Production of Foam Glass by Waste Glass and Boron Mineral

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ABSTRACT

In this study, a foam glass material was produced by using green container glass waste as main component, quartz mining tailings for compositional adjustment, marble powder as a source of $CaCO_3$ for foaming agent and ulexite, a boron oxide mineral, as fluxing agents in the varying amounts of 1, 2 and 3 wt%. The aims of the study were determined as utilisation of different solid wastes in foamed structure and benefication of ulexite for value added products as well as observing fluxing agent characteristics of ulexite. The samples were initially weighed, mixed and uniaxially pressed into pellet shape under 0.65 MPa pressing conditions , and then heated at 850 and 900 °C by applying two different heating rates of 5 and 10 °C/min in a separate processes. The optimal results were obtained with 1 wt% of ulexite addition at 900 °C for 10 °C/min heating rate without having almost no cracking or bedding form. The density value was 0.5389 g/cm^3 while porosity was found as 67%. All in all, a foamed glass of this study has enabled to utilize solid wastes towards to circular economy model by creating value added products with ulexite, as well. The experimental results showed that a foamed glass material can successfully be produced. However, porosity percentage should be increased with closed pores to improve heat insulation purposes.

Keywords: Foam glass, Marble powder, Quartz mining tailings, Ulexite, Waste glass

1. INTRODUCTION

Recently, waste management strategies have extensively been paid more attention due to increasing environmental concerns both in Turkey and all over the world. Not only catastrophic consequences of wastes occurred but also depletion of natural resources to meet the demand of growing civilisation and industrilisation have forced many scientist to find out alternative solutions for dealing with waste materials [1]. One has focused on gases emission minimisation to some extent in order to decrease greenhouse effect while others have tried to striving for preventing the mix of liquid wastes with spring water. On one hand, vast majority have firmly tackled with solid wastes like million tonnes of fly ashes, blast furnace slags, mining tailings, waste glasses which accumulate in landfills, constructed artifical lakes or municipal storage areas[2–5]. In this sense, circular economy model involving valorisation of waste materials in another processes to foster sustainable economic growth should be taken into account. The idea of utilizing different solid waste materials as starting material in various mass production routes may be considered [6].

For solid waste materials, recycling of glass materials have widely been practiced in all over the world. Since production of glasses are very dependent of high energy consumption many producers encourage community to collect waste glasses seperately via recycling containers at around everywhere so that recycled glass can be added into glass batches in companies. However, the awareness of people are highly required to successfully manage this strategy. Even though almost all European countries as well as USA have advanced on recycling strategies Turkey is still lack of recycling management. For that reason, such kind of accumulating waste glasses should be brought together in order to produce high-value-added products. On the other hand, mining tailings are the other solid waste materials that we are not able to utilize commonly, but accumulate in the surrounding of mining areas. For instance, quartz mineral is highly preferred in ceramic and glass productions that reaching up to several millions of tonnes usage in an annual period. However, smaller particle size ones under 50 μm in average cannot be used in mass productions due to causing dusting problems as well as risk levels for process conditions. Therefore, valorisation of those wastes as a source of silica in another process which takes no more critical importance will end up with value-added products. Similarly, marble deposits are found in common trend and especially the reserves take great significance in Turkey. That is, nearly 14B tonnes of marble reserves are located in the different regions of Turkey like Afyonkarahisar, İzmir, Denizli, etc [7]. During mining and processing conditions, these deposits come up with high amounts of powders that accumulated in landfill or artifical lakes. Because of this reason, marble wastes can be used as a source of $CaCO_3$ in other process, easily. All in all, there are huge amounts of different solid wastes that are stored in the nature or throw away different areas irregularly.

In addition to the importance of valorisation of solid wastes, there are some critical minerals that provides many superiorities with abundant reserves and technical aspect. Boron minerals are one of those critical substances providing lower melting points, higher mechanical strengths and great thermal stabilities and vitrification ability . Knowing that Turkey has huge amounts of boron deposits reaching up to holding nearly 70% of all world resources is another advance for implementing new technologies. There are great numbers of studies that have tried to make use of superior properties of boron minerals from traditional materials to advanced ones. As known, boron from borate compounds like tincalconite *($Na_2O.2B_2O_3.5H_2O$)*, colemanite*($2CaO.3B_2O_3.5H_2O$)* and ulexite *($Na_2O.2CaO.5B_2O_3.16H_2O$)* are of importance for our country's visions in the near future [8]. Many attempts are provided to produce high-value-added products via boron minerals, not just supplying boron minerals to the market. In brief, boron minerals can ensure many great properties when added properly.

