特约专栏

Research and Development of Some Typical Ti-Alloys in China in Recent 5 Years

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Abstract: Ti and its alloys have been widely used because of their excellent comprehensive properties. In order to meet the requirement of market, science and technology, great attentions were paid to new Ti-alloys. R & D of new Ti-alloys developed by China was made big progresses in recent 5 years. Their research scale is enlarged and their materials varieties are improving. This paper reviews the development of some typical Ti-alloys in China in recent 5 years and quantitative design of new high strength Ti-alloys.

Key words: Ti-alloys; research; development; quantitative design

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近 5 年中国典型新型钛合金研究与发展

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摘　要：钛及钛合金因其优异的综合性能得到广泛的应用，为满足市场的要求及科技发展，新型钛合金研究受到高度重视。近 5 年中国创新研制的钛合金得到长足发展，研究规模扩大，合金品种逐步完善，基本满足了用户的需求。文章简要评述了近 5 年国内典型新型钛合金的发展及新型超高强钛合金的定量设计，以期为钛合金的发展及批量生产提供技术支撑。

关键词：钛合金；研究；发展；定量设计

1　Introduction

Because of their excellent comprehensive properties, Ti and its alloys have been widely used for aviation, aerospace and so on. The high development of economy and industrial technology in China in recent 5 years promotes the high development of national Ti industry. The output of Ti sponge increases from 9 511 t in 2005 to 40 785 t in 2009, and the output of mill products increases from 10 135 t in 2005 to 24 965 t in 2009. The fast development of Ti industry drives the development of new Ti-alloys in China. More than 30 kinds of new Ti-alloys were designed and researched in recent 5 years in China, such as high strength high toughness TC21 alloy with damage tolerance, middle strength high toughness TC4-DT alloy with damage tolerance, high strength Ti-1300 alloy, low cost Ti8LC and Ti12LC alloys, biomedical TLM alloy and so on. This paper briefly reviews R & D of these typical Ti-alloys and the quantitative design of new high strength Ti-alloys.

2　High strength high toughness TC21 alloy with damage tolerance

TC21 alloy is the first high strength high toughness Ti-alloy with damage tolerance in China[1]. It was designed and developed in 2003[2] and it was paid great attentions and made big progresses after 2005. The research scale of TC21 alloy increased from 1 t in 2005 to 8 t in 2009 and the size of bars was from ϕ20, 90, 130, 180 mm to ϕ300 mm and ϕ500 mm in diameter. The macro profile of the bars is shown in Fig. 1. Their typical properties are listed in Table 1. The properties of different bars are stabile and consistent. Compared with TC4 and Ti62222S, TC21 has good comprehensive properties[3]. Its typical microstructure is demonstrated in Fig. 2. It is $\beta_{\mathrm{tran.}}$ and equiaxed α one, resulting in good damage tolerance performance. The level of flaw detection of bars meets the requirement of corresponding standards.

Its sheets of 2 mm and plates of 12 mm in thickness were also made and manufactured.

The main new technologies used for TC21 bars and wrought are quasi β forging[3] and near β forging in order to damage tolerance.

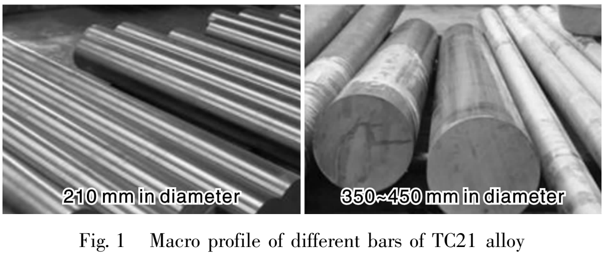

Fig. 1　Macro profile of different bars of TC21 alloy

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Table 1 Mechanical property of different bars of TC21 alloy

Diameter of bars/mm	UTS/MPa	YS/MPa	El/%	RA/%	K_{IC}/MPa · $m^{1/2}$	da/dN/mm · $cycle^{-1}$
20	1 200	1 130	13	52	—	—
90	1 100	1 000	12	35	85	1.39×10^{-5}
130	1 110	1 020	12	30	80	1.47×10^{-5}
180	1 110	1 030	12	30	90	2.03×10^{-5}
300	1 110	1 060	18	48.5	86	7.88×10^{-4}

