

The Effects of Fe₂O₃ and B₂O₃ on the Glass Structural, Thermal, *in Vitro* Degradation Properties of Phosphate Based Glasses

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Abstract

Currently, phosphate based glasses have been potential future biomaterial for medical application due to excellent cytocompatibility and fully bioresorbability. In this study, phosphate based glass system with composition of $48P_2O_5 - 12B_2O_3 - (25 - X)MgO - 14CaO - 1Na_2O - (X)Fe_2O_3$ (X = 6, 8, 10) and $45P_2O_5$ -(Y)B_2O_3-(32-Y)MgO-14CaO-1Na_2O-8Fe_2O_3 (Y = 12, 15, 20), was prepared via a melting quenching process. The effect of replacing MgO with Fe₂O₃ and B₂O₃ on the structural, thermal, degradation properties of phosphate based glass was investigated. Fourier Transform Infrared (FTIR) spectroscopy and Raman spectroscopy analysis confirmed the polymerisation of phosphate based glass network with addition of Fe₂O₃, thus the processing window was observed to increase whilst the dissolution rate was reduced, attributed to the formation of Fe-O-P cross-link. As the effect on the glass structure stability was demonstrated by both B₂O₃ and MgO, the nonlinear variation of thermal stability and degradation behaviour was observed for glass system with substitution of MgO by B_2O_3 . However, due to the lower dissolution rate of glass system when compared to the biocompatible phosphate based glass in preliminary study, the expected cytocompatibility could be confirmed in the downstream activities.

Keywords

Phosphate Based Glass, Boron, Iron, Thermal Properties, Degradation Study

1. Introduction

A number of bioresorbable and bioactive materials with the required biocompatibility and sufficient mechanical properties have been the subject of much interest in recent studies [1] [2] [3] [4] [5]. The first bioactive glasses (Bioglass 45S5) developed by Hench *et al.* [6] [7] in 1970s, were presenting a specific biological response resulting in the formation of a bond between the bioactive glass surface and bone tissue, thus becoming the benchmark for novel silicate based bioactive glasses with application in dentistry and orthopaedics [8] [9]. However, partial degradation behaviour of Bioglass limits its application and has stimulated research for new bioactive and bioresorbable glasses as potential alternative [10].

In the last two decades, phosphate based glasses have been considered as potential materials for the repair and reconstruction of bone [11] [12] [13]. As their hydrolytic degradation rate can be varied from hours to months by changing the glass composition which can closely match that of the inorganic phase of bone [14] [15] [16], many phosphate glass formulations synthesised are biocompatible and subtle alterations to their composition permit a wide variation of mechanical and thermal properties [17] [18] [19]. Ahmed *et al.* [20] investigated phosphate based glass in the system $40P_2O_5$ -25CaO-20MgO-15Na₂O which showed good cellular response and Hasan *et al.* [21] studied the system $45P_2O_5$ -16CaO-24MgO-11Na₂O-4Fe₂O₃, which also showed good cytocompatibility and proved successful for fibre drawing.

In current publication, it was reported that addition of B_2O_3 into phosphate based glass could improve chemical durability and mechanical stability of phosphate based glass [22] [23] [24] [25]. Sharmin *et al.* [26] developed several borophosphate based glass compositions and reported that the glass transition temperature was increased whilst the degradation rate was reduced significantly with addition of B_2O_3 into the glass network. It was confirmed, and also reported by Lim *et al.*, [27] that the formation of covalent B-O-P bonding produced a stronger, better chemically resistant glass network with higher packing density and lower crystallisation tendency.

Additionally, preliminary studies also show that the addition of MgO into phosphate based glass could connect chain structure of phosphate based glass and transfer open metaphosphate glass structure to more compact structure, thus improving the glass structure stability [20]. Moreover, Fe_2O_3 dropped into the glass network could show a much more durable degradation behaviour and favourable cytocompatibility [28]. However, till to date, the effect on thermal properties, degradation behaviour and glass structure of phosphate based glass by substitution of MgO with B_2O_3 and replacing MgO with Fe_2O_3 has not been investigated significantly.

