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# Correlation between glass transition temperature and Vogel-Fulcher-Tamman temperature in amorphous alloys

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ABSTRACT

The correlation between the glass transition temperature $T_g$ and the Vogel-Fulcher-Tamman temperature $T_0$ in metallic glasses is investigated. The linear relationships, $T_0 = 0.897T_g$-100.9, are discovered. Amorphous alloys with desired the Vogel-Fulcher-Tamman temperature $T_0$ can be predicted and designed by the linear relationship.



## 1. Introduction

The amorphous alloy is a less-stable material and can transform into crystalline phase when it is heated. Whether non-isothermal or isothermal crystallization process, amorphous alloy will transform into a supercooled liquid when glass transition occurs, which suggests that the glass transition temperature is a important parameter. The study of $T_g$ found $T_g = 2.5E$ and $T_g \propto$ MG [1], where $E$ is the Young's modulus, $M$ is the molar mass and $G$ is the shear modulus. The relationship between $T_g$ and $\theta_D$ is $T_g = aM\theta_D^2$ [2], where $\theta_D$ is the Debye temperature and a is a constant. A linear relationship, $T_g = 0.385<T_m>$ [3], where $T_m$ is the average melting temperature. Besides, the glass transition temperature varies with the variation of the heating rate $\beta$ [4–7]. The heating rate $\beta$ as a function of $T_g$ can be expressed as the Vogel-Fulcher-Tamman equation [8,9]: $\beta = A\exp\{DT_0/(T_0\text{-}T_g)\}$, where $A$, $D$, and $T_0$ is the onset of the glass transition in the limit of $\beta \rightarrow 0$. In general, the deviation of actual measured the glass transition temperature is minor by different heating rate $\beta$ [6,7]. Therefore, the actual measured the glass transition temperature $T_g$ can be approximately seen as a constant for a certain amorphous alloy. Although the glass transition temperature $T_g$ and the Vogel-Fulcher-Tamman temperature $T_0$ of large amounts of amorphous alloys were studied, respectively [6–12], the correlation between the glass transition temperature $T_g$ and the Vogel-Fulcher-Tamman temperature $T_0$ of these different amorphous alloys has not been studied.

In this paper, the relationship between the glass transition temperature $T_g$ and the Vogel-Fulcher-Tamman temperature $T_0$ is investigated. The purpose of this article is that the glass transition temperature $T_g$ can be used to predict the Vogel-Fulcher-Tamman temperature $T_0$ of amorphous alloys.

## 2. Experimental

Master alloy ingot with nominal composition of $Cu_{50}Zr_{50}$ and $Cu_{48}Zr_{45}Al_7$ (at.%) was prepared by arc-melting the mixtures of Cu, Zr and Al elements with a purity of 99.99% in an argon atmosphere, while the ingot was remelted for at least four times to ensure homogeneity. With a single copper roller melt spinning method, the $Cu_{50}Zr_{50}$ and $Cu_{48}Zr_{45}Al_7$ samples were prepared at the wheel surface velocity of 40 m/s under a high argon atmosphere. X-ray diffraction (XRD-6000) with Cu-$K\alpha$ radiation and transmission electron microscopy (JEM-2010) were applied to ascertained amorphous structure at room temperature. Thermal analysis was performed using a differential scanning calorimeter (DSC823e) under a purified argon atmosphere. To study non-isothermal and isothermal crystallization conditions of amorphous alloys, the $Cu_{48}Zr_{45}Al_7$ metallic glass is heated from 298 K to 805K at a heating rate of 20 K/min; The $Cu_{50}Zr_{50}$ metallic glass is heated from 298 K to 728K at a heating rate of 20 K/min and is isothermally heated at 728K until the end of crystallization process.

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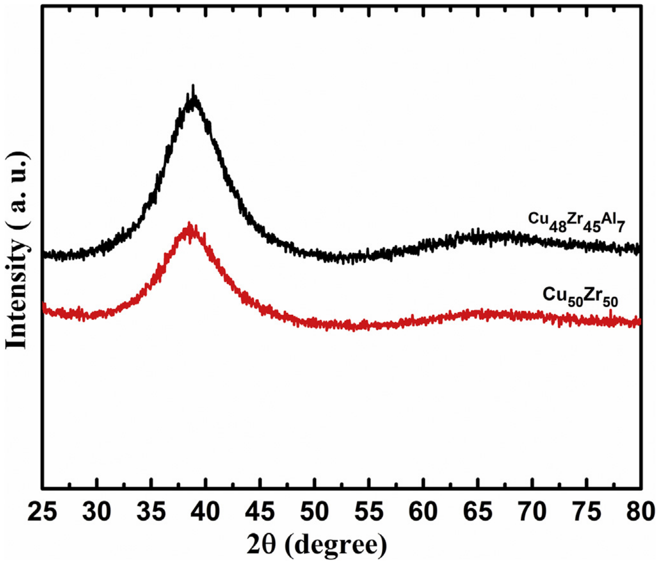


**Fig. 1.** X-ray diffraction patterns of $Cu_{50}Zr_{50}$ and $Cu_{48}Zr_{45}Al_7$ amorphous alloys.

## 3. Results and discussion

Fig. 1 shows X-ray diffraction patterns of the $Cu_{50}Zr_{50}$ and $Cu_{48}Zr_{45}Al_7$ amorphous alloys. It can be seen that only a broad diffraction peak at the $2\theta \approx 40^\circ$ from Fig. 1, which suggests that the structure of the as-quenched ribbons is amorphous state. The microstructure of the $Cu_{50}Zr_{50}$ and $Cu_{48}Zr_{45}Al_7$ samples is further confirmed by high-resolution transmission electron microscopy (HR-TEM), respectively. As shown in Fig. 2, selected-area electron diffraction (SEAD) and HR-TEM micrograph exhibit no evidence of any crystallization as well.

