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Effect of deformation processing parameter on microscopic structure of Ti14 alloy under semi-solid

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Abstract: Hot compressive deformation test of Ti-Al-Cu-Si alloy was performed on Gleeble-3500 hot-Simulator over the range of deformation temperature from 1 000 to 1 300 ℃, strain rate from 0.005 s^{-1} to 5 s^{-1}, deformation degree from 40% to 70%, and samples of *d* 8 mm×15 mm were used. Change rules of microstructure were mainly studied. The results show that deformation temperature directly influences the nucleation growth and globurizing of grain, and with the temperature rising, the diameter of grain increases, the grain boundary widens. The effect of deformation degree on microstructure varies with deformation temperature. Equivalent diameter of grains shows a trend of falling before elevation with strain rate increasing and temperature rising.

Key words: Ti14 titanium; semi-solid deformation; microscopic structure

1 Introduction

Semi-solid processing technology is a new metal forming technology, which is thought as one of the most promising high-tech manufacturing methods for metal materials in the 21st century [1−5]. It is situated between solid-metal forming and liquid-one, and fuses processing feature about casting and plastic forming, which has the features of high efficiency and energy saving. Many researches on the semi-solid deformation behaviors of Al, Mg and steel have been carried out by scientists all over the world and many useful results have been obtained[6], however the semi-solid deformation behavior of titanium alloys has not been investigated yet. Researches on change rule of microscopic structure have been carried out for Ti14 alloy under the semi-solid condition, which may provide bases for the breakthrough titanium processing technology. Ti14 alloy (Ti-Al-Cu-Si)[7−8] is a new α+Ti_2Cu type alloy, there are many Ti_2Cu phases in the alloy[9−10], the melting point of Ti2Cu is 990 ℃. If the deformation temperature is above 990 ℃, Ti14 alloy changes to a semi-solid state. The research is talked by the Northwest Institute for Nonferrous Metal Research the first time, which has an important significance for settlement high-temperature forming craft to obtain a good microstructure properties. Simultaneously, processing of semi-solid titanium alloy can reduce the cost from the processing ways, which may improve titanium application.

2 Experimental

The Ti14 alloy used in this paper is a 25 kg ingot, after conventional ingot break-up forging to bars with diameter of 20 mm. The bars were cut into samples of 8 mm in diameter and 15 mm in length. The samples were heated up to above 990 ℃ in a gleeble-3500 thermal-simulator, and at different temperature, such as at 1 000, 1 100, 1 200 ℃, compressive deformation behaviors were studied at the different strain rate(0.005, 0.05, 0.5, 5 s^{-1}) different deformation degree (40%−70%) and holding for 1min before being tested, the samples were quickly quenched after deformation. Hot compression samples were sectioned axially, polished, and etched. OM and TEM were used to investigate the microstructures.

3 Results and discussion

3.1 Effect of deformation temperature

In the process of semi-solid deformation, the

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deformation temperature impacts not only the proportion of liquid phase directly, but also the growth of nucleation and globurizing of crystal grain, so the deformation process and micrographs are affected. Fig.1 shows the micrographs of deformation temperature at 1 000, 1 050, 1 100 ℃, strain rate of 0.5 s^{-1} and deformation degree of 40%. From Fig.1(a) we can see that, at a lower temperature during the semi-solid deformation, the liquid-phase content of the sample interior is less, the solid plastic deformation and grain boundary slipping are mainly in the mode of texture. The microstructure after deformation is regular and grain boundary is distinct. However the proportion of liquid-phase grows at 1 050 ℃, the mixed regime of flow between the solid phase and liquid phase is mainly in deformation ways, the liquid phase in the core of sample diffuses outside in the process of deformation and original grains grow further, which makes the scattered grains combine together. Simultaneously, the grain boundary and shape of grains become more regular under the common actions of atom diffusion and curvature change, and the size of grain becomes uniform. In a word, with rising temperature, the diameter of grain increases obviously, and the grain boundary becomes widen.