In the scope of mass production like construction materials, foamed materials have been begun to be practiced due to energy conservation perspectives. Especially, a great attention has been drawn on mineral based insulating materials rather than polymer based ones because of developing insulating characteristics as well as fire-resistance features [9]. Foamed materials are generally known as highly porous and lightweight materials which are commonly preferred for heat insulation purposes. In particular, mineral based foam glass materials can be used for high temperature heat insulation or even for soundproofing applications [10]. Foam glass can quite easily be produced by mixing appropriate amounts of any waste glasses and foaming agents at elevated temperatures. Due to simplicity of batch mixture preparation and low processing temperatures for foam glass materials it is very convenient for mass production with required properties. Thanks to the foam glasses, many great properties like high mechanical strength, perfect chemical stability and superior water as well as steam resistance in comparison to traditional foamy materials can be obtained. In addition to foam glasses, a great number of different solid waste materials can be added in batch designs, as well. Hence, utilisation of solid waste materials to eliminate accumulation in the nature can predominantly be achieved while value-added products for empowering economical aspects can efficiently be produced.

In literature, there are many studies focusing on foam glass production, in particular utilisation of solid wastes, manupilation of foaming agents and changing heating conditions since 1930s. All of these studies aim at obtainment of lightweight, thermally insulative and mechanically strength enough foam glass materials. However, the occurrence of pores governs the exact properties of foam glasses, and for that reason attempts have been concentrated on pore characteristics, nowadays.

In the perspective of thermal insulation, foam glass should have low density, closed porosity, trapped gases inside pores and adding waste glass with low thermal conductivity coefficient values. In here, foaming process is very essential due to ensuring insulation ability to the body. Foaming is a sum of opened and closed porosities. That means, reaching up to at least 95% porosity values can be obtained with the help of several mechanisms. These mechanisms can be given as oxidation of a carbon-containing compound like carbon black or SiC (i), decomposition of sulphates or carbonates like $CaCO_3$ or Na_2SO_4 (ii), and oxidation/reduction reactions of valance electrons like MnO_2 or Fe_2O_3 (iii) [11]. The gases occurred as a result of one of these mechanisms must be trapped in the structure so as to achieve closed pores. Besides, there should be a good correlation between glass viscosity and gases-releases for obtainment of homogeneously distributed closed pore morphology [12]. Hence, the type of foaming agent which determines foaming mechanism are of importance for foam glass production.

In this study, a foam glass material for heat insulation purposes was investigated by using green container glass waste as main component, quartz mining tailings for compositional adjustment, marble powder as a source of $CaCO_3$ for foaming agent and ulexite as fluxing agents in the varying amounts of 1, 2 and 3 wt%. The details of this study will be given as below.

2. METHODS

a. Materials

The waste green container glass collected from Afyonkarahisar municipal solid waste storage area has a typical chemical composition of *71.7SiO$_2$-13.9Na$_2$O-8.3CaO-3.7MgO-1.7Al$_2$O$_3$ and others* in wt%. The quartz mining tailings was obtained with minimum *99 wt% of SiO$_2$ and others* as a result of grinding & milling operation. The waste marble powder supplied from Afyonkarahisar industrial zone has a chemical composition of *49.5CaO-3.5MgO-1.8SiO$_2$ and others* in wt%. The boron mineral of ulexite was supplied from Eti Kırka Borax Inc. with chemical composition of *7.65Na$_2$O-18.85CaO-42.95B$_2$O$_3$ and others* in wt%.

b. Methods

The collected green container glass was initially crushed and grinded followed by milling via plenatry ball milling until average particle size of lowering than 200 µm was achieved. The quartz stone was also crushed, grinded and milled so as to obtain average particle size of lowering than 74 µm with the help of plenatry ball milling. The sieving operation was carried out for waste marble powders to have average particle size of lowering than 40 µm. On one hand, the boron compound of ulexite was supplied with particle size of lowering than 43 µm. For preparation, at first, waste glass, quartz mining tailings, waste marble powders and ulexite mineral were carefully weighed with respect to batch designs given in Table 1 and followed to the homogeneously mixing operation for 2h. The amounts of quartz mining tailings and waste marble powder were kept constant while waste glass amount was varied with respect to varying amounts of ulexite mineral. Secondly, the powder mixtures were moisturised with 1 wt% of water prior to uniaxially pressing (at 0.65 MPa) stage to form cylinderical pellets with approximate dimensions of Ø as 15 mm and height as 10 mm. After drying at 105 °C for 4h, the pelletes were heated at 850 & 900 °C with heating rates of 5 & 10 °C/min for 30 min in a conventional electrical resistance furnace. Finally, the samples were cooled down to ambient temperature without applying any cooling rate trend.

