Characterization of CuO substituted 45S5 Bioactive Glasses and Glass - ceramics

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Abstract — CuO substituted 45S5 bioactive - glasses were prepared. Glass - derived Bioactive Glass - ceramics were obtained through controlled crystallization of bioactive glasses. Nucleation and crystallization regimes were determined by the parameters obtained from differential thermal analysis (DTA) of bioactive - glasses. The formed crystalline phases in bioactive glass - ceramics were identified using X - ray diffraction (XRD) analysis. Surfaces of bioactive glasses and glass - ceramics were investigated by fourier transform infrared (FTIR) reflectance spectrometry. The bioactivity of bioactive glasses and glass - ceramics was investigated through immersion studies in simulated body fluid (SBF) solution for different time periods by FTIR reflectance spectrometry with monitoring the pH changes and the concentration of silicon, sodium, calcium, phosphorus and copper ions in SBF solution. The density, micro hardness and flexural strength of bioactive glasses and glass - ceramics were measured.
Experimental results show that a decrease in glass nucleation and crystallization temperature of 45S5 bioactive - glass by doping of CuO in it and the formation of crystalline phases of sodium calcium silicate and calcium silicate in bioactive glass - ceramics. The bioactivity nearly remains same by doping 1% of CuO by weight, but after that it decreases. Crystalliziation of bioactive glasses decreases the bioactivity. The density, micro hardness and flexural strength of bioactive glass - ceramics are higher than their respective bioactive glasses and also it increases with increasing CuO content.

Index Terms — Bioceramics, Bioactive Glasses, Bioactive Glass - ceramics, Chemical Properties, Physical Properties, Bioactivity, Mechanical Properties

1 Introduction

Various types of bioactive materials have been developed over the last three decades. Among these, the main bioactive materials used clinically are: bioactive glasses in the SiO_2 - Na_2O - CaO - P_2O_5 system [1], bioactive glass - ceramic A - W containing crystalline oxyfluoroapatite [$Ca_{10}(PO_4)_6(O, F)_2$] and β - wollastonite [$CaO.SiO_2$] in a MgO - CaO - SiO_2 glassy matrix [2], hydroxyapatite (HA) [$Ca_{10}(PO_4)_6(OH)_2$] [3] and β - tricalcium phosphate (TCP) [$Ca_3(PO_4)_2$] [4]. A bioactive material is considered as the one that elicits a specific biological response at the interface that results in the formation of a bond between tissues and the materials [5]. The most widely researched bioactive material is 45S5 bioactive glass [composition: wt. %: 45 SiO_2 - 24.5 Na_2O - 24.5 CaO - 6 P_2O_5], where S denotes the network former SiO_2 in 45% by weight followed by a specific Ca / P molar ratio 5.2 [6]. I t was invented by Hench in 1969. The 45S5 bioactive glass is biocompatible and shows high bioactivity which is in fact clinically used for middle ear prostheses and as endosseous ridge implants [7]. A major disadvantage of 45S5 bioactive glass is connected to its slow degradation rate. In addition, the mechanical property of 45S5 bioactive glass is not completely adequate for significant load - bearing applications [8]. Previous studies [9] have shown that the substitution of 5 - 15% B_2O_3 for SiO_2 or 12.5% CaF_2 for CaO or Na_2O in 45S5 bioactive glass has minor effect on the ability of this bioactive glass to form a tissue bond. Some authors [10] argued that the crystallization of 45S5 bioactive glass has a little effect on the ability of this bioactive glass to form a tissue bond. A first aim of present investigation is to determine the bioactive behaviour of 45S5 bioactive glass by exploiting its compositional flexibility with CuO and to extend such studies on glass - derived bioactive glass ceramics. A further aim of this investigation is to determine the density, micro hardness and flexural strength of these bioactive glasses and glass - ceramics.

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2 Experimental

2.1 Preparation of Bioactive Glasses and Glass - ceramics

Fine grained quartz was used as the source of SiO_2 while Na_2O and CaO were introduced in the form of anhydrous sodium carbonate [Na_2CO_3] and anhydrous calcium carbonate [$CaCO_3$] respectively, P_2O_5 was added in the form of ammonium dihydrogen orthophosphate [$NH_4H_2PO_4$] and CuO was added as such for preparation of bioactive glasses. All the batch materials were of analytical grade chemicals and used without further purification. The compositions of bioactive glasses are given in Table 1. The weighed batches were melted in alumina crucibles for 3 hours in an electric furnace at the temperature 1400 ± 10 ^{0}C. The homogeneous melts were cast into preheated stainless steel moulds of the required dimensions. The prepared bioactive glass samples were directly transferred to a regulated muffle furnace at the temperature 500 ^{0}C for annealing. After 1 h, the muffle furnace was left to cool to room temperature at a rate of 30 ^{0}C/ h. In order to obtain the bioactive glass - ceramics, the bioactive glass samples were heated in the muffle furnace in two step regime at the deduced temperatures and times as shown in Table 2.

Table 1: Composition of Bioactive Glasses

Sample	Composition (wt %)				
	SiO_2	Na_2O	CaO	P_2O_5	CuO
45S5	45.00	24.50	24.50	6.00	—
C1	44.00	24.50	24.50	6.00	1.00
C2	43.00	24.50	24.50	6.00	2.00
C3	42.00	24.50	24.50	6.00	3.00
C4	41.00	24.50	24.50	6.00	4.00

Table 2: Heat treatment schedule for crystallization of Bioactive Glasses

Sample	Nucleation		Growth	
	Temperature (^{0}C)	Time (hours)	Temperature (^{0}C)	Time (hours)
45S5	533	6	717	3
C1	518	6	675	3
C2	510	6	651	3
C3	504	6	631	3
C4	499	6	616	3

Table 3: Ion Concentration of Simulated Body Fluid and Human Blood Plasma

Ion Concentration (mM)								
Ion	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	HCO_3^-	HPO_4^-	SO_4^{2-}
Simulated Body Fluid	142.0	5.0	1.5	2.5	147.8	4.2	1.0	0.5
Human Blood Plasma	142.0	5.0	1.5	2.5	103.0	27.0	1.0	0.5

These temperatures were obtained from differential thermal analysis (DTA) of bioactive glasses. Each bioactive glass sample was heated slowly to the first nucleation temperature for the formation of sufficient nuclei sites and after holding for the definite time, was then further heated to reach the second chosen crystal growth temperature for performing the perfect crystal growth process and after a second hold for the specific time, the sample was left to cool inside the muffle furnace to room temperature at a rate of 20 ^{0}C/h.