Based on the established phosphate glass system $P_2O_5-B_2O_3-CaO-MgO-Na_2O-Fe_2O_3$ [21] [26] [29], a range of novel complex PBGs in the system of $48P_2O_5-12B_2O_3-(25-X)MgO-14CaO-1Na_2O-(X)Fe_2O_3$ and $45P_2O_5$ -(Y) B_2O_3 -(32-Y)MgO-14CaO-1Na_2O-8Fe_2O_3 was considered in this study, and an investigation into their structural, thermal and degradation properties has been conducted. The effects on the glass density were also evaluated. Degradation studies of the glasses were conducted in phosphate buffer saline (PBS) solution.

2. Materials and Methods

2.1. Glass Preparation

The glasses in this study were manufacture in Sinoma Co., Ltd. (China) using phosphorous pentoxide (P_2O_5), boric acid (H_3BO_3), calcium hydrogen phosphate dehydrate (CaHPO₄·2H₂O), magnesium hydrogen phosphate trihydrate (MgHPO₄·3H₂O), sodium dihydrogen phosphate dehydrate (NaH₂PO₄·2H₂O), potassium dihydrogen phosphate (KH₂PO₄), and iron (III)-phosphate Tetrahydrate (FePO₄·4H₂O) (Sinopharm Group, China). The precursors were weighted out and placed into a large Pt crucible which was built in the customised furnace composed of Al₂O₃. When all the mixed precursors had been added, they were heated using a silicon carbide rod by direct resistance heating. After 24 hours heating at 1200°C, the melted glass was poured into a stainless steel bucket water for cooling and collecting. The cooled glasses were then removed from the bucket and dried in oven for 12 hours. 5 kg glass batches were manufactured for each composition.

The bulk glasses were then re-melted and cast as 9 mm diameter rods by pouring into a graphite mould at 450°C. After 2 hours at this temperature, the glass rods in the mould were cooled to room temperature at a cooling rate of 0.3°C/min. Then, the rods were re-placed into the furnace for annealing process via heating at the temperature of T_a (T_g + 10°C) for 90 minutes isothermally. After that, the rods were allowed to cool to room temperature at 0.3°C/min cooling rate.

2.2. Powder X-Ray Diffraction Analysis (XRD)

In order to confirm the amorphous state of all the glass compositions, powder X-ray diffraction spectra were obtained using a Bruker D8 advance X-ray diffractometer. The measurements were taken at room temperature and ambient atmosphere with Ni-filtered CuK α radiation ($\lambda = 0.15418$ nm), operated at 40 kV and 35 mA. The scans were performed with an angular range 2θ from 10° to 100°, a step size of 0.01° and a step time of 0.1 s.

2.3. Fourier Transform Infrared Spectroscopy (FTIR)

Fourier transform infrared spectroscopy was performed on around 1 - 2 mg samples of glass powder, using a Bruker Vertex 70 spectrometer (Bruker Optics, Germany). Spectra were recorded in the region of 500 to 4000 wavenumbers using a standard MKII Golden GateTM Single Reflection Attenuated Total Reflectance (ATR) system (Specac Ltd.) and analysed using OPUS software version 5.5.

2.4. Raman Spectroscopy

Raman spectra were recorded at room temperature using inVia-Reflex Raman spectrometer (Renishaw, 633 nm laser). Bulk glass with good surface quality was placed on the sample stage and observed via objective turret in order to focus laser on glass surface. D0.3 filter was used to control transparency (50%) and Raman spectra from 400 cm⁻¹ to 2000 cm⁻¹ were taken into account in this study.

