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Microstructure and properties of burn-resistant Ti-Al-Cu alloys

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Ti-Al-Cu series burn-resistant alloys are newly developed materials which have low density, low cost and are easy to process. The results show that Ti-Al-Cu alloys have good burn resistance due to their good thermal conductivity, low melting point, and the existence of Ti_2Cu phase which also has a very low melting point. Ti-Al-Cu alloys have excellent thermal processability and good room and high temperature tensile properties, but an increase in copper content harms their thermal stability. After thermal exposure for a long time, Ti_2Cu phase will coalesce and coarsen, but the addition of Si and Al will be useful for their thermal stability. The Ti-13Cu-1Al-0.2Si alloy has good thermal stability at 540°C and good creep resistance at 300°C and 100 MPa. The phases of Ti-Al-Cu alloys were found to be composed of α phase and Ti_2Cu. The character of the Ti_2Cu phase changes with the increasing copper content. *© 2000 Kluwer Academic Publishers*

1. Introduction

Many titanium alloys have been used on fan compressor and other parts for modern gas turbine engines. Under the conditions of high air pressure and temperature, conventional titanium alloys can be ignited, and the significant heat of burning can seriously damage surrounding metal components. Since 1956, a few incidents of titanium component ignition in aircraft gas turbine engines has occurred. With the increasing thrust-to weight ratio in aero-engines, air pressures and service temperatures have increased, making the development of burn-resistant titanium alloys imperative. The U.S.A and Russia have developed various kinds of burn-resistant titanium alloys such as Alloy C (Ti-35V-15Cr) [1] and the BTT-1 and BTT-3 alloys (Ti-Al-Cu alloys whose content are not reported) [2]. At present, reported information about Ti-Al-Cu series alloys is very limited. NIN in China began the study of burn-resistant alloys which are Ti-V- Cr-Si (Ti40) [3–9] and Ti-Al-Cu (Ti14) [3, 10]. Although Ti-Al-Cu alloys exhibit lower burn resistance than the Ti-V-Cr alloy, they offer low density, low cost, and good processability. This study evaluates the microstructures, processing and properties of these Ti-Al-Cu alloys.

2. Experimental procedure

The alloys evaluated in this study were as follows: Ti-13Cu (B1), Ti-3Al-13Cu (B2), Ti-3Al-15Cu (B3), Ti-3Al-20Cu (B4), and Ti-1Al-13Cu-0.2Si (B5). B1-B4 alloys were 400 g button ingots which were vacuum-arc melted with sponge titanium. Pure copper and pure aluminum. They were remelted four times to make the composition homogeneous. After being hot upset forged to pancakes of 8 mm thickness, they were hot rolled into 3–4 mm thick plate and then cold rolled. B5 was a 4 kg ingot which was melted by vacuum consumable arc furnace, then it was forged to 20 mm bar. After solution and aging heat treatment, the mechanical properties were examined, burn resistance was evaluated by the liquid metal method [11]; and the microstructure and phase constituents were studied by optical microscope, H600 transmission electron microscope (TEM) and PW1700 X-ray diffraction instrument.

3. Results

3.1. Processability

The processing behavior of B10B4 alloys during forging, hot-rolling and cold-rolling is described in Table I.

It can be seen that B1-B4 alloys had excellent hot workability. B1 alloy also had good cold workability, while B2 and B4 alloys had relatively poor cold workability. Generally, the addition of Al and increasing Cu content decreased alloy cold-workability.

3.2. Burn-resistance

After being ignited by liquid metal drop, the area burning rate of pure Ti, TC4 (Ti-6Al-4V), TB3(Ti-3.5Al-10Mo-8V-1Fe), Ti40 (Ti-25V-15Cr) and B1 alloys were examined, as shown in Fig. 1. The burning rate of B1 alloy was 3%, which was higher than that of Ti40 alloy (0%), but it was much lower than that of conventional titanium alloys and had good burn resistance. It has already been suggested [1] that alloys possessed good burn resistance when Cu content exceeded 10%. Therefore, B1-B5 alloys should also be expected to exhibit good burn resistance.

