Study of Glass Transition Temperatures in Sugar Mixtures by DSC

Jeong-Ah Seo, Su Jae Kim, Jiyoung Oh, Y.S.Yang[a], Hyung Kook Kim, Yoon-Hwae Hwang*

RCDAMP and Department of Physics, Pusan National University
[a] *Institute of Nanoscience and Technology, Pusan National University*

Abstract. We studied the glass transition temperatures of mono-monosaccharide and mono-disaccharide mixtures by differential scanning calorimetry. We found that glass transition temperatures of mono-monosaccharide mixtures can be described by the Gordon-Taylor equation. However the glass transition temperatures of mono-disaccharide showed a deviation form the Gordon-Taylor equation, indicating that the molecule size has an effect on the glass transition temperature of sugar mixtures.

INTRODUCTION

We were interested in sugar glasses mainly by two reasons. There have been no published studies of the glass transition dynamics in sugars designed to reveal the full structural relaxation process and sugars are also useful materials for studying aging phenomena. Aging phenomena is a special property of non-equilibrium state of a glass phase and the study of aging phenomena including two-time scaling, fluctuation-dissipation violations, and rejuvenation effects is a relatively unknown area. The motivation for selecting sugars as the materials for this study was the glass transition temperature of several sugars lies above room temperature. This characteristic is particularly attractive for physical aging experiments which require a rapid temperature quench in order to study the evolution of relaxation dynamics with time. In this study, we measured the glass transition temperature of sugar mixtures, mono-monosaccharide and mono-disaccharide mixtures by differential scanning Calorimetry (DSC).

EXPERIMENTS

It is very difficult to make a glass phase of a sugar because sugars are very sensitive to heat. When a sugar was heated, it changed into brown colored material called caramel due to a dehydration [1]. To prevent the caramelization, we have to heat the sugar uniformly and quickly. For melting sugar without caramelization we used Thermogravimetry – Differential Thermal Analysis (TG-DTA : MAC science, DTA 2000S, Japan) because TG-DTA was effective method to heat the sample uniformly and quickly. The melting temperatures of sorbitol, glucose and sucrose were 99℃, 155℃ and 186℃, respectively. The difference of melting temperatures, Δ T, between glucose and sorbitol was about 60℃ and between glucose and sucrose was about 30℃. But we need the higher heating rate for glucose-sucrose mixture than sorbitol-glucose mixture because the caramelization phenomenon was holdback in sorbitol. IR(infrared) furnace was used for glucose-sucrose mixtures with 600℃/min heating rate and electric furnace was used for sorbitol-glucose mixtures with maximum heating rate of 40℃/min.

The glass transition temperatures of mono-mono saccharide and mono-disaccharide mixtures were measured by using Differential Scanning Calorimetry (DSC ; MAC science, DSC3100, Japan). The heating rate used in this measurement was 4℃/min and the glass transition temperatures were taken as midpoint between the onset and end point. We used a cylindrical shape aluminum cell and the size of sample cell was

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5.2 mm in diameter and 5.1 mm in height, and Al_2O_3 was used for a reference material. All sugar chemicals (D-glucose, sorbitol and sucrose) were purchased from Sigma Chemical Co. and were used without further purification.

RESULTS & DISCUSSIONS

The glass transition temperature of sugar mixtures has been expressed by the Gordon-Taylor equation.

$$T_g = \frac{w_1 T_{g1} + k w_2 T_{g2}}{w_1 + k w_2}$$

Here, T_g is glass transition temperature of the mixture, w_1 and w_2 are weight fractions of components 1 and 2, T_{g1} and T_{g2} are glass transition temperatures of component 1 and 2, and k is a constant [2].

We found that glass transition temperatures of mono-monosaccharide mixtures can be described by the Gordon-Taylor equation as shown in Fig. 1. The value of constant k was 0.46. But we observed different result in the mono-disaccharide mixtures. Figure 2 shows a glass transition temperatures of glucose-sucrose mixtures (mono-disaccharide mixtures). The glass transition temperatures showed a deviation form the Gordon-Taylor equation. The value of constant k was 0.43. A careful inspection revealed that the curve was crossed at the point where the weight fraction of monosaccharide was 0.35. In the mono-mono saccharide mixture the weight fraction $\mathcal{W}$ and the number fraction $\mathcal{N}$ are the same but in the mono-disaccharide mixture $\mathcal{W}$ and $\mathcal{N}$ are different because the molecular weight of glucose, sorbitol and sucrose are 180.16, 182.2 and 342.3, respectively. The point where $\mathcal{W}= 0.35$ represents when the number of sugar units of monosaccharide and disaccharide are the same. From this result, we found that the molecule size has an effect on the glass transition temperature of sugar mixtures.

In summary, we measured the glass transition temperature of mono-monosaccharide and mono-di saccharide mixture, respectively. The results of mono-mono saccharide obeyed the Gordon-Taylor equation but mono-disaccharide mixture showed a deviation form Gordon-Taylor equation. Mono-di saccharide mixture data were crossed with the Gordon- Taylor equation at the point where the number of monosaccharide and disaccharide were the same. From this result, we found that the molecule size has an effect on the glass transition temperature of sugar mixtures.

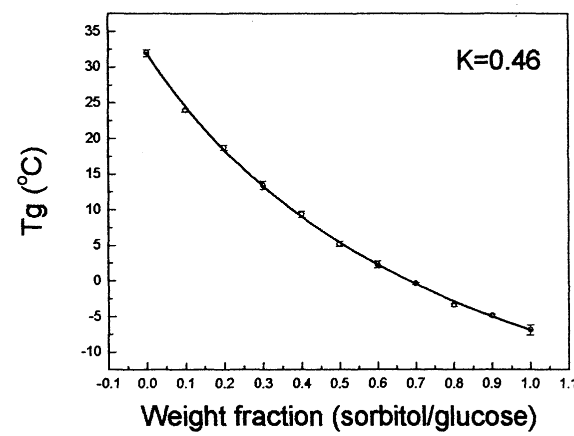

FIGURE 1. Glass transition temperatures of sorbitol-glucose mixtures. (Mono-monosaccharide mixtures)

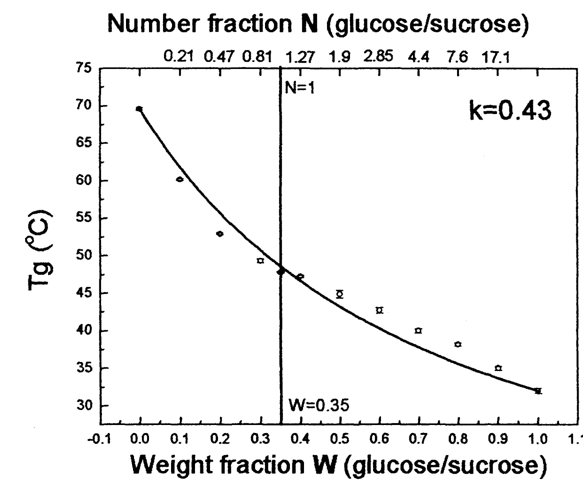

FIGURE 2. Glass transition temperatures of glucose-sucrose mixtures. (Mono-disaccharide mixtures)

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