2.2 Physical Analysis

Differential thermal analysis (DTA) was carried out on bioactive glass samples which were examined from the temperature 300 ^{0}C up to 900 ^{0}C, using alumina as a reference material and the heating rate was 10 ^{0}C/ min. Identification of the crystalline phases after heat - treatment of bioactive glass samples was carried out by X - ray diffraction (XRD) analysis. The bioactive glass - ceramics were examined using a X - ray diffractometer, adopting Ni filter and Cu target with voltage of 40 KV and a current of 25 mA. The XRD patterns were recorded in a 2θ range of 10 - 70^0. The JCPDS - International Center for Diffraction Data Cards was used as a reference data for the interpretation of XRD patterns in the present work. The bioactive glass and glass - ceramic samples were investigated by fourier transform infrared (FTIR) reflectance spectrometry. The FTIR reflectance spectra were obtained between wavenumber1400 and 400 cm^{-1} at 2 cm^{-1} resolution with reference to KBr using FTIR reflectance spectrometer.

2.3 In Vitro Bioactivity Tests

In 1991, Kokubo proposed that the concept of in vitro bioactivity test which is carried out in simulated body fluid instead of living body, called in vivo bioactivity test. The ion concentration of simulated body fluid is nearly equal to that of human blood plasma and is given in Table 3 [11]. The simulated body fluid (SBF) solution was prepared by dissolving the required amounts of reagent grade chemicals, the sodium chloride [NaCl], sodium bicarbonate [$NaHCO_3$], potassium chloride [KCl], di - potassium hydrogen phosphate [$K_2HPO_4{\cdot}3H_2O$], magnesium chloride hexahydrate [$MgCl_2{\cdot}6H_2O$], calcium chloride dehydrate [$CaCl_2{\cdot}2H_2O$] and sodium sulphate [Na_2SO_4] in distilled water. It was buffered at a pH value of 7.40 with 50 mM tris (hydroxymethyl) aminomethane [$NH_2C(CH_2OH)_3$] and 1N - hydrochloric [HCl] acid at the temperature 37 °C. We carried out in vitro studies by soaking polished pieces with dimension 10 mm x 10 mm x 2 mm of each bioactive glass and glass - ceramic sample in 50 ml SBF solution, at the temperature 37 °C, for 1, 3, 7 and 15 days. After soaking, the samples were filtered, rinsed with distilled water, and dried in a desiccator before investigated by fourier

transform infrared (FTIR) reflectance spectrometry. All the reacted SBF solution was saved for atomic absorption spectroscopic (AAS) analysis to measure ionic concentration of Si, Ca, Na, P and Cu in SBF solution. In addition, the SBF solution was also monitored for changes in pH using a pH meter before and after exposure to the SBF solution.

2.4 Density and Mechanical Properties Measurement

Archimedes principle was employed to obtain the density of bioactive glass and glass - ceramic samples using distilled water as buoyant. All the weight measurements have been made using a digital balance having an accuracy of ± 0.0001 g. Density of sample was obtained employing the relation (1) [12] as given below.

$$= \frac{\qquad}{-} \qquad (1)$$

where is the weight of sample in air, is the weight of sample in buoyant and is the density of buoyant. Micro indentations were made on the polished surfaces of bioactive glass and glass - ceramic specimens using a diamond Vickers indenter on a micro hardness Tester. The size of the specimen was 10 mm x 10 mm x 10 mm according to ASTM Standard: C730 - 98. The indentations have been made for loads ranging between 30 mN and 2000 mN, applied at a velocity of 1 mm/s and allowed to equilibrate for 15 seconds before measurement. Micro hardness (GPa) of specimen is calculated using the formula (2) [13] as given below:

$$= 1.854 \frac{}{} \qquad (2)$$

where (N) is the applied load on specimen and (m) is the diagonal of the impression.

Three-point flexural strength tests were carried out for polished bioactive glass and glass - ceramic specimens, using a universal testing machine. The size of the specimen was 4 mm x 4 mm x 50 mm according to ASTM Standard: C158 - 02. The load was applied over a 40 mm span and at the mid - point of the 4 mm x 40 mm surface using a cross - head speed of 0.5 mm/min. Flexural Strength of specimen is calculated using the formula (3) [14] as given below:

$$= \frac{3}{2\ h} \qquad (3)$$

where is the load at which specimen being fractured, is the length of specimen over which the load is applied, is the width of specimen, and h is the height of specimen.

3 Results

3.1 Physical Analysis

3.1.1 Differential Thermal Analysis (DTA)

The Differential Thermal Analysis (DTA) traces of bioactive glasses are shown in Figure 1. The DTA traces of bioactive glasses show that the incorporation of CuO in the base bioactive glass (45S5) causes a decrease in its endothermic peak temperature as well as its exothermic peak temperature.

3.1.2 X - Ray Diffraction (XRD) Analysis

The X - ray diffraction (XRD) patterns for bioactive glass - ceramics are shown in Figure 2. The XRD patterns of all the bioactive glass - ceramics show the presence of crystalline phase of sodium calcium silicate [$Na_2Ca_2\ Si_3O_9$ (card number: PDF # 01 - 1078 & PDF # 02 - 0961), $Na_2CaSi_3O_8$ (card number: PDF # 12 - 0671)]. Each CuO substituted bioactive glass - ceramics (C1, C2, C3 and C4) also, show the presence of crystalline phase of calcium silicate [$CaSiO_3$ (card number: PDF # 42 - 0550)].

3.1.3 Fourier Transform Infrared (FTIR) Reflectance Spectrometric Investigation

The fourier transform infrared (FTIR) reflectance spectra of bioactive glasses and glass - ceramics before immersion in simulated body fluid (SBF) solution are shown in Figure 3. The FTIR reflectance spectra of bioactive glass 45S5 reveals sharp peaks at wavenumbers 471, 930 and 1100 cm^{-1} while its glass - ceramic shows additional peaks at wavenumbers 580, 650 and 1041 cm^{-1}. The FTIR reflectance spectra of each CuO substituted bioactive glasses (C1, C2, C3, and C4) and their glass - ceramics seems to be repetitive to that obtained from the base bioactive glass (45S5) and its glass - ceramic respectively.

