Interfacial microstructure and bonding mechanisms in diffusion bonded similar/dissimilar Ti and TiAl alloys

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Outline

1. Background
2. Bonding of similar Ti/Ti alloy
3. Bonding of dissimilar Ti/TiAl alloy
4. Summary

1. Background

□ Diffusion bonding

Diffusion bonding is a solid state joining process in which two independent surfaces can be joined at an elevated temperature using an applied pressure for a time ranging from a few minutes to several hours.

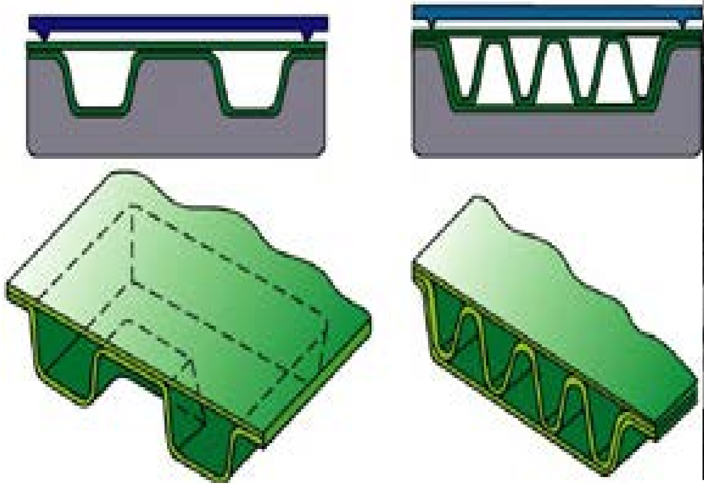
Advantages:

① Without fusion and heat affected zone;

② Comparable microstructure and property to base;

③ Full cross-sectional bonding;

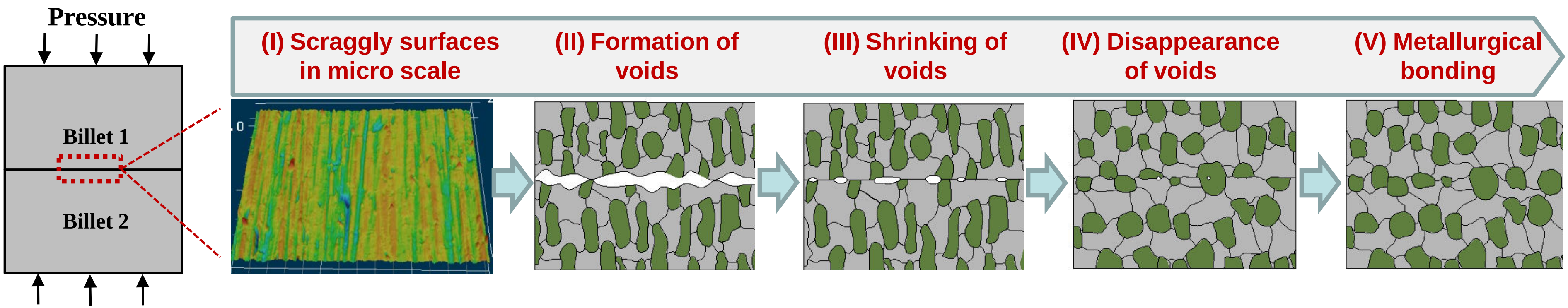
④ Being suitable for the bonding of similar/dissimilar materials.



1. Background

◻ Challenges

Bonding processes:



Two steps: Close contact between bonding surfaces by void shrinking

Metallurgical bonding by atom diffusion across bond line

Process characteristics:

High temperature

Long time

Low pressure (<10MPa)

Limit macroscopic plastic deformation

Low efficiency

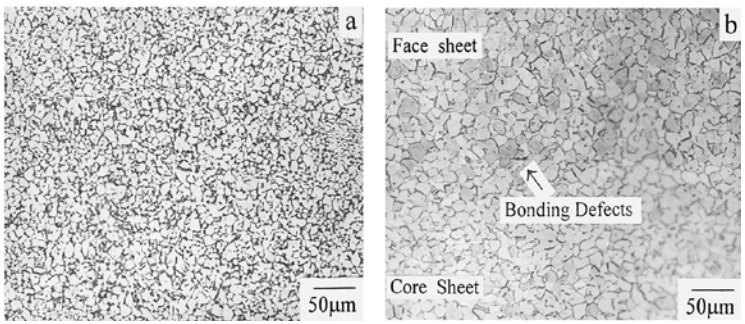
High cost

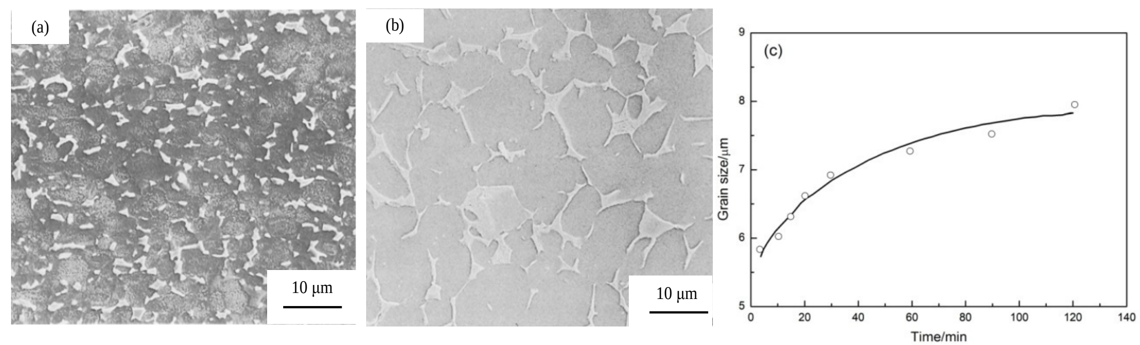
Limit application

1. Background

□ Challenges

Titanium alloy ⇨ **High temperature** / **Prolonging time** ⇨ **Coarsening grain** / **Decreasing properties**





Tensile strength of the base ↓ 10.2%

Yield strength of the base ↓ 11.3%

Y.W. Xun, M.J. Tan. J. Mater. Proc. Tech., 2000, 99(1-3): 80~85

F.A. Calvo, J.M. Gómez De Salazar, A. Urena, et al. J. Mater. Sci.，1992, 27(2): 391~398

Imposing plastic deformation caused by large pressure?

High quality

High efficiency

Low cost

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2. 1 Experiment

□ Materials

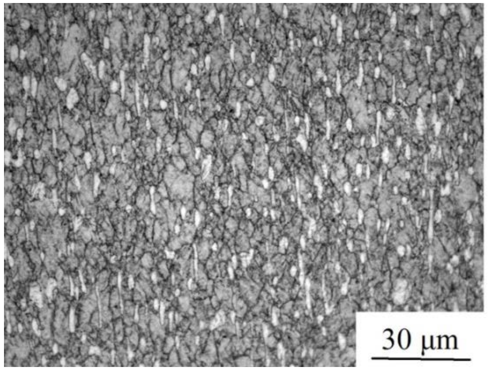
TC17 alloy

(Ti-5.1Al-2.3Sn-2.0Zr-4.1Mo-4.1Fe)