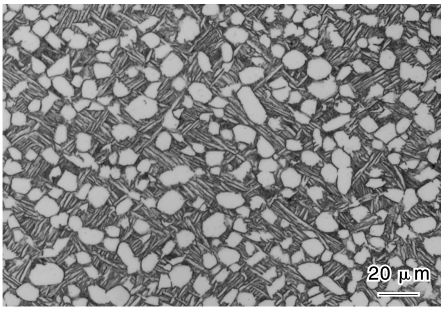

Fig. 2 Typical microstructure of different bars of TC21 alloy

3 Middle strength and high toughness TC4-DT alloy with damage tolerance

TC4-DT alloy[4] was developed based on TC4ELI in 2005. After 2005, more attentions were paid to it and it got fast development. The research scale of TC4-DT was from 1 t in 2005 to 8 t in 2009 and its size of bars was from ϕ20, 90, 130, 210, 350 to ϕ500 mm and ϕ600 mm in diameter. Fig. 3 shows its macro structure of ϕ350 mm in diameter. Its structure is even and grains are obscure. Its typical property is shown in Table 2. The properties of different bars is table and consistent. Its typical microstructure is demonstrated in Fig. 4, which is β trans. and equiaxed α one, resulting in good damage tolerance performance. The level of flaw detection of bars meets the requirement of corresponding standards.

The main new technologies used for TC4-DT bars and wrought are quasi β forging[3] and near β forging in order for damage tolerance.

Its plates of 30 ~ 90 mm in thickness and 2 500 mm in width, and sheet/plate of 1 ~ 20 mm in thickness and 1 500 mm in width is made and manufactured. The macro profile of the plate is shown in Fig. 5. Their properties meet the corresponding standards.

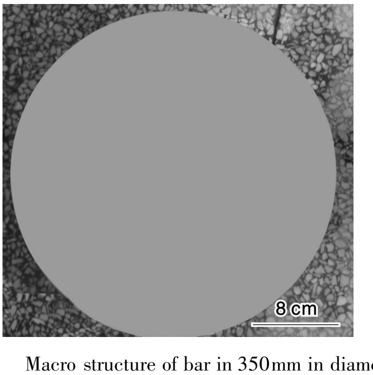

Fig. 3 Macro structure of bar in 350mm in diameter of TC4-DT alloy

Table 2 Mechanical properties of different bars of TC4-DT alloy

Diameter of bar/mm	UTS /MPa	YS /MPa	El /%	RA /%	K_{IC} /MPa · $m^{1/2}$	da/dN /mm · $cycle^{-1}$
50	915	845	16	48	—	—
90	925	855	18	53	109	3.733×10^{-6}
140	920	860	15	53	112	2.309×10^{-6}
300	920	850	14	33	93	5.109×10^{-6}

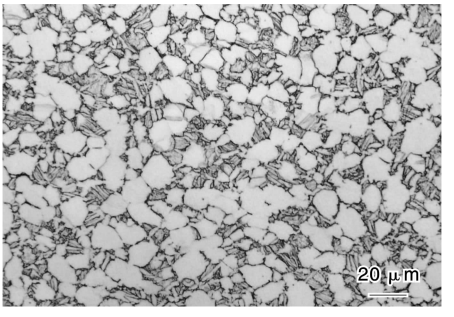

Fig. 4 Typical microstructure of bars of TC4-DT alloy

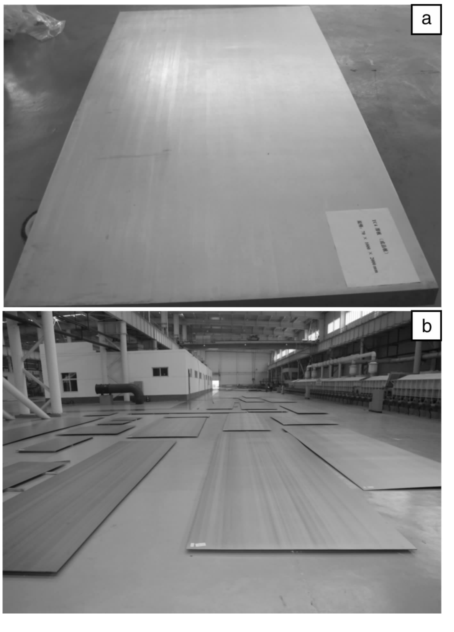

Fig. 5 Macro profiles of TC4-DT plate of 30 ~ 90 mm in thickness and 2 500 mm in width (a), and 1 ~ 20 mm in thickness and 1 500 mm in width (b)

4 Super high strength Ti-1300 alloy

New Ti-1300 alloy with 1 350 MPa strength scale was designed and developed in 2005[5]. Its research scale was from 5 kg to 1 000 kg. Its bars were from 20, 90, 150 to

200 mm in diameter. The typical properties are listed in Table 3. Their properties are stable.