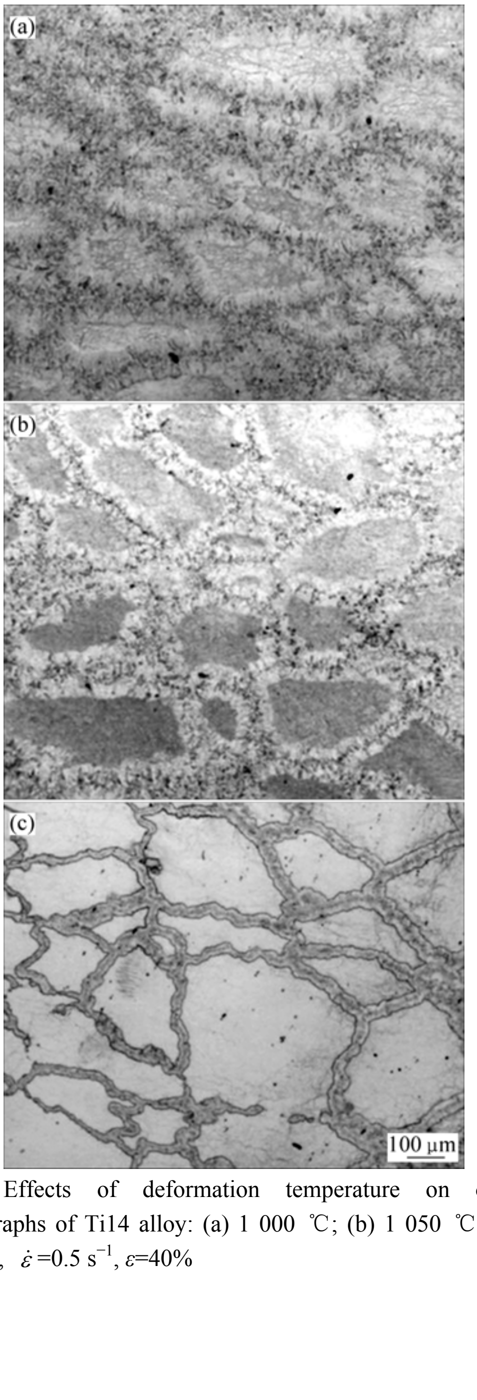

Fig.1 Effects of deformation temperature on optical micrographs of Ti14 alloy: (a) 1 000 ℃; (b) 1 050 ℃; (c) 1 100 ℃, $\dot{\varepsilon}$=0.5 s^{-1}, ε=40%

3.2 Effect of deformation degree

In the process of semi-solid deformation, the energy of deformation in the center of the alloy is different under different deformation degrees, the regulation of liquid-phase flowing is also different, which surely influences on the microstructure, simultaneously, the samples contain liquid phase in the process of semi-solid deformation, so the effect of deformation degree on the microstructure is restricted by deformation temperature.

Fig.2 shows that microstructure of different deformation degree at 1 000 ℃ and 1 100 ℃. From Fig.2, we can see that, at 1 000 ℃ and deformation degree of 40%, the grains of bigger deformation region have been lengthen, and the grain boundary becomes widen. With increasing deformation degree, the grains become longer along perpendicular direction to pressure; and the liquid phase permeates on the grain boundary. When the deformation degree gets to 60%, the solid grain is crushed into pieces to form vague grain, the dynamic recrystallization occurs in this procedure, many little grains are found on the grain boundary of original grains, the shape and size of the original grain are out of regulation, and the size is remarkably decreases. However, it is shown the effect of deformation degree on the microstructure is different at 1 100 ℃ from that at 1 000 ℃. The crystal grain becomes ripe and combines to grow when the deformation degree increases from 40% to 50%, which makes the size of part grains increase, and the grain boundary be widen. When the deformation degree gets to 60%, the solid-particles are broken into pieces in a short time, and the size of grain become uniform under the condition of liquid-phase, the shape is regular.

Thus we can see that the effect of deformation degree on the microstructure varies with deformation temperature, which embodies the synthetic and intricate properties of the effect of deformation processing parameter on the microstructure. Solid plastic deformation mainly occurs at a lower temperature because of a lower liquid phase content. With increasing deformation degree, the energy of deformation increases. The dynamic recrystallization occurs when the deformation degree gets to a critical value, and many grains present on the boundary which makes the average size of grain be more greatly reduced. While at a higher

