

Experimental studies on the dynamic tensile behavior of Ti–6Al–2Sn–2Zr–3Mo–1Cr–2Nb–Si alloy with Widmanstatten microstructure at elevated temperatures

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ABSTRACT

The tensile behavior of a newly developed Ti–6Al–2Sn–2Zr–3Mo–1Cr–2Nb–Si alloy, referred as TC21, is investigated at temperatures ranging from 298 to 1023 K and under constant strain rate loadings ranging from 0.001 to 1270 s^{−1}. The results show that temperature and strain rate have significant effects on the tensile behavior of the material. At low strain rates of 0.001 and 0.05 s^{−1}, a discontinuity is found in the yield stress–temperature curve. And the discontinuity temperature increases with increasing strain rate. The analysis of temperature and strain rate dependence of unstable strain indicates a high-velocity-ductility phenomenon at elevated temperatures. Scanning electron microscope (SEM) analysis shows that the material is broken in a mixture manner of ductile fracture and intergranular fracture under low strain rates at room temperature, while the fracture manner changes to totally ductile fracture under other testing conditions. The width and depth of ductile dimples increase with increasing temperature. No adiabatic shear band is found in the tensile deformation of the material.

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1. Introduction

Titanium alloys, especially $\alpha + \beta$ titanium alloys, have been widely used due to their good corrosion resistance, low density, high strengths at elevated temperatures and good formability. Over the last few decades, the deformation behavior of $\alpha + \beta$ titanium alloy has been extensively studied including quasi-static mechanical testing at low strain rates and testing at high strain rates using the split Hopkinson bar [1–6].

As a new developed titanium alloy in China, Ti–6Al–2Sn–2Zr–3Mo–1Cr–2Nb–Si alloy, referred as TC21 in China, is an $\alpha + \beta$ high strength, high toughness and high damage-tolerant alloy that belongs to eight-component system [7]. The α/β phase transition temperature of TC21 is about 1233 ± 5 K. During the last few years, the researches mainly focused on the relationship between processing technology, microstructure and mechanical properties [8–12]. Several studies on the effect of temperature, strain rate on mechanical properties of TC21 have been performed. Feng et al. [13] investigated the high temperature compressive deformation characteristics of TC21 at temperature range of 1173–1373 K and strain

rate range of 0.01–50 s^{−1}. Qu et al. [14] studied the microstructure evolution of TC21 and coherent deformation mechanism under compression at different temperatures and at strain rate range of 0.01–50 s^{−1}. Li et al. [15] conducted compressive experiments on Ti700 (former serial number of TC21) at temperature range of 293–1073 K and strain rate of 10⁴ s^{−1}. However, there are few researches reported on the effects of temperature and strain rate on tensile behavior of TC21 especially researches at elevated temperatures and high strain rates because of difficulty in experiment process.

In the present research, quasi-static and dynamic tensile tests on TC21 with Widmanstatten microstructure are performed within temperature range of 298–1023 K and strain rate range of 0.001–1270 s^{−1}. The effects of temperature and strain rate on tensile behavior of TC21 are discussed. The fracture surfaces and the possibility of adiabatic shear band formation are studied by SEM and metallographic observations.

2. Experiments

The chemical components of the tested material (supplied by Titanium Research Center of Northwest Institute for Nonferrous Metals Research of China) are listed in Table 1. The material with Widmanstatten microstructure (Fig. 1) was prepared by the follow-

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Table 1
Chemical components of the test material.

Component	Al	Sn	Zr	Mo	Cr	Nb	Si
Concentration (wt.%)	6.2	1.94	1.7	2.62	1.6	1.96	0.13
Component	Fe	C	N	O	H	Ti	Ese
Concentration (wt.%)	0.03	0.08	0.014	0.09	0.001		

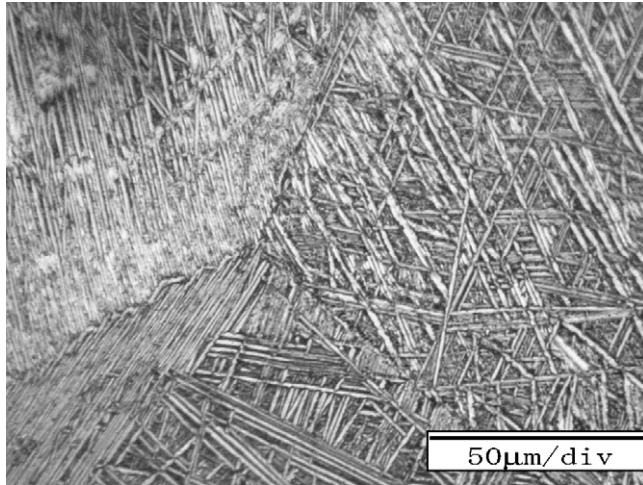


Fig. 1. Optical micrograph of TC21.

ing process:

1203 K forging → 1233 K annealed 1 h → AC → 873 K aged 6 h

→ AC

Quasi-static tests at strain rates of 0.001 and 0.05 s⁻¹ are performed on MTS809 servo-hydraulic materials tester at a temperature range of 298–1023 K (detailed in Table 2). Dynamic tensile

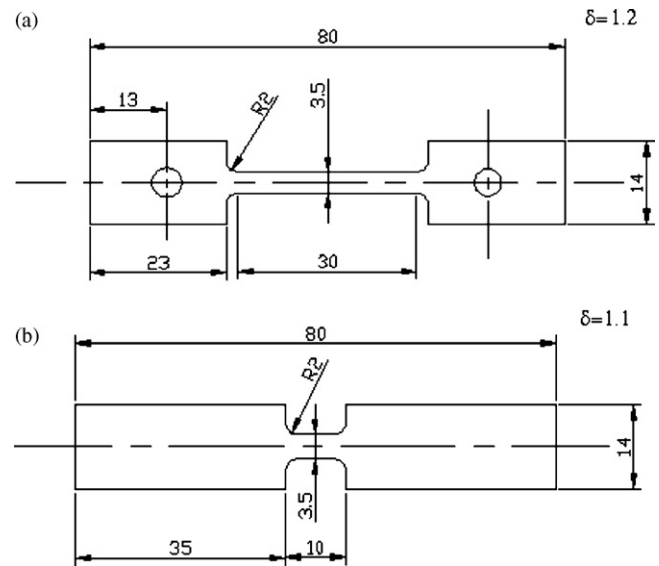


Fig. 2. Diagram of specimens used in (a) quasi-static and (b) dynamic tensile tests.

tests at strain rates of 240 and 1270 s⁻¹ are performed on self-designed rotating disk indirect bar-bar tensile impact apparatus [16–18] at a temperature range of 298–1023 K (detailed in Table 2). The specimens used in quasi-static tests and dynamic tensile tests are shown in Fig. 2(a) and (b) respectively.

3. Results and discussion

The engineering stress-engineering strain curves ($\sigma^e = \sigma^e(\varepsilon^e)$, σ^e is engineering stress, ε^e is engineering strain) of TC21 are first obtained from the tests, then the curves are converted to true stress-true strain curves ($\sigma = \sigma(\varepsilon)$, σ is true stress, ε is true strain) by the following formulations: $\sigma = \sigma^e(1 + \varepsilon^e)$, $\varepsilon = \ln(1 + \varepsilon^e)$. True stress-true

Table 2
Values of σ_s , σ_b , ε_s , elongation and RSD under various conditions.

Strain rate (s ⁻¹)	Temperature (K)	σ_s (MPa)	RSD (%)	σ_b (MPa)	RSD (%)	ε_b (%)	RSD (%)	Elongation (%)	RSD (%)
0.001	298	1019	0.12	1174	0.50	6.50	0.22	6.50	0.25
	473	843	0.15	1053	0.32	7.74	1.92	7.82	2.03
	673	743	0.40	971	0.22	7.05	1.83	7.24	1.71
	773	686	1.17	927	0.71	8.75	4.40	9.51	4.04
	823	678	1.72	827	1.12	5.44	3.14	8.60	2.87
	873	631	1.00	715	0.45	3.60	3.07	12.41	3.25
	923	507	0.95	581	0.57	2.52	4.25	12.25	3.56
	973	317	3.02	409	0.14	2.34	4.13	15.28	5.31
	1023	199	2.24	281	0.11	2.12	4.21	19.75	5.52
0.05	298	1078	0.51	1202	0.51	6.15	1.12	6.15	1.12
	473	888	0.55	1057	1.08	7.30	2.53	7.62	2.87
	673	750	0.65	976	0.66	6.34	0.74	6.72	0.78
	873	657	0.87	804	0.74	5.41	3.34	8.25	3.02
	923	622	1.05	737	0.52	4.27	2.82	9.18	4.51
	973	574	0.25	651	0.65	2.62	2.50	11.12	4.07
	1023	413	1.07	504	0.12	2.24	2.76	12.35	5.58
240	298	1259	0.50	1348	0.44	4.82	3.74	6.71	4.44
	473	1051	1.71	1178	0.52	7.58	3.03	10.11	4.15
	673	856	0.88	1031	0.75	7.21	2.82	10.25	3.50
	873	740	0.62	893	0.33	6.70	3.61	8.82	4.24
	973	664	0.44	797	0.35	6.13	3.15	8.97	3.30
	1023	616	1.26	716	1.54	3.77	3.73	7.92	4.55
1270	298	1430	3.31	1468	1.01	4.72	3.34	7.31	3.07
	473	1056	3.30	1245	1.04	9.45	3.75	10.94	4.28
	673	925	2.22	1061	1.73	7.42	3.63	10.21	4.22
	873	786	0.34	930	1.05	7.85	0.31	8.61	1.21
	973	695	3.98	842	1.15	6.54	4.01	9.33	4.54
	1023	660	1.13	770	0.87	5.80	0.17	8.62	3.55

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