3.2 In Vitro Bioactivity Tests

3.2.1 Fourier Transform Infrared (FTIR) Reflectance Spectrometric Investigation

The fourier transform infrared (FTIR) reflectance spectra of bioactive glasses and glass - ceramics after soaking in simulated body fluid (SBF) solution for a period of 1, 3, 7, and 15 days are given in Figures 4, 5, 6 and 7 respectively. Following changes were observed in the FTIR reflectance spectra of bioactive glass 45S5 at various reaction times. After soaking for 1 day in SBF solution peak at wavenumber 471 cm^{-1} shifted to lower wavenumber at 461 cm^{-1} and peak at wavenumber 1100 cm^{-1} shifted to higher wavenumber at 1125 cm^{-1} with decreasing their intensity, while the peak at wavenumber 930 cm^{-1} had disappeared. Appearance of new peaks at wavenumbers 557, 607, 794, 871, 1050, and 1250 cm^{-1} were observed. After 3 days

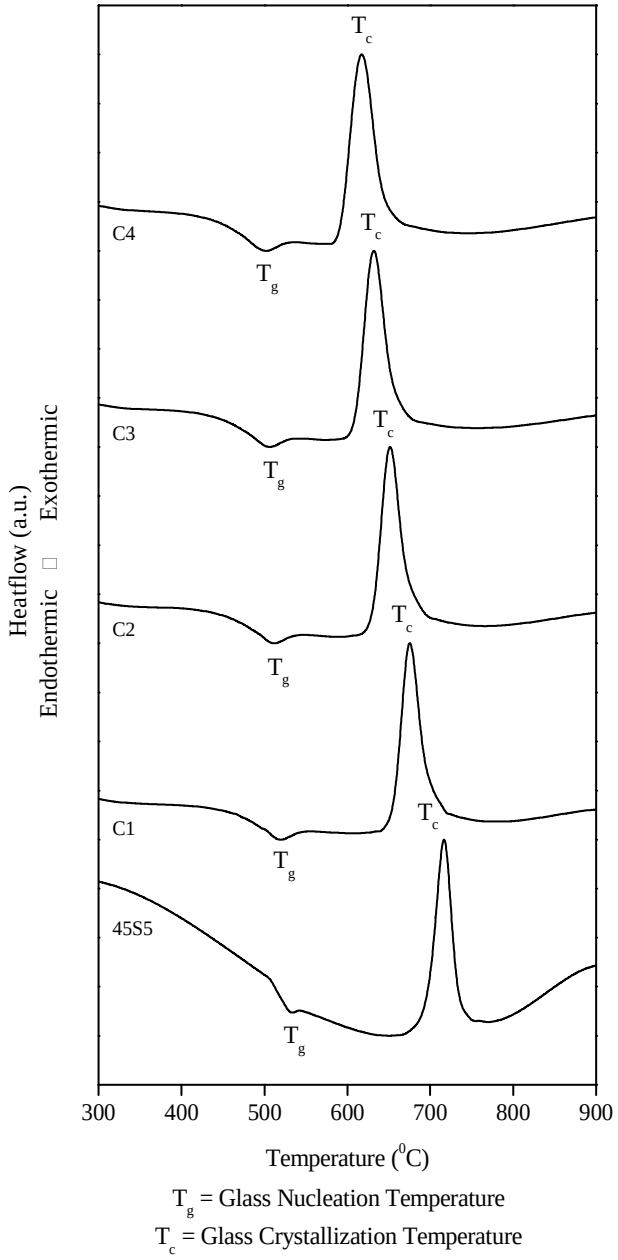

Figure 1: DTA Traces of Bioactive Glasses

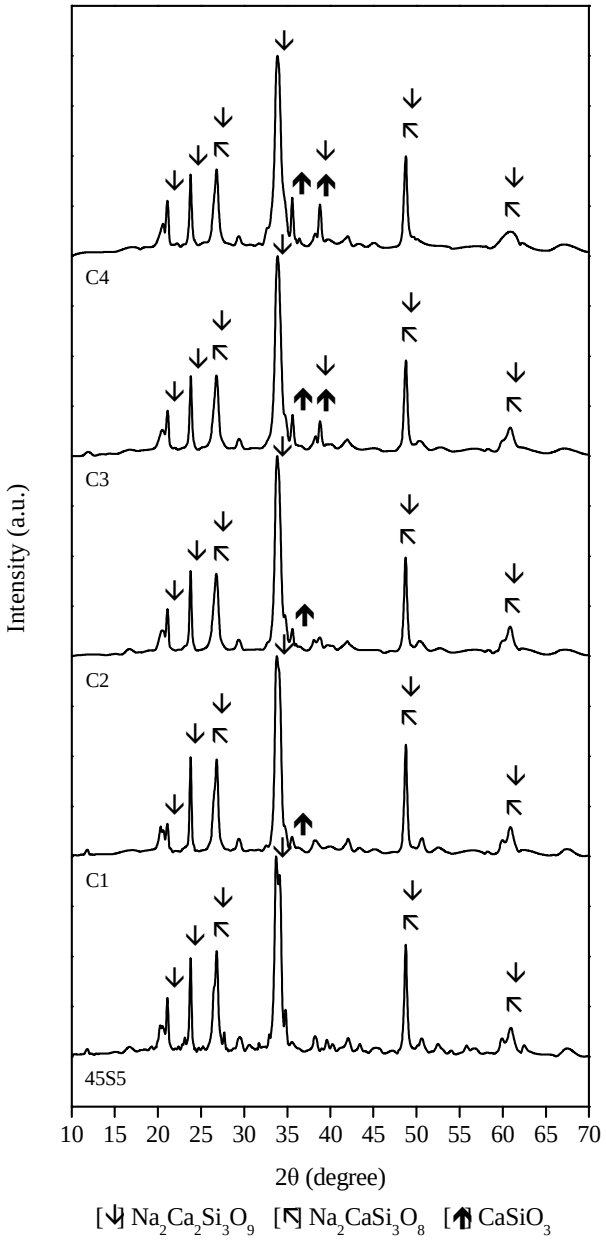

Figure 2: XRD Patterns of Bioactive Glass - ceramics

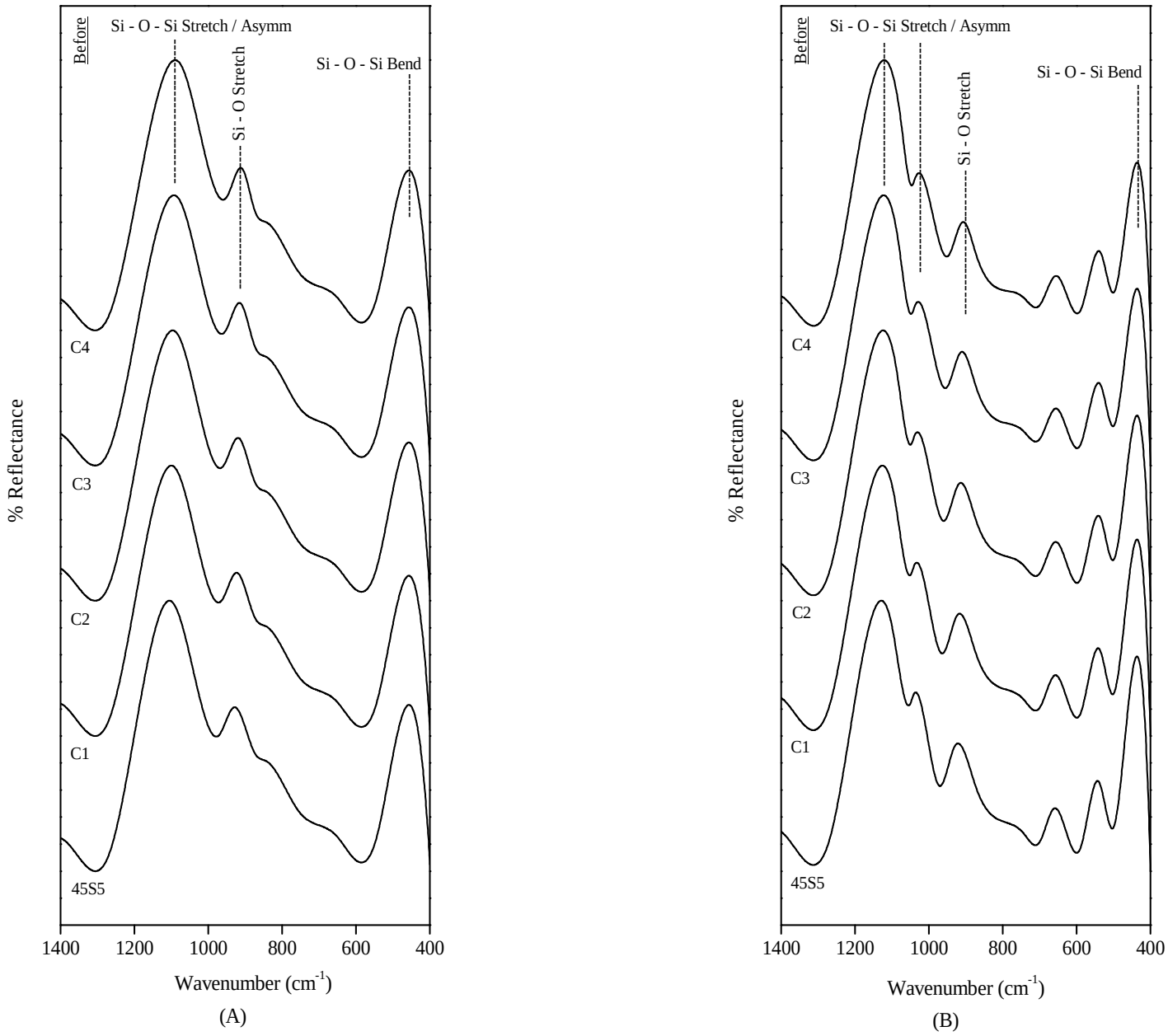

Figure 3: FTIR reflectance spectra of (A) Bioactive glasses (B) Bioactive Glass - ceramics before immersion in SBF solution

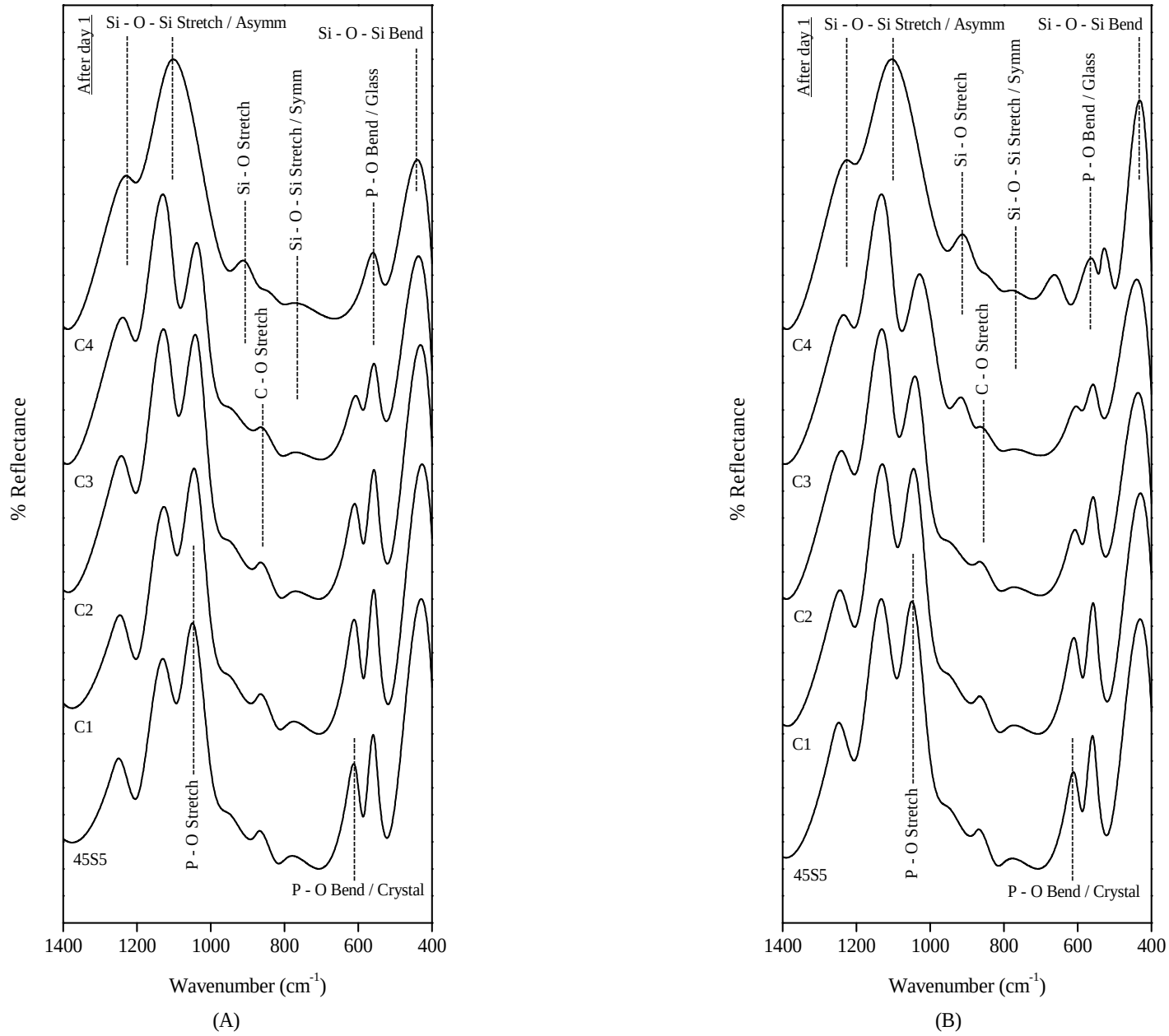

Figure 4: FTIR reflectance spectra of (A) Bioactive glasses (B) Bioactive Glass - ceramics after soaking for a period of 1 day in SBF solution