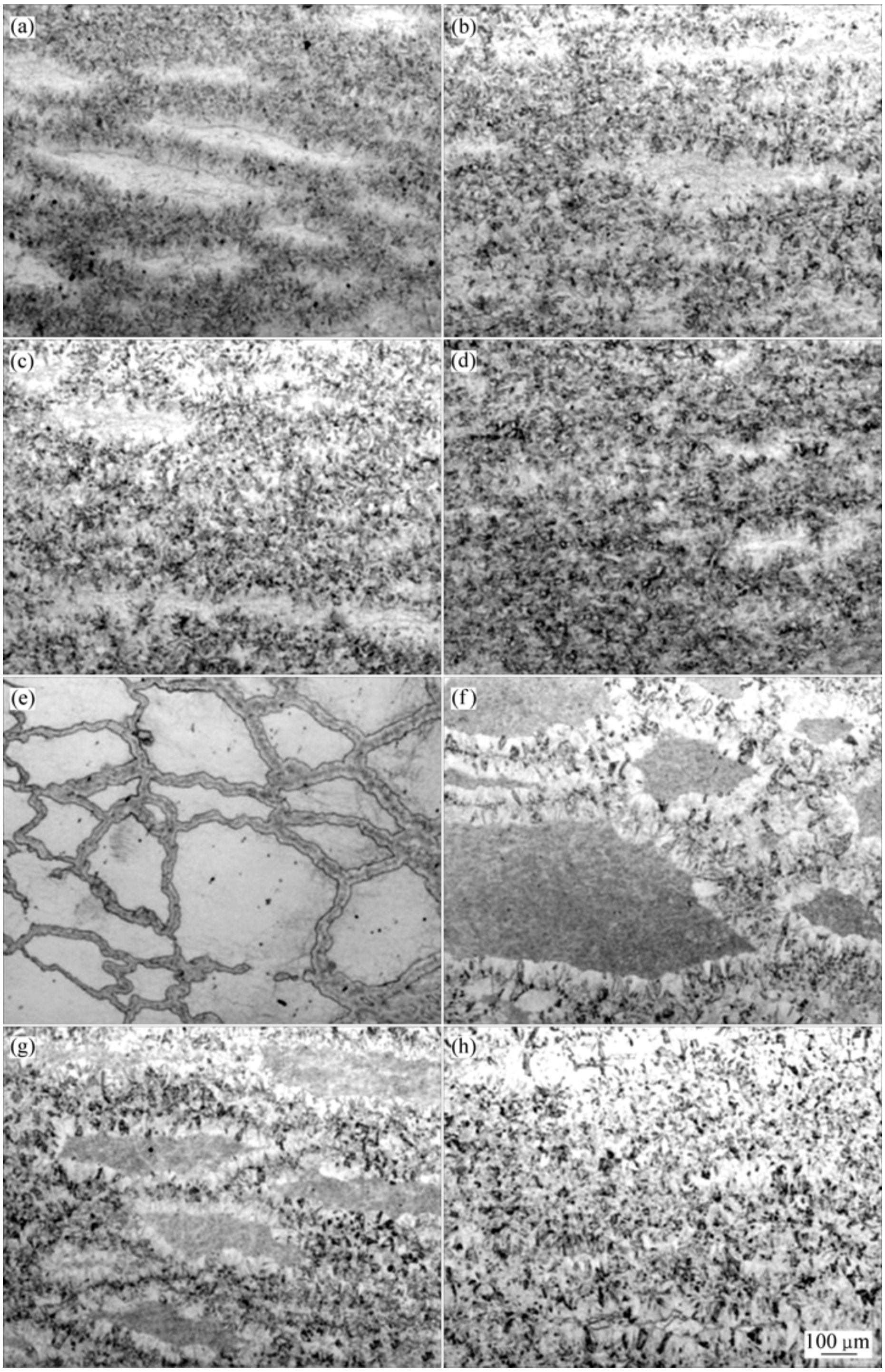

Fig.2 Effects of deformation degree on optical micrographs of Ti14 alloy under different conditions: (a) 1 000 ℃, ε=40%; (b) 1 000 ℃, ε=50%; (c) 1 000 ℃, ε=60%; (d) 1 000 ℃, ε= 70%; (e) 1 100 ℃, ε= 40%; (f) 1 100 ℃, ε=50%; (g) 1 100 ℃, ε=60%; (h)1 100 ℃, ε=70%

temperature and an early stage of deformation, the solid phase particles slide more easily because of lubricating of liquid phase on the grain boundary with increasing deformation degree, which makes the plastic-deformation of solid particle reduce. What's more, some solid particles are welded together to form a bigger grain because of the melted intergranular. With the deformation degree increasing continually, the bigger grains separate with the sliding of the intergranular and drawback, which is produced by intergranular liquid phase flowing.

