ZINC AND FLOURIDE CONTAINING BIOACTIVE GLASSES IN DENTISTRY

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ABSTRACT

The bioactive glasses have been used in the medical field due to their wide spread benefits as implant coatings, bone substitutes and for treatment of dentine sensitivity. The purpose of this study was to incorporate zinc and fluoride in the bioactive glass for potential use in dentifrices as antibacterial and anticaries agents. A series of glass compositions based on SiO_2, CaO, CaF_2, MgO, and ZnO were prepared with varied amounts of ZnO content ranging from 0% to 15%. Glass synthesis was done by using melt-quench route and fine powder having particle size <38μm was obtained by grinding and sieving. Particle size analysis and Differential scanning calorimetry were performed on powder samples. The dissolution study was done in Tris buffer and Acetic acid.

Zinc in bioactive glass caused a decrease in glass transition and crystallization temperature. The behavior of zinc free glass was entirely different from zinc containing glass in both Tris and acetic acid. There was rapid release of high concentrations of zinc along with other ions in acetic acid whereas relatively small amount was released in Tris. The fluoride release was slow and small concentrations were recorded in Tris while in acetic acid there was relatively high concentration of fluoride as compared to Tris. The release of calcium and magnesium has been affected in the presence of zinc in Tris and acetic acid. Zinc and fluoride containing bioglasses which are degradable in acetic acid were formulated. But the stability of glass in normal physiological condition has to be further improved with future research work.

Key Words: *Bioactive glass, transition temperature, dentifrices, particle size, Hydroxy apatite, caries, gingivitis.*

INTRODUCTION

Bioactive glasses (BG) have been widely used in dentistry for making dental cements, implant coatings, bone substitutes and for treatment of dentin sensitivity.[1] Originally when Hench developed Bioglass 45S5 it was considered to be bioactive due to its surface reactivity and its ability to form bond with the tissue.[2] A major limitation of BGs was their high solubility[3] and limited mechanical properties.[4] Studies have been done to modify bioactive glasses by substitutions with different ions; fluoride and zinc being examples.[3,5,6]

Enamel and other dental hard tissues are composed of hydroxy apatite (HA) crystals. Addition of calcium fluoride (CaF_2) in bioactive glasses favors the formation of fluor-apatite which is more acid resistant than HA and aids in caries retardation and occlusion of open dentinal tubules thereby reducing dentin sensitivity.[5,7] Zinc is a potent antibacterial agent[8,9], inhibits demineralization[10] and calculus formation[11-13], and prevents gingivitis.[14] Zinc plays an important role in the modulation of crystallinity in the apatite crystals.[15] The solubility of carbonated and non-carbonated apatite is reduced after incorporation of zinc.[16] ZnO in the glass might act as divalent network modifier or network former.[17] The combination of fluoride and zinc proved more effective in reducing the structural disorder of HA which is produced due to incorporation of carbonate.[18] Still much research has to be done to see the effect of zinc in BG.

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The aim of this study was to formulate a zinc and fluoride containing bioactive glass which can be used as dentifrices and is effective against caries and gingivitis.

