Studies of Substitution Effect of B_2O_3 on Structure and Properties of 1393 Bioactive Glass

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ABSTRACT

Bioactive glass is mainly familiar for its outstanding biocompatibility and bioactive behavior and it's known for important bone bonding ability. Bioactive glass is a reproduction fillet joint meant for orthopedic in addition to periodontal function of one of the leading applications. A silica based bioactive glass designated 1393 bio-glass® [wt.% (53) SiO_2–(6) Na_2O–(12) K_2O–(20) CaO–(5) gO–(4)P_2O_5] 1393 is like 45S5 bio-glass®, other than it has a high SiO_2 content and network modifiers, such as potassium oxide and magnesium oxide, bioactive glass, is also used clinically. In this communication, study of destructive (DT) & non-destructive (NDT) behavior of SiO_2 replaced by boron trioxide (B_2O_3) in 1393 bioactive glass has been reported. The formed amorphous phase using x-ray diffraction (X-RD) analysis in bioactive glass will be identified. Density and mechanical properties measured using different types of instrument and using ultrasonic wave velocities study the elastic properties like young's, shear, bulk modulus and Poisson's ratio of bioactive glasses were reported. The results point to the substitution of boron trioxide in 1393 bioactive glass enhanced its density, mechanical properties and elastic properties, similarly for silica.

Keywords: Destructive (Test), Non-destructive (Test), Bioactive glass, Boron trioxide, Density and mechanical properties.

INTRODUCTION

For substituted damaged or diseased tissues used biomaterials. This is a first generation material it's considered as a property of bio-inertness. Bio-glass by means of the character of genetic material commencement was second-hand for tissue reinstatement and curative was chosen for the third age group of bio-materials[1]. The thought of a protected bond between the bone and the artificial material that occurs on the surface of the bio-glass due to chemical reactions is presented by Hench. These chemical reactions are very useful in repairing the damaged bone which greatly helps in forming a bond between the bio-glass® and the bone. For medical applications for this characteristic quality bio-glass is considered one of the very stable biomaterials. The inside of the body usually contains

silicon, potassium, sodium, magnesium, calcium, oxygen, and phosphorus, which are commonly found in bio-glass®, so there are no toxic effects being detected. The concentration levels of the ions do not increase to the extent that bio-glass® would affect the surrounding tissue during bone formation and binding. Several studies have shown[2]. Bioactive-glass (BGs) such as "45S5 bio-glass®" (45) SiO_2, (24.5) CaO, (24.5) Na_2O, and (6) P_2O_5) weight[3] and "1393 bioactive glass" (53) SiO_2, (6) Na_2O, (12) K_2O, (5)MgO, (20)CaO, and (4)P_2O_5) weight%[4], for tissue engineering applications compositions have been generally used for bone. Also various applications such as silicate glass, borate and borosilicate glass have been found in biomedical and technical applications[5,6,7]. The hydroxyapatite (HA) layer is formed because bio-glass undergoes chemical degradation when exposed to biological conditions and facilitates bonding between bones and tissues[8]. Improved convenient rate of degradation to form HA than silicate glass were In the middle of the previous mention bio-glass® borate based glasses.[9,10] makes potential materials for prospect. 1393 bioactive glasses identify physically powerful bonding to rigid and spongy tissue and have been exposed to support orthogenesis via the establishment of more than a few pertinent genes[11]. Boron is commonly established in minute amounts in the human body[12]. In general, boron in bio-glass is either four- or three-fold coordinated. In a previous research, it was found that low amounts of boron trioxide (B_2O_3) are present in the form of [BO_3] structural units, which leads to a rigid and more cross-linked structure. On the other hand, it has the possibility to be well thought-out as a catalyst in novel organic behavior and can be utilized in pharmaceutical remedies. For the most part, the boron (B)-containing bioactive molecules are of two types; first one is molecules containing a single boron atom and second is boron cluster. The research of this experiment is to provide information of (X-RD) analysis, Density and mechanical properties measured using different type of instrument and using ultrasonic wave velocities study the elastic properties like young's , bulk, shear modulus, and Poisson's ratio of bioactive glass were reported.