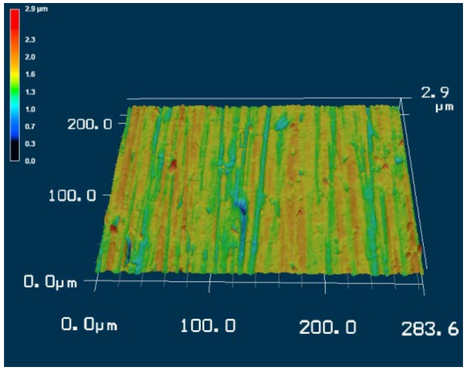
β transus temperature: 890-900℃

Shear strength: 871.8 MPa

Specimens：Φ30.0 mm×20.0 mm

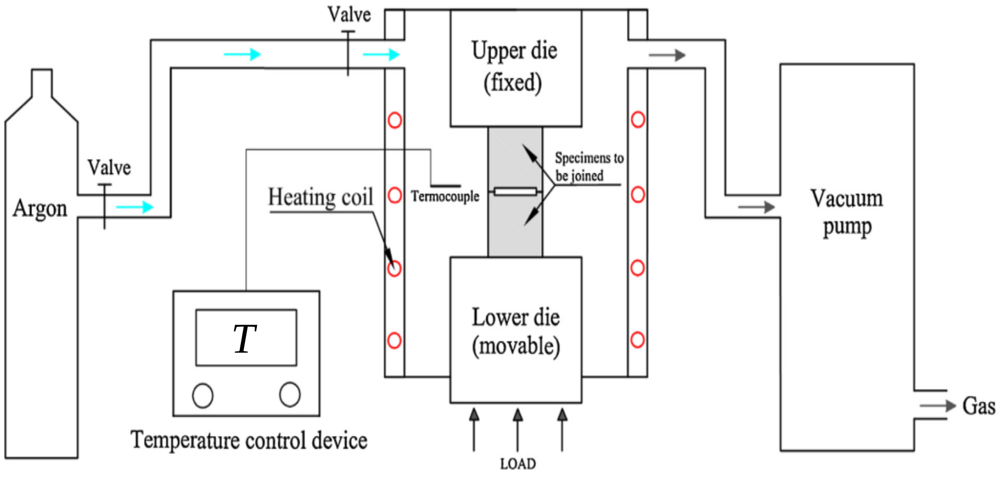


Initial microstructure of TC17 alloy



Surface roughness Ra=0.46μm

□ Bonding procedure



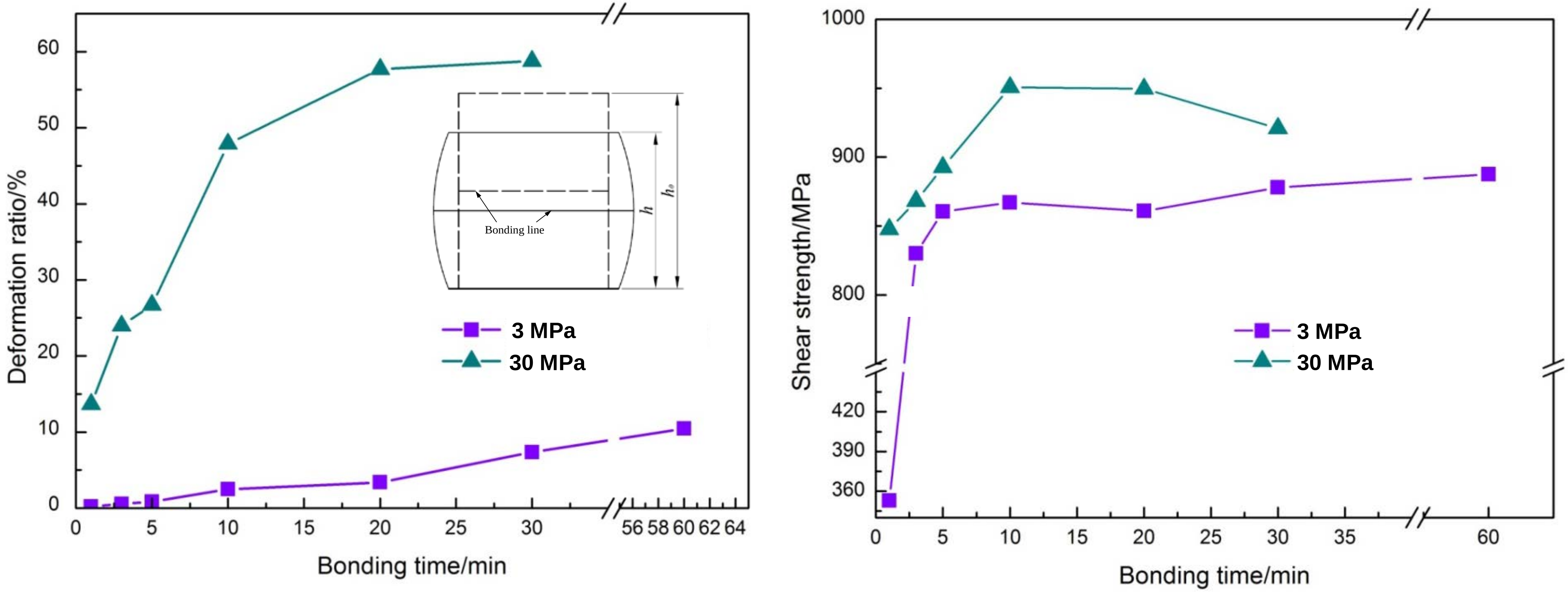
Schematic illustration of bonding procedure

Bonding parameters

Temperature (T)/℃	860
Pressure (p)/MPa	**3, 30**
Time (t)/min	1,3,5,10,20,30,60

2. 2 Interface characteristic under large pressure

◻ Effect of time on plastic deformation and shear strength of bond



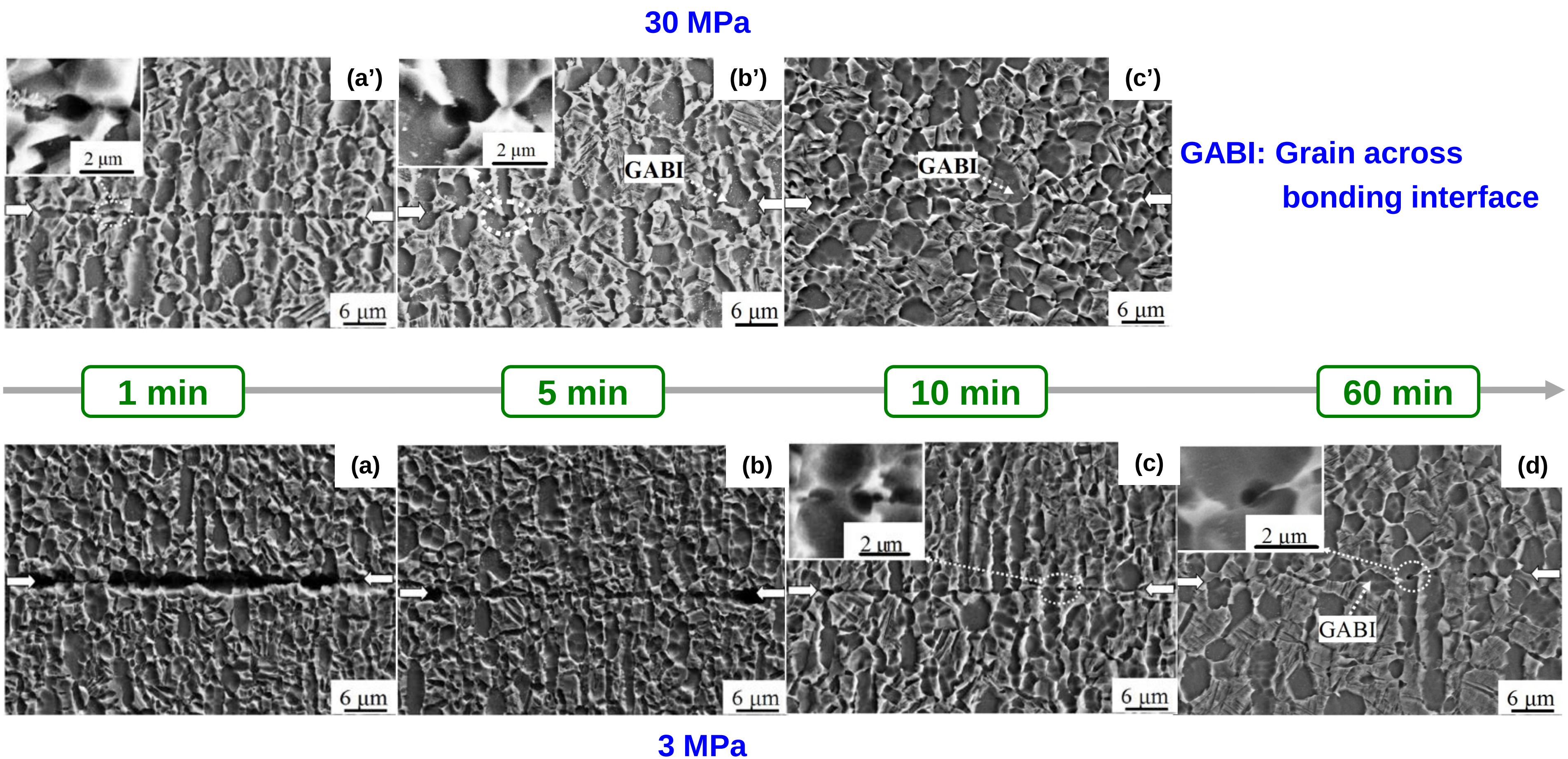
Effect of time on plastic deformation and shear strength of bond at different pressures

① **A macroscopic plastic deformation occurs under the larger pressure.**

② **The bond with higher shear strength can be obtained in 10 min.**

2. 2 Interface characteristic under large pressure

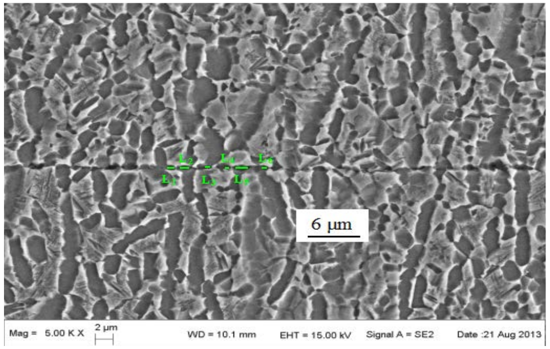
□ Effect of time on interfacial microstructure



The remained void is much smaller and the bonding areas free of voids are larger as the pressure is 30 MPa.

