

# Deformation of $Zr_{41}Ti_{14}Cu_{12.5}Ni_{10}Be_{22.5}$ bulk amorphous alloy under isobaric pressure in super cooled liquid region<sup>①</sup>

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**Abstract:** The curve of crystallization transition during continuous heating for the  $Zr_{41}Ti_{14}Cu_{12.5}Ni_{10}Be_{22.5}$  bulk amorphous alloy was measured by means of dilatation(Fully automatic transformation recording/measuring instrument) and X-ray diffraction(XRD) method. The deformation behavior of the alloy at various heating rates in the supercooled liquid region was studied. The results show that the glass transition temperature of the alloy increases slightly and the supercooled liquid region(SLR) increases significantly with increasing heating rate. The deformation amount under isobaric pressure of 1 N for the alloy in the SLR increases with increasing heating rate. As the heating rate of the alloy increases from 5 to 100 °C/min, the amount of deformation of the alloy increases from 8.3% to 45%.

**Key words:**  $Zr_{41}Ti_{14}Cu_{12.5}Ni_{10}Be_{22.5}$  alloy; bulk amorphous alloy; supercooled liquid region; deformation

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## 1 INTRODUCTION

The formation of metallic glass by melt quenching from the liquid state with high cooling rate( $10^6$  K/s) was first proposed by Duwez et al<sup>[1]</sup> in 1960. Since then, a considerable number of metallic glass and nanostructured systems have been prepared by this technique<sup>[2-4]</sup> and some industrial applications are well established. However, the high cooling rate limits the sample geometry to thin sheets and lines, which are unlikely to be widely applied. During the past years, a number of complex multicomponent bulk amorphous alloys with excellent glass forming ability(GFA) are developed<sup>[5-12]</sup>. The minimum critical cooling rate for glass formation has been reported to be about 1 K/s<sup>[8]</sup>. These amorphous alloys, which exhibit advantageous properties such as high thermal stability and easy processing<sup>[8-17]</sup>, are believed to have considerable potential as advanced engineering materials. In addition to their interesting applications, these alloys, with an excellent stability in a larger super-cooled liquid region(SLR), provide a large experimental time scale to measure their physical properties, such as specific heat<sup>[10]</sup>, diffusion<sup>[11]</sup>, and viscosity<sup>[12]</sup> in the super-cooled liquid state. The Zr-Ti-Cu-Ni-Be alloy system represents one group of such alloys, which shows the best

glass forming ability<sup>[8, 9]</sup>; and its GFA approaches that of the traditional oxide glasses. The ability to form amorphous alloys very easily in large cross sections from common metallic elements, and possessing unique properties have aroused great interest and led to rapid development.

Multicomponent bulk amorphous alloys have been developed in recent years. The bulk amorphous alloy in Zr-Ti-Cu-Ni-Be system is an alloy system with the large glass forming ability(GFA). The amorphous alloy has drawn plenty of intensive investigations because of its unique mechanical and physical properties<sup>[18, 19]</sup>. One of the most important characteristics of the Zr-Ti-Cu-Ni-Be system bulk amorphous alloy is the wide SLR( $\Delta T$ ).  $\Delta T$  is defined as the difference between the glass transition temperature( $T_g$ ) and crystallization temperature( $T_x$ ). When  $\Delta T (= T_x - T_g)$  reaches 100 K, it can provide conditions for studying the mechanical behavior of bulk amorphous alloy in the SLR. In the present paper the deformation behavior of  $Zr_{41}Ti_{14}Cu_{12.5}Ni_{10}Be_{22.5}$  alloy under isobaric pressure at various heating rates in the supercooled liquid region is studied.

## 2 EXPERIMENTAL

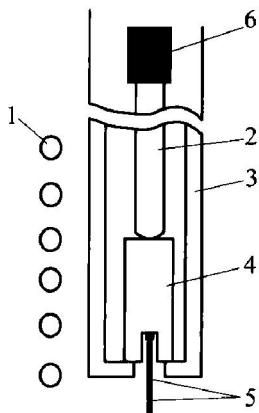
The bulk amorphous alloy with composition of

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$Zr_{41}Ti_{14}Cu_{12.5}Ni_{10}Be_{22.5}$  was quenched in water to get rods (diameter of 8 mm). The amorphous nature of the as-quenched rods was confirmed by XRD. The rods were machined to specimens of 3 mm in diameter and 10 mm in length. The heating crystalline transition curves at a constant rate and the deformation under the isobaric pressure of 1 N in the SLR at various heating rates for the alloy were measured with fully automatic instrument. The schematic diagram of the sample assembly is shown in Fig. 1. The specimens were fixed in the quartz tube. The specimen's change was fed to D. T core by quartz rod moving up or down along the differential transformer core (D. T core), which changes the output voltage of transformer, thus the dilation signal was transformed into electric signal. A differential transformer of very high sensitivity, stability, linearity and response, permits accurate measurement of even very small deformation.