Methods of preparation materials
Bioactive glass preparation of different composition

Bio-glass samples replaced by boron trioxide (B_2O_3) are shown in Table 1. Raw resources were required to organize bioactive glass samples which have been taken in a systematic manner. Fine grained quartz has been taken in place of SiO_2. Sodium carbonate (Na_2CO_3) has been taken in place of sodium oxide (Na_2O).Calcium carbonate ($CaCO_3$) has been used in place of calcium oxide (CaO). Phosphorus penta-oxide (P_2O_5) has been replaced by ammonium dihydrogen orthophosphate ($NH_4H_2PO_4$). Magnesium carbonate ($MgCO_3$) has been taken in place of magnesium oxide. Potassium carbonate (K_2CO_3) has been taken in place of potassium oxide. Boron trioxide has been taken up directly. We made 5 batches after weighing them according to their weight. The five batches were mixed separately by putting them in the agate jar. Now glass samples were prepared by putting one batch each in a muffle furnace at 35 to 1400°C, alumina crucibles were used to prepare the glass samples. Then all the five samples were prepared for different measurements.

Measurements of X-ray diffraction

To measurements of X-ray diffraction, the bioactive glass sample was made into a powder with a grain size of 75 μm. The five bioactive glass samples have been separated into a for X-ray diffraction measurements.

Table 1: Bioactive Glass Composition (weight%)

	(SiO_2)	(Na_2O)	(CaO)	(P_2O_5)	(MgO)	(K_2O)	(B_2O_3)
1393	53	6	20	4	5	12	0
G-1	39.75	6	20	4	5	12	13.25
G-2	26.5	6	20	4	5	12	26.5
G-3	13.25	6	20	4	5	12	39.75
G-4	0	6	20	4	5	12	53

Machine is used for X-ray diffraction

Machine Name-RIGAKU-Miniflex II difractometer
Radiation-(Cu-Kα) radiation (λ=1.5405 Å)
Voltage and current-40kV and current of 35
Mili amperes
Range-between 20 degree to 80 degree

The step size was set to 0.02 degree and the measuring speed was one degree/minute. JCPDS data cards were used as a position for identifying the peaks in the graph.

Density measurement

To find the density were calculated at normal temperature with a digital weighing scale (Satorius, Model-BP221S, USA) which has an

accurateness of ±0.0001 g after that we cut 1-1 pieces from the five glass samples, the size (1cm*1cm*1cm) of all the bioactive glass sample was kept the same. We measured the weight of the entire glass sample, once put in water take weight of glass sample and once removed from the water take dry weight of bioactive glass sample. Then by using the density formula, we will find the densities of all bioactive glass samples. Using the Archimedes principle Density is determined. Formula is given below.

$$Density = [W_{air}/(W_{air}-W_{water})] \times 0.989$$
Where, 'W'_{air} weight in air, 'W_{water}' weight in water

Mechanical Properties Measurement
Flexural Strength

To measure the mechanical properties, a glass sample was cut into a size of (1cm x 1cm x 1cm) cube, and then polished. Using an Instron Universal Testing Machine (AGS 10kND, SHIMADZU) whose cross- head speed was 0.5 mm/min bearing a full scale load of 2500 kg three point bending test at normal temperature for calculation of flexural strength. Formula is given below.

$$F = (3P_f L)/(2bh^2)$$

Where 'P_f' is the load and 'L-Length', 'b-breadth', 'h-height' of sample respectively.

Compressive strength

To find out the compressive strength, we used the Kinston Universal Testing Machine (UTM) was used having a cross-speed of 0.05 cm/min and full scale load of 2500 kg. We cut bioactive glass pieces according to the ASTM standard D3171 to perform the test. The size of the bioactive glass sample was kept at 2 cm* 2 cm* 1 cm. We conducted the test at normal temperature.

Hardness

To find out hardness, we used the Hardness Testing Machine have used loads- range of 30mN-2000mN and velocity of 0.1 cm/sec cut the glass pieces according to the ASTM standard C730-98 to carry out the test. The size of the glass pieces was kept at (1 cm* 1 cm* 1 cm). We conducted the test at room temperature. Formula of Hardness of bioactive glass is given below.

$$H = 1.854 \times (P/d^2)$$
'P-Load' and 'd-diagonal of the indentation'

Elastic Properties

The instrument we used to find the Elastic Properties of a glass sample is named Olympus (M-45, USA). According to the instrument, we cut the glass sample, whose size we kept (1 cm* 1 cm* 1 cm) then polished the glass sample with a polishing machine, after that we used the instrument to find two types of velocity. The name is shear and longitudinal wave velocities. To find the value of shear and longitudinal wave velocities we used two types of gel. The first one is sonfech shear gel and second is couplant glycerin. Using the various formulas, find the Elastic properties.

