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Research on microstructure and mechanical properties of a new $\alpha + Ti_2Cu$ alloy after semi-solid deformation

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Abstract

The microstructures and tensile mechanical properties of Ti14, a new typical $\alpha + Ti_2Cu$ alloy, after semi-solid forging were researched. The results reveal that its microstructure is coarse and the grain boundary is wide after semi-solid forging, leading to low plasticity at room temperature. Recrystallization heat treatment leads to fine microstructure, which is similar to that of conventional forging, resulting in improvement of tensile mechanical properties. The mechanical properties of semi-solid forging are similar to that of conventional one at high temperature.
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Keywords: Titanium alloy; Ti14 alloy; Semi-solid deformation; Microstructure; Mechanical property

1. Introduction

Titanium alloys are widely used because of their excellent comprehensive properties, however, their high cost limits their more wide applications, especially in the civil field. In order to reduce their cost, low cost technologies for titanium alloys have been carrying out in the main titanium industrial countries, such as USA, UK, Japan and China, and every country develops its own low cost Ti alloys and its own low cost technologies. For example, Ti62S [1] and Ti-LCB [1] low cost Ti alloys were developed in USA, by using cheap alloying element Fe to replace the expensive one. A series of Ti–O–N–Fe low cost alloys [2] developed by Japan adopted cheap alloying elements Fe, O and N. Ti12LC [3] and Ti8LC [4] low cost Ti alloys were developed in China, by adopting the cheap Fe–Mo master alloy, which is widely used in steel. SP700 [5] alloy designed in Japan has good low temperature superplasticity that reduces the processing cost. FFC [6] developed in UK is a new method to manufacture titanium sponge with low cost. And near net shape methods are to reduce the cost from the processing ways. However, these methods do not reduce the cost from the essential ways. The essential way to reduce the cost is the titanium semi-solid deformation.

Since the proposal of semi-solid processing technology by Flemings [7] in the 1970s, semi-solid forming has become one of the hot research topics, which is commonly thought as one of the most promising high-tech manufacturing methods for materials in the coming 21st century. Many researches on the semi-solid deformation behaviors of Al, Mg and steel have been carried out by scientists and engineers all over the world and many useful results have been obtained. However, the semi-solid deformation behavior of titanium alloys has not been investigated yet. The research group led by the first author studied the semi-solid deformation and semi-solid oxidation behavior of Ti14 alloy (Ti–Al–Cu–Si, the Cu content is over 10%). The results have shown that the behavior of semi-solid deformation and semi-solid oxidation is quite different from the conventional one [8,9]. This paper is to research the microstructures and mechanical properties of Ti14 alloy [10] after semi-solid deformation, which maybe provides bases for the breakthrough of titanium processing technology. Ti14 is a new $\alpha + Ti_2Cu$ type burn resistant Ti alloy [11,12]. There are many Ti_2Cu phases in the alloy. The melting point of Ti_2Cu is 990 °C. If the deformation or testing temperature rises above 990 °C, Ti14 alloy changes to a semi-solid state.

2. Experimental procedure

The Ti14 alloy used in this paper is a 25 kg ingot. After conventional ingot break-up forging to bars with diameter of 50 mm, two processing ways are used: (1) semi-solid forging to bars with diameter of 20 mm and (2) conventional forging to bars

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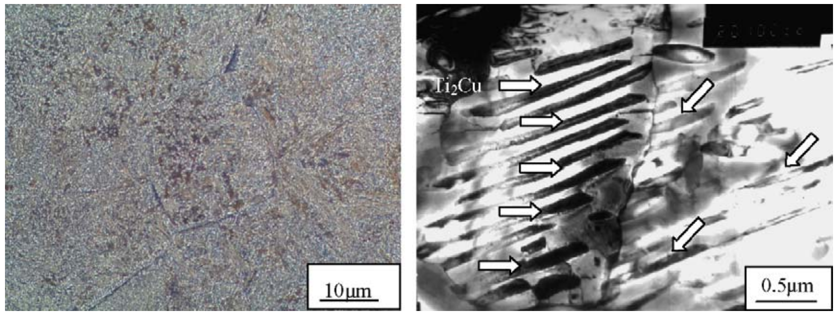