Table 1: Batch designs and heat treatment conditions.

Sample Code	Heating Temperature (°C)	Heating Rate (°C/min)	Waste Glass (wt%)	Quartz Tailings (wt%)	Marble Powder (wt%)	Ulexite (wt%)
1a	900	10	91	5	3	1
1b	900	10	90	5	3	2
1c	900	10	89	5	3	3
2a	850	10	91	5	3	1
2b	850	10	90	5	3	2
2c	850	10	89	5	3	3
3a	900	5	91	5	3	1
3b	900	5	90	5	3	2
3c	900	5	89	5	3	3
4a	850	5	91	5	3	1
4b	850	5	90	5	3	2
4c	850	5	89	5	3	3

c. Characterisation

The bulk density of samples produced were measured by mass to volume ratio or Archimede's principle in demineralized water. The water absoprtion of samples were specified by immersing samples into boiling water by providing free circulation of water all around the specimen at 105 °C for 4h. Then, the cooling was performed through room temperature, naturally. The equation (I) was used to calculate the percentage of appearant porosity where weight of water absorbed sample in air, weight of dry sample in air, weight of water absorbed sample in demineralised water for w_d, w_k and w_a, respectively.

$$AP\% = [\ (w_d - w_k) / (w_d - w_a)\ ] \qquad (I)$$

Mechanical properties, particularly, compressive strength was measured by using Shimadzu Universal Testing 100 kN device. The phase patterns were determined by X-ray diffraction (XRD). The measurements with powders were carried out by Shimadzu 6000 diffractometer using Cu K_{α} radiation with 40 kV voltage and 30 mA current parameters. Also, 2Θ was selected in the range of 5 to 70° with a scan speed of 2°/min.

Thermal conductivity measurement was performed by C-Therm TCi device by applying sensitive sensor having 3-cm diameter on samples with smooth surfaces.

3. RESULTS AND DISCUSSION

The samples produced was revealed in Fig.1. The temperature performed with heating rates were stated in the upper side whereas the varying amounts of ulexite were indicated in the left side. As can be appreciated from Fig.1 that an increase in heating temperature as well as heating rate led to higher expansion of specimen (from right to left). In addition, as ulexite amount was increased from 1 to 3% in the mixture, a cracking phenomenon leading to bedding form, which is not desired, was sharply observed. In consequence, the samples of 1a, 1b and 1c seem to be the best ones in terms of visual aspects.

Fig. 1: Images of samples produced in terms of varying temperatures & heating rates with changing amounts of ulexite.

The bulk densities, apparent porosities and compressive strengths of samples produced were listed in Table 2. The bulk density values are in the range of 0,5389 to 0.7783 g/cm^3. Several studies focusing on $CaCO_3$ as foaming agent in similar to our study are shown in Table 3, as well. As can be seen that bulk densities of this study provide parallel results with listed studies [2], [13–16]. The lowest density values was achieved with the sample of 1a whereas the heaviest one with the sample of 4a. Additionally, the total or open porosity values were found as between 52 and 72 percentages. When compared to studies given in Table 3, these values show similar results. The highest porosity percentage was experienced with the sample of 1c while the lowest one with 2b. In compressive strength values perspective, the samples produced were found a lower values when it comes to compare with studies in Table 3. The highest compressive strength was obtained as 2,14 MPa with 3a while the lowest one as 1,01 MPa with 1c. Nevertheless, these values can be considered as expected results from a foam material.

Table 2: Physical aspects of samples produced in terms of bulk density, apparent porosity and compressive strengths.

Sample Code	Bulk Density (g/cm^3)	Appearant Porosity (%)	Compressive Strength MPa
1a	0,5389	67	1,19
1b	0,5858	66	1,15
1c	0,5406	72	1,01
2a	0,7323	59	1,46
2b	0,7310	52	1,16
2c	0,6773	56	1,67
3a	0,7662	60	2,14
3b	0,7528	59	1,54
3c	0,7117	61	1,92
4a	0,7783	60	1,47
4b	0,7480	59	1,61
4c	0,7086	62	1,97

Table 3: Several studies focusing on foam glasses by using $CaCO_3$ as foaming agent. (N/M: not mentioned).