2.5. Differential Scanning Calorimetry (DSC)

Bulk glasses of the different compositions were ground to fine powder using a pestle and mortar. The glass transition temperature T_g , crystallisation temperature T_c , melting point T_m and liquidus temperature T_l of the glasses was determined using a differential scanning calorimetry (DSC, TA Instruments SDT Q600, UK). Samples of approximately 30 mg of the glass powders were heated from room temperature to 1200°C at 10°C·min⁻¹ in flowing nitrogen gas. A blank run was carried out to determine the baseline which was then subtracted from the traces obtained. The T_g was extrapolated from the midpoint in the endothermic reaction of the heat flow. The first deviation of the DSC curve from the base line above T_g and before the crystallisation peak was taken as the onset of crystallisation temperature T_{onc} . The thermal stability of the glass was indicated in terms of processing window T_{pw} by measuring the interval between T_g and T_{onc} [30] [31]:

$$T_{pw} = T_{onc} - T_g \tag{1}$$

2.6. Density Measurement

The density of the glasses was determined using Ultrapyc 1200e (Quantachrome, USA). The equipment provides an accurate measurement of volume and is calibrated by using a standard steel calibration ball (2.18551 cm³), with errors of $\pm 0.05\%$. Triplicate, bubble-free bulk glass samples with an average weight of approximately 7 g were used for the volume measurements.

2.7. Degradation Study

Three PBG glass rods of each composition, 9 mm diameter and 10 mm length, were put into 30 ml glass vials, immersed in phosphate buffer saline (PBS) and then placed into an incubator at 37°C. The surface area of each disc was calculated from dimensional measurements taken using a micrometer (Mitutoyo, Japan) and their mass was measured to 4 decimal places using a digital balance (Mettler Toledo, USA). The period of degradation analysis was 60 days and the time points were days 1, 2, 3, 4, 7, 9, 12, 16, 20, 23, 26, 30, 33, 37, 40, 44, 47, 50, 54, 58 and 60. At each time point, the glass rods were taken out of the vials, excess moisture was removed by blotting the samples dry with tissue and they were then dried in an oven at 50°C for 60 minutes. Dimension and mass measurements were taken and the pH of the solution was measured by using a microprocess pH meter (Mettler Toledo, USA) before returning the samples to the

vials with fresh PBS solution. The rate of mass loss was calculated using the following equation:

Mass loss(%) =
$$\frac{M_0 - M_t}{M_0}$$
 (2)

where M_o is the initial mass (g) and M_t is the mass at time *t*. The values of mass loss per unit area, determined via Equation (4), were plotted against time. The slope of the graph was determined by fitting a straight line through the data and passing through the origin point gave the dissolution rate in terms of kg·m⁻²·s⁻¹

Mass loss per unit area
$$\left(\text{kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \right) = \frac{M_0 - M_t}{A_o}$$
 (3)

where A_o is surface area of glass disc at time t.

2.8. Statistical Analysis

The average values and standard deviation of all data involved in this study were calculated and analysed using the Prism software (version 6.0, GraphpPad Software, San Diego, CA, USA). A one-way analysis of variance (ANOVA) was calculated with the Tukey multiple post-test to compare the significance of change in one factor with time. The error bars on all the data represent standard error of mean.

3. Results

3.1. Glass Composition and Properties

In this study, six glass formulations of phosphate based glasses were considered as two groups, MgP-Fe(X) for glass system

 $48P_2O_5-12B_2O_3-(25-X)MgO-14CaO-1Na_2O-(X)Fe_2O_3$ and MgP-B(Y) for glass system $45P_2O_5-(Y)B_2O_3-(24-Y)MgO-14CaO-1Na_2O-8Fe_2O_3$. The density analysis of bulk glass presented the value of density increased from 2.86 to 3.01×10^3 kg·m⁻³ with increase of Fe₂O₃ content for MgP-Fe glass system, whilst the decrease in the density was observed for MgP-B glass system when B_2O_3 content increased from 15 mol% to 20 mol%.