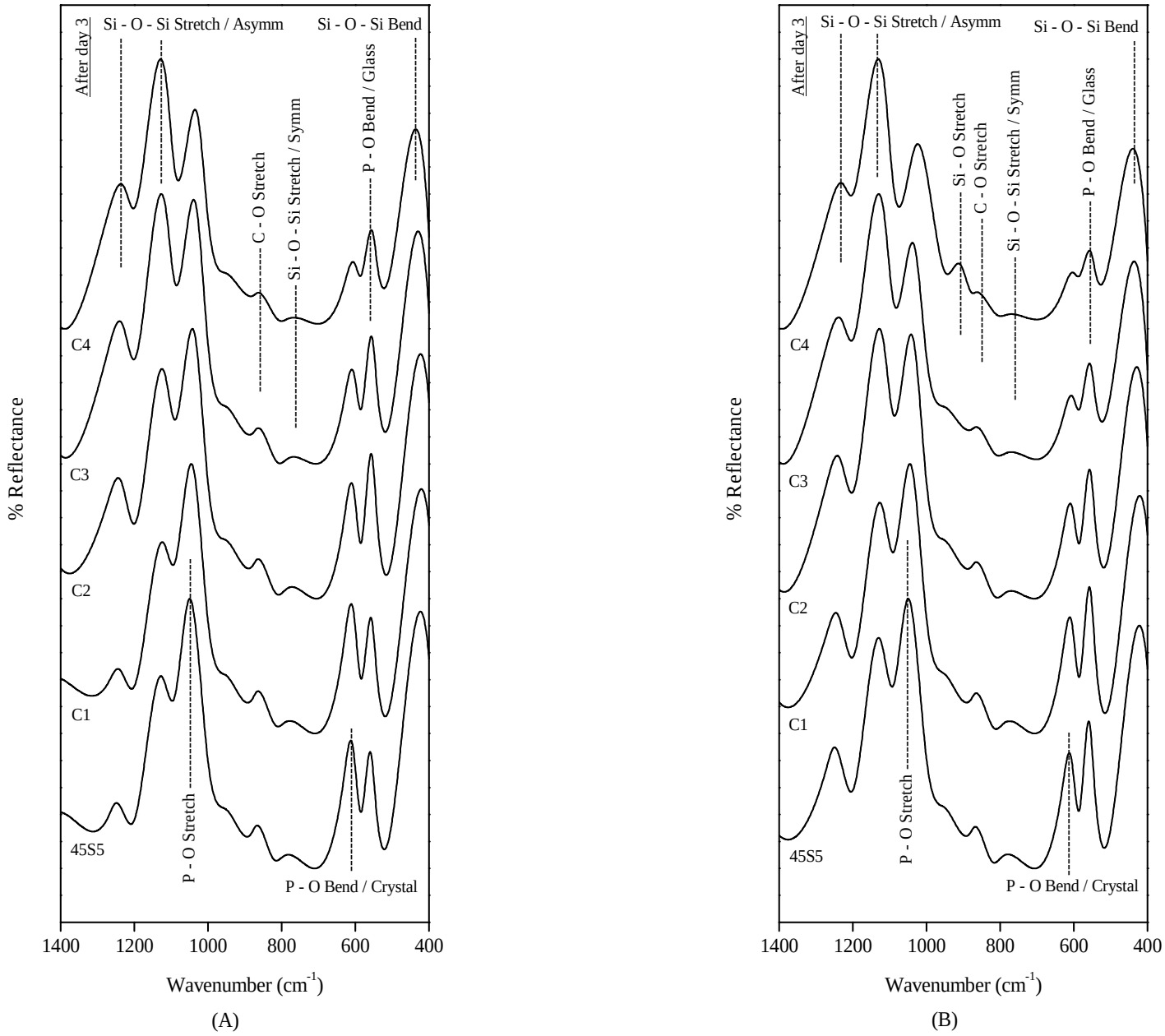

Figure 5: FTIR reflectance spectra of (A) Bioactive glasses (B) Bioactive Glass - ceramics after soaking for a period of 3 days in SBF solution

