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PRODUCTION OF GLASS FOAM FROM WASTE GLASS AND BUFFALO BONES

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Abstract: *Waste glass is primarily disposed into landfills and the remaining waste is either recycled or reused for different purposes. Recycling is significant as it plays a vital role in reduction of both the wastes and its harmful environmental impacts. In this particular study, waste glass is recycled into glass foams. The glass foam is produced at a temperature of 860 degree ^oC in 600sec. In order to check the morphology and mechanical strength, the prepared glass foam samples were tested structurally and mechanically. High strength values between 17.86 ± 2.41 and 28.98 ± 2.16 MPa were recorded for the produced glass foams. The glass foam prepared in this study can be used in advanced material and structural systems.*

Keywords: *Sintering temperature, flexural strength, porosity, surface morphology***.**

1. Introduction

In order to prevent pharmaceutical products, beverages and chemical compounds from the deterioration effect of light; a large quantity of amber glass is produced [1]. Amber glass is composed of oxides of calcium, carbon, silica, sodium and iron which resist the light rays to pass through it [2]. It is reported that waste glass is about 4.5% of the total municipal solid wastes generated in the United States [3]. Hence a huge amount of waste amber glass is generated every year. Most of the waste glass is either recycled or reused while the rest is disposed into landfills [4]. The improper waste disposal results into challenging social and environmental issues [5]. Therefore, proper waste management and recycling of waste amber glass is of high need and interest.

The issue is how to utilize waste amber glass to produce recycled products efficiently. Though, amber glass contains important major oxides i.e., SiO_2 and CaO [2]. Therefore an environmental friendly recycling technique should be adopted. One suggested method is to recycle waste glass by making its powder and mixing it with concrete for constructional purposes. But amber glass contains sodium contents which causes decrease in the concrete strength [6,7,8]. Hence this method cannot be followed. Another useful technique is to recycle common borosilicate glasses into porous silica by heating along with hydrofluoric etching. The end product is mostly used in research activities [9]. Porous silica production is expensive [10] and it needs phase separated glass whereas amber glass is not a phase separated glass therefore it cannot be used in its preparation. For these reasons, both the concrete mixing and porous silica techniques are not ideal for recycling of the waste amber glass. Another productive technique is to recycle waste amber glass into glass foams [11-20]. Glass foam is used as heat insulating, sound proof and shock absorbing material [16, 17]. Also it is normally produced at lower temperature than other glass melting processes used for waste glass recycling [11, 13, 15-17, 19, 22]. And lower process temperature is effective for both economic and environmental concerns. Therefore, formation of glass foam from waste materials is an efficient recycling technique. Furthermore, glass foam possesses important physical properties of heat insulation, shockwave and sound absorption and good mechanical strength. For this reason it can be used for different purposes e.g. as a constructional material [16, 17]. Although, these unique properties are due to the development of its porous structure at high temperature. Whereas, such porous structure is developed by mixing glass powder with some foam agent and then processing it at some particular temperature. At high temperatures, the foam agent liberates different gases which produce bubbles in glass matrix and hence a porous structure is developed. Normally, the foam agents used are; carbides [16], alkali-carbonates [19, 21, 23], and other chemicals [22]. But the problem is that most of the foam agents are expensive and are not easily available. For this reason, an economical and easily obtainable foam agent is required for the production of glass foam. In recent studies, pork bone is reported as an efficient foam agent but no further studies were done on bone family. Whereas, food industry produces a large quantity of different waste bones including huge amount of buffalo bones. And buffalo bone is never reported as an active ingredient in material system.

Therefore in this study, high strength glass foam was successfully sintered from waste amber glass and buffalo bone. The waste glass and buffalo bone were used as a matrix and foam agent respectively. Mechanical strength and porosity of the prepared glass foams were investigated. The resultant product suggests a better way for productive recycling of waste buffalo bone and glass.