Table 3　Mechanical properties of different bars of Ti1300

Diameter of bars/mm	UTS/MPa	El/%	RA/%	K_{IC} /MPa · $m^{1/2}$
20	1400	12	40	70
90	1380	9	25	63
150	1350	10	32	57

5　Low cost Ti8LC and Ti12LC alloys

Ti8LC[6] and Ti12LC[7] was designed and developed in 2002 with the replace of low cost alloying elements to expensive ones. After 2005, in order to meet the requirement of market, Ti8LC and Ti12LC were developed fast. The research scale was from 5 kg to 1 t, and its size of bars was from 20, 80 to 200 mm in diameter. Table 4 lists its typical properties. The properties are good and stable. The typical parts made from Ti8LC and Ti12LC are shown in Fig. 6. These parts have been used.

Table 4　Typical properties of Ti8LC and Ti12LC alloys

Diameter of bar/mm	Alloy	UTS/MPa	YS/MPa	El/%	RA/%
20	Ti8LC	1 050	990	12	30
	Ti12LC	1 100	1 050	12	40
80	Ti8LC	945	870	14	38
200	Ti8LC	960	882	13	32

6　Biomedical TLM Ti-alloy

Near β TLM Ti-alloy with low modulus was designed and developed in 2003[8]. Its typical characteristics are high strength, low modulus, high attack toughness, high fatigue performance, shape-memory, super elasticity, easy cold, hot deformation and so on. In order to meet the requirement of market and application, TLM alloy was developed fast after 2005. Research scale was from 5 kg to 1 t, and its bars, plate/sheet, tube, wire, foil and other special shapes, such as capillary, special profile tubes, wrought and castings, were made[9].

Its typical properties are as follows: UTS is greater than 600 MPa, elongation is greater than 42% and modulus is less than 50 GPa. Its typical microstructure is shown in Fig. 7. The typical parts made from TLM is shown in Fig. 8

Fig. 6　Typical parts made from Ti8LC and Ti12LC alloys

Fig. 7　Typical microstructure of TLM alloy 500X

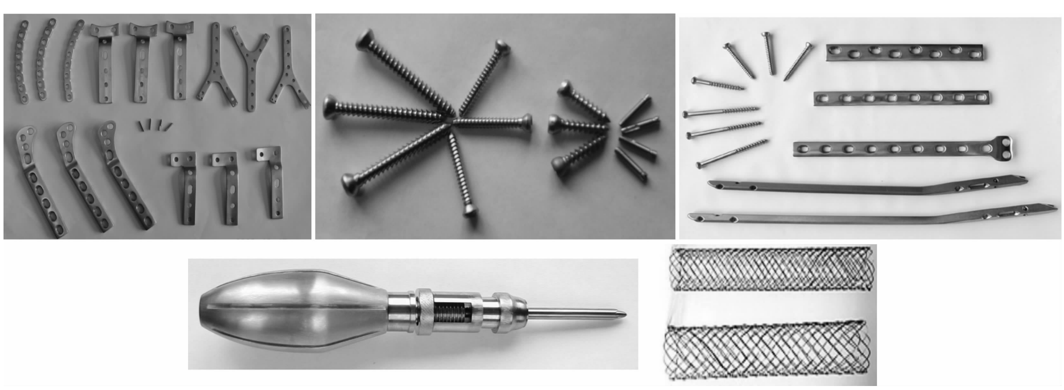

Fig. 8　Typical parts made from TLM alloy

7　Cryogenic CT20 alloy

CT20 is a new near α type Ti alloy with middle strength[10]. Fig. 9 is its typical microstructure, which is equiaxed α one resulting in good comprehensive properties. Table 5 shows its mechanical properties at room and 20 K temperature. CT20 has good super cryogenic physical properties, decreasing heat transfer, which is suitable for 20 K application. Its winding tubes, connecting tube and connecting flanges (Fig. 10) were

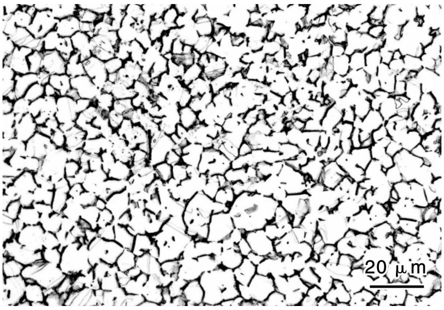

Fig. 9 Typical microstructure of CT20 tube

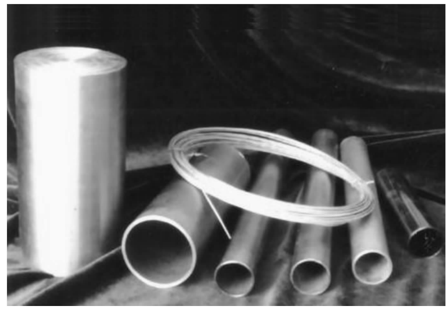

Fig. 10 Typical products of CT20

made and they were used successfully. Lots of its tubes, bars, wires were manufactured in recent 5 years. Its spiral winding tubes, special three-way pipes and right angle three-way products were also made (Fig. 11).

