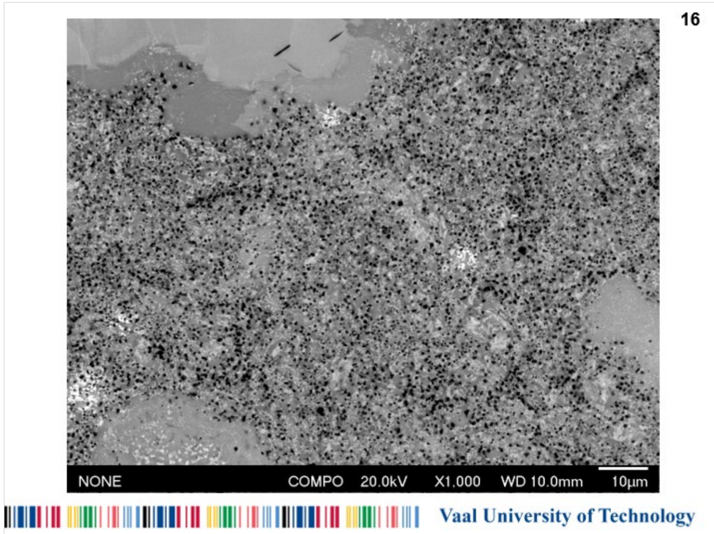

Ti
SEI 20kV WD11mm SS60 x500 50µm

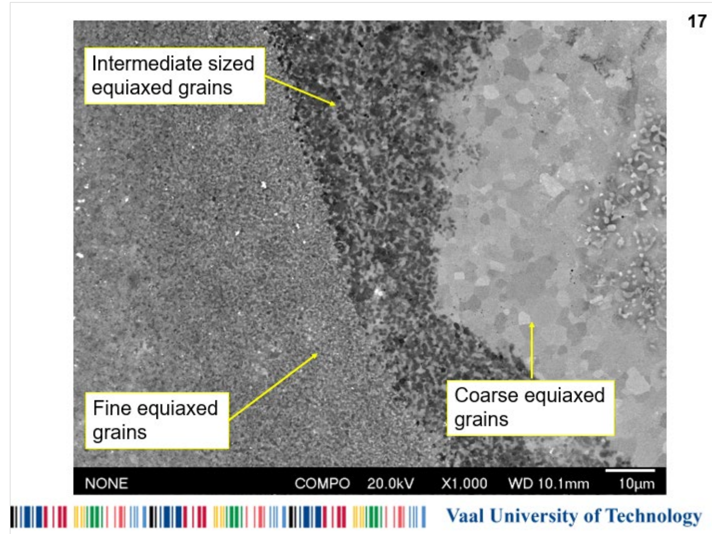