The thermal analysis of phosphate based glasses were summarised in Table 1,

Table 1. The composition, density, glass transition temperature (T_g) and processing window (T_{pw}) of the glasses in this study.

Glass code -	Composition						Density	T_g	T_{pw}
	P_2O_5	CaO	Na ₂ O	MgO	B_2O_3	Fe_2O_3	$(\times 10^3 \text{kg} \cdot \text{m}^{-3})$	(°C)	(°C)
MgP-Fe6	48	14	1	19	12	6	2.86 ± 0.01	512 ± 3	270 ± 3
MgP-Fe8	48	14	1	17	12	8	2.93 ± 0.02	520 ± 2	213 ± 4
MgP-Fe10	48	14	1	15	12	10	3.01 ± 0.01	527 ± 4	193 ± 2
MgP-B12	45	14	1	20	12	8	2.91 ± 0.03	534 ± 2	184 ± 5
MgP-B15	45	14	1	17	15	8	2.99 ± 0.02	524 ± 3	224 ± 3
MgP-B20	45	14	1	12	20	8	2.87 ± 0.01	543 ± 3	209 ± 2

an increase in T_g was observed with increasing Fe₂O₃ from 6 to 10 mol% for glass MgP-Fe system. However, a decline was revealed for MgP-B system when B₂O₃ content increased from 12 mol% to 15 mol%, whilst the increase was observed for MgP-B20 when B₂O₃ increased to 20 mol%. The value of processing window T_{pw} ($T_{onc} - T_g$) for MgP-Fe glasses system were seen to decrease from 207°C to 193°C with increase of Fe₂O₃ from 6 to 10 mol%, whilst the T_{pw} of MgP-B was increased from 184°C for MgP-B12 to 224°C for MgP-B15, then declined to 209°C for MgP-B20.

3.2. Powder X-Ray Diffraction Analysis

XRD analysis was conducted to investigate the amorphous nature of the formulations produced. According to the XRD trace shown in **Figure 1**, there was a single broad peak for values of 2θ between 20° and 40° for each composition, with no sharp crystalline peaks. This indicated that all the glasses produced were amorphous.

3.3. Glass Structure Analysis

Fourier transform infrared (FTIR) spectroscopy was utilized for characterizing structure groups in the glasses. Spectra for the six glasses were shown in **Figure 2**. Peaks were positioned at approximately 770, 850, 950, 1070 and 1270 cm⁻¹ for glass MgP-B12, MgP-B15 and MgP-B20, whilst glass MgP-Fe6, MgP-Fe8 and MgP-Fe10 had four dominant peaks at 770, 850, 940, 1070 and 1280 cm⁻¹. It was evident that the peaks in the spectra were broad, due to multiple vibration modes from both phosphate and borate structural units linked to four metallic elements in the glass system. Peak assignments are summarized in **Table 2**.

Table 2. Peak assignments for the infrared analysis.

Wavenumber (cm ⁻¹)	IR Assignments	Ref
750 - 780	Symmetric stretching mode of P-O-P linkage in the Q ² units	[43] [44]
	Stretch vibration of P-O-B linkage in BO_4 units	[30] [45]
840 - 880	Symmetric mode of P-O-P in linear Q ² units (metaphosphate)	[43] [46]
930 - 950	Stretch vibration of B-O in BO ₄ units (diborate $B_4O_7^{2-}$ group)	[47] [48]
1020 - 1070	Stretch vibration of B-O in BO_4 units (triborate, tetraborate, pentaborate)	[30] [49]
1237 - 1280	Modes of boron–oxygen triangular BO3 units (Pyro and ortho borate groups)	[50] [51]
1230 - 1290	Asymmetric stretching mode of the two non-bridging oxygen atoms bonded to phosphorus atoms in the Q ² tetrahedral sites	[52] [53]
	P=O asymmetric stretching vibration	[54] [55]



Figure 1. Powder X-ray diffraction pattern for the glasses system.