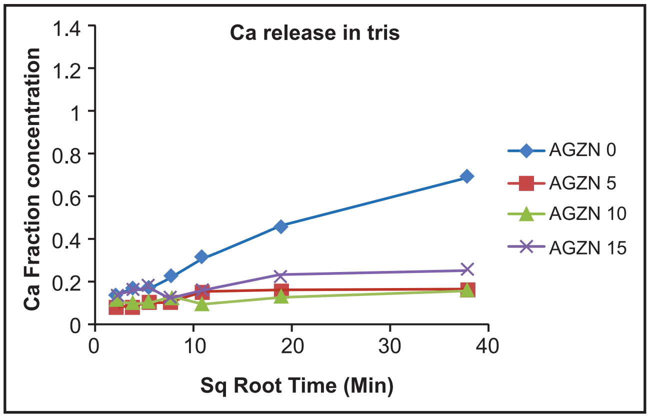

Fig 1: Calcium ion release in Tris from all glass compositions

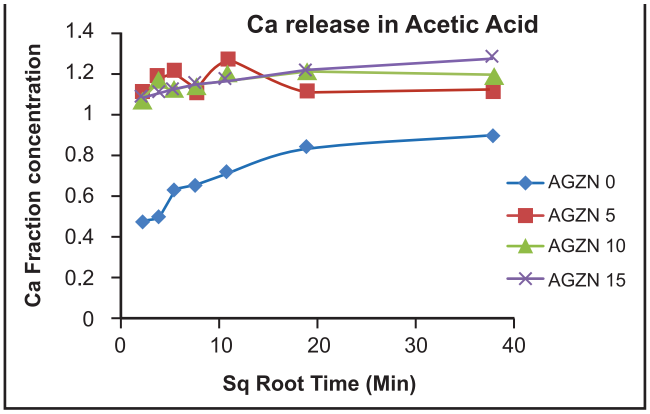

Fig 2: Calcium ion release in acetic acid from all glass compositions

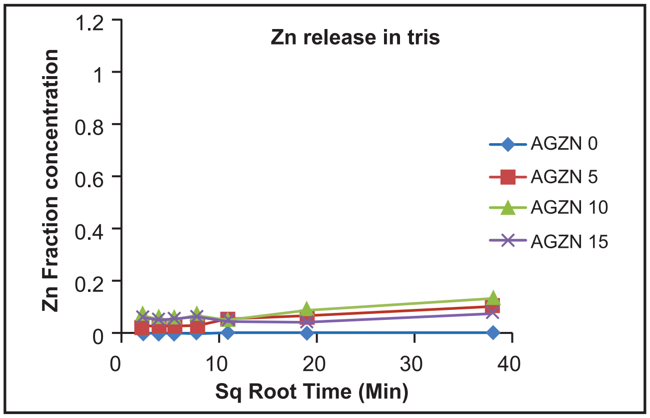

Fig 3: Zinc ion release in Tris from all glass batches

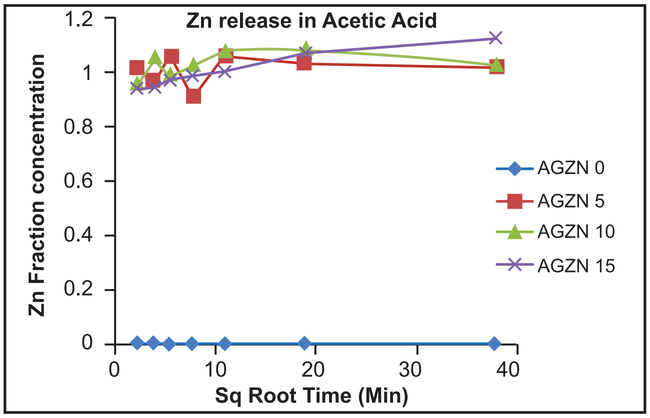

Fig 4: Zinc ion release in acetic acid from all batches

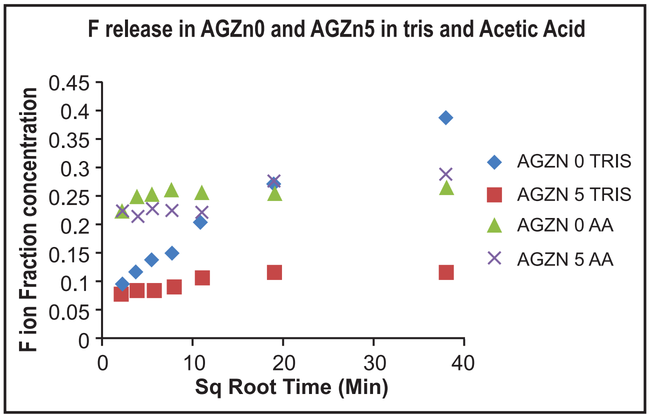

Fig 5: Comparison of Fluoride ion release from AGZN0 and AGZN5 in Tris and Acetic acid

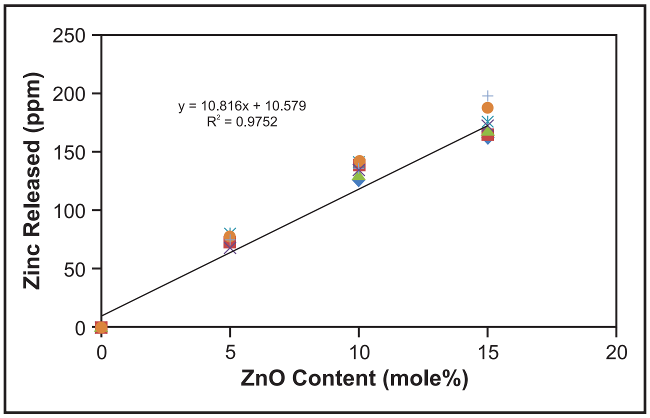

Fig 6: Zinc release in acetic acid with respect to molar percentage

Since the addition of different components may alter the properties of glass so compositions were developed in such style that the glass remains reasonably reactive