Al
SEI 20kV WD11mm SS60 x2 000 10µm


Ta
SEI 20kV WD11mm SS60 x1 000 10µm

Results and discussion

- Microstructural observation





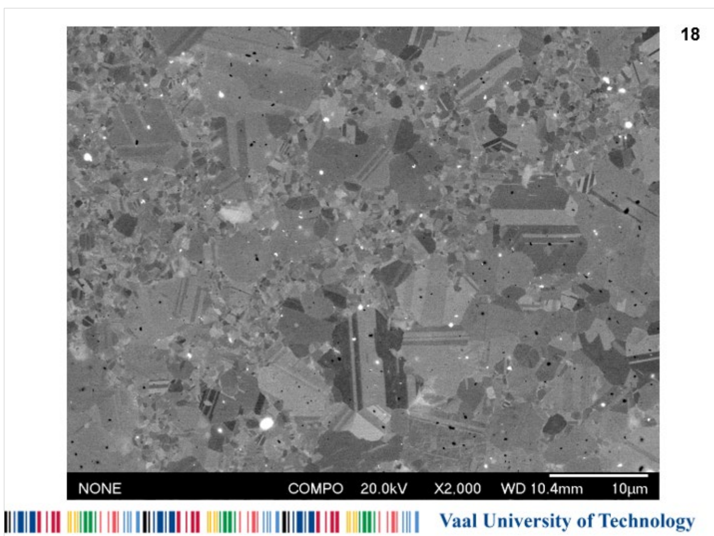