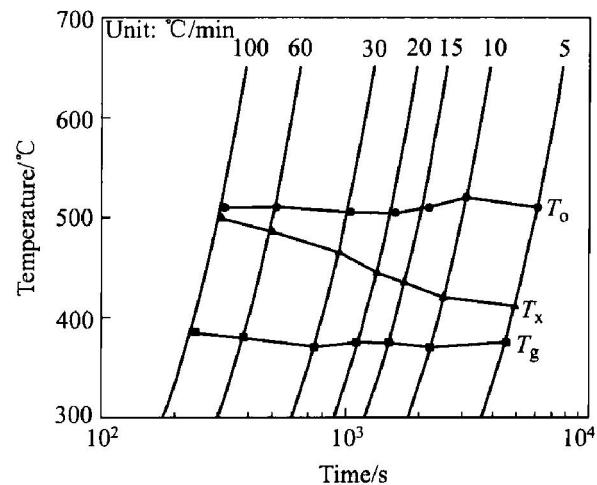
**Fig. 1** Schematic diagram of sample assembly  
1—Work coil; 2—Quartz rod; 3—Quartz tube;  
4—Specimen; 5—Thermocouple(T. C.);  
6—Differential transformer core

The deformation experiment was carried out in the vacuum of  $10^{-4}$  Pa and at different heating rates of 5, 10, 15, 20, 30, 60 and 100 K/min respectively. The highest heating temperature was 650 °C. The XRD patterns were obtained using D/MAX-γB diffractometer with graphite monochromator and Cu K $\alpha$  radiation.

### 3 RESULTS AND DISCUSSION

Fig. 2 shows the curves of the heating crystallization transition for the  $Zr_{41}Cu_{12.5}Ni_{10}Be_{22.5}$  bulk amorphous alloy. It can be seen that glass transition temperature ( $T_g$ ) increases slightly and the onset crystallization temperature ( $T_x$ ) significantly increases with increasing heating rate, which causes the SLR ( $\Delta T = T_g - T_x$ ) larger. The crystallization temperature region ( $T_o - T_x$ ) decreases with increasing heating rate. The super-cooled liquid region  $\Delta T = T_g - T_x$  is a main factor when evaluating

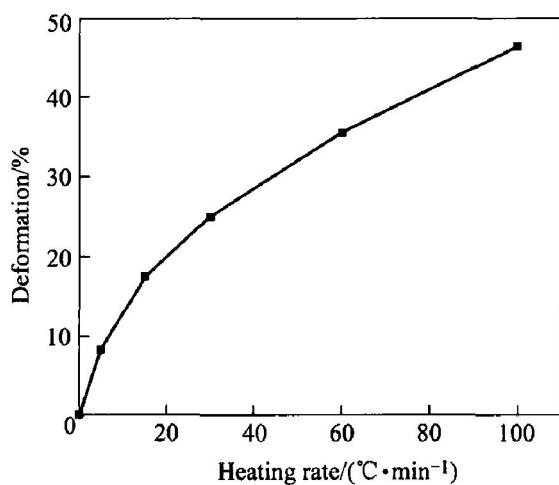
the stability of amorphous alloy, so increasing the SLR to some degree can increase the stability of amorphous alloy. And it provides conditions for studying the mechanical behavior and microstructure of bulk amorphous alloy in the SLR. As the heating rate increases from 5 to 60 °C/min, the SLR ( $\Delta T$ ) increases from 35 to 105 °C, and the crystallization temperature region decreases from 100 to 25 °C. As the heating rate reaches 100 °C/min, it is rather difficult to measure the crystallization temperature using dilatometry. The crystallization temperature of amorphous alloy approaches 500 °C and  $\Delta T$  reaches 115 °C by XRD.



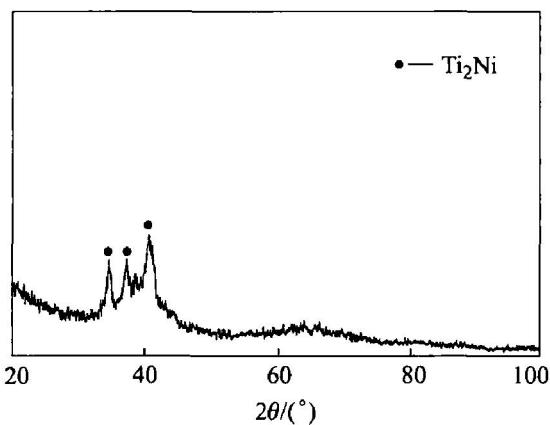
**Fig. 2** Curves of continuous heating crystallization transition curves of alloy

The deformation for the alloy under isobaric pressure at various heating rates in the SLR is shown in Fig. 3. It is noted that the amount of deformation for the alloy in the SLR increases with increasing heating rate. As the heating rate increases from 5 to 100 °C/min, the amount of deformation increases from 8.3% to 45%. Fig. 4 shows XRD pattern for the alloy heated at 100 °C/min to 500 °C. The analysis shows that the crystallization phase in the alloy consists of a little  $Ti_2Ni$  nanocrystal and amorphous phase.

The strength of the amorphous specimen is very high at the temperature below glass transition temperature, then the deformation under the pressure exerted by the quartz rod is neglected. As the temperature reaches the glass transition temperature, the specimen's strength suddenly decreases owing to the effect of tension creep behavior of viscosity cropping up<sup>[20]</sup>, so the deformation of specimens occurs. With increasing heating rate, owing to the asynchronism of the specimen's surface and core temperature arriving at  $T_g$  and  $T_x$ , causing extra deformation of inside tension, the amount of deformation under the same pressure in the SLR becomes bigger. It is obvious that when outside force is a constant, the deformation ability of the



**Fig. 3** Deformation of alloy under same pressure at various heating rates in SLR



**Fig. 4** XRD pattern of alloy heated at 100 °C/min to 500 °C

amorphous alloy in the super-cooled liquid region increases with increasing heating rate. Using this characteristic, we can make the amorphous alloy become amorphous alloy ball and minisize gear wheel very smooth and light. The increase in the heating rate can increase not only the stability but also the amount of deformation, which improves the glass-processing behavior of the alloy.

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