TABLE 1: MOLAR PERCENTAGES OF GLASS COMPOSITIONS

Batch ID	SiO2	CaO	CaF2	MgO	ZnO	NC
AGZN 0	47.32	10.41	11.04	31.23	0	2.24
AGZN 5	41.33	17.39	9.64	27.28	4.36	2.24
AGZN 10	36.68	22.8	8.56	24.21	7.75	2.23
AGZN 15	32.98	27.11	7.69	21.76	10.46	2.23

TABLE 2: TRANSITION AND CRYSTALLIZATION TEMPERATURES OF ALL GLASS COMPOSITIONS

Batch ID	Transition temp (Tg)	Cystallization temp (Tc)
	°C	°C
AGZN 0	647	801
AGZN 5	643	781
AGZN 10	634	776
AGZN 15	615	737

and stable under physiological conditions and zinc from glass should only be released when there is an acid challenge resulting in pH drop.

METHODOLOGY

Three glass batches with different molar %age of zinc were prepared and synthesized using melt-quench route. (Table 1). The glass frit from all batches were grounded one by one using vibratory mill (Glen Creston Gy-Ro mill, Middlesex UK) for 14 minutes. Powder was then sieved using 38µm mesh analytical sieve (Endecotts ltd., London, UK) for 30 minutes and fine powder less than 38µm was obtained in the receiving pot. The tank of Master Sizer/E laser analyzer was filled with Deionized (DI) water and the required lens was selected. Laser beam intensity was measured and adjusted. It took about 11 minutes to calculate the particles size for each glass batch. The starting temperature was 25ºC and the maximum temperature was set to 1000ºC with the heating rate of 20K/min and air was used as atmosphere medium. About 50mg (±1mg) of powder was measured using analytical balance (Precisa 125A) and placed in DSC apparatus (1500 series Stanton Redcroft) to analyze the Tg (transition temperature) and Tc (crystallization temperature). Analytical grade Alumina was used as the reference powder. This method was repeated for all the batches separately. The dissolution study was done by immersing 75mg of glass powder in 50 mL of AA in polyethylene bottles. Bottles were closed and placed in orbital shaker (Ks 4000 I control, IKA) at 37ºC with rotation speed of 60 rpm for 5min, 15min, 30min, 1hr, 2hr, 6hr, and 24hr. Process was repeated for each glass batch. The solutions were filtered by filter paper at designated time points. Obtained solutions were collected in falcon tubes and stored at 4ºC. Solutions were prepared with Tris Buffer in the exact same manner and repeated for all glass batches. There were 56 samples in total tested on inductive couple plasma emission spectroscopy (ICP-OES). The experimental solutions were diluted before the ICP measurements. 1mL of original solution was diluted with 8.5 mL DI water and acidified with 0.5 ml nitric acid to achieve 10 mL of diluted sample for a subsequent run on ICP machine (ICP-OES, Varian Vista Pro). Fluoride released was measured by selective electrode analyzer (Elit, 9808).

RESULTS

90% powder particles present in each glass batch were below 25µm. Differential Scanning Calorimetry showed effect of zinc substitution on glass transition and crystallization temperatures (Table 2).

1. Inductive Couple Plasma Spectroscopy

1.1. Calcium

In Tris Buffer, AGZN0 showed more prominent release of calcium with time (Fig 1) whereas in AA, calcium release was lower as compared to zinc containing batches (Fig 2).

1.2. Magnesium

In Tris, Mg release was very low in zinc containing batches; but in AGZN0, release was slightly more which increased with time. Higher and abrupt release of Mg was observed in AA which remained constant throughout time except for AGZN5 which showed some fluctuations after release. AGZN0 released less Mg initially which slightly increased with time.

1.3. Silicon

Si released in Tris was very low in all batches whereas in AA, all glass batches showed different trends.

1.4. Zinc

Zinc containing batches remained somewhat stable in Tris (Fig 3). Zinc release in AA was similar to other ion released (Fig 4).

1.5. Fluoride

AGZN0 released more fluoride initially in AA which stabilized with time, meanwhile fluoride release from AGZN5 with the passage of time showed an increase. Fluoride release in Tris in AGZN0 was quite slow initially (Fig 5).