Young's modulus $(E) = \rho V_L^2 [(1+d) (1-2d) / (1-d)]$,
d = Poisson's Ratio
V_L = longitudinal velocity, V_T = Shear velocity
Shear Modulus $(G) = V_T^2 \rho$, ρ= density
Bulk modulus $(K) = E/3(1-2d)$, E= Young's modulus
Poisson's Ratio = $[1-2(VT/V_L)^2]/[2-2(V_T/V_L)^2]$

RESULTS AND DISCUSSION

Bioactive glasses analysis by X-Ray

The X-RD results of each and every one 1393 and substitution of boron trioxide (B_2O_3) bioactive glass samples are shown in Fig. 1. As per the obtained result, it was observed that no crystalline phase was found in the glass sample. This shows that our glass samples are of amorphous nature. The lump for 2 theta values between 25 degree and 35 degree intensifies with the substitution of boron trioxide (B_2O_3) and is the only change visible in the different graphs. It also shows that boron trioxide (B_2O_3) is totally dissolved in the glass matrix. Katharina et. al. also show that this type of result in paper title of paper is influence of the replacement of silica by boron trioxide on the in paper properties of bioactive glass scaffolds[13].

Density Measurements of 1393, G-1, G-2, G-3 and glass samples

Using Archimedes' principle the variation in density measurement data are show in Table 2 and calculation is depicted in Fig. 2 which obviously show that the SiO_2 replace by boron trioxide (B_2O_3) in 1393 bioactive glass sample small change in density from 2.88 to 2.97 g/cm³. This small change can be ascribed due to the density of SiO_2 and boron trioxides (B_2O_3) near to the same level as each other. Contracting volume type of behavior shows the borate based

bioactive glass. Density is dependent on particle size on the basis of particle size density is increased boron trioxide (B_2O_3) in 1393 bioactive glass samples.
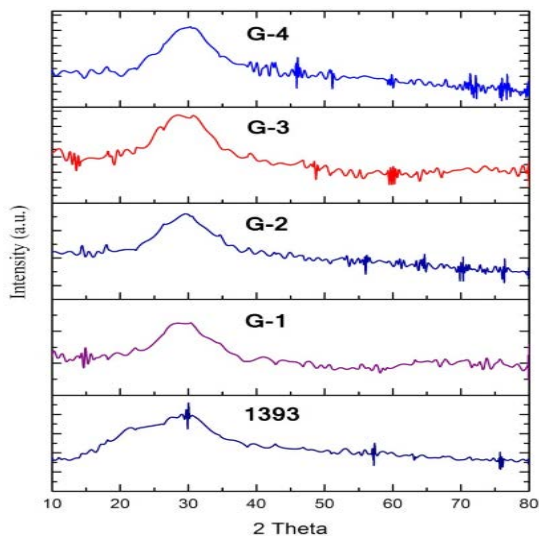

Fig. 1. X-RD 1393 & SiO$_2$ replace by boron trioxide (B_2O_3) bioactive glass sample

Table 2: Density of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples

Glass Sample	(1393)	(G-1)	(G-2)	(G-3)	(G-4)
Density(gm/cm³)	2.88	2.91	2.93	2.94	2.97

Fig. 2. Density of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples

Mechanical Properties of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples
Flexural strength

Flexural strength results data given in Table 3 and all 1393 and substitution of boron trioxide (B_2O_3) in Fig. 3 shows bioactive glass samples. The outcome of the flexural strength of 1393 is [44.45], G-1[57.24], G-2 [58.41], G-3 [62.49] and G-4 [66.55] M-Pa bioactive glass samples. Increasing tendency shows the results and in flexural strength as the percentage of boron trioxide (B_2O_3) is increased in 1393 bioactive glass samples to replace SiO_2. B^{3+} ions may act as network intermediate increase

results may be due to this region, thus more the solidity of glass structure[14].