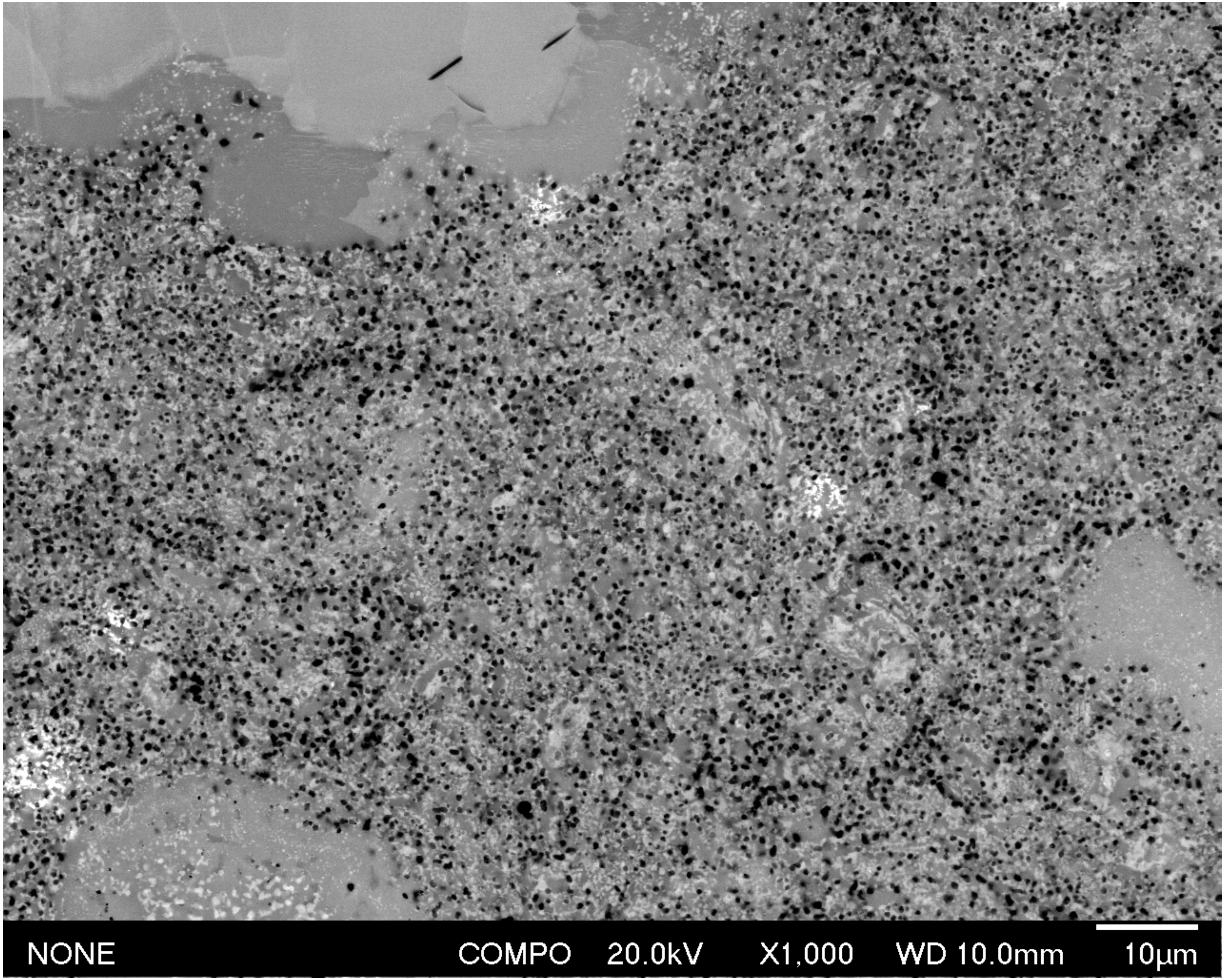
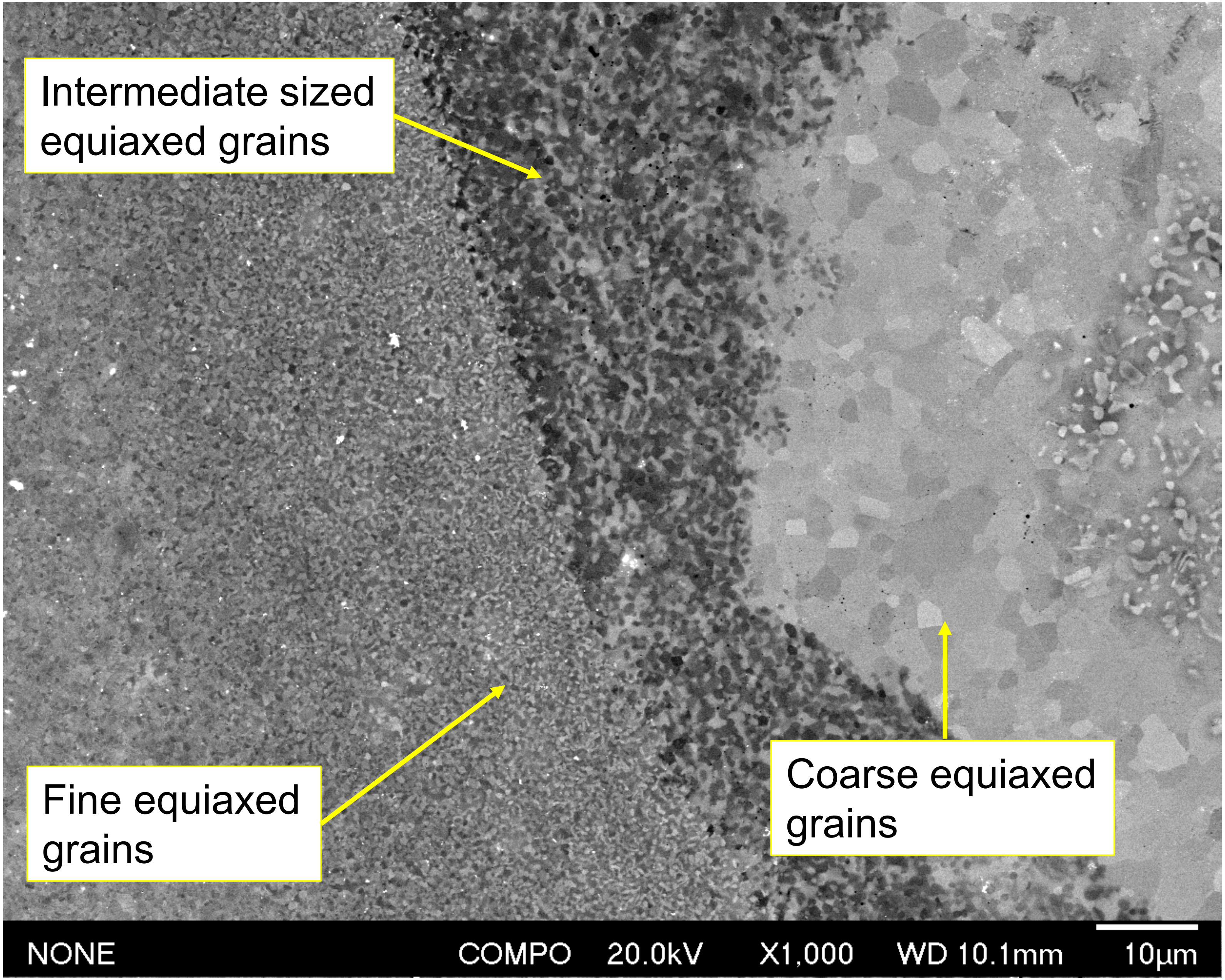
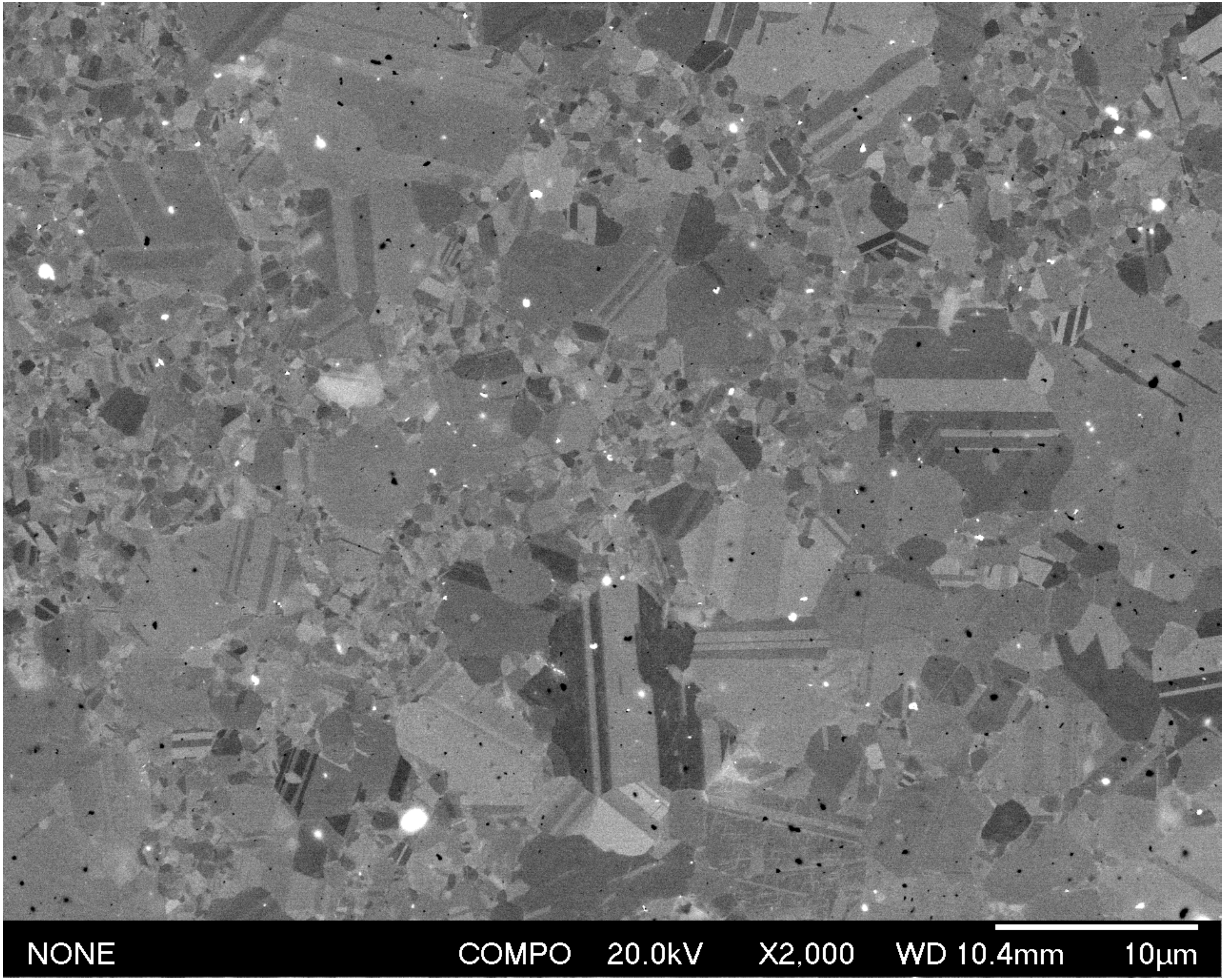