2. Materials and methods

2.1. Processing

Pharmaceutical amber glass was used as a glass matrix. The size of amber glass cullet was reduced into powder by using a Gyro Mill. The amber glass powder was kept in acetone and cleaned ultrasonically for 10 min. The wet glass powder was dried in a vacuum dryer at 90 ^{o}C. Dried buffalo bones were used as foaming agent. The bones were cooked at almost 90 ^{o}C and then dried. After the drying operation the bones were pulverized in a ball mill and sieved through a 100 mesh. In order to remove any organic compound the bone powder was soaked in acetone bath for 24 h. Both the bone and glass powders were then mixed into different percentages by weight (e.g. 98%-2%, 95%-5%, 92%-8% and 80%-20%). The quantity of foam agent mixed with the glass is normally in the range of 1wt% to 20wt% [19, 24]. An excess amount of 20wt% bone was mixed to the glass powder to investigate its effect on structural and mechanical properties of the produced glass foam. The powders were then properly mixed with an electrical stand mixer. The mixed powder of each batch was subjected to a pressure of 30 MPa in 30 mm cylindrical mould for making small pellets. The compacts were then heated in an electrical furnace at 860 ^{o}C for 10 min to produce the glass foams [19]. The as-produced foam samples were kept in an oven for cooling purpose.

2.2. Mechanical strength

Flexural strength test of the as prepared glass foams was done by performing a three-point load bending test of each sample. The glass foam specimens of 10 mm x 4 mm x 3 mm dimensions prepared with the help of a disc grinder and then polished with SiC grinding paper (1200 grade). The polishing of the sample bars minimises the uncertainties of sample dimensions in the mechanical strength calculations. A cross-head rate of 2 mm/min was applied during the measurement of flexural strength, using an axial-torsion (8874) testing system (Instron, USA). A total of 5 bars tested for calculating flexural strength of each series of the specimen. The following formula was used for the calculation of standard error in flexural strength test.

$$\sigma_{error} = \frac{\sqrt{(\sigma_1 - \sigma_{average})^2 + \cdots + (\sigma_n - \sigma_{average})^2}}{n}$$

Where σ represents the flexural strength and n is the number of specimen tested.

2.3. Micro structural characterization

The glass foam fractures obtained after the flexural strength test were subjected to Scanning Electron Microscope (SEM, JSM-IT100, JEOL, Japan). The SEM was run on a low vacuum of 6 x10^{-1}torr with an emission current and accelerating voltage of 272 mA and 20 kV respectively. All images were captured from back scattered electrons (BSE). Area percentage porosity was statistically calculated from scanning electron micrographs, having 100magnifications, according to the ASTM standard (B276-05, vol.02.05, 2010) (ASTM, 2010).For statistical significance in quantification, area percentage porosity along with the standard error was calculated by using 5 images of each sample.

3. Results and discussion

3.1. Micro structural analysis

Effect of foaming agent concentration on the microstructure of produced glass foam was investigated through SEM as shown in fig. 1. All the micrographs show porous structures, having non-uniform spherical shaped pores which are randomly distributed. The uneven size, shape and distribution of pores are attributed to the non-uniform particle size of bone agent[25].The percentage porosity based on area is 21.9 ± 1.1%, 41.6 ± 0.9%, 45.0 ± 1.9% and 60.0 ± 1.4% for 2 wt%, 5 wt%, 8 wt% and 20 wt% bone addition, respectively. Generally, the porosity increases by increasing the addition of foaming agent. The values of area percentage porosity were found almost similar between 5 wt% and 8 wt% bone addition. Also the values recorded, among all the scanned spots, were consistent statistically. The similarity and consistency of values reported in both the series of sample suggest an equivalent structure having almost similar porosity and endothermic peak positions (~980 ^{o}C and ~950 ^{o}C).Therefore, it is concluded that the amount of bone addition has a direct impact on the area percentage porosity. Likewise results of similar findings are being reported in the literature [20, 25, 26].