3.3. Mechanical properties

The tensile properties at room and high temperature of alloy pancake, plate and bar samples are listed in

TABLE I Processing characteristics of Ti-Al-Cu alloys

	Processability		
Alloy	Forging	Hot-rolling	Cold-rolling
B1	Deformed easily (deformation of every heating reached 80%), no surface cracking	Rolled easily (deformation of every heating heating reached 56%), no surface cracking, smooth	Bright and smooth surface, no cracking (deformation reached 71%)
B2	Deformed easily (deformation of every heating reached 80%), no surface cracking	Rolled easily (deformation of every heating heating reached 56%), no surface cracking, smooth	Cracked surface
B3	Deformed easily (deformation of every heating reached 80%), no surface cracking	Rolled easily (deformation of every heating heating reached 56%), no surface cracking, smooth	Bright and smooth surface, many cracks in border zone
B4	Deformed easily (deformation of every heating reached 80%), no surface cracking	Rolled easily (deformation of every heating heating reached 56%), no surface cracking, smooth	Cracked surface

TABLE II Room temperature tensile properties of Ti-Al-Cu alloys

Alloy		UTS (MPa)	YS (MPa)	Elong. (%)	RA (%)
Plate	B1	833	664	14	-
Pancake	B1	1062	927	13.5	21
	B3	1052	971	12	14.5
	B4	1050	963	11	10.8
Bar	B5	960	810	11	20

TABLE III High temperature tensile properties of Ti-Al-Cu alloys

Alloy		Temperature (°C)	UTS (MPa)	YS (MPa)	Elong. (%)	RA (%)
Pancake	B2	400	880	712	16	54
		500	762	627	21	83
	B4	370	873	700	25	53
Bar	B5	400	840	609	18	60
		500	620	486	38	94

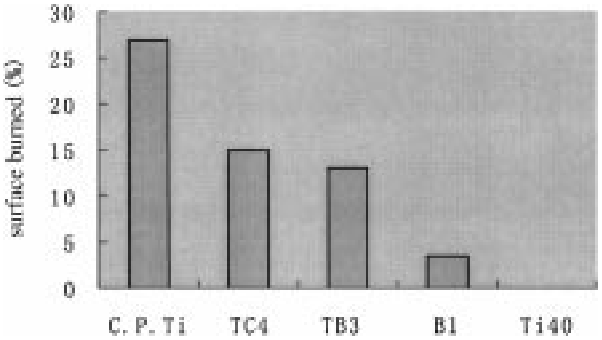

Figure 1 Surface area burning rate of several titanium alloys.

Tables II and III, and the thermal stability and creep property are listed in Tables IV and V.

It was shown that Ti-Al-Cu series alloys had good room and high temperature tensile properties. The B1 alloy pancake had the best tensile properties at room temperature. With the increasing Cu content, the room temperature strength of pancakes showed little change, whereas ductility decreased dramatically.

After thermal exposure for a long time, the strength and ductility of B1 pancake decreased greatly. The strength and ductility of B5 bar changed little after exposure at 540°C for 100 h. The B5 alloy had good creep resistance at 300°C and 100 MPa.

TABLE IV Thermal stability of Ti-Al-Cu alloys

Alloy		Condition	UTS (MPa)	YS (MPa)	Elong. (%)	RA (%)
Pancake	B1	300°C/100 h	813	696	5.7	6
	B3	300°C/100 h	1062	973	8.9	16
Bar	B5	540°C/100 h	912	760	12	18

TABLE V Creep resistance of a Ti-Al-Cu alloy

Alloy	Creep condition	Creep strain ε (%)
B5 (bar)	300°C/100 h/100 MPa	0.02

4. Discussion

4.1. Mechanism of burn resistance

Under the service condition of gas turbine engines, possible friction between titanium alloy components can generate a great deal of localized heat which can elevate temperature above their melting point due to the poor thermal conductivity. These parts can ignite in high air flow and oxidize at very high speed.