Figure 3: Microstructures of the as-sintered Ti-46.5Al-0.8Ta (at.%)


NONE
COMPO
20.0kV
X1,000
WD 10.0mm
10µm


Intermediate sized equiaxed grains
Fine equiaxed grains
Coarse equiaxed grains
NONE
COMPO
20.0kV
X1,000
WD 10.1mm
10µm


NONE
COMPO
20.0kV
X2,000
WD 10.4mm
10µm

Results and discussions

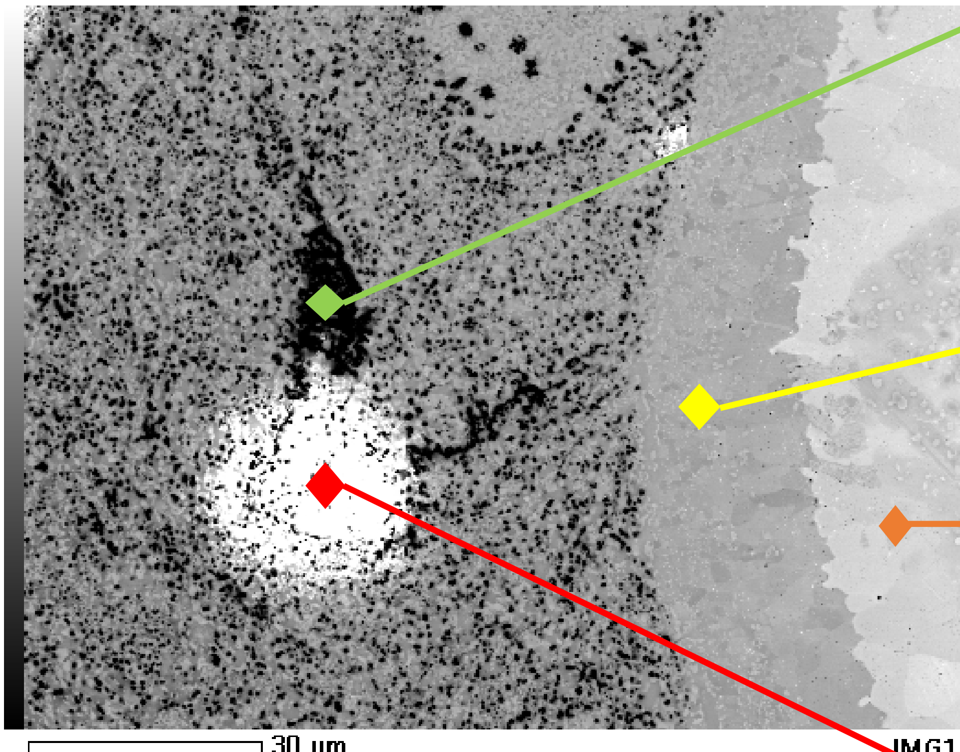


Figure 4: SEM-EDX spot analysis of the as-sintered Ti-46.5Al-0.8Ta (at.%)