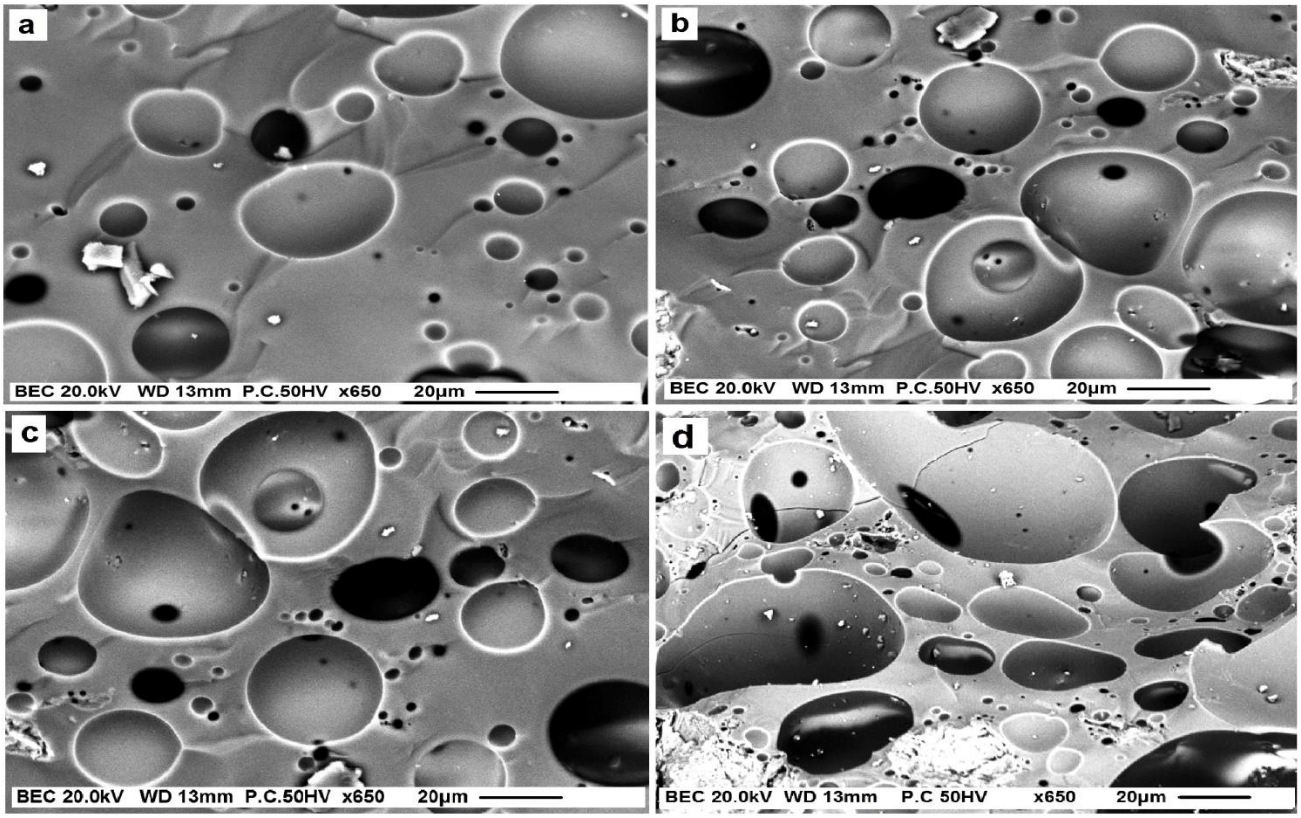

Figure.1: Micrographs of the glass foam samples with a) 2 wt%, b) 5 wt% c) 8 wt% d) 20wt% bone.