Free electrons play a primary role in thermal conductivity. Copper has the best thermal conduction ability. The addition of copper to titanium increases the number of thermal conduction electrons, thus, greatly enhancing thermal of conductivity [12]. Therefore, Ti-Al-Cu alloys have good thermal diffusibility which is advantageous to burn resistance. In addition, Ti-Al-Cu alloys have low melting point around 1400°C which is about 200°C lower than that of other titanium alloys and there is a large amount of Ti_2Cu phase whose melting point is only 990°C in those alloys. So before it reaches the ignition point, the alloy has already softened and absorbed most of the heat, thereby decreasing surface temperature and inhibiting ignition.

4.2. Effect of alloying elements and microstructures on properties

The results of X-ray diffraction analysis (Fig. 2) showed that the phase constituents of B1-B5 alloys were all α phase and Ti_2Cu phase after solution and aging heat treatment. The Ti_2Cu phase could be clearly identified

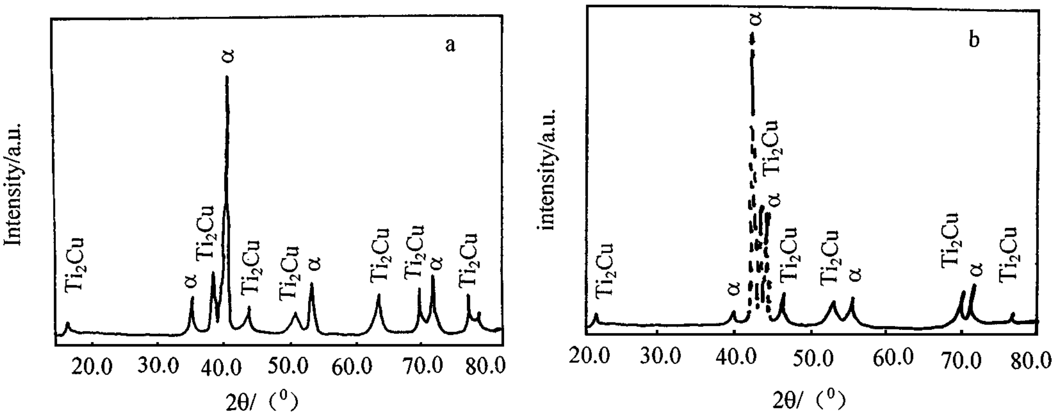

Figure 2 X-ray diffraction patterns for Ti-Al-Cu alloys after solution treat and aging heat treatment. (a) B1; (b) B4.