2. 2 Interface characteristic under large pressure

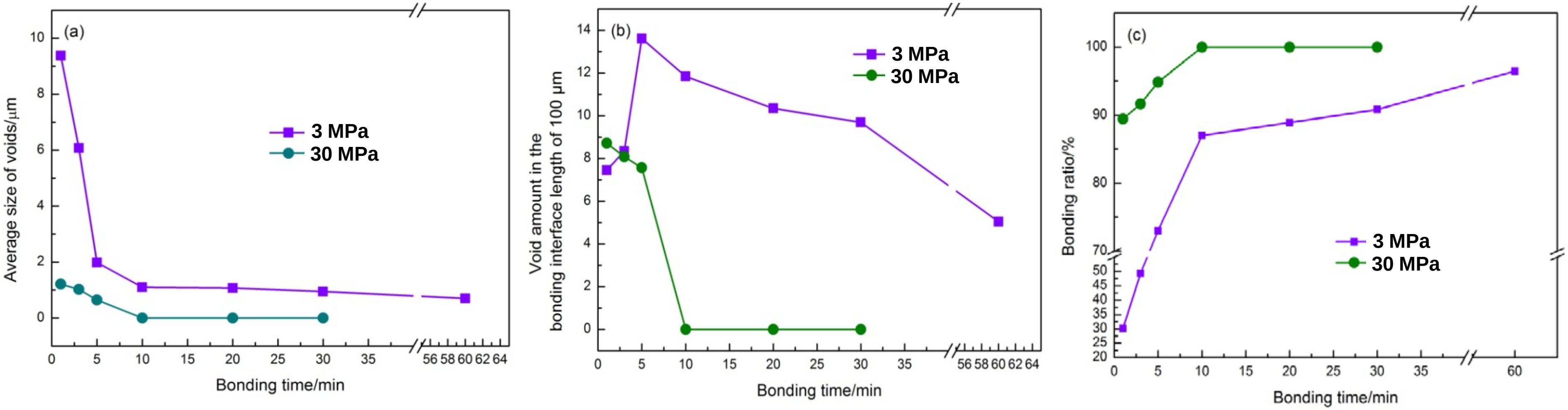
□ Effect of time on void size and bonding ratio



Void size measuring method

Void size**:** The maximum linear length of the void in the direction of bonding interface.

Bonding ratio**:** The ratio of the length of interface free of void to the length of the whole interface.



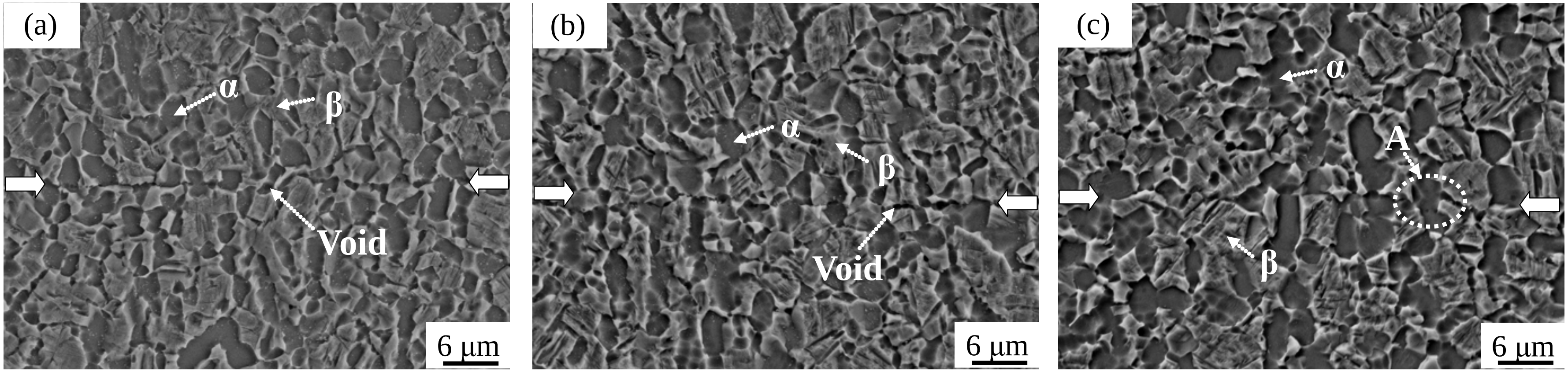
Effect of time on void size, void amount and bonding ratio

- **The void can be quickly shrunk in a short time by imposing larger pressure**
- **The bond free of voids can be obtained in 10 min as the pressure is 30 MPa.**

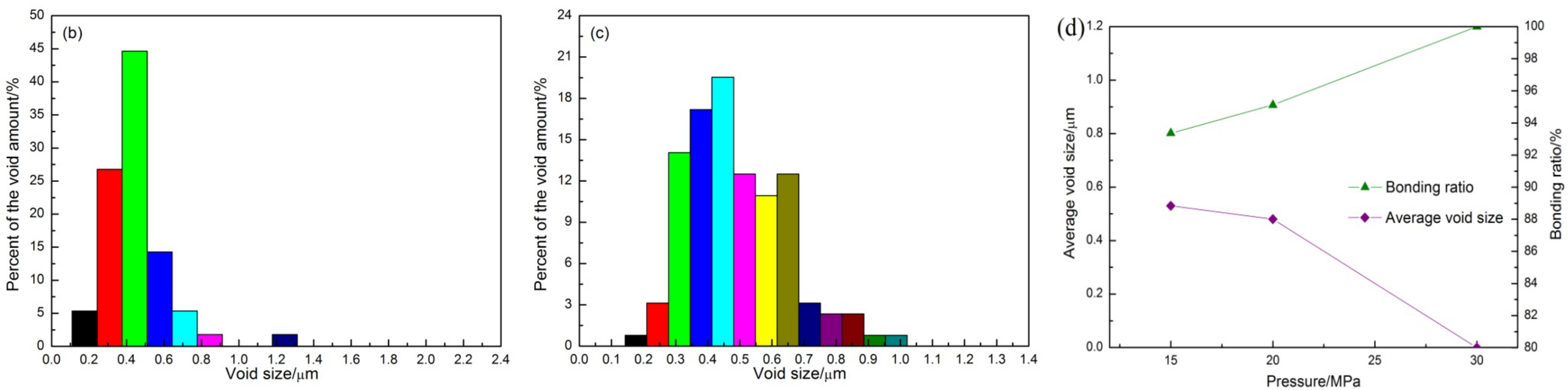
2. 3 Effect of plastic deformation

□ Interfacial microstructure

Different deformation ratios 16%, 21.2%, 47.9% were given by imposing different pressures 15 MPa, 20 MPa, 30 MPa in 860℃ for 10 min.



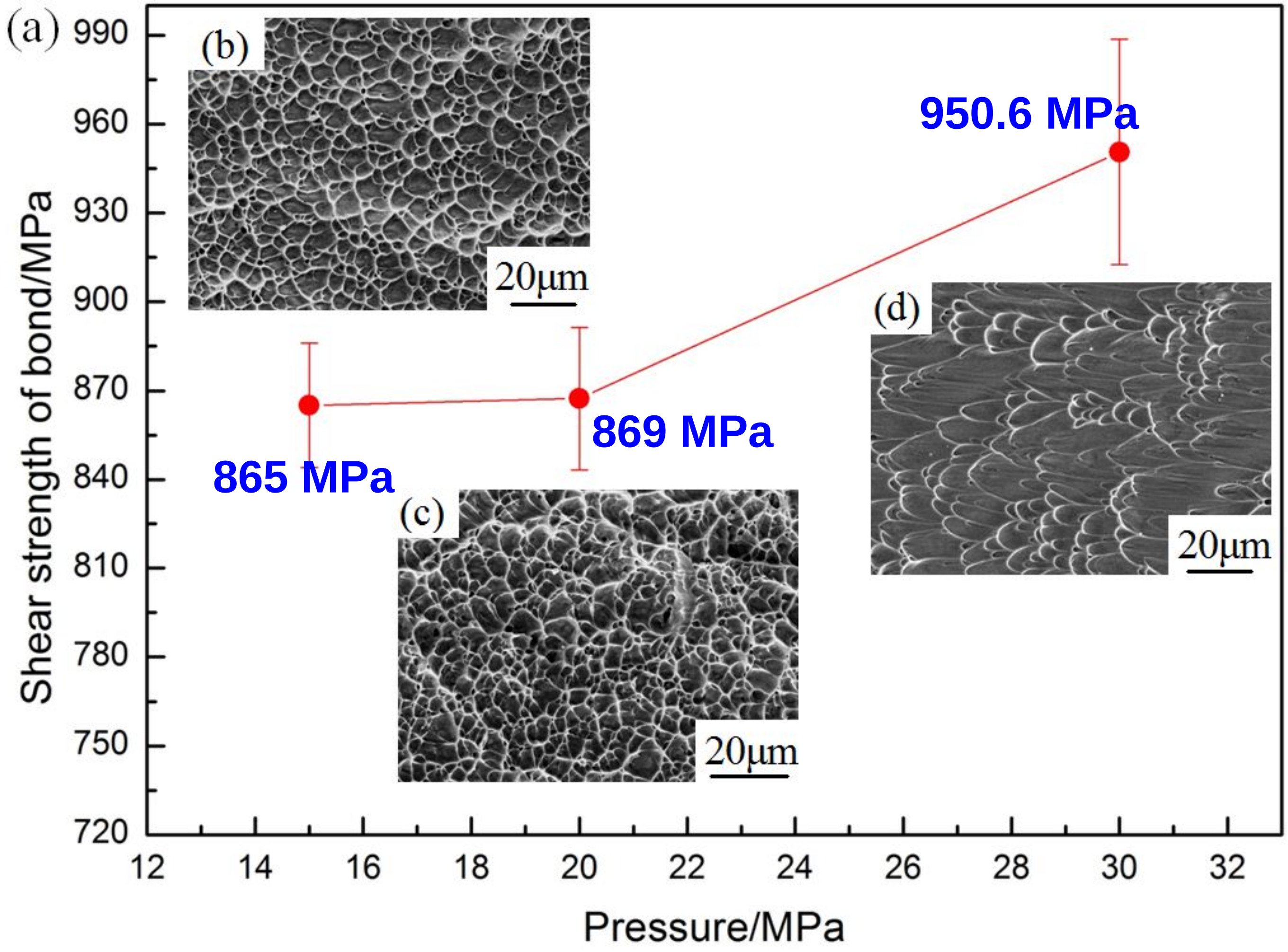
Interfacial microstructure at different deformation ratios：(a) 16%；(b) 21.2%；(c) 47.9%