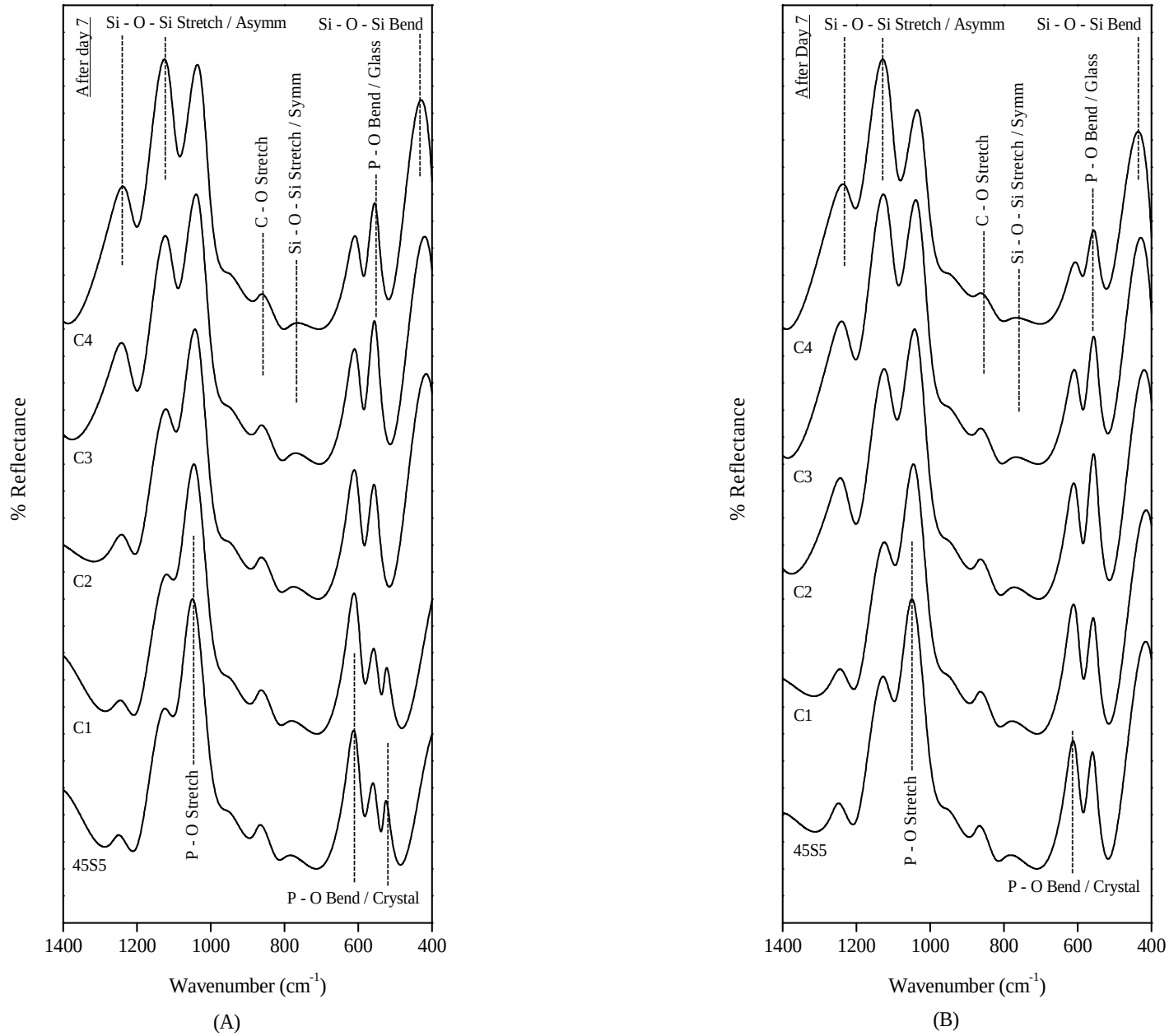

Figure 6: FTIR reflectance spectra of (A) Bioactive glasses (B) Bioactive Glass - ceramics after soaking for a period of 7 days in SBF solution

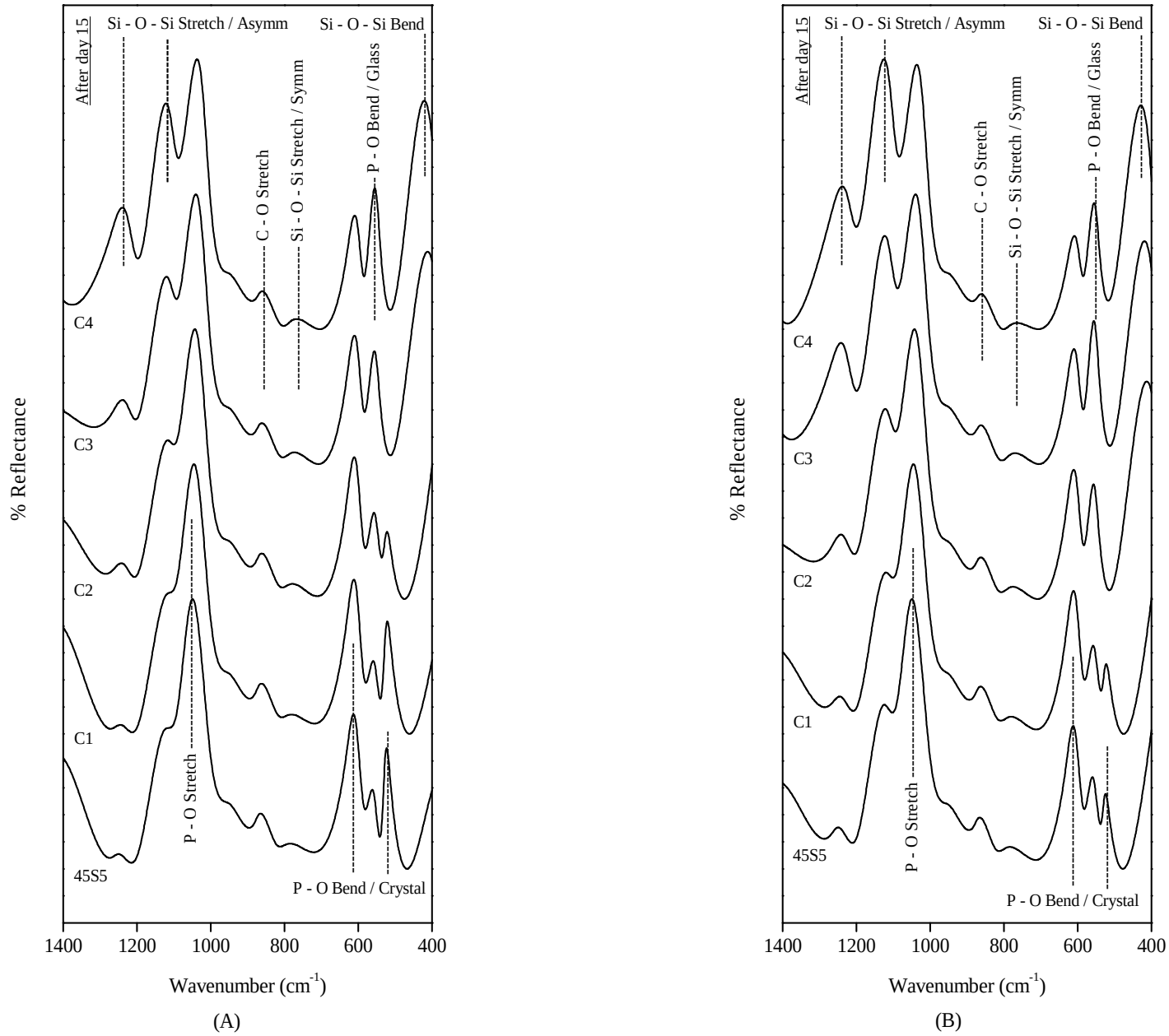

Figure 7: FTIR reflectance spectra of (A) Bioactive glasses (B) Bioactive Glass – ceramics after soaking for a period of 15 days in SBF solution

Table 4: Density, Micro hardness and Flexural Strength of bioactive glasses and glass - ceramics

Sample	Density (g/cm^3)		Micro hardness (GPa)		Flexural Strength (MPa)	
	Glasses	Glass - ceramics	Glasses	Glass - ceramics	Glasses	Glass - ceramics
45S5	2.707	2.912	5.75	7.70	43.48	104.17
C1	2.732	2.943	5.87	7.80	49.28	112.18
C2	2.742	2.954	5.93	7.85	52.50	117.53
C3	2.759	2.972	6.05	7.96	57.13	124.43
C4	2.772	2.986	6.13	8.03	61.30	130.38

Intensity of peaks at wavenumbers 557, 794, 1125, 1250 cm^{-1} decreased while the intensity of peaks at wavenumbers 607, 871, 1050 cm^{-1} increased. After 7 days peak at wavenumber 471 cm^{-1} has founded disappear. Appearance of peak at wavenumbers 527 cm^{-1} was observed. After 15 days, peaks at wavenumbers 527, 607, 871, 1050 cm^{-1} were dominant in the FTIR reflectance spectra. Careful inspection of FTIR reflectance spectra of all the CuO substituted bioactive glasses (C1, C2, C3, and C4) in comparison with the base bioactive glass (45S5) reveals minor or limited variation of the positions and intensities of the reflectance peaks. The main differences can be summarized in bioactive glasses, where there was time delay in the formation of peaks at wavenumbers 527 and 607 cm^{-1}. After soaking for 15 days in SBF solution (Figure 7A) it was found that the intensity of peak at these wavenumbers nearly remains same by doping 1% of CuO by weight with respect to parent bioactive glass (45S5), but afterwards as well as CuO content increases a decrease in intensity was observed. The FTIR reflectance spectra of bioactive glasses and glass - ceramics after soaking for 15 days in SBF solution (Figure 7A and 7B respectively) shows that peaks at wavenumbers 527 and 607 cm^{-1} was found less intense in the bioactive glass - ceramics than their respective bioactive glasses.

