International Journal of Engineering Research ISSN:2319-6890)(online),2347-5013(print)
Volume No.5 Issue: Special 2, pp: 418-420 11-12 Feb. 2016

Crystallization Kinetics in Amorphous $Fe_{74}Y_6B_{20}$ Alloy

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Abstract: ***The crystallization kinetics of amorphous $Fe_{74}Y_6B_{20}$ alloy has been carried out using Differential Scanning Calorimetry (DSC) technique. The alloy showed two stage crystallization. The activation energy (E_a) has been calculated usingMasutika-Sakka, Augis-Bennet and Kissinger methods and the average value is found to be 513.82 kJ/mol and 384.33 kJ/mol for the first and second crystallization peaks, respectively.***

Keywords : Differential Scanning Calorimetry, X-Ray Diffraction, Rare Earth

1. INTRODUCTION

Amorphous alloys of magnetic nature produced by rapid quenching of melt of iron rich alloys; have been of scientific and technological interest in the recent past. Even though these alloys lack long-range crystalline order, they show ferromagnetic properties. They represent a metastable state and tend to show structural relaxation with time which gets accelerated at higher temperature. At high enough temperatures, they crystallize irreversibly in a more stable state. The kinetics of crystallization plays an important role in physics, chemistry, ceramic and metallurgical sciences. Rare Earth (RE) containing alloys (usually Fe-RE-B) obtained in amorphous state by Melt-Spinning technique show enhanced magnetic properties compared to traditional permanent magnets. These materials have raised considerable interest in recent years because of their essential properties like high saturation induction, high coercivity, large energy product etc., as the cost is lowered due to the substantial reduction of the rare-earth content, and it therefore accounts for a new generation of permanent magnetic materials. It is mentioned that the addition of a small percentage of rare earth additives such as Pr, Gdand Dy in iron-boron amorphous alloys stabilizes the amorphous state [1, 2]. Thermal analysis methods, including DSC, are extensively used for studying kinetics of chemical reactions and crystallization of these alloys. The determination of basic data on crystallization kinetics is important in establishing the mechanism of crystal nucleation and growth [1]. The study of crystallization kinetics of these alloys gives useful insight about their thermal stability. In this paper, the crystallization Kinetics of amorphous $Fe_{74}Y_6B_{20}$ alloy using Differential Scanning Calorimetry (DSC) technique is reported.

2. EXPERIMENTATION

Amorphous ribbon of $Fe_{74}Y_6B_{20}$ alloy having thickness of about 30µm and width of 1mm produced by single roller melt spinning was procured from our other group of Researchers. The amorphous nature of the ribbon was confirmed by X-Ray Diffraction (XRD). The thermal behavior of the alloy was investigated by high temperature differential scanning calorimetry (DSC) conducted at different heating rates of 10^0C/min, 20^0C/min, 30^0C/min and 40^0C/min.

3. RESULTS AND DISCUSSION

The DSC curves of fresh (as-quenched) samples of Amorphous $Fe_{74}Y_6B_{20}$ alloy at different heating rates of 20^0C/min(Blue), 30^0C/min(Red) and 40^0C/min(Green) show two-step crystallization as shown in Fig. 1. Also, Fig. 1 reveals that the alloy undergoes two stage crystallization reactions with wide temperature interval between two crystallization stages. Observation of two step crystallization is more common in metallic glasses contained more than three elements than in those containing less components. The first broad peak in the present case arises due to (1)Structural relaxation occurring with a broad range of relaxation times due to a variety of atomic rearrangement and (2)Formation of intermediate metastable phases. The second peak arises due to crystallization as in glass which is a defined nucleation and growth reaction. Broadening also occurs due to kinetic reasons as the kinetics involving structural processes slows down due to the disappearance of free volume during relaxation processes.

The activation energy(E_c) for crystallization of an amorphous alloy under a linear heating rate(non-isothermal) is calculated using Masutika-Sakka, Augis-Bennet and Kissingermethods[2,3,4], which relates the peak temperature(T_p) with heating rate(β)using the relations.

$$\ln\beta = -[E_a/(RT_p)] + \text{Constant} \quad \ldots\ldots(1)$$

$$\ln(\beta/T_p) = -[E_a/(RT_p)] + \text{Constant} \quad \ldots\ldots(2)$$

$$\ln(\beta/T_p^2) = \text{Constant} - [E_a/(RT_p)] \quad \ldots\ldots(3)$$

where'R' is Gas constant.

ISSN:2319-6890)(online),2347-5013(print)
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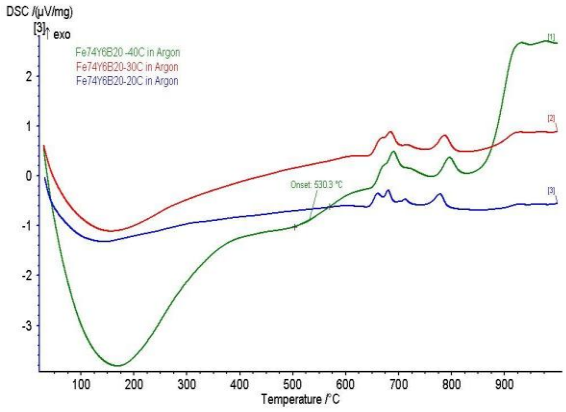


Figure 1. DSC thermograms of amorphous $Fe_{74}Y_6B_{20}$ alloy at different heating rates of 20^0C/min(Blue), 30^0C/min(Red) and 40^0C/min(Green)

Table1 shows the heating rate, first peak and second peak temperatures of amorphous**$Fe_{74}Y_6B_{20}$a**lloy, calculated from the DSC curves.Figures 2,3 and 4 show the plots of Masutika-Sakka, Augis-Bennet and Kissinger methods for amorphous **$Fe_{74}Y_6B_{20}$** alloy.The values of the activation energy (**E_a**)obtained for the present sample using the above three methods are given in Table 2. Comparison of the **E_a** values obtained for different non-isothermal methods shows that the values are in good agreement with each other. This means that one can use any of the three methods to calculate the activation energy of crystallization.