Void size distribution at different deformation ratios：(a) 16%；(b) 21.2% and (c) bonding ratio and average void size

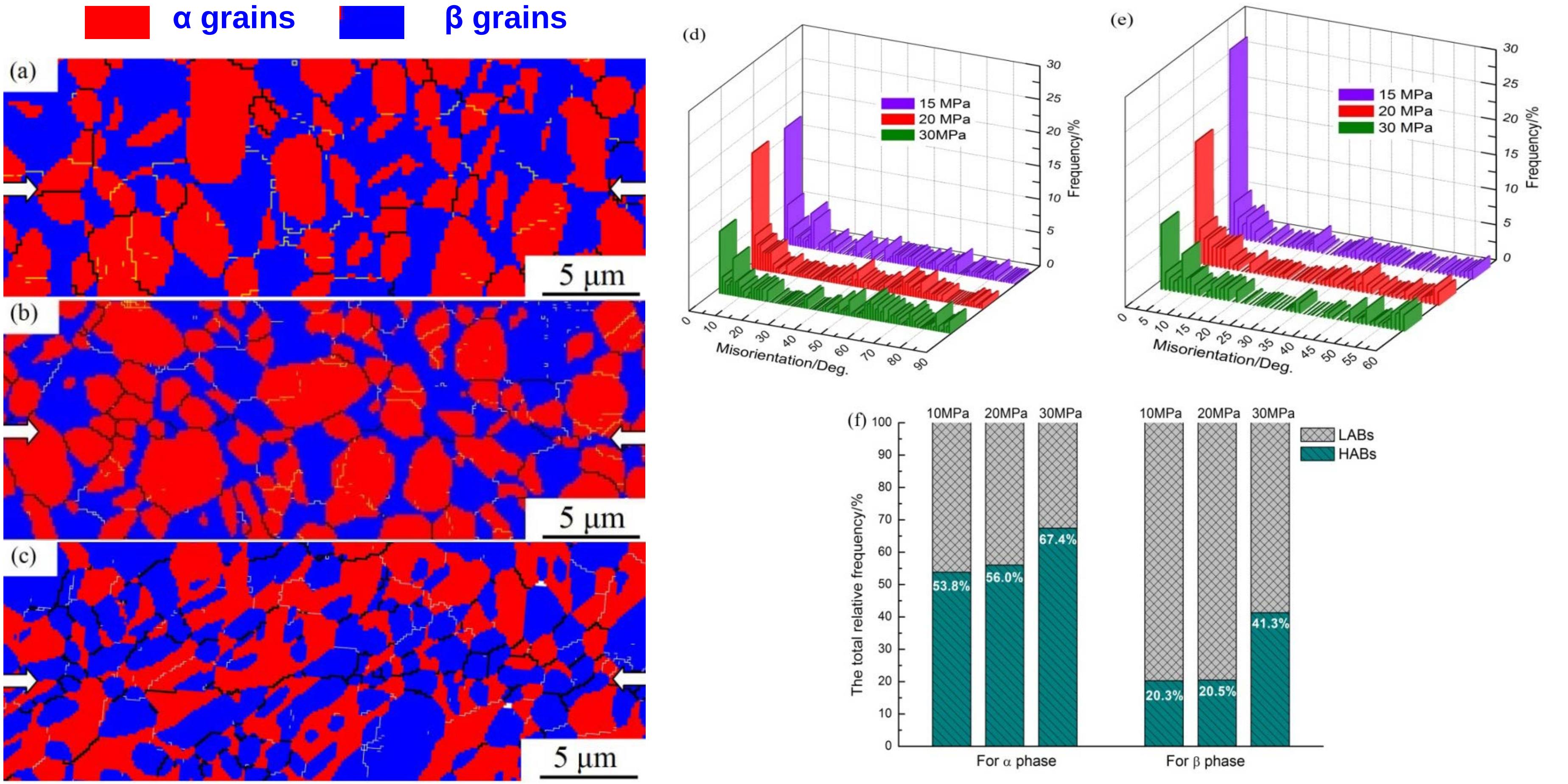
2. 3 Effect of plastic deformation

☐ Shear strength of bond



2. 3 Effect of plastic deformation

□ Interfacial grain boundary



EBSD orientaion maps of bonds at different bonding ratios: (a) 16%; (b) 21.2%; (c) 47.9% and misorientation angle distribution of (d) α grains and (e) β grians, and (f) the total relative frequency of HABs and LABs.

Larger deformation ratio induces more HABs with higher atom diffusion coefficient.

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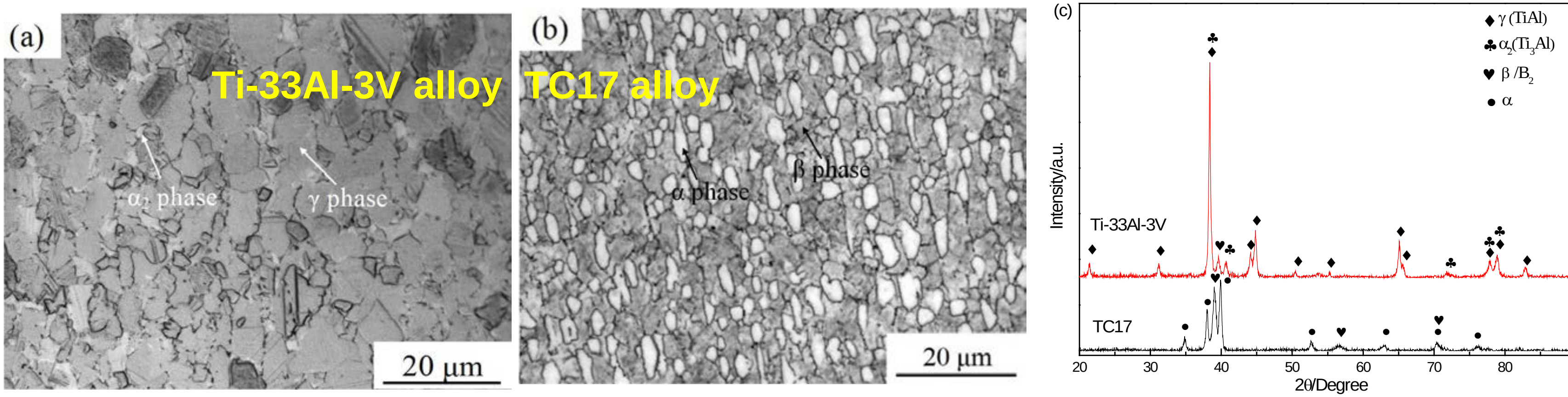
3. 1 Experiment

☐ Materials



Microstructure of as-received alloys: (a) Ti-33Al-3V; (b) TC17. (c) XRD patterns of Ti-33Al-3V and TC17.

☐ Bonding parameters and microstructure analysis

I. Diffusion bonding:

Pressure (MPa): 23, 39, 50;

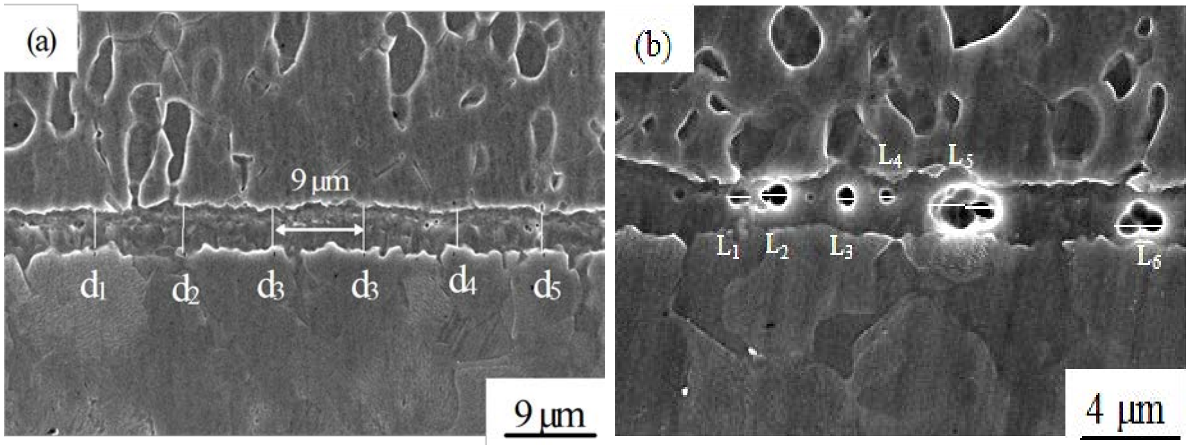
Temperature (℃): 850;

Time (min): 10.