3.2.2 Ion Release Analysis

Variations of Si, Na, Ca, P and Cu concentration in simulated body fluid (SBF) solution due to soaking of bioactive glasses and glasses - ceramics for various time periods are shown in Figure 8. As can be observed in all cases that Si concentration in SBF solution increased during first 7 days of soaking and then a slight decrease was obtained. Na concentration increased rapidly during first 3 days of soaking and then it attains nearly a constant value where as Ca concentration increased during first day of soaking and then it decreased continuously. Increase in Cu concentration and a decrease in P concentration were also observed. It was also observed that the addition of CuO in the base bioactive glass (45S5) decreases the leaching rate of ions and crystallization of bioactive glasses also decreases the leaching rate of ions.

3.2.3 PH Measurements

The variation in pH values of simulated body fluid (SBF) solution due to soaking of bioactive glasses and glass - ceramics for various time periods is shown in Figure 9. The pH Value of SBF solution increased during first 3 days of soaking and then it attained nearly a constant value in all cases. It was also observed that the addition of CuO in the base bioactive glass (45S5) decreases the pH value and crystallizing the bioactive glasses also decreases pH value of SBF solution.

3.3 Density and Mechanical Properties Measurement

Experimental values of density, micro hardness and flexural strength of bioactive glasses and glass ceramics are given in Table 4. It has been observed that the increase of CuO in the base bioactive glass (45S5) causes an increase in its density, micro hardness and flexural strength. It also has been observed that the density, micro hardness and flexural strength of bioactive glass - ceramics are higher than their respective bioactive glasses.

4 Discussions

4.1 Physical Analysis

4.1.1 Differential Thermal Analysis (DTA)

In the differential thermal analysis (DTA) traces of bioactive glasses (Figure 1) endothermic peak show the nucleation region and the exothermic peak corresponding to the crystallisation process. Previous studies [15] have shown that in silicate glasses, the presence of transition metal ions in low doping percent is not expected to form separate structural units. It can be assumed that the transition metal ions in low level behave as a network modifier. A decrease of glass nucleation and crystallization temperature of the base bioactive glass (45S5) with the addition of CuO can be related to lower structural bonding [16].

4.1.2 X – Ray Differaction (XRD) Analysis

The XRD patterns of all the bioactive glass - ceramics show the presence of crystalline phases. The reason for the ease of crystallization of bioactive glasses can be correlated with the presence of silicate and phosphate network, as well as the possible phase separation even in micro scale of the two phases on heat - treatment.

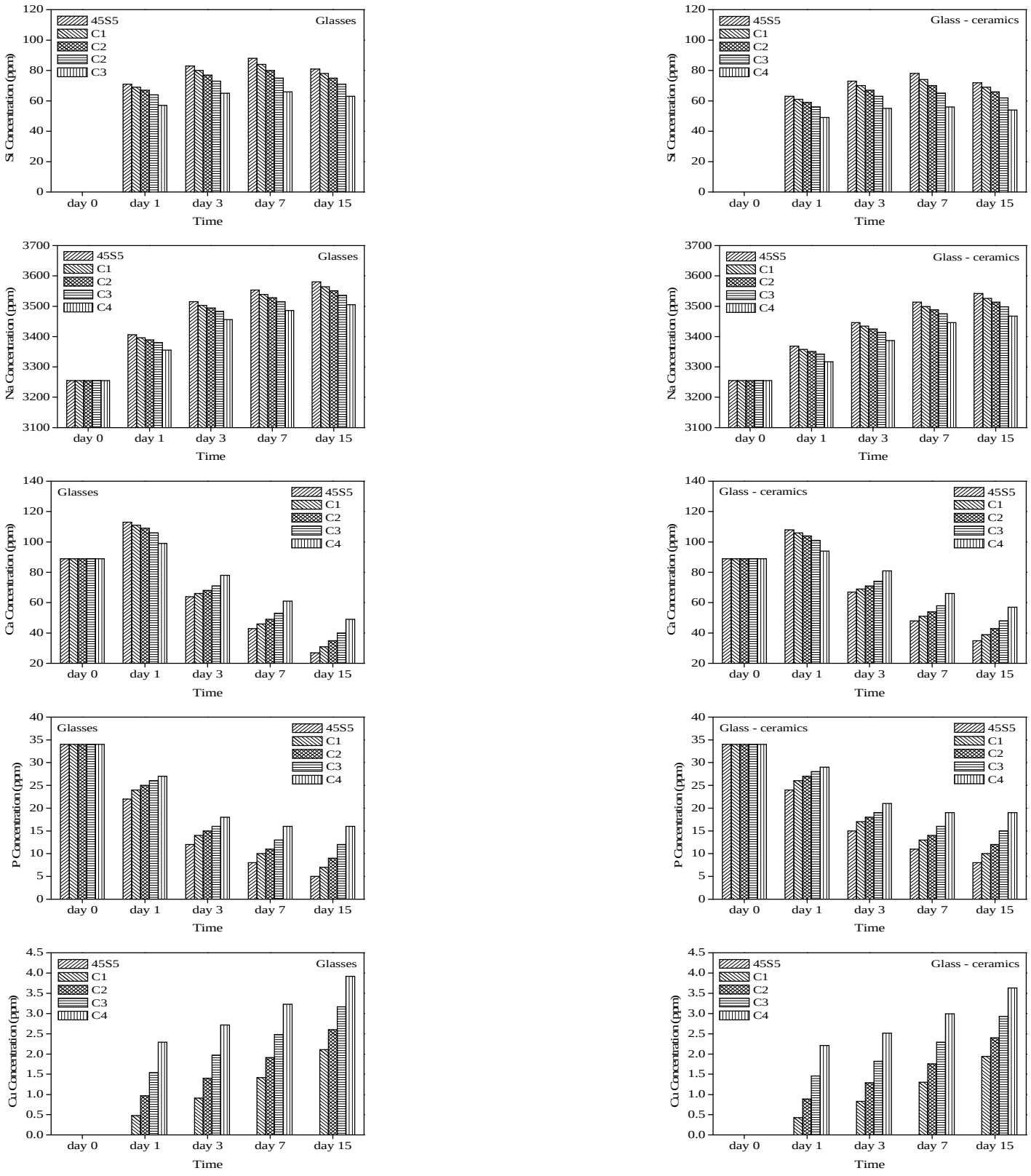

Figure 8: Variation in Si, Na, Ca, P and Cu concentration in SBF solution due to soaking for various time periods