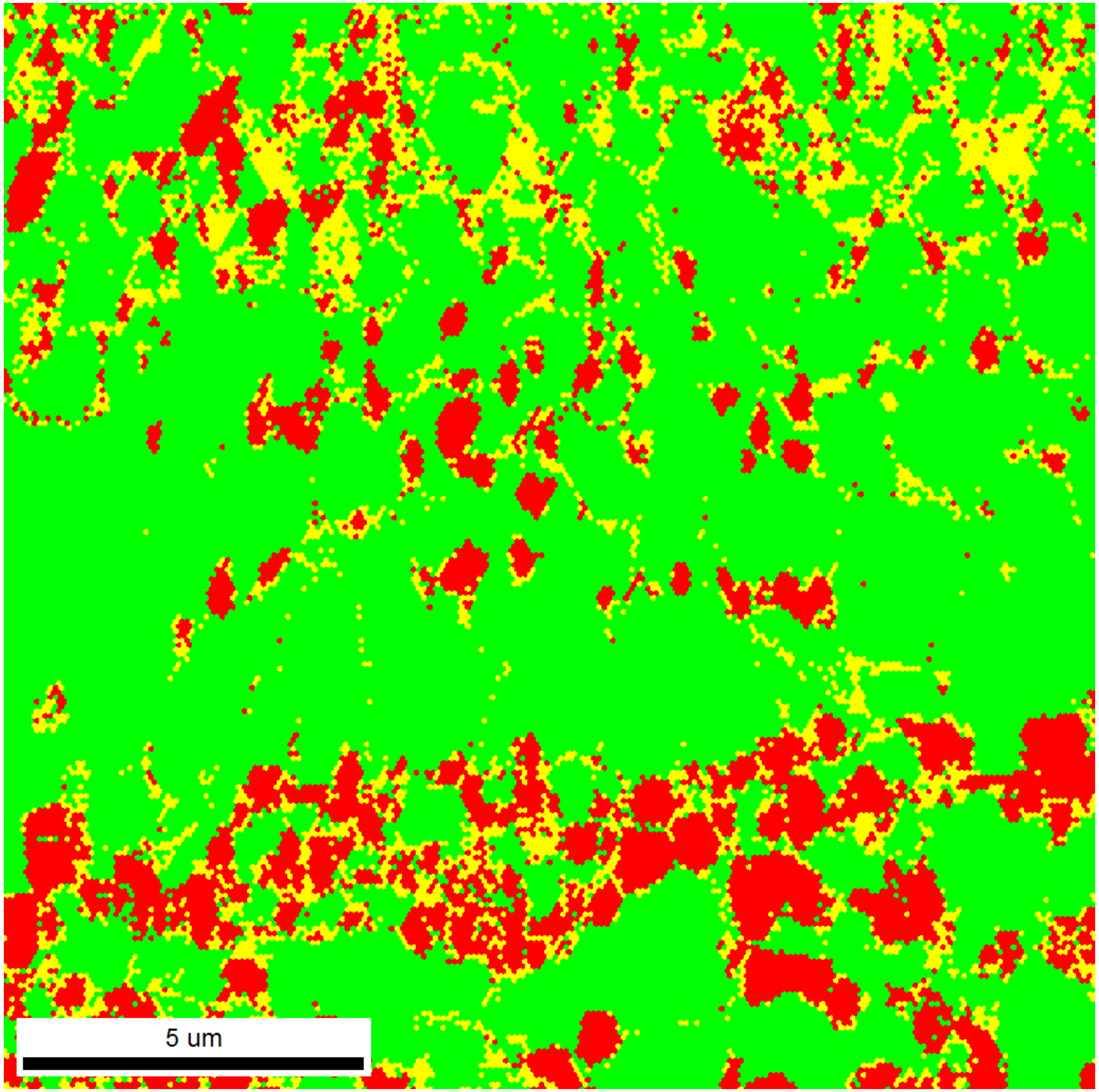
Element	Atom %	% Error
O	56.01	+/- 0.71
Al	35.08	+/- 1.57
Ti	8.85	+/- 0.85
Ta	0.07	+/- 0.01

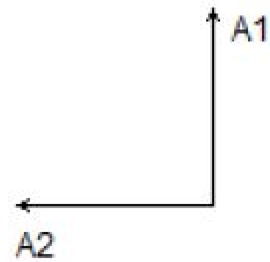
Element	Atom %	% Error
O	3.44	+/- 1.90
Al	48.01	+/- 2.55
Ti	48.47	+/- 1.93
Ta	0.10	+/- 0.02

Element	Atom %	% Error
O	6.27	+/- 0.81
Al	25.93	+/- 3.10
Ti	67.69	+/- 2.29
Ta	0.12	+/- 0.01

Element	Atom %	% Error
O	3.35	+/- 0.45
Al	52.80	+/- 0.72
Ti	34.51	+/- 0.26
Ta	9.35	+/- 0.92

Results and discussions





Color Coded Map Type: Phase

Phase	Total Fraction	Partition Fraction
Ti3Al-194	0.171	0.171
TiAl-123	0.699	0.699
TaAl-217	0.130	0.130

Figure 5: SEM-EBSD phase area fraction and distribution in the as-sintered Ti-46.5Al-0.8Ta (at.%)

Results and discussions

Influence of high oxygen presence in the as-sintered Ti-46.5Al-0.8Ta (at.%) alloy.