II. Post heating:

Temperature (℃): 840;

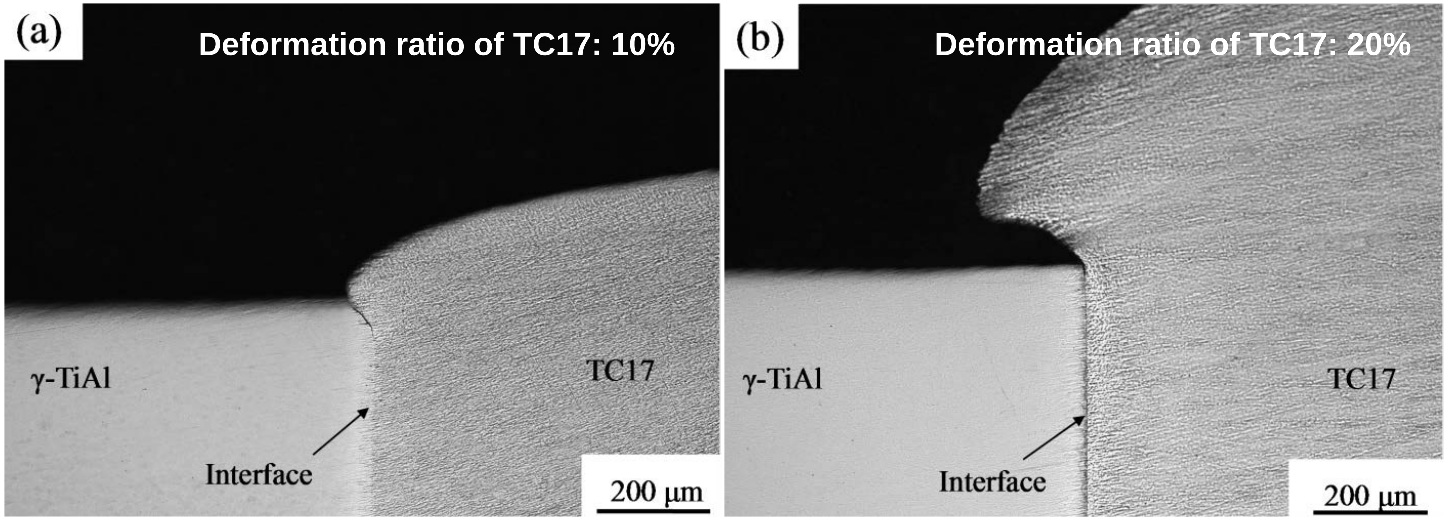
Time (min): 60 .

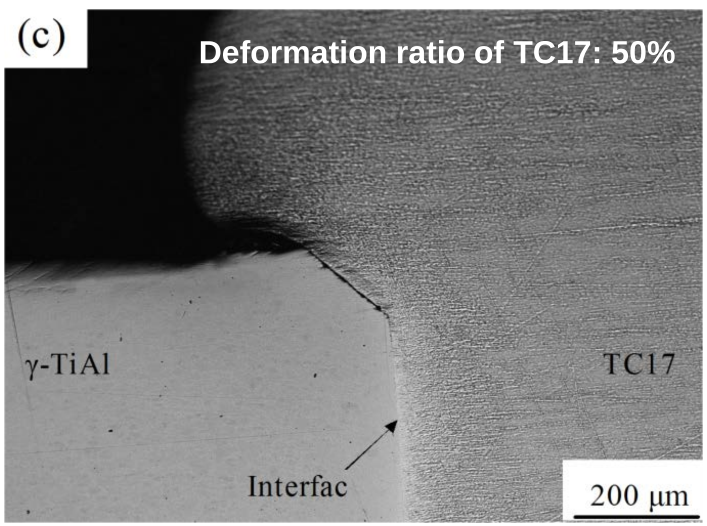


Schematic diagram for measuring (a) the width of interfacial zone and (b) void size

3. 2 Microstructure of Ti/TiAl bond

□ Macroscopic morphologies of bond





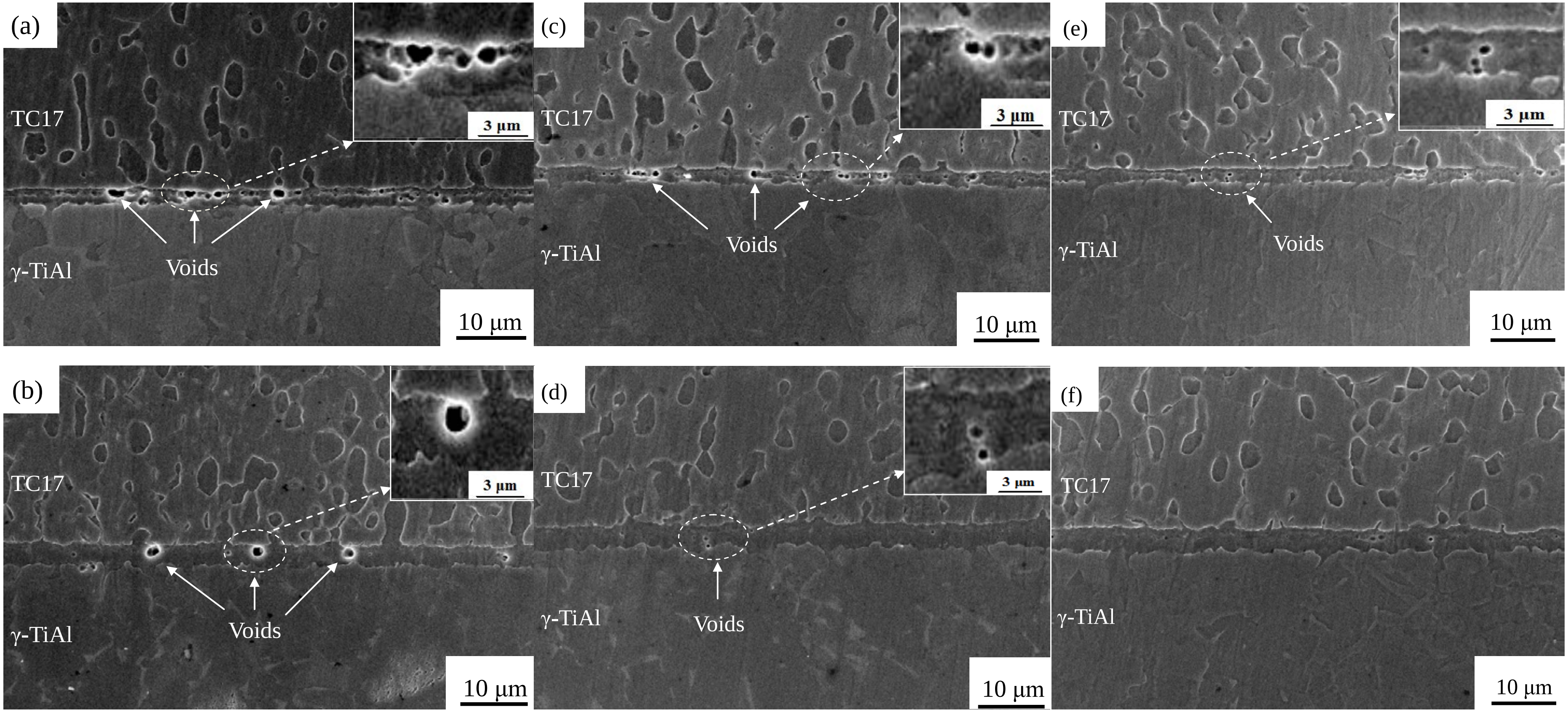
① **Ti-33Al-3V and TC17 have been metallurgically bonded and become an inseparable entity.**

② **The plastic deformation of Ti-33Al-3V base is rarely observed, whereas the plastic deformation of TC17 base is obvious and increases with the increase in pressure.**

Macroscopic morphologies of Ti-33Al-3V/TC17 bonds at the temperature of 850℃, time of 10 min and different pressures: (a) 23 MPa; (b) 39 MPa; (c) 50 MPa.