Figure 9: Variation in pH of SBF solution due to soaking for various time periods

It is well known that the addition of a few percentage of P_2O_5 to silicate glass compositions, promotes the volume nucleation and glass - ceramic formation [17]. There is some evidence for precipitation of phosphate crystals which subsequently act as heterogeneous nucleation sites for the subsequent crystallization of the major phases, although the detailed role of P_2O_5 remains to be discussed [18]. Previous studies [19 - 21] have shown that the heat - treatment of 45S5 bioactive glass at a nucleation temperature of 550 ^{0}C and followed by heating at a crystallization temperature of 680 ^{0}C produces a bioactive glass - ceramic containing the sodium calcium silicate [$Na_2Ca_2Si_3O_9$] as main crystalline phase. In all the bioactive glass - ceramics sodium calcium silicate [Na_2Ca_2 Si_3O_9 & $Na_2CaSi_3O_8$] is present as main crystalline phase. Crystalline phase of calcium silicate [$CaSiO_3$] is also observed in each CuO substituted bioactive glass - ceramics (C1, C2, C3 and C4). This is due to the fact that transition metal oxides increase the tendency towards phase separation [22]. The studied bioactive glass - ceramics did not contain Cu as separate crystalline phases. This can be related to their relatively low content in bioactive glass composition.

4.1.3 Fourier Transform Infrared (FTIR) Reflectance Spectrometric Investigation

The fourier transform infrared (FTIR) reflectance spectra of bioactive glasses and glass - ceramics before immersion in simulated body fluid (SBF) solution (Figure 3) reveal Si - O - Si bending (500 - 400 cm^{-1}), Si - O stretching (940 - 860 cm^{-1}) and Si - O - Si stretching (asymmetric) (1200 - 970 cm^{-1}) bands, which are known and accepted to be mainly characteristic of silicate network [23 - 25]. This may be attributed due to the presence of major SiO_2 as a basic building constituent. The FTIR reflectance spectra of bioactive glasses and glass - ceramics did not show separate bands due to the presence of phosphate network and this may be due to the limited percentage of P_2O_5. The FTIR reflectance spectra of bioactive glass - ceramics also, show the additional bands at wavenumbers 650 - 619 cm^{-1} and 580 - 570 cm^{-1} which are due to presence of sodium calcium silicate [Na_2Ca_2 Si_3O_9] crystalline phase [26].

4.2 In Vitro Bioactivity Tests

4.2.1 Fourier Transform Infrared (FTIR) Reflectance Spectrometric Investigation

The fourier transform infrared (FTIR) reflectance spectra of bioactive glasses and glass - ceramics after soaking in simulated body fluid (SBF) solution for different times (Figures 4 - 7) reveal Si - O - Si stretching (symmetric) (820 - 770 cm^{-1}) and (asymmetric) (1200 - 970 cm^{-1}) bands, which indicates the formation of silica - rich layer. The presence of P - O bending (amorphous) (560 - 550 cm^{-1}) bands indicates the formation of CaO - P_2O_5 layer. Emerging of P - O bending (crystalline) (610 - 600 cm^{-1} and (530 - 515 cm^{-1}) bands indicates the formation of hydroxyl carbonate apatite (HCA) layer. Presence of C - O stretching (890 - 800 cm^{-1}) bands shows the crystalline nature of HCA layer and P - O stretching (1040 - 910 cm^{-1}) bands are attributed due to HCA layer [27 - 29]. Intensity of silica - rich layer and CaO - P_2O_5 layer goes on decreasing but intensity of HCA layer increases with time in all cases after soaking for 1 day in SBF solution. Hench et.al. were the first to detail a number of sequential steps in the in vitro and in vivo reactivity of silicate glasses that are responsible for the tissue bonding ability of these glasses. Briefly, these involve cation release from the glass with consequential increase in pH of solution, formation of silica - rich layer and precipitation of a CaO - P_2O_5 rich layer that further crystallizes as HCA layer [30 - 32].The degree of bioactivity in bioactive material is usually expressed by the formation of HCA surface. Finally, the FTIR reflectance spectra of bioactive glasses after soaking for 15 days in SBF solution (Figure 7A) indicates that addition of more than 1% of CuO by weight in the base bioactive glass (45S5) decreases its bioactivity.. This is because of the fact that transition metals enhance the chemical durability of silicate glasses [33]. The FTIR reflectance spectra of bioactive glasses and glass - ceramics after soaking for 15 days in SBF solution (Figure 7A and 7B) shows that the bioactivities of bioactive glass - ceramics are less than their respective bioactive glasses. This phenomenon is explained by considering that the amorphous phase is usually more prone to ion leaching phenomena than crystalline phases [34]. Therefore, the

suppression of the formation of silica - rich layer leads to the suppression of CaO - P_2O_5 layer and hence suppression of the formation of HCA surface.

4.2.2 Ion Release Analysis

The quantitative determination of Si, Na, Ca, P and Cu ions in simulated body fluid (SBF) solution for various times (Figure 8) is important to understand the kinetics of surface reactions in bioactive glasses and glass - ceramics. The decrease in Ca and P concentrations with a simultaneous increase in Si concentrations is consistent with the formation of CaO - P_2O_5 layer. The participation of Cu in the nucleation process can be ascertained by the observed variation in its concentration with soaking time.

4.2.3 PH Measurements

During initial period of soaking, faster release of Ca and Na ions increased the pH value, but after that pH attained nearly a constant value since rate of release of Na ion decreased (Figure 9).

4.3 Density and Mechanical Properties Measurement

The increase of CuO in the base bioactive glass (45S5) leads to an increase its density because of replacement of a lighter element, Si (density = 2.33 g/cm^3) with a heavier element, Cu (density = 8.96 g/cm^3). The increase of CuO in the base bioactive glass (45S5), also leads to an increase its micro hardness and flexural strength. This is easily understood that the more the density of glass, the more the compactness of glass structure, and consequently, the more micro hardness and flexural strength. The density, micro hardness and flexural strength of bioactive glass - ceramics are higher than their respective bioactive glasses due to densification.

5 Conclusions

In the present investigation, a comparative study was made on physical, bioactive and mechanical properties of CuO substituted 45S5 bioactive glasses and glass - ceramics. The following conclusions are obtained from this investigation: [1] Increasing the CuO content in 45S5 bioactive glass decreases its glass nucleation and crystallization temperature. There is no effect on bioactivity by doping of 1% of CuO by weight in 45S5 bioactive glass but afterwards it goes on decreasing successively. Increasing the CuO content in 45S5 bioactive glass enhances its chemical durability, density, micro hardness and flexural strength.
[2] Crystallization of bioactive glasses decreases their bioactivity but increases their chemical durability, density, micro hardness and flexural strength.

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