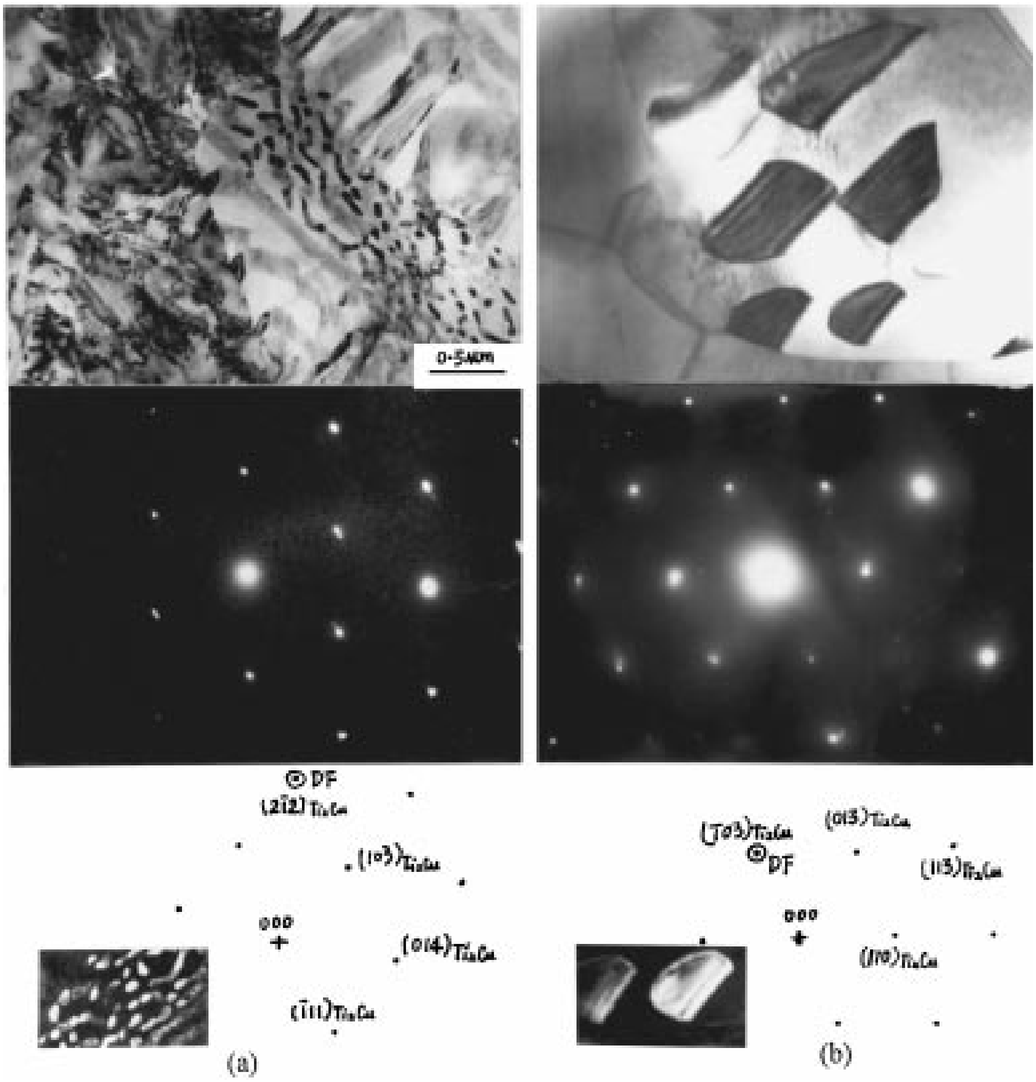

Figure 3 TEM photographs and corresponding diffraction patterns of Ti-Al-Cu alloys. (a) B1 ×20 K; (b) B4 ×50 K.

from the TEM spectra (Fig. 3). Although B1-B5 alloys had the same phase constituents, the phase morphology changed with the increasing copper content. The Ti_2Cu phase in B1 alloy was mainly fine laths (Fig. 3a) which were well distributed within grains, whereas Ti_2Cu phase in B4 alloy occurred as relatively large lumps (Fig. 3a) which were distributed inhomogeneously. The B5 alloy had the same structure feature as B1 which was only a slightly finer than that of B1. It could be seen that the addition of Si and Al would be of benefit to fine structures. The morphology of Ti_2Cu phase had a significant effect on the properties. When Ti_2Cu phase was thick and distributed inhomogeneously, the cold workability became poorer. The addition of Al hardened the α phase, explaining the slight increase in strength and large reduction in ductility.