Table 5 Mechanical properties of 4 kinds of bars at RT and cryogenic temperature

Diameter of bars/mm	RT				20 K			RT
	UTS/MPa	YS/MPa	El/%	RA/%	UTS/MPa	El/%	RA/%	J/cm^2
25	662	625	22	60	1 340	21	40	120
90	622	530	18	38	1 290	20	33	98
100	603	515	18	44	1 250	23	35	100
150	630	540	20	39	1 283	16	49	100

Fig. 11 Spiral winding tubes of CT20

8 Burn resistant Ti40 alloy

Ti40 was designed and developed in 1995, which is a stable β type burn resistant Ti alloy[11]. Its normal composition is Ti-25V-15Cr-0.2Si. From 1993 to 2004, the research scale was from 5 kg to 1 t. Its composition[12] and technologies of ingot break-down[13], hot processing[14] and heat treatment[15] were decided. The mechanisms of burn resistance[16], oxidation[17], creep[18] and thermal stability[19] were researched. Its bars, pancakes and rings were made. The typical mechanical properties were listed in Table 6. Ti40 possesses good comprehensive properties.

Table 6 Typical mechanical properties of Ti40 alloy

Condition	UTS/MPa	YS/MPa	El/%	RA/%
RT	990	966	24	34
540 ℃	822	705	16	33
Thermal stability (500 ℃/100 h)	1 077	1 007	8	12
Creep property (500 ℃/100 h/250 MPa)	$\varepsilon \leqslant 0.1\%$			

From 2005 to 2010, its product's specifications were enlarged. Based on the previous technical technologies, its size of bars was changed from 20 to 90 mm and 300 mm in diameter. Their properties meet the requirement of technical standards and their properties are stable. And its plates were also made.

9 Ti-600—600 ℃ high temperature Ti alloy

Ti-600 is a new near α high temperature Ti alloy [20]. It has good comprehensive properties, especially its creep properties, which can be used at 600 ~ 650 ℃.

Based on its compositions, melting technology, hot processing technology and hot rolling technology, the research scale was changed from 5, 25, 50, 300, 500 kg to 2 t, and different diameter bars (ϕ14, ϕ46, ϕ60, ϕ100 mm) and plate/sheet (2.5, 5, 12, 30 mm in thickness) were manufactured. Their mechanical properties meet the requirement of technical standards. And, Ti-600 has good welding properties and its welding coefficient is greater than 0.9. In recent years, its mill products were used in a Germany company.

10 Quantitative design of new super high strength Ti-alloy

In the past, the design for Ti-alloy's composition was mainly based on many trial-and-error experiments and several empirical rules (such as Al equivalent, Mo equivalent and theory of electronic density) rather than quantitative method. Recently a quantitative method was proposed[21], which has been applied to design three targets for high strength titanium alloys (Table 8), their compositions are quantitatively designed.

Table 8 Quantitative design results of three new high strength Ti-alloys

Alloy No.	Target value		Calculating result	
	UTS/MPa	El/%	UTS/MPa	El/%
1[22]	1 650	8	1 639	7.7
2[23]	1 550	8	1 567	7.9
3[24]	1 300	9	1 319	9.4

The three alloys were prepared using standard procedure for titanium alloys. 25 kg ingots were fabricated by two-times vacuum consumable arc melting using pure Ti (0 grade), Zr (atomic energy level), Cr, Fe and Al-Mo, Al-V, Al-Sn, Ti-Nb intermediate alloys as raw materials. The ingots were hot forged and rolled to round bars of 22 mm in diameter.

Table 9 shows the expected and measured tensile properties of the three alloys. It indicates that the errors for tensile strength and elongation are less than 2% and 7%, respectively.

Table 9 A comparison of expected and measured tensile properties of three alloys

Alloy No.	Tensile Strength/MPa			Elongation/%		
	Expected	Measured	Error	Expected	Measured	Error
1	1650	1650	0	8	8.3	3.7%
2	1550	1580	1.9%	8	8.5	6.2%
3	1300	1325	1.9%	9	9	0

11 Conclusions

The fast development of Ti-alloys promotes the fast development of National Ti industry. TC21, TC4-DT and other alloys will be the important structural materials in many fields in China. This will further enlarge the applications of Ti-alloys. Quantitative design for high strength Ti-alloy is successful, and it will be used to design new Ti-alloys to meet the requirement of users and market.

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