3. 2 Microstructure of Ti/TiAl bond

☐ Microstructure of bond

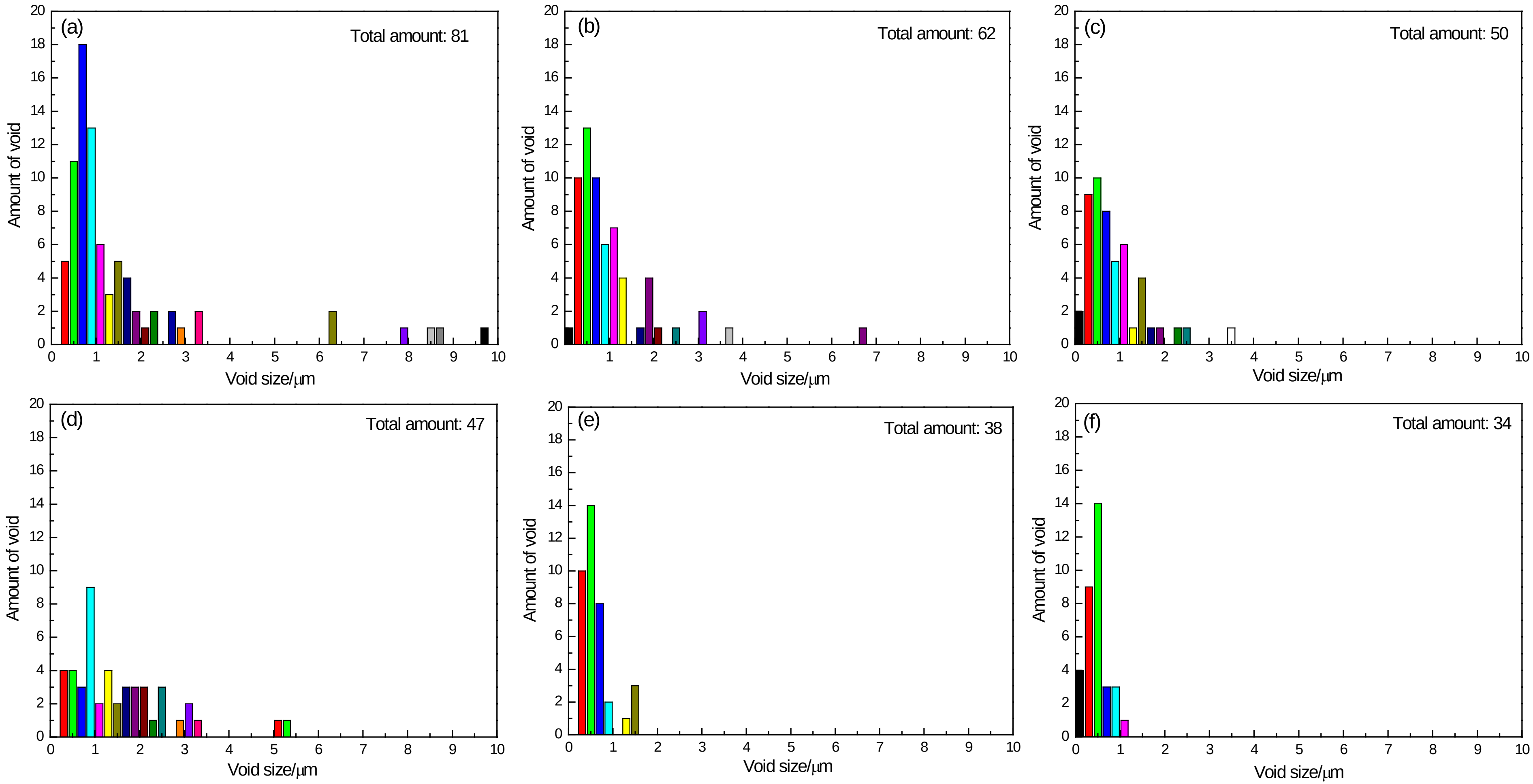


The SEM images of Ti/TiAl bond at a temperature of 850℃, time of 10 min and a deformation ratio of: (a) 10%; (b) 10%+heating; (c) 20%; (d) 20%+heating; (e) 50%; (f) 50%+heating.

Increasing the deformation ratio and post heating induce the void shrinkage and the increasing of interfacial zone width.

3. 2 Microstructure of Ti/TiAl bond

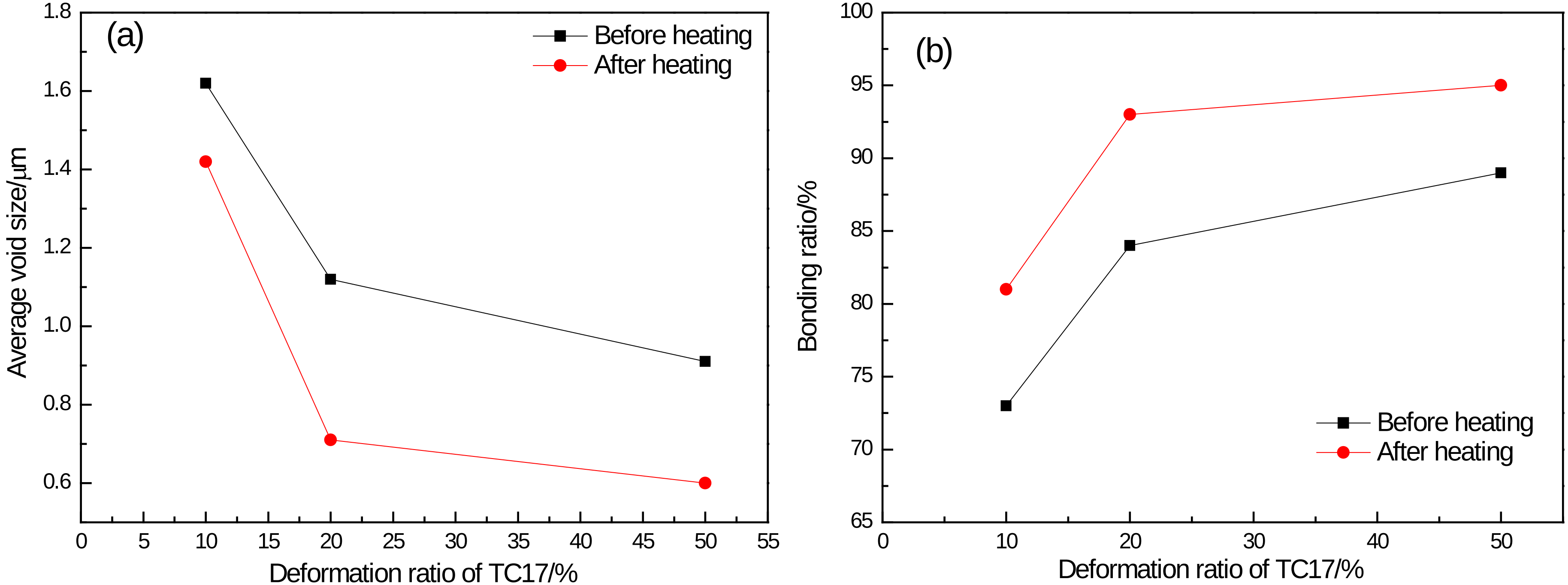
□ Void evolution



Amount of void with different size in the γ-TiAl/TC17 bond at different deformation ratios of TC17: (a) 10%; (b) 20%; (c) 50%; (d) 10%+heating; (e) 20%+heating; (f) 50%+heating.

3. 2 Microstructure of Ti/TiAl bond

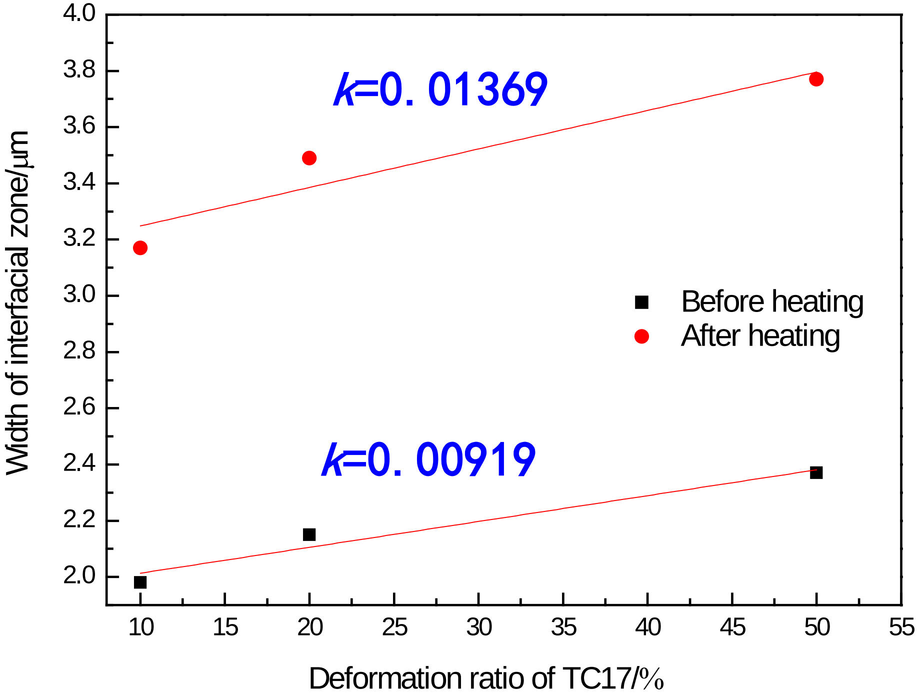
□ Void evolution



Influence of deformation ratio of TC17 on the average void size (a) and bonding ratio (b) in the γ-TiAl/TC17 bond without and with post heating.