After thermal exposure for a long time, the phase constituents did not change, which was confirmed by

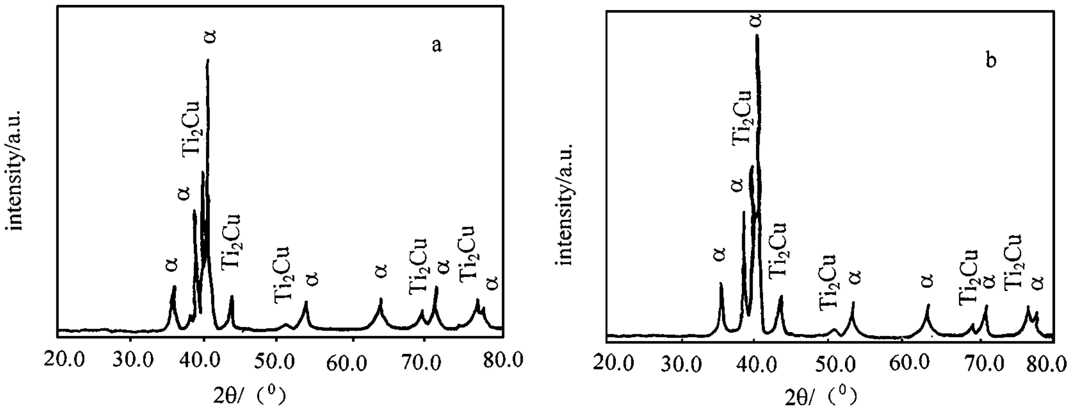

Figure 4 X-ray diffraction analysis of the B5 alloy. (a) Before thermal exposure; (b) After thermal exposure.

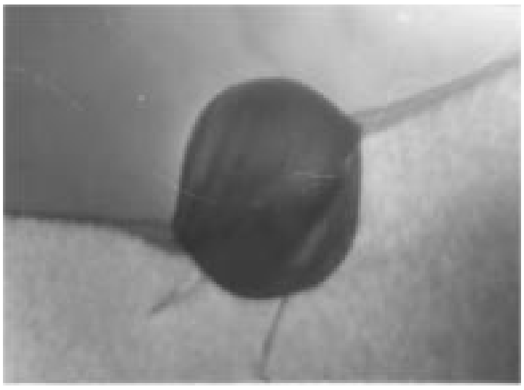

Figure 5 Phase morphology of B5 alloy after thermal exposure ×80 K.

X-ray diffraction analysis (Fig. 4). However, the Ti_2Cu phase coalesced and coarsened, especially in high copper containing alloys such as the B4 alloy (Fig. 5) where Ti_2Cu phase grew into rather spherical precipitates. The strength and ductility would deteriorate with the growth of Ti_2Cu phase. The addition of Al and Si to the B4 alloy would improve stability. The creep resistance of Ti-Al-Cu alloys at high temperature (such as 540°C) and high stress (such as 250 MPa) was not good, which is related to the low strength and high ductility at high temperature to some extent in low Al content Ti-Al-Cu alloys. The essential factors are probably the size and distribution of the Ti_2Cu phase, and the Ti_2Cu/α phase interface, To apply Ti-Al-Cu alloys in practice, further studies and metallurgical optimization are necessary.

5. Conclusions

1. Ti-Al-Cu series ($Cu > 10\%$) alloys had good burn-resistance due to their good thermal conductivity, low melting point, and the existence of Ti_2Cu phase.

2. Ti-Al-Cu series alloys exhibited excellent hot workability. Their cold workability deteriorated with the increase in Cu content and the addition of Al. The B1 alloy also had good cold workability.

3. Phase constituents of Ti-Al-Cu series alloys were α phase and Ti_2Cu phase. The character of Ti_2Cu phase changed with an increase in Cu content.

4. Ti-Al-Cu pancake and bar samples had reasonably good tensile properties at room and high temperature. The increase in Cu content diminished thermal stability. After long-term thermal exposure, Ti_2Cu phase coalesced and coarsened. The addition of Si and Al would improve thermal stability. Ti-1Al-13Cu-0.2Si had quite good thermal stability.

5. Ti-1Al-13Cu-0.2Si exhibited good creep resistance at 300°C and 100 MPa.

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