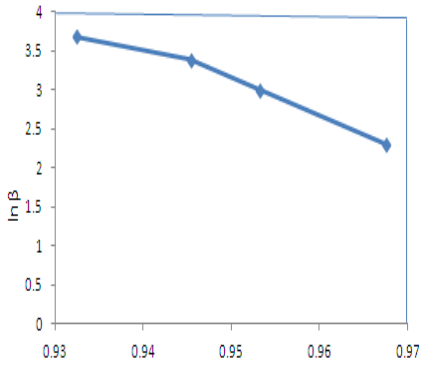
Table 1: Heating rate, First peak and Second peak temperatures of amorphous $Fe_{74}Y_6B_{20}$Alloy

S. No.	Heating Rate(^{0}C/min)	First peak temperature(^{0}C/min)	Second peak temperature(^{0}C/min)
1	10	670.66	760.66
2	20	681.19	776.19
3	30	684.85	784.85
4	40	689.91	799.49

Table 2: Activation energy of crystallization(E_a), in kJ/mol, ofamorphous $Fe_{74}Y_6B_{20}$ Alloy calculated from non-isothermal methods.

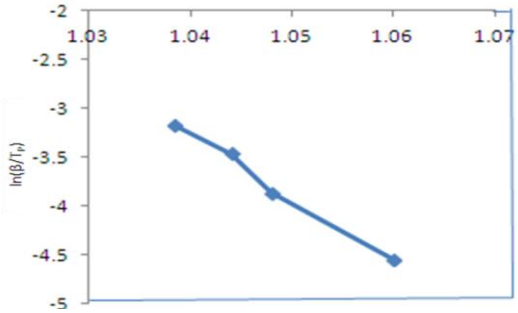
	Masutika-Sakka Method	Augis-Bennet's Method	Kissinger's Method	Average Value
Peak 1	527.10	498.87	515.50	513.82
Peak 2	380.09	382.47	390.42	384.33

MatusikaSakka method (peak 1)

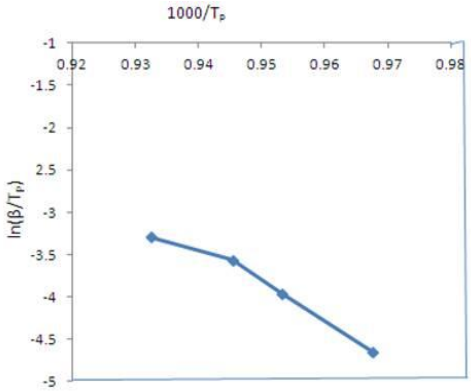


MatusikaSakka method (peak 2)
$1000/T_p$

Fig. 2: Matusita- Sakka plots for amorphous $Fe_{74}Y_6B_{20}$ alloy

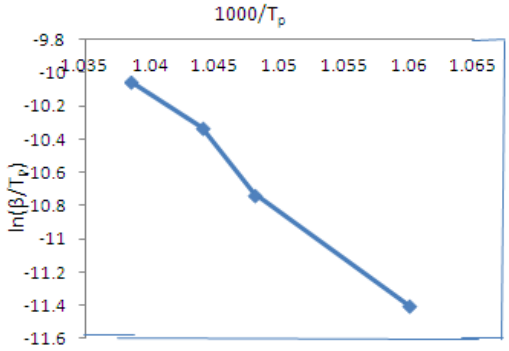


Augis and Bennet (peak 1)



Augis and Bennet(peak 2)

Fig. 3:Augis and Bennett plots for amorphous $Fe_{74}Y_6B_{20}$ alloy



Kissinger plot (peak 1)

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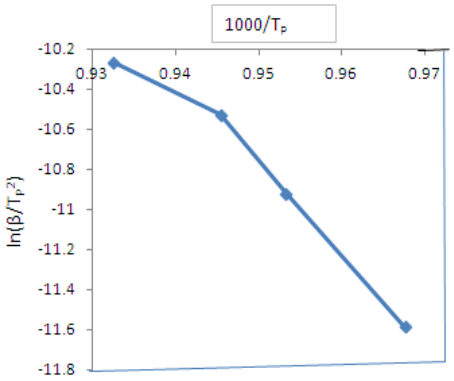

Kissinger plot (peak 2)

Figure 4. Kissinger plots for amorphous $Fe_{74}Y_6B_{20}$ alloy

CONCLUSIONS:

Amorphous $Fe_{74}Y_6B_{20}$alloy showed two stage crystallization. The average activation energy (E_a) has been calculated using Masutika-Sakka, Augis-Bennet Kissinger methods and is found to be equal to 513.82 kJ/mol and 384.33 kJ/mol for the first and second crystallization peaks, respectively.

Acknowledgements

The authors would like to thank our Management, Principal, Head of sciences & Humanities and staff of M.V.S.R, Engineering College, Nadergul, Hyderabad for continuous support and encouragement in completing the work.

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