The amorphous alloy is a less-stable material and can transform into crystalline phase when it is heated. The non-isothermal DSC curve of $Cu_{48}Zr_{45}Al_7$ amorphous alloy are shown in Fig. 3(a). It can be seen that amorphous state transform into a supercooled liquid region when temperature reaches the glass transition temperature, $T_g$. Then, the DSC curve exhibits a single exothermic peak corresponding to crystallization process after a supercooled liquid region. The isothermal DSC curve of $Cu_{50}Zr_{50}$ amorphous alloy are shown in Fig. 3(b). The glass transition of $Cu_{50}Zr_{50}$ metallic glass occurs when amorphous alloy is heated from 298 K to 728K at a heating rate of 20 K/min; During isothermal process, crystallization

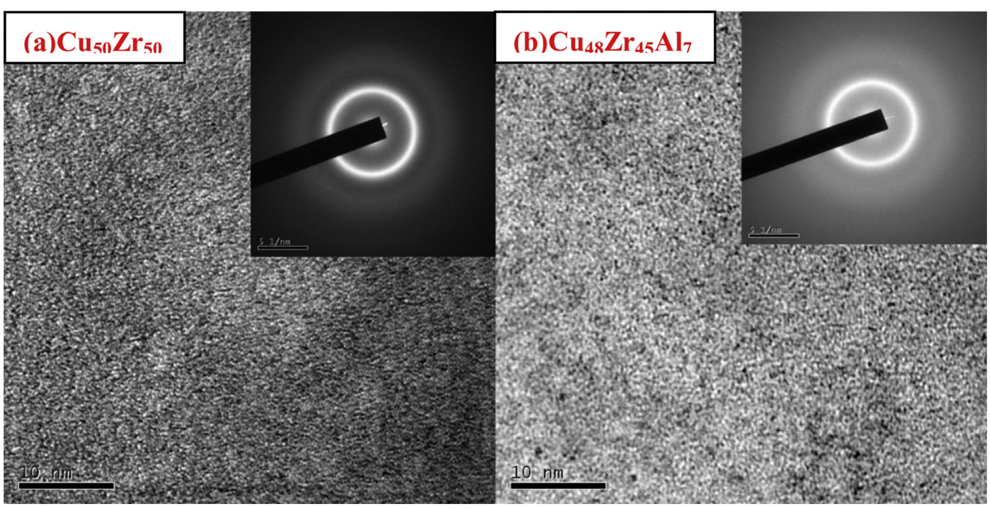


**Fig. 2.** The high-resolution TEM image and the SAED pattern (inset) of the $Cu_{50}Zr_{50}$ and $Cu_{48}Zr_{45}Al_7$ amorphous alloys.

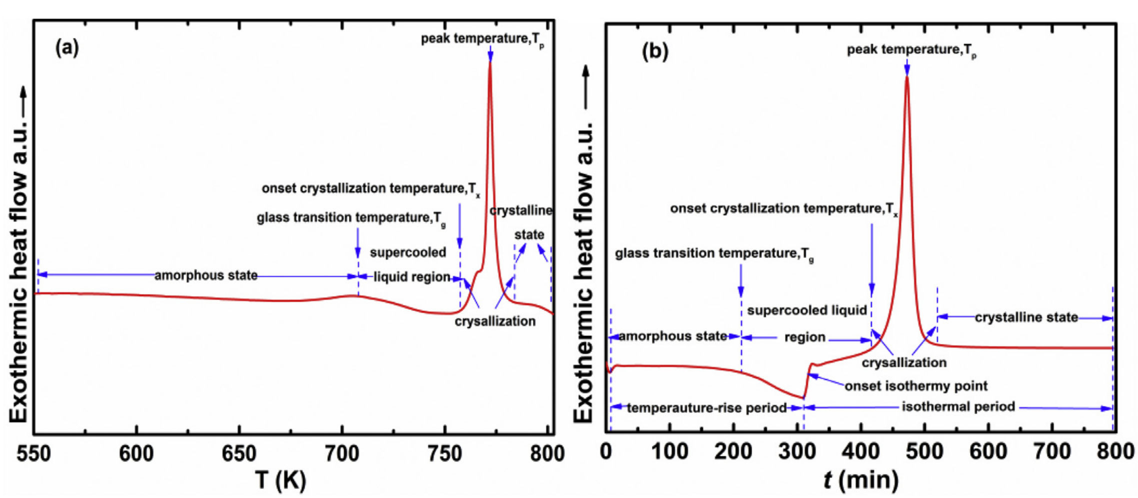


**Fig. 3.** DSC curves of amorphous alloys. (a) non-isothermal crystallization process of $Cu_{48}Zr_{45}Al_7$ amorphous alloy (b) isothermal crystallization process of $Cu_{50}Zr_{50}$ amorphous alloy.