Reference Study	**Kahina C. et. al**	**Z. Li et. al**	**M. Zhu et. al**	**Z. Li et. al**	**L. Ding et. al**
Type of waste glass	Float	-	Container	Water glass	E-glass
Type of solid wastes	Bricks and clay	Quartz	Fly ashes	Coal gangue	Blast furnace slag
Foaming Agent	$CaCO_3$	$CaCO_3$	$CaCO_3$	$CaCO_3$	$CaCO_3$
Foaming Conditions	850 °C ; 15 - 30 min	1120 - 1170 °C ; 60min	600 - 600 °C ; 45 min	1120 °C ; 60 min	950 °C ; 120 min
Porosity (%)	N/M	87,5	N/M	69,5 - 73,0	N/M
Bulk density (g/cm3)	0,60 - 1,10	0,39	0,46	0,59 - 0,68	0,79
Comp. Strength (MPa)	N/M	2,4	5	N/M	N/M
Thermal Cond. (W/mK)	0,040 - 1,400	0,085	0,36	N/M	N/M

The X-ray diffractometer result was shown in Fig.2. As revealed, the amorphous characteristics can be observed with hump-like shape. However, two different peaks were appeared in measurement as red star symbol for SiO_2 and blue circle for $CaSiO_3$. This is because quartz mining tailings as well as marble powders were added and these were seen as silicon dioxide and wollastonite peaks.

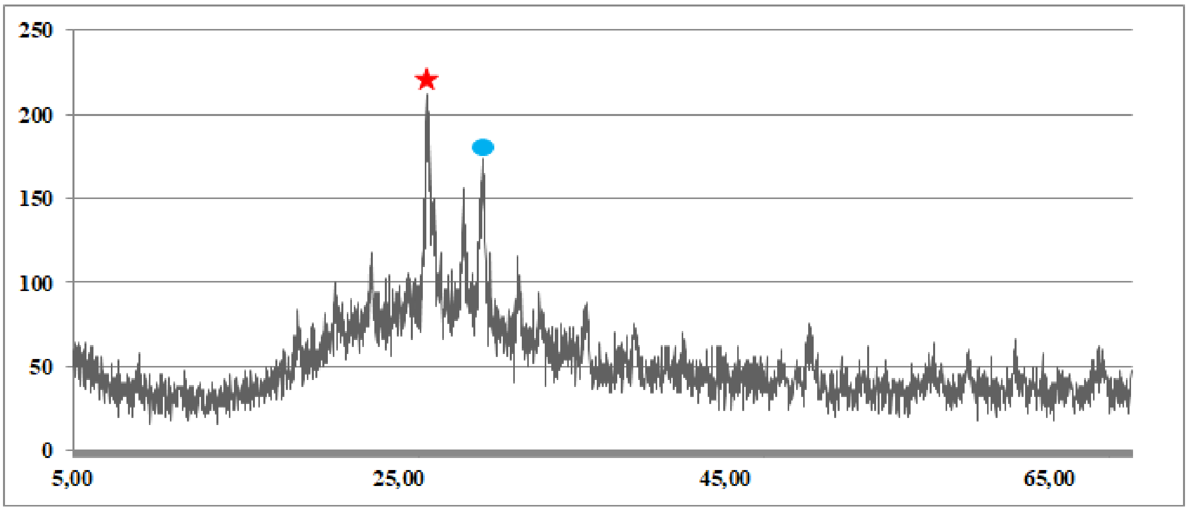

Fig. 2: X-ray patterns of samples coded 1a and 1c.

Heat insulation materials are desired to have very low thermal conductivity values. It was measured that 0.127 W/mK values of thermal conduction was obtained. When compared to values given in Table 3, the measured thermal conductivity can be considered as average value, but it should definetely be decreased so as to achieve better insulation characteristics.

4. CONCLUSIONS

Two different heating temperatures by conducting two different heating rates for determined waiting period in order to produce foam glass composed of waste glass, quartz mining tailings, marble powders and varying ulixite amounts were studied. The following consequences can be summarized :

1- Utilisation of various solid wastes such as waste glass, quartz mining tailings and marble powders can be fabricated for manufacturing of foam glass materials used for heat insulation purposes with lightweight features.

2- Accumulation of those wastes in environment causing many problems like penetration into soil or ground water can be prevented thanks to the foam glass material production.

3- As the amount of ulexite mineral increase in foam glass the density values decrease except of samples of 1-series.

4- Increasing heating temperatures with higher heating rates provide more expansion as well as lower densities.

5- As boron content is increased in the sample the compressive strength is increased with the temperature of 850°C. However, this situation is contrary for 900°C. That is, the compressive strength is decreased as boron amount is increased.

6- The best foam glass material can be produced with the addition of 1% ulexite at 900 °C for 10 °C/min heating rates.

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