- expand the α-phase field and raise the eutectoid temperature of Ti-Al alloy systems[8].
- Hence during cooling, oxygen favoured the chemical ordering of $\alpha \rightarrow \alpha_2$ as a result of the significant difference in solubility of oxygen between the γ and α_2, with the equiaxed γ phase unaltered[8].

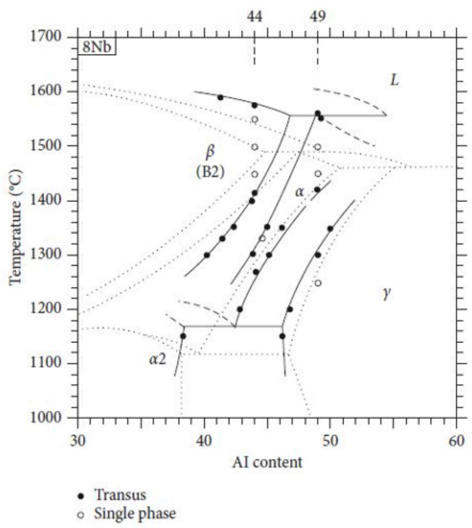


Figure 6: Quasi-phase diagram of TiAl-8Nb-xO[3]

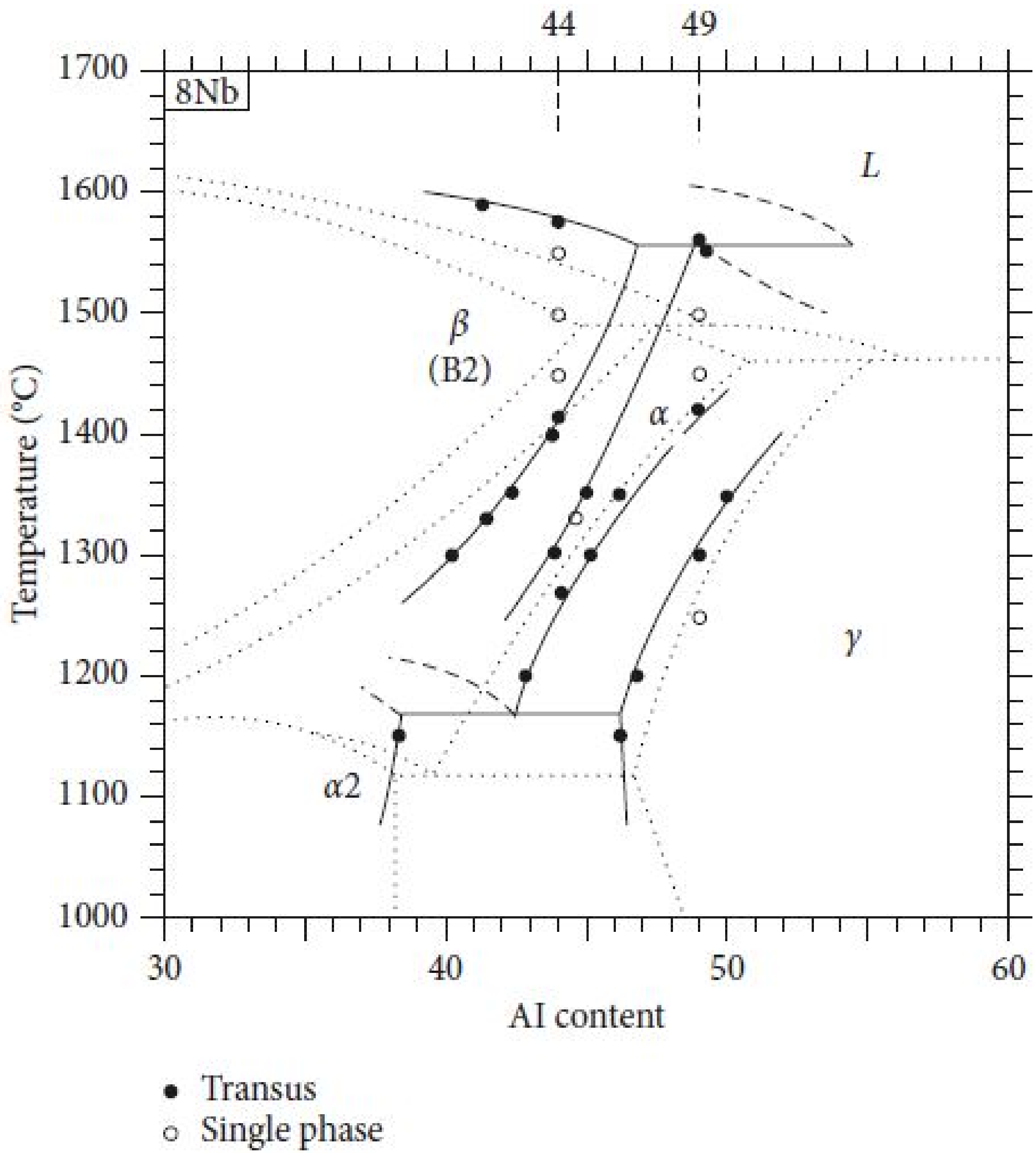


Figure 6: Quasi-phase diagram of TiAl-8Nb-xO[3]

Results and discussions

Formation of α-Al_2O_3

- *in situ* reaction occurred during the mechanical alloying process[9].

- when the ratio of Ti/Al is <1 or Ti/Al ratio ≥1 with high oxygen content, precipitation of α-Al_2O_3 is likely to occur in the α-phase then in the α_2 and γ-phases[10].

Presence of 0.8Ta (at.%)

- exhibit slow diffusivity in TiAl alloy which influenced the diffusion, chemistry and thermodynamic processes taking place in the alloys' microstructure formation[6].

Conclusions

The following conclusions were drawn from the study:

- The chemical compositions and microstructures of all the fabricated alloys were inhomogeneous. The predominant phases formed included the γ-TiAl, α_2-Ti_3Al, TaAl and α-Al_2O_3.