3. 2 Microstructure of Ti/TiAl bond

□ Width of interfacial zone



$$W = W_0 + k\delta$$

W **is the final width of diffusion zone;**

W_0 is the original width of diffusion zone without the action of plastic deformation;

k **is the rate constant;**

δ is the deformation percentage of TC17.

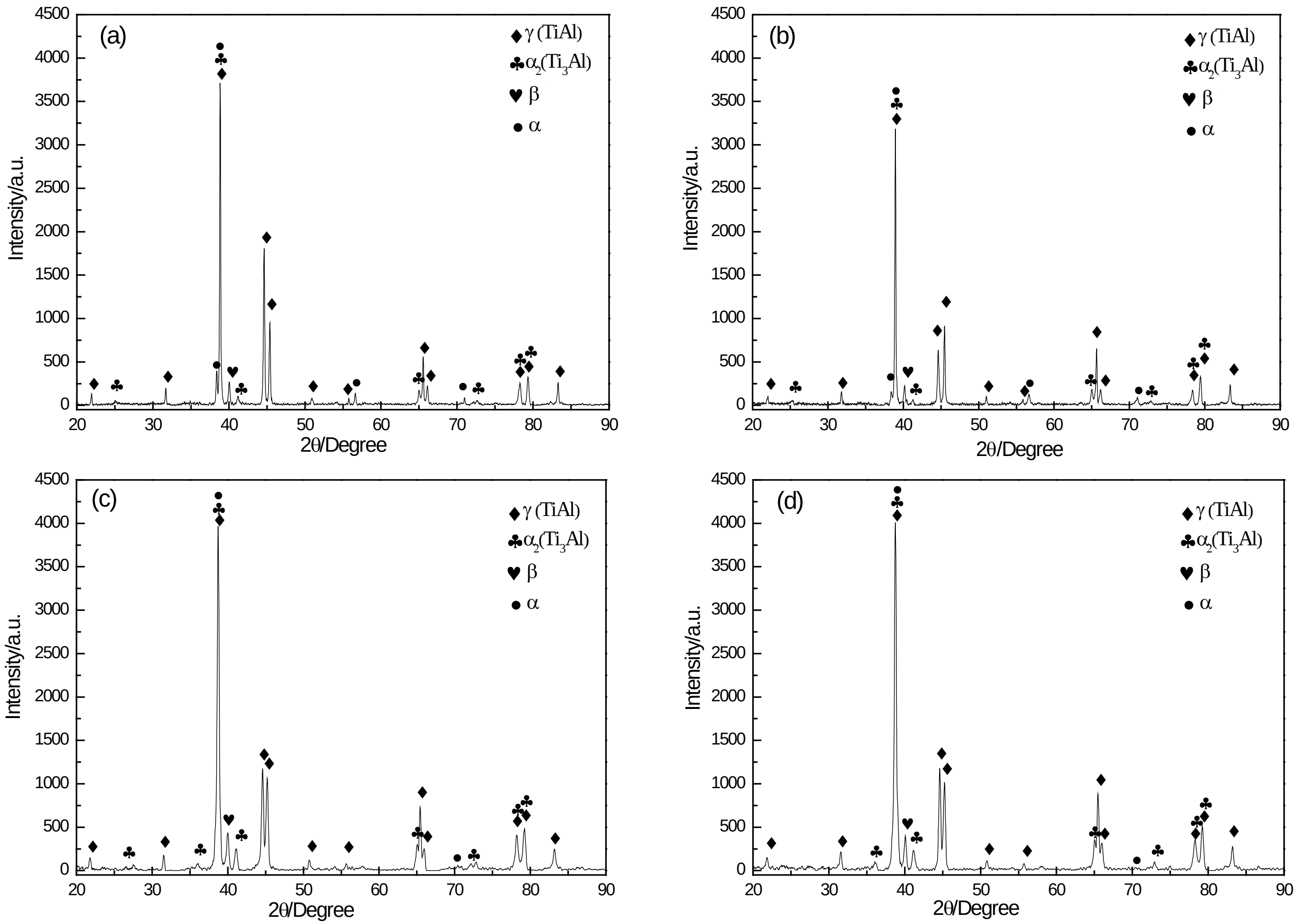
① **The variation of the width of interfacial zone with pressure obeys the linear increasing law；**

② **The heating promotes the increase in width of interfacial zone ；**

③ **The increment of width of interfacial zone during heating is more significant as the deformation ratio is higher.**

3. 2 Microstructure of Ti/TiAl bond

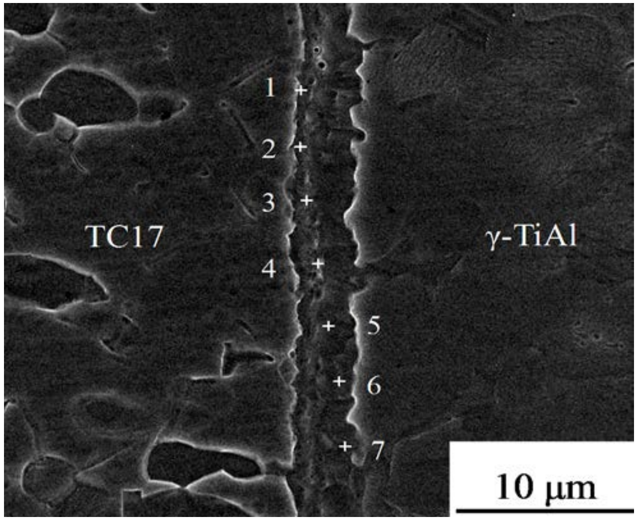
□ Phase compositions



Results of XRD analysis of γ-TiAl/TC17 bonds at different deformation ratios of TC17: (a) 10%; (b) 10%+heating; (c) 50%; (d) 50%+heating

3. 2 Microstructure of Ti/TiAl bond

□ Phase compositions



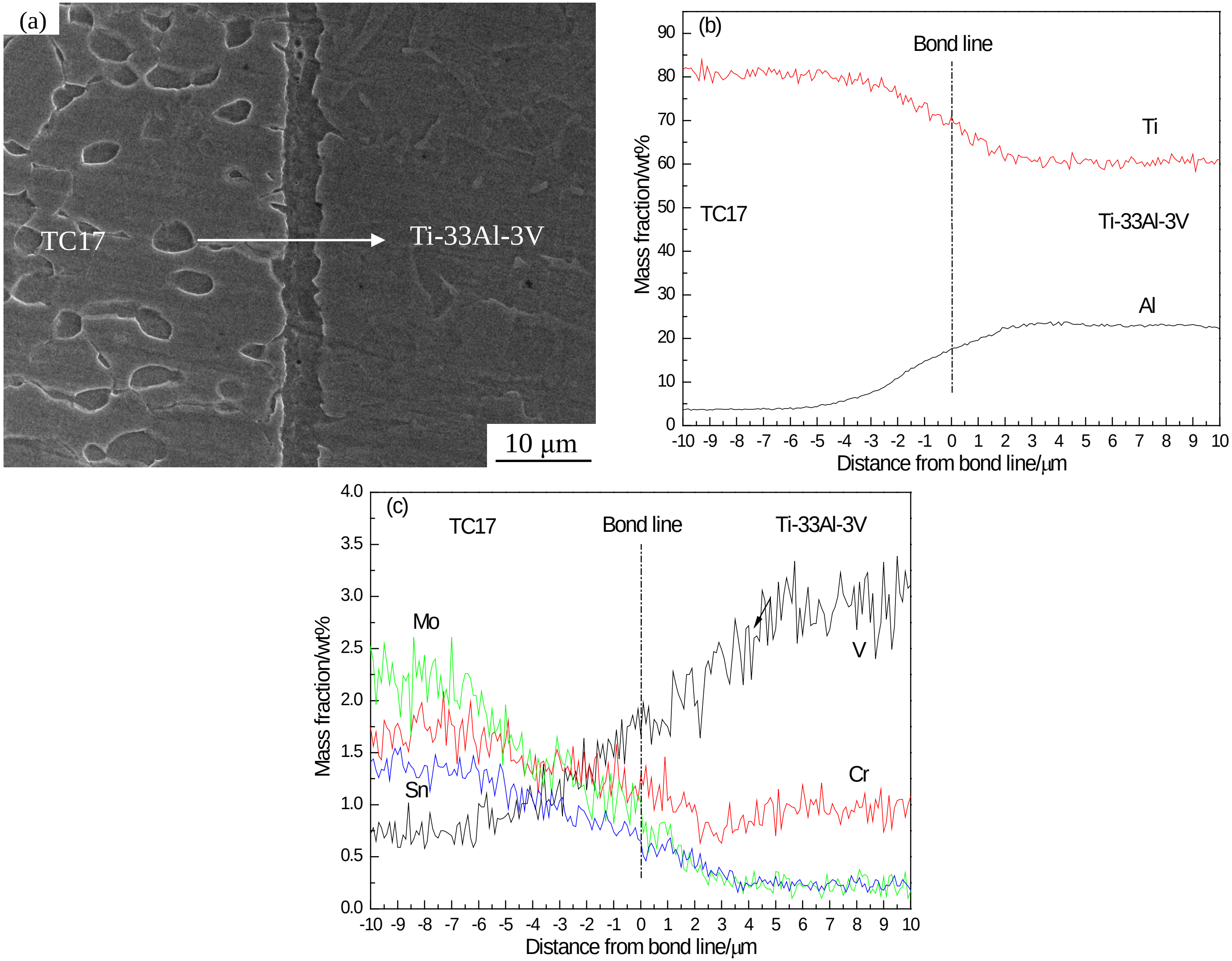
Selected positions for EDS point analysis in the interfacial zone.