3.3 Effect of strain rate

In the process of semi-solid deformation, the effect of strain rate mainly represents in two ways: time and energy. We can see from Fig.3(c) that the average size of the grain is the least, and most of the grains have not grown quickly at 1 000 ℃. While Fig.3(b) shows that average size of grain has a tendency to rise, and Fig.3(a) shows the size is biggest and the shape is regular. When the temperature is at 1 200 ℃, the size of partial grain increases with increasing strain rate. The reason is that the liquid phase and solid particle are incompatible, and the liquid phase distributes non-uniform with increasing strain rate, which leads to non-uniform stress distribution and non-uniform size of grains. So with increasing strain rate, the equivalent diameter of grain reduces at a lower temperature. With increasing temperature, the equivalent diameter has a trend to enlarge with increasing strain rate. The reason is that strain rate is low, and the deformation time is long at identical deformation degree, which equivalents to delay the holding time to make the grain sufficiently merge and grow up. What's more, the atom diffuses sufficiently with prolonging time, and the fuse mechanics of the grains make the boundary become regular by the combined action of grain diffusion and curvature change, which makes the equivalent diameter increase. Otherwise, the temperature rises and strain rate increases, and intragranular dump energy augments, the deformation energy increases to make driving-force of grain growth and mean size of grains increase. The results of two mechanics make the equivalent diameter of grains reduce after lifting with increasing strain rate and temperature.

3.4 TEM microstructure

To learn about the deformation mechanics of Ti14 semi-solid alloy, the author observes TEM organize of the alloy. From Fig.4 we can see that the deformation organize is divided into two areas as follows: 1) coarse organize regions of isometric trend; 2) acicular regions. Electron diffraction analysis shows the black part in coarse organization and acicular regions is Ti2Cu phase. Analyzes shows that the low melting point phase of