Figure 2. FTIR spectra of the glasses system.

The Raman spectrum was performed on these two glass system with varying amount of magnesium, iron and boron (see **Figure 3**). For the glasses with addition of B_2O_3 ;MgP-B12, MgP-B15 and MgP-B20 glasses, three distinct peaks where observed and located at 670, 770 and 1120 cm⁻¹, and two broad peaks at approximately 950 and 1260 cm⁻¹. It can be seen that no significant peak shift on the curve with addition of B_2O_3 from 12 mol% to 20 mol%. However, for the glass system MgP-F with addition of Fe₂O₃, the position of peak 720 cm⁻¹ shifted to a higher wavenumber 770 cm⁻¹ and the peak 1170 cm⁻¹ moved to a lower wavenumber 1120 cm⁻¹. Moreover, the broad shape of peak 1120 cm⁻¹ when the amount of Fe₂O₃ reached 10 mol%, was the attributed to overlap of two peaks producing a single broad peak. In addition, the peaks at 950 and 1260 cm⁻¹ were



Figure 3. Raman spectrum for the glasses in this study.

the shoulder of the peak 1160 cm⁻¹, no distinct variation in intensity with increasing concentration of Fe_2O_3 to 10 mol%. The summary of the peak assignments for the Raman spectra had been summarized in Table 3.

3.4. Degradation Analysis

The mass loss (%) of the glasses as a function of degradation time (day) when immersed in PBS at 37°C was presented in **Figure 4(a)**. With the substitution of Fe₂O₃ for MgO in the MgP-Fe glass system, the mass loss over the full duration of 30 days study was seen to decrease from 1.32% to 0.76%. Furthermore, the dissolution rate shown in **Figure 5(a)**, indicated the dissolution rate decreased from 9.34×10^{-9} kg·m⁻²·s⁻¹ for MgP-Fe6 with 6 mol% Fe₂O₃ to 5.52×10^{-9} kg·m⁻²·s⁻¹ for MgP-Fe10 with 10 mol% Fe₂O₃. On the other hand, addition of B₂O₃ into phosphate based glass system with replacing MgO presented nonlinear variation of dissolution rate and mass loss. As can been seen from **Figure 4(b)**, the total mass loss observed over the 30-day degradation study was seen to increase from 0.69% to 0.92% when B₂O₃ increased from 12 mol% to 15 mol%, then decreased to 0.85% for MgP-B20 with 20 mol% B₂O₃. Additionally, with addition of B₂O₃ at the expense of MgO, the dissolution rate increased from 5.05 $\times 10^{-9}$ kg·m⁻²·s⁻¹ for MgP-B12 to 6.61 $\times 10^{-9}$ kg·m⁻²·s⁻¹ for MgP-B15, then decreased to 6.03 $\times 10^{-9}$ kg·m⁻²·s⁻¹ for MgP-B20.

4. Discussion

The purpose of this study was to investigate the effect of B_2O_3 and Fe_2O_3 replacing MgO on the glass structure, thermal and degradation properties of a new range of PBG which was based on the lass system P_2O_5 - B_2O_3 -CaO-MgO-Na₂O-Fe₂O₃. It is well known that the thermal, degradation and physical properties are de-



Figure 4. Plot of mass loss of (a) borophosphate glass with variation of Fe_2O_3 and (b) borophosphate glass with variation of B_2O_3 .



Figure 5. Graph of dissolution rate of (a) borophosphate glass with variation of Fe_2O_3 and (b) borophosphate glass with variation of B_2O_3 .