The new α_2 (Ti_3Al) phase forms in the interfacial zone.

Results of EDS point analyses of interfacial zone and base alloys

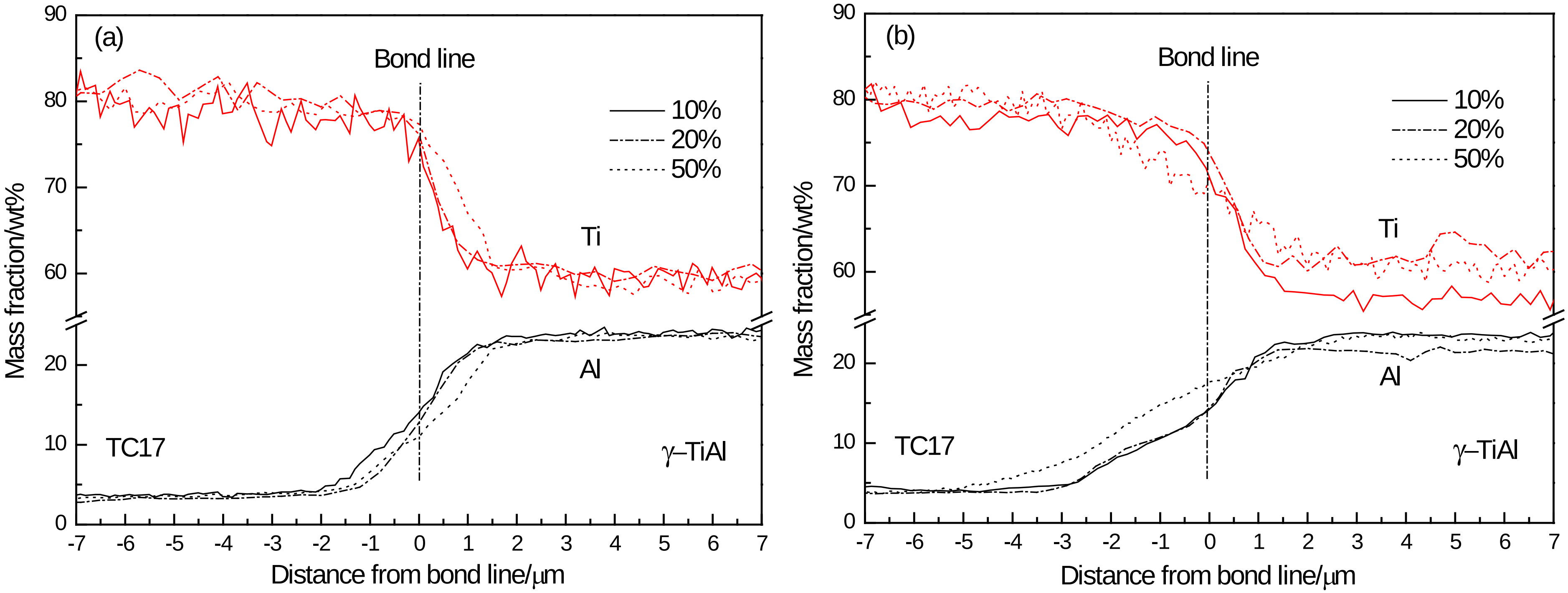
Position		Chemical composition/at%						
		Al	Ti	V	Cr	Zr	Mo	Sn
Diffusion zone	1	9.61	84.58	0.51	1.91	1.04	1.45	0.91
	2	11.5	82.83	—	2.48	1.05	1.69	0.87
	3	21.85	74.26	—	1.33	1.06	0.78	0.72
	4	23.64	74.39	0.14	0.66	0.59	0.28	0.3
	5	27.48	70.36	0.59	0.59	0.5	0.31	0.17
	6	33.8	60.58	3.33	1.67	0.4	0.18	0.04
	7	40.66	56.62	2.56	0.98	0.34	0.11	0.09
TC17 alloy	β	7.75	83.62	—	4.38	1.14	2.49	1.00
	α	9.62	84.92	—	2.87	0.92	1.50	0.93
γ-TiAl alloy	γ	47.01	49.97	2.33	0.74	0.02	—	0.12
	α_2	36.78	58.28	3.18	1.50	0.14	0.16	—

3. 3 Atomic diffusion behavior



EPMA line analysis results in the Ti-33Al-3V/TC17 bond at the pressure of 50 MPa with post heating: (a) position of analysis, (b) concentration profiles of Ti and Al; (c) concentration profiles of V, Mo, Cr and Sn.

3. 3 Atomic diffusion behavior

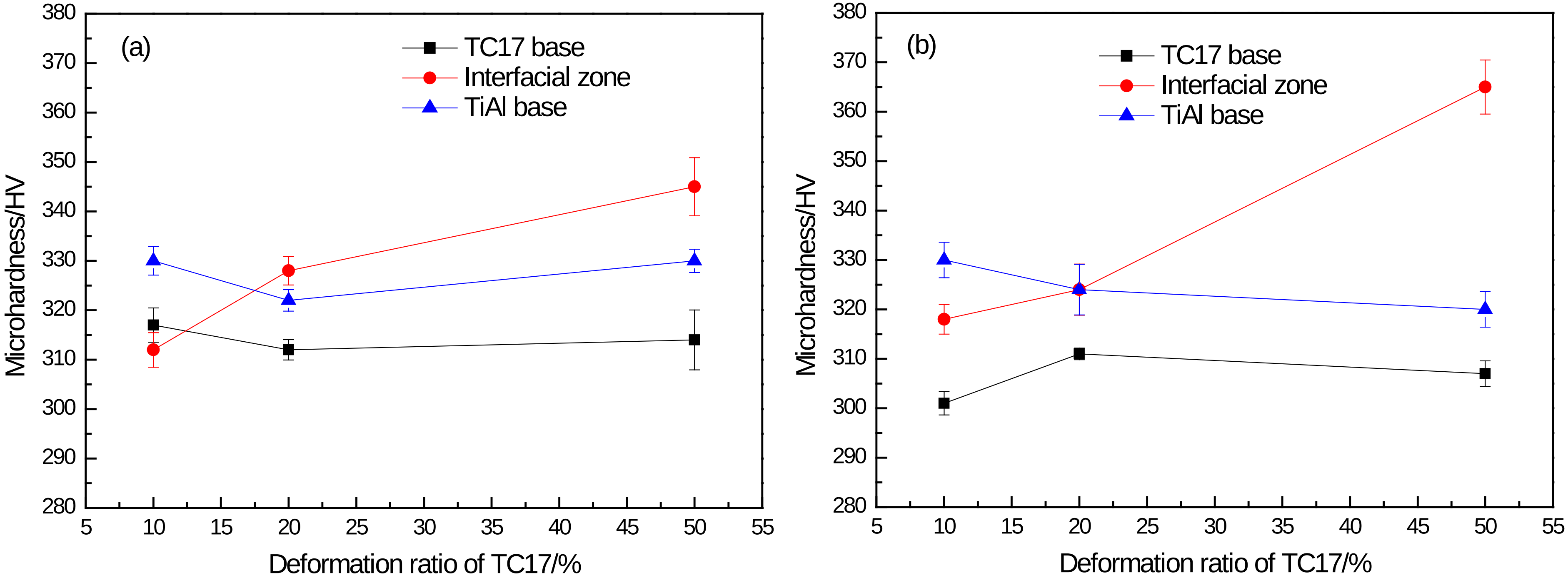


EPMA line analysis results of Al atom and Ti atom in the γ-TiAl/TC17 bonds with different deformation ratios of TC17 without (a) and with (b) post heating.

① **The diffusion flux of Ti atom is from TC17 towards TiAl and the diffusion flux of Al atom is in the inverse direction.**

② **The higher deformation ratio induces the farther distance of atom diffusion, and this variation becomes more sufficient during post heating.**

3. 4 Microhardness of Ti/TiAl bond



Microhardness of interfacial zone and base alloys at different deformation ratios of TC17 without (a) and with (b) post heating.

① **The influence of deformation ratio and heating on the microhardness of base alloys can be ignored. TC17 base: 298-320 HV; TiAl base: 320-334 HV;**

② **The microhardness of bond increases with the increase in deformation ratio, and the variation is more significant during the post heating。**

4 Summary

① **By imposing the large plastic deformation, the bonding quality can be improved significantly, and the bonding temperature and time decrease.**

② **The contribution of plastic deformation on the bonding process is from two aspects: one is to promote the interfacial void shrinkage and the other is to enhance the atom diffusion across bond line.**

③ **In future, more attention should be paid to the increasing the bonding efficiency and decreasing the cost by improving the bonding process and developing of related equipments.**

Thank you

for your attention!

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