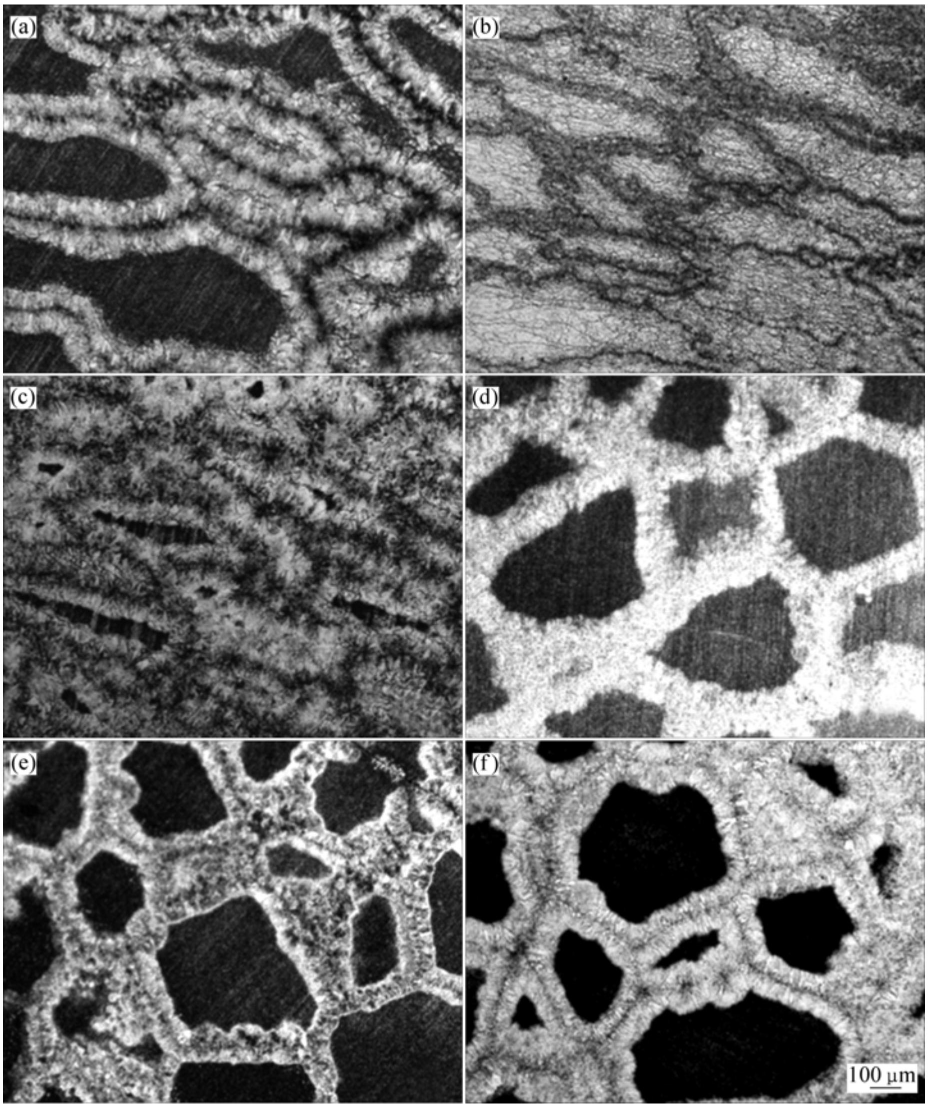

Fig.3 OM images of Ti14 alloy after deformation at 1 000 and 1 200 ℃: (a) 1 000 ℃, $\dot{\varepsilon}$=0.005 s^{-1}; (b) 1 000℃, $\dot{\varepsilon}$=0.5 s^{-1}; (c) 1 000 ℃, $\dot{\varepsilon}$=5 s^{-1}; (d) 1 200 ℃, $\dot{\varepsilon}$=0.05 s^{-1}; (e) 1 200 ℃, $\dot{\varepsilon}$=0.5 s^{-1}; (f) 1 200 ℃, $\dot{\varepsilon}$=5 s^{-1}

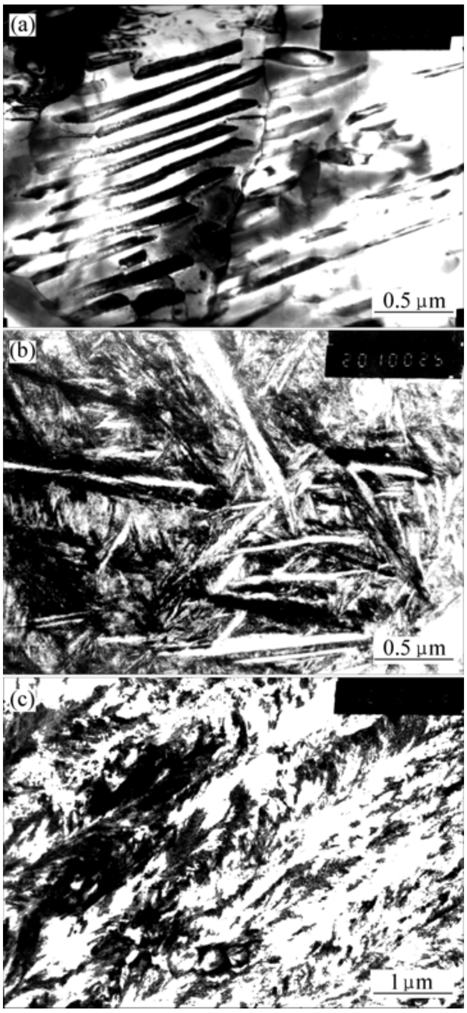

Fig.4 TEM images of Ti14 alloy before and after semi-solid deformation at 1 100 ℃: (a) As-annealed; (b) $\dot{\varepsilon}$=0.005 s^{-1}, fine structure; (c) $\dot{\varepsilon}$=0.005 s^{-1}, coarse structure

intergranular and intracrystalline is melted, and a large number of liquid phases appear on intergranular where Ti2Cu phase enriches, the liquid phase agglomerates and flows along the deformation direction under the condition of compressive stress. In this process crystals trend of Ti2Cu precipitates phase changes: the original acicular separates out, coincidences and grows up to form banding. The coarse organize region is formed on the grain boundary by large of liquid phase coagulation; minute Ti2Cu phase in intracrystalline appears in the region of acicular zone.

Small amount of intracrystalline liquid phase aggregates to grain boundary where a large number of liquid phases exist in the process of deformation. Simultaneously liquid phase on intergranular diffuses to intracrystalline, but diffusion rate is less than aggregation speed. The higher the deformation temperature is, the more the liquid is, and the quicker the aggregation speed is. Otherwise, with rising strain-rate, the deformation time is short and liquid phase enriching on grain boundary can't diffuse into intracrystalline enough quickly, which leads to a large number of intracrystalline liquid phase aggregate on grain boundary on the condition of compressive stress and freezing to form coarse organization zone, and intracrystalline Ti2Cu phase reduces. So Ti2Cu precipitated phase has obvious tend to coarse with increasing strain rate and the rising deformation temperature, acicular Ti2Cu phase is obviously reduced.

4 Conclusions

1) The deformation temperature affects not only proportion of liquid phase directly, but also the growth of nucleation and globurizing of crystal grain. With rising the temperature, the diameter of grain increases obviously, and the grain boundary becomes widen.

2) The effect of deformation degree on the microstructure varies with deformation temperature, the solid plastic deformation is mainly in the mode of texture at a lower temperature. With increasing the deformation degree increasing, the size of grain is reduced. While at a higher temperature with increasing deformation degree, the size of grain increases before reducing.

3) At a lower deformation temperature, equivalent diameter of grains reduces with strain rate increasing. While at a higher deformation temperature, equivalent diameter of grains appears a trend to elevation with strain rate increasing.

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