- The presence of oxygen expanded the α-phase field and raised the eutectoid temperature of the Ti-Al alloy system.

- The formation of α-Al_2O_3 (when the ratio of Ti/Al is <1 or Ti/Al ratio ≥1 with high oxygen content, precipitation of α-Al_2O_3 is likely to occur in the α-phase then in the α_2 and γ-phases).

- The slow diffusivity of the 0.8Ta (at.%) influenced the alloy microstructure formation

References

1. Geddes, B., Leon, H. and Huang, X. (2010) Superalloys - alloying and performance. ASM International.

2. Appel, F., Paul, J.D.H. and Oehring, M. (2011) Gamma Titanium Aluminide Alloys: Science and Technology. John Wiley & Sons.

3. Cobbinah, P.V., Matizamhuka, W.R. (2019) Adv. Mater. Sci. Eng. 2019, 21.

4. Loria, E. A., (2001) Intermetallics 9(12), 997.

5. Kothari, K., Radhakrishnan, R., and Wereley, N.M. (2012) Prog Aerosp Sci. 55, 1.

6. Saage, H., Huang, A., Hu, D., Loretto, M., and Wu, X. (2009) Intermetallics, 17(1-2) 32.

7. Banumathy, S., Sruti Neelam, N., Chandravanshi, V., Bhattacharjee, A., and Ravi, K.R. (2018) Mater. Today-Proc. 5(2). 5514.

8. Naka, S. (1996) Curr Opin Solid St Mat. 1(3), 333.

9. Li, Z. W., Gao, W., Zhang, D. L., and Cai, Z. H. (2004) Corros. Sci. 46(8), 1997.

10. Kawabata, T., Abumiya, T. and Izumi, O. (1992) Acta Metal. et Mat. 40(10), 2557.

Thank you