Wavenumber (cm ⁻¹)	Assignment	Ref
670	Symmetric stretching of link O-P-O in Q^2 group	
720	Chain type metaphosphate Q ² group	[27] [56]
770	B-O bonding in BO ₄ units	[57]
950	B-O bonding in BO ₄ units	[48] [56]
1160	symmetric stretching of non-bridging oxygen in Q ² units	[56]
1250 - 1300	asymmetric stretching vibration of non-bridging oxygen atoms in \mathbf{Q}^2 units	[58]

Table 3. Peak assignments for the Raman spectrum analysis in this study.

pendent on structure and composition [32]. As seen from the XRD trace in **Fig-ure 1**, all the glass samples investigated in this study were confirmed to be amorphous. Even though it was difficult to obtain quantitative measurements of the distribution of structural groups from the FTIR spectra due to overlapping

peaks and stretching modes associated with the presence of different structural groups in glass system MgP-Fe and MgP-B, the significant shift for MgP-Fe glass system in the Raman spectrum was observed. The Raman peak at 720 cm⁻¹ shifted toward to 770 cm⁻¹ due to the substitution of Fe₂O₃ for MgO which increased the content of Oxygen atom in the glass system, resulted in more Oxygen in the glass bonding to the Boron of BO₃ triangular units and forming BO₄ tetrahedral units with extra oxygen [33] [34]. The symmetric stretching of non-bridging oxygen in Q² units was assigned to a band at 1170 cm⁻¹ where the shift to a lower wavenumber 1120 cm⁻¹ was suggested to the depolymerisation of metaphosphate chain structure of PBG via the addition of Fe₂O₃ to break the bridging oxygen, whilst also crosslink the metaphosphate chain structure via forming ionic bonding Fe-O-P [35] [36]. Even though the MgO content was reduced with addition of Fe₂O₃, the network structure would significantly polymerised due to that the Fe³⁺ (trivalent metal) could crosslink three oxygen more than that bonded to Mg²⁺ (divalent metal) [37].

According to the DSC results in **Table 1**, the T_{e} values increased significantly with the replacement of MgO with Fe₂O₃ for MgP-Fe glass system. An increase of 15°C was observed with the content of Fe₂O₃ increasing from 6 to 10 mol%. This increase was also reported by Parsons et al. [37] and Karabulut et al. [38] who suggested that addition of metal into the glass might disrupt the glass structure and drop T_e, whereas addition of Fe₂O₃ could form F-O-P linkage, polymerise the glass network and improve structure stability which also resulted in the increase of density with addition of Fe₂O₃. The processing window T_{pw} was also seen to reduce as well (see Table 1). According to Hruby's method [31], the greater the temperature difference between Crystallisation temperature (T_{onc}) and T_g, the more stable the glass is and the easier it is to avoid partial crystallisation during its working operation, such as fibre drawing [39]. Thus, the thermal stability of the glasses in this study was reduced with substitution of Fe₂O₃ for MgO. Even though Fe₂O₃ probably polymerise the glass network and improved network stability, an decrease in the content of MgO, which also contributed to connectivity, could have enhanced the crystallisation tendency the glass [22].

For MgP-B glass system with substitution of MgO by B_2O_3 , the variation of process window was not linear. It was evident that the thermal stability could be binary effect by both B_2O_3 and MgO. Massera *et al.* [22] confirmed that addition of B_2O_3 into phosphate based glass could replace P-O-P bonds with P-O-B bonds and form BPO₄ groups, thus increasing cross-linking and improving thermal stability and reduce crystallisation tendency. Additionally, MgO in the phosphate glass network was observed as network former like B_2O_3 as cross-link P-O-Mg could change the glass structure from metaphosphate which is less stable to the much more stable structure pyrophosphate [20]. In this case, when B_2O_3 substituted MgO from 12 to 15 mol%, positive effect could be observed on glass structure thermal stability due to increase of BO₄ units in the glass network forming B-O-P linkage. However, when B_2O_3 content increased to 20 mol% with

reduction of MgO, the decrease in process window could be demonstrated by the negative impact from the decrease of MgO.