DISCUSSION

Among the four glass samples studied, zinc free (AGZN0) can be used as a reference and the effect of zinc in glass can easily be compared. The glasses used in this study were developed for dentifrices so smaller particle size was required. Particle size influences crystallization temperature of the glass.[19] The DSC results of all the studied samples shows that Tg and Tc dropped in all zinc containing glasses hence giving an indication that Tg and Tc are also effected by zinc rather than by particle size alone. With the increasing amount of zinc, the Tc peaks also showed some variations and 2 crystallization peaks appeared which might be due to 2 phase transformations in the glass. This variation in Tc shows that Zn is entering in the glass network structure, changing its microstructure and also affecting the chemical bonding. Zinc is therefore acting as a network modifier. Lusvardi[20] also reported that addition of ZnO in glass led to reduction in glass transition temperature. This study shows increase in amount of zinc in glass causes decrease in glass transition and crystallization temperatures.

The dissolution of glass in AA was much rapid than in Tris showing that the chemical bond present in glass is acid degradable. The ion release in Tris was much less and slower as compared to AA showing the stability of glass in Tris than in acid. Zinc free glass behaved entirely differently when compared with zinc containing glasses, confirming that ZnO has affected the dissolution and is forming Si-O-Zn bond in the glass which is prone to acid hydrolysis whereas it remains stable in Tris. Since ions are also being released in Tris, which suggests that ions are leached out of glass or because of ion exchange mechanism.

If we see Ca release from AGZN0, its release is almost similar in both solutions showing the absence of acid hydrolysis bond in AGZN0. The same case is with Mg release from AGZN0 which clearly displays its similarity to Ca release. The other glass compositions however reacted differently. As soon as AGZN5 comes in contact with acid there is burst of ion release whereas in AGZN0 very low concentrations are released gradually with time. The unusual difference is seen in Si release from AGZN0, where very less amount is released even in AA. This could be because of strong Si bonding in glass network or because of presence of zinc, which might have affected its release. The Si release is linear to the Sq Root of time so we can interpret that its release is purely due to diffusion process. This rapid release of ions from zinc containing composition may conclude the role of zinc as network modifier but to confirm this, further spectroscopic investigations regarding structural analysis is required. The experiments done by Boyd and Towler[21] showed that zinc as network modifier is more susceptible to acid attack. On the other hand Ca ions show more tendency of coordination by non bridging oxygen (NBO) in silicate network providing stronger field strength[22] but on adding ZnO, it decreased NBO in the glass structure and made segregated zones of Ca, acting as modifier, along with Si-NBO bonds. The zinc had some impact on release of Ca, Mg and Si in AA. The addition of zinc reduces the surface area of the glass dramatically when compared with zinc free glass when soaked in Tris[23], this might be one of the reason of less reactivity of the glasses used in this study when dissolved in Tris.

Zinc released in Tris was not much as compared to AA and all zinc containing batches showed almost similar fraction release. This showed that zinc might be leaching out from glass in Tris as it remained there for longer time. Zinc release in AA was more rapid and most of it was released as soon as it comes in contact with the acidic medium (Fig 4) confirming that how fast the Si-O-Zn bond breaks in acid. This was the main aim of the study to release zinc at acidic pH.

More ppm of zinc is released with increasing amount of ZnO content in each glass composition (Fig 6). The release of fluoride was not according to the expectation and only small concentrations were released in both AA and Tris. The trend of fluoride release was similar to the other ions and more amounts were released in AA rather than Tris. In AA fluoride release is not affected by zinc and even the time does not have much influence on the release suggesting that there may be diffusion release process going on in AA. The glass compositions also contained Zn, Ca and Mg and all these ions have ability to form complexes with F- ions thus complicating the picture of ion release in solution.

In this study we were unsuccessful in being able to design a glass composition containing zinc which would remain stable in water (Tris buffer) but only degrade in AA. We assumed zinc to act as intermediate oxide but it probably acts slightly as a glass modifier. So in future new compositions could be formulated which would have less calcium and more silica in it so that zinc can act as intermediate oxide. The amounts of other cations should also be reduced because their increased amount makes the glass more degradable.

The fluoride in the composition led to the formation of complexes with other ions and proportionately less fluoride was measured. The ionic strength of the solutions used for fluoride measurement was not fixed so these factors can be corrected by using buffer solution such as TISAB. In the future fluoride could be removed from the composition as it makes the study more complex and the results more difficult to analyze.

CONCLUSION

The presence of zinc in the glass composition caused a decrease in the transition temperature of the glass along with decline in the crystallization temperatures. The degradation of zinc containing glasses in acetic acid is much more and faster than zinc free glass and this is due to presence of Si-O-Zn bonds which are more prone to acid hydrolysis. Zinc released into Tris buffer is comparatively much less than acetic acid. The release of calcium, magnesium and silica is affected in the presence of zinc. Lower concentrations of fluoride were released with zinc containing glasses when compared with the zinc free glass.

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