Table 3: Flexural strength (MPa) of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples

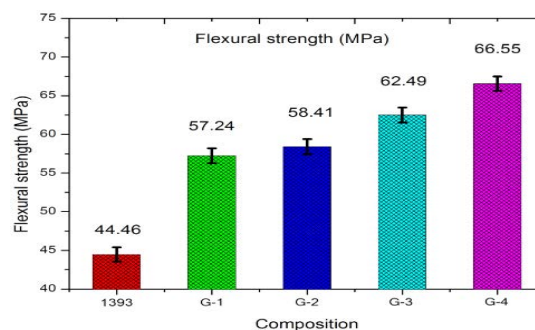| Glass samples	(1393)	(G-1)	(G-2)	(G-3)	(G-4)
Flexural strength	44.45	57.24	58.41	62.49	66.55

Fig. 3. Flexural strength of 1393, G-1, G-2, G-3 and G-4 glass samples

Mechanical Properties of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples
Flexural strength

Flexural strength results data given in Table 3 and all 1393 and substitution of boron trioxide (B_2O_3) in Fig. 3 shows bioactive glass samples. The outcome of the flexural strength of 1393 is [44.45], G-1[57.24], G-2 [58.41], G-3 [62.49] and G-4 [66.55] M-Pa bioactive glass samples. Increasing tendency shows the results and in flexural strength as the percentage of boron trioxide (B_2O_3) is increased in 1393 bioactive glass samples to replace SiO_2. B^{3+} ions may act as network intermediate increase results may be due to this region, thus more the solidity of glass structure[14].

Table 4: Compressive strength (MPa) of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples

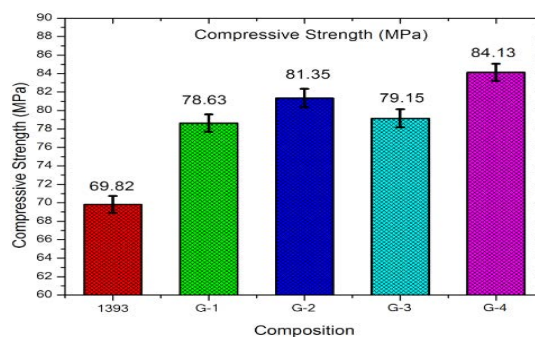| Glass samples	(1393)	(G-1)	(G-2)	(G-3)	(G-4)
Compressive strength	69.82	78.63	81.35	79.15	84.13

Fig. 4. Compressive strength (MPa) of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples

Compressive strength

Compressive strength results data given in Table 4 and all 1393 and substitution of boron trioxide (B_2O_3) in Fig. 4 shows bioactive glass samples. The outcome of the compressive strength of 1393 is [69.82], G-1 [78.63], G-2 [81.35], G-3 [79.15] and G-4 [84.13] M-Pa glass samples. An increasing tendency of compressive strength since the % of boron trioxides (B_2O_3) is increases in 1393 bioactive glass sample replace SiO_2. This enhance may be owed to the boron ion may act as network intermediate, thus more stiffens of glass arrangement[14].

Table 5: Micro Hardness (MPa) of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples

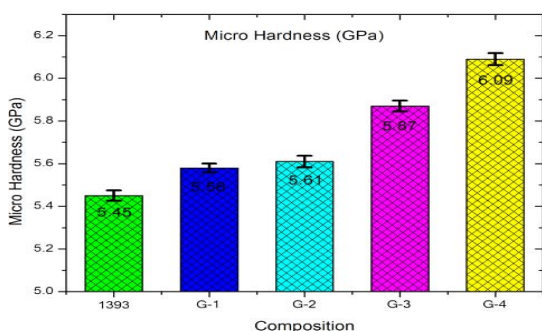| Glass samples	(1393)	(G-1)	(G-2)	(G-3)	(G-4)
Micro Hardness	5.45	5.58	5.61	5.87	6.09

Fig. 5. Micro Hardness of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples

Micro Hardness

Data of micro hardness is given Table 5 and in Fig. 5 shows bioactive glass samples result of the micro hardness of 1393 is [5.45], G-1 [5.58], G-2 [5.61], G-3 [5.87] and G-4 [6.09] M-Pa glass samples. An increasing tendency in micro hardness results shown as the % of boron trioxides (B_2O_3) is increased in 1393 bioactive glass samples to replace SiO_2. This enhancement may be due to the B^{3+} ion may act as network intermediate, thus more the solidity of glass structure[14]. We found in the present study that the mechanical properties change in glass samples (SiO_2 replaced by B_2O_3) because the boron ion acts as an intermediate and simultaneously stiffens the structure. This justifies the changing trends in the mechanical properties.
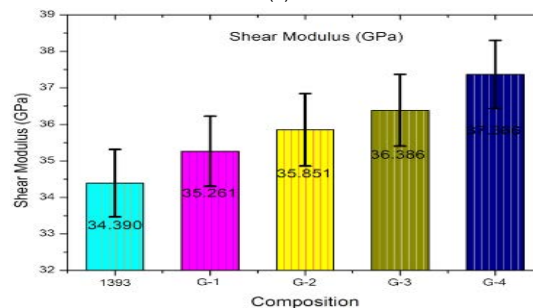
Elastic Properties

The elastic properties of all bioactive glass samples measured Using the longitudinal and shear ultrasonic wave velocities are shown graphically in Fig. 6(a),(b),(c),(d). Young's, Shear and Bulk modulus of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples are increase but Poisson's ratio slight decrease. An increase in boron ion concentration in bioactive glass

samples can increase the values of Young's, shear and bulk modulus but a slightly decreasing trend in values is observed for Poisson's ratio. Author Gaafar and Kannapan[15,16] when increase in connectivity in the glass network show the increase tendency in elastic modulus values but type of bonding in the glass structure show the slight reduction in Poisson's ratio[17].
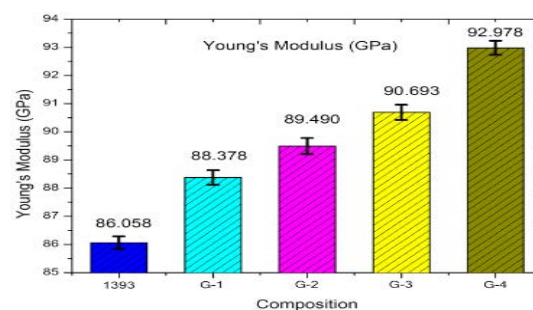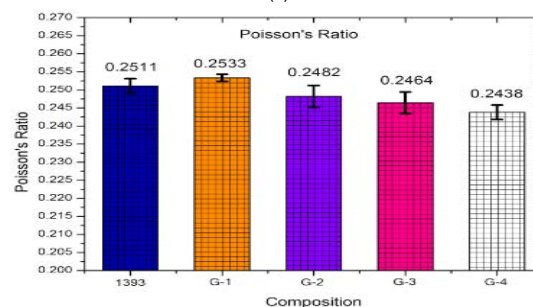

(a)

(b)
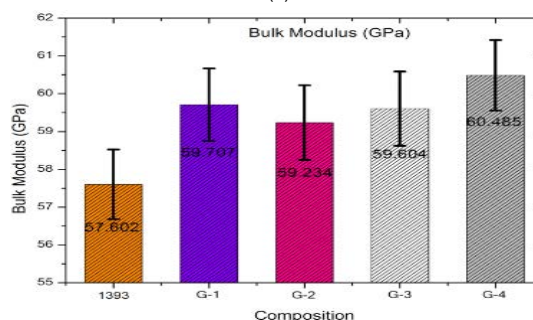
(c)

(d)

Fig. 6. Elastic properties of (1393), (G-1), (G-2), (G-3) and (G-4) glass samples

CONCLUSION

We found in the present investigation that if boron had been taken in place of silica in 1393 glass samples, various types of properties were carried out in the following results obtained. Firstly, the X-RD analysis confirmed that no crystalline phase has been found in glass samples and shows that our glass samples are of amorphous nature and the mechanical properties namely flexural strength, compressive strength, hardness and elastic properties namely Young's, bulk and shear moduli show an upward trend on increasing the concentration of B_2O_3 in the bioactive glass. However, the values for Poisson's ratio reduce slightly on boron ion addition. Therefore on summarizing the results obtained from this investigation it can be concluded that boron trioxides (B_2O_3) substituted 1393 bioactive glass can be used in biomedical applications as a potential biomaterial.

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Conflict of interest

My name is Neeraj Gupta. I have taken my M. Tech degree from Department of Ceramic Engineering Indian Institute of Technology (Banaras Hindu University) Varanasi-221005, India.

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