During the degradation studies, a decrease of 44% was observed in the dissolution rate and mass loss with increasing Fe_2O_3 content from 6 to 10 mol%. Several preliminary studies showed that the addition of Fe_2O_3 into phosphate based glass in order to enhance biocompatibility via improve chemical durability [40] [41]. It was attributed to the replacement of P-O-P bonds in the glass by Fe-O-P bonds and to strong cross-linking of phosphate chains by iron ions. Additionally, Fu *et al.* [42] suggested that only the form Fe(III) strengthened the network structure of the glasses more like a network former. However, the status of Fe in Fe(II) or Fe(III) form of Fe form could not be confirmed in this study yet.

On the other hand, the increase of 31% in degradation rate was observed for dissolution rate of glass system MgP-B with increase B_2O_3 from 12 to 15 mol%, then 10% of degradation rate was reduced when B_2O_3 content varied from 15 to 20 mol%. This variation behaviour on degradation was attributed to both effect from variation of B_2O_3 and MgO, both of which were key to demonstrate the glass structure stability and glass properties. As results from literature, addition of B_2O_3 could increase cross-linking and improving chemical durability due to B-O-P linkage forming [29]. On the other hand, MgO in the phosphate glass network was observed as network former like B_2O_3 to cross link glass network and improve chemical durability [20]. Thus, substitution of B_2O_3 for MgO could result in both positive and negative effects on the glass structure stability and chemical durability. In this case, the glass structure was evidently demonstrated by MgO when B_2O_3 increased from 12 to 15 mol%, resulting in a increase of dissolution rate, and then controlled by B_2O_3 which increased to 20 mol% and resulted an decrease of dissolution rate conversely.

Dissolution rate is important on cytocompatibility assessment of biomaterials due to ion release and pH variation during the biomaterial degradation. Zhu *et al.* [29] and Sharmin *et al.* [26] have developed several phosphate based glass system with good cytocompatibility and dissolution rate. When compared to the glass dissolution rate of them, the glass in this study presented lower dissolution rate (9.3 * 10^{-9} kg·m⁻²·s⁻¹ for glass formula

 $48P_2O_5$ - $12B_2O_3$ -19MgO-14CaO- $1Na_2O$ - $6Fe_2O_3$). Potentially, it was expected that the glass system in this study was able to present good cytocompatibility for medical application. However, the *in vitro* cytocompatibility study should be taken into account in the future research, to confirm the bioactivity of glass.

5. Conclusions

Six phosphate based glass formulations were produced and divided to be two glass system $48P_2O_5-12B_2O_3-(25-X)MgO-14CaO-1Na_2O-(X)Fe_2O_3$ (X = 6, 8, 10) and $45P_2O_5-(Y)B_2O_3-(32-Y)MgO-14CaO-1Na_2O-8Fe_2O_3$ (Y = 12, 15, 20). The XRD analysis confirmed that all glasses were amorphous nature.

With the substitution of Fe₂O₃ for MgO, the Fe-O-P cross-link demonstrated

the glass network and enhanced the glass structure stability and degradation behaviour. Thus, the process window T_{pw} and glass transition temperature T_g were increased whilst the dissolution rate was reduced with replacement of MgO by Fe₂O₃.

For glass system with substation of B_2O_3 for MgO, the results of thermal analysis and degradation studies were nonlinear. The B_2O_3 concentration increased from 12 to 15 mol%, and the process window T_{pw} and dissolution rate were increased, whilst, both were reduced when B_2O_3 concentration reached 20 mol%. This variation behaviour of thermal stability and degradation was demonstrated by the positive effect and negative effect from both B_2O_3 and MgO during the variation.

To compare with glass formulation developed in preliminary study, the dissolution rate of glass in this study presented lower dissolution rate, thus the better cytocompatibility could be expected. The further study will focus on the cytocompatibility investigation of glass and fibre drawing performance characterization, to confirm potential commercialisation of glass system. With production of multifilament of phosphate glass fibre, the bio-composite reinforced by phosphate glass fibre would be future biomaterial in medical area.

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