Fig. 1. OM (a) and TEM (b) images of Ti14 alloy rod after conventional forging (arrows show the Ti_2Cu phases).

with diameter of 20 mm (its OM and TEM images are shown in Fig. 1). Their mechanical properties at room and high temperature were examined before and after recrystallization heat treatment, i.e. solution at 810 °C for 30 min followed by aging at 450 °C for 8 h AC [11]. OM and SEM were used for investigation the microstructures and tensile fractograph.

3. Results

3.1. Mechanical properties

Table 1 shows its mechanical properties at room temperature just after semi-solid and conventional forging. Compared with the conventional forging, the strength after semi-solid forging increases obviously, that is, the tensile strength increases by 21% and the yield strength by 25%. However, its plasticity decreases greatly, that is, both elongation and reduction in area decrease by 73%.

Table 2 lists the mechanical properties at RT of Ti14 alloy heat treatment for the semi-solid and conventional forging. Being similar to the forging state, the strength after semi-solid forging is high and plasticity is low, that is, the tensile strength increases by 16%, the yield strength by 19%, while the elongation decreases by 38% and reduction in area by 56%.

Comparison with the values before and after heat treatment, the strength after heat treatment decreases and the plasticity increases greatly, that is, the elongation increases from 6.8 to 13%, which increases by 48%, and the reduction in area increases from 12 to 18%, which increases by 33%. These results reveal that the mechanical properties as semi-solid forging recover obviously after heat treatment. The mechanical properties as conventional forging decrease slightly after heat treatment.

Fig. 2 shows the relationship between mechanical properties and temperature of Ti14 alloy as semi-solid and conventional forging after heat treatment. With increasing temperature, the strength reduces and the plasticity increases, which is similar to the conventional laws. Compared with the conventional forging, the strength is high and the plasticity is low as semi-solid forging if the tensile temperature is below 300 °C; while tensile at 400 °C, the strength and the plasticity of the two forging ways are very close. That is to say, the alloy after semi-solid forging can be used to high temperature as the alloy by conventional forging.

3.2. Microstructures and tensile fractographs

3.2.1. As-forging

Fig. 3 shows the microstructures of Ti14 alloy after semi-solid and conventional forging. The bars as semi-solid forging have the typical microstructure, that is, coarse grains, new grains appearing within big grains and wide grain boundaries

Table 1
Tensile properties at RT of Ti14 alloy bar as-forging

Forging way	UTS/MPa	ΔUTS (%)	YS/MPa	ΔYS (%)	El (%)	ΔEl (%)	RA (%)	ΔRA (%)
Semi-solid	925	+21	755	+25	6.8	−73	12	−73
Conventional	765	–	605	–	25	–	44	–

Remarks: (1) UTS, tensile strength; YS, yield strength; El, elongation; RA, reduction in area. (2) $\Delta UTS\ (\%) = (UTS_{semi\text{-}solid} - UTS_{conventional})/UTS_{conventional} \times 100\%$. $\Delta YS\ (\%) = (YS_{semi\text{-}solid} - YS_{conventional})/YS_{conventional} \times 100\%$. $\Delta El\ (\%) = (El_{semi\text{-}solid} - El_{conventional})/El_{conventional} \times 100\%$. $\Delta RA\ (\%) = (RA_{semi\text{-}solid} - RA_{conventional})/RA_{conventional} \times 100\%$.

Table 2
Tensile properties at RT of Ti14 alloy bar after heat treatment

Forging way	UTS/MPa	ΔUTS (%)	YS/MPa	ΔYS (%)	El (%)	ΔEl (%)	RA (%)	ΔRA (%)
Semi-solid	843	+16	694	+19	13	−38	18	−56
Conventional	727	–	585	–	21	–	41	–

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