3.2. Mechanical property

A flexural strength of 29.04 ± 2.71, 24.53 ± 1.63, 25.44 ± 1.37 and 18.21 ± 1.25 MPa was recorded for 2 wt% to 20 wt% foam glass specimens as shown in fig. 2. The mechanical strength values are noticeably higher than the likewise systems reported in the literature [14, 17, 20]. Moreover, the mechanical strength of all the glass foams produced here, decreases with the increase in quantity of foaming agent. The same trend is reported in the literature of [12, 14, 27-29].High amount of foaming agent upon heating increases the gas release rate. The gases produce at high rate result in more porous glass foams with less flexural strength [12, 14, 27-29]. Similarly glass foams produced at a relatively low gas release rate, results in high flexural strength [14, 16]. However, the flexural strength of the 5 wt% and 8 wt% samples is almost closed to one another. Hence, it is suggested that the closeness in the flexural strength values is attributed to the resemblance in the microstructure of 8wt% and 5wt% samples.

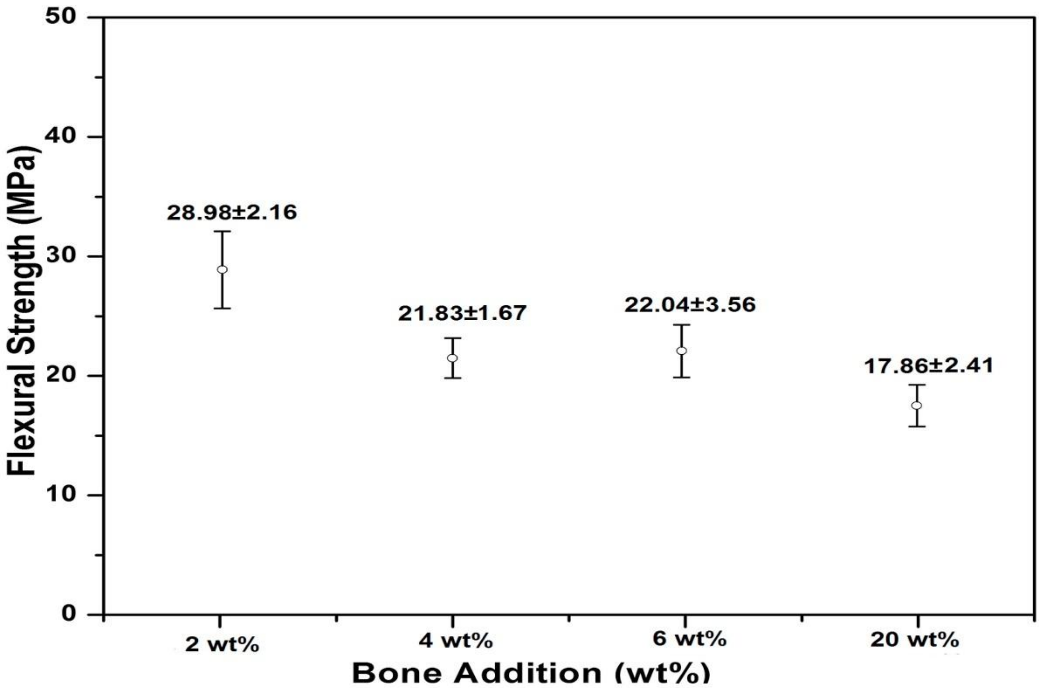

Figure. 2: Prepared glass foam flexural strength verses the weight percentage of buffalo bone added.

4. Conclusions

High strength glass foams (between 17.86 ± 2.41 and 28.98 ± 2.16 MPa) were prepared using waste amber glass and waste buffalo bones. The amount of bone was studied as a function of flexural strength. It is noticed that percentage porosity of glass foam increases by increasing the amount of foam agent and hence the mechanical strength decreases. The foam is prepared in at relatively low temperature and in less time which can decrease the processing and energy cost of glass foam production. Moreover, the high strength foam produced in this study is capable to be used as a constructional and building material.

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